FOR COMMENT

Information Technology-

Telecommunications and Information Exchange Between Systems –

LAN/MAN Specific Requirements –

Air Interface for Fixed Broadband Wireless Access Systems

Sponsor

LAN MAN Standards Committee

of the IEEE Computer Society

Abstract: This document is FOR COMMENT as a potential DRAFT standard for medium-access and physical layer components that meet the functional requirements of a point-to-multipoint Broadband Wireless Access (BWA) system as defined by the IEEE 802.16 Working Group. Detailed logical, electrical, and signal processing specifications are presented that enable the production of interoperable equipment.

Keywords: wireless metropolitan area network (WirelessMAN^{TM}) standards, fixed broadband wireless access networks, millimeter waves

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Introduction

(This introduction is not part of IEEE Std 802.16.1, IEEE Standard for Broadband Wireless Access.)

This document defines services and protocol elements that permit the exchange of management information between stations attached to IEEE 802 local and metropolitan area networks. The standard includes the specification of managed objects that permit the operation of the protocol elements to be remotely managed.

Participants

At the time the draft of this standard was sent to sponsor ballot, the IEEE 802.16 Working Group on Broadband Wireless Access had the following members:

Roger B. Marks, Chair
Louis Olsen, Vice Chair
J. Scott Marin, Secretary
James F. Mollenauer and Brian Petry, Chief Technical Editors, Standard 802.16.1
Glen E. Sater, 802.16.1 MAC Editor
Jeffrey R. Foerster, 802.16.1 PHY Editor
Carl Eklund, 802.16.1 MAC Task Group Chair
Jay Klein, 802.16.1 PHY Task Group Chair

<list of voting members>

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Donald N. Heirman, *Chair*

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Judith Gorman, *Secretary*

Satish K. Aggarwal
Mark D. Bowman
Gary R. Engmann
Harold E. Epstein
H. Landis Floyd
Jay Forster*
Howard M. Frazier
Ruben D. Garzon
James H. Gurney
Richard J. Holleman
Lowell G. Johnson
Robert J. Kennelly
Joseph L. Koepfinger*
Peter H. Lips
L. Bruce McClung
Daleep C. Mohla
James W. Moore
Robert F. Munzner
Ronald C. Petersen
Gerald H. Peterson
John B. Posey
Gary S. Robinson
Akio Tojo
Donald W. Zipse

*Member Emeritus

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Alan Cookson, *NIST Representative*
Donald R. Volzka, *TAB Representative*

Gregory Kohn
IEEE Standards Project Editor

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1 Overview

This standard includes specifications for the air interface, including the physical layer and medium access control layer, of fixed point-to-multipoint broadband wireless access systems providing multiple services operating in the vicinity of 30 GHz. It is broadly applicable to systems operating between 10 and 66 GHz.

1.1 Normative references

This standard shall be used in conjunction with the following publications.

[DOCSIS] Data-Over-Cable Service Interface Specifications, "Radio Frequency Interface Specification", SP-RFIv1.1-I03-991103.

[EN 300 421] ETSI EN 300 421 V1.1.2 (1997-08), "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for 11/112 GHz satellite services".

[EN 301 199] ETSI EN 301 199 v1.2.1 (1999-06), "Digital Video Broadcasting (DVB); Interaction channel for Local Multi-point Distribution Systems (LMDS)".

[EN 301 210] ETSI EN 301 210 V1.1.1 (1999-03), "Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for Digital Satellite News Gathering (DSNG) and other contribution applications by satellite".

[F.BWA] ITU-R 9B/134-E, JRG 8A-9B, New Recommendation ITU-R F.BWA, "Radio Transmission Systems for Fixed Broadband Wireless Access (BWA) Based on Cable Modem Standards (Annex B of ITU-T Rec. J.112)".

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[FIPS-74]Federal Information Processing Standards Publication (FIPS PUB) 74, “Guidelines for Implementing and Using the Data Encryption Standard”, April 1981.

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[FIPS-140-1]Federal Information Processing Standards Publication (FIPS PUB) 140-1, “Security Requirements for Cryptographic Modules”, April 1982.

[FIPS-180-1]Federal Information Processing Standards Publication (FIPS PUB) 180-1, “Secure Hash Standard”, April 1995.

[FIPS-186]Federal Information Processing Standards Publication (FIPS PUB) 186, “Digital Signature Standard”, 18 May 1994.

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[IEEE802]IEEE Std 802-1990, “IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture, December 1990”.

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[J.83] ITU-T Recommendation J.83 (04/97), Series J: Transmission of Television, Sound Programme and Other Multimedia Signals: Digital transmission of television signals, "Digital multi-programme systems for television, sound and data services for cable distribution".

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[RFC-1123] Braden, R., “Requirements for Internet Hosts -- Application and Support”, IETF RFC-1123, October 1989.

[RFC-1157] Schoffstall, M., Fedor, M., Davin, J. and Case, J., “A Simple Network Management Protocol (SNMP)”, IETF RFC-1157, May, 1990.

[RFC-1633] R. Braden et al., "Integrated Services in the Internet Architecture: An Overview", IETF RFC-1633, June 1994.

[RFC-1750]D. Eastlake, S. Crocker, J. Schiller, “Randomness Recommendations for Security”, IETF RFC-1750, December 1994.

[RFC-2104]H. Krawczyk, M. Bellare, R. Canetti, “HMAC: Keyed-Hashing for Message Authentication”, IETF RFC-2104, February 1997.

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[RSA1] RSA Laboratories, “PKCS #1: RSA Encryption Standard. Version 1.5”, November 1993.

[RSA2] RSA Laboratories, “Some Examples of the PKCS Standards,” RSA Data Security, Inc., Redwood City, CA, November 1, 1993.

[RSA3] RSA Laboratories, “PKCS #1 v2.0: RSA Cryptography Standard”, October xxxxx

1.2 Definitions

Base Station (BS): A generalized equipment set providing connectivity, management, and control of the subscriber station.

Burst Profile: Set of parameters that describe the upstream transmission properties that are associated with an IUC. Each profile contains parameters such as modulation type, preamble length, guard times, etc.

Connection: A unidirectional mapping between equivalent BS and SS peers. Connections are identified by a CID. All traffic is carried on a connection.

Connection Identifier (CID): A unidirectional, MAC-layer address that identifies a connection to equivalent peers in the SS and BS MAC. A CID maps to a SFID, which defines the QoS parameters to the Service Flow associated with that connection. Security associations also exist be keying material and CIDs.

Downlink: A flow of information that exists in the downstream.

Downstream: The direction from a BS to the SS.

Frame: A frame is a fixed duration of time, which contains both transmit and receive intervals.

Information Element (IE): A component of the UL-MAP that defines the length and address assignment associated with an IUC. Taken as a whole, each IE represents a type of upstream transmission. Mulitple IEs may exist in the UL-MAP.

Interval Usage Code (IUC): Defines the type of usage of an Information Element. IUCs are defined for bandwidth requests, data grants, etc.

Grant Per Connection (GPC): A bandwidth allocation method in which grants are aggregated for all connections and are allocated to the SS terminal as that aggregate. Note that bandwidth requests are always made for a connection.

Grant Per Terminal (GPT): A bandwidth allocation method in which grants are allocated to a connections within a SS. Note that bandwidth requests are always made for a connection.

MAC Service Access Point (MSAP): The point in the protocol stack where services of the MAC layer (Medium Access Control) are requested by the layer above and delivered by the MAC layer.

Mini-slot: A unit of bandwidth allocation equivalent to N PS, where N = 2m (m = 0,...7).

Multicast Group: Agroup of zero or more SSs or connections that are assigned a mulitcast address for the purposes of polling.

Physical-Slot (PS): A unit of granularity equal to 4 modulation symbols. Each PS represents 8, 16, or 24 bits (using QAM-4, QAM-16, or QAM-64 modulation, respectively).

Privacy Key Management Protocol (PKM): A client/server model between the BS and SS that is used to secure distribution of keying material.

Security Association (SA): The set of security information a BS and one or more of its client SS share in order to support secure communications across the BWA network.

Service Flow: A Service Flow is a unidirectional flow of PDUs on a connection that is provided a particular Quality of Service.

Service Flow Class: A grouping of Service Flow properties to allow higher layer entities and external applications to request Service Flows with desired QoS parameters in a globally consistent way.

Service Flow Name: An ASCII string that is used to reference a set of QoS parameters that (partially) define a Service Flow.

Subscriber Station (SS): A generalized equipment set providing connectivity between subscriber equipment and a BS.

SS Uplink: A flow of information that exists in the upstream.

Uplink: The direction from a SS to the BS.

Uplink MAP (UL-MAP): A set of information that defines the entire access for a scheduling interval.

Upstream: The direction from a SS to the BS.

1.3 Terminology

Throughout this document, the words that are used to define the significance of particular requirements are capitalized. These words are:

"MUST" or “SHALL” These words or the adjective "REQUIRED" means that the item is an absolute requirement for any implementation conforming to this standard.

"MUST NOT" This phrase means that the item is an absolute prohibition.

"SHOULD" This word or the adjective "RECOMMENDED" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighed before choosing a different course.

"SHOULD NOT" This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.

"MAY" This word or the adjective "OPTIONAL" means that this item is optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

1.4 Acronyms and abbreviations

ARP	Address Resolution Protocol
ATDD	Adaptive Time Division Duplexing
ATM	Asynchronous Transfer Mode
BR	Bandwidth Request
BS	Base Station
CG	Continuous Grant
CID	Connection Identifier
SS	Customer Premises Equipment
CS	Convergence Subprocess
CSI	Convergence Subprocess Indicator
CTG	SS Transition Gap
DAMA	Demand Assign Multiple Access
DCD	Downlink Channel Descriptor
DES	Data Encryption Standard
DL	Down Link
DIUC	Downlink Interval Usage Code
DSA	Dynamic Service Addition
DSC	Dynamic Service Change
DSD	Dynamic Service Deletion
EC	Encryption Control
EKS	Encryption Key Sequence
EUI	Ethernet Unique Identifier
FC	Fragment Control
FDD	Frequency Division Duplex
FSN	Fragment Sequence Number
GM	Grant Management
GPC	Grant Per Connection
GPT	Grant Per Terminal
HCS	Header Check Sequence
H-FDD	Half-duplex FDD
HL-MAA	High Level Mediaum Access Arbitration
HT	Header Type
IE	Information Element
IUC	Interval Usage Code
IP	Internet Protocol
LLC	Logical Link Control
LL-MAA	Low Level Mediaum Access Arbitration
LOS	Line of Sight
MAA	Medium Access Arbitration
MAC	Medium Access Control
MPEG	Moving Pictures Experts Group
MPLS	MultiProtocol Label Switching
MSAP	MAC Service Access Point
MIC	Message Integrity Check
MTG	Modulation Transition Gap
PBR	Piggy-Back Request
PDU	Protocol Data Unit

PHY	Physical layer
PI	PHY Information element
PKM	Privacy Key Management
PM	Poll Me bit
PS	Physical Slot
QoS	Quality of Service
RS	Reed-Solomon
SAP	Service Access Point
SI	Slip Indicator
SDU	Service Data Unit
TC	Transmission Convergence
TDD	Time Division Duplex
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
TFTP	Trivial File Transfer Protocol
TDU	TC Data Unit
TLV	Type-Length-Value
TRGTTG	Tx/Rx Transmission Gap
UIUC	Uplink Interval Usage Code
DIUC	Downlink Interval Usage Code
UCD	Uplink Channel Descriptor
UGS	Unsolicited Grant Service
UGS-AD	Unsolicited Grant Service with Activity Detection
UL	Uplink

1.5 Scope

For the purposes of this document, a “system” constitutes: an 802.16.1 MAC and PHY implementation, in which at least one subscriber station communicates with a base station via a point-to-multipoint (P-MP) radio air interface, the interfaces to external networks, and services transported by the MAC and PHY protocol layers.

The 802.16.1 air interface interoperability standard is part of a family of standards for local and metropolitan area networks. The following diagram illustrates the relationship of 802.16.1 protocols to other 802 standards, and to the OSI reference model. (The numbers in the figure refer to IEEE standard numbers.)

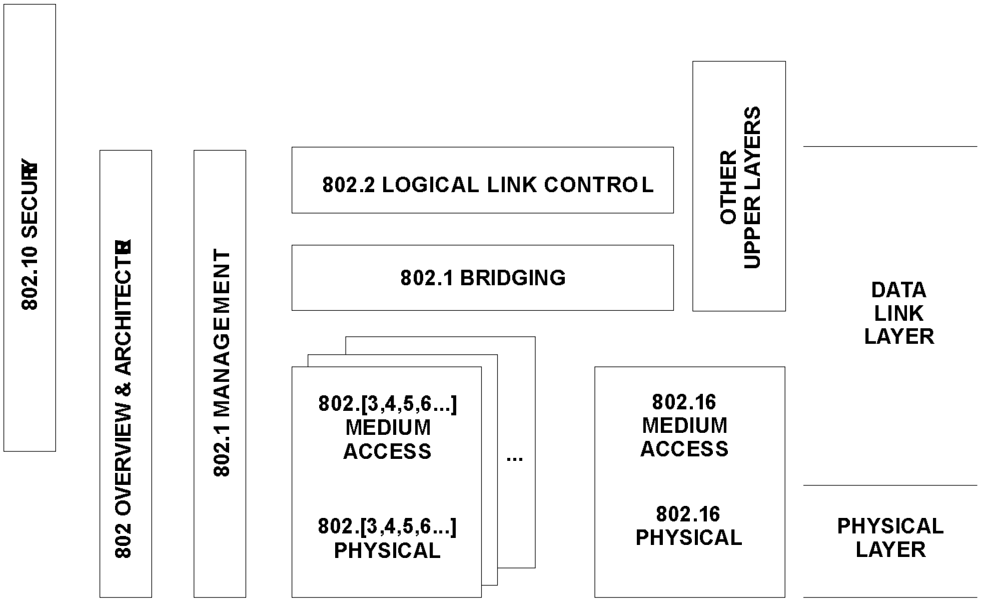


Figure 1—Relationship between 802.16.1 and other Protocol Standards (the numbers in the figure refer to IEEE standard numbers

This family of standards deals with the Physical and Data Link layers as defined by the International Organization for Standardization (ISO) Open Systems Interconnection Basic Reference Model (ISO 7498: 1984). The access standards define several types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. Other types are under investigation.

The standards that define the technologies noted in the above diagram are as follows:

IEEE Std 802: Overview and Architecture. Provides an overview to the family of IEEE 802 Standards. This document forms part of the 802 scope of work.
ANSI/IEEE Std 802.1B [ISO/IEC 15802-2]: LAN/MAN Management. Defines an Open Systems Interconnection (OSI) management-compatible architecture, environment for performing remote management.
ANSI/IEEE Std 802.1D [ISO/IEC 10038]: MAC Bridging. Specifies an architecture and protocol for the interconnection of IEEE 802 LANs below the MAC service boundary.
ANSI/IEEE Std 802.1E [ISO/IEC 15802-4]: System Load Protocol. Specifies a set of services and protocols for those aspects of management concerned with the loading of systems on IEEE 802 LANs.
ANSI/IEEE Std 802.2 [ISO/IEC 8802-2]: Logical Link Control
ANSI/IEEE Std 802.3 [ISO/IEC 8802-3]: CSMA/CD Access Method and Physical Layer Specifications
ANSI/IEEE Std 802.4 [ISO/IEC 8802-4]: Token Bus Access Method and Physical Layer Specifications
IEEE Std 802.10: Interoperable LAN/MAN Security, Secure Data Exchange (SDE)

1.6 Supported Services

The 802.16.1 standard is intended to provide for a metropolitan wireless network that operates as a third-party or public entity providing contractual services to its customers. As such, it differs from a local area network, which is intended to serve users who are members of the same organization.

A public network must have mechanisms to verify that traffic originates with legitimate users and means to prevent users from utilizing resources beyond their contractual limits. Also, any attempted violation of such limits (intentional and inadvertent) must not adversely impact the service extended to other customers. It must be possible to measure the resources used by a given customer in order to bill for services, and finally privacy must be enforceable through the use of encryption.

A LAN, in contrast, needs very few of these features beyond the actual movement of data. Authentication and privacy are seldom issues in wired networks, and billing for services is likewise a rarity in the LAN world.

As a substitute for a wireline network, a BWA network must be able to carry a variety of traffic types, many of which are legacy applications of long standing with well-established expectations of service quality and availability.

This standard is an attempt to provide interoperability in equipment that meets the general requirements cited above, with specific details in the following sections.

1.7 Target Applications

A broadband wireless access (BWA) system based on 802.16.1 protocols is expected toaddress markets similar to wire- or fiber-based broadband access technologies, such as copper digital subscriber line (DSL) technologies, digital cable TV hybrid fiber/coax (HFC) networks, Integrated Services Digital Network (ISDN) andlegacy TDM digital transmission systems (e.g., full and fractional T1, E1, ISDN-PRI etc.), and the services that such legacy systems carry: data, voice and audio/video.

The optimization of 802.16.1 is for businesses and multi-tenant dwellings. Future standards in the 802.16 family may address access for the single-family residential market.

A key word in BWA is "access:" *access* to some other network such as the Internet, a private network, a telephony network, etc. An 802.16.1 system generally provides access to an external network and is not intended to form an end-to-end communication system by itself. 802.16.1 systems are expected to be fixed rather than mobile.

Sometimes, the word *subscriber* is associated with a single customer that is billed for a service. But a BWA system may support more than one customer at a single access point to a subscriber BWA radio. In other words, the subscriber access point provides "wholesale" connection of multiple "retail" subscribers [14]. An office building may be well served by a singleBWA radio, but house many tenants who contract for services separately.

The 802.16.1 network is point-to-multipoint, with one base station serving a multiplicity of subscriber terminals at millimeter-wave frequencies. As such, it shares its total capacity among users based on their service contracts and immediate transmission needs. In its ability to provide bandwidth to customers, it falls between dedicated point-to-point wireless links and lower-frequency systems (such as those in the microwave region).

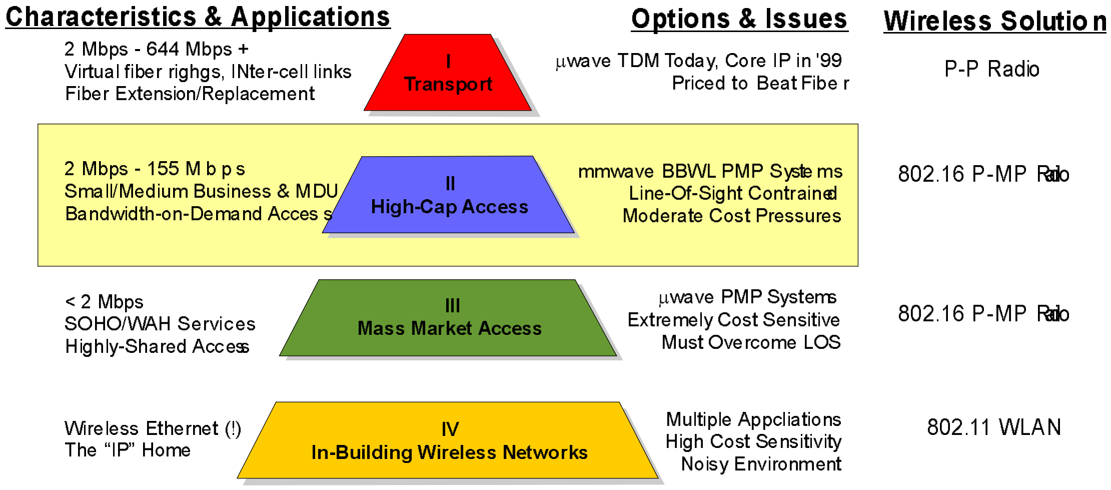


Figure 2—A Multi-Tier Perspective of Wireless Transmission and Distribution Systems

1.7.1 Bearer Services

This section describes typical services, transported by an 802.16.1 system. In this document, *bearer service* refer to the services provided by the protocols that can appear in the layer sitting directly over the MAC layer. The meaning of bearer services in this document also includes the types of networks that are able to interface with 802.16.1-based BWA networks. [I.210]

1.7.1.1 Digital Audio/Video Multicast

802.16.1 protocols efficiently transport digital audio/video streams to subscribers. The streams flow in the direction of the infrastructure network to subscriber(s) only, although use of acknowledgements is not precluded. Digital Audio/Video Multicast service is thus similar to digital video capabilities of digital cable TV and digital satellite television service.

In addition, this standard supports non-multicast video in applications like video conferencing. In this case, the video stream is two-way and the delay requirements are very stringent due to the level of interactivity involved.

1.7.1.2 Digital Telephony

802.16.1 systems support telephone service to subscribers in a way that eases the migration of legacy equipment and public switched telephone network (PSTN) access technologies to 802.16.1 systems. 802.16.1 protocols may transport any layer in the nationally- and internationally-defined digital telephony service hierarchies: Synchronous Digital Hierarchy (SDH) or Plesiochronous Digital Hierarchy (PDH). (Please see the glossary entries in section 1.2.)

It is expected that a significant application for 802.16.1 systems is connecting a business PBX to an 802.16.1 system. Most PBXs use channelized SDH/PDH circuits for their connection to the public switched telephone network (PSTN), such as T1/E1, and multiples or fractions thereof.

1.7.1.3 ATM Cell Relay Service

ATM standards define a rich set of quality of service (QoS) guarantees for various service categories. ATM transmits data using small, 53-byte, fixed-length cells which are “routed” by ATM switches along virtual connections with an ATM network. ATM cell relay service is carried over a wide variety of links and bit rates, whether copper, optical fiber or wireless. ATM standards define a rich set of quality of service (QoS) guarantees for various service categories.

802.16.1 protocols are defined such that an 802.16.1 system can efficiently transport ATM cell relay service and preserve its QoS features (see section 1.11, Class of Service and Quality of Service). Thus, 802.16.1 systems broadly address the target applications mentioned in section 1.7. Also note that, since ATM cell relay service is connection-oriented, it employs message-based signaling protocols to establish, maintain and tear down switched virtual circuits as well as signal QoS-based services and perform network management. 802.16.1 protocols may need to be cognizant of such ATM signaling to enable an 802.16.1 system to preserve QoS.

802.16.1 provides a means to utilize ATM addresses such as ITU-T E.164. The ATM convergence sublayer provides a means to translate ATM addresses to MAC addresses.

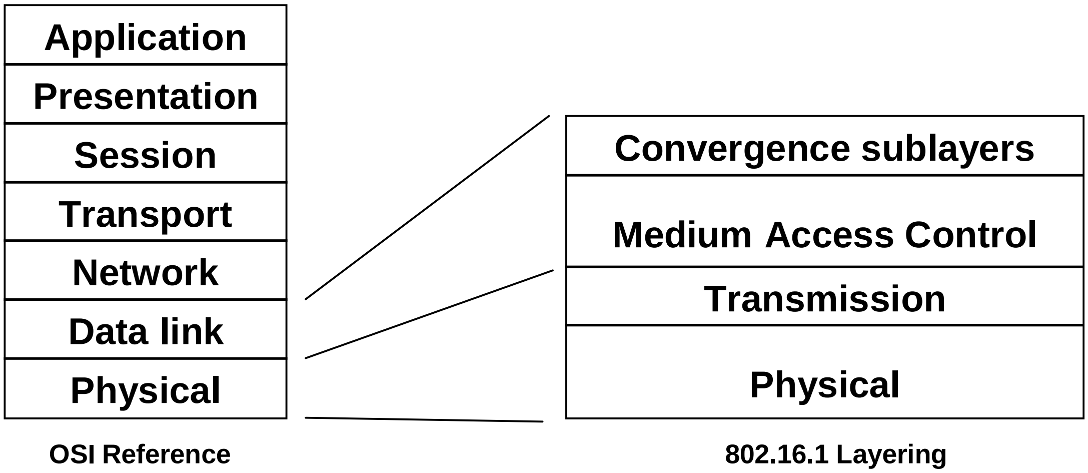


Figure 3—Protocol layers

1.7.1.4 Internet Protocol Service

The 802.16.1 systems directly transport variable length IP datagrams efficiently. Both IP version 4 and 6 are supported. Especially for efficient transport of IPv6, TCP/IP header compression over the air interface is supported.

The 802.16.1 IP service provides support for real-time and non-real-time services. It is possible to support the emerging IP Quality of Service (QoS) efforts: Differentiated Services [RFC-2475] and Integrated Services [RFC-1633].

1.7.1.5 Bridged LAN Service

The 801.16.1 protocols support bridged LAN services, directly or indirectly.

1.7.1.6 Other Services

Other services that for instance require QoS-based delivery of the MAC services similar to channelized SDH/PDH telephony, cell relay service, IP service or bridging service (see above sections), are envisaged. These services do not place any special requirements on 802.16.1 systems (MAC and PHY protocols) not already covered in the above sections. Some services are:

Back-haul service for cellular or digital wireless telephone networks. An 802.16.1 system may be a convenient means to provide wireless trunks for wireless telephony base stations. The channelized SDH/PDH services or ATM cell relay service may be appropriate.

Virtual point-to-point connections for subscriber access to core network services. Here the Internet-oriented point-to-point protocol (PPP) is employed to make virtual connections between subscribers and service providers and PPP is encapsulated directly in the 802.16.1 MAC protocol. PPP has some benefits such as simple authentication, privacy/encryption, data compression, and layer 3 network parameter assignment.

Frame Relay Service Frame Relay is a packet/frame-based protocol, circuit-based data service that uses a simple variable-length frame format. Some basic QoS guarantees are defined for frame relay, but not as rich as ATM. Frame relay networks typically use provisioned permanent virtual circuits (PVCs), although a signaling protocol for switched virtual circuits (SVCs) is defined and in use (Q.933). Frame Relay also defines a management protocol.

1.8 System Model

As mentioned in section Scope, an 802.16.1 “system” constitutes: an 802.16.1 MAC and PHY implementation, in which at least two stations communicate via a radio air interface (an 802.16.1 system), the interfaces to external networks, and services transported by the MAC and PHY protocol layers. An 802.16.1.1 system employs point-to-multipoint radios operating in the vicinity of 30 GHz, but more generally in the range from 11 GHz to 66 GHz, to connect a base transceiver station (BS) to one or more subscriber transceiver stations (SS). Radio communications around 30 GHz require line-of-sight (LOS) between a BS and SS. LOS blockage by foliage also contributes heavily to signal attenuation.

802.16.1 systems are generally multiple-cell systems with frequency reuse. In this respect they are similar to cellular wireless telephone systems, but mobility of the subscriber station is not allowed. The range of the radios varies with transmit power, LOS blockage, and rainfall.

An 802.16.1 system consists of one base station radio and one or more subscribers. Thus an 802.16.1 system also defines 802.16.1 base station and subscriber station radios that communicate using the 802.16.1 MAC and PHY protocols. The BS radio is P-MP, radiating its downstream signal with a shaped sector antenna providing a broad azimuthal beam covering a number of subscribers. Each SS employs a highly directional antenna pointed at the BS.

With this arrangement, direct radio communication between subscriber stations is not possible. Furthermore, the 802.16.1 system does not define radio communications between base stations. Since the BS radios are sector-oriented, multiple BS radios may, in practice, be co-located (subject to frequency re-use requirements), and even share physical hardware.

The frequency bands used by 802.16.1 systems vary between countries. To achieve international applicability, 802.16.1 protocols are frequency-independent. Typical bands allocated for 802.16.1 use are very wide, allowing them to be channelized.

1.8.1 System reference points

Figure 4 shows the 802.16.1 system reference points, depicting the relevant elements between a subscriber network and the “core” network (the network to which 802.16.1 is providing *access*). A greater system encompassing user terminals, base station interconnection networks, network management facilities, etc., may be envisaged, but the 802.16.1 protocols focus on the simplified model shown in the figure. Also not shown are the internal physical characteristics of the base station and subscriber station: the concepts of “indoor” and “outdoor” units. The description of possible separation of base station and subscriber stations into indoor and outdoor units is beyond the scope of this document.

One addition to this model to be considered is security systems (see section Security). Two key external interfaces are shown in the figure: the Base Station Network Interface (BNI) and the Subscriber Station Network Interface (SNI). A single SNI may support multiple subscriber networks: LANs, Voice PBXs, etc. And recall that the SNI may support multiple paying subscribers, such as within a multi-tenant office building or dwelling. A BS interfaces to one or more core networks through one or more BNIs.

For the purposes of 802.16.1, the SNI and BNI are abstract concepts. The details of these inter-working functions (IWFs), are beyond the scope of this document and are not specified by the forthcoming interoperability standard. Since many subscriber and core network technologies are possible, many different IWFs are conceivable. The simplified reference model serves to discuss the impact of core network technologies and bearer services (see section 1.7.1) on the requirements of 802.16.1 protocols by drawing focus to the air interface and the immediate requirements imposed by the surrounding networks. The standard describes a common access protocol and several common modulation techniques.

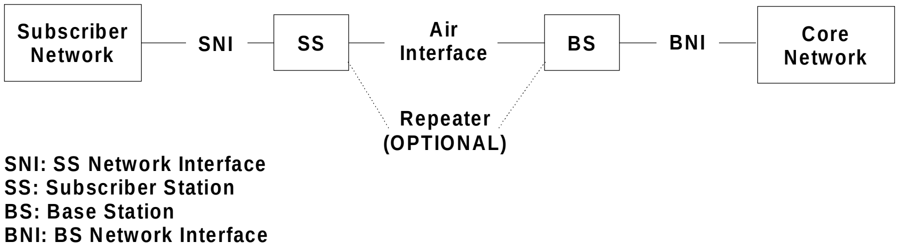


Figure 4—System Reference Points

1.8.2 Topology

Since all data traffic in an 802.16.1 network goes through the base transceiver station (BS), it is convenient for the BS to control the allocation of bandwidth on the radio channel. The SS stations request bandwidth to achieve their QoS objectives (see section Class of Service and Quality of Service), but the BS performs the bandwidth allocation and scheduling.

In the downstream direction, within a channel, the network topology is similar to a contention-less broadcast bus (using LAN terminology), since all transmissions originate at the BS, and more than one SS share a downstream channel. In the upstream direction, 802.16.1 protocols provide the means to resolve contention and multiplex traffic from multiple SS.

The topology is similar to a Hybrid Fiber Coax (HFC) cable TV network, but with some differences. The BS antenna is generally sectorized, dividing the circle into sectors that operate independently of each other. Subscribers with high bandwidth requirements may reside in a narrower sector beam than subscribers with low bandwidth requirements. Also, a single SS may serve multiple customers in the same building.

1.9 Protocols

Standardized protocols provide for interoperability of multiple vendors' equipment. Protocol interoperability occurs at each level in the protocol "stack". IEEE 802 protocols reside at layer 1 and 2 and consist primarily of Logical Link Control (802.2) and the various MAC and PHY layers for each LAN or MAN standard. The IEEE Std 802-1990 Overview and Architecture describes these layers.

The 802.16.1 protocol stack reference diagram is shown in Figure 3. In addition to the LLC, MAC and PHY layers suggested by the generic 802 architectures, 802.16.1 protocols transport other categories of "upper protocols" that correspond to the requirements of the bearer services described in section 1.7.1.

Each of the protocols above the MAC and PHY is given a convergence sub-layer. The convergence sub-layers (see section 1.15) do the following:

- Encapsulate PDU framing of upper layers into the native 802.16.1 MAC/PHY PDUs.
- Map an upper layer's addresses into 802.16.1 addresses
- Translate upper layer CoS/QoS parameters into native 802.16.1 MAC format
- Adapt the time dependencies of the upper layer traffic into the equivalent MAC service

The central purpose of the Medium Access Control (MAC) protocol layer in 802.16.1 is sharing of radio channel resources. The MAC protocol defines how and when a base or subscriber station may initiate transmission on the channel. Since key layers above the MAC, such as ATM and STM, require service guarantees, the MAC protocol defines interfaces and procedures to provide guaranteed service to the upper layers. In the downstream direction, since only one base station is present, it controls its own transmission without need of a protocol operating between stations. But in the upstream direction, if a radio channel is used by more than one SS, the MAC protocol resolves contention and bandwidth allocation.

The PHY layer is similarly subdivided between the Transmission Convergence layer and the physical layer proper. Like the MAC convergence layers, the Transmission Convergence layer adapts the needs of the MAC and services to generic physical layer services.

1.10 Performance and Capacity

This section specifies the target performance levels and some of the issues for 802.16.1 capacity planning. Providing system capacity at the target performance levels for all subscribers, given local LOS obstruction and rapidly changing channel characteristics (due to rain) will be a challenging task.

1.10.1 Scalability

The 802.16.1 protocols allow for different levels of capacity and performance for 802.16.1 system instances.

1.10.2 Delivered Bandwidth

802.16.1 systems provide a peak capacity ranging from 2 to 155 Mbps to an SS sufficiently close to the BS. Rates beyond 155 Mbps may be accommodated at some future time, dependent on PHY issues.

1.10.3 Flexible Asymmetry

The 802.16.1 protocol allows for flexibility between delivered upstream and downstream bandwidth and CoS/QoS. Some applications utilize asymmetrical bandwidth, such as for Internet access---most of the bandwidth is consumed in the downstream direction. Some applications use more bandwidth upstream, such as a video multicast from a corporate or distance-learning source. Other applications require more-symmetrical bandwidth; these include telephony and video conferencing.

1.10.4 Radio Link Availability

An 802.16.1 system SHOULD be available to transport all services at better than their required maximum error rates (see section 5.5) from about 99.9 to 99.999% of the time, assuming that the system and radios receive adequate power 100% of the time and not counting equipment availability. Note that 99.999% availability amounts to approximately 5 minutes of outage a year. The 802.16.1 specifications SHALL NOT preclude the ability of the radio link to be engineered for different link availabilities, based on the preference of the system operator. A period of unavailable time begins at the onset of ten consecutive SES events based on the following definitions:

Severely Errored Second (SES) is defined as a one-second period which contains (30% errored blocks.

Errored Block (EB): A block is defined as a set of consecutive bits associated with the path. Consecutive bits may not be contiguous in time. A block is typically a data block containing an error detection code for in-service performance monitoring. An errored block is a block in which one or more bits are received in error.

It is expected that the highest contributor to 802.16.1 system outage will be excessive attenuation due to rainfall (rain rate and droplet size). 802.16.1 MAC and PHY protocols accommodate rainfall, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements. Since statistical rain rates vary widely in geography, the 802.16.1 protocols are flexible with respect to consumed radio bandwidth (spectral efficiency based on modulation and coding), modulation, FEC, and transmit power. These are critical components of system/cell capacity planning (also see section 1.10.7). Such operating parameters may be changed quickly to accommodate changing weather conditions.

1.10.5 Error Performance

The error rate, after application of the appropriate error correction mechanism (e.g., FEC), delivered by the PHY layer to the MAC layer meets the IEEE 802 functional requirements: a bit error rate (BER) of 10^{-9} or better. The PHY meets the requirement for a Hamming Distance of at least 4 (detection of errors in a block with up to 3 bit errors).

1.10.6 Delay

System delay requirements come in several categories:

- Medium Access Delay. The delay imposed by the MAC protocol layer between when a BS or SS becomes ready to transmit and when it actually begins transmission on the channel.
- Transit Delay. The total 802.16.1 system delay from BNI to SNI and from SNI to BNI (see section Topology). This includes the Medium Access Delay.
- End-to-End Delay. The total delay between a terminal in the subscriber network, to the ultimate service beyond the core network. For instance, the total delay between two telephony terminals (handsets). This includes the 802.16.1 Transit Delay.

In addition to the above categories, variation of delay, or jitter, is important to consider. For example, a high variation of delay can severely impact telephony services. But generic Internet access can tolerate a high degree of delay variation.

The end-to-end delay is a subjective metric and depends on an entire application-specific network encompassing all 7 layers of the OSI model. In a telephony network, for example, the maximum acceptable end-to-end delay for the longest path is recommended to be less than 300ms [G.114].

The radio propagation time is 3.3µsec/km see G.114]. If the distance between the SS and BS is 5 km, this propagation time is 16.7µsec. The MAC layer may have different requirements for each direction, upstream and downstream. In the upstream direction, time is

budgeted for requesting bandwidth and contending among nodes. The budget for 802.16.1 transit delay is should be 19.5 ms for "stringent QoS" services.

ITU I.356 recommends end-to-end variation (jitter) for "stringent QoS class" to be less than 3 ms. Multimedia videoconferencing requires delay variation to be less than 200 ms end-to-end to allow for reasonable synchronization of audio and video streams. It is suggested that the budget for 802.16.1 systems be 1.5 ms for "stringent QoS" services.

1.10.7 Capacity Issues

802.16.1 system capacity requirement is defined as the product of the number of subscribers, their peak bandwidth requirements and quality of service guarantees. The delivered capacity can vary depending on rain attenuation, LOS blockage, transmit power, etc. In a given 802.16.1 system instance, capacity must be carefully planned to ensure that subscribers' quality of service guarantees and maximum error rates are met. Given the atmospheric condition statistics in a geographic area, a channel link budget can be developed using the following parameters of an 802.16.1 system:

- Radio range (shaped sector radius)
- Width of the sector
- Downstream channels' data rates
- Allocation of prospective subscriber data rate to channels
- Types of modulation

The time-variant impairments, rain fade and multipath interference, are expected to be the most significant contributors to channel impairments and complexity in cell capacity planning. Common metrics, such as dispersive fade margin (DFM) for frequency-selective fading environments, may be employed to compare the performance of 802.16.1 equipment (e.g., radios and modems).

1.11 Class of Service and Quality of Service

This section describes the classes of service and quality of service for 802.16.1 systems. Terminology is borrowed from the ATM Forum and Internet Engineering Task Force (IETF).

802.16.1 protocols support classes of service with various quality of service (QoS) guarantees to support the bearer services (see section 1.7.1) that an 802.16.1 system transports. Each bearer service defines guarantees that it expects to be preserved by an 802.16.1 system.

For QoS-based, connectionless, but not circuit-based, bearer services, the 802.16.1 protocols support bandwidth negotiation on demand. For instance, the MAC protocol may allocate bursts of time slots to bearer services that require changes in bandwidth allocation. Such allocation is thus performed in a semi-stateless manner. A connection-oriented bearer service may require state information to be maintained for the life of a connection. But the 802.16.1 MAC layer interface may provide a connectionless service interface that requires higher-layer adaptation to maintain the state of a connection and periodically allocate bandwidth. For instance, the MAC may need to maintain state information about a QoS data flow only for the duration of an allocation.

Traffic may be roughly categorized as follows (ATM terminology):

- Constant Bit Rate (CBR). The bearer service requires a constant, periodic access to bandwidth. SDH/PDH falls into this category.
- Variable Bit Rate: Real-Time (VBR-rt). The bandwidth requirements vary over time, within a specified range, but delay and delay variance limits are specified. Examples that fall into this category are voice-over-IP (VoIP), videoconferencing, video on demandand other "multimedia" applications.
- Variable Bit: Non-Real-Time Rate (VBR-nrt). The bandwidth varies, within a specified range, but has loose delay and delay variance requirements. Applications, which are limited in their bandwidth usage, may fall into this category. In one example, corporate database transactions could be relegated to this category.
- Available Bit Rate (ABR). The bandwidth varies within a wide range, and is allowed to burst up to the maximum link bandwidth when CBR and VBR traffic are not using bandwidth. Higher variations of delay may be tolerable since applications that fall into this category allow for priority traffic to consume bandwidth they do.
- Unspecified Bit Rate (UBR). The bandwidth and delay requirements are not specified. Bandwidth is delivered on a "best effort" basis.

The Internet Engineering Task Force (IETF) "Integrated Services" model uses the following terminology to classify network applications [RFC-1633]:

Elastic. Applications that are tolerant of various bandwidths and/or delay variations:

- Interactive burst (Telnet, The X Window System, NFS, Microsoft or Novell File Sharing, etc.)
- Interactive bulk (FTP)
- Asynchronous bulk (Email, FAX, Remote Printing, Backup, etc.)

Real-Time. Applications that require some level of bandwidth and/or delay variation:

- Guaranteed Service. A fixed upper bound on the arrival of data is required. For instance, audio and video conferencing may fall into this category.
- Predictive Service. Applications are tolerant of some late data, a higher variation of delay, or may adapt to less available bandwidth. For example, a video playback service may be able to adapt its playback buffer to accommodate variation of delay.

An IETF architecture for differentiated services [RFC-2475] defines how Internet Protocol-based service classes may be given quality-of-service. Traffic flows are identified in terms of their profiles: rates and burst sizes.

1.11.1 Bearer Service QoS Mappings

The classes of service and QoS parameters of bearer services are translated into a common set of parameters defined by 802.16.1. A network node that serves as an inter-working function (IWF) between a QoS-capable LAN or WAN and an 802.16.1 system participates in signaling protocols to set up QoS parameters for connection-oriented services.

For example, if an ATM network is to be transported over an 802.16.1 system,ATM switched virtual circuits negotiate QoS parameters for the circuit. TheATM Convergence Layer participates in the signaling protocol that sets up the connection and request the proper QoS.

Similarly, a QoS-based IP network may employ the Resource Reservation Protocol (RSVP) [RFC-2205] to signal the allocation of resources along a routed IP path. If 802.16.1 is to be a link in the IP network, the IP Convergence Layer interfaces with the MAC to negotiate resource allocation.

1.12 Management

As outlined in IEEE Std 802-1990 [IEEE802], The LLC Sublayer, MAC Sublayer and Physical Layer standards also include a management component that specifies managed objects and aspects of the protocol machine that provide the management view of managed resources. The aspect of management considered are:

- Fault management
- Configuration management
- Accounting management
- Performance management (see also section 1.10)
- Security management (see also section 1.13)

The 802 standards define a framework for LAN/MAN management in ISO/IEC 15802-2: 1995(E). The framework contains guidelines for managed objects, management protocol, and the relationship to ITU management protocols (CMIP/CMIS).

1.12.1 Service Level Agreements

The 802.16.1 protocol permits network operators to enforce service level agreements (SLAs) with subscribers by restricting access to the air link, discarding data, or dynamically controlling bandwidth available to a user. Subscribers are also able to measure performance provided at the delivery point.

1.12.2 Accounting and Auditing

The 802.16.1 system management framework, architecture, protocols and managed objects allow for operators to effectively administer accounting and auditing. An operator is able to account for time- and bandwidth-utilization and the various QoS parameters for each subscriber.

1.13 Security

The 802.16.1 system enforces security procedures described in this section.

1.13.1 Authentication

There are two levels of authentication for an 802.16.1 system. The first level of authentication is when the SS authenticates itself with the BS at the SS's network entry. This initial authentication prevents an SS from entering the network or an unauthorized BS from emulating a real BS. Once the initial authentication at this level is complete, further authentication at this level is less stringent. This level of authentication is supported by the 802.16.1 MAC layer.

A second level of authentication is between a specific subscriber and the BWA system, allowing access to the system by one of several subscribers served by the same SS. An additional level of authentication may exist to authenticate the subscriber with the SS.

1.13.2 Authorization

Authorization determines what services an authenticated subscriber is permitted to use. Each subscriber has a set of credentials that describe what the subscriber is contractually permitted to do. The 802.16.1 standard identifies a standard set of credentials and allows for vendors to extend the defined credentials with additional ones.

1.13.3 Privacy

Privacy protects transmitted data from being intercepted and understood by third parties (e.g., an unauthorized SS, BS or a passively listening radio). The 802.16.1 standard allows a strong cryptographic algorithm to be employed that is internationally applicable. Facilities are also defined in the protocol for the use of alternate cryptographic algorithms that can be used in certain localities and that can replace algorithms as they are obsoleted or “legalized” for international use.

1.14 IEEE 802 Architectural Conformance

As mentioned earlier in this document, 802.16.1 conforms to the 802 system model. Some specifics (see *IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture* (IEEE Std 802-1990) [IEEE802]) are:

The 802.16.1 MAC supports the 48-bit IEEE address format. An 802.16.1 system supports MAC multicast in the downstream direction only, not upstream.

The protocols support 802.1 bridging services and protocols, including support of virtual LAN tag and priority ID.

The protocols support encapsulation of 802.2 (LLC) by the MAC protocol .

Conform to the 802 conventions and structures for “interface primitives:” logical structures that are passed between protocol layers to invoke processes and transact data.

Address the 802 system management guidelines (see section Management).

Provide a MAC service interface that complies to 802 conventions.

1.15 MAC Services to the convergence sublayers (CL)

In a layered protocol system, the information flow across the boundaries between the layers can be defined in terms of primitives that represent different items of information and cause actions to take place. These primitives do not appear as such on the medium (the air interface) but serve to define more clearly the relations of the different layers. The semantics are expressed in the parameters that are conveyed with the primitives.

Since there are several sublayers, we can divide the primitives into those providing MAC services to the convergence sublayer above and a set of services provided to the external (non-802.16) layers above. The service access point (SAP) is shown in Figure 5.

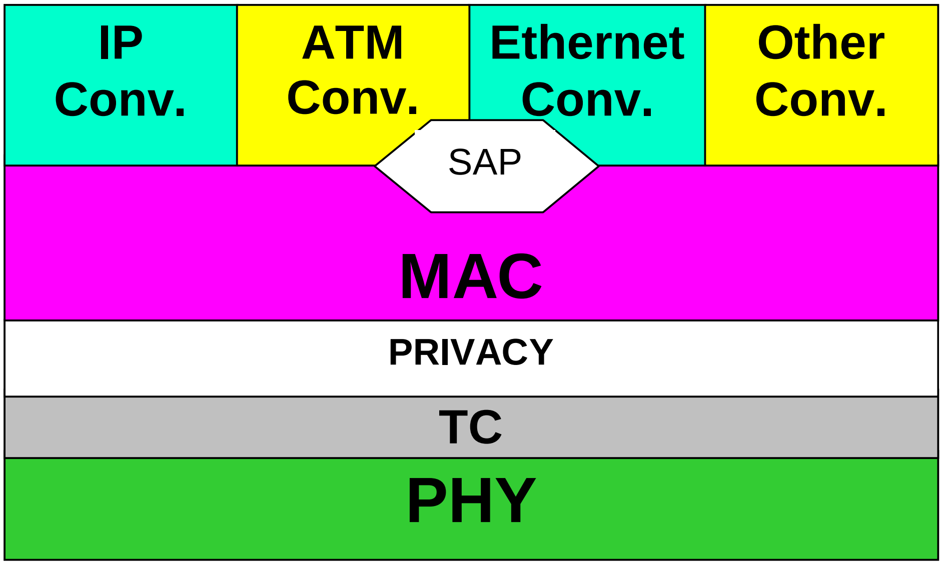


Figure 5—802.16.1 protocol layering, showing service access point.

1.15.1 Primitives

The IEEE 802.16 Medium Access Control layer supports the following primitives at the Service Access Point:

MAC-CREATE-CONNECTION.request
MAC-CREATE-CONNECTION.indication
MAC-CREATE-CONNECTION.response
MAC-CREATE-CONNECTION.confirmation

MAC-CHANGE-CONNECTION.request
MAC-CHANGE-CONNECTION.indication
MAC-CHANGE-CONNECTION.response
MAC-CHANGE-CONNECTION.confirmation

MAC-TERMINATE-CONNECTION.request
MAC-TERMINATE-CONNECTION.indication
MAC-TERMINATE-CONNECTION.response
MAC-TERMINATE-CONNECTION.confirmation

MAC-DATA.request
MAC-DATA.indication

The use of these primitives to provide peer communication is shown in Figure 6. The initial request for service from a lower layer is provided by the “request” primitive. When this request is sent across the air link to the peer MAC layer, it generates an “indicate” primitive to inform the peer convergence layer of the request; the convergence entity responds with a “response” to the MAC. Again this is sent across the the air link to the MAC on the originating side, which sends a “confirm” primitive to the original requesting entity.

In some cases, it is not necessary to send information to the peer station and the “confirm” primitive is issued directly by the MAC on the originating side. Such cases may occur, for example, when the request is rejected by the MAC on the requesting side. In cases where it is necessary to.to keep the other side of the link informed, an unsolicited “response” may be sent, in turn leading to the generation of an unsolicited “confirmation” for benefit of the convergence layer.

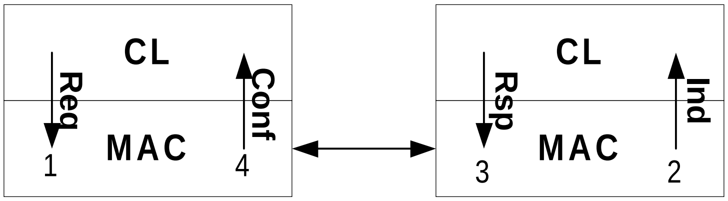


Figure 6—Use of primitives to request service of MAC layer and generate response.

For actions other than DATA.request and DATA.indication, the initiating CL sends a REQUEST primitive to its MAC layer. The initiating side MAC layer sends the appropriate Dynamic Service Request message (Addition, Change, or Deletion; see section 2.13.8) to the receiving MAC. The non-initiating side MAC sends an INDICATION primitive to its CL. The non-initiating CL responds with a RESPONSE primitive, stimulating its MAC to respond to the initiating side MAC with the appropriate Dynamic Service Response message. The initiating side MAC responds to its CL with a CONFIRMATION primitive and, if appropriate, with the appropriate Dynamic Service Acknowledge message. At any point along the way, the request may be rejected (for lack of resources, etc), terminating the protocol.

1.15.1.1 MAC-CREATE-CONNECTION.request

1.15.1.1.1 Function

This primitive is issued by a convergence layer entity in a BS or CPE unit to request the dynamic addition of a connection.

1.15.1.1.2 Semantics of the service primitive

The parameters of the primitive are as follows:

```
MAC-CREATE-CONNECTION.request
          (
          service type,
          convergence sublayer,
          traffic parameters,
          encryption indicator,
          CRC request,
          sequence number
          )
```

The service type is one of continuing grant, continuing grant with activity detection, real-time variable rate, non-real-time variable rate, and best efforts.

The convergence sublayer parameter indicates which convergence sublayer layer handles data received on this connection. If the value is 0, then no convergence layer is used; other values for specific convergence layers are given in the relevant annex for that convergence layer.

The traffic parameters include details on such issues as peak and average rate; or reference to a service flow. These parameters are the same as those in the Dynamic Service Change Request MAC management message.

The encryption indicator specifies that the data sent over this connection should be encrypted, if ON. If OFF, then no encryption is used.

CRC Request, if ON, requests that a CRC be added to MSDUs sent over this connection. If this parameter is OFF, then no CRC is added.

The sequence number is used to correlate this primitive with its response from the base station via the MAC.

1.15.1.1.3 When generated

This primitive is generated by a convergence layer of a BS or CPE unit to request the base station to set up a new connection.

1.15.1.1.4 Effect of receipt

If the primitive is generated on the CPE side, the receipt of this primitive causes the MAC to pass the request (in the form of a Dynamic Service Addition – Request message) to the MAC entity in the base station. The CPE MAC remembers the correlation between sequence number and the requesting convergence entity.

If the primitive is generated on the base station side, the base station checks the validity of the request, and if valid, it chooses a connection ID)and includes it in the Dynamic Service Addition – Request message (See section xxx) sent to the CPE. This CID will be returned to the requesting convergence layer via the CONFIRM primitive. If the primitive originated at the CPE, the actions of generating a CID and authenticating the request are deferred to the INDICATION/RESPONSE potion of the protocol.

1.15.1.2 MAC-CREATE-CONNECTION.indication

1.15.1.2.1 Function

This primitive is sent by the non-initiating MAC entity to the CL, to request the dynamic addition of a connection in response to the MAC layer receiving a Dynamic Service Addition - Request message. If the non-initiating MAC entity is at the base station, a CID is generated and the request is authenticated.

1.15.1.2.2 Semantics of the service primitive

The parameters of the primitive are as follows:

```
MAC-CREATE-CONNECTION.indication
          (
         service type,
         convergence sublayer,
         traffic parameters,
         sequence number
         )
```

Parameters: see MAC-CREATE-CONNECTION.request. The encryption and CRC flags are not delivered with the .indication primitive since they will have already been acted on by lower layers, to decrypt the data or to check a CRC, before the PDU is passed up to the convergence sublayer.

1.15.1.2.3 When generated

This primitive is generated by the MAC layer of the non-initiating side of the protocol when it receives a Dynamic Service Addition – Request message from the initiating side of the connection.

1.15.1.2.4 Effect of receipt

When the CL this primitive from , it checks the validity of the request from the point of view of its own resources. It accepts or rejects the request via the MAC-CREATE-CONNECTION.RESPONSE primitive, and enters the CID into appropriate algorithms.

If the connection request originated on the CPE side, the BS sends the CID to the CPE side in this RESPONSE primitive. Otherwise, if the origin was the base station, the RESPONSE contains the CID contained in the INDICATION.

1.15.1.3 MAC-CREATE-CONNECTION.response

1.15.1.3.1 Function

This primitive is issued by a non-initiating MAC entity in response to a MAC-CREATE-CONNECTION.INDICATION requesting the creation of a new connection.

1.15.1.3.2 Semantics of the service primitive

The parameters of the primitive are as follows:

```
MAC-CREATE-CONNECTION.response
        (
        connection ID,
        response code,
        response message,
        sequence number,
        ARQ parameters
        )
```

The connection ID is returned to the requester for use with the traffic specified in the request. If the request is rejected, then this value shall be NULL.

The response code indicates success or the reason for rejecting the request.

The response message provides additional information to the requester, in TLV format.

The sequence number is returned to the requesting entity to correlate this response with the original request.

The ARQ parameters are: whether ARQ is used or not for the connection, maximum re-transmission limit and acknowledgment window size.

1.15.1.3.3 When generated

This primitive is generated by the non-initiating CL entity when it has received a MAC-CREATE-CONNECTION.indication.

1.15.1.3.4 Effect of receipt

The receipt of this primitive causes the CPE MAC layer to send the Dynamic Service Addition-Response message to the requesting MAC entity. Once the Dynamic Service Addition – Acknowledgement is received, the MAC is prepared to pass data for this connection on to the air link.

1.15.1.4 MAC-CREATE-CONNECTION.confirmation

1.15.1.4.1 Function

This primitive confirms to a convergence entity that a requested connection has been provided. It informs the CL of the status of its request and provides a CID fro the success case.

1.15.1.4.2 Semantics of the service primitive

The parameters of the primitive are as follows:

MAC-CREATE-CONNECTION.confirmation
(
connection ID,
response code,
response message,
sequence number
)

Parameters: see MAC-CREATE-CONNECTION.response

1.15.1.4.3 When generated

This primitive is generated by the initiating side MAC entity when it has received a Dynamic Service Addition – response message.

1.15.1.4.4 Effect of receipt

The receipt of this primitive informs the convergence entity that the requested connection is available, and it may initiate requests for transmission over it.

1.15.1.5 Changing an existing connection

Existing connections may be changed in their characteristics on a dynamic basis, for example to reflect changing bandwidth requirements. The following primitives are used:

MAC-CHANGE-CONNECTION.request
MAC-CHANGE-CONNECTION.indication
MAC-CHANGE-CONNECTION.response
AC-CHANGE-CONNECTION.confirmation

The semantics and effect of receipt of these primitives are the same as for the corresponding CREATE primitives, except that a new connection ID is not generated.

1.15.1.6 MAC-TERMINATE-CONNECTION.request

1.15.1.6.1 Function

This primitive is issued by a convergence layer entity in a BS or CPE unit to request the termination of a connection.

1.15.1.6.2 Semantics of the service primitive

The parameters of the primitive are as follows:

```
MAC-TERMINATE-CONNECTION.request
        (
        connection ID
        )
```

The connection ID parameter specifies which connection is to be terminated.

1.15.1.6.3 When generated

This primitive is generated by a convergence layer of a BS or CPE unit to request the termination of an existing connection.

1.15.1.6.4 Effect of receipt

If the primitive is generated on the CPE side, the receipt of this primitive causes the MAC to pass the request to the MAC entity in the base station via the Dynamic Service Deletion – Request message. The base station checks the validity of the request, and if it is valid it terminates the connection.

If the primitive is generated on the base station side, it has already been validated and the base station MAC informs the CPE by issuing a Dynamic Service Deletion – Request message.

1.15.1.7 MAC-TERMINATE-CONNECTION.indication

1.15.1.7.1 Function

This primitive is issued by a the MAC entity on the non-initiating side to request the termination of a connection in response to the receipt of a Dynamic Service Deletion – Request message.

1.15.1.7.2 Semantics of the service primitive

The parameters of the primitive are as follows:

```
MAC-TERMINATE-CONNECTION.indication
        (
        connection ID
        )
```

The connection ID parameter specifies which connection is to be terminated.

1.15.1.7.3 When generated

This primitive is generated by the MAC layer when it receives a Dynamic Service Deletion - request message to terminate a connection, or when it finds it necessary for any reason to terminate a connection.

1.15.1.7.4 Effect of receipt

If the protocol was initiated by the CPE, when it receives this primitive, the base station checks the validity of the request. In any case, the receiving CL returns the MAC-TERMINATE-CONNECTION.response primitive, and deletes the connection ID from the appropriate polling and scheduling lists.

1.15.1.8 MAC-TERMINATE-CONNECTION.response

1.15.1.8.1 Function

This primitive is issued by a CL entity in response to a request for the termination of a connection.

1.15.1.8.2 Semantics of the service primitive

The parameters of the primitive are as follows:

MAC-TERMINATE-CONNECTION.response
(
connection ID,
response code,
response message
)

The connection ID is returned to the requesting entity.

The response code indicates success or the reason for rejecting the request.

The response message provides additional information to the requester, in TLV format.

1.15.1.8.3 When generated

This primitive is generated by the CL entity when it has received a MAC-TERMINATE-CONNECTION.INDICATION from its MAC layer.

1.15.1.8.4 Effect of receipt

The receipt of this primitive causes the MAC layer to pass the message to the initiating side via the Dynamic Service Deletion – Response message. The initiating MAC in turn passes the CONFIRM primitive to the requesting convergence entity. The convergence entity may no longer use this connection ID for data transmission

1.15.1.9 MAC-TERMINATE-CONNECTION.confirmation

1.15.1.9.1 Function

This primitive confirms to a convergence entity that a requested connection has been terminated.

1.15.1.9.2 Semantics of the service primitive

The parameters of the primitive are as follows:

MAC-TERMINATE-CONNECTION.confirmation
(
connection ID,
response code,

response message
)

Parameters: see MAC-TERMINATE-CONNECTION.response.

1.15.1.9.3 When generated

This primitive is generated by the MAC entity when it has received a Dynamic Service Deletion – response message.

1.15.1.9.4 Effect of receipt

The receipt of this primitive informs the convergence entity that a connection has been terminated. The convergence entity may no longer use this connection ID for data transmission.

1.15.1.10 MAC-DATA.request

1.15.1.10.1 Function

This primitive defines the transfer of data to the MAC entity from a convergence layer service access point.

1.15.1.10.2 Semantics of the service primitive

The parameters of the primitive are as follows:

MAC-DATA.request
(
connection ID,
length,
data,
discard-eligible flag,
encryption flag
)

The connection ID parameter specifies the connection over which the data is to be sent; the service class is implicit in the connection ID.

The length parameter specifies the length of the MSDU in bytes.

The data parameter specifies the MSDU as received by the local MAC entity. The length of the MSDU shall be less than 2048 bytes.

The discard-eligible flag specifies whether the PDU should be preferentially discarded in the event of link congestion and consequent buffer overflow.

The encryption flag specifies that the data sent over this connection should be encryption, if ON. If OFF, then no encryption is used.

1.15.1.10.3 When generated

This primitive is generated by a convergence layer whenever an MSDU is to be transferred to a peer entity or entities.

1.15.1.10.4 Effect of receipt

The receipt of this primitive causes the MAC entity to process the MSDU through the MAA sublayer and pass the appropriately formatted PDUs to the PHY/TC for transfer to peer MAC layer entities, using the connection ID specified.

1.15.1.11 MAC-DATA.indication

1.15.1.11.1 Function

This primitive defines the transfer of data from the MAC to the convergence layer. The specific convergence layer which will receive the indicate message is implicit in the connection ID.

1.15.1.11.2 Semantics of the service primitive

The parameters of the primitive are as follows:

```
MAC-DATA.indication
        (
        connection ID,
        length,
        data,
        reception status,
        encryption flag
        )
```

The connection ID parameter specifies the connection over which the data was sent.

The length parameter specifies the length of the data unit in bytes.

The data parameter specifies the MSDU as received by the local MAC entity.

The reception status parameter indicates transmission success or failure for those frames received via the MAC-DATA.indication. ERROR is reported if DISCARD_FAILURES is OFF; otherwise errored or uncorrectable data units are discarded without generating the MAC-DATA.indication.

The encryption flag specifies that the data sent over this connection should be encryption, if ON. If OFF, then no encryption is used.

1.15.1.11.3 When generated

This primitive is generated whenever an MSDU is to be transferred to a peer convergence entity or entities.

1.15.1.11.4 Effect of receipt

The effect of receipt of this primitive by a convergence entity is dependent on the validity and content of the MSDU. The choice of convergence layer is determined by the connection ID over which the MSDU was sent.

2 Medium Access Control

In a network that utilizes a shared medium, there must be a mechanism to provide an efficient way to share the medium. A two-way point-to-multipoint wireless network is a good example of a shared medium: here the medium is the space through which the radio waves propagate.

The downlink, from the base station to the user operates on a point-to-multipoint basis. The 802.16.1 wireless link operates with a central base station and a sectorized antenna which is capable of handling multiple independent sectors simultaneously. Within a given frequency channel and antenna sector, all stations receive the same transmission. The base station is the only transmitter operating in this direction, hence it can transmit without having to coordinate with other stations, except for the overall time-division duplexing that divides time into upstream and downstream transmission periods. It broadcasts to all stations in the sector (and frequency); stations check the address in the received messages and retain only those addressed to them.

However, the user stations share the upstream period on a demand basis. Depending on the class of service utilized, the SS may be issued continuing rights to transmit, or the right to transmit may be granted by the base station after receipt of a request from the user.

In addition to individually-addressed messages, messages may also be sent to multicast groups (control messages and video distribution are examples of multicast applications) as well as broadcast to all stations.

Within each sector, users must adhere to a transmission protocol which minimizes contention between users and enables the service to be tailored to the delay and bandwidth requirements of each user application.

This is accomplished through five different types of upstream scheduling mechanism, which are implemented using unsolicitied bandwidth grants, polling, and contention procedures. Mechanisms are defined in the protocol to allow vendors to optimize system performance using different combinations of these bandwidth allocation techniques while maintaining consistent inter-operability definitions. For example, contention can be cidused to avoid the individual polling of SSs which have been inactive for a long period of time.

The use of polling simplifies the access operation and guarantees that applications receive service on a deterministic basis if it is required. In general, data applications are delay tolerant, but real-time applications like voice and video require service on a more uniform basis, and sometimes on a very tightly-controlled schedule.

2.1 Connections and Service Flows

2.1.1 Definitions

2.1.1.1 Service Flows

The concept of Service Flows is central to the operation of the MAC protocol. Service Flows provide a mechanism for upstream and downstream Qconnection iduality of Service management. In particular, they are integral to bandwidth allocation.

A Service Flow ID defines a particular unidirectional mapping between a SS and the BS. Active Upstream Service Flow IDs also have associated Connection IDs or CIDs. Upstream bandwidth is allocated to CIDs, and hence to SSs, by the BS. Connection IDs provide the mechanism by which upstream Quality of Service is implemented.

The BS MAY assign one or more Service Flow IDs (SFIDs) to each SS, corresponding to the Service Flows required by the SS. This mapping can be negotiated between the BS and the SS during SS registration or via-dynamic service establishment (refer to Section 5.5.1).

In a basic SS implementation, two Service Flows (one upstream, one downstream) could be used, for example, to offer best-effort IP service. However, the Service Flow concept allows for more complex SSs to be developed with support for multiple service classes while supporting interoperability with more basic modems. With these more complex modems, it is possible that certain Service Flows will be configured in such a way that they cannot carry all types of traffic. That is, they may have a maximum packet size limitation or be restricted to small fixed size unsolicited grants. Furthermore it might not be appropriate to send other kinds of data on Service Flows that are being used for Constant Bit Rate (CBR)-type applications.

Even in these complex modems, it is necessary to be able to send certain upstream packets needed for MAC management, SNMP management, key management, etc. For the network to function properly, all SSs MUST support at least one upstream and one downstream Service Flow. These Service Flows MUST always be provisioned to allow the SS to request and to send the largest possible unconcatenated MAC frame (refer to Section 5.3.4.3.5). These Service Flows are referred to as the upstream and downstream Primary Service Flows. The CID assigned to the upstream Primary Service Flow is referred to as the Primary CID.

The Primary CID MUST always be assigned to the first provisioned upstream Service Flow during the registration process (which may or may not be the same temporary CID used for the registration process). The Primary Service Flows MUST be immediately activated at registration time. The Primary CID MUST always be used for station maintenance after registration. The Primary Service Flows MAY be used for traffic. All unicast Service Flows MUST use the security association defined for the Primary Service Flow.

All Service Flow IDs are unique within a single MAC-sublayer domain. The length of the Service Flow ID is 32 bits. The length of the Connection ID is 14 bits (although the Connection ID is sometimes carried in the low-order bits of a 16-bit field).

2.1.1.2 Upstream Intervals, Mini-Slots and System Time

The upstream transmission time-line is divided into intervals by the upstream bandwidth allocation mechanism. Each interval is an integral number of mini-slots. A “mini-slot” is the unit of granularity for upstream

transmission opportunities. There is no implication that any PDU can actually be transmitted in a single mini-slot. Each interval is labeled with a usage code which defines both the type of traffic that can be transmitted during that interval and the physical-layer modulation encoding. A single mini-slot’s duration in time is the upstream clock tick x 64. The size of a mini-slot is set at a power-of-two multiple ranging from 1 to 8, i.e., 2,..,256. 1 The relationship between mini-slots, bytes, and time ticks is described further in Section 5.4.1.3. The usage code values are defined in Table 5-23 and allowed use is defined in Section 5.3.3. The binding of these values to physical-layer parameters is defined in Table 5-21..2000-04-14 IEEE 802.16.1mc-00/14r0

2.1.1.3 Frame

A frame is a unit of data exchanged between two (or more) entities at the Data Link Layer. A MAC frameconsists of a MAC Header (beginning with a Frame Control byte; see Figure 5-3), and may incorporate either a variable-length data PDU, a mutliple ATM cell PDU, or a generic user data PDU. The variable-length PDU includes a pair of 48-bit addresses, data, and a CRC. The multiple ATM cell PDU carries one or more ATM cells.

The generic user data PDU may beused to exchange data using a protocol defined in a convergence sublayer above the MAC proper. In special cases, the MAC Header may encapsulate multiple MAC frames (see Section 5.3.4.3.5) into a single MAC frame.

5.3.1.2.4 Ordering of Bits and Bytes

Within a byte, the least-significant bit is the first transmitted on the wire. This follows the convention used by Ethernet and [IEEE802.3]. This is often called bit-little-endian order. This applies to the upstream channel only.

For the downstream channel, the transmission convergence sublayer presents an byte-wide interface to the MAC, so the MAC sublayer does not define the bit order.

Within the MAC layer, when numeric quantities are represented by more than one byte (i.e., 16-bit and 32-bit values), the byte containing the most-significant bits is the first transmitted on the wire. This is sometimes called byte-big-endian order.

This section follows the textual convention that when bit-fields are presented in tables, the most-significant bits are topmost in the table. For example, in Table 5-2, FC_TYPE occupies the two most-significant bits and EHDR_ON occupies the least-significant bit. quantities are The MAC is connection-oriented. For the purposes of mapping to services on SSs and associating varying levels of QoS, all data communications are in the context of a connection. These connections are provisioned when a SS is installed in the system, and set up over the air at SS registration to provide a reference against which to request bandwidth. Additionally, new connections may be established when customer's service needs change. A connection defines both the mapping between peer convergence processes that utilize the MAC and a Service Flow. The Service Flow defines the QoS parameters for the PDUs that are exchanged on the connection.

The concept of a Service Flow on a Connection is central to the operation of the MAC protocol. Service Flows provide a mechanism for upstream and downstream Quality of Service management. In particular, they are integral to the bandwidth allocation process. A SS requests upstream bandwidth on a per-connection basis (implicitly identifying the Service Flow). Bandwidth is granted by the BS either as an aggregate of all grants for a SS (within a scheduling interval) or on a connection basis.

Once connections are established they must be maintained. The maintenance requirements vary depending upon the type of service connected. For example, unchannelized T1 services require virtually no connection maintenance since they have a constant bandwidth allocated every frame. Channelized T1 services require some maintenance due to the dynamic (but relatively slowly changing) bandwidth requirements if compressed, coupled with the requirement that full bandwidth be available on demand. IP services may require a substantial amount of ongoing maintenance due to their bursty nature and due to the high possibility of fragmentation across frames. As with connection establishment, modifiable connections may require maintenance due to stimulus from either the SS or the network side of the connection.

Finally, connections may be terminated. This generally occurs only when a customer's service contract changes. The termination of a connection is stimulated by the BS or SS.

All three of these connection management functions are supported throught the use of static configuration and dynamic addition, modification, and deletion of connections.

2.1.2 Addressing and Connection Identifiers

Each SS shall maintain a 48-bit MAC address for globally-unique addressing purposes. This address uniquely defines the SS from within the set of all possible vendors and equipment types. This address is used during the registration process to establish the appropriate connections for a SS. It is also used as part of the authentication process by which the BS and SS each verify the identity of each other.

Connections are identified by a 16-bit Connection Identifier. Every SS must establish at least two connections in each direction (upstream and downstream) to enable communication with the BS. The Basic Connection IDs assigned to a SS at registration are used by the BS MAC and the SS MAC to exchange MAC control messages. The secondary management connection ID, also assigned to a SS at registration, is used by the BS MAC and the SS MAC to exchange provisioning and higher level management information.

For bearer services, the higher layers of the BS set up connections based upon the provisioning information distributed to the base station. The registration of a SS, or the modification of the services contracted at a SS, stimulates the higher layers of the BS to initiate the setup of the connections.

The CID can be considered a connection identifier even for nominally connectionless traffic likeIP, since it serves as a pointer to destination and context information. The use of a 16-bit CIDpermits a total of 64K connections within the downstream channel.

Requests for transmission are based on these CIDs, since the allowable bandwidth may differ for different connections, even within the same service type. For example, a SS unit serving multiple tenants in an office building would make requests on behalf of all of them, though the contractual service limits and other connection parameters may be different for each of them.

Many higher-layer sessions may operate over the same wireless CID. For example, many users within a company may be communicating with TCP/IP to different destinations, but since they all operate within the same overall service parameters, all of their traffic is pooled for request/grant purposes. Since the original LAN source and destination addresses are encapsulated in the payload portion of the transmission, there is no problem in identifying different user sessions.

The type of service is implicit in the CID; it is accessed by a lookup indexed by the CID.

There are several CIDs defined in Table 1 that having specific meaning. These identifiers shall not be used for any other purposes.

Table 1—Connection Identifiers

Connection Identifier	Value	Description
Initial Ranging	0x0000	Used by a SS during initial ranging as part of network entry process.
Temporary Registration and Basic CID	0x0001..m	
Transport CIDs and Secondary Mgt CIDs	m+1..0xFDFF	
Priority Request CIDs	0xFEXX	Request Information Element Usage If 0x01 bit is set, priority zero can request If 0x02 bit is set, priority one can request If 0x04 bit is set, priority two can request If 0x08 bit is set, priority three can request If 0x10 bit is set, priority four can request If 0x20 bit is set, priority five can request If 0x40 bit is set, priority six can request If 0x80 bit is set, priority seven can request
Multicast Polling CIDs	0xFF00..0xFFFE	A SS may be included in one or more multicast groups for the purposes of obtaining bandwidth via polling. These connections have no associated Service Flow.
Broadcast CID	0xFFFF	Used for broadcast information that is transmitted on a downlink to all SS.

2.2 Parameters and Constants

The BS and SS shall meet the timing requirements contained in Table 2.

Table 2—Parameters and Constants

System	Name	Time Reference	Minimum Value	Default Value	Maximum Value
BS	Sync Interval	Nominal time between transmission of SYNC messages			200 msec
BS	UCD Interval	Time between transmission of UCD messages			2 sec
BS	Max MAP Pending	The number of mini-slots that a BS is allowed to map into the future)			4096 mini-slot times
BS	Ranging Interval	Time between transmission of broadcast Ranging requests			2 sec
SS	Lost DL-MAP Interval	Time since last received Sync message before synchronization is considered lost			600 msec
SS	Contention Ranging Retries	Number of Retries on contention Ranging Requests	16		
SS, BS	Invited Ranging Retries	Number of Retries on inviting Ranging Requests	16		
SS	Request Retries	Number of retries on bandwidth allocation requests	16		
SS	Registration Request Retries	Number of retries on registration requests	3		
SS	Data Retries	Number of retries on immediate data transmission	16		
BS	SS UL-MAP processing time	Time provided between arrival of the last bit of a UL-MAP at a SS and effectiveness of that MAP	200 us		
BS	SS Ranging Response processing time	Minimum time allowed for a SS following receipt of a ranging response before it is expected to reply to an invited ranging request	1 msec		

Table 2—Parameters and Constants

System	Name	Time Reference	Minimum Value	Default Value	Maximum Value
BS	SS Configuration	The maximum time allowed for a SS, following receipt of a configuration file, to send a Registration Request to a BS.	30 sec		
SS	T1	Wait for Physical Change Descriptor DCD timeout			5 *DCD interval maximum value
SS	T2	Wait for broadcast ranging timeout			5 * ranging interval
SS	T3	Wait for ranging response	50 msec	200 msec	200 msec
SS	T4	Wait for unicast ranging opportunity. If the pending-till-complete field was used earlier by this SS, then the value of that field must be added to this interval.	30 sec		35 sec
BS	T5	Wait for Upstream Channel Change response			2 sec
SS	T6	Wait for registration response			3 sec
SS, BS	Mini-slot size	Size of mini-slot for upstream transmission. Must be a power of 2 (in units of the Timebase Tick)	32 symbol times		
SS, BS	Timebase Tick	System timing unit	¼ Symbol		
SS, BS	DSx Request Retries	Number of Timeout Retries on DSA/DSC/DSD Requests		3	
SS, BS	DSx Response Retries	Number of Timeout Retries on DSA/DSC/DSD Responses		3	
SS, BS	T7	Wait for DSA/DSC/DSD Response timeout			1 sec

Table 2—Parameters and Constants

System	Name	Time Reference	Minimum Value	Default Value	Maximum Value
SS, BS	T8	Wait for DSA/DSC Acknowledge timeout			300 msec
SS	TFTP Backoff Start	Initial value for TFTP backoff	1sec		
SS	TFTP Backoff End	Last value for TFTP backoff	16 sec		
SS	TFTP Request Retries	Number of retries on TFTP request	16		
SS	TFTP Download Retries	Number of retries on entire TFTP downloads	3		
SS	TFTP Wait	The wait between TFTP retry sequences	10 min		
SS	ToD Retries	Number of Retries per ToD Retry Period	3		
SS	ToD Retry Period	Time period for ToD retries	5 min		
BS	T9	Registration Timeout, the time allowed between the BS sending a RNG-RSP (success) to a SS, and receiving a REG-REQ from that same SS.	15 min	15 min	
SS, BS	T10	Wait for Transaction End timeout			3 sec

2.3 Encodings for Configuration and MAC-Layer Messaging

The following type/length/value encodings shall be used in both the configuration file (see Section 2.4), in SS registration requests and in Dynamic Service Messages. All multi- quantities are in network-byte order, i.e., the containing the most-significant bits is the first transmitted on the wire.

The following configuration settings shall be supported by all SSs which are compliant with this specification.

2.3.1 Configuration File and Registration Settings

Registration settings are found in the configuration file and shall be forwarded by the SS to the BS in its Registration Request.

In the following sections , length is in bytes.

2.3.1.1 Downstream Frequency Configuration Setting

The receive frequency to be used by the SS. It is an override for the channel selected during scanning. This is the center radio frequency of the downstream channel in kHz stored as a 32-bit binary number.

Type	**Length**	**Value**
1	4	Rx Frequency

Valid Range:
The receive frequency shall be a multiple of 1000 Hz.

2.3.1.2 Upstream Channel ID Configuration Setting

The upstream channel ID which the SS shall use. The SS shall listen on the defined downstream channel until an upstream channel description message with this ID is found. This channel is an override for the channel selected during initialization.

Type	**Length**	**Value**
2	1	Channel ID

2.3.1.3 Network Access Control Object (NACO)

If the value field is a 1, Subscriber Network Equipment attached to this SS are allowed access to the network, based on SS provisioning. If the value of this field is a 0, the SS shall not forward traffic from attached Subscriber Equipment to the MAC network, but shall continue to accept and generate traffic from the SS itself. The value of this field does not affect BS service flow operation and does not affect BS data forwarding operation.

Type	**Length**	**Value**
3	1	1 or 0

Note: The intent of “NACO = 0” is that the SS does not forward traffic from any attached Subscriber Network Equipment onto the BWA network. (A Subscriber is any client device attached to that SS, regardless of how that attachment is implemented.) However, with “NACO = 0”, management traffic to the SS is not restricted. Specifically, with NACO= 0, the SS remains manageable, including sending/receiving management traffic such as (but not limited to):

- ARP: allow the SS to resolve IP addresses, so it can respond to queries or send traps.
- DHCP: allow the SS to renew its IP address lease.
- ISSP: enable network troubleshooting for tools such as “ping” and “traceroute.”
- ToD: allow the SS to continue to synchronize its clock after boot.
- TFTP: allow the SS to download either a new configuration file or a new software image.
- SYSLOG: allow the SS to report network events.
- SNMP: allow management activity

With NACO = 0, the primary upstream and primary downstream service flows of the SS remain operational only for management traffic to and from the SS. With respect toBWA provisioning, a BS should ignore the NACO value and allocate any service flows that have been authorized by the provisioning server.

2.3.1.4 Downstream Modulation Configuration Setting

The allowed downstream modulation types.

Type	Length	Value
4	1	bit #0: QPSK
		bit #1: 16-QAM
		bit #2: 64-QAM
		bit #3-7: reserved must be set to zero

2.3.1.5 SS Message Integrity Check (MIC) Configuration Setting

The value field contains the SS message integrity check code. This is used to detect unauthorized modification or corruption of the configuration file.

Type	Length	Value
6	16	d1 d2....... d16

2.3.1.6 BS Message Integrity Check (MIC) Configuration Setting

The value field contains the BS message integrity check code. This is used to detect unauthorized modification or corruption of the configuration file.

Type	Length	Value
7	16	d1 d2....... d16

2.3.1.7 Trivial File Transfer Protocol (TFTP) Server Timestamp

The sending time of the configuration file in seconds. The definition of time is as in [RFC-868]

Type	Length	Value
19	4	Number of seconds since 00:00 1 Jan 1900

Note: The purpose of this parameter is to prevent replay attacks with old configuration files.

2.3.1.8 TFTP Server Provisioned SS Address

The IP Address of the SS requesting the configuration file.

Type	Length	Value
20	4 or 16	IP Address

Note: The purpose of this parameter is to prevent IP spoofing during registration.

2.3.1.9 Upstream Service Flow Encodings

This field defines the parameters associated with upstream scheduling for one Service Flow. Refer to Section 2.3.5.1.

Type	Length	Value
24	n	

2.3.1.10 Downstream Service Flow Encodings

This field defines the parameters associated with downstream scheduling for one Service Flow. Refer to Section 2.3.5.2.

2.3.1.11 Privacy Enable

This configuration setting enables/disables Privacy on the Primary Service Flow and all other Service Flows for this SS.

Type	**Length**	**Value**
29	**1**	**0 — Disable** **1 — Enable**

The default value of this parameter is 1 — privacy enabled.

2.3.1.12 Vendor-Specific Information

Vendor-specific information for SSs, if present, shall be encoded in the vendor specific information field (VSIF) (code 43) using theVendor ID field (2.3.3.2) to specify which

tuples apply to which vendors products. The Vendor ID shall be the first TLV embedded inside VSIF. If the first TLV inside VSIF is not a Vendor ID, then the TLV must be discarded.

This configuration setting may appear multiple times. The same Vendor ID may appear multiple times. This configuration setting may be nested inside a Packet Classification Configuration Setting, a Service Flow Configuration Setting, or a Service Flow Response. However, there shall not be more than one Vendor ID TLV inside a single VSIF.

Type	**Length**	**Value**
43	n	per vendor definition

Example:

Configuration with vendor A specific fields and vendor B specific fields:

VSIF (43) + n (number of bytes inside this VSIF)
8 (Vendor IDType) + 3 (length field) +Vendor ID ofVendor A
Vendor A Specific Type #1 + length of the field +Value #1
Vendor A Specific Type #2 + length of the field +Value #2

VSIF (43) + m (number of bytes inside this VSIF)
8 (Vendor IDType) + 3 (length field) +Vendor ID ofVendor B
Vendor B Specific Type + length of the field + Value

2.3.2 Configuration-File-Specific Settings

These settings are found in only the configuration file. They shall not be forwarded to the BS in the Registration Request.

2.3.2.1 End-of-Data Marker

This is a special marker for end of data. It has no length or value fields.

Type
255

2.3.2.2 Pad Configuration Setting

This has no length or value fields and is only used following the end of data marker to pad the file to an integral number of 32-bit words.

Type
0

2.3.2.3 Software Upgrade Filename

The filename of the software upgrade file for the SS. The filename is a fully qualified directory-path name. The file is expected to reside on a TFTP server identified in a configuration setting option defined in Section 2.3.1.8.

Type	**Length**	**Value**
9	n	filename

2.3.2.4 SNMP Write-Access Control

This object makes it possible to disable SNMP “Set” access to individual MIB objects. Each instance of this object controls access to all of the writeable MIB objects whose Object ID (OID) prefix matches. This object may be repeated to disable access to any number of MIB objects.

Type	**Length**	**Value**
10	n	OID prefix plus control flag

Where n is the size of the ASN.1 Basic Encoding Rules [ISO8025] encoding of the OID prefix plus one byte for the control flag.

The control flag may take values:

0 - allow write-access
1 - disallow write-access

Any OID prefix may be used. The Null OID 0.0 may be used to control access to all MIB objects. (The OID 1.3.6.1 will have the same effect.)

When multiple instances of this object are present and overlap, the longest (most specific) prefix has precedence. Thus, one example might be

someTabledisallow write-access
someTable.1.3allow write-access

This example disallows access to all objects in someTable except for someTable.1.3.

2.3.2.5 SNMP MIB Object

This object allows arbitrary SNMP MIB objects to be Set via the TFTP-Registration process.

Type	**Length**	**Value**
11	n	variable binding

where the value is an SNMP VarBind as defined in [RFC-1157]. The VarBind is encoded in ASN.1 Basic Encoding Rules, just as it would be if part of an SNMP Set request.

The SS shall treat this object as if it were part of an SNMP Set Request with the following caveats:

It shall treat the request as fully authorized (it cannot refuse the request for lack of privilege).
SNMP Write-Control provisions (see previous section) do not apply.
No SNMP response is generated by the SS.

This object may be repeated with different VarBinds to “Set” a number of MIB objects. All such Sets shall be treated as if simultaneous.

Each VarBind shall be limited to 255 bytes.

2.3.2.6 Software Upgrade TFTP Server

The IP address of the TFTP server, on which the software upgrade file for the SS resides. See Section 2.3.2.3

Type	**Length**	**Value**
21	4 or16	ip1,ip2,ip3,ip4

2.3.3 Registration-Request/Response-Specific Encodings

These encodings are not found in the configuration file, but are included in the Registration Request. Some encodings are also used in the Registration Response.

The SS shall include SS Capabilities Encodings in its Registration Request. If present in the corresponding Registration Request, the BS shall include SS Capabilities in the Registration Response.

2.3.3.1 SS Capabilities Encoding

The value field describes the capabilities of a particular SS, i.e., implementation dependent limits on the particular features or number of features which the SS can support. It is composed from a number of encapsulated type/length/value fields. The encapsulated sub-types define the specific capabilities for the SS in question. Note that the sub-type fields defined are only valid within the encapsulated capabilities configuration setting string.

Type	**Length**	**Value**
5	n	

The set of possible encapsulated fields is described below.

2.3.3.1.1 Privacy Support

The value is the BPI support of the SS.

Type	**Length**	**Value**	
5.6	1	0	Privacy Supported
		1 - 255	Reserved

2.3.3.1.2 Upstream CID Support

The field shows the number of Upstream CIDs the SS can support.

Type	Length	Value
5.8	2	Number of Upstream CIDs the SS can support.

The minimum value is 2; a SS must support a basic CID, a secondary management CID, and 0 or more transport CIDs.

2.3.3.1.3 SS Demodulator Types

This field indicates the different modulation types supported by the SS for downstream reception.

Type	Length	Value
5.12	1	bit #0: QPSK bit #1: 16-QAM bit #2: 64-QAM bit #3-7: reserved must be set to zero

2.3.3.1.4 SS Modulator Types

This field indicates the different modulation types supported by the SS for upstream transmission.

Type	Length	Value
5.13	1	bit #0: QPSK bit #1: 16-QAM bit #2: 64-QAM bit #3-7: reserved must be set to zero

2.3.3.1.5 Duplexing Support

This field indicates the different duplexing modes the SS is able to support.

Type	Length	Value
5.14	1	bit #0: FDD (continuous downstream) bit #1: FDD (burst downstream) bit #2: Half-Duplex FDD bit #3: TDD bit #4-7: reserved must be set to zero

2.3.3.1.6 Bandwidth Allocation Support

This field indicates the different bandwidth allocation modes the SS is able to support.

Type	Length	Value
5.15	1	bit #0: Grant per Connection bit #1: Grant per Terminal (SS) bit #2-7: reserved must be set to zero

2.3.3.2 Vendor ID Encoding

The value field contains the vendor identification specified by the three-byte vendor-specific Organization Unique Identifier of the SS MAC address.

The Vendor ID shall be used in a Registration Request, but shall not be used as a stand-alone configuration file element. It may be used as a sub-field of the Vendor Specific Information Field in a configuration file.

When used as a sub-field of the Vendor Specific Information field, this identifies the Vendor ID of the SSs which are intended to use this information. When the vendor ID is used in a Registration Request, then it is the Vendor ID of the SS sending the request.

Type	**Length**	**Value**
8	3	v1, v2, v3

2.3.3.3 Service(s) Not Available Response

This configuration setting shall be included in the Registration Response message if the BS is unable or unwilling to grant any of the requested classes of service that appeared in the Registration Request. Although the value applies only to the failed service class, the entire Registration Request shall be considered to have failed (none of the class-of-service configuration settings are granted).

Type	**Length**	**Value**
13	3	Class ID, Type, Confirmation Code

Where

Class ID is the class-of-service class from the request which is not available

Type is the specific class-of-service object within the class which caused the request to be rejected

Confirmation CodeRefer to 2.3.7.

2.3.4 Dynamic-Service-Message-Specific Encodings

These encodings are not found in the configuration file, nor in the Registration Request/Response signaling. They are only found in Dynamic Service Addition, Dynamic Service Change and Dynamic Service Deletion Request/Response messages:

2.3.4.1 HMAC-Digest

The HMAC-Digest setting is a keyed message digest. If privacy is enabled, the HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service message’s Attribute list. The message digest is performed over the all of the Dynamic Service parameters (starting immediately after the MAC Management Message Header and up to, but not including the HMAC Digest setting), other than the HMAC-Digest, in the order in which they appear within the packet.

Inclusion of the keyed digest allows the receiver to authenticate the message. The HMAC-Digest algorithm, and the upstream and downstream key generation requirements are documented in Section 7.

This parameter contains a keyed hash used for message authentication. The HMAC algorithm is defined in [RFC-2104]. The HMAC algorithm is specified using a generic cryptographic hash algorithm. Baseline Privacy uses a particular version of HMAC that employs the Secure Hash Algorithm (SHA-1), defined in [SHA].

A summary of the HMAC-Digest Attribute format is shown below. The fields are transmitted from left to right.

Type	**Length**	**Value**
27	20	A 160-bit (20) keyed SHA hash

2.3.4.2 Authorization Block

The Authorization Block contains an authorization “hint” from the SS to the BS. The specifics of the contents of this “hint” are beyond the scope of this specification.

The Authorization Block may be present in SS-initiated DSA-REQ and DSC-REQ messages. This parameter shall not be present in DSA-RSP and DSC-RSP message, nor in BS-initiated DSA-REQ nor DSC-REQ messages.

The Authorization Block information applies to the entire contents of the DSC message. Thus, only a single Authorization Block may be present per DSA-REQ or DSC-REQ message. The Authorization Block, if present, shall be passed to the Authorization Module in the BS. The Authorization Block information is only processed by the Authorization Module.

Type	**Length**	**Value**
30	n	Sequence of n s

2.3.5 Quality-of-Service-Related Encodings

The following type/length/value encodings shall be used in the configuration file, registration messages, and Dynamic Service messages to encode parameters for Service Flows. All multi- quantities are in network-byte order, i.e., the containing the most-significant bits is the first transmitted on the wire.

The following configuration settings shall be supported by all SSs which are compliant with this specification.

2.3.5.1 Upstream Service Flow Encodings

This field defines the parameters associated with upstream scheduling for a Service Flow. It is somewhat complex in that is composed from a number of encapsulated type/length/value fields.

Note that the encapsulated upstream and downstream Service Flow configuration setting strings share the same subtype field numbering plan, because many of the subtype fields defined are valid for both types of configuration settings. These type fields are not valid in other encoding contexts.

Type	**Length**	**Value**
24	n	

2.3.5.2 Downstream Service Flow Encodings

This field defines the parameters associated with downstream scheduling for a Service Flow. It is somewhat complex in that is composed from a number of encapsulated type/length/value fields.

Note that the encapsulated upstream and downstream flow classification configuration setting strings share the same subtype field numbering plan, because many of the subtype fields defined are valid for both types of configuration settings except Service Flow encodings.

Type	**Length**	**Value**
25	n	

2.3.5.3 General Service Flow Encodings

2.3.5.3.1 Service Flow Reference

The Service Flow Reference is used to associate a packet classifier encoding with a Service Flow encoding. A Service Flow Reference is only used to establish a Service Flow ID. Once the Service Flow exists and has an assigned Service Flow ID, the Service Flow Reference shall no longer be used by the MAC.

Type	Length	Value
[24/25].1	2	1 - 65535

2.3.5.3.2 Service Flow Identifier

The Service Flow Identifier is used by the BS as the primary reference of a Service Flow. Only the BS can issue a Service Flow Identifier. It uses this parameterization to issue Service Flow Identifiers in BS-initiated DSA/DSC-Requests and in its REG/DSA/DSC-Response to SS-initiated REG/DSA/DSC-Requests. The SS specifies the SFID of a service flow using this parameter in a DSC-REQ message.

The configuration file shall not contain this parameter.

Type	Length	Value
[24/25].2	4	1 - 4,294,967,295

2.3.5.3.3 Connection Identifier

The value of this field specifies the Connection Identifier (CID) assigned by the BS to a Service Flow with a non-null AdmittedQosParameterSet or ActiveQosParameterSet. This is used in the bandwidth allocation MAP to assign upstream bandwidth. This field shall be present in BS-initiated DSA-REQ or DSC-REQ message related to establishing an admitted or active upstream Service Flow. This field shall also be present in REG-RSP, DSA-RSP and DSC-RSP messages related to the successful establishment of an admitted or active upstream Service Flow.

Even though a Service Flow has been successfully admitted or activated (i.e. has an assigned Connection ID) the Service Flow ID shall be used for subsequent DSx message signalling as it is the primary handle for a service flow. If a Service Flow is no longer admitted or active (via DSC-REQ) its Connection ID may be reassigned by the BS.

SubType	Length	Value
[24/25].3	2	CID

2.3.5.3.4 Service Class Name

The value of the field refers to a predefined BS service configuration to be used for this Service Flow.

Type	Length	Value
[24/25].4	2 to 16	Zero-terminated string of ASCII characters.

Note: The length includes the terminating zero.

When the Service Class Name is used in a Service Flow encoding, it indicates that all the unspecified QoS Parameters of the Service Flow need to be provided by the BS. It is up to the operator to synchronize the definition of Service Class Names in the BS and in the configuration file.

2.3.5.4 Service Flow Error Encodings

This field defines the parameters associated with Service Flow Errors.

Type	Length	Value
[24/25].5	n	

A Service Flow Error Parameter Set is defined by the following individual parameters: Confirmation Code, Errored Parameter and Error Message.

The Service Flow Error Parameter Set is returned in REG-RSP, DSA-RSP and DSC-RSP messages to indicate the recipient's response to a Service Flow establishment request in a REG-REQ, DSA-REQ or DSC-REQ message. The Service Flow Error Parameter Set is returned in REG-ACK, DSA-ACK and DSC-ACK messages to indicate the recipient's response to the expansion of a Service Class Name in a corresponding REG-RSP, DSA-RSP or DSC-RSP.

On failure, the sender shall include one Service Flow Error Parameter Set for each failed Service Flow requested in the REG-REQ, DSA-REQ or DSC-REQ message. On failure, the sender shall include one Service Flow Error Parameter Set for each failed Service Class Name expansion in the REG-RSP, DSA-RSP or DSC-RSP message. Service Flow Error Parameter Set for the failed Service Flow shall include the Confirmation Code and Errored Parameter and may include an Error Message. If some Service Flow Parameter Sets are rejected but other Service Flow Parameter Sets are accepted, then Service Flow Error Parameters Sets shall be included for only the rejected Service Flow.

On success of the entire transaction, the RSP or ACK message shall not include a Service Flow Error Parameter Set.

Multiple Service Flow Error Parameter Sets may appear in a REG-RSP, DSA-RSP, DSC-RSP, REG-ACK, DSA-ACK or DSC-ACK message, since multiple Service Flow parameters may be in error. A message with even a single Service Flow Error Parameter Set shall not contain any QoS Parameters.

A Service Flow Error Parameter Set shall not appear in any REG-REQ, DSA-REQ or DSC-REQ messages.

2.3.5.4.1 Errored Parameter

The value of this parameter identifies the subtype of a requested Service Flow parameter in error in a rejected Service Flow request or Service Class Name expansion response. A Service Flow Error Parameter Set shall have exactly one Errored Parameter TLV within a given Service Flow Encoding.

Subtype	Length	Value
[24/25].5.1	1	Service Flow Encoding Subtype in Error

2.3.5.4.2 Error Code

This parameter indicates the status of the request. A non-zero value corresponds to the Confirmation Code as described in 2.3.7. A Service Flow Error Parameter Set shall have exactly one Error Code within a given Service Flow Encoding.

Subtype	Length	Value
[24/25].5.2	1	Confirmation code

A value of okay(0) indicates that the Service Flow request was successful. Since a Service Flow Error Parameter Set only applies to errored parameters, this value shall not be used.

2.3.5.4.3 Error Message

This subtype is optional in a Service Flow Error Parameter Set. If present, it indicates a text string to be displayed on the SS console and/or log that further describes a rejected Service Flow request. A Service Flow Error Parameter Set may have zero or one Error Message subtypes within a given Service Flow Encoding.

SubType	**Length**	**Value**
[24/25].5.3	n	Zero-terminated string of ASCII characters.

Note: The length N includes the terminating zero.

Note: The entire Service Flow Encoding message must have a total length of less than 256 characters.

2.3.5.5 Common Upstream and Downstream Quality-of-Service Parameter Encodings

The remaining Type 24 & 25 parameters are QoS Parameters. Any given QoS Parameter type shall appear zero or one times per Service Flow Encoding.

2.3.5.5.1 Quality of Service Parameter Set Type

This parameter shall appear within every Service flow Encoding. It specifies the proper application of the QoS Parameter Set: to the Provisioned set, the Admitted set, and/or the Active set. When two QoS Parameter Sets are the same, a multi-bit value of this parameter may be used to apply the QoS parameters to more than one set. A single message may contain multiple QoS parameter sets in separate type 24/25 Service Flow Encodings for the same Service Flow. This allows specification of the QoS Parameter Sets when their parameters are diferent. Bit 0 is the LSB of the Value field.

For every Service Flow that appears in a Registration-Request or Registration-Response message, there shall be a Service Flow Encoding that specifies a ProvisionedQoSParameterSet. This Service Flow Encoding, or other Service Flow Encoding(s), may also specify an Admitted and/or Active set.

Type	**Length**	**Value**	
[24/25].6	1	Bit # 0	Provisioned Set
		Bit # 1	Admitted Set
		Bit # 2	Active Set

Table 3—Values Used in REG-REQ and REG-RSP Messages

Value	Messages
001	Apply to Provisioned set only
011	Apply to Provisioned and Admitted set, and perform admission control
101	Apply to Provisioned and Active sets, perform admission control, and activate this Service flow
111	Apply to Provisioned, Admitted, and Active sets; perform admission control and activate this Service Flow

Table 4—Values Used In Dynamic Service Messages

Value	Messages
000	Sect Active and Admitted sets to Null
010	Perform admission control and apply to Admitted set
100	Check against Admitted set in separate Service flow Encoding, perform admission control if needed, activate this Service Flow, and apply to Active set
110	Perform admission control and activate this Service Flow, apply parameters to both Admitted and Active sets

A BS shall handle a single update to each of the Active and Admitted QoS parameter sets. The ability to process multiple Service Flow Encodings that specify the same QoS parameter set is not required, and is left as a vendor-specific function. If a DSA/DSC contains multiple updates to a single QoS parameter set and the vendor does not support such updates, then the BS shall reply with error code 2, reject-unrecognized-configuration-setting.

2.3.5.5.2 Traffic Priority

The value of this parameter specifies the priority assigned to a Service Flow. Given two Service Flows identical in all QoS parameters besides priority, the higher priority Service Flow SHOULD be given lower delay and higher buffering preference. For otherwise non-identical Service Flows, the priority parameter SHOULD not take precedence over any conflicting Service Flow QoS parameter. The specific algorithm for enforcing this parameter is not mandated here.

For upstream service flows, the BS SHOULD use this parameter when determining precedence in request service and grant generation, and the SS shall preferentially select contention Request opportunities for Priority Request Connection IDs (refer to A.2.3) based on this priority and its Request/Transmission Policy (refer to Section 2.3.5.6.3).

Type	Length	Value
[24/25].7	1	0 to 7 — Higher numbers indicate higher priority

Note: The default priority is 0.

2.3.5.5.3 Maximum Sustained Traffic Rate

This parameter is the rate parameter R of a token-bucket-based rate limit for packets. R is expressed in bits per second, and must take into account all MAC frame data PDU of the Service Flow from the byte following the MAC header HCS to the end of the MAC PDU payload. The number of bytes forwarded (in bytes) is limited during any time interval T by Max(T), as described in the expression

Max(T) = T * (R / 8) + B, (1)

where the parameter B (in bytes) is the Maximum Traffic Burst Configuration Setting (refer to 2.3.5.5.6).

Note: This parameter does not limit the instantaneous rate of the Service Flow.

Note: The specific algorithm for enforcing this parameter is not mandated here. Any implementation which satisfies the above equation is conformant.

Note: If this parameter is omitted or set to zero, then there is no explicitly-enforced traffic rate maximum. This field specifies only a bound, not a guarantee that this rate is available.

2.3.5.5.4 Upstream Maximum Sustained Traffic Rate

For an upstream Service Flow, the SS shall not request bandwidth exceeding the Max(T) requirement in (1) during any interval T because this could force the BS to fill MAPs with deferred grants.

The SS shall defer upstream packets that violate (1) and “rate shape” them to meet the expression, up to a limit as implemented by vendor buffering restrictions.

The BS shall enforce expression (1) on all upstream data transmissions, including data sent in contention. The BS may concer unused grants in calculations involving this parameter. The BS may enforce this limit by any of the following methods: (a) discarding over-limit requests, (b) deferring (through zero-length grants) the grant until it is conforming to the allowed limit, or (c) discarding over-limit data packets. A BS shall report this condition to a policy module. If the BS is policing by discarding either packets or requests, the BS shall allow a margin of error between the SS and BS algorithms.

Type	**Length**	**Value**
24.8	4	R (in bits per second)

2.3.5.5.5 Downstream Maximum Sustained Traffic Rate

For a downstream Service Flow, this parameter is only applicable at the BS. The BS shall enforce expression (1) on all downstream data transmissions. The BS shall not forward downstream packets that violates (1) in any interval T. The BS SHOULD “rate shape” the downstream traffic by enqueuing packets arriving in excess of (1), and delay them until the expression can be met.

This parameter is not intended for enforcement on the SS.

Type	**Length**	**Value**
25.8	4	R (in bits per second)

2.3.5.5.6 Maximum Traffic Burst

The value of this parameter specifies the token bucket size B (in bytes) for this Service Flow as described in expression (1). This value is calculated from the byte following the MAC header HCS to the end of the MAC PDU payload.

Type	**Length**	**Value**
[24/25].9	4	B (bytes)

Note: The specific algorithm for enforcing this parameter is not mandated here. Any implementation which satisfies the above equation is conformant.

2.3.5.5.7 Minimum Reserved Traffic Rate

This parameter specifies the minimum rate, in bits/sec, reserved for this Service Flow. The BS SHOULD be able to satisfy bandwidth requests for a Service Flow up to its Minimum Reserved Traffic Rate. If less bandwidth than its Minimum Reserved Traffic Rate is requested for a Service Flow, the BS may reallocate the excess reserved bandwidth for other purposes. The aggregate Minimum Reserved Traffic Rate of all Service Flows may exceed the amount of available bandwidth. This value of this parameter is calculated from the byte following the MAC header HCS to the end of the MAC PDU payload. If this parameter is omitted, then it defaults to a value of 0 bits/sec (i.e., no bandwidth is reserved for the flow by default).

This field is only applicable at the BS and shall be enforced by the BS.

Type	Length	Value
[24/25].10	4	

Note: The specific algorithm for enforcing the value specified in this field is not mandated here.

2.3.5.5.8 Assumed Minimum Reserved Rate Packet Size

The value of this field specifies an assumed minimum packet size (in bytes) for which the Minimum Reserved Traffic Rate will be provided. This parameter is defined in bytes and is specified as the bytes following the MAC header HCS to the end of the CRC[2]. If the Service Flow sends packets of a size smaller than this specified value, such packets will be treated as being of the size specified in this parameter for calculating the minimum Reserved Traffic Rate and for calculating bytes counts (e.g. bytes transmitted) which may ultimately be used for billing.

The BS shall apply this parameter to its Minimum Reserved Traffic Rate algorithm. This parameter is used by the BS to estimate the per packet overhead of each packet in the service flow.

If this parameter is omitted, then the default value is BS implementation dependent.

Type	Length	Value
[24/25].11	2	

2.3.5.5.9 Timeout for Active QoS Parameters

The value of this parameter specifies the maximum duration resources remain unused on an active Service Flow. If there is no activity on the Service Flow within this time interval, the BS shall change the active QoS Parameter Sets to null. The BS shall signal this resource change with a DSC-REQ to the SS.

If defined, this parameter shall be enforced at the BS and SHOULD not be enforced at the SS.

Type	Length	Value
[24/25].12	2	seconds

The value of 0 means that the flow is of infinite duration and shall not be timed out due to inactivity. The default value is 0.

2.3.5.5.10 Timeout for Admitted QoS Parameters

The value of this parameter specifies the duration that the BS shall hold resources for a Service Flow's Admitted QoS Parameter Set while they are in excess of its Active QoS Parameter Set. If there is no DSC-REQ to activate the Admitted QoS Parameter Set within this time interval, the resources that are admitted but not activated shall be released, and only the active resources retained. The BS shall set the Admitted QoS Parameter Set equal to the Active QoS Parameter Set for the Service Flow and initiate a DSC-REQ exchange with the SS to inform it of the change.

If this parameter is omitted, then the default value is 200 seconds. The value of 0 means that the Service Flow can remain in the admitted state for an infinite amount of time and shall not be timed out due to inactivity. However, this is subject to policy control by the BS.

[2] The payload size includes every PDU in a Concatenated MAC Frame.

This parameter shall be enforced by the BS. The BS may set the response value less than the requested value.

Type	**Length**	**Value**
[24/25].13	2	seconds

2.3.5.5.11 Vendor Specific QoS Parameters

This allows vendors to encode vendor-specific QoS parameters. The Vendor ID shall be the first TLV embedded inside Vendor Specific QoS Parameters. If the first TLV inside Vendor Specific QoS Parameters is not a Vendor ID, then the TLV must be discarded. (Refer to 2.3.1.12)

Type	**Length**	**Value**
[24/25].43	n	

2.3.5.6 Upstream-Specific QoS Parameter Encodings

2.3.5.6.1 Service Flow Scheduling Type

The value of this parameter specifies which upstream scheduling service is used for upstream transmission requests and packet transmissions. If this parameter is omitted, then the Best Effort service shall be assumed.

This parameter is only applicable at the BS. If defined, this parameter shall be enforced by the BS.

Type	**Length**	**Value**
24.15	1	0 Reserved
		1 for Undefined (BS implementation-dependent[3])
		2 for Best Effort
		3 for Non-Real-Time Polling Service
		4 for Real-Time Polling Service
		5 for Unsolicited Grant Service with Activity Detection
		6 for Unsolicited Grant Service
		7 through 255 are reserved for future use
		Bit #2 Reserved
		Bit #3 Reserved

2.3.5.6.2 Nominal Polling Interval

The value of this parameter specifies the nominal interval (in units of microseconds) between successive unicast request opportunities for this Service Flow on the upstream channel. This parameter is typically suited for Real-Time and Non-Real-Time Polling Service.

The ideal schedule for enforcing this parameter is defined by a reference time t_0, with the desired transmission times $t_i = t_0 + i*interval$. The actual poll times, t'_i shall be in the range $t_i <= t'_i <= t_i + jitter$, where interval is the value specified with this TLV, and jitter is Tolerated Poll Jitter. The accuracy of the ideal poll times, t_i, are measured relative to the BS Master Clock used to generate timestamps (refer to Section 2.5.3).

This field is only applicable at the BS. If defined, this parameter shall be enforced by the BS.

[3] The specific implementation dependent scheduling service type could be defined in the message type 24.43, Vendor Specific Information Field.

Type	**Length**	**Value**
24.17	4	µsec

2.3.5.6.3 Request/Transmission Policy

The value of this parameter specifies a variety of uplink request and transmission restrictions, including the capability to further restrict the scheduling service rules outlined in Table 20. Each restriction is enabled by setting its associated bit to 1. If a bit is set to 0, the service flow uses the normal rules for the type of service flow (UGS, UGS/AD, etc.) Bit #0 is the LSB of the value field.

Type	**Length**	**Value**
24.16	4	Bit #0 – Service flow shall not use broadcast bandwidth request opportunities. Bit #1 – The service flow shall not use Priority Request multicast opportunities. Bit #2 – The service flow shall not piggyback requests with data. Bit #3 – The service flow shall not fragment data. Bit #4 – The service flow shall not suppress payload headers (convergence sublayer parameter) All other bit positions are reserved.

2.3.5.6.4 Tolerated Poll Jitter

The values in this parameter specifies the maximum amount of time that the unicast request interval may be delayed from the nominal periodic schedule (measured in microseconds) for this Service Flow.

The ideal schedule for enforcing this parameter is defined by a reference time t_0, with the desired poll times $t_i = t_0 + i*\text{interval}$. The actual poll, t'_i shall be in the range $t_i <= t'_i <= t_i + \text{jitter}$, where jitter is the value specified with this TLV and interval is the Nominal Poll Interval. The accuracy of the ideal poll times, t_i, are measured relative to the BS Master Clock used to generate timestamps (refer to Section 2.5.3).

This parameter is only applicable at the BS. If defined, this parameter represents a service commitment (or admission criteria) at the BS.

Type	**Length**	**Value**
24.18	4	µsec

2.3.5.6.5 Unsolicited Grant Size

The value of this parameter specifies the unsolicited grant size in bytes. The grant size includes the entire MAC PDU.

This parameter is applicable at the BS and shall be enforced at the BS.

Type	**Length**	**Value**
24.19	2	

Note: For UGS, this parameter should be used by the BS to compute the size of the unsolicited grant in minislots.

2.3.5.6.6 Nominal Grant Interval

The value of this parameter specifies the nominal interval (in units of microseconds) between successive data grant opportunities for this Service Flow. This parameter is required for Unsolicited Grant and Unsolicited Grant with Activity Detection Service Flows.

The ideal schedule for enforcing this parameter is defined by a reference time t_0, with the desired transmission times $t_i = t_0 + i*interval$. The actual grant times, t'_i shall be in the range $t_i <= t'_i <= t_i + jitter$, where interval is the value specified with this TLV, and jitter is the Tolerated Grant Jitter. When an upstream Service Flow with either Unsolicited Grant or Unsolicited Grant with Activity Detection scheduling becomes active, the first grant shall define the start of this interval, i.e. the first grant shall be for an ideal transmission time, t_i. When multiple grants per interval are requested, all grants shall be within this interval, thus the Nominal Grant Interval and Tolerated Grant Jitter shall be maintained by the BS for all grants in this Service Flow. The accuracy of the ideal grant times, t_i, are measured relative to the BS Master Clock used to generate timestamps (refer to Section 2.5.3).

This field is mandatory for Unsolicited Grant and Unsolicited Grant with Activity Detection Scheduling Types. This field is only applicable at the BS, and shall be enforced by the BS.

Type	**Length**	**Value**
24.20	4	µsec

2.3.5.6.7 Tolerated Grant Jitter

The values in this parameter specifies the maximum amount of time that the transmission opportunities may be delayed from the nominal periodic schedule (measured in microseconds) for this Service Flow.

The ideal schedule for enforcing this parameter is defined by a reference time t_0, with the desired transmission times $t_i = t_0 + i*interval$. The actual transmission opportunities, t'_i shall be in the range $t_i <= t'_i <= t_i + jitter$, where jitter is the value specified with this TLV and interval is the Nominal Grant Interval. The accuracy of the ideal grant times, t_i, are measured relative to the BS Master Clock used to generate timestamps (refer to Section 2.5.3).

This field is mandatory for Unsolicited Grant and Unsolicited Grant with Activity Detection Scheduling Types. This field is only applicable at the BS, and shall be enforced by the BS.

Type	**Length**	**Value**
24.21	4	µsec

2.3.5.6.8 Grants per Interval

For Unsolicited Grant Service, the value of this parameter indicates the actual number of data grants per Nominal Grant Interval. For Unsolicited Grant Service with Activity Detection, the value of this parameter indicates the maximum number of Active Grants per Nominal Grant Interval. This is intended to enable the addition of sessions to an existing Unsolicited Grant Service Flow via the Dynamic Service Change mechanism, without negatively impacting existing sessions.

The ideal schedule for enforcing this parameter is defined by a reference time t_0, with the desired transmission times $t_i = t_0 + i*interval$. The actual grant times, t'_i shall be in the range $t_i <= t'_i <= t_i + jitter$, where interval is the Nominal Grant Interval, and jitter is the Tolerated Grant Jitter. When multiple grants per interval are requested, all grants shall be within this interval, thus the Nominal Grant Interval and Tolerated Grant Jitter shall be maintained by the BS for all grants in this Service Flow.

This field is mandatory for Unsolicited Grant and Unsolicited Grant with Activity Detection Scheduling Types. This field is only applicable at the BS, and shall be enforced by the BS.

Type	**Length**	**Value**	**Valid Range**
24.22	1	# of grants	0-127

2.3.5.7 Downstream-Specific QoS Parameter Encodings

2.3.5.7.1 Maximum Downstream Latency

The value of this parameter specifies the maximum latency between the reception of a packet by the BS on its NSI and the forwarding of the packet to its RF Interface.

If defined, this parameter represents a service commitment (or admission criteria) at the BS and shall be guaranteed by the BS. A BS does not have to meet this service commitment for Service Flows that exceed their minimum downstream reserved rate.

Type	**Length**	**Value**
25.14	4	µsec

2.3.6 Privacy Configuration Settings Option

This configuration setting describes parameters which are specific to Privacy. It is composed from a number of encapsulated type/length/value fields.

Type	**Length**	**Value**
17 (= P_CFG)	n	

2.3.7 Confirmation Code

The Confirmation Code (CC) provides a common way to indicate failures for Registration Response, Registration Ack, Dynamic Service Addition-Response, Dynamic Service Addition-Ack, Dynamic Service Delete-Response, Dynamic Service Change-Response and Dynamic Service Change-Ack MAC Management Messages.

Confirmation Code is one of the following:

okay / success(0)
reject-other(1)
reject-unrecognized-configuration-setting(2)
reject-temporary / reject-resource(3)
reject-permanent / reject-admin(4)
reject-not-owner(5)
reject-service-flow-not-found(6)
reject-service-flow-exists(7)
reject-required-parameter-not-present(8)
reject-header-suppression(9)
reject-unknown-transaction-id(10)
reject-authentication-failure(11)
reject-add-aborted(12)

2.3.8 Convergence Sub-Layer Parameter Encodings

Configuration files will contain parameter information used by the convergence sub-layers. Each convergence sub-layer defines a set of TLV parameters that are encoded as a set of TLVs within a subindex under the type value 99. For example, convergence sub-layer “a” would define a set of TLVs using the subtype index of 99.1. Convergence sub-layer “b” would define a set of TLVs using a subtype index of 99.2, etc.

Type	**Length**	**Value**
99	n	TLV Subindex

2.4 Configuration File

2.4.1 SS IP Addressing

2.4.1.1 DHCP Fields Used by the SS

The following fields shall be present in the DHCP request from the SS and shall be set as described below:

The hardware type (htype) shall be set to 1 (Ethernet).

The hardware length (hlen) shall be set to 6.

The client hardware address (chaddr) shall be set to the 48-bit MAC address associated with the RF interface of the SS.

The “client identifier” option shall be included, with the hardware type set to 1, and the value set to the same MAC address as the chaddr field.

The “parameter request list” option shall be included. The option codes that shall be included in the list are:

Option code 1 (Subnet Mask)

Option code 2 (Time Offset)

Option code 3 (Router Option)

Option code 4 (Time Server Option)

Option code 7 (Log Server Option)

Option code 60 (Vendor Specific Option) — A compliant SS shall send the following ASCII coded string in Option code 60, “802.16.1:xxxxxxx”. Where xxxxx shall be the hexidecimal encoding of the SS Capabilities, refer to Section 2.3.3.1.

The following fields are expected in the DHCP response returned to the SS. The SS shall configure itself based on the DHCP response.

The IP address to be used by the SS (yiaddr).

The IP address of the TFTP server for use in the next phase of the bootstrap process (siaddr).

If the DHCP server is on a different network (requiring a relay agent), then the IP address of the relay agent (giaddr). Note: this may differ from the IP address of the first hop router.

The name of the SS configuration file to be read from the TFTP server by the SS (file).

The subnet mask to be used by the SS (Subnet Mask, option 1).

The time offset of the SS from Universal Coordinated Time (UTC) (Time Offset, option 2). This is used by the SS to calculate the local time for use in time-stamping error logs.

A list of addresses of one or more routers to be used for forwarding SS-originated IP traffic (Router Option, option 3). The SS is not required to use more than one router IP address for forwarding.

A list of time servers [RFC-868] from which the current time may be obtained (Time Server Option, option4).

A list of SYSLOG servers to which logging information may be sent (Log Server Option, option 7).

2.4.2 SS Configuration

2.4.2.1 SS Binary Configuration File Format

The SS-specific configuration data shall be contained in a file which is downloaded to the SS via TFTP.This is a binary file in the same format defined for DHCP vendor extension data [RFC-2132].

It shall consist of a number of configuration settings (1 per parameter) each of the form

Type Length Value

Where

Type is a single- identifier which defines the parameter

Length is a single containing the length of the value field in s (not including type and length fields)

Value is from one to 254 s containing the specific value for the parameter

The configuration settings shall follow each other directly in the file, which is a stream of s (no record markers).

Configuration settings are divided into three types:

Standard configuration settings which shall be present

Standard configuration settings which may be present

Vendor-specific configuration settings.

SSs shall be capable of processing all standard configuration settings. SSs shall ignore any configuration setting present in the configuration file which it cannot interpret. To allow uniform management of SS's conformant to this specification, conformant SS's shall support a 8192-byte configuration file at a minimum.

Authentication of the provisioning information is provided by two message integrity check (MIC) configuration settings, SS MIC and BS MIC.

SS MIC is a digest which ensures that the data sent from the provisioning server were not modified en route. This is not an authenticated digest (it does not include any shared secret).

BS MIC is a digest used to authenticate the provisioning server to the BS during registration. It is taken over a number of fields one of which is a shared secret between the BS and the provisioning server.

Use of the SS MIC allows the BS to authenticate the provisioning data without needing to receive the entire file.

Thus the file structure is of the form shown in Figure 12:

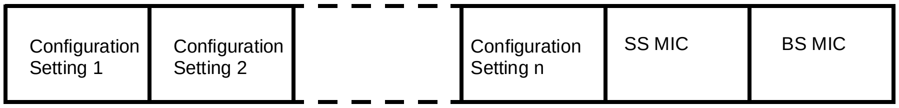


Figure 7—Binary Configuration File Format

2.4.2.2 Configuration File Settings

The following configuration settings shall be included in the configuration file and shall be supported by all SSs.

Network Access Configuration Setting
SS MIC Configuration Setting
BS MIC Configuration Setting
End Configuration Setting
Upstream Service Flow Configuration Setting
Downstream Service Flow Configuration Setting

The following configuration settings shall be included in the configuration file and shall be supported by all SSs that support the specific Convergence Sub-layer:

Convergence Sub-layer Configuration Setting(s)

The following configuration settings may be included in the configuration file and if present shall be supported by all SSs.

Downstream Frequency Configuration Setting
Upstream Channel ID Configuration Setting
Privacy Configuration Setting
Software Upgrade Filename Configuration Setting
SNMP Write-Access Control
SNMP MIB Object
Software Server IP Address
SS Ethernet MAC Address
Maximum Number of SSs
Privacy Enable Configuration Setting
Payload Header Suppression
TFTP Server Timestamp
TFTP Server Provisioned SS Address
Pad Configuration Setting

The following configuration settings may be included in the configuration file and if present may be supported by a SS.

- Vendor-Specific Configuration Settings

2.4.2.3 Configuration File Creation

The sequence of operations required to create the configuration file is as shown in Figure 8 through Figure 11.

Create the type/length/value entries for all the parameters required by the SS.

type, length, value for parameter 1
type, length, value for parameter 2
type, length, value for parameter n

Figure 8—Create TLV Entries for Parameters Required by the SS

Calculate the SS message integrity check (MIC) configuration setting as defined in Section 2.4.2.3.1 and add to the file following the last parameter using code and length values defined for this field.

type, length, value for parameter 1
type, length, value for parameter 2
type, length, value for parameter n
type, length, value for SS MIC

Figure 9—Add SS MIC

Calculate the BS message integrity check (MIC) configuration setting as defined in Section 2.4.3.1 and add to the file following the SS MIC using code and length values defined for this field.

type, length, value for parameter 1
type, length, value for parameter 2
type, length, value for parameter n
type, length, value for SS MIC
type, length, value for BS MIC

Figure 10—Add BS MIC

Add the end of data marker.

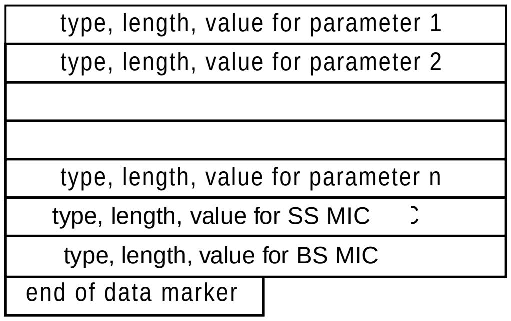

type, length, value for parameter 1
type, length, value for parameter 2
type, length, value for parameter n
type, length, value for SS MIC
type, length, value for BS MIC
end of data marker

Figure 11—Add End of Data Marker

2.4.2.3.1 SS MIC Calculation

The SS message integrity check configuration setting shall be calculated by performing an MD5 digest over the bytes of the configuration setting fields. It is calculated over the bytes of these settings as they appear in the TFTPed image, without regard to TLV ordering or contents. There are two exceptions to this disregard of the contents of the TFTPed image:

The bytes of the SS MIC TLV itself are omitted from the calculation. This includes the type, length, and value fields.

The bytes of the BS MIC TLV are omitted from the calculation. This includes the type, length, and value fields.

On receipt of a configuration file, the SS shall recompute the digest and compare it to the SS MIC configuration setting in the file. If the digests do not match then the configuration file shall be discarded

2.4.3 Configuration Verification

It is necessary to verify that the SS's configuration file has come from a trusted source. Thus, the BS and the configuration server share an Authentication String that they use to verify portions of the SS's configuration in the Registration Request.

2.4.3.1 BS MIC Calculation

The BS message integrity check configuration setting shall be calculated by performing an MD5 digest over the following configuration setting fields, when present in the configuration file, in the order shown:

Downstream Frequency Configuration Setting
Upstream Channel ID Configuration Setting
Network Access Configuration Setting
Privacy Configuration Setting
Vendor-Specific Configuration Settings
SS MIC Configuration Setting
Maximum Number of SSs
TFTP Server Timestamp
TFTP Server Provisioned SS Address
Upstream Service Flow Configuration Setting

Downstream Service Flow Configuration Setting
Privacy Enable Configuration Setting

The above list specifies the order of operations when calculating the BS MIC over configuration setting Type fields. The BS shall calculate the BS MIC over TLVs of the same Type in the order they were received. Within Type fields, the BS shall calculate the BS MIC over the Subtypes in the order they were received. To allow for correct BS MIC calculation by the BS, the SS shall not reorder configuration file TLVs of the same Type or Subtypes within any given Type in its Registration-Request message.

All configuration setting fields shall be treated as if they were contiguous data when calculating the SS MIC.

The digest shall be added to the configuration file as its own configuration setting field using the BS MIC Configuration Setting encoding.

The authentication string is a shared secret between the provisioning server (which creates the configuration files) and the BS. It allows the BS to authenticate the SS provisioning. The authentication string is to be used as the key for calculating the keyed BS MIC digest as stated in D.3.1.1.

The mechanism by which the shared secret is managed is up to the system operator.

On receipt of a configuration file, the SS shall forward the BS MIC as part of the registration request (REG-REQ).

On receipt of a REG-REQ, the BS shall recompute the digest over the included fields and the authentication string and compare it to the BS MIC configuration setting in the file. If the digests do not match, the registration request shall be rejected by setting the authentication failure result in the registration response status field.

2.4.3.1.1 Digest Calculation

The BS MIC digest field shall be calculated using HMAC-MD5 as defined in [RFC-2104].

2.5 Message Formats

MAC Protocol Data Units (PDU) shall be of the form illustrated in Figure 12. Each PDU is preceeded by a fixed-length generic MAC header. The PDU may contain optional payload information from a convergence sub-layer. The payload information can vary in length, so that a MAC PDU will represent a variable number of bytes. The payload information is divided into a convergence sub-layer header and data portions. The definition and use of these message components is defined outside of the scope of the core MAC protocol. This allows the MAC to tunnel various higher layer traffic types without knowledge of the formats or bit patterns of those messages.

A 32-bit CRC is appended to the MAC PDU.

Messages are always transmitted in the order: Most-Significant-Byte first with the Most-Significant-Bit first in each byte.

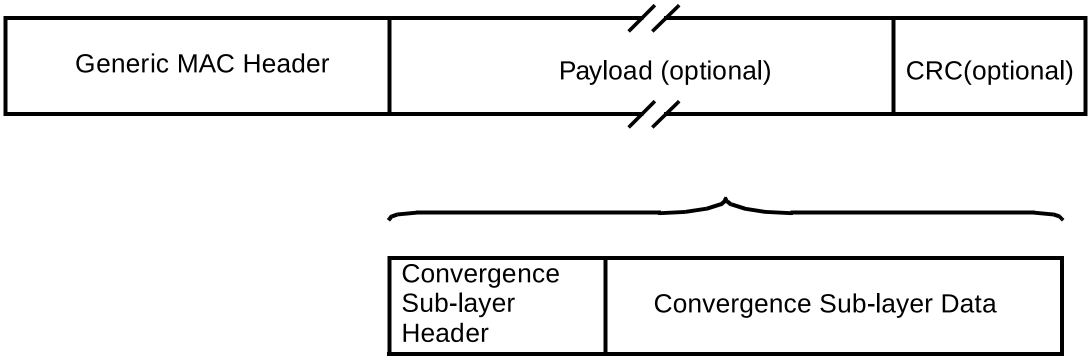


Figure 12—MAC PDU Formats

When a connection is designated as requiring CRC, every MAC PDU shall have an appended checksum field four bytes long using the CRC-32 as defined in ISO8802-3.

Three MAC header formats are defined. The first two are generic headers that precede each MAC Message, including both management and convergence sub-layer data. The third format is used to request additional bandwidth. The single bit Header Type (HT) field distinguishes the generic and bandwidth request header formats. The HT field shall be set to 0 for generic headers. The HT field shall be set to 1 for a bandwidth request header.

The format shown in Figure 13 shall be used for all PDUs transmitted by the SS to the BS in the uplink direction. For downlink transmissions, the format shown in Figure 14 shall be used.

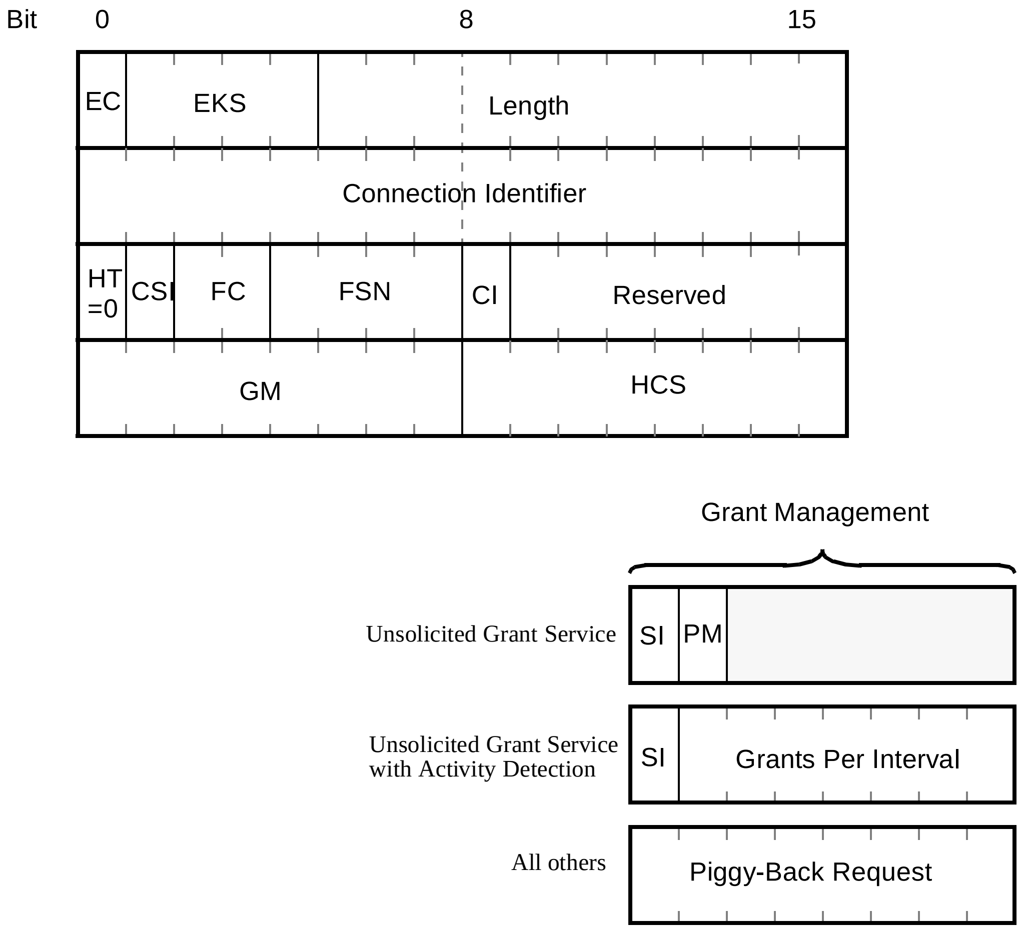


Figure 13—Generic MAC Header Format (Uplink)

These two generic header formats are equivalent with the exception of the Grant Mangament field, which is only present in uplink transmissions.

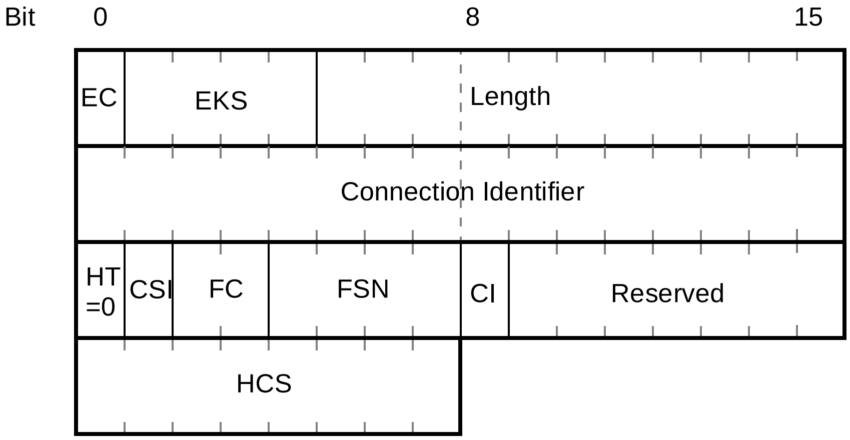


Figure 14—Generic MAC Header Format (Downlink)

The Grant Management (GM) field is one byte in length and is used by the SS to convey bandwidth management needs to the BS. This field is encoded differently based upon the type of connection (as given by the Connection ID). The use of this field is defined in Section 2.10.

The third header is a special format used by a SS to request additional bandwidth. This header shall always be transmitted without a PDU. The format of the Bandwidth Request Header is given in Figure 15.

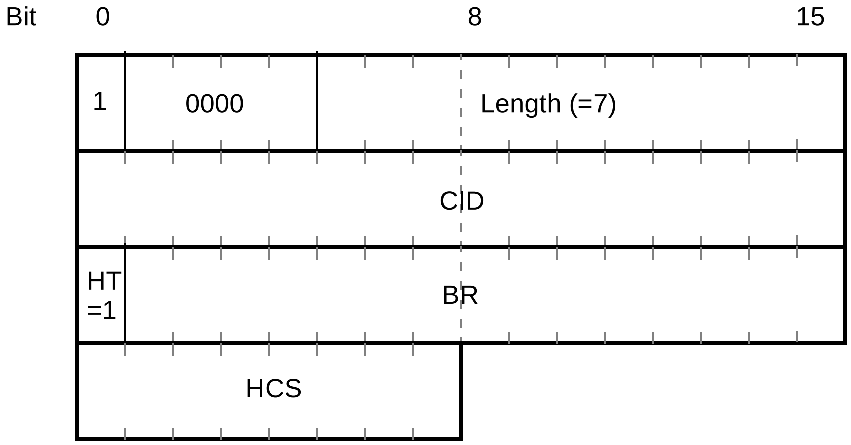


Figure 15—Bandwidth Request Header Format

The Bandwidth Request (BR) Header is used by a SS to request uplink bandwidth. A Bandwidth Request Header shall not have an associated payload:

The length of the header shall always be 7 bytes.
The EC field shall be set to 1, indicating no encryption.
The CID shall indicate the Service Flow for which uplink bandwidth is requested.

The Bandwidth Request (BR) field shall indicate the number of bytes requested.

A SS receiving a Bandwidth Request Header on the downlink shall discard the PDU.

The various fields of the header formats are defined in Table 5. Every header is encoded starting with the EC and EKS fields. The coding of these fields is such that the first byte of a MAC header shall never have the value of 0xFX. This prevents false detection on the stuff byte used in the Transmission Convergence Sub-layer.

Table 5—MAC Header Fields

Name	Length (bits)	Description
BR	15	Bandwidth Request The number of bytes of uplink bandwidth requested by the CPE. The bandwidth request is for the CID. The request shall not include any PHY layer overhead
CID	16	Connection Identifier
CSI	1	Convergence Sub-layer Indication This bit is allocated to a convergence layer process for signaling between equivalent peers.
EC	1	Encryption Control 1 = Payload is not encrypted 0 = Payload is encrypted
EKS	4	Encryption Key Sequence The index of the Traffic Encryption Key and Initialization Vector used to encrypt the payload. This field is only meaningful if the Encryption Control field is set to zero. This field must be set to all zeros when the EC is 1.

Table 5—MAC Header Fields

Name	Length (bits)	Description
FC	2	Fragmentation Control Indicates the fragmentation state of the payload: 00 = no fragmentation 01 = last fragment 10 = first fragment 11 = continuing (middle) fragment
FSN	4	Fragmentation Sequence Number Defines the sequence number of the current fragment. The initial fragment (FC=10) sets this field to 0. This field increments by one (modulo 16) for each fragment. When fragmentation is not used (FC= 00), this field shall be set to 0.
GPI	7	Grants Per Interval The number of grants required by a connection using UGS with Activity Detection
HCS	8	Header Check Sequence An 8-bit field used to detect errors in the header. The generator polynomial is $g(D)=D^8 + D^2 + D + 1$.
HT	1	Header Type 0 = Generic Header 1 = Bandwidth Request Header
LEN	11	Length The length in bytes of the entire MAC header and any MAC PDU information that follows this specific header.
PBR	8	Piggy-Back Request The number of bytes of uplink bandwidth requested by the CPE. The bandwidth request is for the CID. The request shall not include any PHY layer overhead.
PM	1	Poll-Me 0 = No action. 1 = Used by the CPE to request a bandwidth poll.
SI	1	Slip Indicator 0 = No action 1 = Used by the CPE to indicate a slip of uplink grants relative to the uplink queue depth.
CI	1	CRC Indicator 1 = CRC is appended to the PDU 0 = No CRC is appended

Multiple MAC PDUs may be concatenated into a single transmission in either the uplink or downlink directions. Figure 16 illustrates this concept for an uplink burst transmission. Since each PDU is identifiied by a unique Connection Identifier, the receiving MAC entity is able to present the PDU to the correct SAP . Grant Management, user data, and bandwidth request PDUs may be concatenated into the same tranmission.

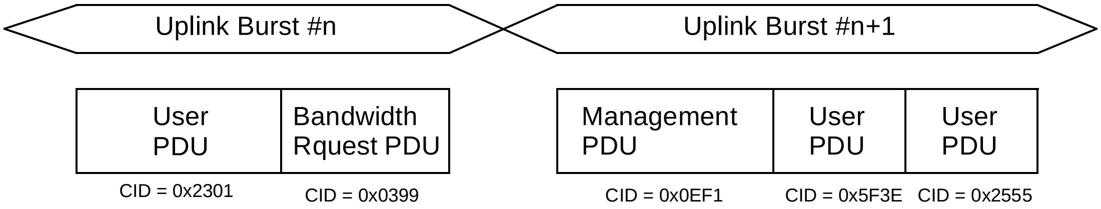


Figure 16—MAC PDU Concatenation showing example CIDs

ARQ is optional for both the SS and the BS.

When ARQ is in use, the ARQ mechanism requires adding control and checksum fields to each ARQ-enabled packet. The checksum field is four bytes long, standard IEEE CRC-32, and it is appended at the end of the packet. The control field is two bytes long and is prepended at the beginning of the packet. The control bit structure contains a 4-bit retry number and a 12 -bit sequence number. The retry number field is reset when a packet is first sent, and is incremented whenever it is retransmitted (up to the terminal value of 15). The sequence number field is assigned to each packet on its first transmission and then incremented. The sequence number does not change when a packet is retransmitted. These ARQ-related fields are added only to packets for which ARQ is in use.

2.5.1 Convergence Sub-layer PDU Formats

The format of the convergence sub-layer PDU shall be as shown in Figure 17. A Convergence Sub-layer PDU may have a zero length payload. Convergence sublayer messages must not be transported on the Basic Connection ID nor on the Secondary Managment CID.

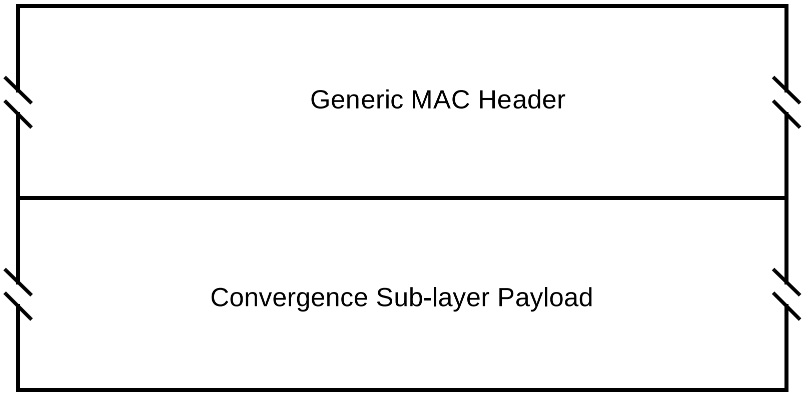


Figure 17—Convergence Sub-layer PDU Format

2.5.2 MAC Management Messages

A set of management Messages are defined within the core MAC. These Messages shall use the standard Message format as given in Section 2.5.1. All management Messages shall begin the payload content with a single byte field indicating the management Message type. The format of the management Message is given in Figure 18. The encoding of the Message type field is given inTable 6. MAC management messages must

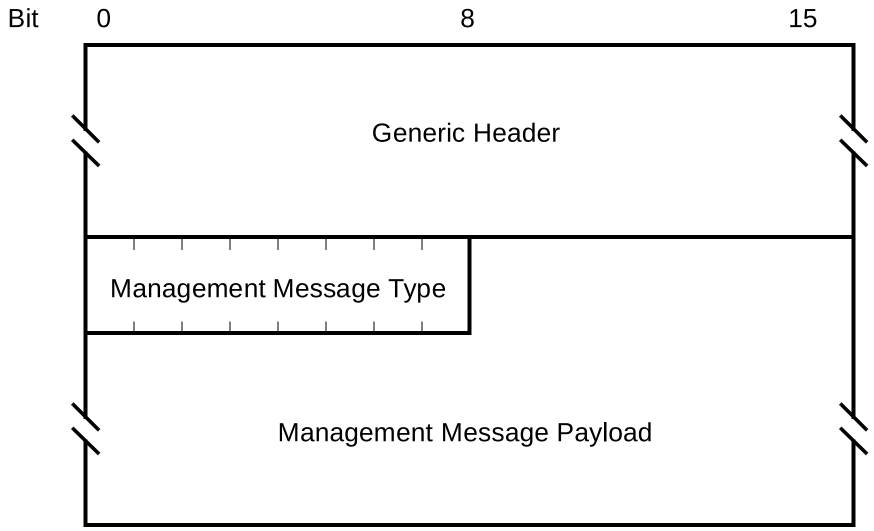


Figure 18—MAC Management Message Format

not be carried on Transport connections.

Table 6—MAC Management Messages

Type	Message Name	Message Description
0	UCD	Uplink Channel Descriptor
1	DCD	Downlink Channel Descriptor
2	DL-MAP	Downlink Access Definition
3	UL-MAP	Uplink Access Definition
4	RNG-REQ	Ranging Request
5	RNG-RSP	Ranging Response
6	REG-REQ	Registration Request
7	REG-RSP	Registration Response
8	REG-ACK	Registration Acknowledge
9	PKM-REQ	Privacy Key Management Request
10	PKM-RSP	Privacy Key Management Response
11	DSA-REQ	Dynamic Service Addition Request
12	DSA-RSP	Dynamic Service Addition Response
13	DSA-ACK	Dynamic Service Addition Acknowledge

Table 6—MAC Management Messages

Type	Message Name	Message Description
14	DSC-REQ	Dynamic Service Change Request
15	DSC-RSP	Dynamic Service Change Response
16	DSC-ACK	Dynamic Service Change Acknowledge
17	DSD-REQ	Dynamic Service Deletion Request
18	DSD-RSP	Dynamic Service Deletion Response
19	DCC-REQ	Dynamic Channel Change Request
20	DCC-RSP	Dynamic Channel Change Response
21	MCA-REQ	Multicast Assignment Request
22	MCA-RSP	Multicast Assignment Response
23	DMC-REQ	Downlink Burst Type Change Request
24	ARQ-ACK	ARQ Acknowledgement
245-255		Reserved for future use

2.5.2.1 Uplink Channel Descriptor (UCD) Message

An Uplink Channel Descriptor shall be transmitted by the BS at a periodic interval to define the characteristics of an upstream physical channel. A separate UCD Message shall be transmitted for each active uplink.

To provide for flexibility the message parameters following the channel ID shall be encoded in a type/length/value (TLV) form in which the type and length fields are each 1 long.

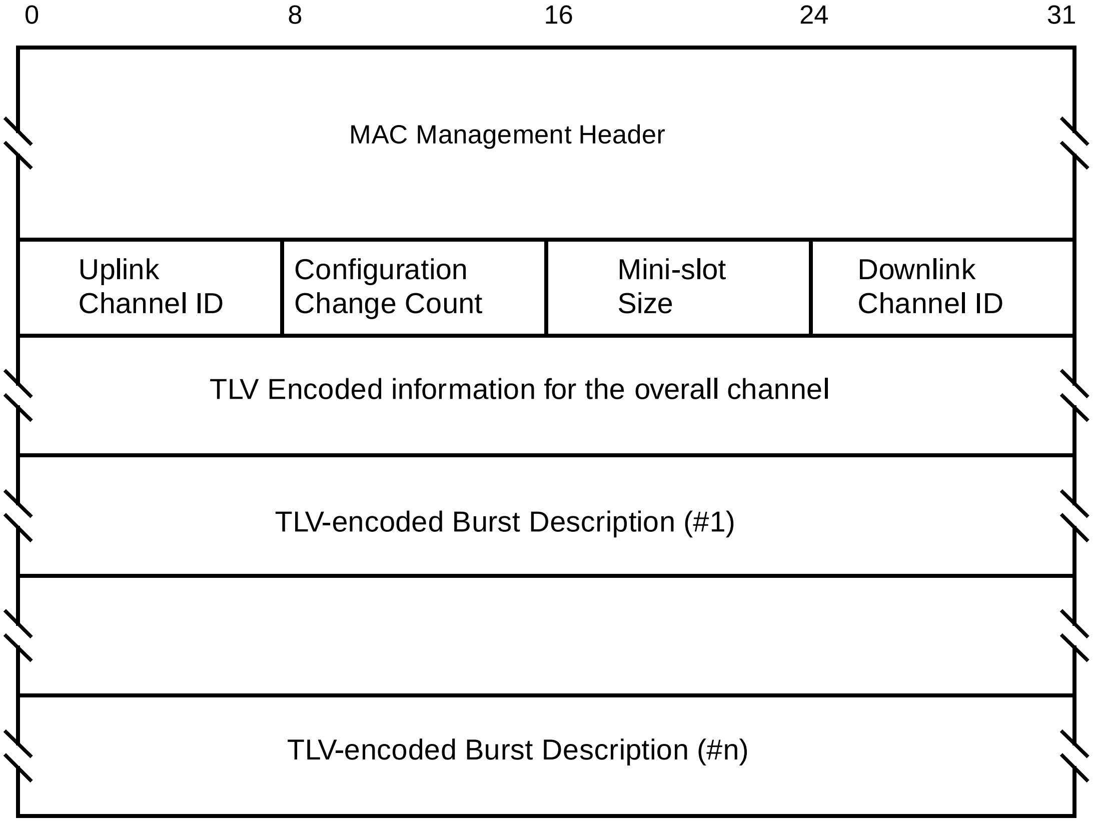

0
8
16
24
31
MAC Management Header
Uplink Channel ID
Configuration Change Count
Mini-slot Size
Downlink Channel ID
TLV Encoded information for the overall channel
TLV-encoded Burst Description (#1)
TLV-encoded Burst Description (#n)

Figure 19—Uplink Channel Descriptor (UCD) Message Format

A BS shall generate UCDs in the format shown in Figure 19, including all of the following parameters:

Configuration Change Count

Incremented by one (modulo the field size) by the BS whenever any of the values of this channel descriptor change. If the value of this count in a subsequent UCD remains the same, the SS can quickly decide that the remaining fields have not changed, and may be able to disregard the remainder of the message. This value is also referenced from the UL-MAP messages.

Mini-Slot Size

The size T of the Mini-Slot for this uplink channel in units of Physical Slots. Allowable values are T = 2^m, where m = 0,...7.

Uplink Channel ID

The identifier of the uplink channel to which this Message refers. This identifier is arbitrarily chosen by the BS and is only unique within the MAC-Sublayer domain.

Downlink Channel ID

> The identifier of the downlink channel on which this Message has been transmitted. This identifier is arbitrarily chosen by the BS and is only unique within the MAC-Sublayer domain.

All other parameters are coded as TLV tuples. The type values used shall be those defined in Table 7, for channel parameters, and Table 9, for uplink physical layer burst attributes. Channel-wide parameters (from Table 7) shall preceed burst descriptors (type 1 below).

Table 7—Uplink Physical Channel Attributes

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
Burst Descriptor	1		May appear more than once; described below. The length is the number of bytes in the overall object, including embedded TLV items.
Symbol Rate	2	2	5 - 40 MBaud. The incremental rates are not yet defined for the PHY layer. The use of a TLV allows future clarification of this field without modification to the MAC.
Frequency	3	4	Uplink center frequency (kHz)
Preamble Pattern	4	1-128	Preamble superstring. All burst-specific preamble values are chosen as bit-substrings of this string. The first byte of the Value field contains the first 8 bits of the superstring, with the first bit of the preamble superstring in the MSB position of the first Value field byte, the eighth bit of the preamble superstring in the LSB position of the firstValue field byte; the second byte in the Value field contains the second eight bits of the superstring, with the ninth bit of the superstring in the MSB of the second byte and sixteenth bit of the preamble superstring in the LSB of the second byte, and so forth.
Tx/Rx Gap	5	1	The number of PS between the end of the downlink and uplink transmissions. This TLV is only used if the PHY Type field of the DL-MAP message is {0, 1} (TDD).
Rx/Tx Gap	6	1	The number of PS between the end of the uplink and downlink transmissions. This TLV is only used if the PHY Type field of the DL-MAP message is {0, 1} (TDD).
Roll-off factor	7	1	0=0.15, 1=0.25, 2=0.35
Spectrum inversion	8	1	0=inverted, 1=non-inverted

Burst Descriptors are compound TLV encodings that define, for each type of uplink usage interval, the physical-layer characteristics that are to be used during that interval. The uplink interval usage codes are defined

Table 8—Uplink Map Information Elements

IE Name	Uplink Interval Usage Code (UIUC)	Connection ID	Mini-slot Offset
Request	1	any	Starting offset of REQ region
Initial Maintenance	2	broadcast	Starting offset of MAINT region (used in Initial Ranging)
Station Maintenance	3	unicast	Starting offset of MAINT region (used in Periodic Ranging)
Data Grant 1	4	unicast	Starting offset of Data Grant assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 2	5	unicast	Starting offset of Data Grant assignment If inferred length = 0, then it is a Data Grant Pending
Data Grant 3	6	unicast	Starting offset of Data Grant 2 assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 4	7	unicast	Starting offset of Data Grant 2 assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 5	8	unicast	Starting offset of Data Grant 3 assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 6	9	unicast	Starting offset of Data Grant 3 assignment If inferred length = 0, then it is a Data Grant pending.
Null IE	10	zero	Ending offset of the previous grant. Used to bound the length of the last actual interval allocation.
Empty	11	zero	Used to schedule gaps in transmission
Reserved	11-14	any	Reserved
Expansion	15	expanded UIUC	# of additional 32-bit words in this IE

in the UL-MAP Message. illustrates the format of each Burst Descruption TLV. Each TLV is encoded with a Type of 1, an eight bit length, and a four bit UIUC.

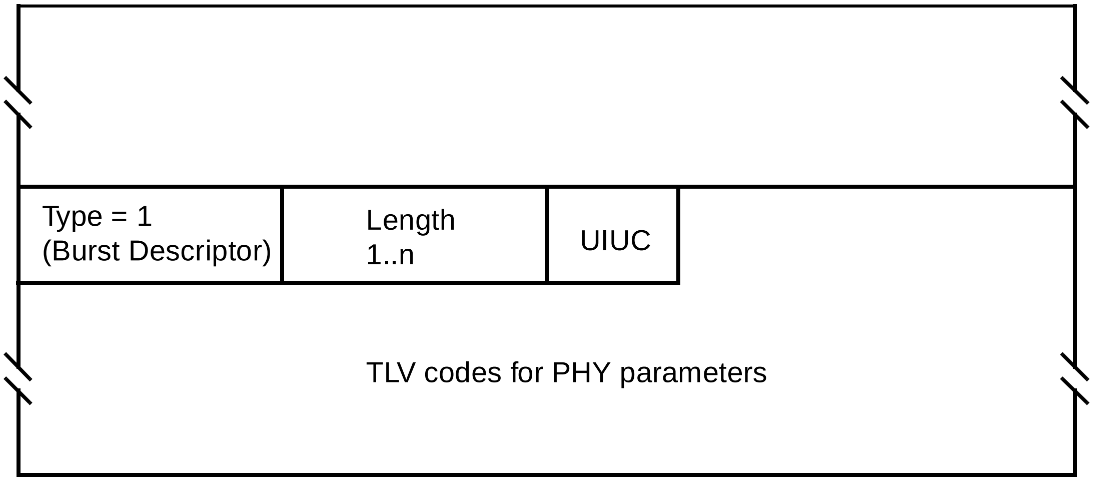


Figure 20—Top-Level Encoding for a Burst Descriptor

A Burst Descriptor shall be included for each Interval Usage Code that is to be used in the UL-MAP. The Interval Usage Code shall be one of the values from Table 13.

Within each Burst Descriptor is an unordered list of Physical-layer attributes, encoded as TLV values. These attributes are shown in Table 9.

2.5.2.2 Downlink Channel Descriptor (DCD) Message

A Downlink Channel Descriptor shall be transmitted by the BS at a periodic interval to define the characteristics of a downstram physical channel. A separate DCD message shall be transmitted for each active downlink.

Table 9—Uplink Physical Layer Burst Profile Parameters

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
Modulation Type	1	1	1 = QPSK, 2 = 16QAM, 3 = 64-QAM
Differential Encoding	2	1	1 = on, 2 = off
Preamble Length	3	2	Up to 1024 bits. The preamble must be an integer number of PSs (a multiple of 2 for QPSK and 4 for 16QAM and 6 for 64QAM)
Preamble Value Offset	4	2	Identifies the bits to be used for the preamble value. This is specified as a starting offset into the Preamble Pattern (see Table 7). That is, a value of zero means that the first bit of the preamble for this burst type is the value of the first bit of the Preamble Pattern. A value of 100 means that the preamble is to use the 101st and succeeding bits from the Preamble Pattern. This value must be a multiple of the symbol size. The first bit of the Preamble Pattern is the firstbit transmitted in the uplink burst.
FEC code type	5	1	1 = Reed-Solomon only 2 = Reed-Solomon + Inner (9,8) Parity Check Code 3 = Reed-Solomon + Inner (24,16) Block Convolutional Code 4 = Block Turbo Code (Optional) 5-255 = Reserved
RS information bytes (K)	6	1	K=6-255
RS error correction capability (T)	7	1	T=0-16
BCC code type	8	1	1 = (24,16) 2-255 = Reserved

Table 9—Uplink Physical Layer Burst Profile Parameters

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
BTC Row code type	9	1	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Column code type	10	1	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Row code shortening	11	1	0-255 columns
BTC Column code shortening	12	1	0-255 rows
BTC Product code shortening bits	13	1	0-255 bits
Scrambler Seed	14	2	The 15-bit seed value left justified in the 2 byte field. Bit 15 is the MSB of the first byte and the LSB of the second byte is not used. (Not used if scrambler is off)
Guard Time Size	15	1	Number of PSs which must follow the end of this burst. (Although this value may be derivable from other network and architectural parameters, it is included here to ensure that the SSs and BS all use the same value.)
Last Codeword Length	16	1	1 = fixed; 2 = shortened
Scrambler on/off	17	1	1 = on; 2 = off
Convergence layer	18	1	0=enabled, 1=disabled

To provide for flexibility the message parameters following the channel ID shall be encoded in a type/length/value (TLV) form in which the type and length fields are each 1 long.

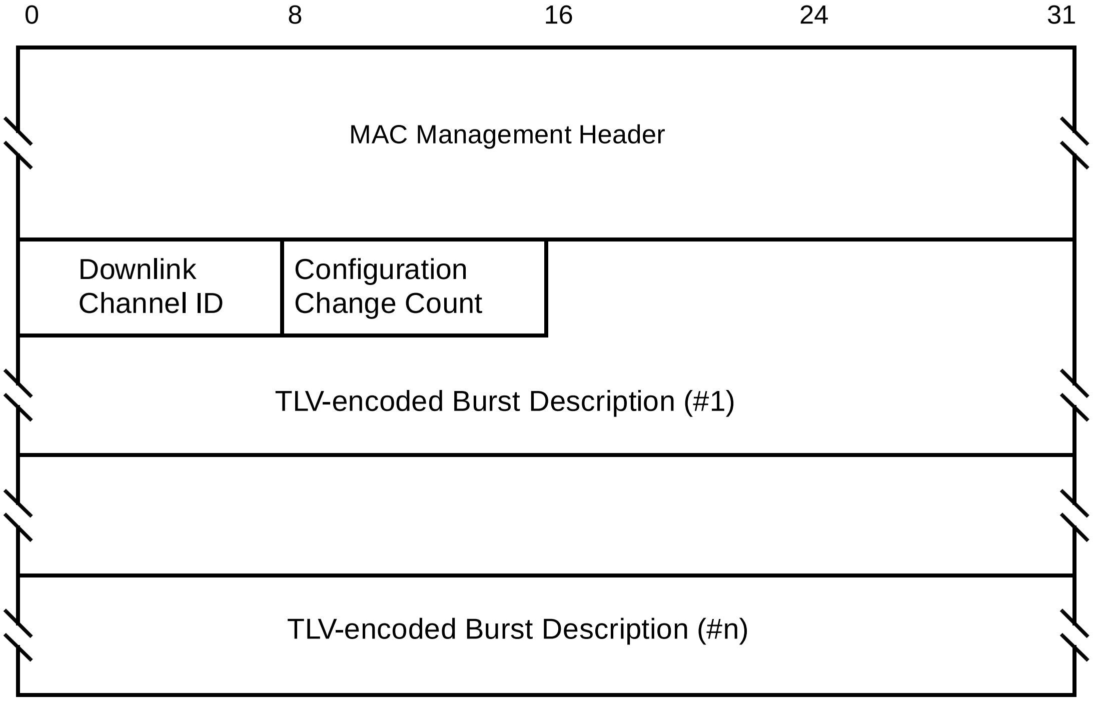

0
8
16
24
31
MAC Management Header
Downlink Channel ID
Configuration Change Count
TLV-encoded Burst Description (#1)
TLV-encoded Burst Description (#n)

Figure 21—Downlink Channel Descriptor (DCD) Message Format

A BS shall generate DCDs in the format shown in Figure 21, including all of the following parameters:

Configuration Change Count

> Incremented by one (modulo the field size) by the BS whenever any of the values of this channel descriptor change. If the value of this count in a subsequent UCD remains the same, the SS can quickly decide that the remaining fields have not changed, and may be able to disregard the remainder of the message. This value is also referenced from the UL-MAP messages.

Downlink Channel ID

> The identifier of the downlink channel to which this Message refers. This identifier is arbitrarily chosen by the BS and is only unique within the MAC-Sublayer domain.

All other parameters are coded as TLV tuples. The type values used shall be those defined in Table 10, for channel parameters, and Table 12, for downlink physical layer burst attributes. Channel-wide parameters (from Table 12) shall preceed burst descriptors (type 1 below).

Burst Descriptors are compound TLV encodings that define, for each type of downlink usage interval, the physical-layer characteristics that are to be used during that interval. The downlink interval usage codes are defined in the DL-MAP Message. The mapping between Burst Type and Downlink Interval Usage Code is given in Table 11.

Table 10—Downlink Physical Channel Attributes

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
Burst Descriptor	1		May appear more than once; described below. The length is the number of bytes in the overall object, including embedded TLV items.
BS Transmit Power	2	1	Signed in units of 1dB
Roll-off factor	3	1	0=0.15, 1=0.25, 2=0.35
FSDD/TDD frame time	8	4	The number of PS contained in a FSDD or TDD frame. This TLV is used only if the PHY Type field of the DL-MAP message is {0, 1, 3} (TDD, FSDD).

Table 11: Mapping of Burst Type to Downlink Interval Usage Code

Burst Type	Downlink Interval Usage Code (DIUC)	Comments
reserved	0	TDM Burst Type 1 is well known
TDM Burst type 2	1	
TDM Burst type 3	2	
TDM Burst type 4	3	
TDM Burst type 5	4	
TDM Burst type 6	5	
reserved	6-7	
TDMA Burst type 1	8	TDM Burst Type 1 with re-sync preamble
TDMA Burst type 2	9	TDM Burst Type 2 with re-sync preamble
TDMA Burst type 3	10	TDM Burst Type 3 with re-sync preamble
TDMA Burst type 4	11	TDM Burst Type 4 with re-sync preamble
TDMA Burst type 5	12	TDM Burst Type 5 with re-sync preamble
TDMA Burst type 6	13	TDM Burst Type 6 with re-sync preamble
Gap	14	TDMA DL only
End of DL MAP	15	

Figure 22 illustrates the format of each Burst Description TLV. Each TLV is encoded with a Type of 1, an eight bit length, and a four bit DIUC. The IUC field is associated with the Downlink Burst Profile and Thresholds. The IUC value is used in the DL-MAP message to specify the Burst Profile to be used for a specific downlink burst.

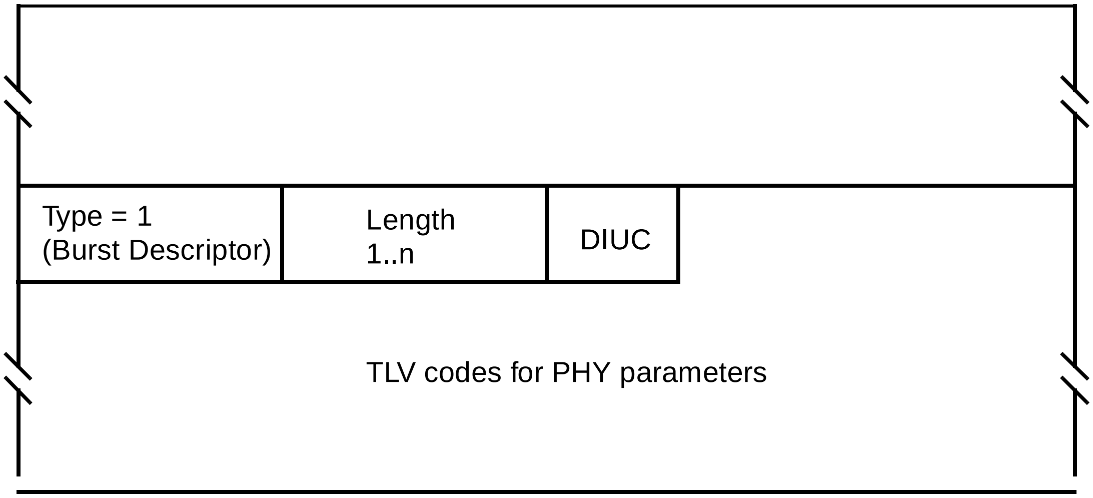


Figure 22—Top-Level Encoding for a Downlink Burst Descriptor

Burst Type Thresholds

> An optional parameter. The thresholds for transition between the various DIUC types on a downlink channel are specified by the BS for use by the SS.

Threshold Delta

> An optional parameter. The delta about which a hysteresis is defined for transition of the SS between modulation types. Used by the SS in conjuction with the 16-QAM and 64-QAM Thresholds to determine when to request a modulation change for the downlink channel.

A Burst Descriptor shall be included for each Interval Usage Code that is to be used in the DL-MAP.

Within each Burst Descriptor is an unordered list of Physical-layer attributes, encoded as TLV values. These attributes are shown in Table 12.

Table 12—Downlink Physical Layer Burst Profile Parameters

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
Modulation Type	1	1	1 = QPSK 2 = 16QAM 3 = 64-QAM
FEC code type	2	1	1 = Reed-Solomon only 2 = Reed-Solomon + Inner (9,8) Parity Check Code 3 = Reed-Solomon + Inner Block Convolutional Code 4 = Block Turbo Code (Optional) 5-255 = Reserved
RS information bytes (K)	3	1	K=6-255
RS error correction capability (T)	4	1	T=0-16
BCC code type	5	1	1 = (24,16) 2-255 = Reserved
BTC Row code type	6	1	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Column code type	7	1	1 = (64,57) Extended Hamming 2 = (32,26) Extended Hamming 3-255 = Reserved
BTC Row code shortening	8	1	0-255 columns
BTC Column code shortening	9	1	0-255 rows
BTC Product code shortening bits	10	1	0-255 bits
Last codeword length	11	1	1=fixed; 2=shortened (optional) This allows for the transmitter to shorten the last codeword, based upon the allowable shortened codewords for the particular code type.
IUC low threshold	13	1	C/I+N required for starting to use this IUC when a changing to a more robust IUC is required, in ¼ dB units.
IUC high threshold	14	1	C/I+N required for starting to use this IUC when a changing to a more less IUC is required, in ¼ dB units.

2.5.3 Downlink MAP (DL-MAP) Message

The Downlink MAP (DL-MAP) message defines the access to the downlink information relative to the PHY mode. The DL-MAP message takes on different formats depending upon the value of the PHY Type field.

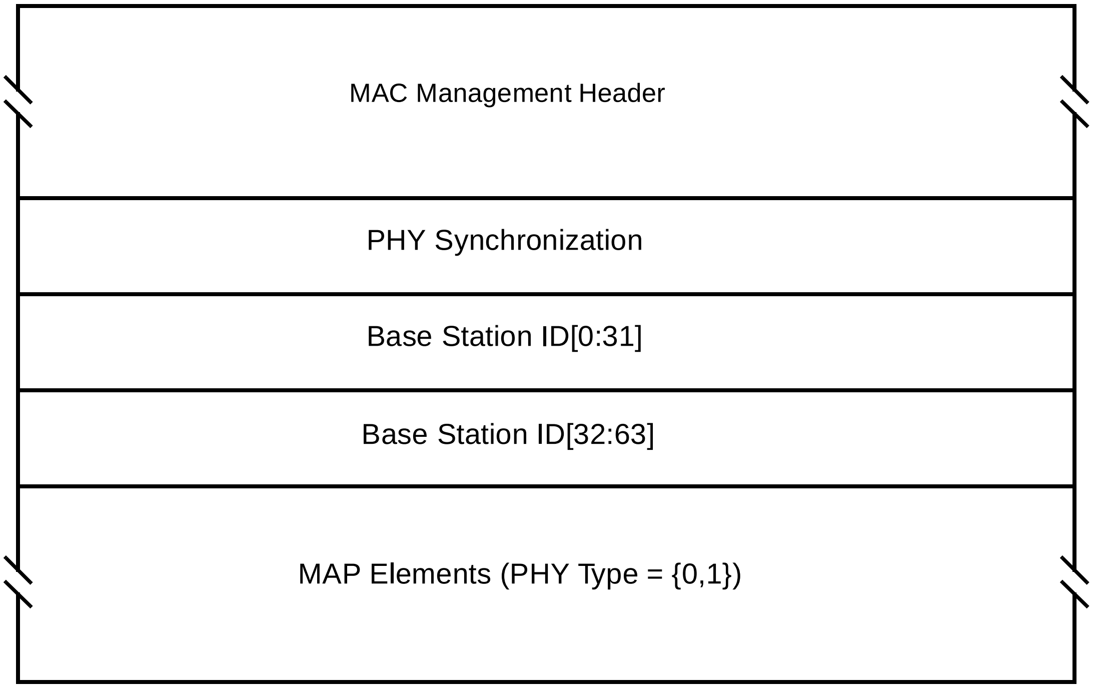


Figure 23—Downlink MAP Message Format

A BS shall generate DL-MAP messages in the format shown in Figure 23, including all of the following parameters:

PHY Synchronization

A four byte field. The first three bits define the PHY type, as given by the following value:
0 = TDD
1 = FDD/TDM (Burst Downlink PHY)
5 = FDD/TDM (Continuous Downlink PHY)

The remaining 29 bits are encoded as shown in Figure 24 for PHY Type = {0,1} or Figure 25 for PHY Type = 5. For burst downlink PHY operations, the bits are encoded as the frame number. For continuous downlink PHY operations, the bits are encoded as a timestamp that synchronizes the uplink transmissions. For PHY type = 5, the time stamp represents the count state of the base station counter at the instant that the first byte of the Downlink MAP Message is transferred from the Downstream Transmission Convergence Sublayer to the Downstream Physical Media Dependent Sublayer. Figure 24 shows the 5 bits that encode the Frame Length types. They are defined by the following values, which map to the frame times defined in section 3.2.2.

0 = 0.5 millisecond

1 = 1 millisecond
2 = 2 milliseconds
All other values are reserved.

The encoding of remaining portions of the DL-MAP message are also based upon the PHY field. For PHY Type = 5, no additional information follows the Base Station ID field. For PHY Type = {0, 1}, a set of mapping information, as defined by the DL Burst Descriptors, is defined as in Figure 26. MAP information elements must be in time order, which is not neccessarily IUC order or connection ID order. For more information, refer to section 3.2.

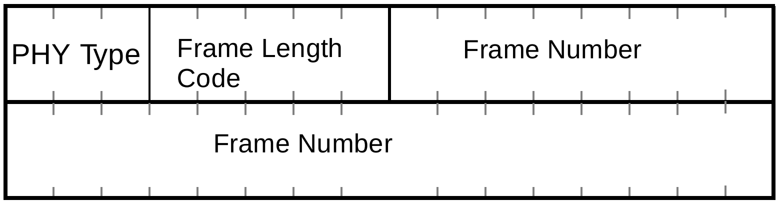


Figure 24—PHY Synchronization Field (PHY Type = {0,1})

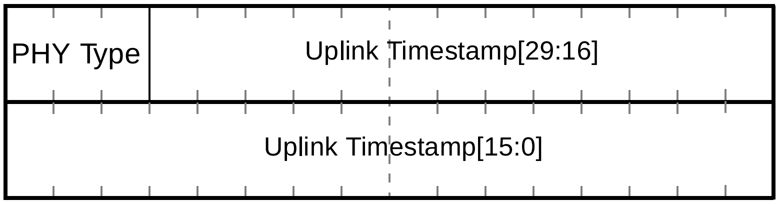


Figure 25—PHY Synchronization Field (PHY Type = 5)

The BS timestamp jitter must be less than 500 ns peak-to-peak at the output of the Downstream Transmission Convergence Sublayer. This jitter is relative to an ideal Downstream Transmission Convergence Sublayer that transfers the TC packet data to the Downstream Physical Media Dependent Sublayer with a perfectly continuous and smooth clock at symbol rate. Downstream Physical Media Dependent Sublayer processing shall not be considered in timestamp generation and transfer to the Downstream Physical Media Dependent Sublayer.

Thus, any two timestamps N1 and N2 (N2 > N1) which were transferred to the Downstream Physical Media Dependent Sublayer at times T1 and T2 respectively must satisfy the following relationship:

$$(N2 - N1)/(4 \text{ x Symbol Rate}) - (T2 - T1) < 500 \text{ nsec}$$

The jitter includes inaccuracy in timestamp value and the jitter in all clocks. The 500ns allocated for jitter at the Downstream Transmission Convergence Sublayer output must be reduced by any jitter that is introduced by the Downstream Physical Media Dependent Sublayer.

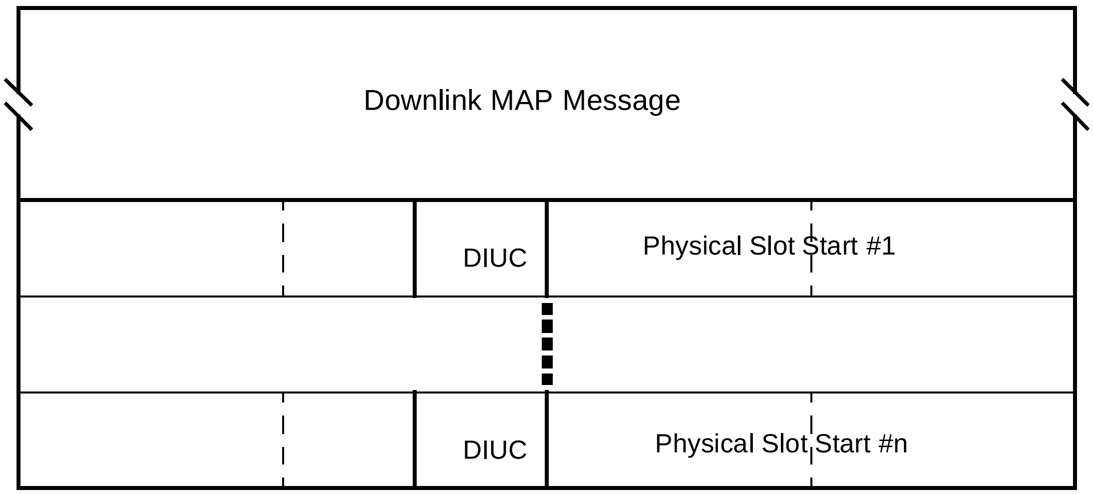


Figure 26—Downlink TDM MAP Message Element Format

The CID entry in the TDMA version of the DL-MAP message defines the allocation of bandwidth for that connection. For a SS operating in GPC mode, the CID shall be the Transport CID. For a SS operating in GPT mode, the CID shall be the Basic CID.

2.5.4 Uplink MAP (UL-MAP) Message

The Uplink MAP (UL-MAP) message allocates access to the upstream channel. The UL-MAP message shall be as shown in Figure 27.

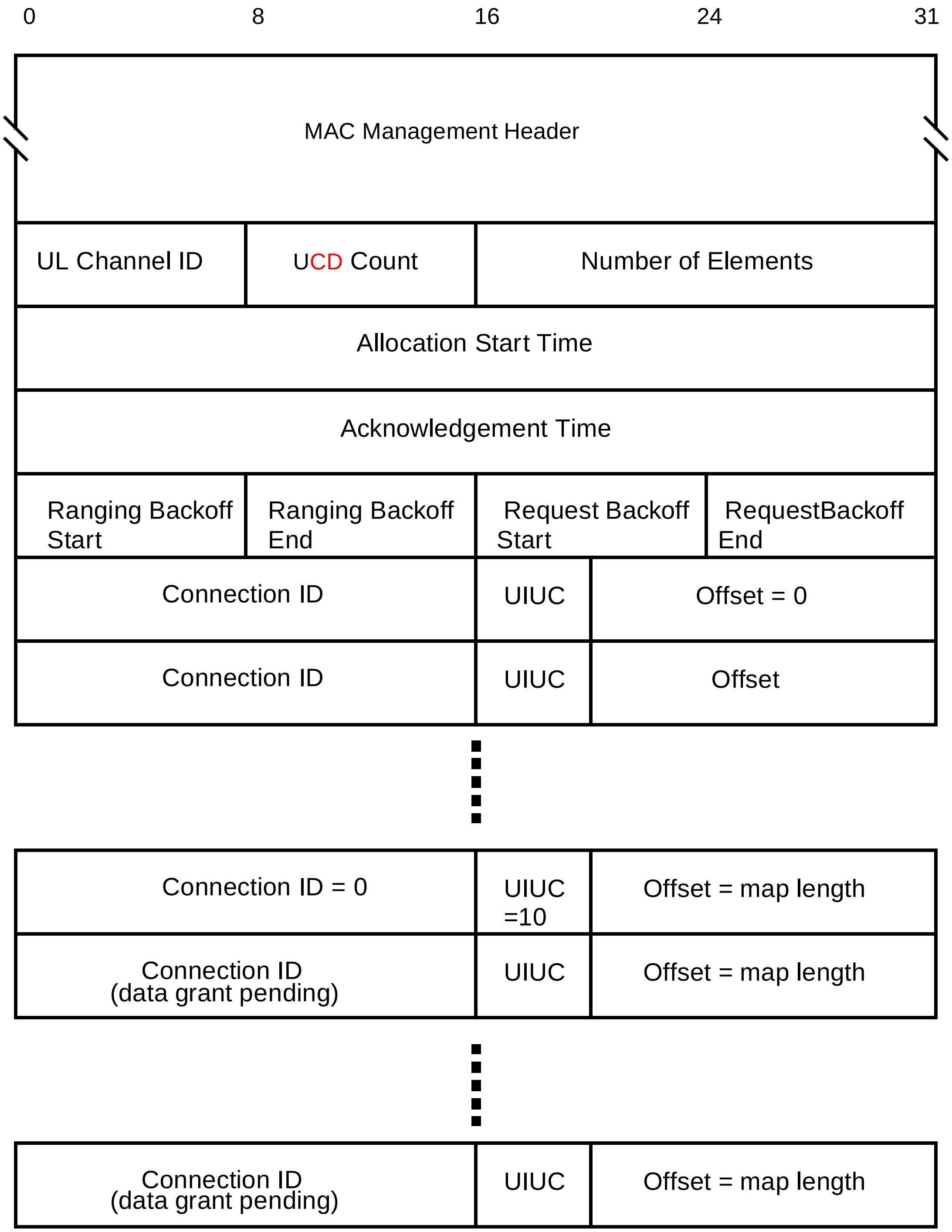


Figure 27—Uplink MAP Message Format

Uplink Channel ID

The identifier of the uplink channel to which this Message refers.

UCD Count

Matches the value of the Configuration Change Count of theUCD which describes the burst parameters which apply to this map.

Number of Elements

Number of information elements in the map.

Alloc Start Time

Effective start time of the uplink allocation defined by the UL-MAP in units of mini-slots. The start time is relative to the start of a frame in which UL-MAP message is transmitted (PHY Type = {0.,1,3}) or from BS initialization (PHY Type = 5).

Ack Time

Latest time processed in uplink in units of mini-slots. This time is used by the SS for collision detection purposes. The ack time is relative to the start of a frame in which UL-MAP message is transmitted (PHY Type = {0,1,3}) or from BS initialization (PHY Type = 5).

Ranging Backoff Start

Initial back-off window size for initial ranging contention, expressed as a power of 2. Values of n range 0-15 (the highest order bits must be unused and set to 0).

Ranging Backoff End

Final back-off window size for initial ranging contention, expressed as a power of 2. Values of n range 0-15 (the highest order bits must be unused and set to 0).

Request Backoff Start

Initial back-off window size for contention data and requests, expressed as a power of 2. Values of n range 0-15 (the highest order bits must be unused and set to 0).

Request Backoff End

Final back-off window size for contention requests, expressed as a power of 2. Values of n range 0-15 (the highest order bits must be unused and set to 0).

MAP Information Elements

Information elements define uplink bandwidth allocations. Each UL-MAP message shall contain at least one Information Element. The format of the IE shall be as shown in Figure 28. Each IE consists of three fields: a Connection Identifer, an Interval Usage Code, and an offset.

The Connection Identifier represent the assignment of the IE to either a unicast, multicast, or broadcast address. When specifically addressed to allocate a bandwidth grant, the CID may be either the Basic CID of the SS or a Traffic CID for one of the connections of the SS. A four-bit Downlink Interval Usage Code (DIUC) shall be used to define the type of uplink access and the burst type associated with that access. Table 13 defines the use of the IUCs. The offset shall be the length from the start of the previous IE to the start of this IE in units of mini-slots. The first IE shall have an offset of 0.

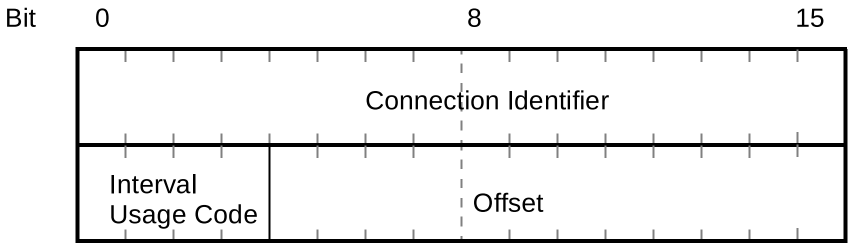


Figure 28—UL-MAP Information Element

Three pairs of data grant Information Elements are defined. This allows each pair to be assigned to a different burst profile pair, typically based upon modulation type. For example, the first pair would be assigned to use QPSK, the second pair would use 16-QAM, and the third would use 64-QAM. Within each pair, the short and long grant usage is distinguished by the maximum burst size. This allows short PDU transmissions for services that are tolerant of packet loss to use less FEC coding (relative to longer grants).

2.5.5 Ranging Request (RNG-REQ) Message

A Ranging Request shall be transmitted by a SS at initialization and periodically on request from BS to determine network delay and request power and/or modulation adjustment. This shall be followed by a Packet PDU in the format shown in Figure 29.

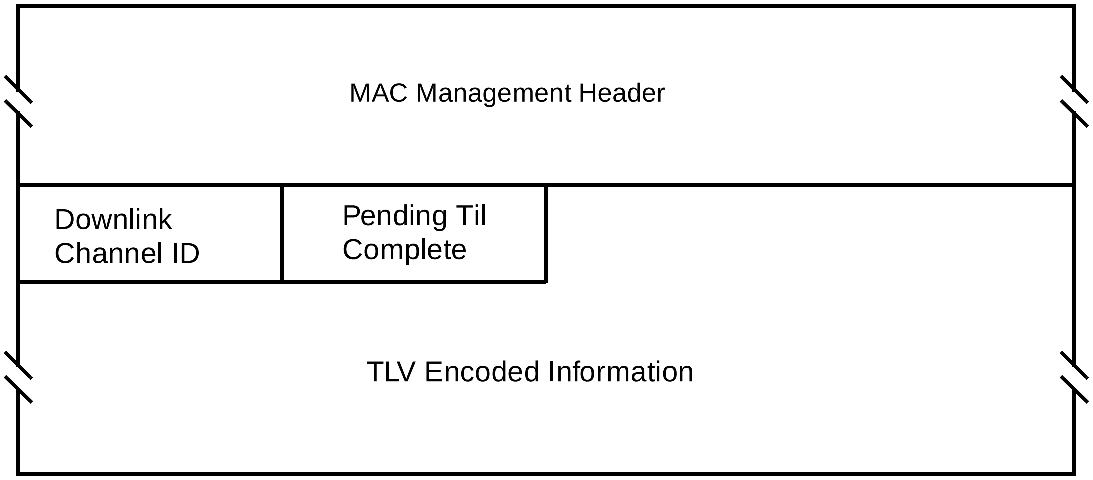


Figure 29—RNG-REQ Message Format

Table 13—Uplink MAP Information Elements

IE Name	Uplink Interval Usage Code (UIUC)	Connection ID	Mini-slot Offset
Request	1	any	Starting offset of REQ region
Initial Maintenance	2	broadcast	Starting offset of MAINT region (used in Initial Ranging)
Station Maintenance	3	unicast	Starting offset of MAINT region (used in Periodic Ranging)
Data Grant 1	4	unicast	Starting offset of Data Grant assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 2	5	unicast	Starting offset of Data Grant assignment If inferred length = 0, then it is a Data Grant Pending
Data Grant 3	6	unicast	Starting offset of Data Grant 2 assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 4	7	unicast	Starting offset of Data Grant 2 assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 5	8	unicast	Starting offset of Data Grant 3 assignment If inferred length = 0, then it is a Data Grant pending.
Data Grant 6	9	unicast	Starting offset of Data Grant 3 assignment If inferred length = 0, then it is a Data Grant pending.
Null IE	10	zero	Ending offset of the previous grant. Used to bound the length of the last actual interval allocation.
Empty	11	zero	Used to schedule gaps in transmission
Reserved	11-14	any	Reserved
Expansion	15	expanded UIUC	# of additional 32-bit words in this IE

The RNG-REQ Message shall be transmitted using QPSK modulation.

Parameters shall be as follows:

CID (from the MAC Management Header)

For RNG-REQ Messages transmitted in Initial Maintenance intervals:

Initialization CID if SS is attempting to join the network

Initialization CID if SS has not yet registered and is changing downlink (or both downlink and uplink) channels as directed by a downloaded parameter file

Temporary CID if SS has not yet registered and is changing uplink (not downlink) channels as directed by a downloaded parameter file

Registration CID (previously assigned in REG-RSP) if SS is registered and is changing uplink channels

For RNG-REQ Messages transmitted in Station Maintenance intervals:
Basic CID

Downlink Channel ID

The identifier of the downlink channel on which the SS received the DCD which described this uplink. This is an 8-bit field.

Pending Till Complete

If zero, then all previous Ranging Response attributes have been applied prior to transmittting this request. If nonzero then this is time estimated to be needed to complete assimilation of ranging parameters. Note that only equalization can be deferred. Units are in unsigned centiseconds (10 msec).

All other parameters are coded as TLV tuples.

Requested downlink burst type

An optional parameter. Downlink burst types requested by the CPE for downlink traffic based on the IUC definitions coneyed by the DCD message, the CPE capabilities (i.e. which of the combinations it supports), and on measurements of the downlink RF channel relative to the IUC transition thresholds (also defined in the DCD message).

SS MAC Address

A required parameter. The link-layer address of the SS.

Ranging Anomalies

An optional parameter indicating a potential error condition detected by the SS. Setting the bit associated with a specific condition indicates that the condition exists at the SS.

2.5.5.1 RNG-REQ TLV Encodings

The type values used shall be those defined in Table 14. These are unique within the ranging request Message but not across the entire MAC Message set. The type and length fields shall each be 1 in length.

2.5.6 Ranging Response (RNG-RSP) Message

A Ranging Response shall be transmitted by a BS in response to received RNG-REQ. It may be noted that, from the point of view of the SS, reception of a Ranging Response is stateless. In particular, the SS shall be prepared to receive a Ranging Response at any time, not just following a Ranging Request.

The RNG-RSP Message shall be transmitted using QPSK modulation.

To provide for flexibility, the Message parameters following the Uplink Channel ID shall be encoded in a type/length/value (TLV) form.

Table 14—Ranging Request Message Encodings

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
Requested Downlink Burst Type	1	1	Downlink IUC for requested burst type
SS MAC Address	2	6	SS MAC Address
Ranging Anomalies	3	1	Bit #0 - SS already at maximum power. Bit #1 - SS already at minimum power. Bit #2 - Sum of commanded timing adjustments is too large.
Reserved	4-255	n	Reserved for future use

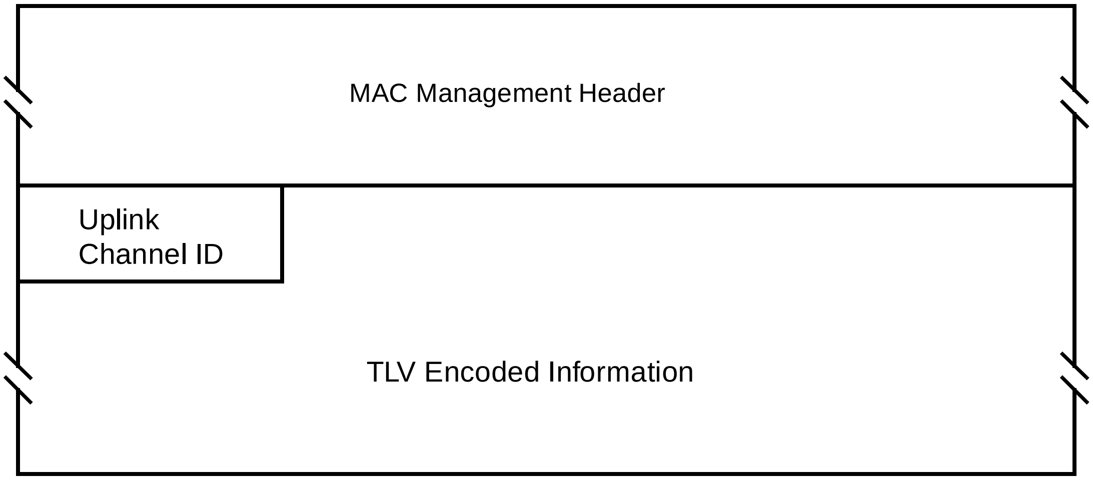


Figure 30—RNG-RSP Message Format

A BS shall generate Ranging Responses in the form shown in Figure 30, including all of the following parameters:

Uplink Channel ID

The identifier of the uplink channel on which the BS received the RNG-REQ to which this response refers.

All other parameters are coded as TLV tuples.

Timing Adjust Information

The time by which to offset frame transmission so that frames arrive at the expected mini-slot time at the BS.

Power Adjust Information

Specifies the relative change in transmission power level that the SS is to make in order that transmissions arrive at the BS at the desired power.

Frequency Adjust Information

Specifies the relative change in transmission frequency that the SS is to make in order to better match the BS. (This is fine-frequency adjustment within a channel, not re-assignment to a different channel)

Ranging Status

Used to indicate whether uplink Messages are received within acceptable limits by BS.

Downlink Frequency Override

An optional parameter. The downlink frequency with which the SS should redo initial ranging.

Uplink Channel ID Override

An optional parameter. The identifier of the uplink channel with which the SS should redo initial ranging.

Requested DL Modulation Maximum Modulation Type Supported

An optional parameter. The maximum allowed set of Modulation types allowed for the SS for downlink traffic. This parameter is sent in response to the RNG-REQ Modulation Type from the SS. The SS responds with the maximum allowed set of modulation types based upon the combination of the requested modulation type and the maximum allowable modulation type determined at registration or from a dynamic service operation.

CID

.A required parameter until the Temporary CID has been received in the Ranging Response message. Note that in all other cases, the CID is encoded in the MAC Management Header and is not sent as a TLV.

SS MAC Address (48- Bit)

The MAC address of the SS. A required parameter when the CID in the MAC header is the initialization CID.

2.5.6.1 RNG-RSP TLV Encodings

The type values used shall be those defined in Table 15 and Figure 33. These are unique within the ranging response Message but not across the entire MAC Message set. The type and length fields shall each be 1 in length.

Table 15—Ranging Response Message Encodings

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
Timing Adjust	1	4	Tx timing offset adjustment (signed 32-bit, units of ¼ symbols)
Power Level Adjust	2	1	Tx Power offset adjustment (signed 8-bit, ¼-dB units)
Offset Frequency Adjust	3	4	Tx frequency offset adjustment (signed 32-bit, Hz units)
Transmit Equalization Adjust	4	n	Tx equalization data - see details below
Ranging Status	5	1	1 = continue, 2 = abort, 3 = success
Downlink frequency override	6	4	Center frequency of new downlink channel in kHz If this TLV is used, the Ranging Status value must be set to 1
Uplink channel ID override	7	1	Identifier of the new uplink channel.
Data Grant 1-6 Thresholds	8	1	TBD
Threshold Delta	10	1	Hysteresis delta for modulation threholds in ¼ dB.
Maximum Modulation Type Supported	11	1	1 = QPSK, 2 = QPSK or 16-QAM, 3 = QPSK or 16/64-QAM
SS MAC Address	12	8	SS MAC Address in EUI-48 format
Reserved	13-255	n	Reserved for future use

type 4	length	main tap location	number of forward taps per symbol
number of forward taps (N)	number of reverse taps (M)		
first coefficient F_1 (real)		first coefficient F_1 (imag)	
last coefficient F_N (real)		last coefficient F_N (imag)	
first reverse coefficient D_1 (real)		first reverse coefficient D_1 (imag)	
last reverse coefficient D_M (real)		last reverse coefficient D_M (imag)	

Figure 31—Generalized Decision Feedback Equalization Coefficients

The number of forward taps per symbol shall be in the range of 1 to 4. The main tap location refers to the position of the zero delay tap, between 1 and N. For a symbol-spaced equalizer, the number of forward taps per symbol field shall be set to “1”. The number of reverse taps (M) field shall be set to “0” for a linear equalizer. The total number of taps may range up to 64. Each tap consists of a real and imaginary coefficient entry in the table.

If more than 255 bytes are needed to represent equalization information, then several type-4 elements may be used. Data shall be treated as if byte-concatenated, that is, the first byte after the length field of the second type-4 element is treated as if it immediately followed the last byte of the first type-4 element.

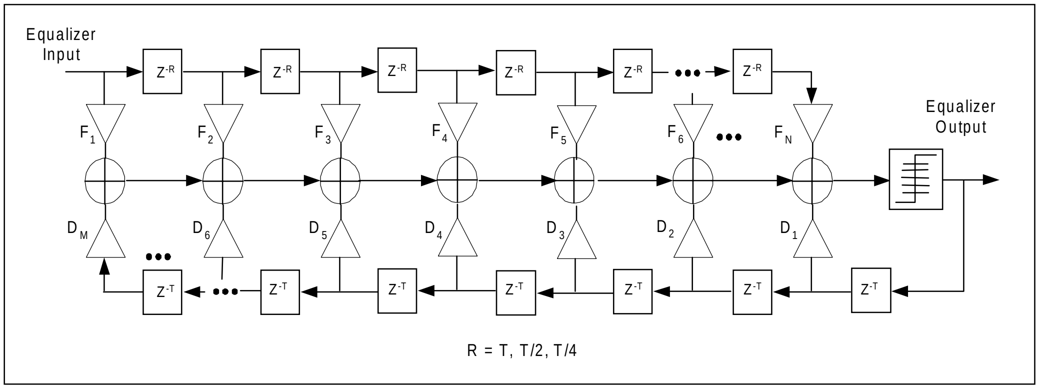


Figure 32—Generalized Equalizer Tap Location Definition

2.5.7 Registration Request (REG-REQ) Message

A Registration Request shall be transmitted by a SS at initialization allowing the CID shall be encoded in a type/length/value form. A SS shall generate Registration Requests in the form shown in Figure 33

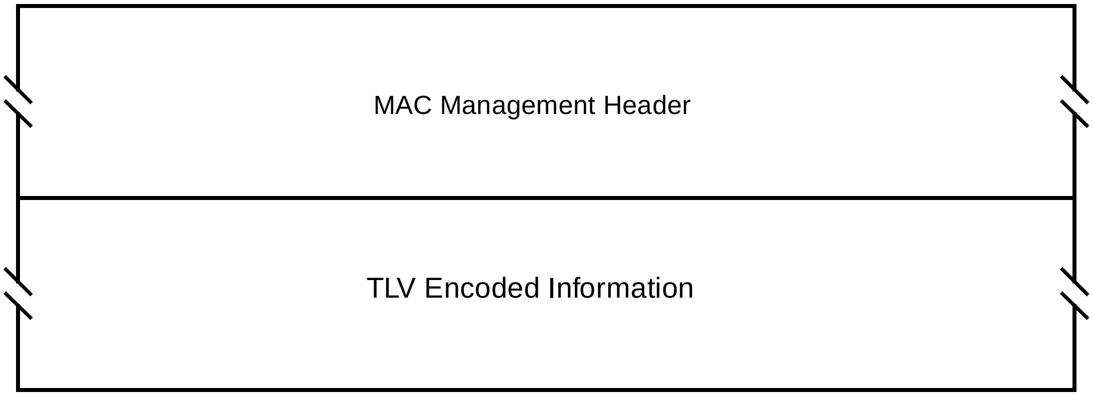


Figure 33—REG-REQ Message Format

CID (from the MAC Management Header)

Temporary CID for this SS.

All other parameters are coded as TLV tuples as defined in 2.3.

Registration Requests can contain many different TLV parameters, some of which are set by the SS according to its configuration file and some of which are generated by the SS itself. If found in the Configuration File, the following Configuration Settings shall be included in the Registration Request.

Configuration File Settings:

Downlink Frequency Configuration Setting
Uplink Channel ID Configuration Setting
Network access Control Object
Uplink Service Flow Configuration Setting
Downlink Service Flow Configuration Setting
Privacy Configuration Setting
Maximum Number of Subscribers
Privacy Enable Configuration Setting
TFTP Server Timestamp
TFTP Server Provisioned SS address
Downlink Modulation Configuration Setting
Vendor-Specific Information Configuration Setting
SS MIC Configuration Setting
BS MIC Configuration Setting

The SS shall forward the vendor specific configuration settings to the BS in the same order in which they were received in the configuration file to allow the Message integrity check to be performed.

The following registration parameter shall be included in the Registration Request.

Vendor Specific Parameter:

Vendor ID Configuration Setting (Vendor ID of SS)

The following registration parameter shall also be included in the Registration Request.

Upstream and Downstream SS Capabilities Encodings
These include the highest modulation order supported by the SS (QPSK, 16-QAM, or 64-QAM), the optional FEC types supported by the SS(BTC1 based on (32,26) Extended Hamming Code or BTC2 based on (64,57) Extended Hamming Code), and the minimum shortened last codeword size supported by the SS

The following registration parameter may also be included in the Registration Request.

SS IP address

The following Configuration Settings shall not be forwarded to the BS in the Registration Request.

Software Upgrade Filename
Software Upgrade TFTP Server IP address
SNMP Write-access Control
SNMP MIB Object
SS 48-bit MAC address
HMAC Digest
End Configuration Setting
Pad Configuration Setting

2.5.8 Registration Response (REG-RSP) Message

A Registration Response shall be transmitted by BS in response to received REG-REQ.

To provide for flexibility, the Message parameters following the Response field shall be encoded in a TLV format.

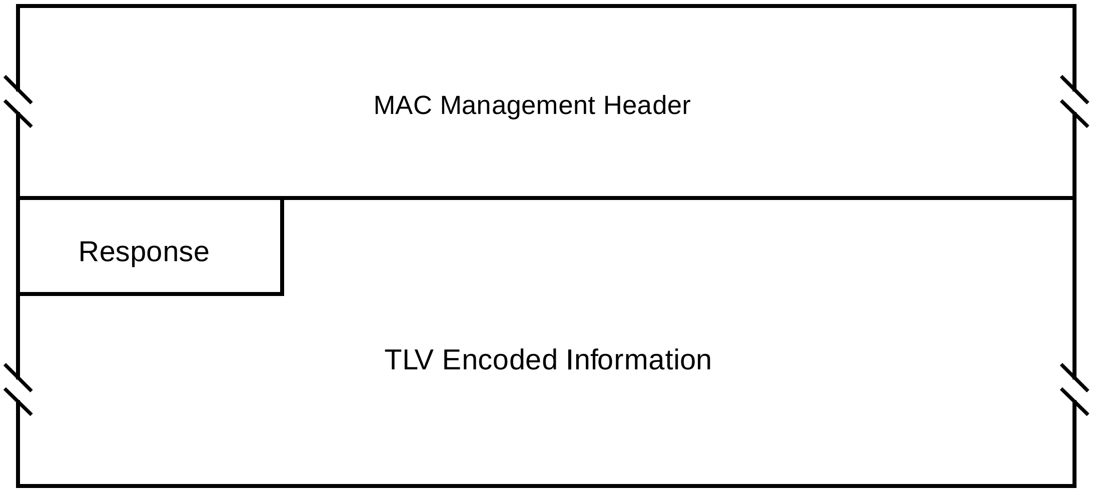


Figure 34—REG-RSP Message Format

A BS shall generate Registration Responses in the form shown in Figure 34, including both of the following parameters:

CID (in the MAC Management Header) from Corresponding REG-REQ

> CID from corresponding REG-REQ to which this response refers. (This acts as a transaction identifier)

Response

> 0 = Okay
> 1 = Authentication Failure
> 2 = Class of Service Failure

Note: Failures apply to the entire Registration Request. Even if only a single requested Service Flow is invalid or undeliverable the entire registration is failed.

If the REG-REQ was successful and contained Service Flow Parameters, the REG-RSP shall contain:

Service Flow Parameters

> All the Service Flow Parameters from the REG-REQ, plus the Connection ID assigned by the BS. Every Service Flow that contained a Service Class Name that was admitted/activated shall be expanded into the full set of TLVs defining the Service Flow. Every uplink Service Flow that was admitted/activated[4] shall have a Connection Identifier assigned by the BS. A Service Flow that was

[4] The ActiveQoSParamSet or AdmittedQoSParamSet is non-null.

only provisioned will include only those QoS parameters that appeared in the REG-REQ, plus the assigned Service Flow ID.

If the REG-REQ failed and contained Service Flow Parameters, the REG-RSP shall contain the following:

Service Flow Error Set

A Service Flow Error Set and identifying Service Flow Reference shall be included for every failed Service Flow in the corresponding REG-REQ. Every Service Flow Error Set shall include every specific failed QoS Parameter of the corresponding Service Flow.

Service Class Name expansion always occurs at admission time. Thus, if a Registration-Request contains a Service Flow Reference and a Service Class Name for deferred admission/activation, the Registration-Response shall not include any additional QoS Parameters except the Service Flow Identifier.

All other parameters are coded as TLV tuples:

Basic CID

The Basic CID for this SS.

Secondary Management CID

CID for secondary management purposes

SS Capabilities

The BS response to the capabilities of the SS (if present in the Registration Request)

Vendor-Specific Data

As defined in 2.3
Vendor ID Configuration Setting (vendor ID of BS)
Vendor-specific extensions

Note: The temporary CID shall no longer be used once the REG-RSP is received.

2.5.8.1 Encodings

The type values used shall be those shown below. These are unique within the Registration Response Message but not across the entire MAC Message set. The type and length fields shall each be 1 .

SS **Capabilities**

This field defines the BS response to the SScapability field in the Registration Request. The BS responds to the SS capabilities to indicate whether they may be used. If the BS does not recognize a SS capability, it must return this as “off” in the Registration Response.

Only capabilities set to “on” in the REG-REQ may be set “on” in the REG-RSP as this is the handshake indicating that they have been successfully negotiated.

Encodings are as defined for the Registration Request, including MAC version.

MAC Version	9	1	Version number of the MAC supported on this channel.

2.5.9 Registration Acknowledge (REG-ACK) Message

A Registration Acknowledge message shall be transmitted by the SS in response to a REG-RSP from the BS. It confirms acceptance by the SS of the QoS parameters of the flow as reported by the BS in it REG-RSP. The format of a REG-ACK shall be as shown in Figure 35.

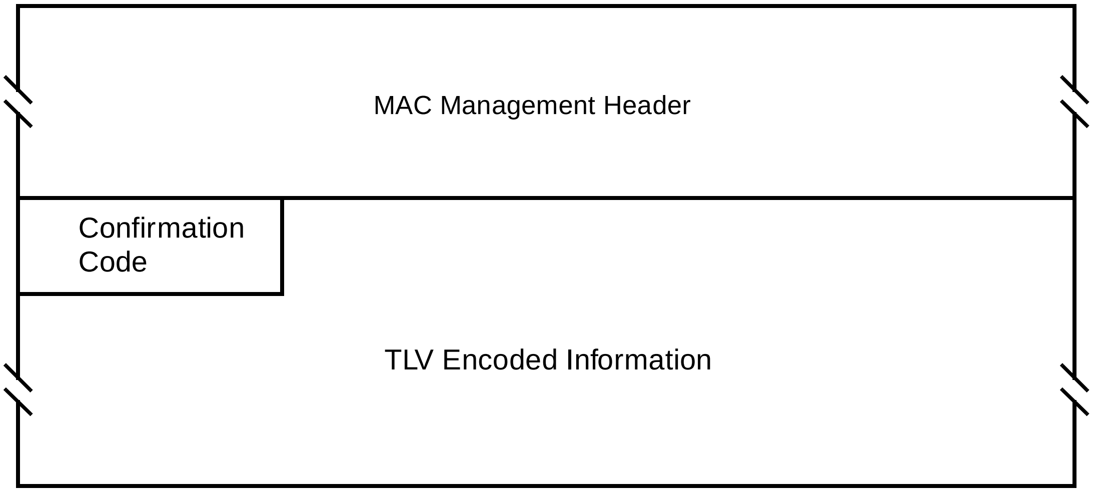


Figure 35—REG-ACK Message Format

The parameter shall be as follows:

CID (in the MAC Management Header) from Corresponding REG-RSP

> CID from corresponding REG-RSP to which this acknowledgment refers. (This acts as a transaction identifier)

Confirmation Code

> The appropriate Confirmation Code (refer to section 2.3) for the entire corresponding Registration Response.

The SS shall forward all provisioned Service Flows to the BS. Since any of these provisioned items can fail, the REG-ACK shall include Error Sets for all failures related to these provisioned items.

Service Flow Error Set

> The Service Flow Error Set of the REG-ACK Message encodes specifics of any failed Service Flows in the REG-RSP Message. A Service Flow Error Set and identifying Service Flow Reference

shall be included for every failed QoS Parameter of every failed Service Flow in the corresponding REG-RSP Message. This parameter shall be omitted if the entire REG-REQ/RSP is successful.

Note: Per Service Flow acknowledgment is necessary not just for synchronization between the SS and BS, but also to support use of the Service Class Name. Since the SS may not know all of the Service Flow parameters associated with a Service Class Name when making the Registration Request, it may be necessary for the SS to NAK a Registration Response if it has insufficient resources to actually support this Service Flow.

2.5.10 Privacy Key Management — Request (PKM-REQ) Message

Privacy Key Management protocol Messages transmitted from the SS to the BS shall use the form shown in Figure 36.

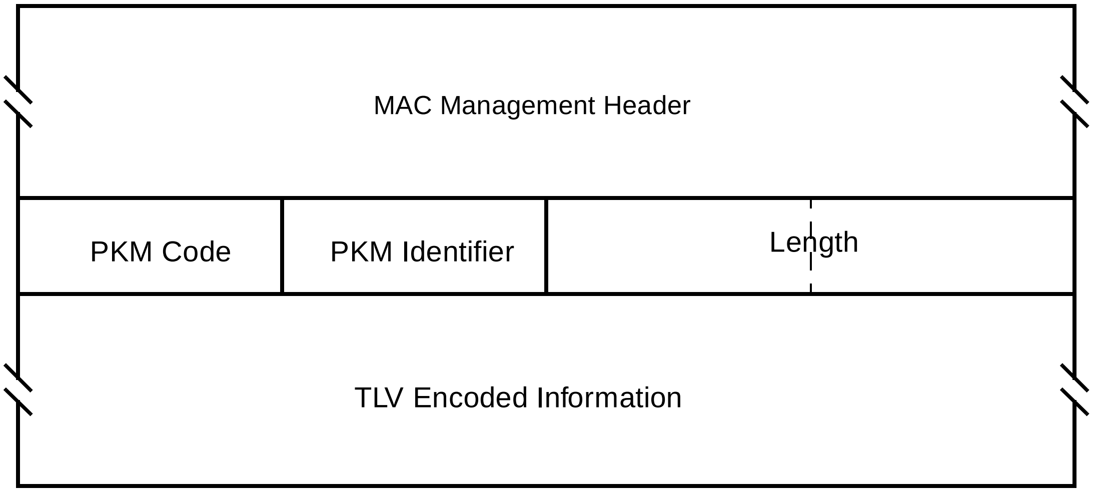


Figure 36—PKM-REQ Message Format

Parameters shall be as follows:

PKM Code

The Code field is one octect and identifies the type of PKM packet. When a packet is recieved with an invalid Code field, it shall be silently discarded. The Code values are defined in 2.16.2.1.

PKM Identifier

The Identifier field is one octect. A SS uses the identifier to match a BS response to the SS's requests.

The SS shall change (e.g., increment, wrapping around to 0 after reaching 255) the Identifier field whenever it issues a new PKM Message. A "new" Message is an Authorization Request, Key Request or SA Map Request that is not a retransmission being sent in response to a Timeout event. For retransmissions, the Identifier field shall remain unchanged.

The Identifier field in Authentication Information Messages, which are informative and do not effect any response messaging, may be set to zero. The Identifier field in a BS's PKM response Message shall match the Identifier field of the PKM Request Message the BS is responding to. The Identifier field in Traffic Encryption Key (TEK) Invalid Messages, which are not sent in response to BPKM requests, shall be set to zero. The Identifier field in unsolicited Authorization Invalid Messages shall be set to zero.

On reception of a BPKM response Message, the SS associates the Message with a particular state machine (the Authorization state machine in the case of Authorization Replies, Authorization Rejects, and Authorization Invalids; a particular TEK state machine in the case of Key Replies, Key Rejects and TEK Invalids; a particular Security Association (SA) Mapping state machine in the case of SA Map Replies and SA Map Rejects).

A SS may keep track of the Identifier of its latest, pending Authorization Request. The SS may silently discard Authorization Replies and Authorization Rejects whose Identifier fields do not match those of the pending requests.

A SS may keep track of the Identifier of its latest, pending Key Request. The SS may silently discard Key Replies and Key Rejects whose Identifier fields do not match those of the pending requests.

A SS may keep track of the Identifier of its latest, pending SA Map Request. The SS may silently discard SA Map Replies and SA Map Rejects whose Identifier fields do not match those of the pending requests.

Length

The Length field is two s. It indicates the length of the Attribute fields in s. The length field does not include the Code, Identifier and Length fields. s outside the range of the Length field shall be treated as padding and ignored on reception. If the packet is shorter than the Length field indicates, it should be silently discarded. The minimum length is 0 and maximum length is <TBD>.

All other parameters are encoded as TLV tuples as defined in 2.3.

2.5.11 Privacy Key Management — Response (PKM-RSP) Message

Privacy Key Management protocol Messages transmitted from the BS to the SS shall use the form shown in Figure 37.

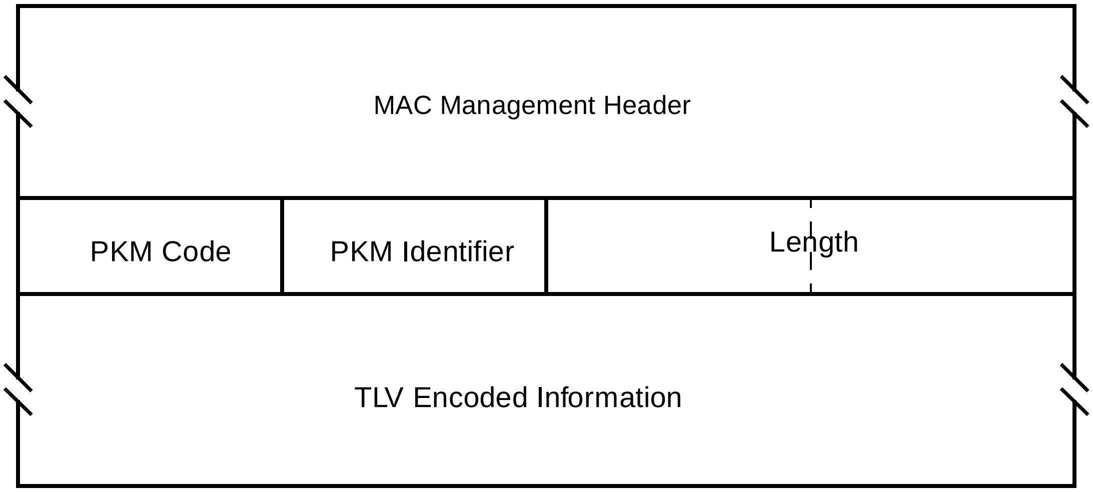


Figure 37—PKM-RSP Message Format

2.5.12 Dynamic Service Addition — Request (DSA-REQ) Message

A Dynamic Service Addition Request may be sent by a SS or BS to create a new Service Flow.

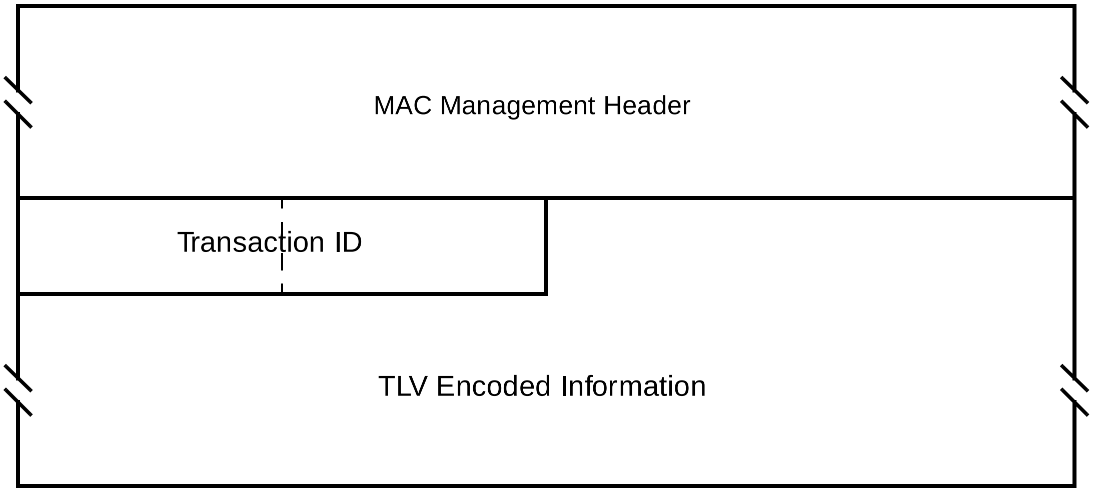


Figure 38—DSA-REQ Message Format

A SS or BS shall generate DSA-REQ Messages in the form shown in Figure 38 including the following parameter:

Transaction ID

Unique identifier for this transaction assigned by the sender.

All other parameters are coded as TLV tuples as defined in 2.3. A DSA-REQ Message shall not contain parameters for more than one Service Flow in each direction, i.e., a DSA-REQ Message shall contain parameters for either a single uplink Service Flow, or for a single downlink Service Flow, or for one uplink and one downlink Service Flow.

The DSA-REQ Message shall contain:

Service Flow Parameters

Specification of the Service Flow's traffic characteristics and scheduling requirements.

If Privacy is enabled, the DSA-REQ Message shall contain:

HMAC-Digest

The HMAC-Digest Attribute is a keyed Message digest (to authenticate the sender). The HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service Message's Attribute list. (Refer to 2.3.4.1)

2.5.12.1 SS-Initiated Dynamic Service Addition

Values of the Service Flow Reference are local to the DSA Message; each Service Flow within the DSA-Request shall be assigned a unique Service Flow Reference. This value need not be unique with respect to the other service flows known by the sender.

SS-initiated DSA-Requests may use the Service Class Name (refer to 2.3.5.3.4) in place of some, or all, of the QoS Parameters.

2.5.12.2 BS-Initiated Dynamic Service Addition

BS-initiated DSA-Requests for Uplink Service Flows shall also include a Connection ID. Connection Identifiers are unique within the MAC domain.

BS-initiated DSA-Requests for named Service Classes shall include the QoS Parameter Set associated with that Service Class.

2.5.13 Dynamic Service Addition — Response (DSA-RSP) Message

A Dynamic Service Addition Response shall be generated in response to a received DSA-Request. The format of a DSA-RSP shall be as shown in Figure 39.

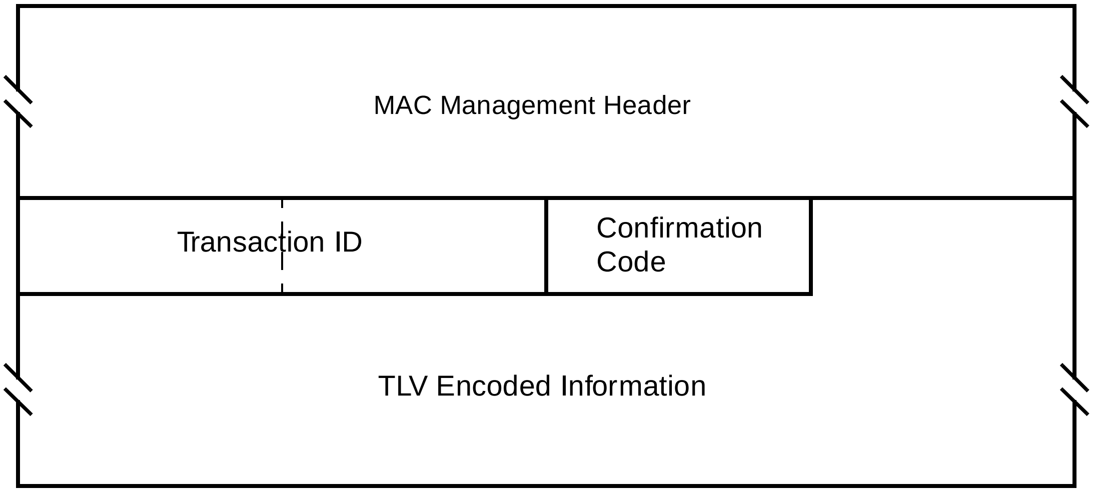


Figure 39—DSA-RSP Message Format

Parameters shall be as follows:

Transaction ID

Transaction ID from corresponding DSA-REQ.

Confirmation Code

The appropriate Confirmation Code for the entire corresponding DSA-Request.

All other parameters are coded as TLV tuples as defined in 2.3.

If the transaction is successful, the DSA-RSP may contain the following:

Service Flow Parameters

The complete specification of the Service Flow shall be included in the DSA-RSP only if it includes a newly assigned Connection Identifier or an expanded Service Class Name.

If the transaction is unsuccessful, the DSA-RSP shall include:

Service Flow Error Set

A Service Flow Error Set and identifying Service Flow Reference/Identifier shall be included for every failed Service Flow in the corresponding DSA-REQ Message. Every Service Flow Error Set shall include every specific failed QoS Parameter of the corresponding Service Flow. This parameter shall be omitted if the entire DSA-REQ is successful.

If Privacy is enabled, the DSA-RSP Message shall contain:

HMAC-Digest

> The HMAC-Digest Attribute is a keyed Message digest (to authenticate the sender). The HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service Message's Attribute list. (Refer to 2.3.4.1)

2.5.13.1 SS-Initiated Dynamic Service Addition

The BS's DSA-Response for Service Flows that are successfully added shall contain a Connection ID. The DSA-Response for successfully Admitted or Active uplink QoS Parameter Sets shall also contain a Connection ID.

If the corresponding DSA-Request uses the Service Class Name (refer to 2.3.5.3.4) to request service addition, a DSA-Response shall contain the QoS Parameter Set associated with the named Service Class. If the Service Class Name is used in conjunction with other QoS Parameters in the DSA-Request, the BS shall accept or reject the DSA-Request using the explicit QoS Parameters in the DSA-Request. If these Service Flow Encodings conflict with the Service Class attributes, the BS shall use the DSA-Request values as overrides for those of the Service Class.

If the transaction is unsuccessful, the BS shall use the original Service Flow Reference to identify the failed parameters in the DSA-RSP.

2.5.13.2 BS-Initiated Dynamic Service Addition

If the transaction is unsuccessful, the SS shall use the Connection Identifier to identify the failed parameters in the DSA-RSP.

2.5.14 Dynamic Service Addition — Acknowledge (DSA-ACK) Message

A Dynamic Service Addition Acknowledge shall be generated in response to a received DSA-RSP. The format of a DSA-ACK shall be as shown in Figure 40.

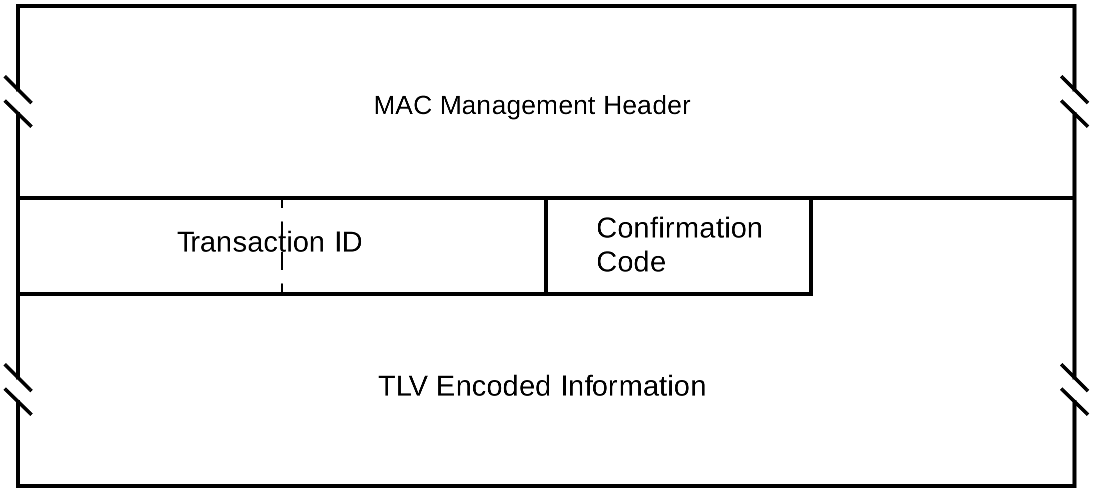


Figure 40—DSA-ACK Message Format

Parameters shall be as follows:

Transaction ID

Transaction ID from corresponding DSA-Response.

Confirmation Code

The appropriate Confirmation Code (refer to 2.3.7) for the entire corresponding DSA-Response.[5]

All other parameters are coded TLV tuples.

Service Flow Error Set

The Service Flow Error Set of the DSA-ACK Message encodes specifics of any failed Service Flows in the DSA-RSP Message. A Service Flow Error Set and identifying Service Flow Reference shall be included for every failed QoS Parameter of every failed Service Flow in the corresponding DSA-REQ Message. This parameter shall be omitted if the entire DSA-REQ is successful.

If Privacy is enabled, the DSA-ACK Message shall contain:

HMAC-Digest

[5] The confirmation code is necessary particularly when a Service Class Name (refer to 2.3.5.3.4) is used in the DSA-Request. In this case, the DSA-Response could contain Service Flow parameters that the SS is unable to support (either temporarily or as configured).

The HMAC-Digest Attribute is a keyed Message digest (to authenticate the sender). The HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service Message's Attribute list. (Refer to 2.3.4.1)

2.5.15 Dynamic Service Change — Request (DSC-REQ) Message

A Dynamic Service Change Request may be sent by a SS or BS to dynamically change the parameters of an existing Service Flow.

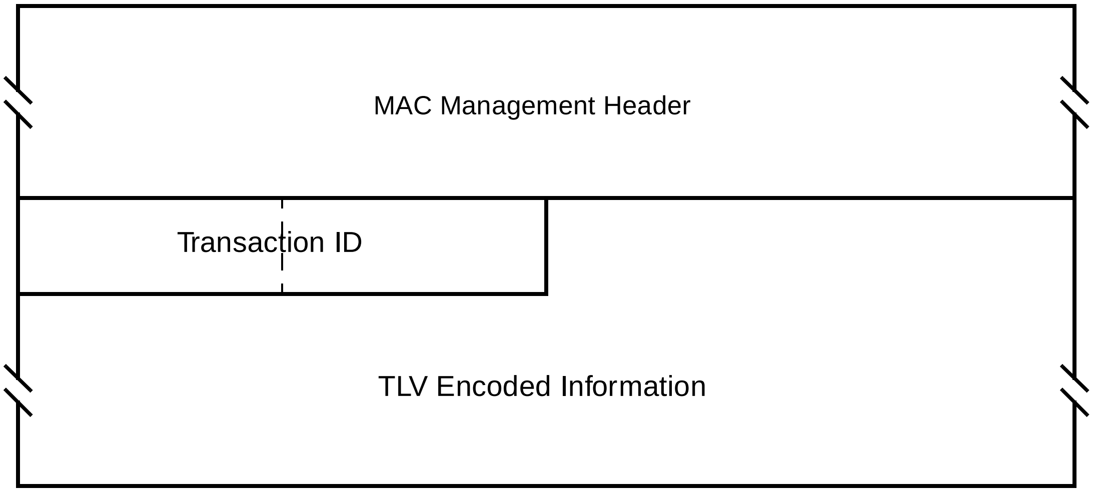


Figure 41—DSC-REQ Message Format

A SS or BS shall generate DSC-REQ Messages in the form shown in Figure 41 including the following parameters:

Transaction ID

Unique identifier for this transaction assigned by the sender.

All other parameters are coded as TLV tuples as defined in 2.3. A DSC-REQ Message shall not carry parameters for more than one Service Flow in each direction, i.e., a DSC-REQ Message shall contain parameters for either a single uplink Service Flow, or for a single downlink Service Flow, or for one uplink and one downlink Service Flow. A DSC-REQ shall contain the following:

Service Flow Parameters

Specification of the Service Flow's new traffic characteristics and scheduling requirements. The Admitted and Active Quality of Service Parameter Sets currently in use by the Service Flow. If the DSC Message is successful and it contains Service Flow parameters, but does not contain replacement sets for both Admitted and Active Quality of Service Parameter Sets, the omitted set(s) shall be set to null. If included, the Service Flow Parameters shall contain a Service Flow Identifier.

If Privacy is enabled, a DSC-REQ shall also contain:

HMAC-Digest

The HMAC-Digest Attribute is a keyed Message digest (to authenticate the sender). The HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service Message's Attribute list. (Refer to 2.3.4.1)

2.5.16 Dynamic Service Change — Response (DSC-RSP) Message

A Dynamic Service Change Response shall be generated in response to a received DSC-REQ. The format of a DSC-RSP shall be as shown in Figure 42.

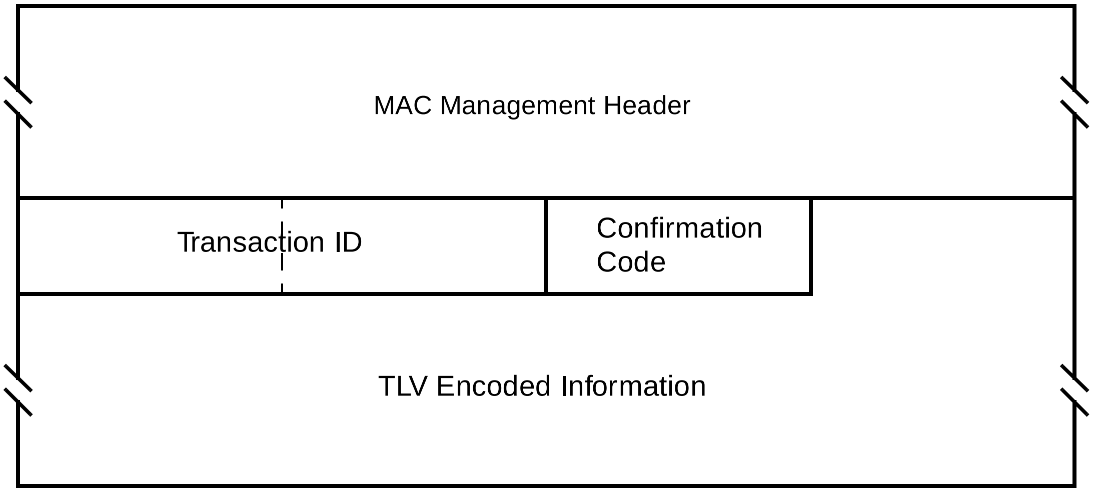


Figure 42—DSC-RSP Message Format

Parameters shall be as follows:

Transaction ID

Transaction ID from corresponding DSC-REQ

Confirmation Code

The appropriate Confirmation Code (refer to 2.3.7) for the corresponding DSC-Request.

All other parameters are coded as TLV tuples as defined in 2.3.

If the transaction is successful, the DSC-RSP may contain the following:

Service Flow Parameters

> The complete specification of the Service Flow shall be included in the DSC-RSP only if it includes a newly assigned Connection Identifier or an expanded Service Class Name. If a Service Flow Parameter set contained an uplink Admitted QoS Parameter Set and this Service Flow does not have an associated CID, the DSC-RSP shall include a CID. If a Service Flow Parameter set contained a Service Class Name and an Admitted QoS Parameter Set, the DSC-RSP shall include the QoS Parameter Set corresponding to the named Service Class. If specific QoS Parameters were also included in the Classed Service Flow request, these QoS Parameters shall be included in the DSC-RSP instead of any QoS Parameters of the same type of the named Service Class.

If the transaction is unsuccessful, the DSC-RSP shall contain the following:

Service Flow Error Set

> A Service Flow Error Set and identifying Connection ID shall be included for every failed Service Flow in the corresponding DSC-REQ Message. Every Service Flow Error Set shall include every specific failed QoS Parameter of the corresponding Service Flow. This parameter shall be omitted if the entire DSC-REQ is successful.

Regardless of success or failure, if Privacy is enabled for the SS the DSC-RSP shall contain:

HMAC-Digest

> The HMAC-Digest Attribute is a keyed Message digest (to authenticate the sender). The HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service Message's Attribute list. (Refer to 2.3.4.1)

2.5.17 Dynamic Service Change — Acknowledge (DSC-ACK) Message

A Dynamic Service Change Acknowledge shall be generated in response to a received DSC-RSP. The format of a DSC-ACK shall be as shown in Figure 43.

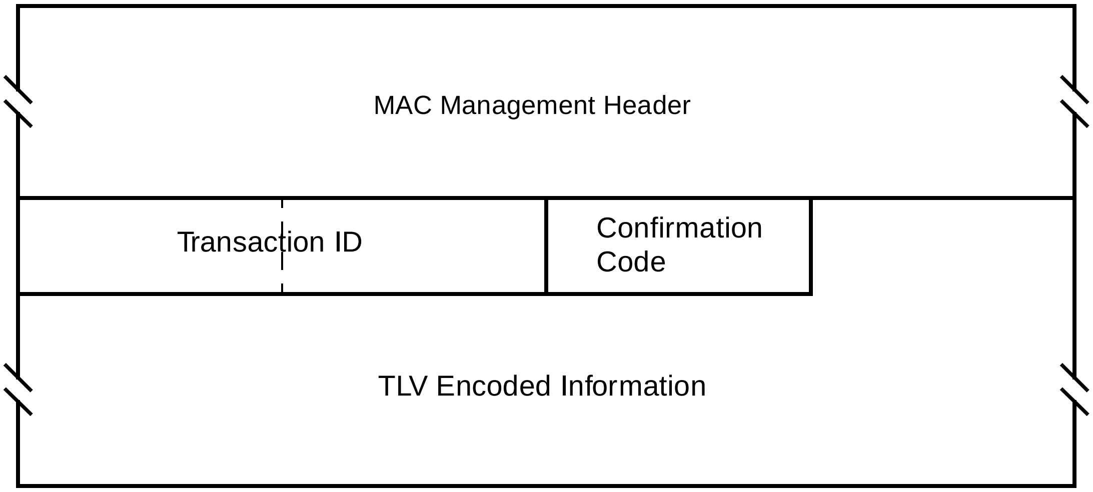


Figure 43—DSC-ACK Message Format

Parameters shall be as follows:

Transaction ID

Transaction ID from the corresponding DSC-REQ

Confirmation Code

The appropriate Confirmation Code (refer to 2.3.7) for the entire corresponding DSC-Response.

All other parameters are coded TLV tuples.

Service Flow Error Set

The Service Flow Error Set of the DSC-ACK Message encodes specifics of any failed Service Flows in the DSC-RSP Message. A Service Flow Error Set and identifying Service Flow Identifier shall be included for every failed QohS Parameter of each failed Service Flow in the corresponding DSC-RSP Message. This parameter shall be omitted if the entire DSC-RSP is successful.

If Privacy is enabled, the DSC-ACK Message shall contain:

HMAC-Digest

The HMAC-Digest Attribute is a keyed Message digest (to authenticate the sender). The HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service Message's Attribute list. (Refer to 2.3.4.1)

2.5.18 Dynamic Service Deletion — Request (DSD-REQ) Message

A DSD-Request may be sent by a SS or BS to delete an existing Service Flow. The format of a DSD-Request shall be as shown in Figure 44.

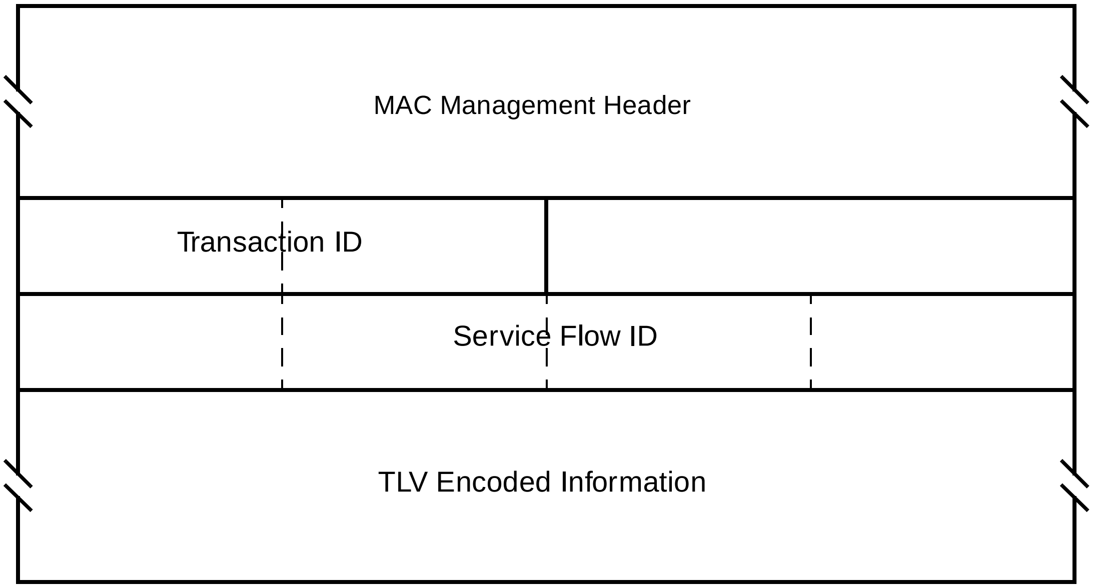


Figure 44—DSD-REQ Message Format

Parameters shall be as follows:

Service Flow Identifier

The SFID to be deleted.

Transaction ID

Unique identifier for this transaction assigned by the sender.

All other parameters are coded as TLV tuples as defined in 2.3.

If Privacy is enabled, the DSD-REQ shall include:

HMAC-Digest

The HMAC-Digest Attribute is a keyed Message digest (to authenticate the sender). The HMAC-Digest Attribute shall be the final Attribute in the Dynamic Service Message's Attribute list. (Refer to 2.3.4.1)

2.5.19 Dynamic Service Deletion — Request (DSD-RSP) Message

A DSD-RSP shall be generated in response to a received DSD-REQ. The format of a DSD-RSP shall be as shown in Figure 45.

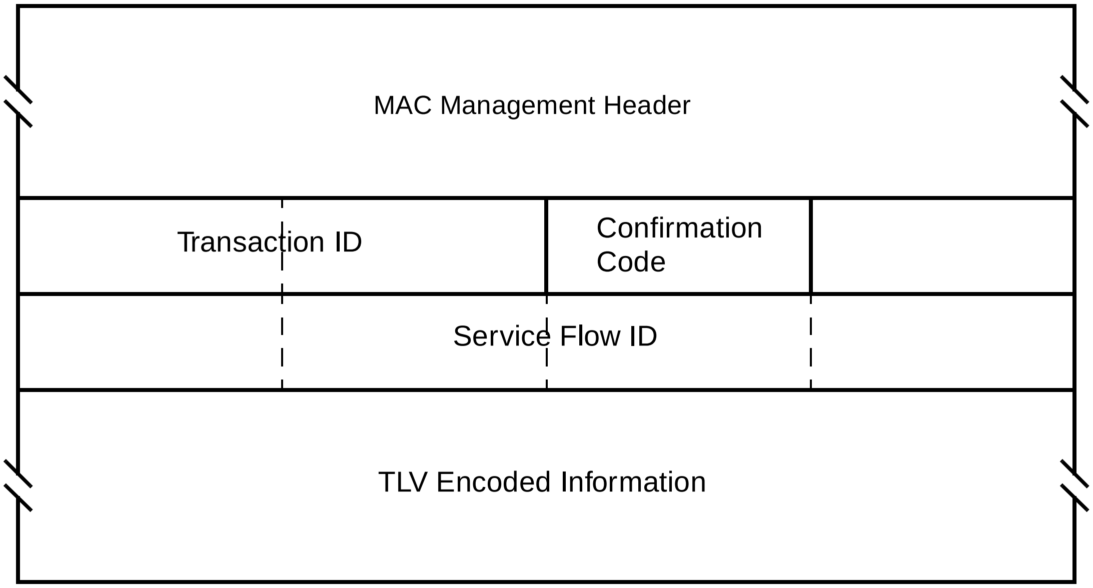


Figure 45—DSD-RSP Message Format

Parameters shall be as follows:

Service Flow Identifier

SFID from the DSD-REQ to which this acknowledgement refers.

Transaction ID

Transaction ID from the corresponding DSD-REQ.

Confirmation Code

The appropriate Confirmation Code (refer to 2.3.7) for the corresponding DSD-REQ.

2.5.20 Multicast Polling Assignment Request (MCA-REQ) Message

The Multicast Polling Assignment message is sent to a SS to include it in a multicast polling group. This message is normally sent on a SS's basic CID. It may also be sent to a group of SS's on a previously set up multicast CID. This shall be followed by a Packet PDU in the format shown in Figure 46.

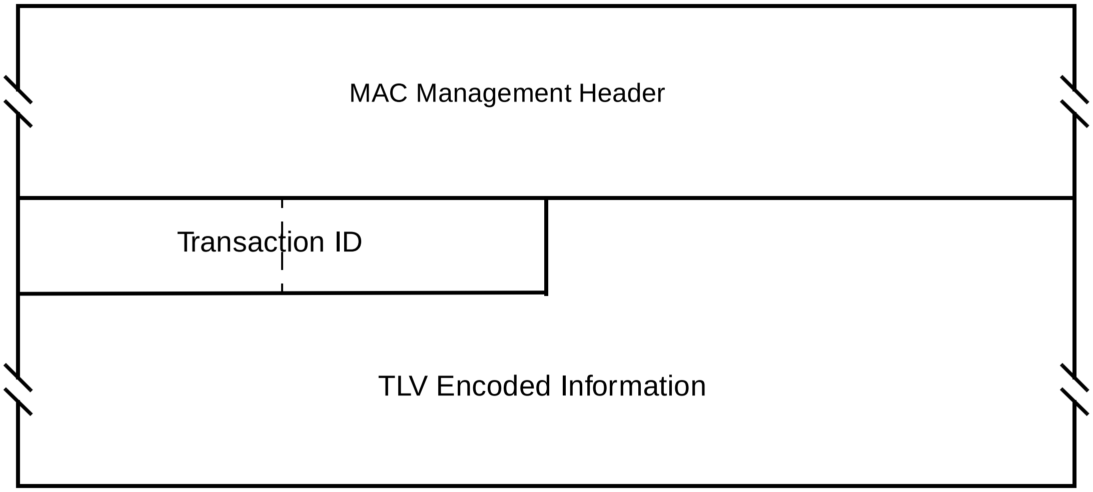


Figure 46—Multicast Polling Assignment Request (MCA-REQ) Message Format

Parameters shall be as follows:

Transaction ID

Unique identifier for this transaction assigned by the sender.

All other parameters are coded as TLV tuples.

Multicast Connection Identifier

The CID to which the SS is either added or removed.

Assignment

0x00 = Leave multicast group
0x01 = Join multicast group

2.5.20.1 MCA-REQ TLV Encodings

The type values used shall be those defined in Table 16. The type and length fields shall each be 1 in length.

Table 16—Multicast Assigment Request Message Encodings

Name	Type (1 byte)	Length (1 byte)	Value (Variable Length)
Multicast CID	1	2	
Assignment	2	1	0x00 = Leave multicast group 0x01 = Join multicast group
Reserved	2-255	n	Reserved for future use

2.5.21 Multicast Polling Assignment Response (MCA-RSP) Message

The Multicast Polling Assigment Response is sent by the SS in response to a MCA-REQ. The message format shall be as shown in Figure 47.

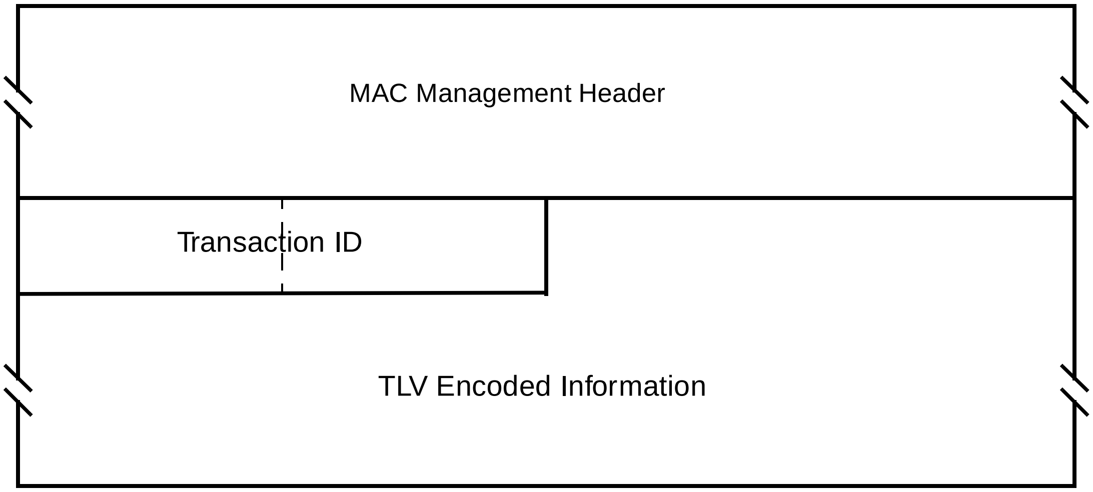


Figure 47—Multicast Polling Assignment Response (MCA-RSP) Message Format

Parameters shall be as follows:

Transaction ID

Unique identifier for this transaction assigned by the sender.

All other parameters are coded as TLV tuples.

Confirmation Code

0 (okay)
1 (request failed)

2.5.22 ARQ-ACK Message

The message ise an acknowledgment message sent to a sender for packets received correctly. The acknowledgment message may group together more than one packet, and shall carry the sequence number(s) for packets that have been correctly received.

Message format TBD.

2.5.23 Downlink Burst Type Change Request (DBTC-REQ) Message

The Downlink Burst Type Change Request (DBTC-REQ) Message is sent by the SS to the BS on the SS's basic CID to request a change of the downlink burst type used by the BS to transport data to the SS. Note that a change of downlink burst type can also be requested by means of a Ranging Request message as defined in section 2.5.5.

Normally, it is sent at the current operational data grant type for the SS. If the SS has been inactive on its uplink for some period of time and detects fading on the downlink, the SS uses this message to request to go to a more robust (lower bits per symbol) data grant type. In this case, the message is sent using the most robust data grant type to increase the likelihood of reception by the SS. Since the SS may not have been allocated any uplink bandwidth, the SS uses contention slots. The message formant shall be as shown in Figure 48.

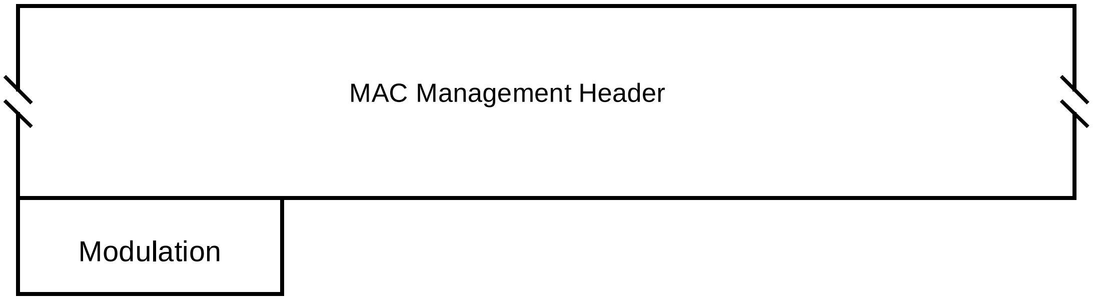


Figure 48—Downlink Burst Type Change Request (DMC-REQ) Message Format

Parameters shall be as follows:

0x02 = 64-QAM

Data Grant Types

0x00 = Data Grant Type 1
0x01 = Data Grant Type 2
0x02 = Data Grant Type 3
0x03 = Data Grant Type 4
0x04 = Data Grant Type 5
0x05 = Data Grant Type 6

2.6 Duplexing Techniques, Framing, and Scheduling Intervals

The MAC is able to support both a framed and non-framed physical layer. For a framed PHY layer, the MAC aligns its scheduling intervals with the underlying PHY layer framing. For an unframed PHY layer, the scheduling intervals are chosen by the MAC to optimize system performance.

A frame is a fixed duration of time, which contains both transmit and receive intervals. The relationship between upstream and downstream transmission intervals is fixed within the frame, and are both defined relative to the BS internal timing. The TDD and Burst FDD modes of operation use a framed PHY layer. The Continuous FDD mode of operation has no explicit PHY layer framing. Instead, the upstream and downstream transmission timings are linked via the Uplink TimeStamp within the DL-MAP message and the Allocation Start Time in the UL-MAP message.

2.6.1 Duplexing Techniques

Several duplexing techniques are supported in this standard in order to allow for greater flexibility in spectrum usage. The choice of duplexing technique may effect certain physical layer parameters, as will be discussed later.

2.6.1.1 Continuous Frequency Division Duplexing (FDD)

In a system employing FDD, the upstream and downstream channels are located on separate frequencies and all subscriber stations can transmit and receive simultaneously. The frequency separation between carriers is set either according to the target spectrum regulations or to some value sufficient for complying with radio channel transmit/receive isolation and desensitization requirements. In this type of system, the downstream channel is “always on” and all subscriber stations are always listening to it. Therefore, traffic is sent in a broadcast manner using time division multiplexing (TDM) in the downstream channel, while the upstream channel is shared using time division multiple access (TDMA), where the allocation of upstream bandwidth is controlled by a centralized scheduler.

2.6.1.2 Burst FDD

A burst FDD system refers to a system in which the upstream and downstream channels are located on separate frequencies, but some or all subscriber stations cannot transmit and receive simultaneously (for simplicity, these subscriber stations are referred to as half duplex capable). This mode of operation imposes a restriction on the bandwidth controller not to allocate upstream bandwidth for a subscriber at the same time it is expected to receiver data on the downstream channel. Note that this type of system may also have some subscriber stations that can transmit and receive simultaneously (i.e., these subscriber stations are referred to as full duplex capable).

The following figure describes the basics of the burst FDD mode of operation. In order to simplify the bandwidth allocation algorithms, the upstream and downstream channels are divided into fixed sized frames.

During the time a subscriber station is not transmitting in the upstream channel, it must always attempt to listen to the downstream channel.

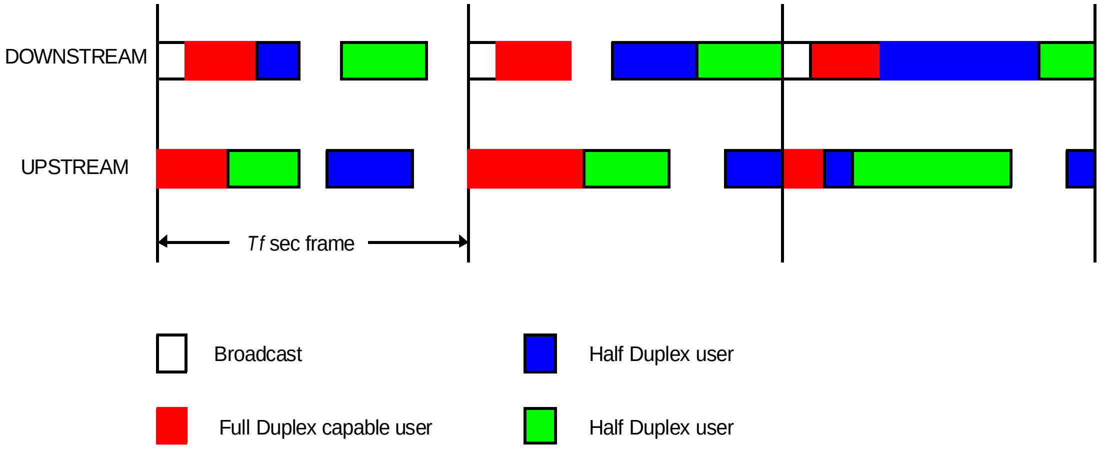


Figure 49—Example of Burst FDD Bandwidth Allocation

2.6.1.3 Time Division Duplexing (TDD)

In the case of TDD, the upstream and downstream transmissions share the same frequency, but are separated in time. A TDD frame also has a fixed duration and contains one downstream and one upstream subframe. The frame is divided into an integer number of physical slots (PS), which help to partition the bandwidth easily. The TDD framing is adaptive in that the bandwidth allocated to the downstream versus the upstream can vary. The split between upstream and downstream is a system parameter and is controlled at higher layers within the system.

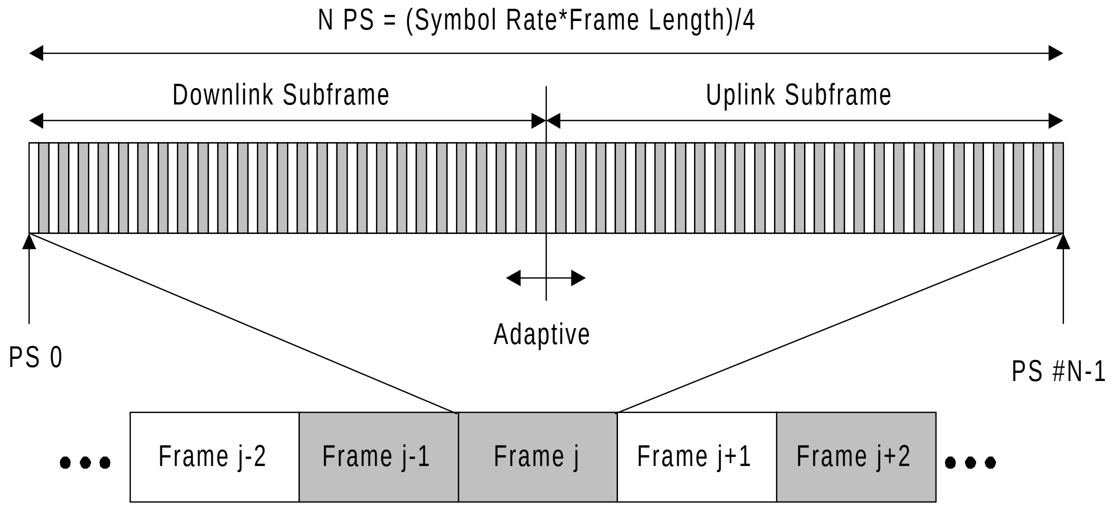


Figure 50— TDD Frame Structure

2.6.1.3.1 Tx / Rx Transition Gap (TTG)

The TTG is a gap between the Downstream burst and the Upstream burst. This gap allows time for the BS to switch from transmit mode to receive mode and SSs to switch from receive mode to transmit mode. During this gap, the BS and SS are not transmitting modulated data, but it simply allows the BS transmitter carrier to ramp down, the Tx / Rx antenna switch to actuate, and the BS receiver section to activate. After the TTG, the BS receiver will look for the first symbols of upstream burst. The TTG has a variable duration, which is an integer number of PSs. The TTG starts on a PS boundary.

2.6.1.3.2 Rx / Tx Transition Gap (RTG)

The RTG is a gap between the Upstream burst and the Downstream burst. This gap allows time for the BS to switch from receive mode to transmit mode and SSs to switch from transmit mode to receive mode. During this gap, BS and SS are not transmitting modulated data but simply allowing the BS transmitter carrier to ramp up, the Tx / Rx antenna switch to actuate, and the SS receiver sections to activate. After the RTG, the SS receivers will look for the first symbols of QPSK modulated data in the downstream burst. The RTG is an integer number of PSs. The RTG starts on a PS boundary.

2.6.2 PHY Burst Mode Support

In the burst mode, the uplink and downlink can be multiplexed in a TDD fashion as described in 2.6.1.3 or in an FDD fashion as described in 2.6.1.2. Each uses a frame with a duration as specified in section 3.3.1. Within this frame are a downlink subframe and an uplink subframe. In the TDD case, the downlink subframe comes first, followed by the uplink subframe. In the burst FDD case, the downlink and uplink subframes occur simultaneously on their respective frequencies, and occupy the whole frame. In both cases, the downlink subframe is prefixed with information necessary for frame synchronization.

The available bandwidth in both directions is defined with a granularity of one PHY slot (PS), which is a multiple of 4 modulation symbols each. The number of PHY slots with each frame is a function of the modulation rate. The modulation rate is selected in order to obtain an integral number of PS within each frame. For example, with a 20 Mbaud modulation rate, there are 5000 PS within a 1-ms frame.

2.6.3 PHY Continuous Mode Support

2.6.3.1 Continuous FDD Operation

In continuous FDD operation, the upstream and downstream signals have no defined framing, and they operate on separate frequencies, which allows all subscribers to transmit on the upstream independently of what is being transmitted on the downstream signal.

The BS periodically transmits downstream and upstream MAP messages, which are used to syncronize the upstream burst transmissions with the downstream. The usage of the mini-slots is defined by the UL-MAP message, and can change according to the needs of the system.

2.6.4 PHY Burst Mode Support

This standard provides the capability to efficiently support either a fixed modulation level per downstream carrier or an adaptively changing modulation level and FEC coding set on a per subscriber station basis. Depending on the deployment scenario, one may be preferred over the other. When a fixed modulation level is used with the downstream Mode A physical layer, there is no explicit framing mechanism needed.

The adaptive modulation/FEC capability is supported on a frame-by-frame basis when the downstream Mode B physical layer is implemented. In this case, the downstream channel is divided into frames, where each frame is subdivided into an integer number of physical slots (PSs). The length of each frame, denoted by *Tf* msec, may vary, depending on the different channel sizes. Each PS represents a multiple of 4 symbols.

The structure of the downlink subframe used by the BS to transmit to the SSs, using time division multiplexing (TDM), is shown in Figure 51. The structure of the downlink subframe used by the BS to transmit to the SSs, using Burst FDD, is shown in Figure 52. These burst structurse define the downlink physical channel. It starts with a Frame Control Header that is always transmitted in QPSK. This frame header contains a preamble used by the PHY for synchronization and equalization. It also contains control sections for both the PHY and the MAC that is encoded with a fixed FEC scheme defined in this standard in order to ensure interoperability. The Frame Control Header also may periodically contain PHY Parameters as defined in the DCD.

Within the TDD downlink subframe, transmissions are organized into different modulation and FEC groups, where the modulation type and FEC parameters are defined through MAC layer messaging. The PHY Control portion of the Frame Control Header contains a downlink map stating the PSs at which the different modulation/FEC groups begin. Data should be transmitted in modulation order QPSK, followed by 16-QAM, followed by 64-QAM. There is a Tx/Rx Transmission Gap (TTG) separating the downstream subframe from the upstream subframe in the case of TDD.

Each SS continuously receives the entire downstream burst, decodes the data in the DS burst, and looks for MAC headers indicating data for that SS.

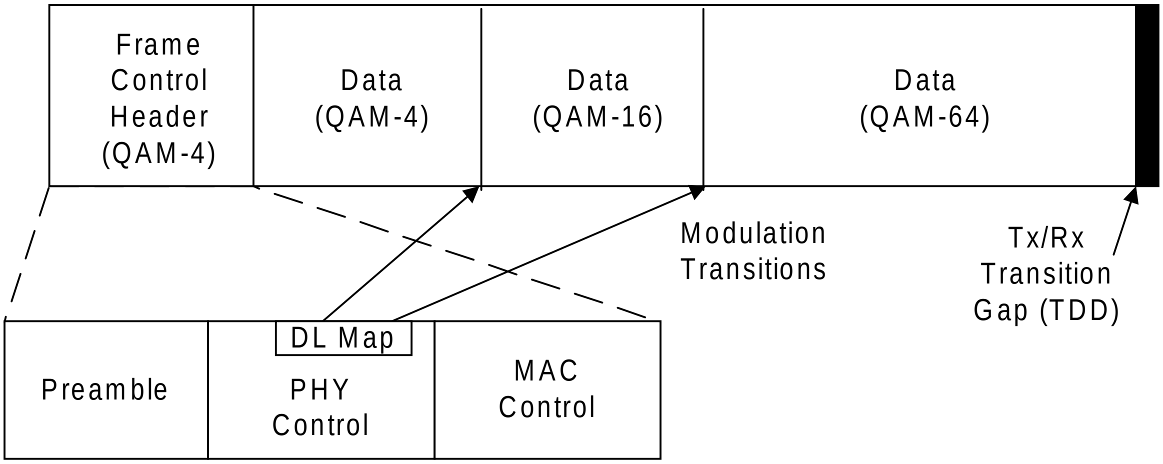


Figure 51—TDD Downlink Subframe Structure

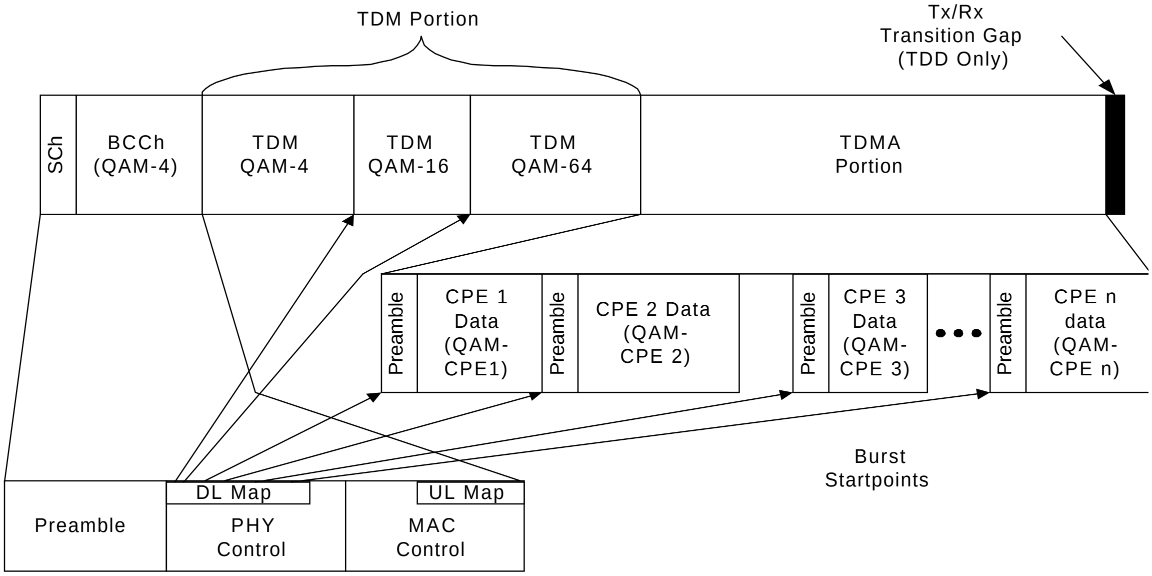


Figure 52—Burst FDD Downlink Subframe Structure

Like the TDD downlink subframe, the burst FDD subframe starts with a TDM section that is organized into different modulation and FEC groups. This portion of the downlink subframe contains data transmitted to SSs that are either full-duplex, are scheduled to transmit later in the frame than they receive, or are not scheduled to transmit this frame. The downlink subframe continues with a TDMA section. This portion of the downlink subframe contains data transmitted to half-duplex SSs that are scheduled to transmit earlier in the frame than they receive, if any. This allows an individual SS to decode a specific portion of the downstream without the need to decode the whole DS burst. In this particular case, each transmission associated with different SSs is required to start with a short preamble for phase re-synchronization. This data is always FEC coded and is transmitted at the current operating modulation of the individual SS. The PHY control portion contains a downlink map stating the PSs at which the different modulation/FEC groups begin in the TDM section and stating the PS (and modulation/FEC) of each of the TDMA sub-bursts

Note that the TDD downlink subframe, which inherently contains data transmitted to SSs that can only transmit later in the frame than they receive, is identical in structure to the Burst FDD downlink subframe for a frame in which no half-duplex SSs are scheduled to transmit before they receive.

2.6.4.1 PHY/MAC Control

The PHY Control portion of the downlink subframe is used for physical information destined for all CPEs. The PHY Control information is FEC encoded, but is not encrypted. The information transmitted in this section is always transmitted using a well known DL Burst Type. This burst type is specified separately in each PHY specification.

The PHY/MAC control section must contain a DL-MAP message for the channel followed by one UL-MAP message for each associated uplink channel. In addition the PHY/MAC control section may contain DCD and UCD messages following the last UL-MAP message. No other messages may be sent in the PHY/MAC Control portion of the frame.

The MAC Control portion of the downlink subframe is used for MAC messages destined for multiple SSs. For information directed at an individual SS, MAC messages are transmitted in the established control connection at the operating modulation of the SS to minimize bandwidth usage. The MAC Control messages are FEC encoded, but are not encrypted. The information transmitted in this section is always transmitted in QAM-4 and includes:

MAC Version Identifier
Uplink Map (SS/mini-slot/start symbol triplets)
Whether any bandwidth request contention periods (see Section TBD) are included in the frame (in UL-MAP)
Starting point and length of bandwidth request contention period, if any (in UL-MAP)
Whether registration is allowed on this physical channel
Whether a registration contention period is included the frame (in UL-MAP)
Starting point and length of registration contention period, if any (in UL-MAP)

2.6.4.2 Downlink Data

The downlink data sections are used for transmitting data and control messages to the specific SSs. This data is always FEC coded and is transmitted at the current operating modulation of the individual SS. Message headers are sent unencrypted. Payloads of user data connections are encrypted. Payloads of MAC control connections are not encrypted. In the burst mode cases, data is transmitted in modulation order QAM-4, followed by QAM-16, followed by QAM-64. The PHY Control portion of the Frame Control Header contains a map stating the PS and symbol at which modulation will change. In the TDMA case, the data is grouped into SS specific bursts, which do not need to be in modulation order.

If the downlink data does not fill the entire downlink subframe and the PHY mode is burst downstream, the transmitter is shut-down.

2.6.4.3 Allowable frame times

The following table indicates the various frame times that are allowed for the current downstream Mode B physical layer. The actual frame time used by the downstream channel can be determined by the periodicity of the frame start preambles.

Table 17— Allowable frame times

Frame time (T_F)	**Units**
0.5	**msec**
1	**msec**
2	**msec**

Table 18—Downstream Physical Layer

2.6.5 Uplink Burst Subframe Structure

The structure of the uplink subframe used by the SSs to transmit to the BS is shown in Figure 53. There are three main classes of MAC/TC messages transmitted by the SSs during the uplink frame:

Those that are transmitted in contention slots reserved for station registration.
Those that are transmitted in contention slots reserved for response to multicast and broadcast polls for bandwidth needs.
Those that are transmitted in bandwidth specifically allocated to individualSSs.

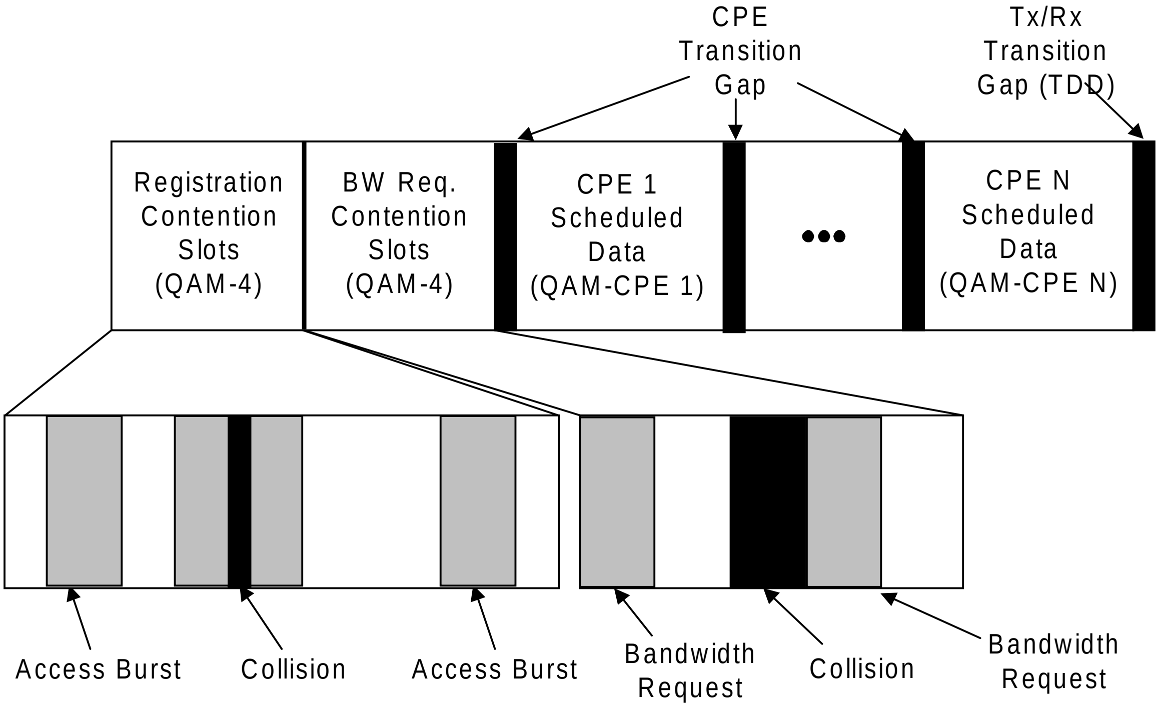

CPE Transition Gap
Tx/Rx Transition Gap (TDD)
Registration Contention Slots (QAM-4)
BW Req. Contention Slots (QAM-4)
CPE 1 Scheduled Data (QAM-CPE 1)
•••
CPE N Scheduled Data (QAM-CPE N)
Access Burst
Collision
Access Burst
Bandwidth Request
Collision
Bandwidth Request

Figure 53—Uplink Subframe Structure

2.6.5.1 Upstream Burst Mode Modulation

Adaptive modulation is used in the upstream, in which different users are assigned different modulation types by the base station.

In the adaptive case, the bandwidth allocated for registration and request contention slots is grouped together and is always used with QAM-4 modulation. The remaining transmission slots are grouped by SS. During its scheduled bandwidth, a SS transmits with the modulation specified by the base station, as determined by the effects of distance and environmental factors on transmission to and from that SS. SS Transition Gaps (CTG) separate the transmissions of the various SSs during the uplink subframe. The CTGs contain a gap to allow for ramping down of the previous burst, followed by a preamble allowing the BS to synchronize to the new SS. The preamble and gap lengths are broadcast periodically in theUCD message by the base station in the Frame Control Header.

2.6.6 Continuous Downstream and Upstream Structure

In the continuous PHY mode, the BS periodically broadcasts the Upstream MAP message (UL-MAP) on the downstream, which defined the permitted usage of each upstream mini-slot within the time interval covered by that MAP message (see Figure 54). The timing of the upstream bursts are based upon a downstream syncronization message (DS-SYNC). The UL-MAP messages are transmitted approximately 250 times a second, but this can vary to optimise the system's operation.

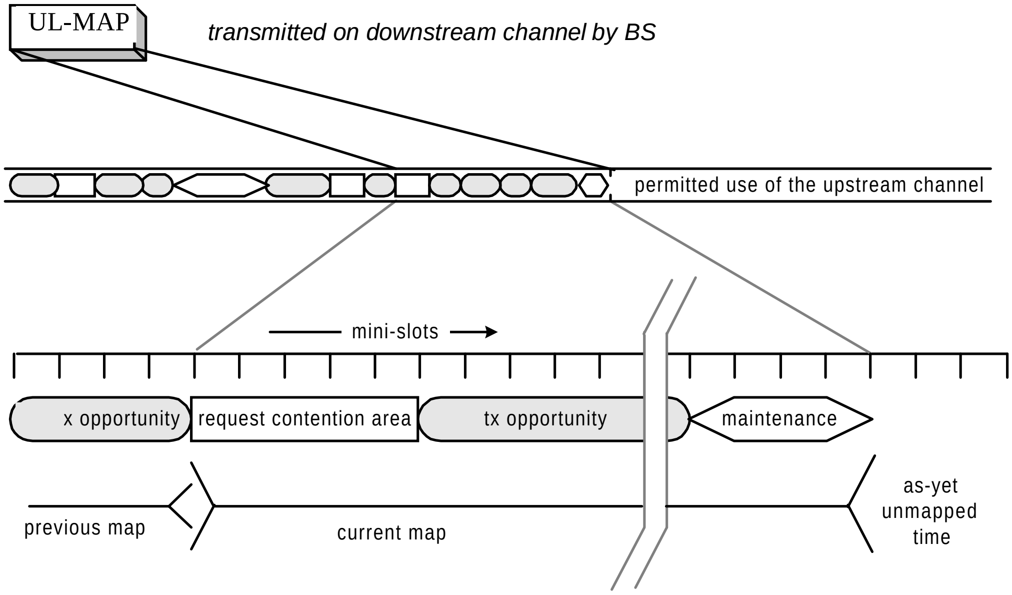


Figure 54—Continuous Downstream FDD Mapping

2.6.7 Upstream Map

Whether in the Burst or Continuous PHY modes, the upstream MAP message (UL-MAP) defines the usage for the upstream mini-slots using a series of Information Elements (IE), which define the useage of each upstream interval. The UL-MAP defines the upstream usage in terms of the offset from the prevoius IE start (the lenfth) in numbers of mini-slots.

Each IE consists of a 16-bit Connection ID, a 4-bit type code, and a 12-bit starting mini-slot offset as defined in 2.5.4. Since all SS must scan all IE within each MAP, it is critical that IEs be short and relatively fixed format. IEs within the MAP are strictly ordered by starting offset. For most purposes, the duration described by the IE is inferred by the difference between the IE's starting offset and that of the following IE. For this reason, a Null IE shall terminate the list.

2.6.7.1 Upstream Timing

The upstream timing is based on the Upstream Time Stamp reference, which is a 29-bit counter that increments at a rate that is 4 times the modulation rate. It therefore has a resolution that equals ¼th of the modulation symbol period. This allows the SS to track the BS clock with a small time offset.

The BS maintains a separate Upstream Time Stamp for each upstream at the base station. The value of the BS Upstream Time Stamp is broadcast to all the SS using the Physical Channel Descriptor (UCD) message. Each SS maintains its own Upstream Time Stamp so that it is syncronous with the BS Time stamp for the upstream channel that it is using. The SS Time Stamp must change at the same rate as its BS counterpart, but will be offset so that the upstream bursts arrive at the BS at the correct time. This offset is set by the BS using the RNG-RSP message.

2.6.7.1.1 Continuous Mode Upstream Timing

The downstream MAP message (DL-MAP) in the continuous PHY mode broadcasts the Upstream Time Stamp value to all SS. The Upstream Time Stamp from the BS is then used to adjust the SS internal Time

Stamp so that it tracks the BS timing. The SS Time Stamp is offset from the BS Time Stamp by the Timing Adjustment amount sent to each SS in the RNG-RSP message. The offset causes the upstream bursts arrive at the BS at the proper time. After either the BS or SS Time Stamps reach the maximum value of 2^{29}-1, they roll over to zero and continue to count.

2.6.7.1.2 Burst Mode Upstream Timing

In the burst PHY modes, at the start of each frame the Upstream Time Stamp counter in the BS is reset to zero, while in the SS it is reset using the current Timing Adjustment value as sent from the BS using the RNG-RSP message. Thus, the SS Time Stamp will be offset from the BS Time Stamp so that the upstream bursts arrive at the BS at the proper time.

2.6.7.2 Upstream Mini-Slot Definition

The upstream bandwidth allocation MAP (UL-MAP) uses time units of “mini-slots.” The size of the mini-slot (N) is specified as a number of PHY slots (PS) and is carried in the Physical Channel Descriptor for each upstream channel. One mini-slot contains N PHY slots (PS), where N = 2^m (where m = 0..7). Since each PS contains 4 modulation symbols, the number of modulation symbols contained in one mini-slot equals 4N.

Practical mini-slots are expected to represent relatively few PS to allow efficient bandwidth utilization with respect to the mini-slot size. Larger mini-slot sizes allow the BS to define large contention intervals (up to 2^{12}-1 or 4095 mini-slots) using the current UL-MAP. Note that the modulation level and hence the symbols/byte is a characteristic of an individual burst transmission, not of the channel.

A “mini-slot” is the unit of granularity for upstream transmission allocations. There is no implication that any PDU can actually be transmitted in a single mini-slot.

In a framed mode of operation, the mini-slot represents the granularity of upstream allocation units. In the non-frame mode, the mini-slot definition is related to a timestamp generated by the BS. Figure 55 illustrates the mapping of the Upstream Time Stamp maintained in the BS to the BS Mini-slot Counter.

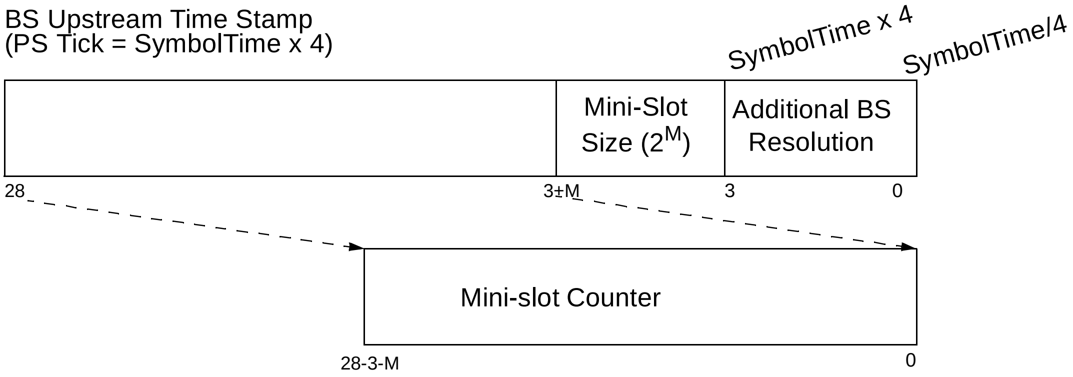


Figure 55—BS System and Mini-slot Clocks

The BS and SS base the upstream allocations on a 29-bit counter that normally counts to (2^{29} - 1) and then wraps back to zero. The bits (i.e., bit 0 to bit 28-3-M) of the mini-slot counter shall match the most-significant bits (i.e., bit 3+M to bit 28) of the DL-MAP timestamp counter. That is, mini-slot N begins at timestamp value (N*T*16), where T = 2^M is theUCD multiplier that defines the mini-slot size (i.e., the number of PS per mini-slot).

The constraint that the UCD multiplier be a power of two has the consequence that the number of PS per mini-slot must also be a power of two.

2.6.7.3 Upstream Interval Definition

All of the Information Elements defined below shall be supported by conformant SSs. Conformant BS may use any of these Information Elements when creating a U L-MAP message.

2.6.7.3.1 The Request IE

Via the Request IE, the Base Station specifies an upstream interval in which requests may be made for bandwidth for upstream data transmission. The character of this IE changes depending on the type of Connection ID used in the IE. If broadcast, this is an invitation for SSs to contend for requests. If unicast, this is an invitation for a particular SS to request bandwidth. Unicasts may be used as part of a Quality of Service scheduling scheme that is vendor dependent. PDUs transmitted in this interval shall use the Bandwidth Request Header Format (refer to 2.5).

A small number of Priority Request CIDs are defined in 2.1. These allow contention for Request IEs to be limited to service flows of a given Traffic Priority (2.3.5.5.2).

2.6.7.3.2 The Initial Maintenance IE

Via the Initial Maintenance IE, the Base Station specifies an interval in which new stations may join the network. A long interval, equivalent to the maximum round-trip propagation delay plus the transmission time of the Ranging Request (RNG-REQ) message, shall be provided in some UL-MAPs to allow new stations to perform initial ranging. Packets transmitted in this interval shall use the RNG-REQ MAC Management message format (refer to 2.5.5).

2.6.7.3.3 The Station Maintenance IE

Via the Station Maintenance IE, the Base Station specifies an interval in which stations are expected to perform some aspect of routine network maintenance, such as ranging or power adjustment. The BS may request that a particular SS perform some task related to network maintenance, such as periodic transmit power adjustment. In this case, the Station Maintenance IE is unicast to provide upstream bandwidth in which to perform this task. Packets transmitted in this interval shall use the RNG-REQ MAC Management message format (see 2.5.5).

2.6.7.3.4 Data Grant IEs

The Data Grant IEs provide an opportunity for a CPE to transmit one or more upstream PDUs. These IEs are issued either in response to a request from a station, or because of an administrative policy providing some amount of bandwidth to a particular station (see class-of-service discussion in Section TBD). These IEs may also be used with an inferred length of zero mini slots (a zero length grant), to indicate that a request has been received and is pending (a Data Grant Pending).

There are six different Data Grants that may be defined: Data Grants 1 through 6 are associated with IUCs 4 through 9 respectively. Each Data Grant description is defined in the UCD message.

If this IE is a Data Grant Pending (a zero length grant), it shall follow the NULL IE. This allows CPE modems to process all actual allocations first, before scanning the Map for data grants pending and data acknowledgments.

2.6.7.3.5 Expansion IE

The Expansion IE provides for extensibility, if more than 16 code points or 32 bits are needed for future IEs.

2.6.7.3.6 Null IE

A Null IE terminates all actual allocations in the IE list. It is used to infer a length for the last interval. All Data Acknowledge IEs and All Data Grant Pending IEs (Data Grants with an inferred length of 0) must follow the Null IE.

2.6.8 MAP Relevance and Synchronization

2.6.8.1 MAP Relevance for Burst PHY Systems

The information in the PHY Control portion of the Frame Control Header pertains to the current frame (i.e., the frame in which it was received). The information in the Uplink Subframe Map in the MAC Control portion of the Frame Control Header pertains to the current or following frame. This timing holds for both the TDD and FDD variants of the burst system. The TDD variant is shown in Figure 56 and Figure 59. The FDD variant is shown in Figure 57 and Figure 58.

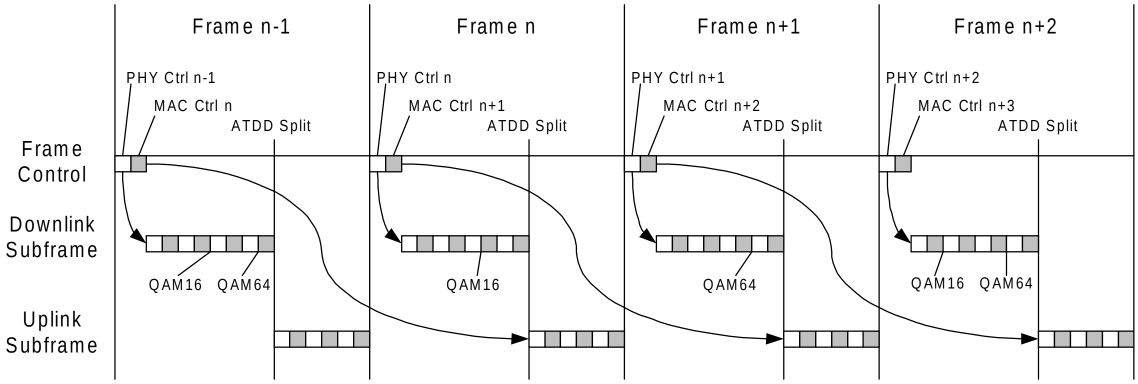


Figure 56—Maximum Time Relevance of PHY and MAC Control Information (TDD)

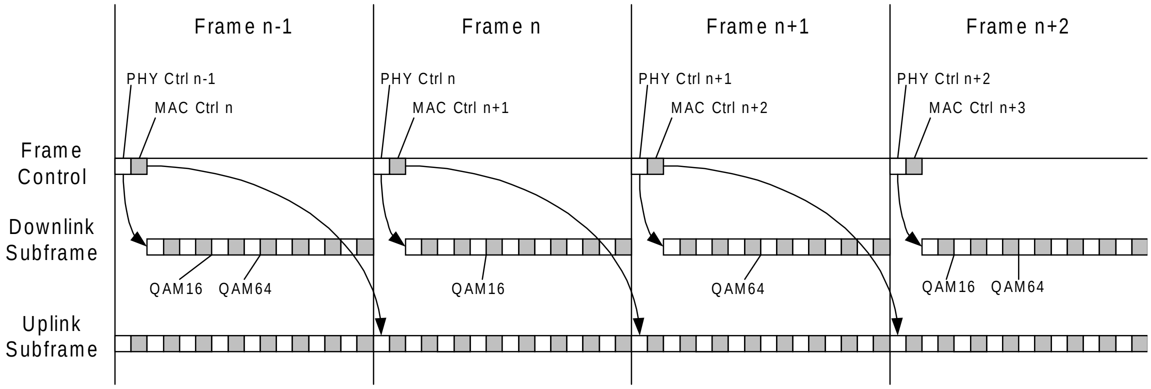


Figure 57—Maximum Time Relevance of PHY and MAC Control Information (FDD)

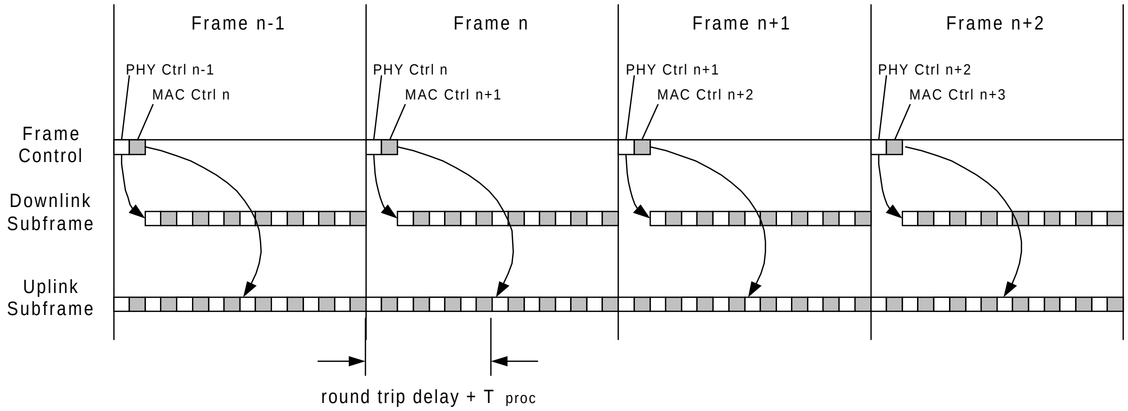


Figure 58—Minimum Time Relevance of PHY and MAC Control Information (FDD)

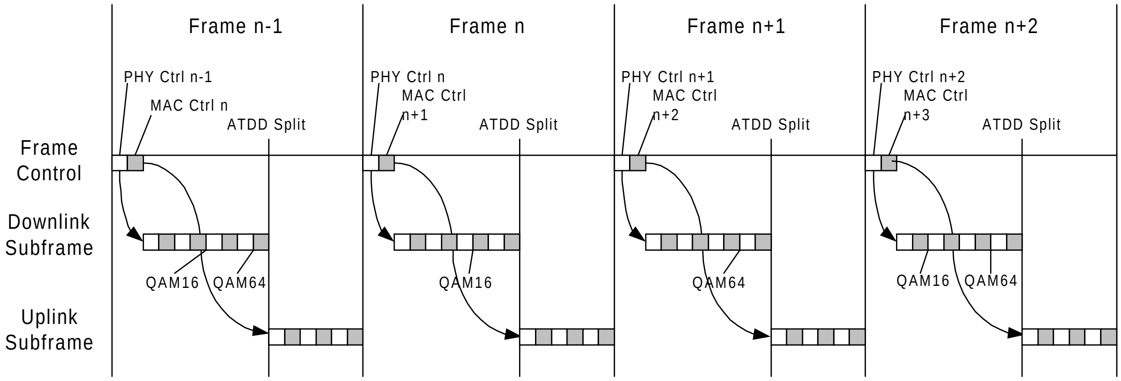


Figure 59—Minimum Time Relevance of PHY and MAC Control Information (TDD)

2.6.8.2 MAP Relevance for Continuous PHY Systems

In the Continuous PHY system, the downstream MAP (DL-MAP) only contains the Upstream Time Stamp, and does not define what information is being transmitted. All SS continuously search the downstream signal for any downstream message that is addressed to them. The Upstream MAP (UL-MAP) message in the downstream contains the Time Stamp that indicates the first mini-slot that the MAP defines.

The delay from the end of the UL-MAP to the beginning of the first Upstream interval defined by the MAP shall be greater than maximum round trip delay plus the processing time required by the SS.(see Figure 60)

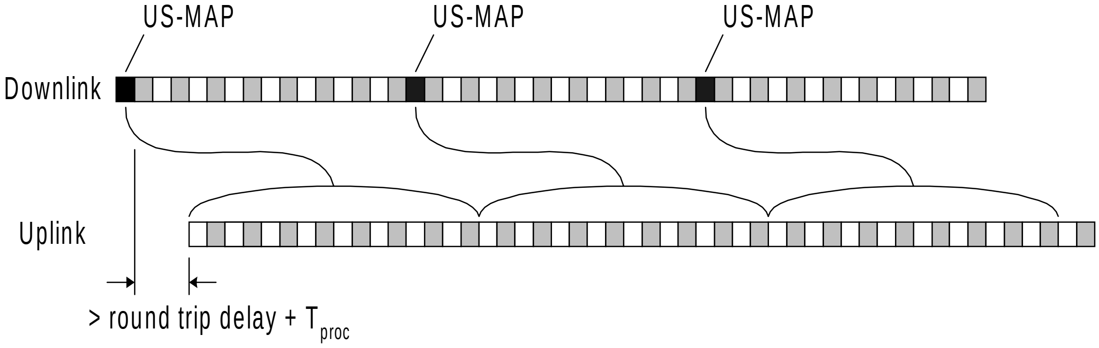


Figure 60—Time Relevance of Upstream MAP Information (Continuous FDD)

2.7 Contention Resolution

The BS controls assignments on the upstream channel through the UL-MAP and determines which mini-slots are subject to collisions. The BS may allow collisions on either requests or maintenance PDUs. This section provides an overview of upstream transmission and contention resolution. For simplicity, it refers to the decisions a SS makes, however, this is just a instructional tool. Since a SS can have multiple upstream Service Flows (each with its own CID) it makes these decisions on a per service queue or per CID basis.

The mandatory method of contention resolution which shall be supported is based on a truncated binary exponential back-off, with the initial back-off window and the maximum back-off window controlled by the BS. The values are specified as part of the Upstream Bandwidth Allocation Map (UL-MAP) MAC message and represent a power-of-two value. For example, a value of 4 indicates a window between 0 and 15; a value of 10 indicates a window between 0 and 1023.

When a SS has information to send and wants to enter the contention resolution process, it sets its internal back-off window equal to the Data Backoff Start defined in the UL-MAP currently in effect.[6]

The SS shall randomly select a number within its back-off window. This random value indicates the number of contention transmit opportunities which the SS shall defer before transmitting. A SS shall only consider contention transmit opportunities for which this transmission would have been eligible. These are defined by either Request IEs in the UL-MAP. Note: Each IE can represent multiple transmission opportunities.

As an example, consider a SS whose initial back-off window is 0 to 15 and it randomly selects the number 11. The SS must defer a total of 11 contention transmission opportunities. If the first available Request IE is for 6 requests, the SS does not use this and has 5 more opportunities to defer. If the next Request IE is for 2 requests, the SS has 3 more to defer. If the third Request IE is for 8 requests, the SS transmits on the fourth request, after deferring for 3 more opportunities.

After a contention transmission, the SS waits for a Data Grant (Data Grant Pending) in a subsequent MAP. Once received, the contention resolution is complete. The SS determines that the contention transmission was lost when it finds a MAP without a Data Grant (Data Grant Pending) for it and with an Ack time more recent than the time of transmission. The SS shall now increase its back-off window by a factor of two, as

[6] The MAP currently in effect is the MAP whose allocation start time has occurred but which includes IEs that have not occurred.

long as it is less than the maximum back-off window. The SS shall randomly select a number within its new back-off window and repeat the deferring process described above.

This re-try process continues until the maximum number of retries (16) has been reached, at which time the PDU shall be discarded. Note: The maximum number of retries is independent of the initial and maximum back-off windows that are defined by the BS.

If the SS receives a unicast Request or Data Grant at any time while deferring for this CID, it shall stop the contention resolution process and use the explicit transmit opportunity.

The BS has much flexibility in controlling the contention resolution. At one extreme, the BS may choose to set up the Data Backoff Start and End to emulate an Ethernet-style back-off with its associated simplicity and distributed nature, but also its fairness and efficiency issues. This would be done by setting Data Backoff Start = 0 and End = 10 in the UL-MAP. At the other end, the BS may make the Data Backoff Start and End identical and frequently update these values in the UL-MAP so all SS are using the same, and hopefully optimal, back-off window.

2.7.1 Transmit Opportunities

A Transmit Opportunity is defined as any mini-slot in which a SS may be allowed to start a transmission. Transmit Opportunities typically apply to contention opportunities and are used to calculate the proper amount to defer in the contention resolution process.

The number of Transmit Opportunities associated with a particular IE in a MAP is dependent on the total size of the region as well as the allowable size of an individual transmission. As an example, assume a REQ IE defines a region of 12 mini-slots. If the UCD defines a REQ Burst Size that fits into a single mini-slot then there are 12 Transmit Opportunities associated with this REQ IE, i.e., one for each mini-slot. If theCD defines a REQ that fits in two mini-slots, then there are six Transmit Opportunities and a REQ can start on every other mini-slot.

Transmit opportunities shall not overlap and the start time of the transmit opportunity shall align with either the start of the IE interval or at the end of the previous transmit opportunity.

2.8 Fragmentation

Fragmentation is the process by which a portion of a convergence sub-layer payload is divided into two or more MAC PDUs. This process is undertaken to allow efficient use of available bandwidth relative to the QoS requirements of a connections Service Flow.

Fragmentation may be initiated by a BS for a downlink connection. Fragmentation may be initiated by a SS for an uplink connection. A connection may be in only one fragmentation state at any given time. A connection that is not in the fragmentation state shall set the FC and FSN fields of a Connection’s Service Flow to 0 and 0000, respectively.

The authority to fragment a traffic on a connection is defined when the connecion is created by a MSAP.

The fragments are set in accordance with Table 19.

The sequence number allows the receiving terminal to re-create the original payload and to detect the loss of any intermediate packets. Upon loss, the receiving station shall discard all PDUs on the connection until a new fragment is detected or a non-fragmented PDU is detected.

Table 19—Fragmentation Rules

Fragment	FC	FSN
First Fragment	10	0000
Continuing Fragment	11	incremented modulo 16
Last Fragment	01	incremented modulo 16
Unfragmented	00	0000

2.9 Upstream Service

The following sections define the basic upstream Service Flow scheduling services and list the QoS parameters associated with each service. A detailed description of each QoS parameter is provided in 2.3.5.

Table 20—Scheduling Services and Usage Rules

Scheduling Type	Piggy-Back Request	Bandwidth Stealing	Pollng
UGS	Not Allowed[a]	Not allowed	PM bit is used to request a unicast poll for bandwidth needs of non-UGS connections
UGS-AD	Not Allowed	Not allowed	Unicast polling is allowed when the flow is inactive
rtPS	Allowed	Allowed for GPT	Scheduling only allows unicast polling
nrtPS	Allowed	Allowed for GPT	Scheduling may restrict a service flow to unicast polling via the transmission/request policy; otherwise all forms of polling are allowed
BE	Allowed	Allowed for GPT	All forms of polling allowed

[a] Also a function of the MAC Header

Scheduling services are designed to improve the efficiency of the poll/grant process. By specifying a scheduling service and its associated QoS parameters, the BS can anticipate the throughput and latency needs of the upstream traffic and provide polls and/or grants at the appropriate times.

Each service is tailored to a specific type of data flow as described below. The basic services comprise: Unsolicited Grant Service (UGS), Real-Time Polling Service (rtPS), Unsolicited Grant Service with Activity Detection (UGS-AD), Non-Real-Time Polling Service (nrtPS) and Best Effort (BE) service.

2.9.1 Unsolicited Grant Service

The Unsolicited Grant Service (UGS) is designed to support real-time service flows that generate fixed size data packets on a periodic basis, such as T1/E1 and Voice over IP. The service offers fixed size grants on a real-time periodic basis, which eliminate the overhead and latency of SS requests and assure that grants will be available to meet the flow’s real-time needs. The BS shall provide fixed size data grants at periodic intervals to the Service Flow. In order for this service to work correctly, the Request/Transmission Policy (refer to 2.3.5.6.3) setting shall be such that the SS is prohibited from using any contention request opportunities and the BS SHOULD not provide any unicast request opportunities for that connection. Piggy-back requests may be used in the GPT mode to request additional bandwidth for a different connection using the Bandwidth Request Header. This will result in the SS only using unsolicited data grants for upstream transmission on that connection. All other bits of the Request/Transmission Policy are not relevant to the fundamental operation of this scheduling service and should be set according to network policy. The key service information elements are the Unsolicited Grant Size, the Nominal Grant interval, the Tolerated Grant Jitter and the Request/Transmission Policy. (Refer to TBD)

The Grant Management fields in the Generic MAC Header (refer to Figure 13) is used to pass status information from the SS to the BS regarding the state of the UGS Service Flow. The most significant bit of the Bandwidth Management field is the Slip Indicator (SI) bit. The SS shall set this flag once it detects that this Service Flow has exceeded its transmit queue depth. Once the SS detects that the Service Flow's transmit queue is back within limits, it shall clear the SI flag. The flag allows the BS to provide for long term compensation for conditions such as lost maps or clock rate mismatch's by issuing additional grants.

The BS shall not allocate more grants per Nominal Grant Interval than the Grants Per Interval parameter of the Active QoS Parameter Set, excluding the case when the SI bit of the Bandwidth Management field is set. In this case, the BS may grant up to 1% additional bandwidth for clock rate mismatch compensation. The active grants field of the Bandwidth Management field is ignored with UGS service.

2.9.2 Real-Time Polling Service

The Real-Time Polling Service (rtPS) is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as MPEG video. The service offers real-time, periodic, unicast request opportunities, which meet the flow's real-time needs and allow the SS to specify the size of the desired grant. This service requires more request overhead than UGS, but supports variable grant sizes for optimum data transport efficiency.

The BS shall provide periodic unicast request opportunities. In order for this service to work correctly, the Request/Transmission Policy setting (refer to 2.3.5.6.3) shall be such that the SS is prohibited from using any contention request opportunities for that connection. The BS may issue unicast request opportunities as prescribed by this service even if a grant is pending. This will result in the SS using only unicast request opportunities in order to obtain upstream transmission opportunites (the SS could still use unsolicited data grants for upstream transmission as well). All other bits of the Request/Transmission Policy are not relevant to the fundamental operation of this scheduling service and should be set according to network policy. The key service information elements are the Nominal Polling Interval, the Tolerated Poll Jitter and the Request/Transmission Policy.

2.9.3 Unsolicited Grant Service with Activity Detection

The Unsolicited Grant Service with Activity Detection (UGS/AD) is designed to support UGS flows that may become inactive for substantial portions of time (i.e. tens of milliseconds or more), such as Voice over IP with silence suppression. The service provides Unsolicited Grants when the flow is active and unicast polls when the flow is inactive. This combines the low overhead and low latency of UGS with the efficiency of rtPS. Though USG/AD combines UGS and rtPS, only one scheduling service is active at a time.

The BS shall provide periodic unicast grants, when the flow is active, but shall revert to providing periodic unicast request opportunities when the flow is inactive. (The BS can detect flow inactivity by detecting unused grants. However, the algorithm for detecting a flow changing from an active to an inactive state is dependent on the BS implementation). In order for this service to work correctly, the Request/Transmission Policy setting (refer to 2.3.5.6.3) shall be such that the SS is prohibited from using any contention request a opportunities. This results in the SS using only unicast request opportunities in order to obtain upstream transmission opportunities. However, the SS will use unsolicited data grants for upstream transmission as well. All other bits of the Request/Transmission Policy are not relevant to the fundamental operation of this scheduling service and should be set according to network policy. The key service parameters are the Nominal Polling Interval, the Tolerated Poll Jitter, the Nominal Grant Interval, the Tolerated Grant Jitter, the Unsolicited Grant Size and the Request/Transmission Policy.

In UGS-AD service, when restarting UGS after an interval of rtPS, the BS SHOULD provide additional grants in the first (and/or second) grant interval such that the SS receives a total of one grant for each grant interval from the time the SS requested restart of UGS, plus one additional grant. Because the Service Flow is provisioned as a UGS flow with a specific grant interval and grant size, when restarting UGS, the SS shall not request a different sized grant than the already provisioned UGS flow. As with any Service Flow, changes can only be requested with a DSC command.

The Bandwidth Management Field allows for the SS to dynamically state how many grants per interval are required to support the number of flows with activity present. In UGS/AD, the SS may use the Slip Indicator Bit in the Bandwidth Management Field. The remaining seven bits of the Bandwith Management Field define the Active Grants field. This field defines the number of grants within a Nominal Grant Interval that this Service Flow currently requires. When using UGS/AD, the SS shall indicate the number of requested grants per Nominal Grant Interval in this field. The Active Grants field is ignored with UGS without Activity Detection. This field allows the SS to signal to the BS to dynamically adjust the number of grants per interval that this UGS Service Flow is actually using. The SS shall not request more than the number of Grants per Interval in the ActiveQoSParameterSet.

2.9.4 Non-Real-Time Polling Service

The Non-Real-Time Polling Service (nrtPS) is designed to support non real-time service flows that require variable size data grants on a regular basis, such as high bandwidth FTP. The service offers unicast polls on a regular basis which assures that the flow receives request opportunities even during network congestion. The BS typically polls nrtPS CIDs on an (periodic or non-periodic) interval on the order of one second or less.

The BS shall provide timely unicast request opportunities. In order for this service to work correctly, the Request/Transmission Policy setting (refer to 2.3.5.6.3) SHOULD be such that the SS is allowed to use contention request opportunities. This will result in the SS using contention request opportunities as well as unicast request opportunities and unsolicited data grants. All other bits of the Request/Transmission Policy are not relevant to the fundamental operation of this scheduling service and should be set according to netowrk policy. The key service elements are Nominal Polling Interval, Minimum Reserved Traffic Rate, Maximum Sustained Traffic Rate, Request/Transmission Policy and Traffic Priority.

2.9.5 Best Effort Service

The intent of the Best Effort (BE) service is to provide efficient service to best effort traffic. In order for this service to work correctly, the Request/Transmission Policy setting SHOULD be such that the SS is allowed to use contention request opportunities. This will result in the SS using contention request opportunities as well as unicast request opportunities and unsoliced data grants. All other bits of the Request/Transmission Policy are not relevant to the fundamental operation of this scheduling service and should be set according to network policy. The key service elements are the Minimum Reserved Traffic Rate, the Maximum Sustained Traffic Rate, and the Traffic Priority.

2.10 Bandwidth Allocation and Request Mechanisms

Note that at registration every SS is assigned two dedicated CIDs for the purpose of sending and receiving control messages. Two connections are used to allow differentiated levels of QoS to be applied to the different connections carrying MAC management traffic. Increasing (or decreasing) bandwidth requirements is necessary for all services except uncompressible constant bit rate UGS connections. The needs of uncompressible UGS connections do not change between connection establishment and termination. The requirements of compressible UGS connections, such as channelized T1, may increase or decrease depending on traffic. DAMA services are given resources on a demand assignment basis, as the need arises.

When a SS needs to ask for bandwidth on a connection with Best Effort scheduling service, it sends a message to the BS containing the immediate requirements of the DAMA connection. QoS for the connection was established at connection establishment and is looked-up by the BS.

There are numerous methods by which the SS can get the bandwidth request message to the BS.

2.10.1 Requests

Requests refer to the mechanism that SSs use to indicate to the BS that it needs upstream bandwidth allocation. A Request may come as a stand-alone Bandwidth Request Header or it may come as a piggyback request (refer to Section 2.5).

Because the modulation format of the upstream can dynamically change, all requests for bandwidth shall be made in terms of the number of bytes needed to carry the MAC header and payload, but not the PHY layer overhead.The Bandwidth Request Message may be transmitted during any of the following intervals:

Request IE
Any Data Grant IE

The number of bytes requested shall be the total number that are desired by the SS for the connection at the time of the request (excluding any physical layer overhead), subject to UCD and administrative limits.

Regarding the grant of the bandwidth requested, there are two modes of operation for SSs: Grant per Connection mode (GPC) and Grant per Terminal mode (GPT). In the first case, the BS grants bandwidth explicitly to each connection, whereas in the second case the bandwidth is granted to all the connections belonging to the SS. The latter case (GPT) allows smaller UL maps and more intelligent SSs to take last moment decisions and perhaps utilize the bandwidth differently than it was originally granted by the BS, which may be useful for real-time applications that require a faster response from the system.

In GPC mode, the SS shall have only one request outstanding at a time per Connection ID. If the BS does not immediately respond with a Data Grant, the SS is able to unambiguously determine that its request is still pending because the BS shall continue to issue a Data Grant Pending in every MAP for as long as a request is unsatisfied. In GPT mode, additional requests or re-requests are based on timers and Data Grant Pending is not required. In GPC mode all requests are incremental. In GPT mode most requests are incremental, but the SS periodically issues aggregate requests (total data pending in queue), resetting the base station's perception of the connection's needs. Piggyback requests are always incremental

The BS shall be able to support both modes of operation. A SS may operate in either of the two modes, depending on its capabilities. The mode of operation shall be agreed upon Registration and shall not change during operation time.

2.10.1.1 Grants per Connection (GPC) mode

When a SS is operating in GPC mode, if the BS does not immediately respond with a Data Grant, the SS is able to unambiguously determine that its request is still pending because the BS shall continue to issue a Data Grant Pending in every MAP for as long as a request is unsatisfied.

The procedure followed by SSs operating in GPC mode is shown in Figure 61

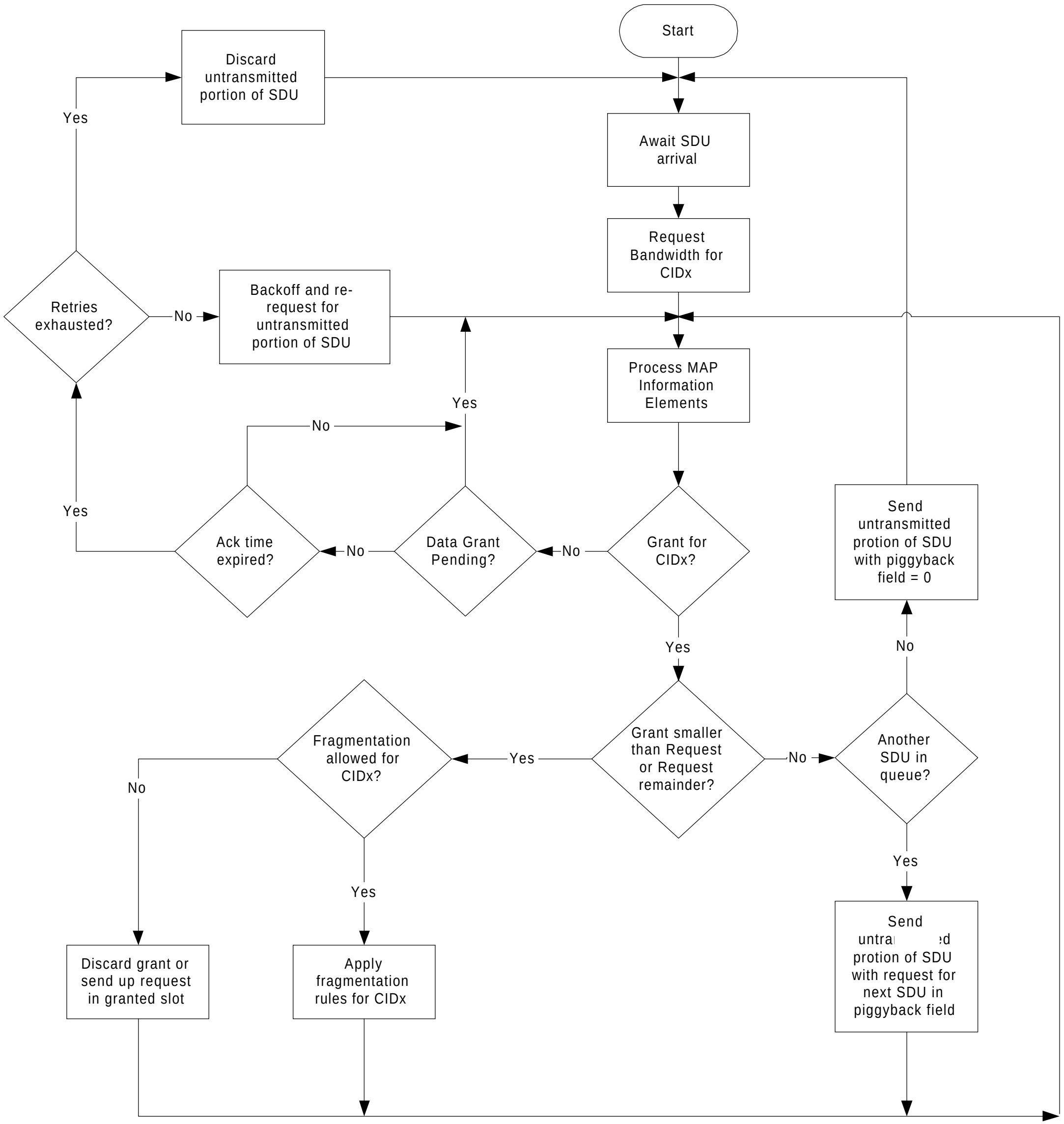

Start
Discard untransmitted portion of SDU
Yes
Await SDU arrival
Request Bandwidth for CIDx
Retries exhausted?
No
Backoff and re-request for untransmitted portion of SDU
Process MAP Information Elements
Yes
No
Yes
Send untransmitted protion of SDU with piggyback field = 0
Ack time expired?
No
Data Grant Pending?
No
Grant for CIDx?
Yes
No
Fragmentation allowed for CIDx?
Yes
Grant smaller than Request or Request remainder?
No
Another SDU in queue?
No
Yes
Yes
Send untransmitted protion of SDU with request for next SDU in piggyback field
Discard grant or send up request in granted slot
Apply fragmentation rules for CIDx

Figure 61—SS GPC mode flowchart

2.10.1.2 Grants per Terminal (GPT) mode

For SSs operating in GPT mode, the bandwidth allocation is issued to its Basic CID and not explicitly to individual CIDs. Since it is non-deterministic which request is being honored in this scheme, when certain connection receives a shorter or null opportunity to transmit (i.e. scheduler decision, request message lost, etc.), no explicit reason is given. In any case, based on the latest information received from the BS and the status of the request, the SS may decide to perform backoff and request again or to discard the frame.

The procedure followed by SSs operating in GPT mode is shown in Figure 62

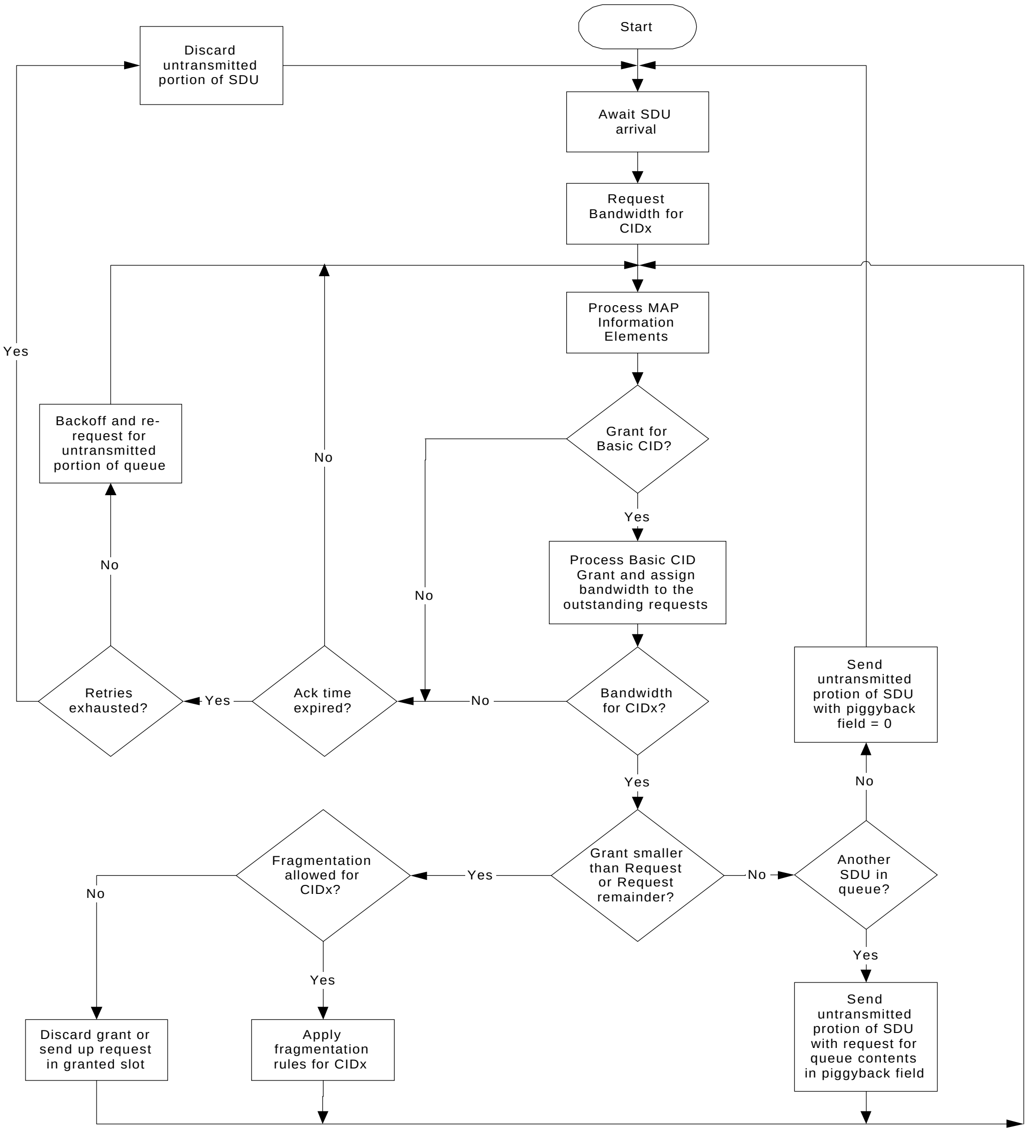

Start
Discard untransmitted portion of SDU
Await SDU arrival
Request Bandwidth for CIDx
Process MAP Information Elements
Yes
Backoff and re-request for untransmitted portion of queue
No
Grant for Basic CID?
Yes
Process Basic CID Grant and assign bandwidth to the outstanding requests
No
No
Send untransmitted protion of SDU with piggyback field = 0
Retries exhausted?
Yes
Ack time expired?
No
Bandwidth for CIDx?
Yes
No
Fragmentation allowed for CIDx?
Yes
Grant smaller than Request or Request remainder?
No
Another SDU in queue?
No
Yes
Yes
Discard grant or send up request in granted slot
Apply fragmentation rules for CIDx
Send untransmitted protion of SDU with request for queue contents in piggyback field

Figure 62—SS GPT mode flowchart

2.10.2 Polling

Polling is the process by which the BS allocates to the SSs bandwidth specifically for the purpose of making bandwidth requests. These allocations may be to individual SSs or to groups of SSs. Allocations to groups of connections and/or SSs actually define bandwidth request contention IEs. The allocations are not in the form of an explicit message, but are contained as a series of Information Elements (IE) within the upstream MAP.

Note that polling is done on either a SS or connection basis. Bandwidth is always requested on a CID basis and bandwidth is allocated on either a connection (GPC mode) or SS (GPT mode) basis, based on the SS capability.

2.10.2.1 Unicast

When a SS is polled individually, no explicit message is transmitted to poll the SS. Rather, the SS is allocated, in the upstream MAP, bandwidth sufficient to respond with a bandwidth request. If the SS does not need bandwidth, it returns a request for 0 bytes (Note that 0 byte requests are only used in the individual polling case since explicit bandwidth for a reply has been allocated.). SSs operating in GPT mode, which have an active UGS connection of sufficient bandwidth, may not be polled individually unless they set the Poll Me (PM) bit in the header of a packet on the UGS connection. Only inactive SSs and SSs explicitly requesting to be polled will be polled individually. This saves bandwidth over polling all SSs individually. Active SSs respond to polling at their current upstream modulation, while inactive SSs must respond at QAM-4 to ensure their transmission is robust enough to be detected by the BS.

The information exchange sequence for individual polling is shown in Figure 63.

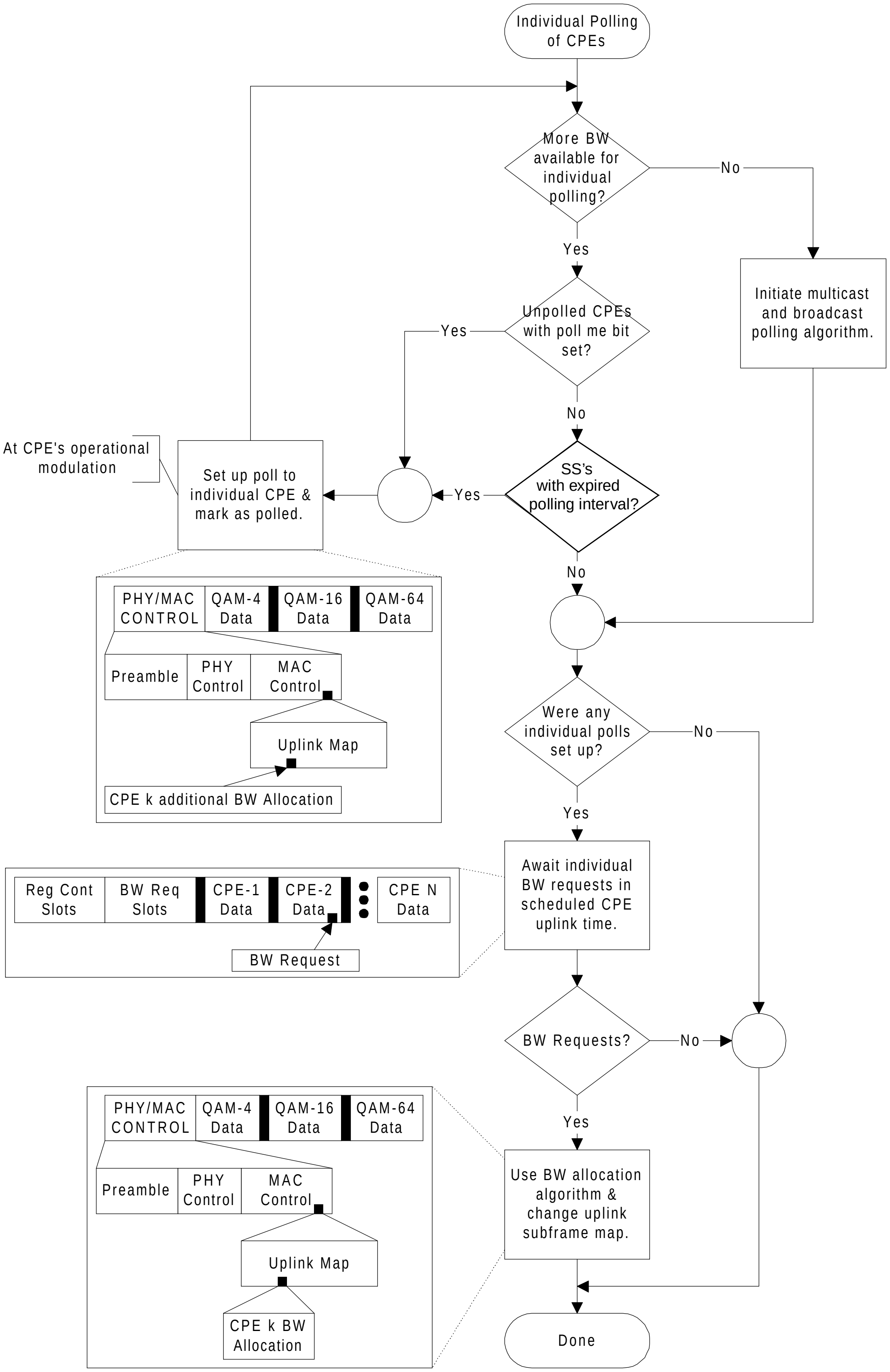

Individual Polling of CPEs
More BW available for individual polling?
No
Yes
Initiate multicast and broadcast polling algorithm.
Unpolled CPEs with poll me bit set?
Yes
No
At CPE's operational modulation
Set up poll to individual CPE & mark as polled.
Yes
SS's with expired polling interval?
No
PHY/MAC CONTROL
QAM-4 Data
QAM-16 Data
QAM-64 Data
Preamble
PHY Control
MAC Control
Uplink Map
CPE k additional BW Allocation
Were any individual polls set up?
No
Yes
Reg Cont Slots
BW Req Slots
CPE-1 Data
CPE-2 Data
CPE N Data
BW Request
Await individual BW requests in scheduled CPE uplink time.
BW Requests?
No
Yes
PHY/MAC CONTROL
QAM-4 Data
QAM-16 Data
QAM-64 Data
Preamble
PHY Control
MAC Control
Uplink Map
CPE k BW Allocation
Use BW allocation algorithm & change uplink subframe map.
Done

Figure 63—Unicast Polling

2.10.2.2 Multicast and Broadcast

If there are more SSs that are inactive than there is bandwidth available for individual polling, some SSs may be polled in multicast groups and a broadcast poll may be issued. Certain CIDs are reserved for multicast groups and for broadcast messages, as described in Table 1. As with individual polling, the poll is not an explicit message but bandwidth allocated in the upstream MAP. The difference is that rather than associating allocated bandwidth with a SS's Basic CID, the allocation is to a multicast or broadcast CID.

Table 21—Sample Upstream MAP with Multicast and Broadcast IE

Interval Description	Upstream MAP Information Element Fields		
	CID (16 bits)	UIUC (4 bits)	Offset (12 bits)
Initial Ranging	0000	2	0
Multicast group 0xFFC5 Bandwidth Request	0xFFC5	1	405
Multicast group 0xFFDA Bandwidth Request	0xFFDA	1	200
Broadcast Bandwidth Request	0xFFFF	1	200
SS 5 Uplink Grant	0x007B	4	156
SS 21 Uplink Grant	0x01C9	7	75
*	*	*	*
*	*	*	*
*	*	*	*

When the poll is directed at a multicast or broadcast CID, SSs belonging to the polled group may request bandwidth Request Intervals allocated in the upstream frame. With multicast and broadcast polling, to reduce the likelihood of collision, only SS's needing bandwidth reply. Zero-length bandwidth requests are not allowed in multicast or broadcast Request intervals. SSs always transmit using the modulation defined in the burst profile in the Request intervals. This will typically be at QPSK modulation.

If the BS does not respond with an error message or a bandwidth allocation within the expiration of timer MT5, the SS assumes a collision has occurred and uses a truncated binary exponential back-off algorithm (see 2.7) to try at another contention opportunity. The multicast and broadcast polling process is shown in Figure 64.

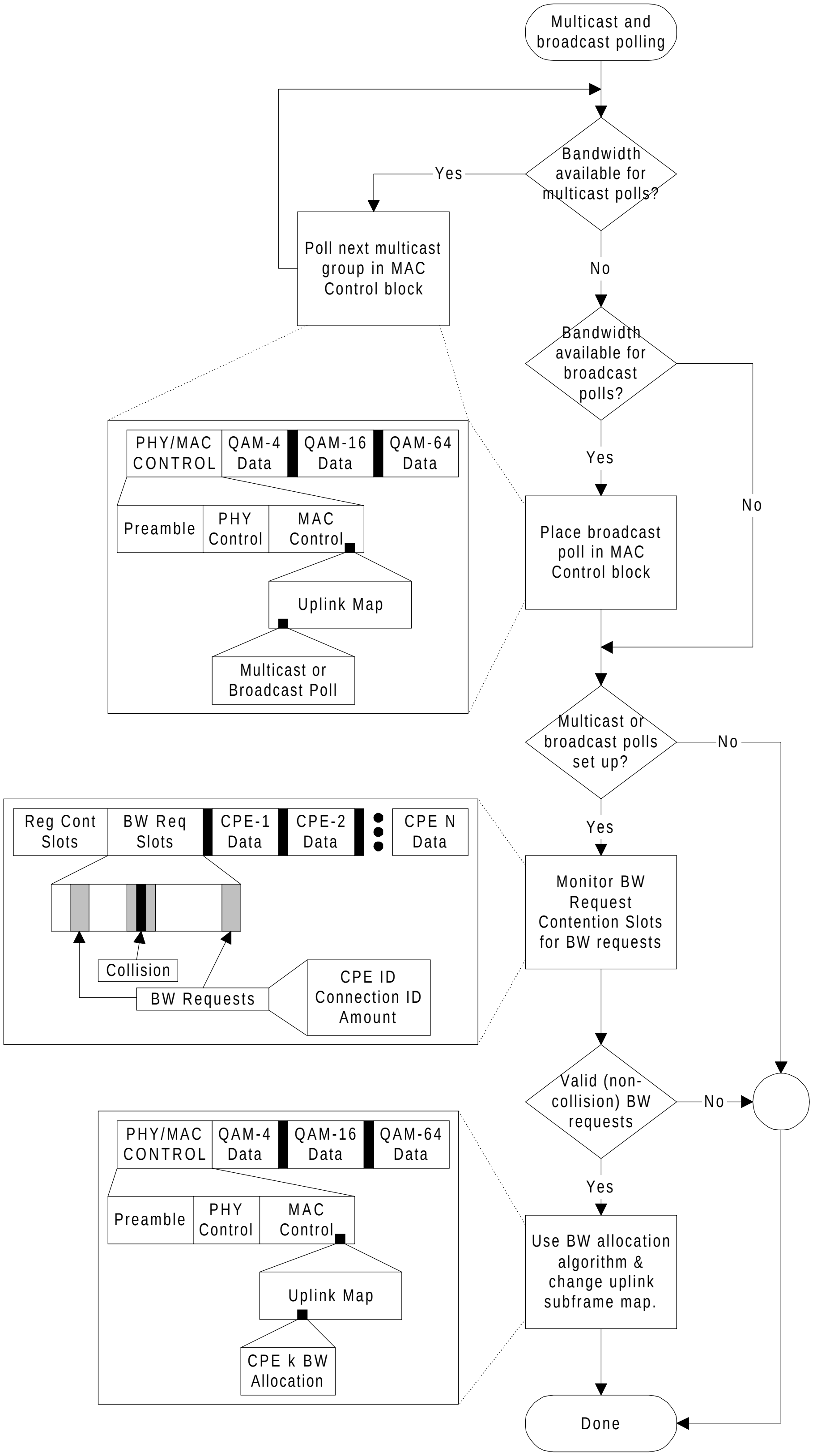

Multicast and broadcast polling
Bandwidth available for multicast polls?
Yes
No
Poll next multicast group in MAC Control block
Bandwidth available for broadcast polls?
Yes
No
Place broadcast poll in MAC Control block
PHY/MAC CONTROL
QAM-4 Data
QAM-16 Data
QAM-64 Data
Preamble
PHY Control
MAC Control
Uplink Map
Multicast or Broadcast Poll
Multicast or broadcast polls set up?
No
Yes
Monitor BW Request Contention Slots for BW requests
Reg Cont Slots
BW Req Slots
CPE-1 Data
CPE-2 Data
CPE N Data
Collision
BW Requests
CPE ID
Connection ID
Amount
Valid (non-collision) BW requests
No
Yes
Use BW allocation algorithm & change uplink subframe map.
PHY/MAC CONTROL
QAM-4 Data
QAM-16 Data
QAM-64 Data
Preamble
PHY Control
MAC Control
Uplink Map
CPE k BW Allocation
Done

Figure 64—Multicast and Broadcast Polling

2.10.3 Poll-Me Bit

SSs with currently active USG connections may set the poll me bit (bit PM in the MAC header GM field) in a MAC packet of the USG connection to indicate to the BS that they need polled to request bandwidth. To reduce the bandwidth requirements of individual polling, SSs with active USG connections need be individually polled only if the Poll-Me bit is set (or if the interval of the USG is too long to satisfy the QoS of the SSs other connections). Once the BS detects this request for polling, the process for individual polling is used to satisfy the request. The procedure by which a SS stimulates the BS to poll it is shown in Figure 65. To minimize the risk of the BS missing the poll me bit, the SS may set the bit in all USG MAC headers in the frame.

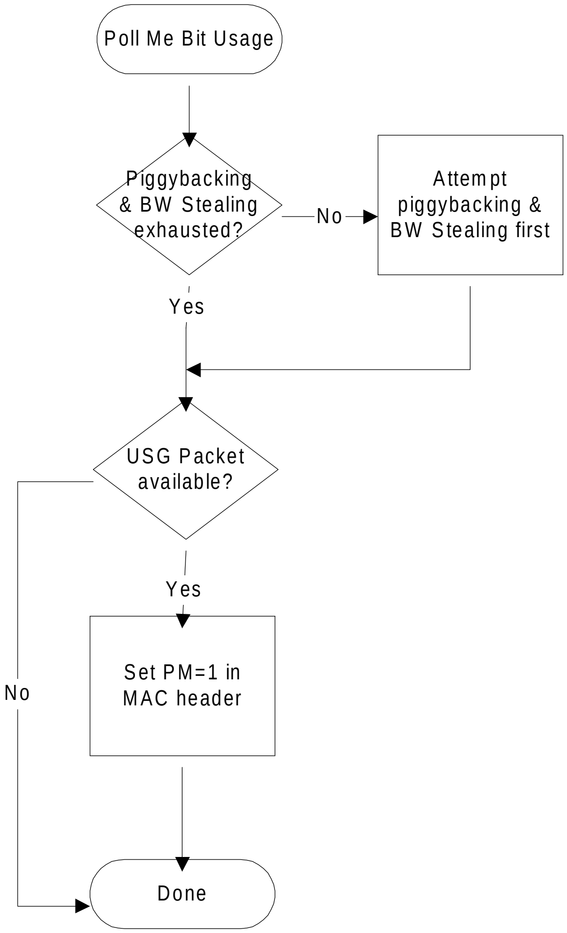

Poll Me Bit Usage
Piggybacking & BW Stealing exhausted?
No
Attempt piggybacking & BW Stealing first
Yes
USG Packet available?
Yes
Set PM=1 in MAC header
No
Done

Figure 65—Poll Me Bit Usage

2.11 Network Entry and Initialization

The procedure for initialization of a SS shall be as shown in Figure 66. This figure shows the overall flow between the stages of initialization in a SS. This shows no error paths, and is simply to provide an overview of the process. The more detailed finite state machine representations of the individual sections (including error paths) are shown in the subsequent figures. Timeout values are defined in 2.2.

The procedure can be divided into the following phases:

Scan for downstream channel and establish synchronization with the BS.
Obtain transmit parameters (from CD message)
Perform ranging
Establish IP connectivity
Establish time of day
Transfer operational parameters
Perform registration
Privacy initialization (if provisioned to utilize Privacy capabilities)

Each SS contains the following information when shipped from the manufacturer:

A unique 48-bit MAC address which is assigned during the manufacturing process. This is used to identify the SS to the various provisioning servers during initialization.
Security information as defined in 2.14 (e.g., X.509 certificate) used to authenticate the SS to the security server and authenticate the responses from the security and provisioning servers.

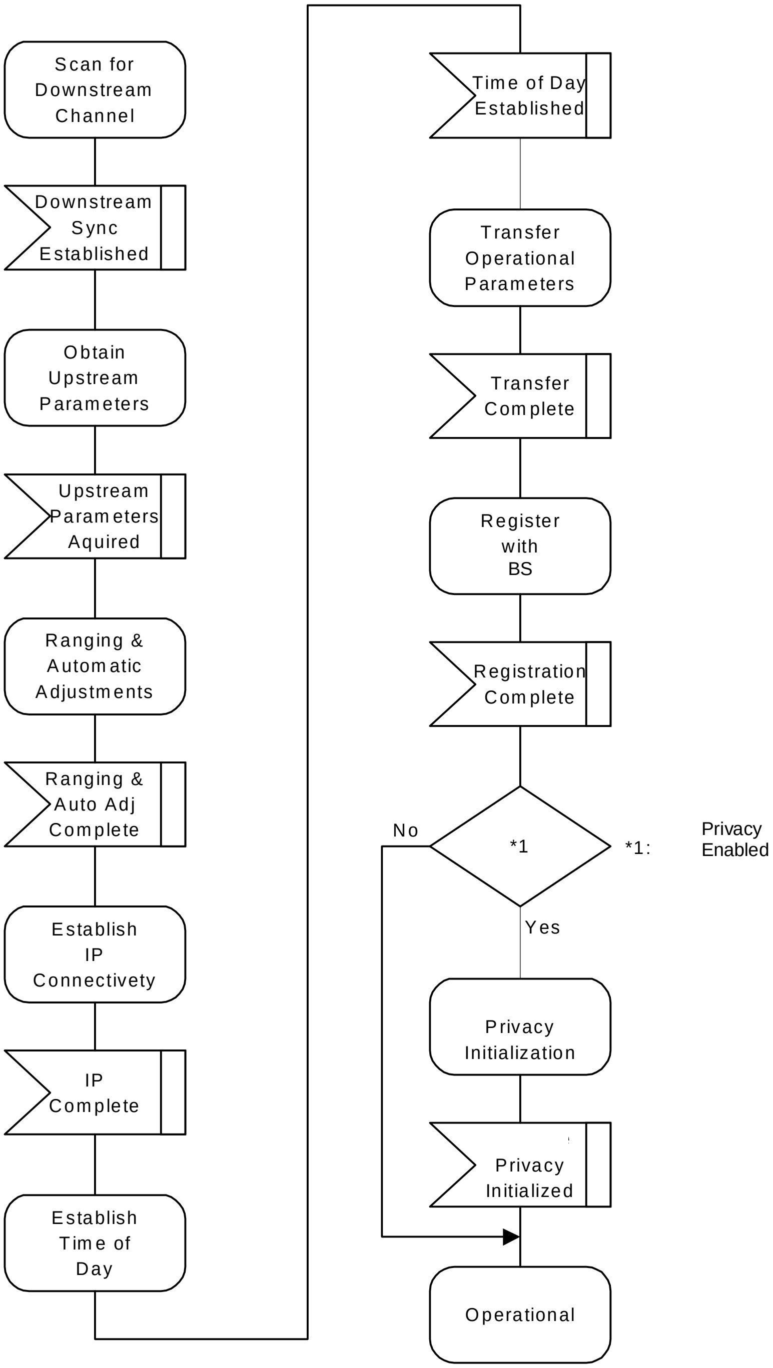

Scan for Downstream Channel
Downstream Sync Established
Obtain Upstream Parameters
Upstream Parameters Aquired
Ranging & Automatic Adjustments
Ranging & Auto Adj Complete
Establish IP Connectivety
IP Complete
Establish Time of Day
Time of Day Established
Transfer Operational Parameters
Transfer Complete
Register with BS
Registration Complete
No
*1
*1:
Privacy Enabled
Yes
Privacy Initialization
Privacy Initialized
Operational

Figure 66— SS Initialization Overview

2.11.1 Scanning and Synchronization to Downstream

On initialization or after signal loss, the SS shall acquire a downstream channel. The SS shall have non-volatile storage in which the last operational parameters are stored and shall first try to re-acquire this downstream channel. If this fails, it shall begin to continuously scan the possible channels of the downstream frequency band of operation until it finds a valid downstream signal.

2.11.2 Scanning and Synchronization to Downstream

On initialization or after signal loss, the SS shall acquire a downlink channel. The SS shall have non-volatile storage in which the last operational parameters are stored and shall first try to re-acquire this downstream channel. If this fails, it shall begin to continuously scan the possible channels of the downlink frequency band of operation until it finds a valid downlink signal. Once the Transmission Convergence Sublayer has achieved synchronization, as defined in >>>**TBD: PHY-Specific acquisition**<<<, the MAC Sublayer shall attempt to acquire the downlink channel parameters.

A downstream signal is considered to be valid when the SS has achieved the following steps:

a) synchronization of the modulation symbol timing
b) synchronization of the convolutional decoder if present
c) synchronization of the FEC framing
d) synchronization of the MPEG packetization
e) recognition of PCD MAC messages

This implies that it has locked onto the correct frequency, equalized the downstream channel, recovered any PMD sublayer framing and the FEC is operational (refer to Section TBD). At this point, a valid bit stream is being sent to the transmission convergence sublayer. The transmission convergence sublayer performs its own synchronization. On detecting the well-known BWA PID, along with a payload unit start indicator per [H.222], it delivers the MAC frame to the MAC sublayer.

2.11.3 Obtain Downlink Parameters

The MAC sublayer shall search for the DL-MAP MAC management messages. The CPE achieves MAC synchronization once it has received at least one DL-MAP messages for the same Upstream Channel ID. A CPE MAC remains in synchronization as long as it continues to successfully receive the UCD and DCD messages for its Channel. If the Lost SYNC Interval (refer to Section 2.2) has elapsed without a valid UCD or DCD message, a CPE shall not use the upstream and shall try to re-establish synchronization again.

2.11.4 Obtain Upstream Parameters

Refer to Figure 67. After synchronization, the SS shall wait for a Physical Channel Descriptor message (UCD) from the BS in order to retrieve a set of transmission parameters for a possible upstream channel. These messages are transmitted periodically from the BS for all available upstream channels and are addressed to the MAC broadcast address. The SS shall determine whether it can use the upstream channel from the channel description parameters.

The SS shall collect all UCDs which are different in their channel ID field to build a set of usable channel IDs. If no channel can be found after a suitable timeout period, then the SS shall continue scanning to find another downstream channel.

The SS shall determine whether it can use the upstream channel from the channel description parameters. If the channel is not suitable, then the SS shall try the next channel ID until it finds a usable channel. If the channel is suitable, the SS shall extract the parameters for this upstream from the UCD. It then shall wait for the next DL-MAP message and extract the upstream mini-slot timestamp from this message. The SS then shall wait for a bandwidth allocation map for the selected channel. It may begin transmitting upstream in accordance with the MAC operation and the bandwidth allocation mechanism.

The SS shall perform initial ranging at least once per Figure 68. If initial ranging is not successful, then the next channel ID is selected, and the procedure restarted fromUCD extraction. When there are no more channel IDs to try, then the SS shall continue scanning to find another downstream channel.

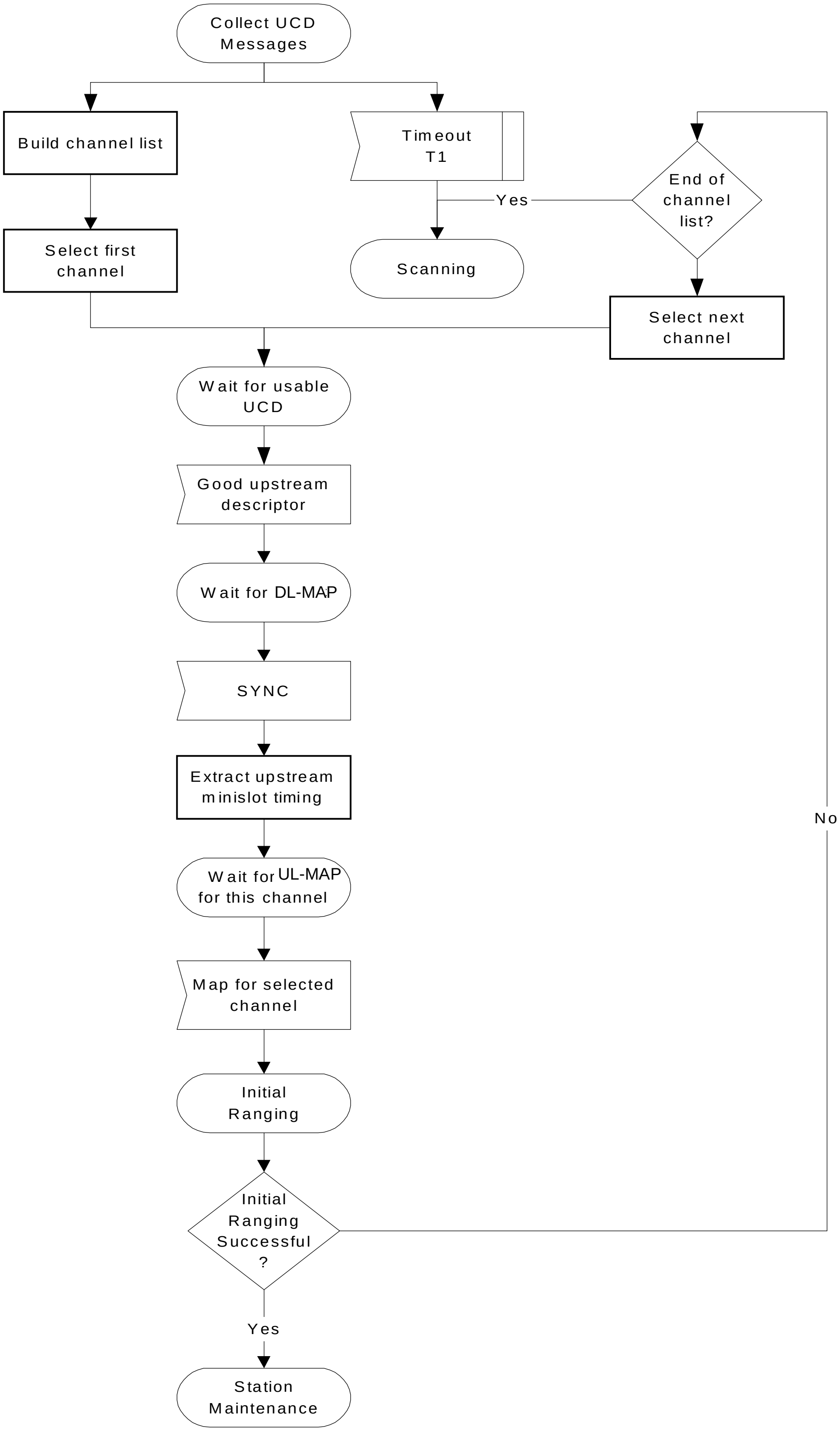


Figure 67— Obtaining Upstream Parameters

2.11.5 Message Flows During Scanning and Upstream Parameter Acquisition

The BS shall generate DL-MAP and UCD messages on the downstream at periodic intervals within the ranges defined in 2.2. These messages are addressed to all SSs. Refer to the following tables and figures.

Table 22—Message Flows During Scanning and Upstream Parameter Acquisition

BS		SS
clock time to send DL-MAP	----------------DL-MAP------------------->	|
clock time to send UCD	----------------UCD------------------------>	|
		|
clock time to send DL-MAP	----------------DL-MAP------------------->	|
		| Example of a UCD cycle
		| prior to SS power-on
		|
clock time to send DL-MAP	----------------DL-MAP------------------->	|
		|
		|
		|
clock time to send DL-MAP	----------------DL-MAP------------------->	|
		|
		|
clock time to send DL-MAP	----------------DL-MAP------------------->	
clock time to send UCD	----------------UCD---------------------->	
clock time to send DL-MAP	----------------DL-MAP------------------->	
		power on sequence complete
clock time to send DL-MAP	----------------DL-MAP------------------->	
		establish PHY synchronization
		& wait for UCD
clock time to send DL-MAP	----------------DL-MAP-------------------->	

Table 22—Message Flows During Scanning and Upstream Parameter Acquisition

BS		SS
clock time to send DL-MAP	----------------DL-MAP------------------->	
clock time to send UCD	----------------UCD----------------->	
		obtain parameters for this upstream channel to use for initialization
clock time to send DL-MAP	----------------DL-MAP------------------->	
		extract slot info for upstream & wait for transmit opportunity to perform ranging
clock time to send DL-MAP	----------------DL-MAP------------------->	
clock time to send UL-MAP	----------------UL-MAP--------------------->	
		start ranging process

2.11.6 Initial Ranging and Automatic Adjustments

Ranging is the process of acquiring the correct timing offset such that the 's transmissions are aligned to a symbol that marks the beginning of a Mini-slot boundary. The timing delays through the PHY layer shall be relatively constant. Any variation in the PHY delays shall be accounted for in the guard time of the upstream PHY layer overhead.

First, a SS shall synchronize to the downstream and learn the upstream channel characteristics through the Physical Channel Descriptor MAC management message. At this point, the SS shall scan the UL-MAP message to find an Initial Maintenance Region. The BS shall make an Initial Maintenance region large enough to account for the variation in delays between any two SSs (maximum round trip propagation delay due to cell size plus maximum allowable implementation delay).

The SS shall put together a Ranging Request message to be sent in an Initial Maintenance region. The CID field shall be set to the non-initialized SS value (zero).

Ranging adjusts each SS's timing offset such that it appears to be co-located with the BS. The SS shall set its initial timing offset to the amount of internal fixed delay equivalent to co-locating the SS next to the BS. This amount includes delays introduced through a particular implementation, and shall include the downstream PHY interleaving latency, if any.

When the Initial Maintenance transmit opportunity occurs, the SS shall send the Ranging Request message. Thus, the SS sends the message as if it was co-located with the BS.

Once the BS has successfully received the Ranging Request message, it shall return a Ranging Response message addressed to the individual SS. Within the Ranging Response message shall be a temporary CID assigned to this SS until it has completed the registration process. The message shall also contain information on RF power level adjustment and offset frequency adjustment as well as any timing offset corrections.

The SS shall now wait for an individual Station Maintenance region assigned to its temporary CID. It shall now transmit a Ranging Request message at this time using the temporary CID along with any power level and timing offset corrections.

The BS shall return another Ranging Response message to the SS with any additional fine tuning required. The ranging request/response steps shall be repeated until the response contains a Ranging Successful notification or the BS aborts ranging. Once successfully ranged, the SS shall join normal data traffic in the upstream. In particular, state machines and the applicability of retry counts and timer values for the ranging process are defined in Table 2.

Note: The burst type to use for any transmission is defined by the Uplink Interval Usage Code (UIUC). Each UIUC is mapped to a burst type in the UCD message.

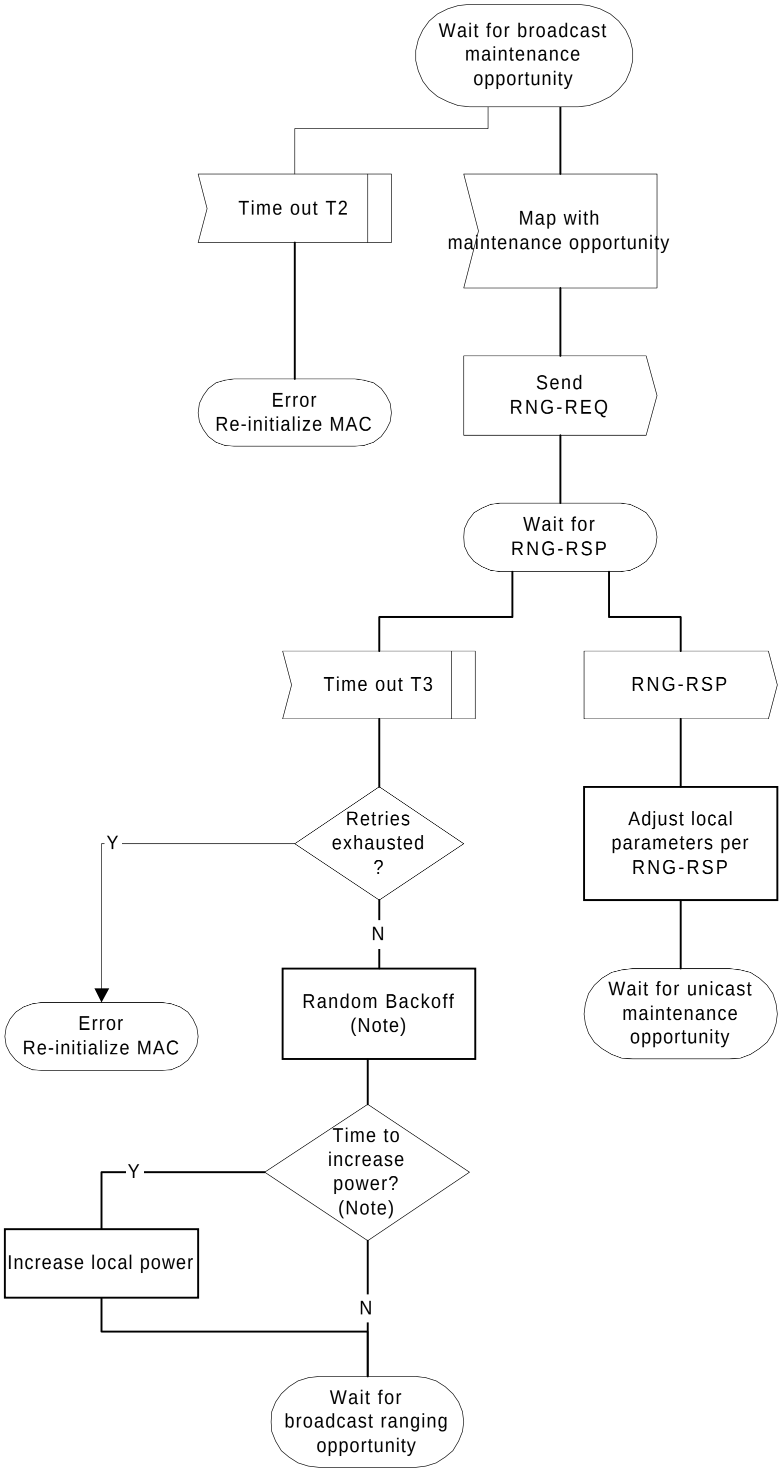
The message sequence chart and flow charts on the following pages define the ranging and adjustment process which shall be followed by compliant SSs and BSs.

Table 23—Ranging and Automatic Adjustments Procedure

BS		SS
[time to send the Initial Maintenance opportunity]		
send map containing Initial Maintenance information element with a broadcast/multicast Connection ID	-----------UL-MAP----------->	
	<---------RNG-REQ-------	transmit ranging packet in contention mode with Connection ID parameter = 0
[receive recognizable ranging packet]		
allocate temporary Connection ID		
send ranging response	----------RNG-RSP------->	
add temporary Connection ID to poll list		store temporary Connection ID & adjust other parameters
[time to send the next map]		
send map with Station Maintenance information element to SS using temporary CID	-----------UL-MAP----------->	recognize own temporary Connection ID in map
	<---------RNG-REQ-------	reply to Station Maintenance opportunity poll
send ranging response	----------RNG-RSP------->	
		adjust local parameters
[time to send an Initial Maintenance opportunity] send map containing Initial Maintenance information element with a broadcast/multicast Connection ID		
send periodic transmit opportunity to broadcast address	------------UL-MAP---------->	

Note: The BS shall allow the SS sufficient time to have processed the previous RNG-RSP (i.e., to modify the transmitter parameters) before sending the SS a specific ranging opportunity. This is defined as SS Ranging Response Time in 2.2.

Ranging Request is within the tolerance of the BS.


Wait for broadcast maintenance opportunity
Time out T2
Map with maintenance opportunity
Error Re-initialize MAC
Send RNG-REQ
Wait for RNG-RSP
Time out T3
RNG-RSP
Retries exhausted ?
Y
N
Adjust local parameters per RNG-RSP
Error Re-initialize MAC
Random Backoff (Note)
Wait for unicast maintenance opportunity
Time to increase power? (Note)
Y
Increase local power
N
Wait for broadcast ranging opportunity

Note: Timeout T3 may occur because the RNG-REQs from multiple SSs collided. To avoid these SS repeating the loop in lockstep, a random backoff is required. This is a backoff over the ranging window specified in the MAP. In addition, the SS should not increase its Tx power after each backoff in case the timeout was due to a collision instead of a low power condition. T3 timeouts can also occur during multi-channel operation. On a system with multiple upstream channels, the SS MUST attempt initial ranging on every suitable upstream channel before moving to the next available downstream channel.

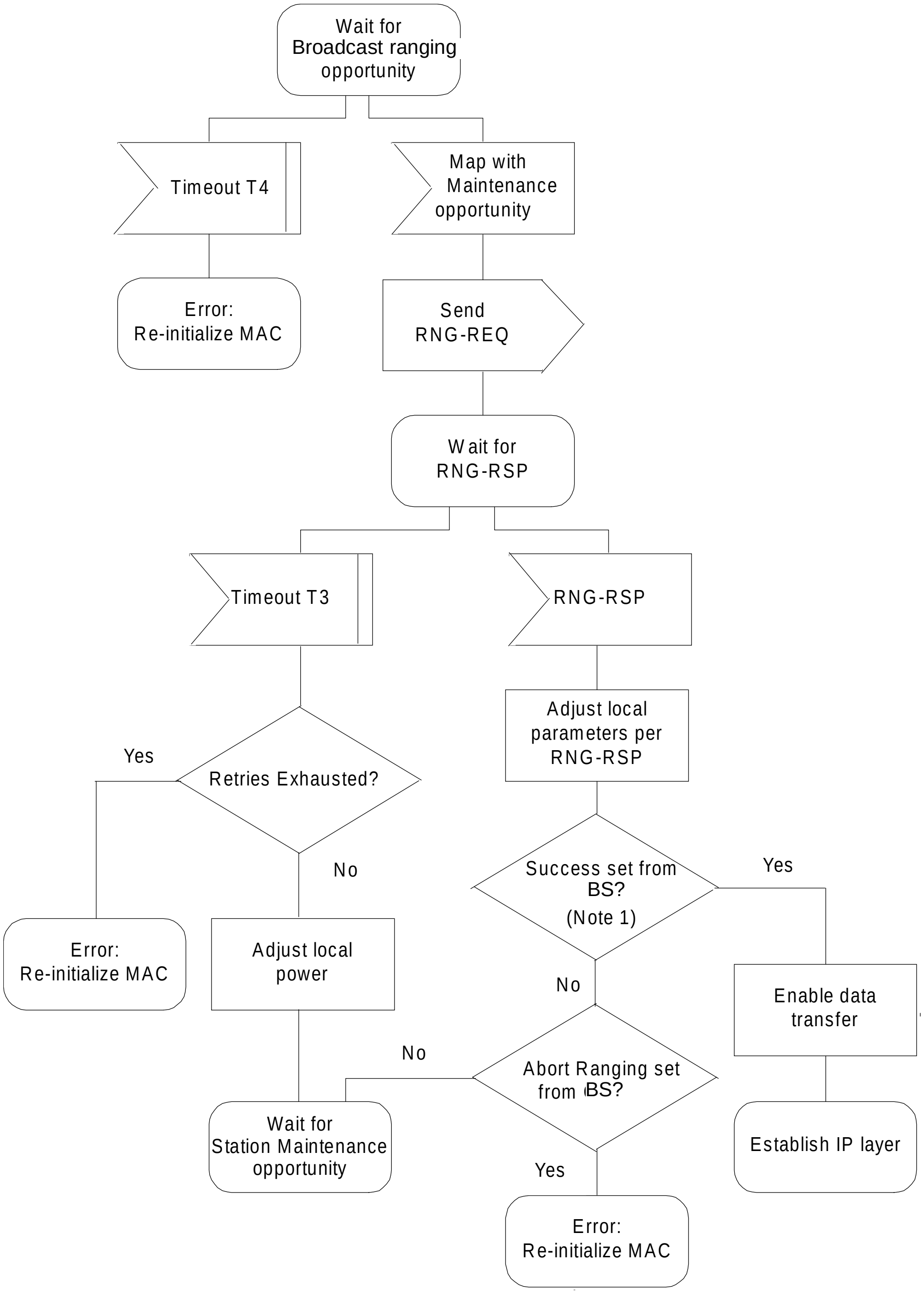


Figure 68—Initial Ranging - SS (continued)

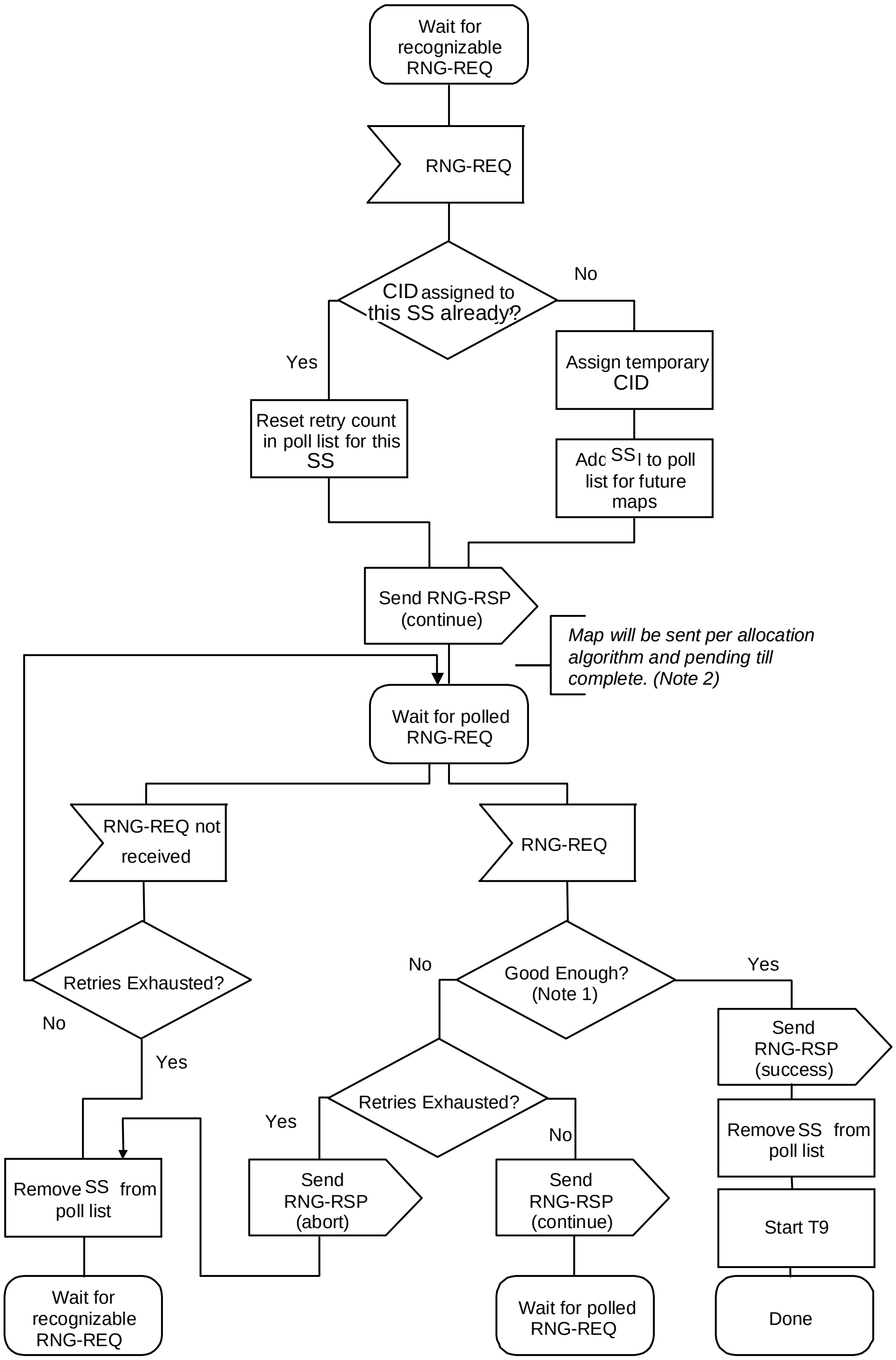


Figure 69—Initial Ranging - BS

Means ranging is within the tolerable limits of the BS.

RNG-REQ pending-till-complete was nonzero, the BS SHOULD hold off the station maintenance opportunity accordingly unless needed, for example, to adjust the SS's power level. If opportunities are offered prior to the pending-till-complete expiry, the “good-enough” test which follows receipt of a RNG-RSP shall not judge the SS's transmit equalization until pending-till-complete expires.

2.11.7 Ranging Parameter Adjustment

Adjustment of local parameters (e.g., transmit power) in a SS as a result of the receipt (or non-receipt) of an RNG-RSP is considered to be implementation-dependent with the following restrictions:

All parameters shall be within the approved range at all times

Power adjustment shall start from the minimum value unless a valid power is available from non-volatile storage, in which case this shall be used as a starting point.

Power adjustment shall be capable of being reduced or increased by the specified amount in response to RNG-RSP messages.

If, during initialization, power is increased to the maximum value (without a response from the BS) it shall wrap back to the minimum.

For multi-channel support, the SS shall attempt initial ranging on every suitable upstream channel before moving to the next available downstream channel.

2.11.8 Initial Connection Establishment

2.11.8.1 Establish IP Connectivity

At this point, the SS shall invoke DHCP mechanisms [RFC-2131] in order to obtain an IP address and any other parameters needed to establish IP connectivity. The DHCP response shall contain the name of a file which contains further configuration parameters. Refer to Table 24.

Table 24—Establishing IP Connectivity

SS		DHCP
send DHCP request to broadcast address		
	----------------DHCP discover------------>	
		check SS MAC address & respond
	<--------------DHCP offer -----------------	
choose server		
	----------------DHCP request-------------->	
		process request
	<--------------DHCP response--------------	
set up IP parameters from DHCP response		

2.11.8.2 Establish Time of Day

The SS and BS need to have the current date and time. This is required for time-stamping logged events which can be retrieved by the management system. This need not be authenticated and need only be accurate to the nearest second.

The protocol by which the time of day shall be retrieved is defined in [RFC-868]. Refer to Table 25. The request and response shall be transferred using UDP. The time retrieved from the server (UTC) shall be combined with the time offset received from the DHCP response to create the current local time

Table 25—Establishing Time of Day

SS		Time Server
send request to time server		
	---------------time of day request----------->	
		process request
	<-------------time of day response-------------	
set up / correct time of day from response		

Successfully acquiring the Time of Day is not mandatory for a successful registration, but is necessary for on-going operation. The specific timeout for Time of Day Requests is implementation dependent. However, the SS shall not exceed more than 3 Time of Day requests in any 5 minute period.

2.11.9 Transfer Operational Parameters

After DHCP is successful, the SS shall download the parameter file using TFTP, as shown in 70. The TFTP configuration parameter server is specified by the “siaddr” field of the DHCP response. The SS shall use an adaptive timeout for TFTP based on binary exponential backoff. Refer to [RFC-1123] and [RFC-2349].

The parameter fields required in the DHCP response and the format and content of the configuration file shall be as defined in 2.4. Note that these fields are the minimum required for interoperability.

If a SS downloads a configuration file containing an upstream channel and/or downstream frequency different from what the SS is currently using, the SS shall not send a Registration Request message to the BS. The SS shall redo initial ranging using the configured upstream channel and/or downstream frequency.

2.11.9.1 Registration

A SS shall be authorized to forward traffic into the network once it is initialized and configured. The SS is authorized to forward traffic into the network via registration.To register with a BS, the SS shall forward its provisioned set of service flows and any other operational parameters in the configuration file (refer to 2.4) to the BS as part of a Registration Request. Figure 70 shows the procedure that shall be followed by the SS.

The configuration parameters downloaded to the SS shall include a network access control object (see 2.3.1.3). If this is set to “no forwarding,” the SS shall not forward data from attached SS to the network, yet the SS shall respond to network management requests. This allows the SS to be configured in a mode in which it is manageable but will not forward data.

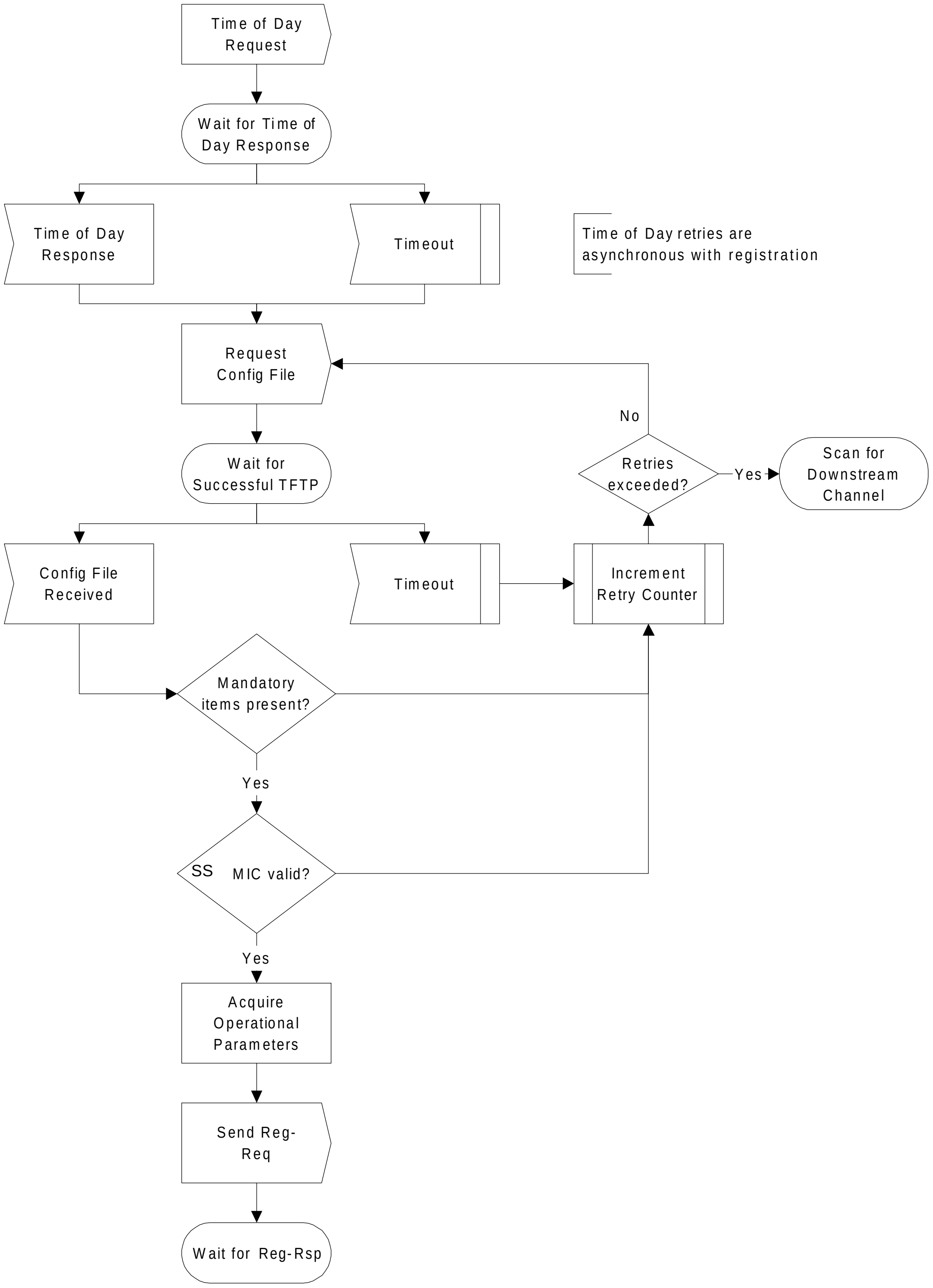


Figure 70—Registration — SS

Once the SS has sent a Registration Request to the BS it shall wait for a Registration Response to authorize it to forward traffic to the network. Figure 71 shows the waiting procedure that shall be followed by the SS.

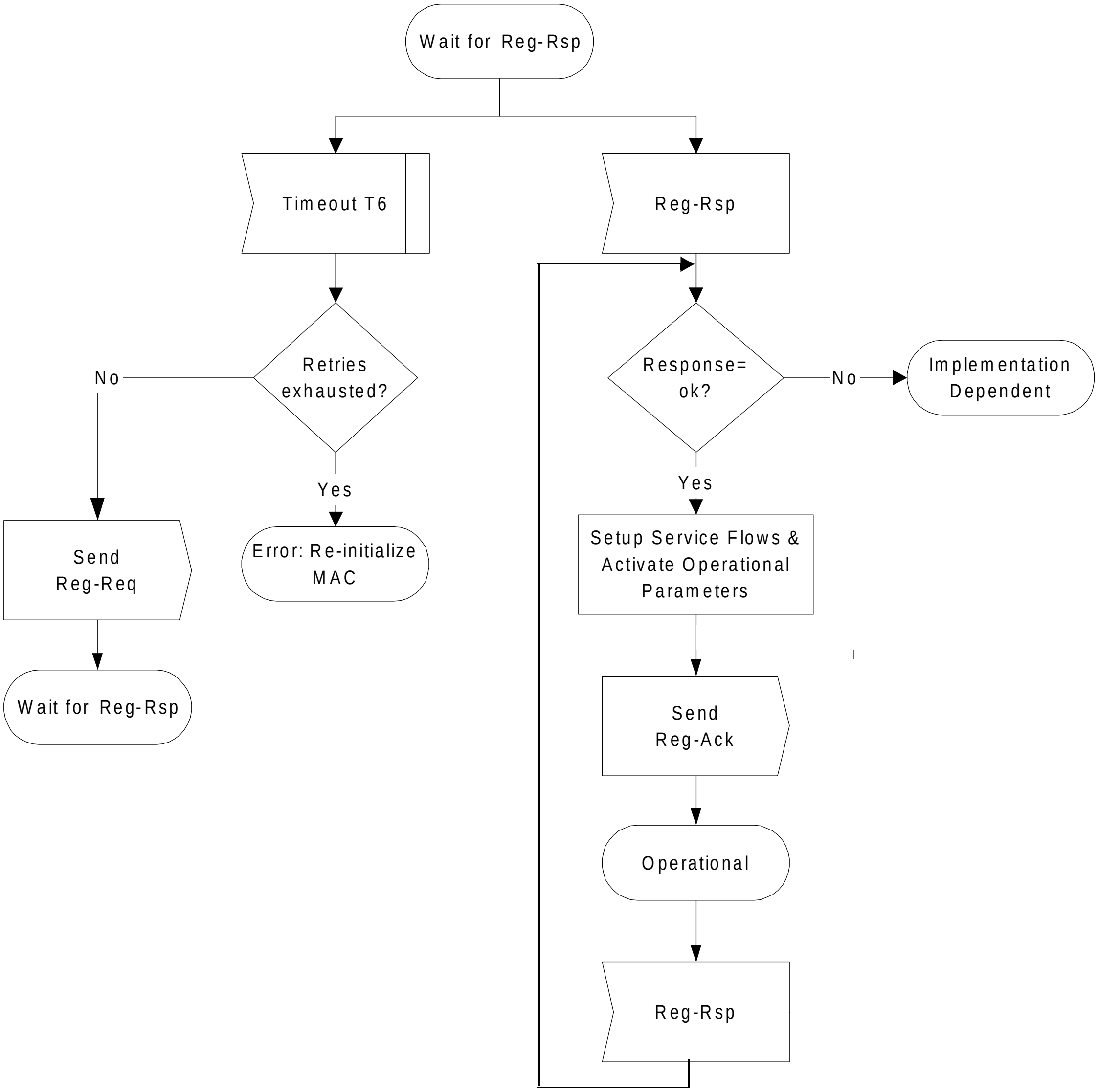


Figure 71—Wait for registration response — SS

The BS shall perform the following operations to confirm the SS authorization (refer to Figure 72):

Calculate a MIC per 2.4 and compare it to the BS MIC included in the Registration Request. If the MIC is invalid, the BS shall respond with an Authorization Failure.

If present, check the TFTP Server Timestamp field. If the BS detects that the time is different from its local time by more than SS Configuration Processing Time (refer to Table 2), the BS shall indicate authentication failure in the REG-RSP. The BS SHOULD also make a log entry stating the SS MAC address from the message.

If present, check the TFTP Server Provisioned SS Address field. If the Provisioned SS Address does not match the requesting SS's actual address, the BS shall indicate authentication failure in the REG-RSP. The BS SHOULD also make a log entry stating the SS MAC address from the message.

If the Registration Request contains Service Flow encodings, verify the availability of the Quality of Service requested in the provisioned Service Flow(s). If unable to provide the Service Flow(s), the BS shall respond with a Class of Service Failure and the appropriate Service Flow Response(s).

Verify the availability of any SS Capabilities requested. If unable or unwilling to provide the SS Capability requested, the BS shall turn that SS Capability 'off' (refer to 6.2.8.1).

Assign a Service Flow ID for each class of service supported.

Reply to the SS in a Registration Response.

If the Registration Request contains Service Flow encodings, the BS shall wait for a Registration Acknowedgment as shown in Figure 73.

If timer T9 expires, the BS shall both de-assign the temporary CID from that SS and make some provision for aging out that CID.

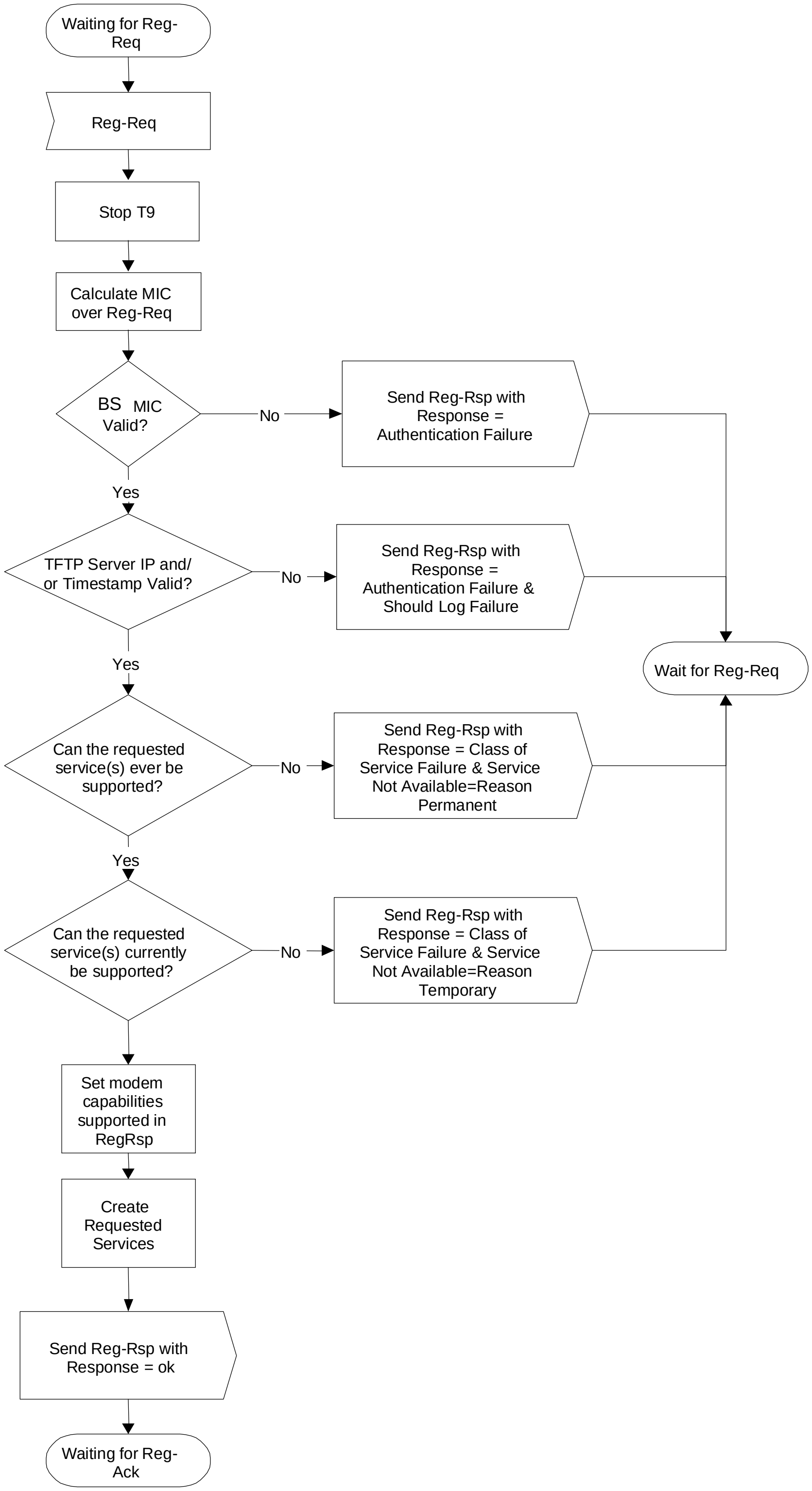

Waiting for Reg-Req
Reg-Req
Stop T9
Calculate MIC over Reg-Req
BS MIC Valid?
No
Send Reg-Rsp with Response = Authentication Failure
Yes
TFTP Server IP and/ or Timestamp Valid?
No
Send Reg-Rsp with Response = Authentication Failure & Should Log Failure
Yes
Wait for Reg-Req
Can the requested service(s) ever be supported?
No
Send Reg-Rsp with Response = Class of Service Failure & Service Not Available=Reason Permanent
Yes
Can the requested service(s) currently be supported?
No
Send Reg-Rsp with Response = Class of Service Failure & Service Not Available=Reason Temporary
Set modem capabilities supported in RegRsp
Create Requested Services
Send Reg-Rsp with Response = ok
Waiting for Reg-Ack

Figure 72—Registration — BS

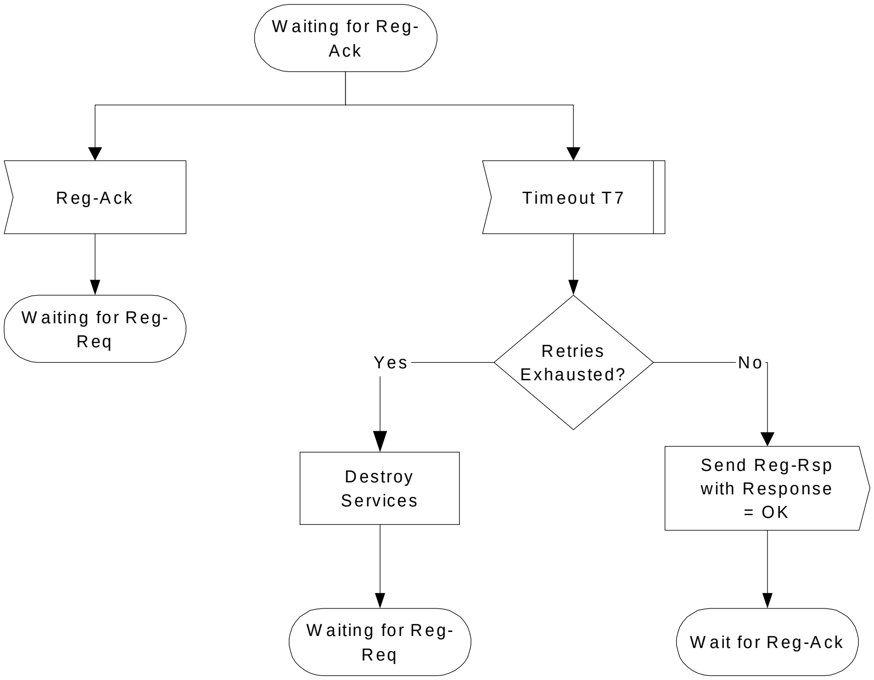


Figure 73—Registration Acknowledgment— BS

2.11.9.2 Privacy Initialization

Following registration, if the SS is provisioned to run Privacy, the SS shall initialize Privacy operations, as described in 2.14. A SS is provisioned to run Privacy if its configuration file includes a Privacy Configuration Setting (2.3.3.1.1) and if the Privacy Enable parameter (2.3.1.11) is set to enable.

2.11.9.3 Connection IDs During SS Initialization

After completion of the Registration process, the SS will have been assigned Service Flow IDs (SFIDs) to match its provisioning. However, the SS must complete a number of protocol transactions prior to that time (e.g., Ranging, DHCP, etc.), and requires a temporary Connection ID in order to complete those steps.

On reception of an Initial Ranging Request, the BS shall allocate a temporary CID and assign it to the SS for initialization use. The BS may monitor use of this CID and restrict traffic to that needed for initialization. It shall inform the SS of this assignment in the Ranging Response.

On receiving a Ranging Response addressed to it, the SS shall use the assigned temporary CID for further initialization transmission requests until the Registration Response is received.

On receiving a Ranging Response instruction to move to a new downstream frequency and/or upstream channel ID, the SS shall consider any previously assigned temporary CID to be deassigned, and must obtain a new temporary CID via initial ranging.

It is possible that the Ranging Response may be lost after transmission by the BS. The SS shall recover by timing out and re-issuing its Initial Ranging Request. Since the SS is uniquely identified by the source MAC address in the Ranging Request, the BS may immediately re-use the temporary CID previously assigned. If the BS assigns a new temporary CID, it shall make some provision for aging out the old CID that went unused (see Section TBD).

When assigning provisioned SFIDs on receiving a Registration Request, the BS may re-use the temporary CID, assigning it to one of the Service Flows requested. If so, it shall continue to allow initialization messages on that CID, since the Registration Response could be lost in transit. If the BS assigns all-new CIDs for class-of-service provisioning, it shall age out the temporary CID. The aging-out shall allow sufficient time to complete the registration process in case the Registration Response is lost in transit.

2.11.9.4 Multiple-Channel Support

In the event that more than one downstream signal is present in the system, the SS shall operate using the best valid downstream signal that it encounters when scanning. It will be instructed via the parameters in the configuration file to shift operation to different downstream and/or upstream frequencies if necessary.

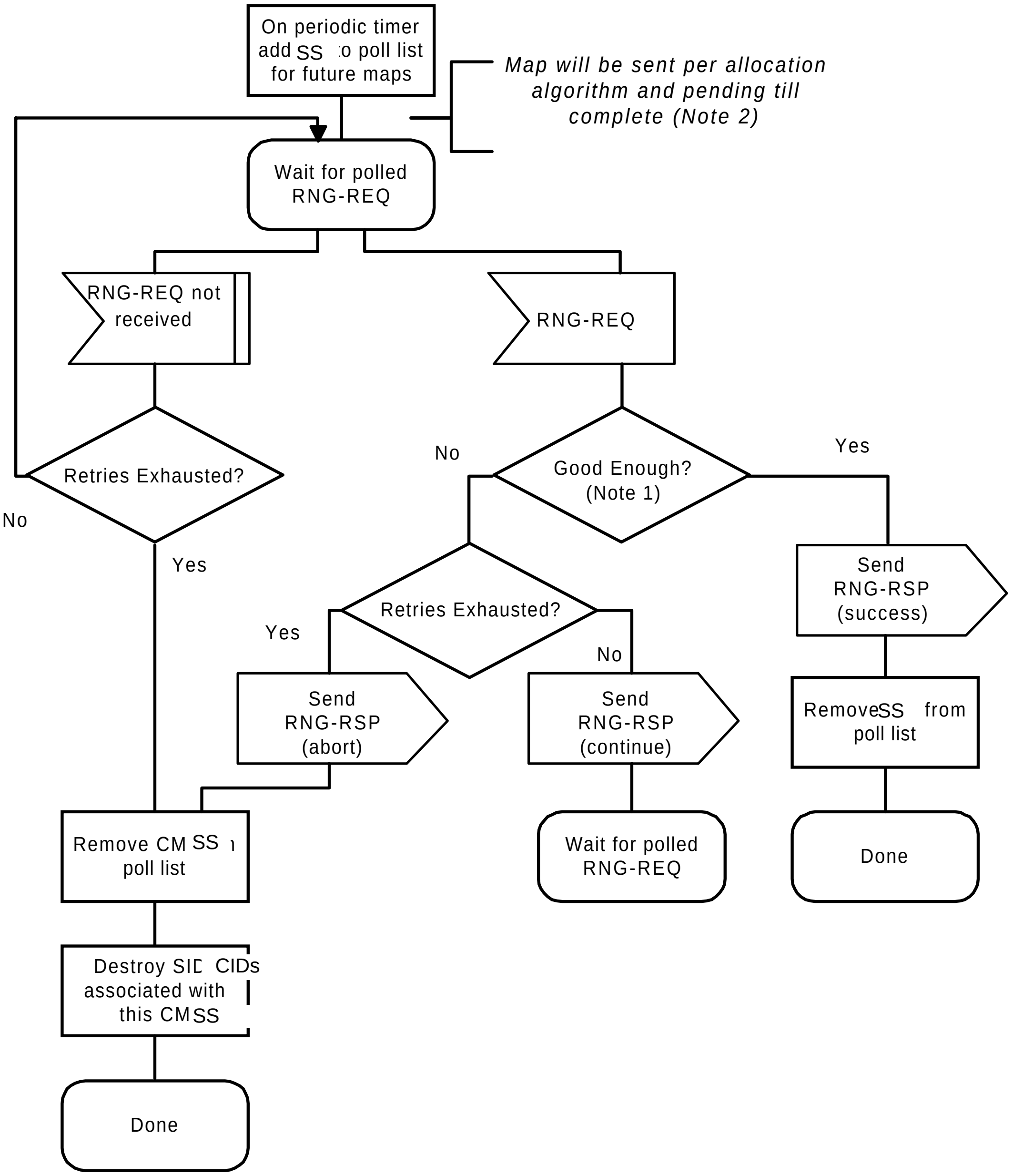
Both upstream and downstream channels shall be identified where required in MAC management messages using channel identifiers.

2.12 Ranging

The BS shall provide each SS a Periodic Ranging opportunity at least once every T4 seconds. The BS shall send out Periodic Ranging opportunities at an interval sufficiently shorter than T4 that a MAP could be missed without the SS timing out. The size of this “subinterval” is BS dependent. For GPT mode terminals, any allocation of uplink bandwidth constitutes a Periodic Ranging opportunity.

The SS shall reinitialize its MAC layer after T4 seconds have elapsed without receiving a Periodic Ranging opportunity.

Remote RF signal level adjustment at the SS is performed through a periodic maintenance function using the RNG-REQ and RNG-RSP MAC messages. This is similar to initial ranging and is shown in Figure 74 and Figure 75. On receiving a RNG-RSP, the SS shall not transmit until the RF signal has been adjusted in accordance with the RNG-RSP and has stabilized.



Note 1: Means Ranging Request is within the tolerance limits of the CMTS fc . BS r and transmit equalization (if supported)
Note 2: RNG-REQ pending-till-complete was nonzero, the CMTS BS D hold off the station maintenance opportunity accordingly unless needed, for example, to adjust the CM's powe SS's l. If opportunities are offered prior to the pending-till-complete expiry, the "good-enough" test which follows receiptof a RNG-RSP MUST NOT judge the CM's tra SS equalization until pending-till-complete expires.

Figure 74—Periodic Ranging - BS

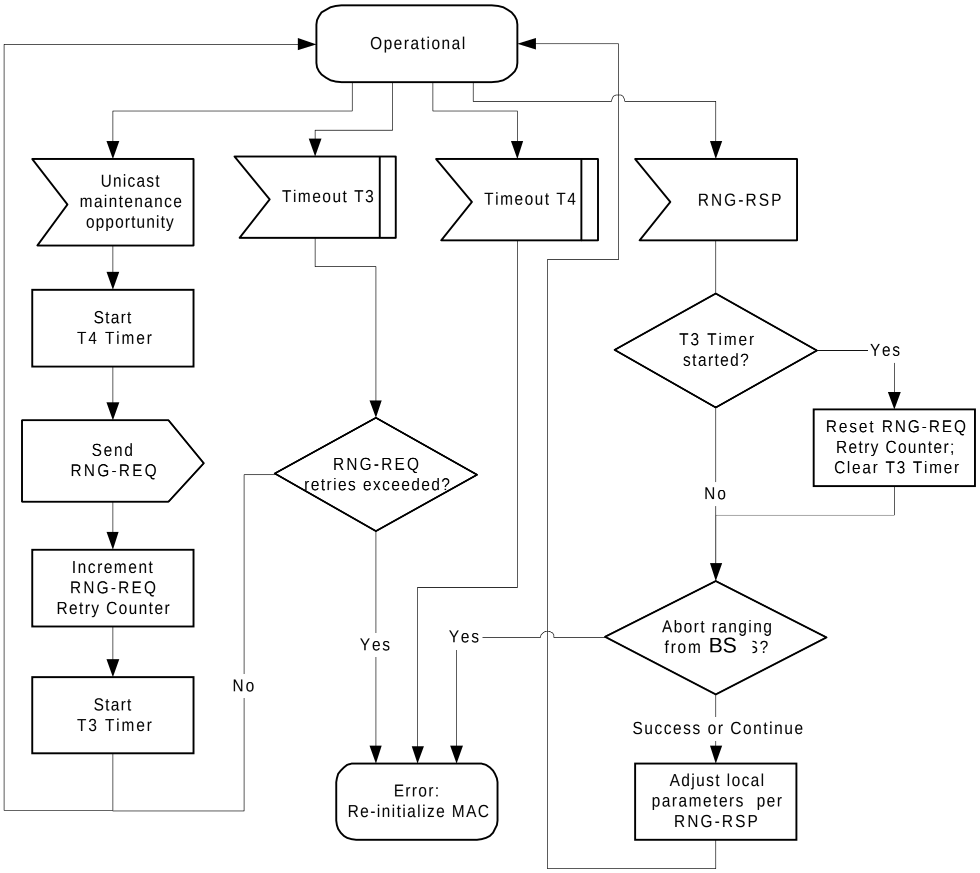


Figure 75—Periodic Ranging - SS

2.12.1 Burst Mode Downstream Modulation/FEC Management

The downstream modulation/FEC format for data transmission (characterized by the burst types) is determined by the BS according to the quality of the signal that is received by each SS. To reduce the volume of upstream traffic, the SS monitors the carrier to noise and interference ratio (CNIR), and compares the averaged value against the allowed region of operation. This region is bounded by threshold levels. If the received CNIR goes outside of the allowed operating region, the SS requests a change to a new burst type using the RNG-REQ message. The BS acknowledges the receipt of the RNG-REQ message using the RNG-RSP message. The RNG-RSP message contains the new SS operating burst type, which can be either the same as or different from the existing type.

The SS applies an algorithm to determine its best operating modulation/FEC region in accordance with the threshold parameters established in the RNG-RSP message.The Threshold Delta parameter shall be applied to the two threshold points in accordance with Figure 76. The Threshold Delta provides hysterisis around which the SS applies the thresholds.

Table 26—Downlink Modulation/FEC Change Initiated from SS

BS		SS
		DL Modulation/FEC Requires Modification
Receive RNG-REQ	<--------- RNG-REQ ----------	Send RNG-REQ
Determine burst type that is now appropriate		
Modify burst type within provisioned limits established for SS		
Send RNG-RSP	---------- RNG-RSP --------->	Receive RNG-RSP
Begin using new burst type for the SS		

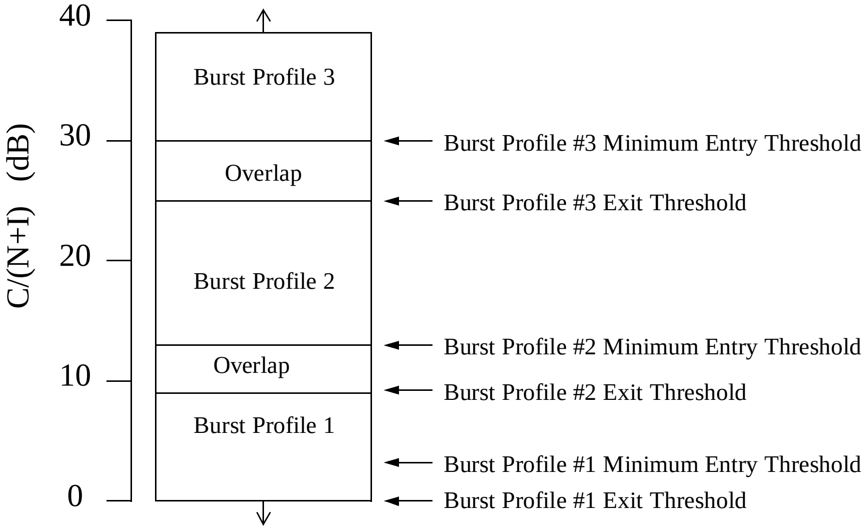

40
30
20
10
0
C/(N+I) (dB)
Burst Profile 3
Overlap
Burst Profile 2
Overlap
Burst Profile 1
Burst Profile #3 Minimum Entry Threshold
Burst Profile #3 Exit Threshold
Burst Profile #2 Minimum Entry Threshold
Burst Profile #2 Exit Threshold
Burst Profile #1 Minimum Entry Threshold
Burst Profile #1 Exit Threshold

Figure 76—Modulation Threshold Usage

2.13 Quality of Service

This standard defines several Quality of Service (QoS) related concepts. These include:

Service Flow QoS Scheduling
Dynamic Service Establishment
Two-Phase Activation Model

2.13.1 Theory of Operation

The various BWA protocol mechanisms described in this document can be used to support Quality of Service (QoS) for both upstream and downstream traffic through the SS and the BS. This section provides an overview of the QoS protocol mechanisms and their part in providing end-to-end QoS.

The requirements for Quality of Service include:

A configuration and registration function for pre-configuring SS-based QoS **Service Flows** and traffic parameters.

A signaling function for dynamically establishing QoS-enabled Service Flows and traffic parameters

Utilization of MAC scheduling and traffic parameters for upstream Service Flows.

Utilization of QoS traffic parameters for downstream Service Flows.

Grouping of Service Flow properties into named **Service Classes**, so upper layer entities and external applications (at both the SS and BS) can request Service Flows with desired QoS parameters in a globally consistent way.

The principal mechanism for providing QoS is to associate packets traversing the RF MAC interface into a **Service Flow** as identified by the **Connection ID**. A Service Flow is a unidirectional flow of packets that is provided a particular Quality of Service. The SS and BS provide this QoS according to the **QoS Parameter Set** defined for the Service Flow.

The primary purpose of the Quality of Service features defined here is to define transmission ordering and scheduling on the air interface. However, these features often need to work in conjunction with mechanisms beyond the air interface in order to provide end-to-end QoS or to police the behavior of SSs.

Service Flows exist in both the upstream and downstream direction, and may exist without actually being activated to carry traffic. Service Flows have a 32-bit **Service Flow Identifier** (SFID) assigned by the BS. All Service Flows have an SFID; active Service Flows also have a 16-bit **Connection Identifier** (CID).

At least two Service Flows must be defined in each configuration file: one for upstream and one for downstream service. The first upstream Service Flow describes the **Primary Upstream Service Flow**, and is the default Service Flow used for otherwise unclassified traffic and all MAC Messages. The first downstream Service Flow describes service to the **Primary Downstream Service Flow**. Additional Service Flows defined in the Configuration file create Service Flows that are provided QoS services.

2.13.2 Service Flows

A **Service Flow** is a MAC-layer transport service that provides unidirectional transport of packets either to upstream packets transmitted by the SS or to downstream packets transmitted by the BS[7]. A Service Flow is characterized by a set of **QoS Parameters** such as latency, jitter, and throughput assurances. In order to standardize operation between the SS and BS, these attributes include details of how the SS requests upstream minislots and the expected behavior of the BS upstream scheduler.

A Service Flow is partially characterized by the following attributes[8]:

[7] A Service Flow, as defined here, has no direct relationship to the concept of a “flow” as defined by the IETF’s Integrated Services (intserv) Working Group [RFC-2212]. An intserv flow is a collection of packets sharing transport-layer endpoints. Multiple intserv flows can be served by a single Service Flow.

[8] Some attributes are derived from the above attribute list. The Service Class Name is an attribute of the ProvisionedQoSParamSet. The activation state of the Service Flow is determined by the ActiveQoSParamSet. If the ActiveQoSParamSet is null then the service flow is inactive.

ServiceFlowID: exists for all service flows

Connection ID: mapping to a SFID only exists when the connection has admitted or active service flow(s)

ProvisionedQosParamSet: defines a set of QoS Parameters which appears in the configuration file and is presented during registration. This may define the initial limit for authorizations allowed by the authorization module. The ProvisionedQosParamSet is defined once when the Service Flow is created via registration.[9]

AdmittedQosParamSet: defines a set of QoS parameters for which the BS (and possibly the SS) are reserving resources. The principal resource to be reserved is bandwidth, but this also includes any other memory or time-based resource required to subsequently activate the flow.

ActiveQosParamSet: defines set of QoS parameters defining the service actually being provided to the Service Flow. Only an Active Service Flow may forward packets.

A Service Flow exists when the BS assigns a Service Flow ID (SFID) to it. The SFID serves as the principal identifier in the SS and BS for the Service Flow. A Service Flow which exists has at least an SFID, and an associated Direction.

The **Authorization Module** is a logical function within the BS that approves or denies every change to QoS Parameters and Classifiers associated with a Service Flow. As such it defines an "envelope" that limits the possible values of the AdmittedQoSParameterSet and ActiveQoSParameterSet.

The relationship between the QoS Parameter Sets is as shown in Figure 14 and Figure 78. The ActiveQoSParameterSet is always a subset[10] of the AdmittedQoSParameterSet which is always a subset of the authorized "envelope." In the dynamic authorization model, this envelope is determined by the Authorization Module

[9] The ProvisionedQoSParamSet is null when a flow is created dynamically.

[10] To say that QoS Parameter Set A is a subset of QoS Parameter Set B the following shall be true for all QoS Parameters in A and B:if (a smaller QoS parameter value indicates less resources, e.g. Maximum Traffic Rate)

A is a subset of B if the parameter in A less than or equal to the same parameter in B

if (a larger QoS parameter value indicates less resources, e.g. Tolerated Grant Jitter)

A is a subset of B if the parameter in A is greater than or equal to the same parameter in B

if (the QoS parameter specifies a periodic interval, e.g. Nominal Grant Interval),

A is a subset of B if the parameter in A is an integer multiple of the same parameter in B

if (the QoS parameter is not quantitative, e.g. Service Flow Scheduling Type)

A is a subset of B if the parameter in A is equal to the same parameter in B (labeled as the AuthorizedQoSParameterSet). In the provisioned authorization model, this envelope is determined by the ProvisionedQoSParameterSet.

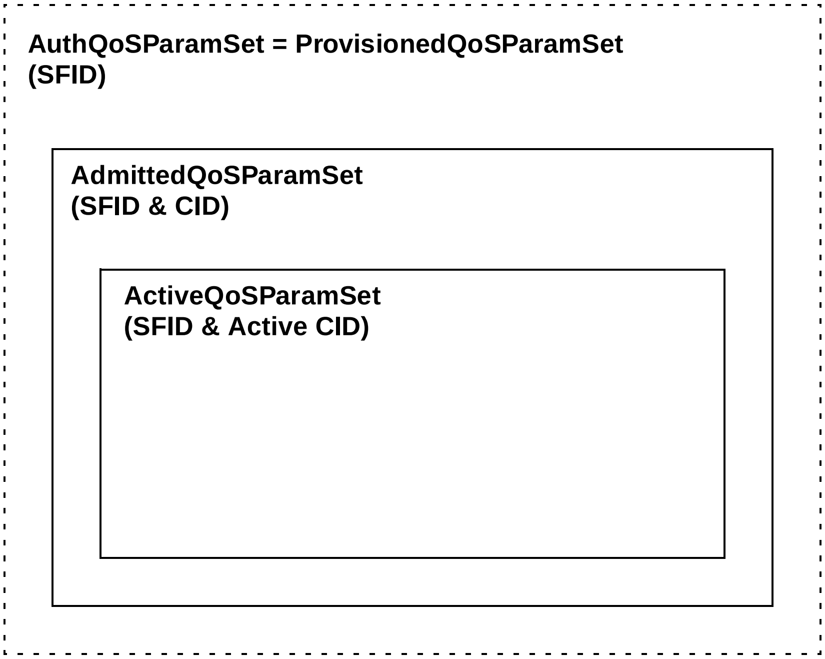


Figure 77—Provisioned Authorization Model “Envelopes”

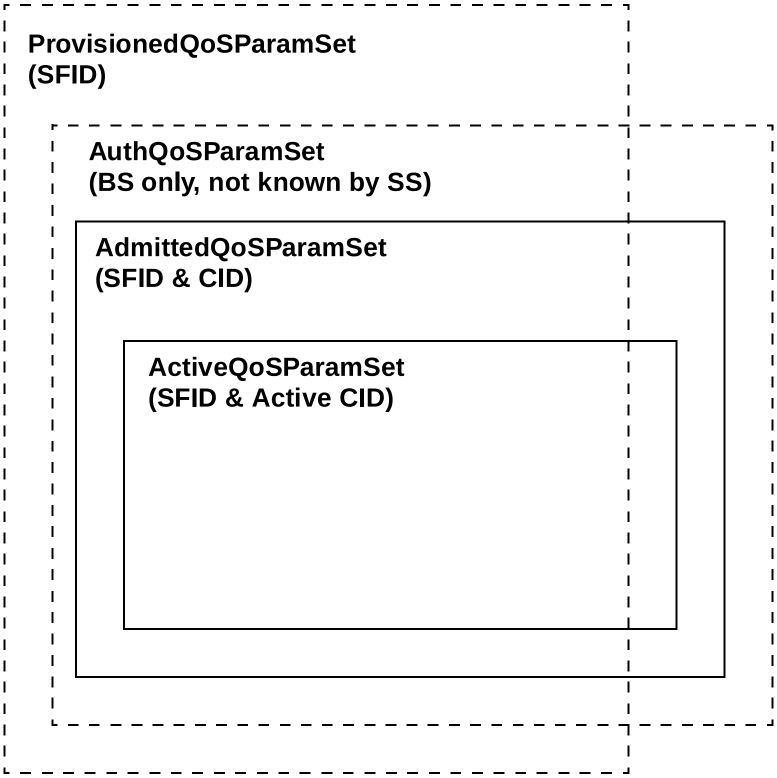


Figure 78—Dynamic Authorization Model “Envelopes”

It is useful to think of three types of Service Flows:

Provisioned: this type of Service Flow is known via provisioning through the configuration file, its AdmittedQoSParamSet and ActiveQoSParamSet are both null.

Admitted: this type of Service Flow has resources reserved by the BS for its AdmittedQoSParamSet, but these parameters are not active (its ActiveQoSParamSet is null). **Admitted Service Flows** may have been provisioned or may have been signalled by some other mechanism.

Active: this type of Service Flow has resources committed by the BS for its QoS Parameter Set, (e.g. is actively sending MAPs containing unsolicited grants for a UGS-based service flow). Its ActiveQoSParamSet is non-null.

2.13.3 Object Model

The major objects of the architecture are represented by named rectangles in Figure 79. The Service Flow is the central concept of the MAC protocol. It is uniquely identified by a 32-bit Service Flow ID (SFID) assigned by the BS. Service Flows may be in either the upstream or downstream direction. Admitted Service Flows are mapped a 16-bit Connection ID (CID).

Outgoing user data is submitted to the MSAP by an convergence sub-layer process for transmission on the MAC interface. The information delivered to the MSAP includes the Connection Identifier identfying the connection across which the information is delivered. The Service Flow for the connection is mapped via the Connection ID (CID).

The Service Class is an optional object that may be implemented at the BS. It is referenced by an ASCII name which is intended for provisioning purposes. A Service Class is defined in the BS to have a particular QoS Parameter Set. The QoS Parameter Sets of a Service Flow may contain a reference to the Service Class Name as a "macro" that selects all of the QoS parameters of the Service Class. The Service Flow QoS Parameter Sets may augment and even override the QoS parameter settings of the Service Class, subject to authorization by the BS.

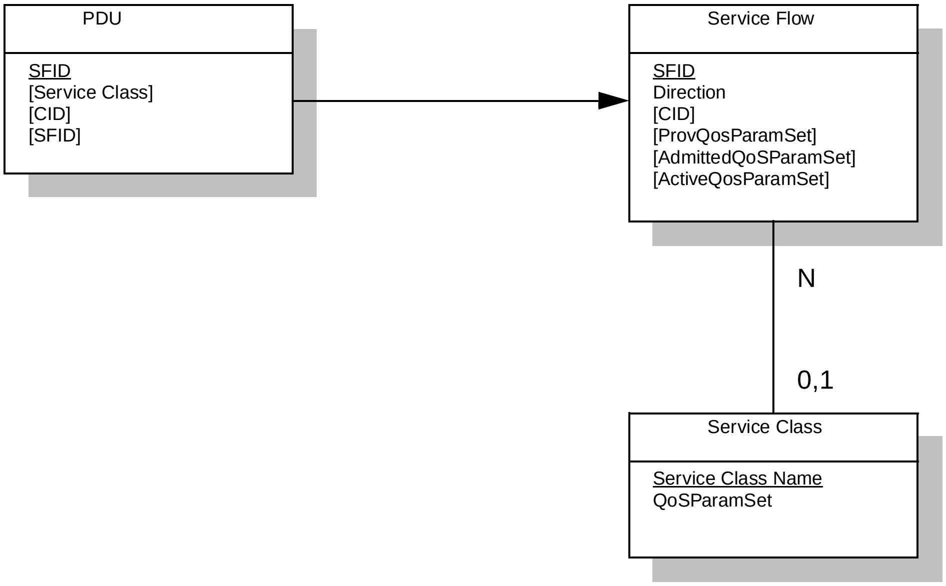


Figure 79—Theory of Operation Object Model

2.13.4 Service Classes

The Service Class serves the following purposes:

It allows operators, who so wish, to move the burden of configuring service flows from the provisioning server to the BS. Operators provision the SSs with the Service Class Name; the implementation of the name is configured at the BS. This allows operators to modify the implementation of a given service to local circumstances without changing SS provisioning. For example, some scheduling parameters may need to be tweaked differently for two different BSs to provide the same service. As another example, service profiles could be changed by time of day.

It allows BS vendors to provide class-based-queuing if they choose, where service flows compete within their class and classes compete with each other for bandwidth.

It allows higher-layer protocols to create a Service Flow by its Service Class Name. For example, telephony signaling may direct the SS to instantiate any available Provisioned Service Flow of class "G711".

Note: The Service Class is optional: the flow scheduling specification may always be provided in full; a service flow may belong to no service class whatsoever. BS implementations may treat such "unclassed" flows differently from "classed" flows with equivalent parameters.

Any Service Flow may have its QoS Parameter Set specified in any of three ways:

By explicitly including all traffic parameters.
By indirectly referring to a set of traffic parameters by specifying a Service Class Name.
By specifying a Service Class Name along with modifying parameters.

The Service Class Name is “expanded” to its defined set of parameters at the time the BS successfully admits the Service Flow. The Service Class expansion can be contained in the following BS-originated Messages: Registration Response, DSA-REQ, DSC-REQ, DSA-RSP and DSC-RSP. In all of these cases, the BS shall include a Service Flow Encoding that includes the Service Class Name and the QoS Parameter Set of the Service Class. If a SS-initiated request contained any supplemental or overriding Service Flow parameters, a successful response shall also include these parameters.

When a Service Class name is given in an admission or activation request, it is possible that the returned QoS Parameter Set may change from activation to activation. This can happen because of administrative changes to the Service Class’ QoS Parameter Set at the BS. If the definition of a Service Class Name is changed at the BS (e.g. its associated QoS Parameter Set is modified), it has no effect on the QoS Parameters of existing Service Flows associated with that Service Class. A BS may initiate DSC transactions to existing Service Flows which reference the Service Class Name to affect the changed Service Class definition.

When a SS uses the Service Class Name to specify the Admitted QoS Parameter Set, the expanded set of TLV encodings of the Service Flow will be returned to the SS in the response Message (REG-RSP, DSA-RSP, or DSC-RSP). Use of the Service Class Name later in the activation request may fail if the definition of the Service Class Name has changed and the new required resources are not available. Thus, the SS SHOULD explicitly request the expanded set of TLVs from the response Message in its later activation request.

2.13.5 Authorization

Every change to the Service Flow QoS Parameters shall be approved by an authorization module. This includes every REG-REQ or DSA-REQ Message to create a new Service Flow, and every DSC-REQ Message to change a QoS Parameter Set of an existing Service Flow. Such changes include requesting an admission control decision (e.g. setting the AdmittedQoSParamSet) and requesting activation of a Service Flow (e.g. setting the ActiveQoSParameterSet). Reduction requests regarding the resources to be admitted or activated are also checked by the authorization module.

In the static authorization model, the authorization module receives all registration Messages, and stores the provisioned status of all “deferred” Service Flows. Admission and activation requests for these provisioned service flows will be permitted, as long as the Admitted QoS Parameter Set is a subset of the Provisioned QoS Parameter Set, and the Active QoS Parameter Set is a subset of the Admitted QoS Parameter Set. Requests to change the Provisioned QoS Parameter Set will be refused, as will requests to create new dynamic Service Flows. This defines a static system where all possible services are defined in the initial configuration of each SS.

In the dynamic authorization model, the authorization module not only receives all registration Messages, but also communicates through a separate interface to an independent policy server. This policy server may provide to the authorization module advance notice of upcoming admission and activation requests, and specifies the proper authorization action to be taken on those requests. Admission and activation requests from a SS are then checked by the Authorization Module to ensure that the ActiveQoSParameterSet being requested is a subset of the set provided by the policy server. Admission and activation requests from a SS that are signalled in advance by the external policy server are permitted. Admission and activation requests from a SS that are not pre-signalled by the external policy server may result in a real-time query to the policy server, or may be refused.

During registration, the SS shall send to the BS the authenticated set of TLVs derived from its configuration file which defines the Provisioned QoS Parameter Set. Upon receipt and verification at the BS, these are handed to the Authorization Module within the BS. The BS shall be capable of caching the Provisioned QoS Parameter Set, and shall be able to use this information to authorize dynamic flows which are a subset of the Provisioned QoS Parameter Set. The BS SHOULD implement mechanisms for overriding this automated approval process (such as described in the dynamic authorization model). For example:

Deny all requests whether or not they have been pre-provisioned
Define an internal table with a richer policy mechanism but seeded by the configuration file information
Refer all requests to an external policy server

2.13.6 Types of Service Flows

It is useful to think about three basic types of Service Flows. This section describes these three types of Service Flows in more detail. However, it is important to note that there are more than just these three basic types. (Refer to 2.3.5.5.1)

2.13.6.1 Provisioned Service Flows

A Service Flow may be Provisioned but not immediately activated (sometimes called “deferred”). That is, the description of any such service flow in the TFTP configuration file contains an attribute which provisions but defers activation and admission (refer to 2.3.5.5.1). During Registration, the BS assigns a Service Flow ID for such a service flow but does not reserve resources. The BS may also require an exchange with a policy module prior to admission.

As a result of external action beyond the scope of this specification, the SS may choose to activate a Provisioned Service Flow by passing the Service Flow ID and the associated QoS Parameter Sets. If authorized and resources are available, the BS shall respond by mapping the Service Flow to a CID. The BS may deactivate the Service Flow, but SHOULD not delete the Service Flow during the SS registration epoch.

As a result of external action beyond the scope of this specification, the BS may choose to activate a Service Flow by passing the Service Flow ID as well as the CID and the associated QoS Parameter Sets. The BS may deactivate the Service Flow, but SHOULD not delete the Service Flow during the SS registration epoch. Such a Provisioned Service Flow may be activated and deactivated many times (through DSC exchanges). In all cases, the original Service Flow ID shall be used when reactivating the service flow.

2.13.6.2 Admitted Service Flows

This protocol supports a two-phase activation model which is often utilized in telephony applications. In the two-phase activation model, the resources for a “call” are first “admitted,” and then once the end-to-end negotiation is completed (e.g. called party’s gateway generates an “off-hook” event) the resources are “activated.” Such a two-phase model serves the purposes a) of conserving network resources until a complete end-to-end connection has been established, b) performing policy checks and admission control on resources as quickly as possible, and, in particular, before informing the far end of a connection request, and c) preventing several potential theft-of-service scenarios.

For example, if an upper layer service were using unsolicited grant service, and the addition of upper-layer flows could be adequately provided by increasing the Grants Per Interval QoS parameter, then the following might be used. When the first upper-layer flow is pending, the SS issues a DSA-Request with the Admit Grants Per Interval parameter equal one, and the Activate Grants Per Interval parameter equal zero. Later when the upper-layer flow becomes active, it issues a DSC-Request with the instance of the Activate Grants-per-Interval parameter equal to one. Admission control was performed at the time of the reservation, so the later DSC-Request, having the Activate parameters within the range of the previous reservation, is guaranteed to succeed. Subsequent upper-layer flows would be handled in the same way. If there were three upper-layer flows establishing connections, with one flow already active, the Service Flow would have Admit(ted) Grants-per-Interval equal four, and Active Grants-per-Interval equal one.

An activation request of a Service Flow where the new ActiveQoSParamSet is a subset of the AdmittedQoSParamSet are being added shall be allowed (except in the case of catastrophic failure). An admission request where the AdmittedQoSParamSet is a subset of the previous AdmittedQoSParamSet, so long as the ActiveQoSParamSet remains a subset of the AdmittedQoSParameterSet, shall succeed.

A Service Flow that has resources assigned to its AdmittedQoSParamSet, but whose resources are not yet completely activated, is in a transient state. A timeout value shall be enforced by the BS that requires Service Flow activation within this period. (Refer to 2.3.5.5.10) If Service Flow activation is not completed within this interval, the assigned resources in excess of the active QoS parameters shall be released by the BS.

It is possible in some applications that a long-term reservation of resources is necessary or desirable. For example, placing a telephone call on hold should allow any resources in use for the call to be temporarily allocated to other purposes, but these resources must be available for resumption of the call later. The AdmittedQoSParamSet is maintained as “soft state” in the BS; this state shall be refreshed periodically for it to be maintained without the above timeout releasing the non-activated resources. This refresh may be signalled with a periodic DSC-REQ Message with identical QoS Parameter Sets, or may be signalled by some internal mechanism within the BS outside of the scope of this specification (e.g. by the BS monitoring RSVP refresh Messages).

2.13.6.3 Active Service Flows

A Service Flow that has a non-NULL set of ActiveQoSParameters is said to be an Active Service Flow. It is requesting[11] and being granted bandwidth for transport of data packets. An admitted Service Flow may be made active by providing an ActiveQoSParameterSet, signaling the resources actually desired at the current time. This completes the second stage of the two-phase activation model. (Refer to 2.13.6.2)

A Service Flow may be Provisioned and immediately activated. This is the case for the Service Flows associated with the Basic CIDs. It is also typical of Service Flows for monthly subscription services, etc. These Service Flows are established at registration time and shall be authorized by the BS MIC. These Service Flows may also be authorized by the BS authorization module.

Alternatively, a Service Flow may be created dynamically and immediately activated. In this case, two-phase activation is skipped and the Service Flow is available for immediate use upon authorization.

2.13.7 General Operation

2.13.7.1 Static Operation

Static configuration of Service Flows uses the Registration process. A provisioning server provides the SS with configuration information. The SS passes this information to the BS in a Registration Request. The BS

[11] According to its Request/Transmission Policy (refer to2.3.5.6.3)

adds information and replies with a Registration Response. The SS sends a Registration Acknowledge to complete registration.

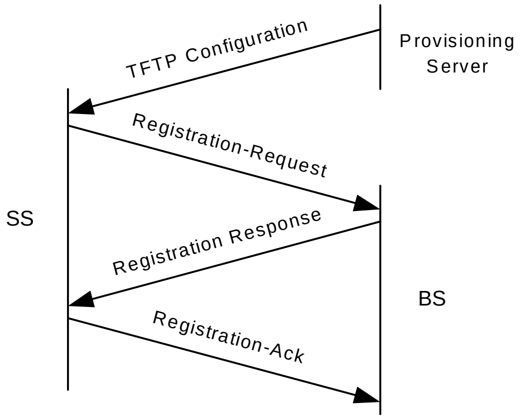


Figure 80—Registration Message Flow

A TFTP configuration file consists of one or more instances of Service Flow Encodings.

Table 27—TFTP File Contents

Items	Service Flow Reference	Service Flow ID
Service Flow Encodings Immediate activation requested, upstream	1..m	None Yet
Service Flow Encodings Provisioned for later activation requested, upstream	(m+1)..n	None Yet
Service Flow Encodings Immediate activation requested, downstream	(n+1)..p	None Yet
Service Flow Encodings Provisioned for later activation requested, downstream	(p+1)..q	None Yet

Service Flow Encodings contain either a full definition of service attributes (omitting defaultable items if desired) or a service class name. A service class name is an ASCII string which is known at the BS and which indirectly specifies a set of QoS Parameters. (Refer to Section 5.3.6.1.3 and C.2.2.3.4)

Note: At the time of the TFTP configuration file, Service Flow References exist as defined by the provisioning server. Service Flow Identifiers do not yet exist because the BS is unaware of these service flow definitions.

The Registration Request packet contains Downstream Classifiers (if to be immediately activated) and all Inactive Service Flows. The configuration file, and thus, the Registration Request, generally does not contain a Downstream Classifier if the corresponding Service Flow is requested with deferred activation. This allows for late binding of the Classifier when the Flow is activated.

Table 28—Registration Request Contents

Items	Service Flow	Service Flow ID
Service Flow Encodings Immediate activation requested, upstream May specify explicit attributes or service class name	1..m	None Yet
Service Flow Encodings Provisioned for later activation requested, upstream Explicit attributes or service class name	(m+1)..n	None Yet
Service Flow Encodings Immediate activation requested, downstream Explicit attributes or service name	(n+1)..p	None Yet
Service Flow Encodings Provisioned for later activation requested, downstream Explicit attributes or service name	(p+1)..q	None Yet

The Registration Response sets the QoS Parameter Sets according to the Quality of Service Parameter Set Type in the Registration Request.

The Registration Response preserves the Service Flow Reference attribute, so that the Service Flow Reference can be associated with SFID and/orCID.

Table 29—Registration Response Contents

Items	Service Flow Reference	Service Flow Identifier	Connection Identifier
Active Upstream Service Flows Explicit attributes	1..m	SFID	CID
Provisioned Upstream Service Flows Explicit attributes	(m+1)..n	SFID	Not Yet
Active Downstream Service Flows Explicit attributes	(n+1)..p	SFID	N/A
Provisioned Downstream Service Flows Explicit attributes	(p+1)..q	SFID	N/A

The SFID is chosen by the BS to identify a downstream or upstream service Flow that has been authorized but not activated. A DSC-Request from a SS to admit or activate a Provisioned Service Flow contains its SFID.

2.13.7.2 Dynamic Service Flow Creation — SS Initiated

Service Flows may be created by the Dynamic Service Addition process, as well as through the Registration process outlined above. The Dynamic Service Addition may be initiated by either the SS or the BS, and may create one upstream and/or one downstream dynamic Service Flow(s). A three-way handshake is used to create Service Flows. The SS-initiated protocol is illustrated in Figure 81 and described in detail in Section 2.13.8.3.1.

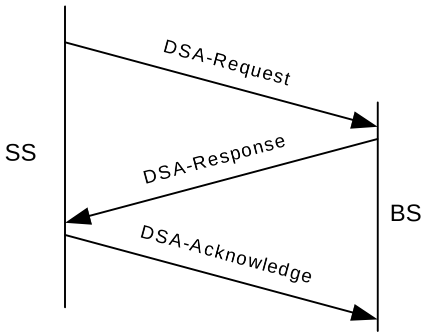


Figure 81—Dynamic Service Addition Message Flow — SS Initiated

A DSA-Request from a SS contains Service Flow Reference(s), and QoS Parameter set(s) (marked either for admission-only or for admission and activation).

2.13.7.2.1 Dynamic Service Flow Creation — BS Initiated

A DSA-Request from a BS contains Service Flow Identifier(s) for one upstream and/or one downstream Service Flow, possibly a CID, and set(s) of active or admitted QoS Parameters. The protocol is as illustrated in Figure 82 and is described in detail in Section 2.13.8.3.

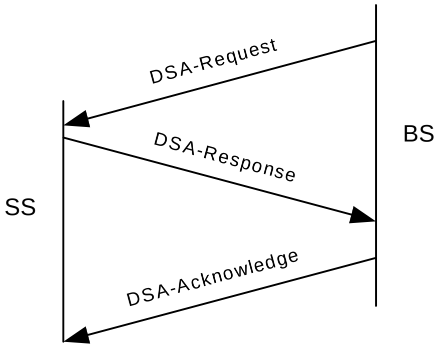


Figure 82—Dynamic Service Addition Message Flow — BS Initiated

2.13.7.2.2 Dynamic Service Flow Modification and Deletion

In addition to the methods presented above for creating service flows, protocols are defined for modifying and deleting service flows. Refer to Section 2.13.8.4 and Section 2.13.8.5.

Both provisioned and dynamically created Service flows are modified with the DSC message, which can change the Admitted and Active QoS Parameter sets of the flow.

A successful DSC transaction changes a Service Flow’s QoS parameters by replacing both the Admitted and Active QoS parameter sets. If the message contains only the Admitted set, the Active set is set to null and the flow is deactivated. If the message contains neither set (‘000’ value used for Quality of Service Parameter

Set type, see Section 2.3.5.5.1) then both sets are set to null and the flow is de-admitted. When the message contains both QoS parameter sets, the Admitted set is checked first and, if admission control succeeds, the Active set in the message is checked against the Admitted set in the message to ensure that it is a subset. If all checks are successful, the QoS parameter sets in the message become the new Admitted and Active QoS parameter sets for the Service Flow. If either of the checks fails, the DSC transaction fails and the Service Flow QoS parameter sets are unchanged.

2.13.8 Dynamic Service

2.13.8.1 Connection Establishment

Service Flows may be created, changed or deleted. This is accomplished through a series of MAC management Messages referred to as Dynamic Service Addition (DSA), Dynamic Service Change (DSC) and Dynamic Service Deletion (DSD). The DSA Messages create a new Service Flow. The DSC Messages change an existing Service Flow. The DSD Messages delete an existing Service Flow. This is illustrated in Figure 83.

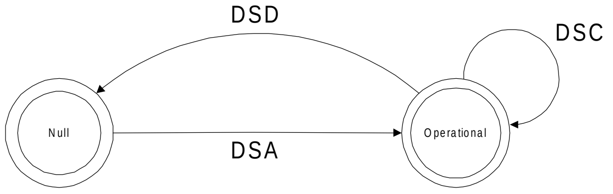


Figure 83—Dynamic Service Flow Overview

The Null state implies that no Service Flow exists that matches the SFID and/or TransactionID in a Message. Once the Service Flow exists, it is operational and has an assigned SFID. In steady state operation, a Service Flow resides in a Nominal state. When Dynamic Service messaging is occurring, the Service Flow may transition through other states, but remains operational. Since multiple Service Flows may exist, there may be multiple state machines active, one for every Service Flow. Dynamic Service Messages only affect those state machines that match the SFID and/or Transaction ID. If privacy is enabled, both the SS and BS shall verify the HMAC digest on all dynamic service Messages before processing them, and discard any Messages that fail.

Service Flows created at registration time effectively enter the SF_operational state without a DSA transaction.

TransactionIDs are unique per transaction and are selected by the initiating device (SS or BS). To help prevent ambiguity and provide simple checking, the TransactionID number space is split between the SS and BS. The SS shall select its TransactionIDs from the first half of the number space (0x0000 to 0x7FFF). The BS shall select its TransactionIDs from the second half of the number space (0x8000 to 0xFFFF).

Each dynamic service Message sequence is a unique transaction with an associated unique transaction identifier. The DSA/DSC transactions consist of a request/response/acknowledge sequence. The DSD transactions consist of a request/response sequence. The response Messages will return a confirmation code of okay unless some exception condition was detected. The acknowledge Messages will return the confirmation code in the response unless a new exception condition arises. A more detailed state diagram, including transition states, is shown below. The detailed actions for each transaction will be given in the following sections.

2.13.8.2 Dynamic Service Flow State Transitions

The Dynamic Service Flow State Transition Diagram is the top-level state diagram and controls the general Service Flow state. As needed, it creates transactions, each represented by a Transaction state transition diagram, to provide the DSA, DSC, and DSD signaling. Each Transaction state transition diagram only communicates with the parent Dynamic Service Flow State Transition Diagram. The top-level state transition diagram filters Dynamic Service Messages and passes them to the appropriate transaction based on Service Flow Identifier (SFID), Service Flow Reference number, and TransactionID.

There are six different types of transactions: locally initiated or remotely initiated for each of the DSA, DSC and DSD Messages. Most transactions have three basic states: pending, holding and deleting. The pending state is typically entered after creation and is where the transaction is waiting for a reply. The holding state is typically entered once the reply is received. The purpose of this state is to allow for retransmissions in case of a lost Message, even though the local entity has perceived that the transaction has completed. The deleting state is only entered if the Service Flow is being deleted while a transaction is being processed.

The flow diagrams provide a detailed representation of each of the states in the Transaction state transition diagrams. All valid transitions are shown. Any inputs not shown should be handled as a severe error condition.

With one exception, these state diagrams apply equally to the BS and SS. In the Dynamic Service Flow Changing-Local state, there is a subtle difference in the SS and BS behaviors. This is called out in the state transition and detailed flow diagrams.

[Note: The ‘Num Xacts’ variable in the Dynamic Service Flow State Transition Diagram is incremented every time the top-level state diagram creates a transaction and is decremented every time a transaction terminates. A Dynamic Service Flow shall not return to the Null state until it’s deleted and all transactions have terminated.]

The inputs for the state diagrams are identified below.

Dynamic Service Flow State Transition Diagram inputs from unspecified local, higher-level entities:

Add
Change
Delete

Dynamic Service Flow State Transition Diagram inputs from DSx Transaction State Transition diagrams:

DSA Succeeded
DSA Failed
DSA ACK Lost
DSA Erred
DSA Ended

DSC Succeeded
DSC Failed
DSC ACK Lost
DSC Erred
DSC Ended

DSD Succeeded
DSD Erred
DSD Ended

DSx Transaction State Transition diagram inputs from the Dynamic Service Flow State Transition Diagram:

SF Add
SF Change
SF Delete

SF Abort Add
SF Change-Remote
SF Delete-Local
SF Delete-Remote

SF DSA-ACK Lost
SF-DSC-REQ Lost
SF-DSC-ACK Lost
SF DSC-REQ Lost

SF Changed
SF Deleted

The creation of DSx Transactions by the Dynamic Service Flow State Transition Diagram is indicated by the notation

DSx-[Local | Remote] (initial_input)

where initial_input may be SF Add, DSA-REQ, SF Change, DSC-REQ, SF Delete, or DSD-REQ depending on the transaction type and initiator.

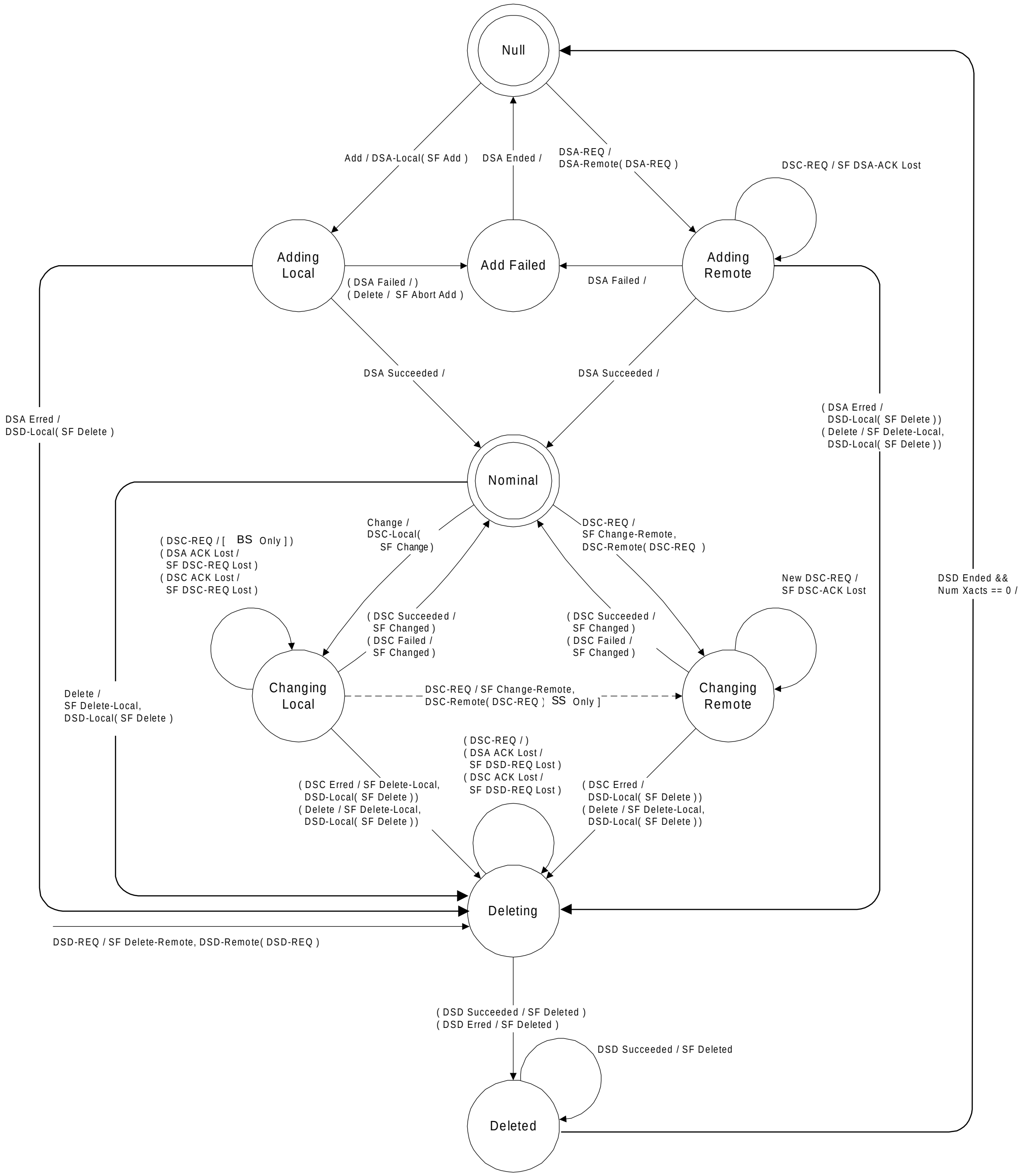


Figure 84—Dynamic Service Flow State Transition Diagram

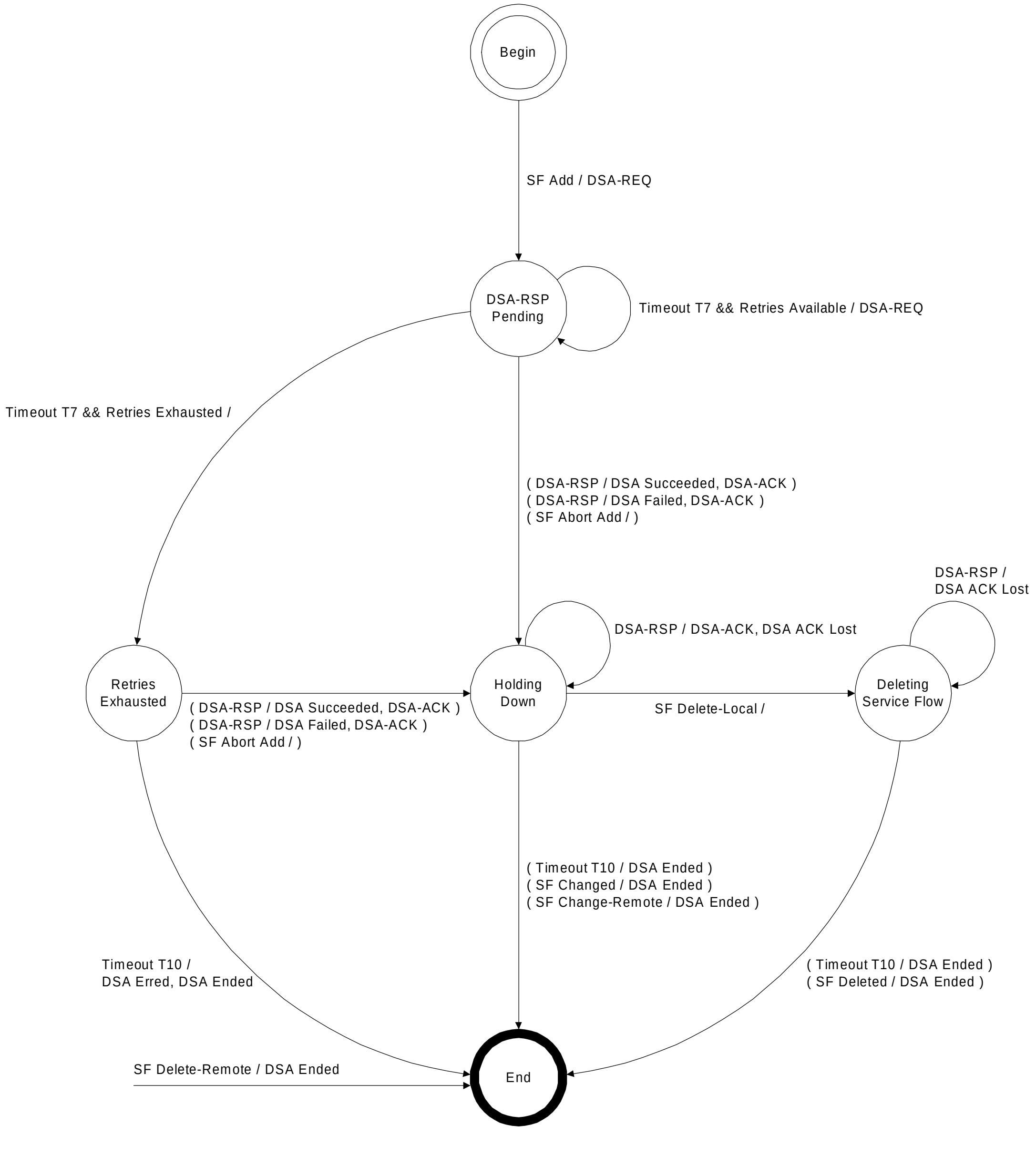

Begin
SF Add / DSA-REQ
DSA-RSP Pending
Timeout T7 && Retries Available / DSA-REQ
Timeout T7 && Retries Exhausted /
(DSA-RSP / DSA Succeeded, DSA-ACK)
(DSA-RSP / DSA Failed, DSA-ACK)
(SF Abort Add /)
DSA-RSP /
DSA ACK Lost
DSA-RSP / DSA-ACK, DSA ACK Lost
Retries Exhausted
Holding Down
Deleting Service Flow
(DSA-RSP / DSA Succeeded, DSA-ACK)
(DSA-RSP / DSA Failed, DSA-ACK)
(SF Abort Add /)
SF Delete-Local /
(Timeout T10 / DSA Ended)
(SF Changed / DSA Ended)
(SF Change-Remote / DSA Ended)
Timeout T10 /
DSA Erred, DSA Ended
(Timeout T10 / DSA Ended)
(SF Deleted / DSA Ended)
SF Delete-Remote / DSA Ended
End

Figure 85—DSA - Locally Initiated Transaction State Transition Diagram

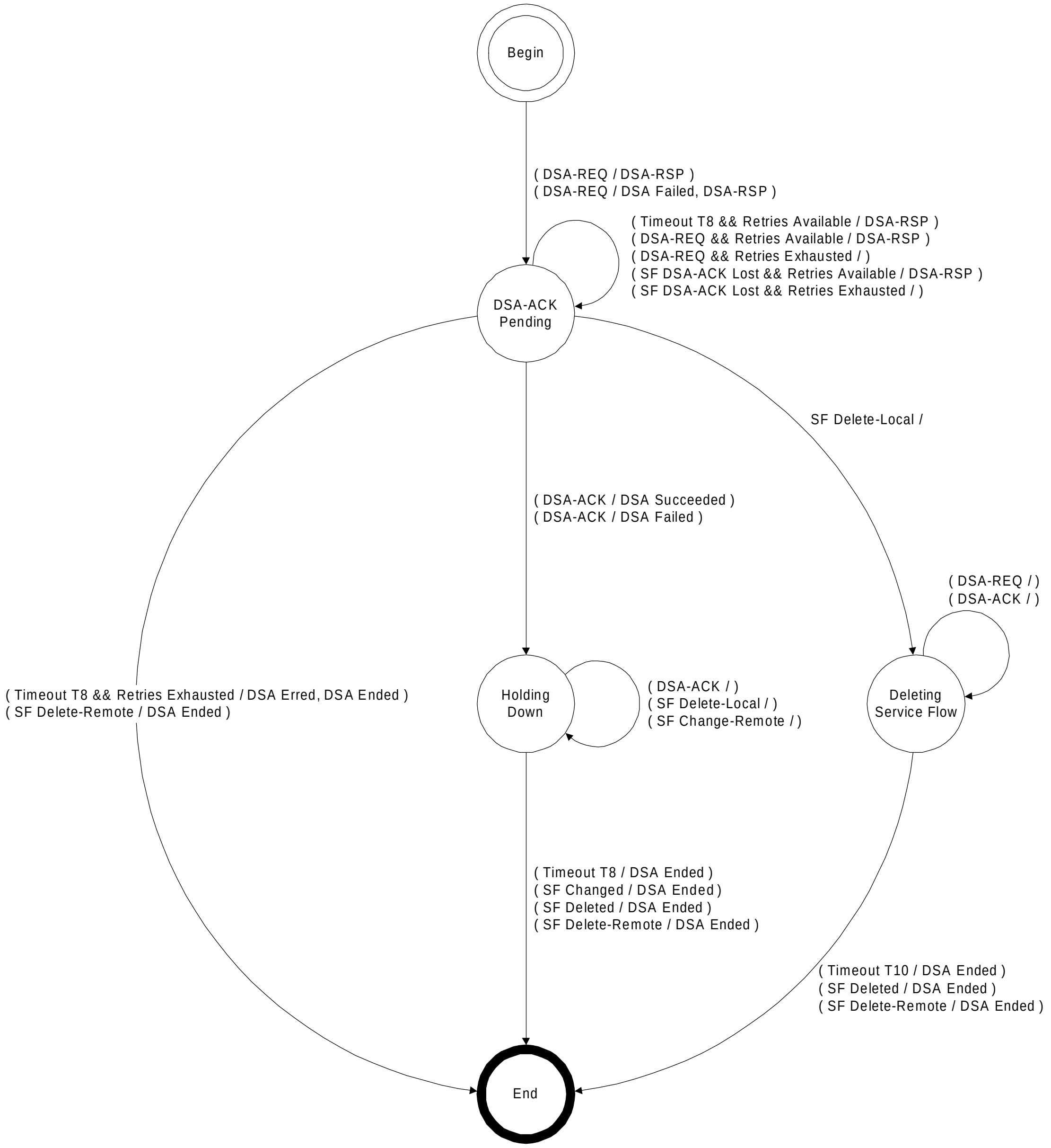

Begin
(DSA-REQ / DSA-RSP)
(DSA-REQ / DSA Failed, DSA-RSP)
(Timeout T8 && Retries Available / DSA-RSP)
(DSA-REQ && Retries Available / DSA-RSP)
(DSA-REQ && Retries Exhausted /)
(SF DSA-ACK Lost && Retries Available / DSA-RSP)
(SF DSA-ACK Lost && Retries Exhausted /)
DSA-ACK Pending
SF Delete-Local /
(DSA-ACK / DSA Succeeded)
(DSA-ACK / DSA Failed)
(DSA-REQ /)
(DSA-ACK /)
(Timeout T8 && Retries Exhausted / DSA Erred, DSA Ended)
(SF Delete-Remote / DSA Ended)
Holding Down
(DSA-ACK /)
(SF Delete-Local /)
(SF Change-Remote /)
Deleting Service Flow
(Timeout T8 / DSA Ended)
(SF Changed / DSA Ended)
(SF Deleted / DSA Ended)
(SF Delete-Remote / DSA Ended)
(Timeout T10 / DSA Ended)
(SF Deleted / DSA Ended)
(SF Delete-Remote / DSA Ended)
End

Figure 86—DSA - Remotely Initiated Transaction State Transition Diagram

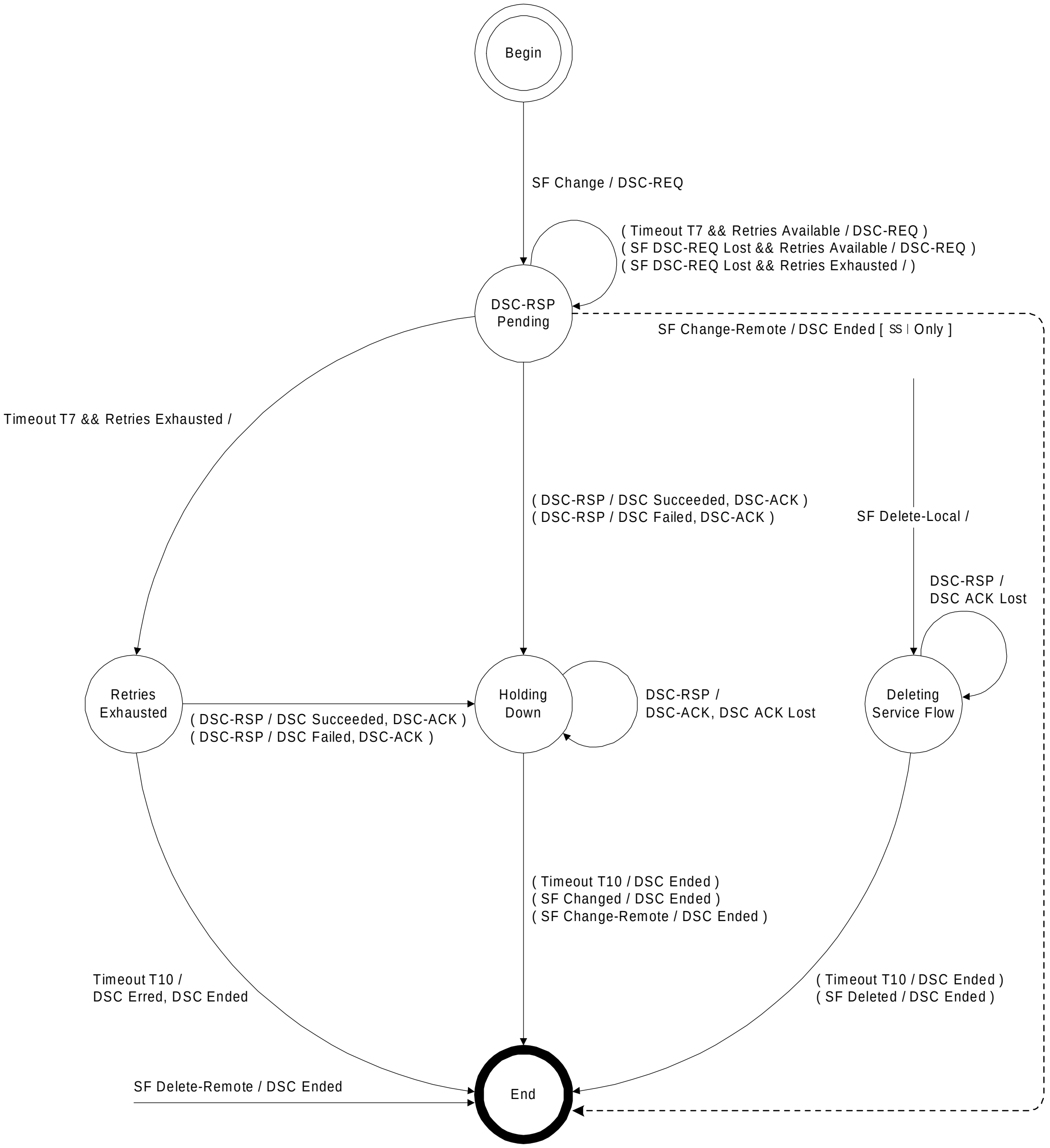

Begin
SF Change / DSC-REQ
(Timeout T7 && Retries Available / DSC-REQ)
(SF DSC-REQ Lost && Retries Available / DSC-REQ)
(SF DSC-REQ Lost && Retries Exhausted /)
DSC-RSP Pending
SF Change-Remote / DSC Ended [SS | Only]
Timeout T7 && Retries Exhausted /
(DSC-RSP / DSC Succeeded, DSC-ACK)
(DSC-RSP / DSC Failed, DSC-ACK)
SF Delete-Local /
DSC-RSP /
DSC ACK Lost
Retries Exhausted
(DSC-RSP / DSC Succeeded, DSC-ACK)
(DSC-RSP / DSC Failed, DSC-ACK)
Holding Down
DSC-RSP /
DSC-ACK, DSC ACK Lost
Deleting Service Flow
(Timeout T10 / DSC Ended)
(SF Changed / DSC Ended)
(SF Change-Remote / DSC Ended)
Timeout T10 /
DSC Erred, DSC Ended
(Timeout T10 / DSC Ended)
(SF Deleted / DSC Ended)
SF Delete-Remote / DSC Ended
End

Figure 87—DSC - Locally Initiated Transaction State Transition Diagram

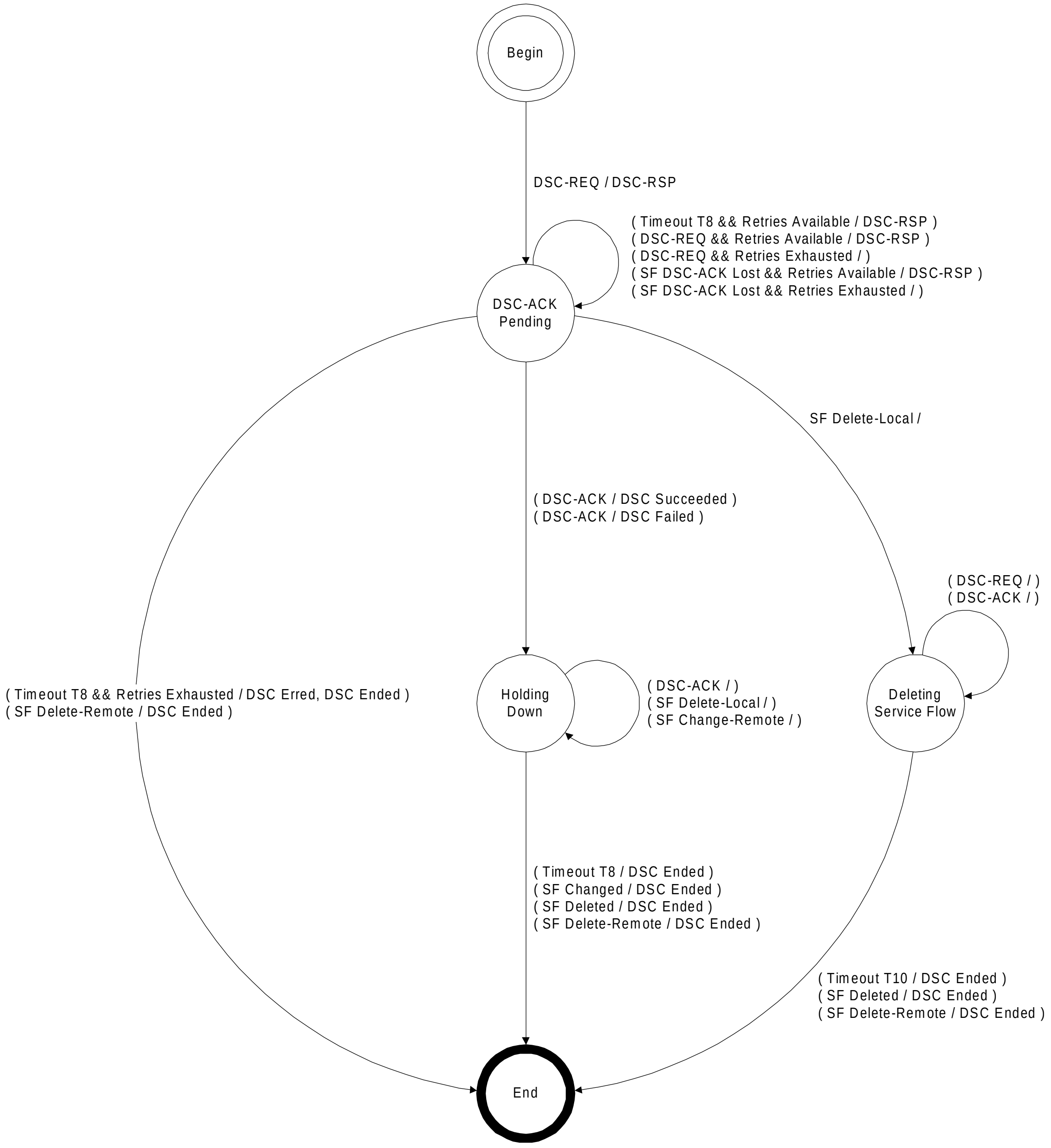

Begin
DSC-REQ / DSC-RSP
(Timeout T8 && Retries Available / DSC-RSP)
(DSC-REQ && Retries Available / DSC-RSP)
(DSC-REQ && Retries Exhausted /)
(SF DSC-ACK Lost && Retries Available / DSC-RSP)
(SF DSC-ACK Lost && Retries Exhausted /)
DSC-ACK Pending
SF Delete-Local /
(DSC-ACK / DSC Succeeded)
(DSC-ACK / DSC Failed)
(DSC-REQ /)
(DSC-ACK /)
(Timeout T8 && Retries Exhausted / DSC Erred, DSC Ended)
(SF Delete-Remote / DSC Ended)
Holding Down
(DSC-ACK /)
(SF Delete-Local /)
(SF Change-Remote /)
Deleting Service Flow
(Timeout T8 / DSC Ended)
(SF Changed / DSC Ended)
(SF Deleted / DSC Ended)
(SF Delete-Remote / DSC Ended)
(Timeout T10 / DSC Ended)
(SF Deleted / DSC Ended)
(SF Delete-Remote / DSC Ended)
End

Figure 88—DSC - Remotely Initiated Transaction State Transition Diagram

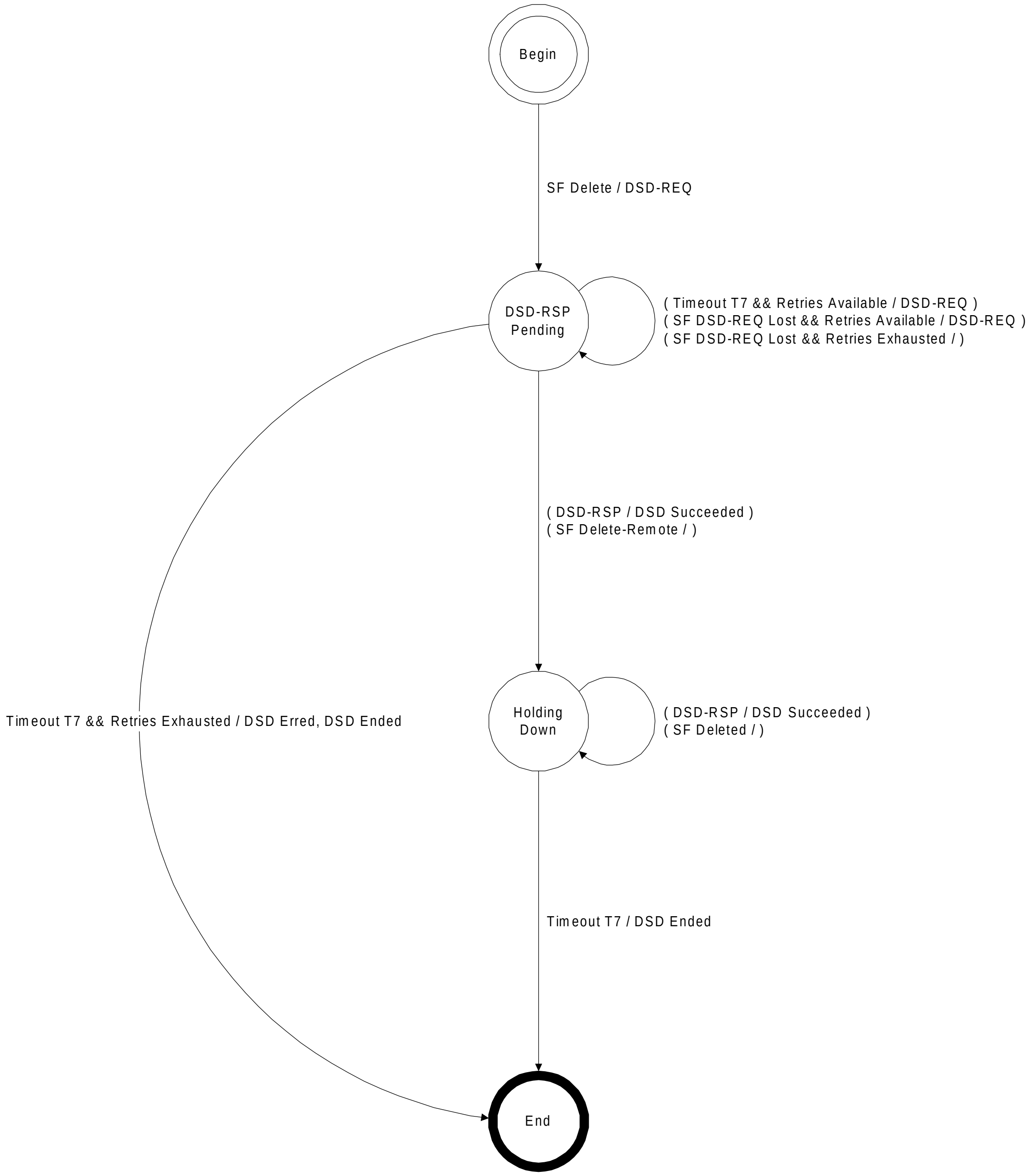

Begin
SF Delete / DSD-REQ
DSD-RSP Pending
(Timeout T7 && Retries Available / DSD-REQ)
(SF DSD-REQ Lost && Retries Available / DSD-REQ)
(SF DSD-REQ Lost && Retries Exhausted /)
(DSD-RSP / DSD Succeeded)
(SF Delete-Remote /)
Timeout T7 && Retries Exhausted / DSD Erred, DSD Ended
Holding Down
(DSD-RSP / DSD Succeeded)
(SF Deleted /)
Timeout T7 / DSD Ended
End

Figure 89—DSD - Locally Initiated Transaction State Transition Diagram

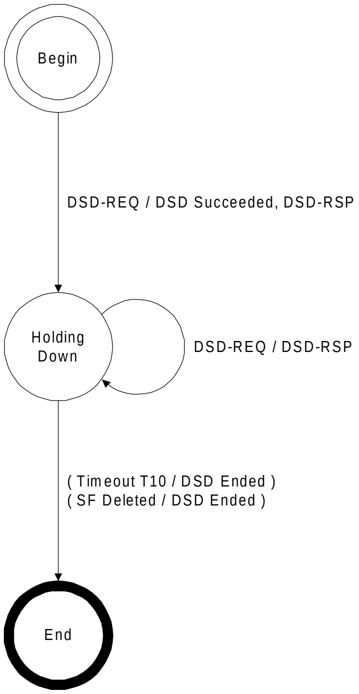

Begin
DSD-REQ / DSD Succeeded, DSD-RSP
Holding Down
DSD-REQ / DSD-RSP
(Timeout T10 / DSD Ended)
(SF Deleted / DSD Ended)
End

Figure 90—Dynamic Deletion (DSD) - Remotely Initiated Transaction State Transition Diagram

2.13.8.3 Dynamic Service Addition

A SS wishing to create an upstream and/or a downstream Service Flow sends a request to the BS using a dynamic service addition request Message (DSA-REQ). The BS checks the SS's authorization for the requested service(s) and whether the QoS requirements can be supported and generates an appropriate response using a dynamic service addition response Message (DSA-RSP). The SS concludes the transaction with an acknowledgment Message (DSA-ACK).

In order to facilitate a common admission response, an upstream and a downstream Service Flow can be included in a single DSA-REQ. Both Service Flows are either accepted or rejected together.

Table 30: Dynamic Service Addition Initiated from SS

SS		BS
New Service Flow(s) needed		
Check if resources are available		
Send DSA-REQ	---DSA-REQ-->	Receive DSA-REQ
		Check if SS authorized for Service(s)[a]
		Check Service Flow(s) QoS can be supported

Table 30: Dynamic Service Addition Initiated from SS

		Create SFID(s)
		If upstream AdmittedQoSParamSet is non-null, map Service Flow to CID
		If upstream ActiveQoSParamSet is non-null, Enable reception of data on new upstream Service Flow
Receive DSA-RSP	<--DSA-RSP---	Send DSA-RSP
If ActiveQoSParamSet is non-null, Enable transmission and/or reception of data on new Service Flow(s)		
Send DSA-ACK	---DSA-ACK-->	Receive DSA-ACK
		If downstream ActiveQoSParamSet is non-null, Enable transmission of data on new downstream Service Flow

[a] Note: authorization can happen prior to the DSA-REQ being received by the BS. The details of BS signalling to anticipate a DSA-REQ are beyond the scope of this specification.

2.13.8.3.1 BS Initiated Dynamic Service Addition

A BS wishing to establish an upstream and/or a downstream dynamic Service Flow(s) with a SS performs the following operations. The BS checks the authorization of the destination SS for the requested class of service and whether the QoS requirements can be supported. If the service can be supported the BS generates new SFID(s) with the required class of service and informs the SS using a dynamic service addition request Message (DSA-REQ). If the SS checks that it can support the service, it responds using a dynamic service addition response Message (DSA-RSP). The transaction completes with the BS sending the acknowledge Message (DSA-ACK).

Dynamic Service Addition State Transition Diagrams

Dynamic Service Addition State Transition Diagrams

Table 31: Dynamic Service Addition Initiated from BS

CPE		BS
		New Service Flow(s) required for CPE
		Check CPE authorized for Service(s)
		Check Service Flow(s) QoS can be supported
		Create SFID(s)
		If upstream AdmittedQoSParamSet is non-null, map Service Flow to CID
		If upstream ActiveQoSParamSet is non-null, Enable reception of data on new upstream Service Flow
Receive DSA-REQ	<--DSA-REQ---	Send DSA-REQ
Confirm CPE can support Service Flow(s)		
Add Downstream SFID (if present)		
Enable reception on any new downstream Service Flow		
Send DSA-RSP	---DSA-RSP-->	Receive DSA-RSP
		Enable transmission & reception of data on new Service Flow(s)
Receive DSA-ACK	<--DSA-ACK---	Send DSA-ACK
Enable transmission on new upstream Service Flow		

2.13.8.3.2 Dynamic Service Addition State Transition Diagrams

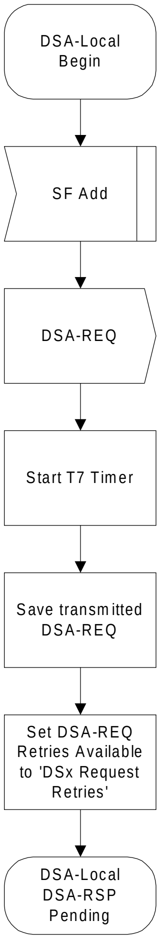

DSA-Local Begin
SF Add
DSA-REQ
Start T7 Timer
Save transmitted DSA-REQ
Set DSA-REQ Retries Available to 'DSx Request Retries'
DSA-Local DSA-RSP Pending

Figure 91—DSA - Locally Initiated Transaction Begin State Flow Diagram

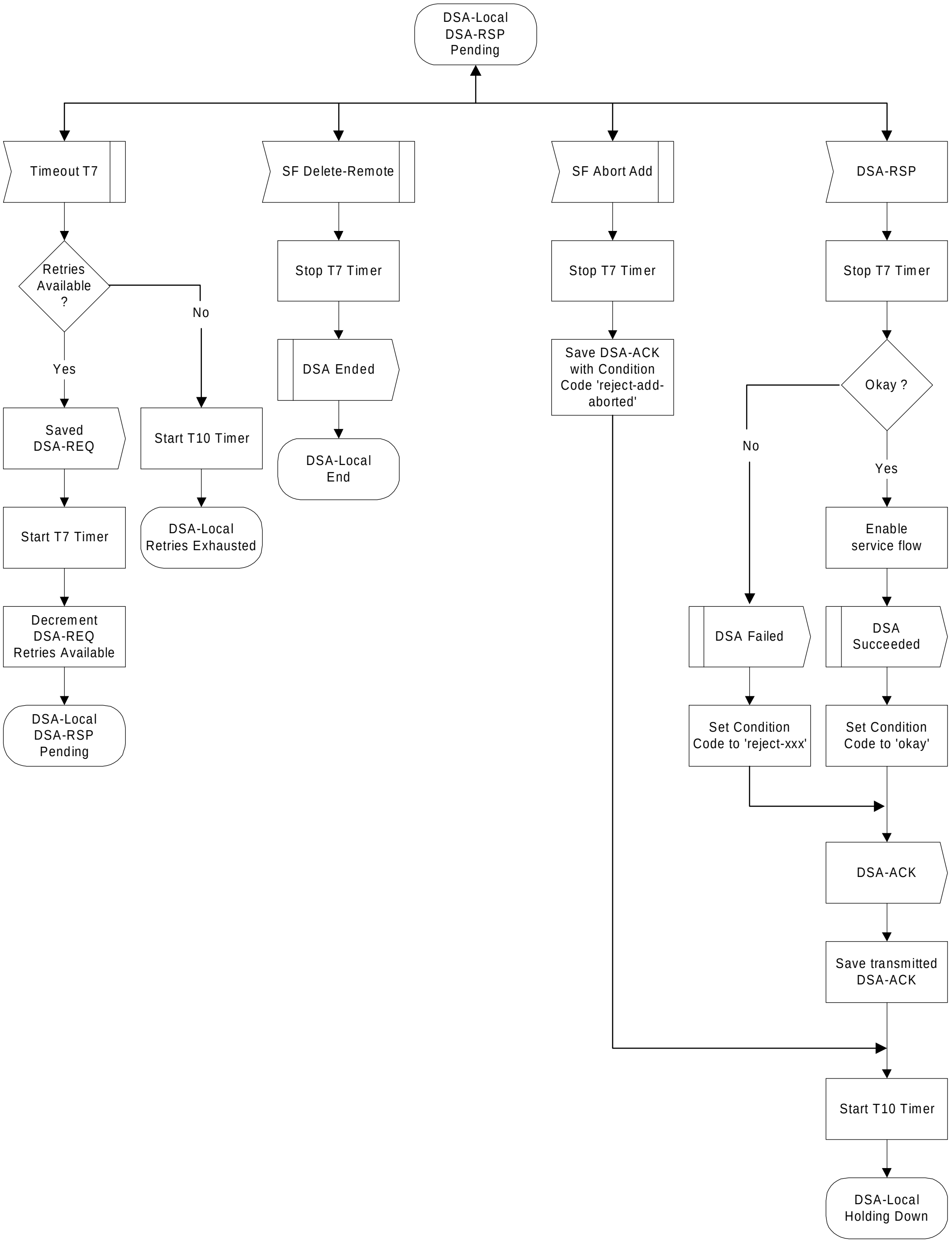


Figure 92—DSA - Locally Initiated Transaction DSA-RSP Pending State Flow Diagram

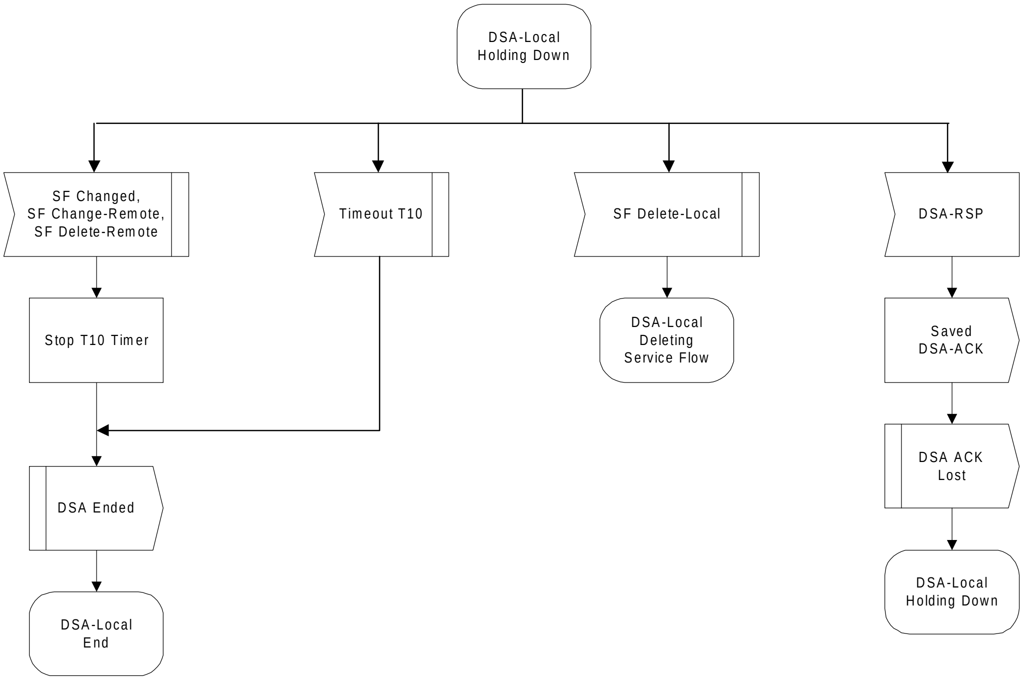


Figure 93—DSA - Locally Initiated Transaction Holding State Flow Diagram

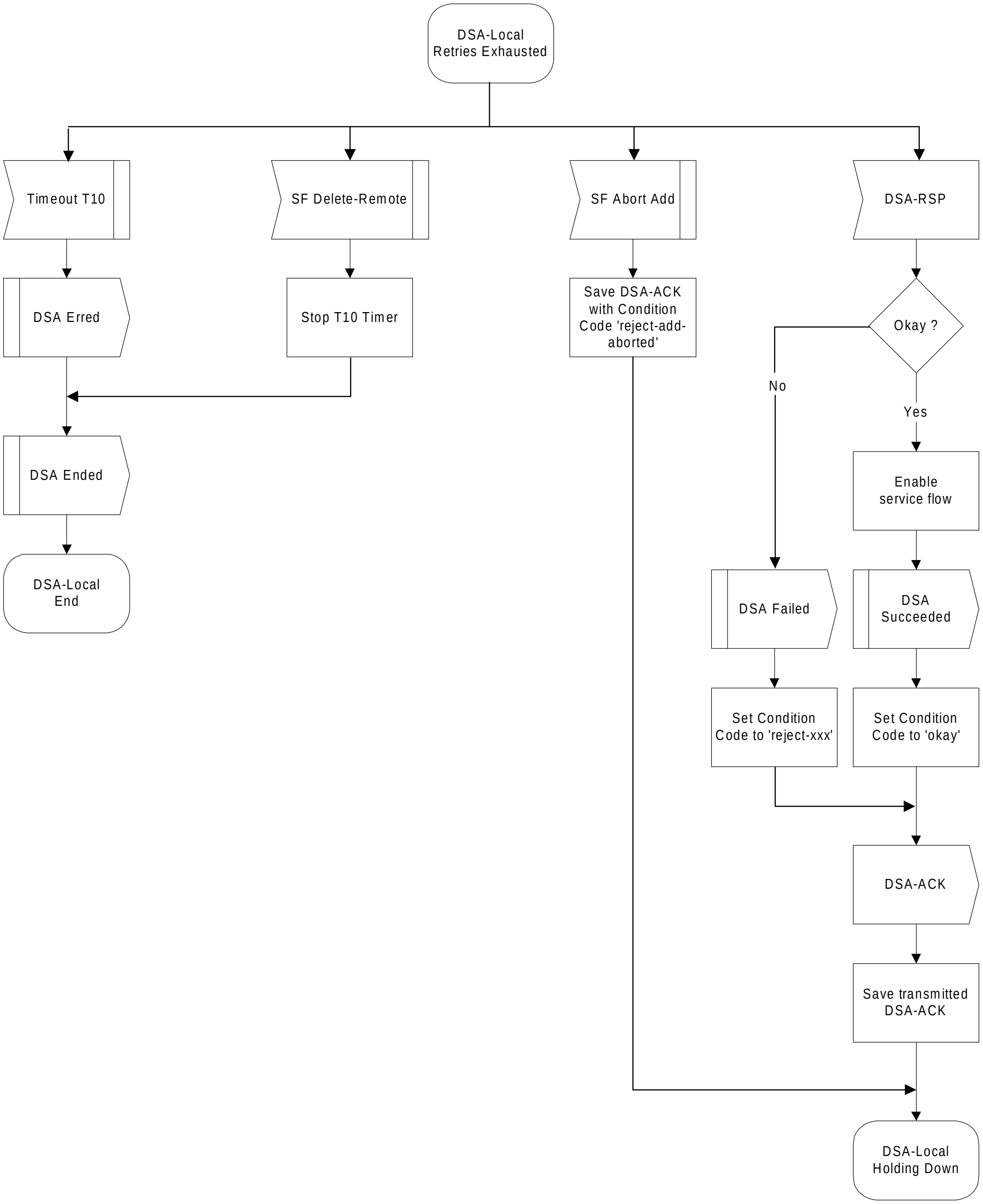


Figure 94—DSA - Locally Initiated Transaction Retries Exhausted State Flow Diagram

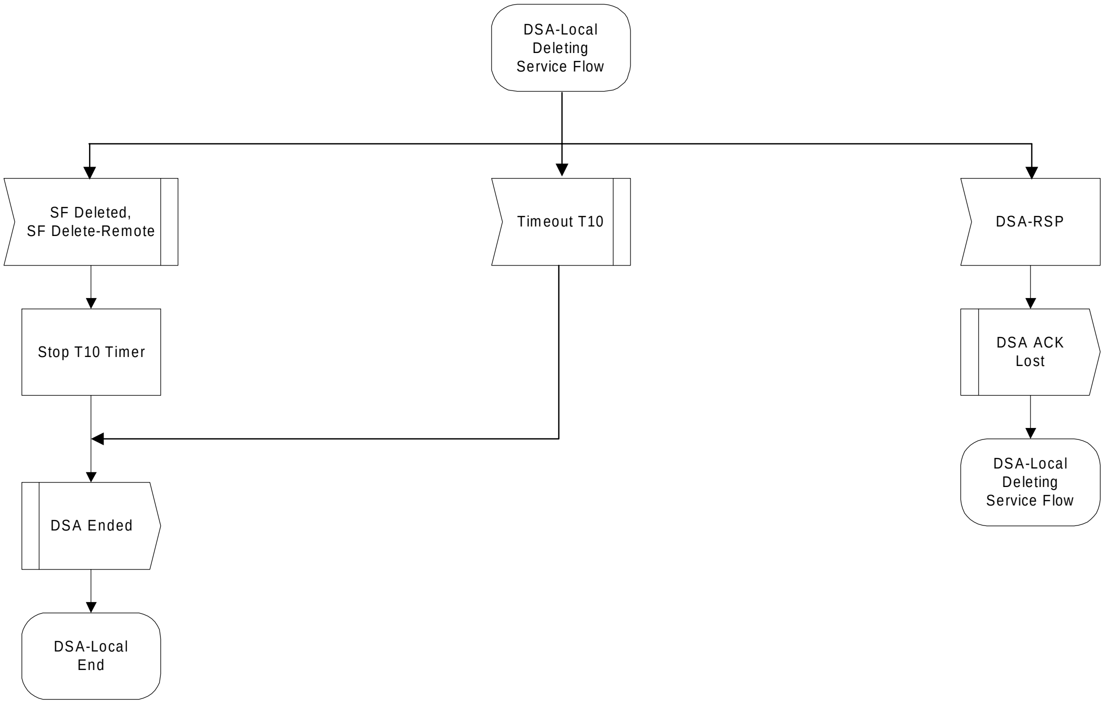


Figure 95—DSA - Locally Initiated Transaction Deleting Service Flow State Flow Diagram

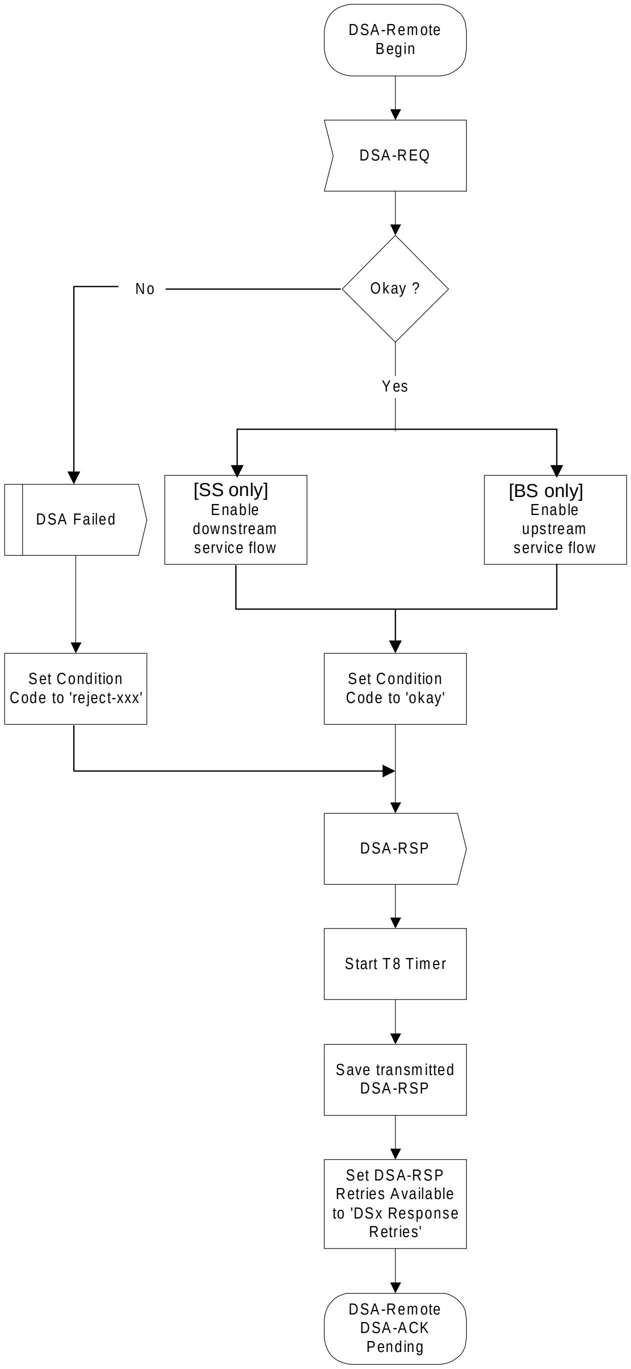

DSA-Remote Begin
DSA-REQ
Okay ?
No
Yes
DSA Failed
[SS only] Enable downstream service flow
[BS only] Enable upstream service flow
Set Condition Code to 'reject-xxx'
Set Condition Code to 'okay'
DSA-RSP
Start T8 Timer
Save transmitted DSA-RSP
Set DSA-RSP Retries Available to 'DSx Response Retries'
DSA-Remote DSA-ACK Pending

Figure 96—DSA - Remotely Initiated Transaction Begin State Flow Diagram

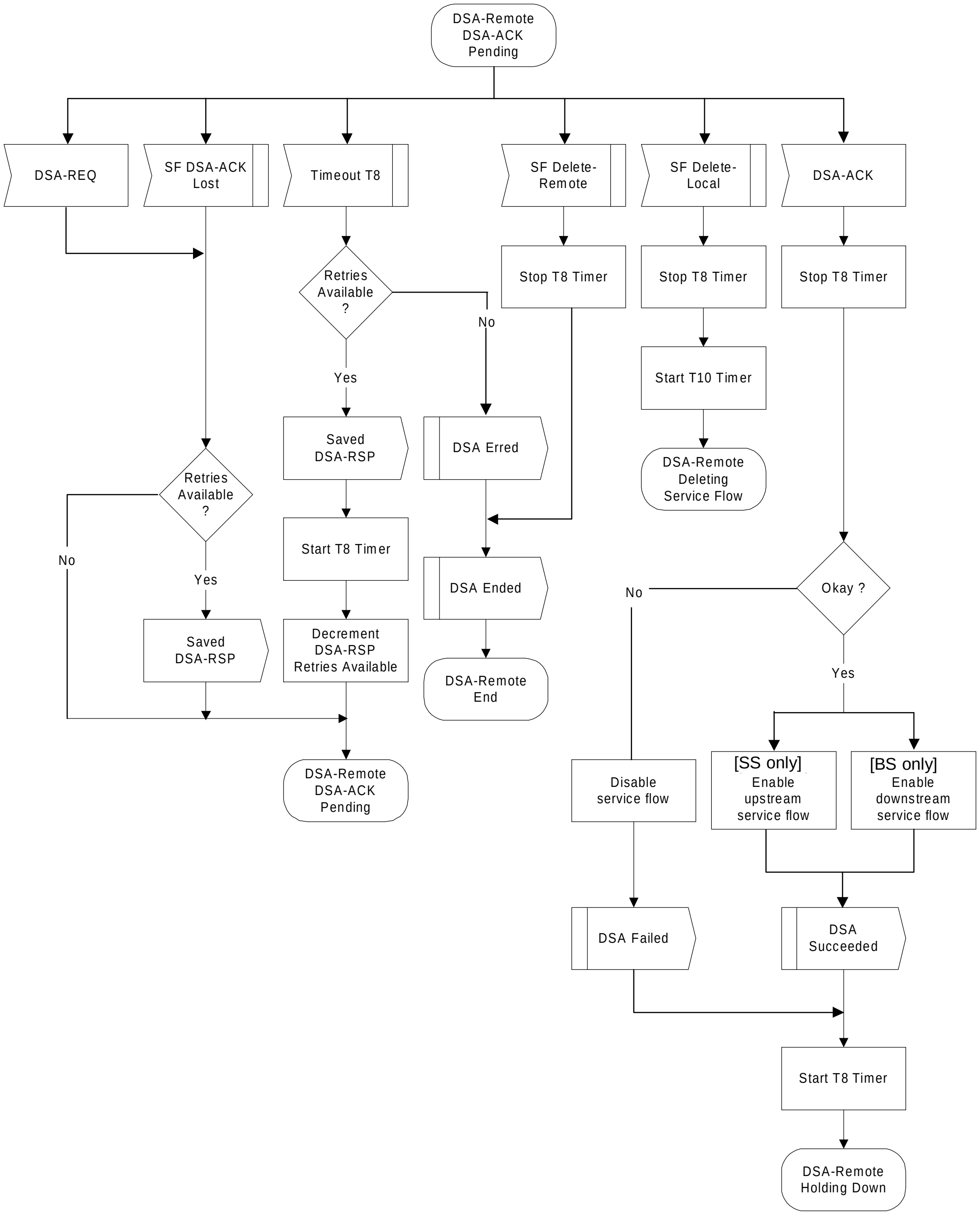


Figure 97—DSA - Remotely Initiated Transaction DSA-ACK Pending State Flow Diagram

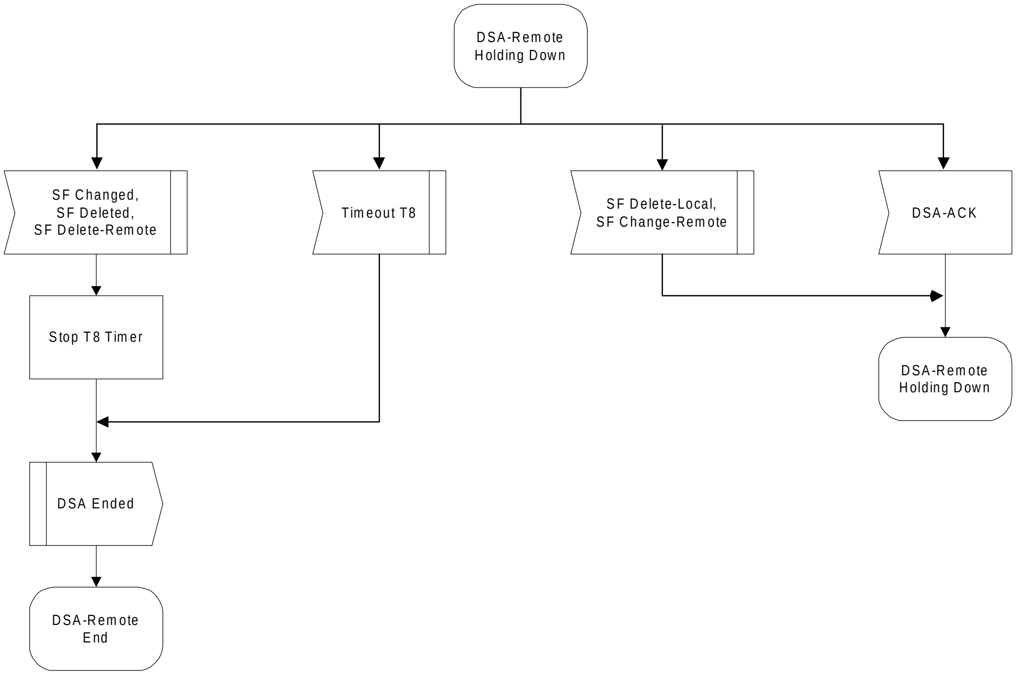


Figure 98—DSA - Remotely Initiated Transaction Holding Down State Flow Diagram

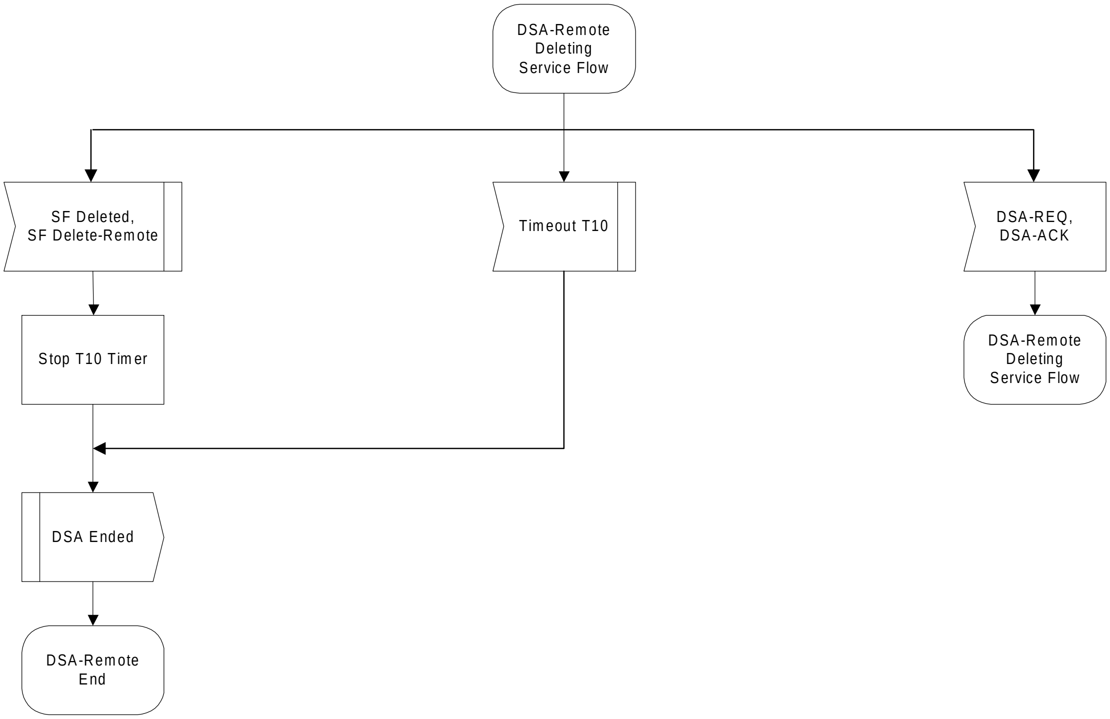

DSA-Remote Deleting Service Flow
SF Deleted, SF Delete-Remote
Timeout T10
DSA-REQ, DSA-ACK
Stop T10 Timer
DSA-Remote Deleting Service Flow
DSA Ended
DSA-Remote End

Figure 99—DSA - Remotely Initiated Transaction Deleting Service State Flow Diagram

2.13.8.4 Dynamic Service Change

The Dynamic Service Change (DSC) set of Messages is used to modify the flow parameters associated with a Service Flow. Specifically, DSC can modify the Service Flow Specification.

A single DSC Message exchange can modify the parameters of one downstream service flow and/or one upstream service flow.

To prevent packet loss, any required bandwidth change is sequenced between the SS and BS.

The BS controls both upstream and downstream scheduling. The timing of scheduling changes is independent of direction AND whether it's an increase or decrease in bandwidth. The BS always changes scheduling on receipt of a DSC-REQ (SS initiated transaction) or DSC-RSP (BS initiated transaction).

The BS also controls the downstream transmit behavior. The change in downstream transmit behavior is always coincident with the change in downstream scheduling (i.e. BS controls both and changes both simultaneously).

The SS controls the upstream transmit behavior. The timing of SS transmit behavior changes is a function of which device initiated the transaction AND whether the change is an “increase” or “decrease” in bandwidth.

If an upstream Service Flow's bandwidth is being reduced, the SS reduces its payload bandwidth first and then the BS reduces the bandwidth scheduled for the Service Flow. If an upstream Service Flow's bandwidth is being increased, the BS increases the bandwidth scheduled for the Service Flow first and then the SS increases its payload bandwidth.

If the bandwidth changes are complex, it may not be obvious to the SS when to effect the bandwidth changes. This information may be signalled to the SS from a higher layer entity.

Any service flow can be deactivated with a Dynamic Service Change command by sending a DSC-REQ Message, referencing the Service Flow Identifier, and including a null ActiveQoSParameterSet. However, if a Primary Service Flow of a SS is deactivated that SS is de-registered and shall re-register. Therefore, care should be taken before deactivating such Service Flows. If a Service Flow that was provisioned during registration is deactivated, the provisioning information for that Service Flow shall be maintained until the Service Flow is reactivated.

A SS shall have only one DSC transaction outstanding per Service Flow. If it detects a second transaction initiated by the BS, the SS shall abort the transaction it initiated and allow the BS initiated transaction to complete.

A BS shall have only one DSC transaction outstanding per Service Flow. If it detects a second transaction initiated by the SS, the BS shall abort the transaction the SS initiated and allow the BS initiated transaction to complete.

Note: Currently anticipated applications would probably control a Service Flow through either the SS or BS, and not both. Therefore the case of a DSC being initiated simultaneously by the SS and BS is considered as an exception condition and treated as one.

2.13.8.4.1 SS-Initiated Dynamic Service Change

A SS that needs to change a Service Flow definition performs the following operations.

The SS informs the BS using a Dynamic Service Change Request Message (DSC-REQ). The BS shall decide if the referenced Service Flow can support this modification. The BS shall respond with a Dynamic Service Change Response (DSC-RSP) indicating acceptance or rejection. The SS reconfigures the Service Flow if appropriate, and then shall respond with a Dynamic Service Change Acknowledge (DSC-ACK).

Table 32—SS-Initiated DSC

BS		SS
		Service Flow Requires Modifying
Receive DSC-REQ	<--------- DSC-REQ ----------	Send DSC-REQ
Validate Request		
Modify Service Flow		
Increase Channel Bandwidth if Required		
Send DSC-RSP	---------- DSC-RSP --------->	Receive DSC-RSP
		Modify Service Flow
		Adjust Payload Bandwidth
Receive DSC-ACK	<--------- DSC-ACK ----------	Send DSC-ACK
Decrease Channel Bandwidth if Required		

2.13.8.4.2 BS-Initiated Dynamic Service Change

A BS that needs to change a Service Flow definition performs the following operations.

The BS shall decide if the referenced Service Flow can support this modification. If so, the BS informs the SS using a Dynamic Service Change Request Message (DSC-REQ). The SS checks that it can support the service change, and shall respond using a Dynamic Service Change Response (DSC-RSP) indicating acceptance or rejection. The BS reconfigures the Service Flow if appropriate, and then shall respond with a Dynamic Service Change Acknowledgment (DSC-ACK)

Table 33—BS-Initiated DSC

BS		SS
Service Flow Requires Modifying		
Send DSC-REQ	---------- DSC-REQ --------->	Receive DSC-REQ
		Modify Service Flow
		Decrease Payload Bandwidth if Required
Receive DSC-RSP	<--------- DSC-RSP ----------	Send DSC-RSP
Modify Service Flow		
Adjust Channel Bandwidth		
Send DSC-ACK	---------- DSC-ACK --------->	Receive DSC-ACK
		Increase Payload Bandwidth if Required

2.13.8.4.3 Dynamic Service Change State Transition Diagrams

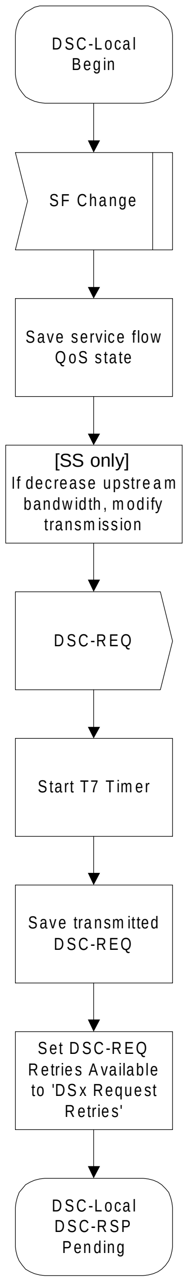

DSC-Local Begin
SF Change
Save service flow QoS state
[SS only] If decrease upstream bandwidth, modify transmission
DSC-REQ
Start T7 Timer
Save transmitted DSC-REQ
Set DSC-REQ Retries Available to 'DSx Request Retries'
DSC-Local DSC-RSP Pending

Figure 100—DSC - Locally Initiated Transaction Begin State Flow Diagram

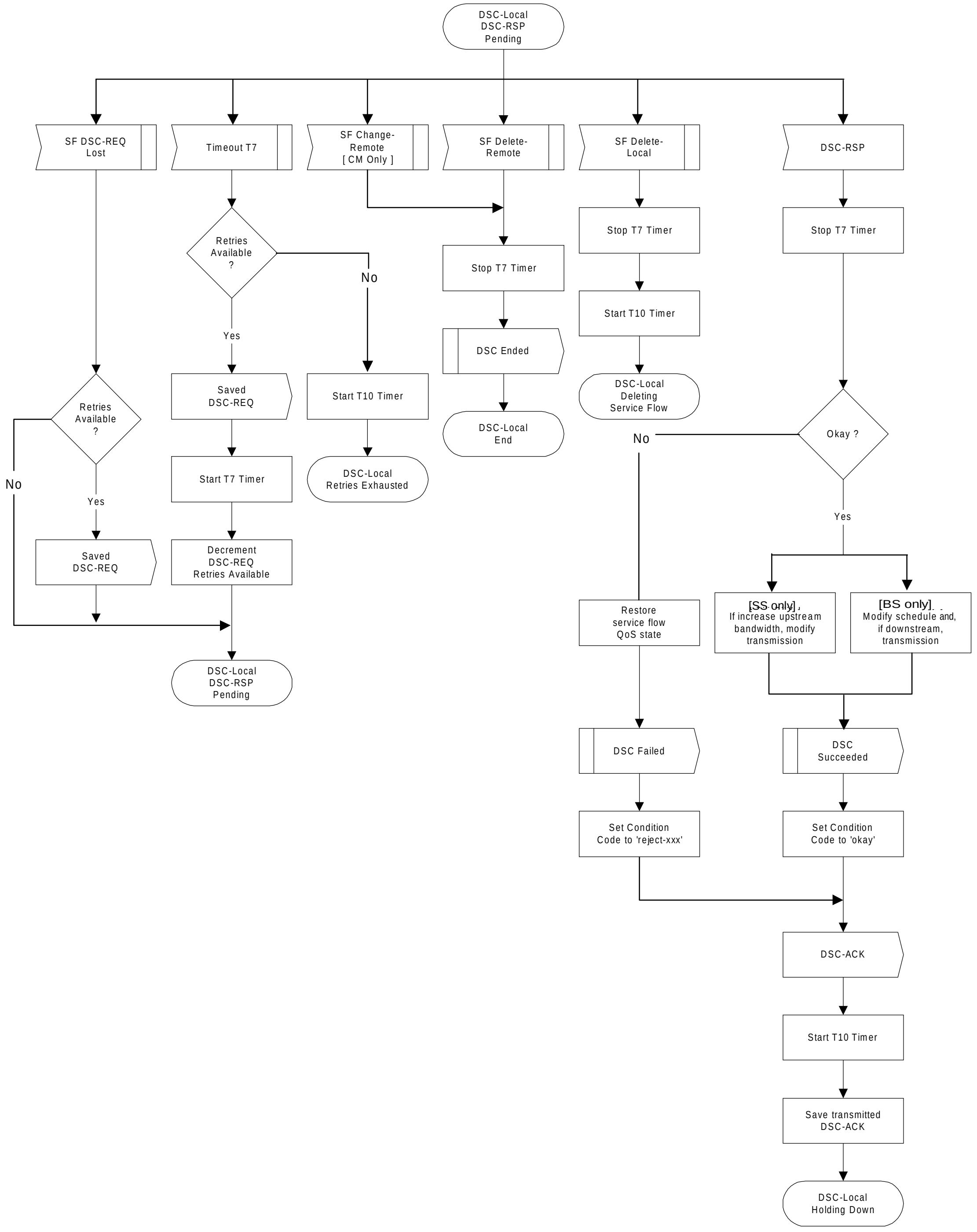


Figure 101—DSC - Locally Initiated Transaction DSC-RSP Pending State Flow Diagram

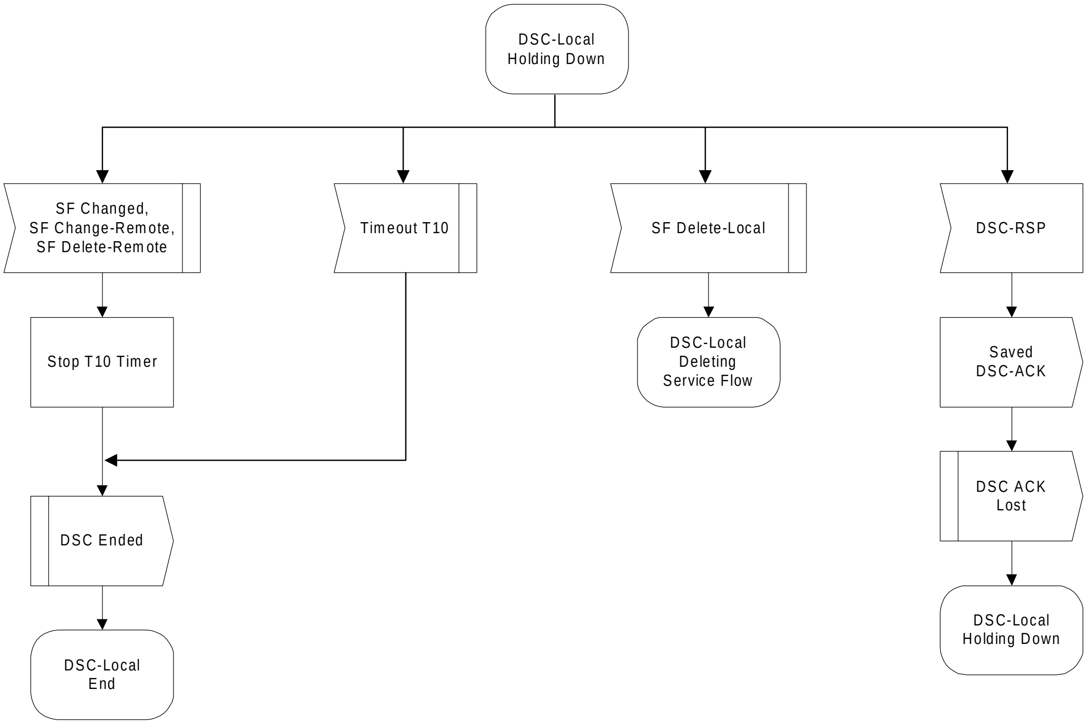


Figure 102—DSC - Locally Initiated Transaction Holding Down State Flow Diagram

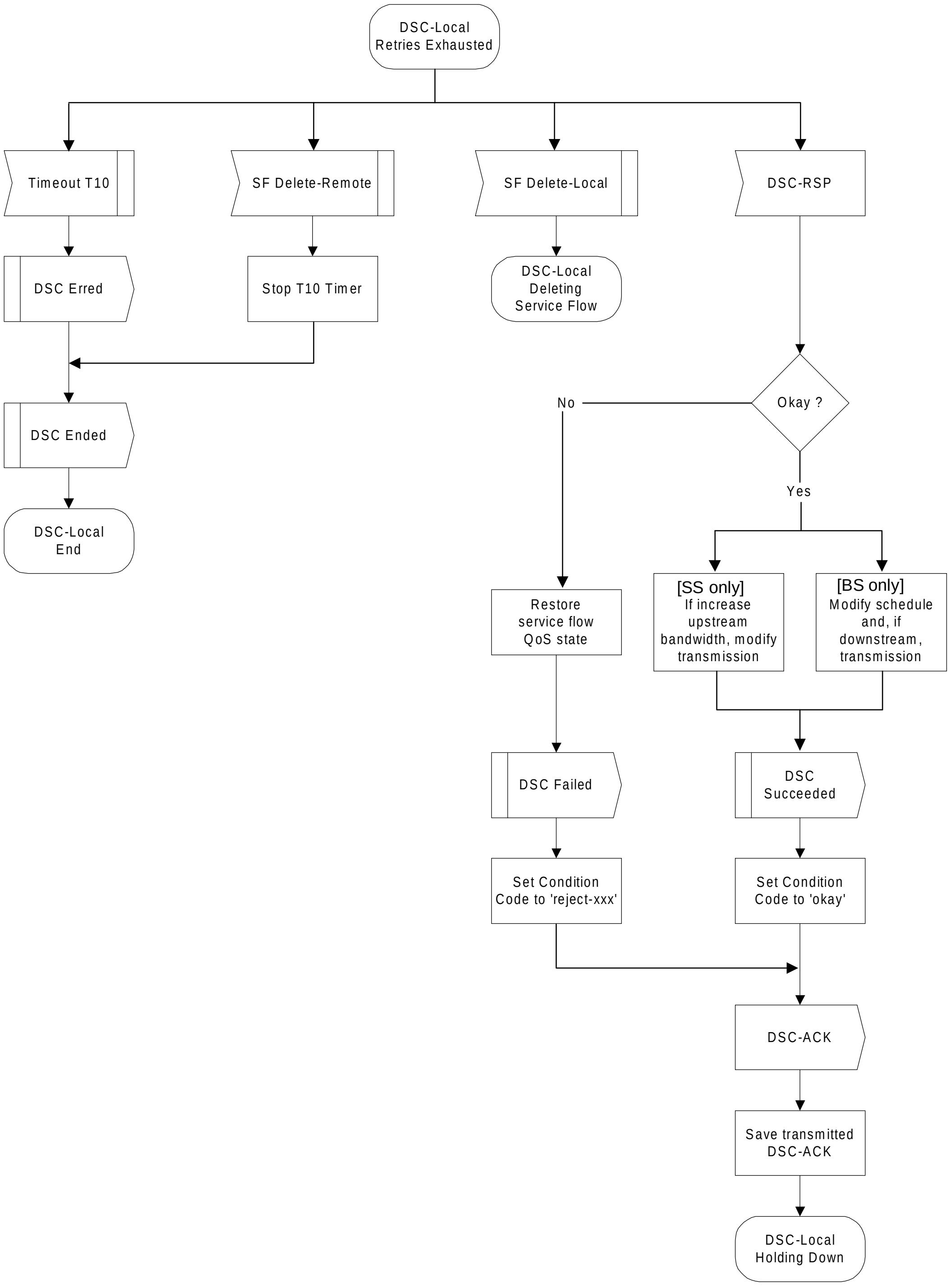


Figure 103—DSC - Locally Initiated Transaction Retries Exhausted State Flow Diagram

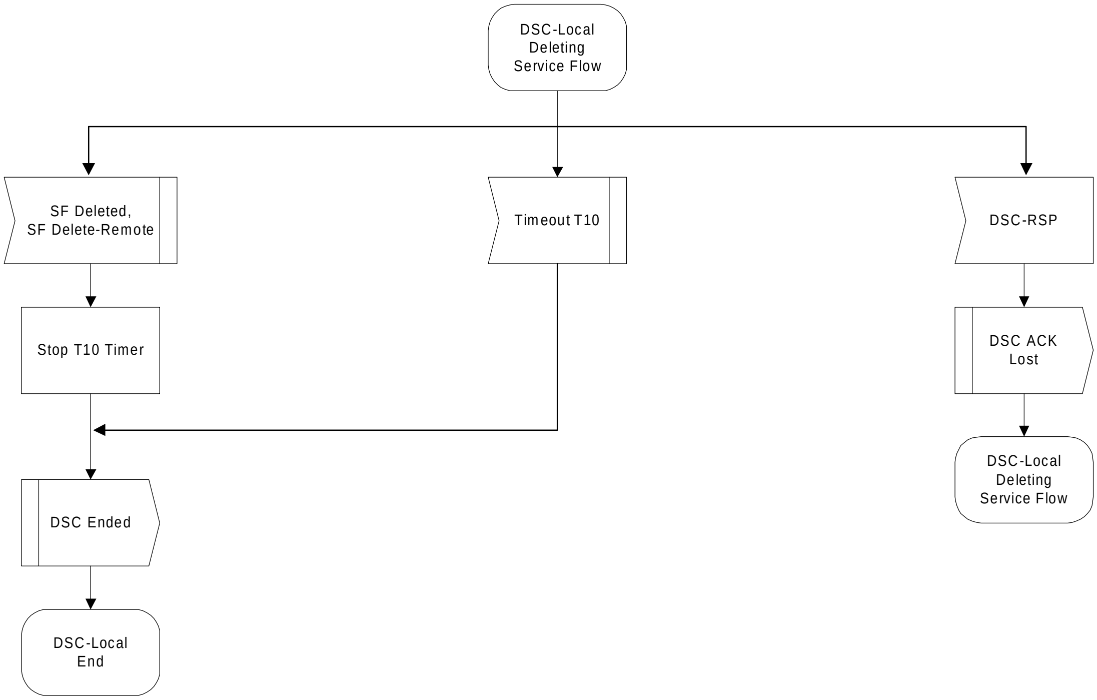


Figure 104—DSC - Locally Initiated Transaction Deleting Service Flow State Flow Diagram

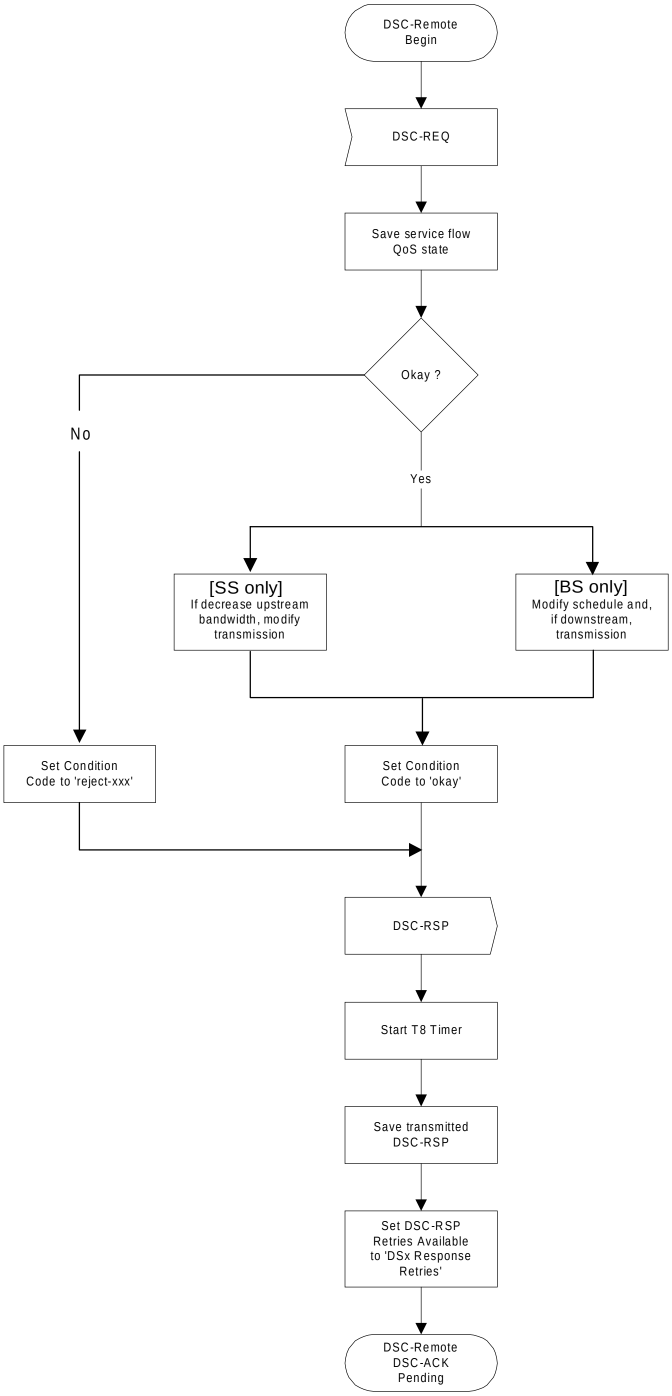


Figure 105—DSC - Remotely Initiated Transaction Begin State Flow Diagram

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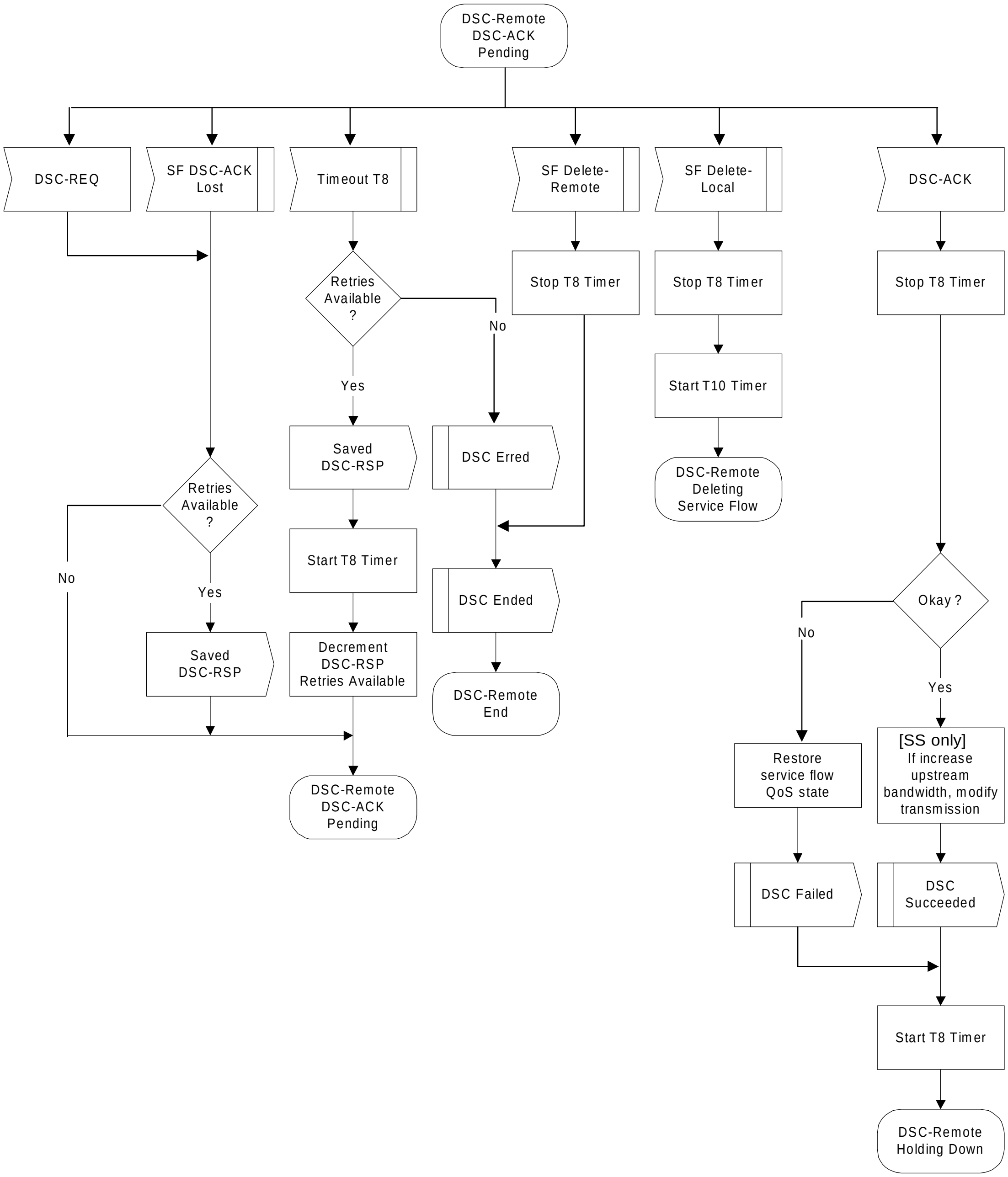


Figure 106—DSC - Remotely Initiated Transaction DSC-ACK Pending State Flow Diagram

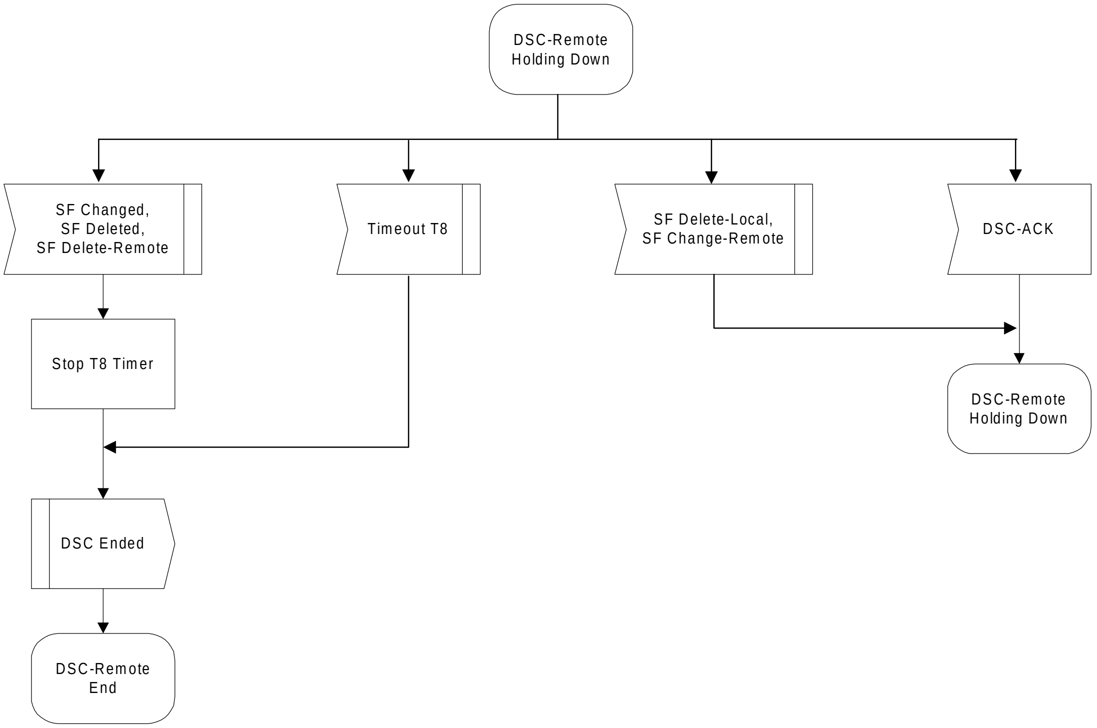


Figure 107—DSC - Remotely Initiated Transaction Holding Down State Flow Diagram

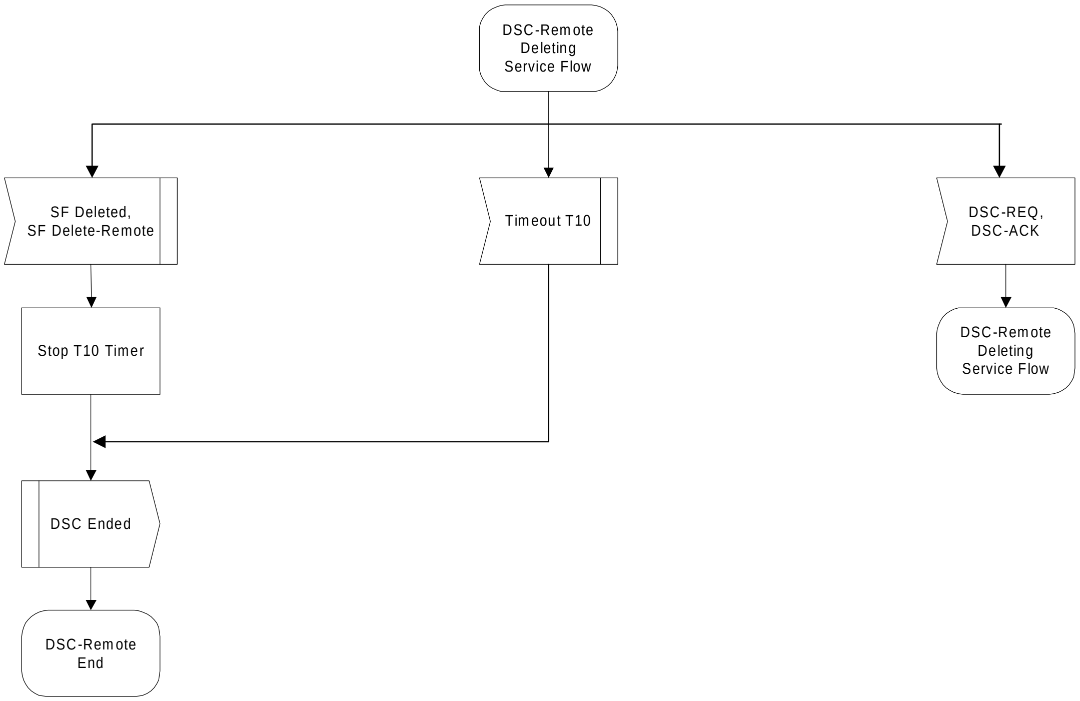

DSC-Remote Deleting Service Flow
SF Deleted, SF Delete-Remote
Timeout T10
DSC-REQ, DSC-ACK
Stop T10 Timer
DSC-Remote Deleting Service Flow
DSC Ended
DSC-Remote End

Figure 108—DSC - Remotely Initiated Transaction Deleting Service Flow State Flow Diagram

2.13.8.5 Connection Release

Any service flow can be deleted with the Dynamic Service Deletion (DSD) Messages. When a Service Flow is deleted, all resources associated with it are released. However, if a Basic Service Flow of a SS is deleted, that SS is de-registered and shall re-register. Also, if a Service Flow that was provisioned during registration is deleted, the provisioning information for that Service Flow is lost until the SS re-registers. However, the deletion of a provisioned Service Flow shall not cause a SS to re-register. Therefore, care should be taken before deleting such Service Flows.

Note: Unlike DSA and DSC Messages, DSD Messages are limited to only a single Service Flow.

2.13.8.5.1 SS Initiated Dynamic Service Deletion

A SS wishing to delete a Service Flow generates a delete request to the BS using a Dynamic Service Deletion-Request Message (DSD-REQ). The BS removes the Service Flow and generates a response using a Dynamic Service Deletion-Response Message (DSD-RSP). Only one Service Flow can be deleted per DSD-Request.

2.13.8.5.2 BS Initiated Dynamic Service Deletion

A BS wishing to delete a dynamic Service Flow generates a delete request to the associated SS using a Dynamic Service Deletion-Request Message (DSD-REQ). The SS removes the Service Flow and generates a response using a Dynamic Service Deletion-Response Message (DSD-RSP). Only one Service Flow can be deleted per DSD-Request.

Table 34: Dynamic Service Deletion Initiated from SS

SS		**BS**
Service Flow no longer needed		
Delete Service Flow		
Send DSD-REQ	---DSD-REQ-->	Receive DSD-REQ
		Verify SS is Service Flow ‘owner’
		Delete Service Flow
Receive DSD-RSP	<--DSD-RSP---	Send DSD-RSP

Table 35: Dynamic Service Deletion Initiated from BS

SS		**BS**
		Service Flow no longer needed
		Delete Service Flow
		Determine associated SS for this Service Flow
Receive DSD-REQ	<---DSD-REQ---	Send DSD-REQ
Delete Service Flow		
Send DSD-RSP	---DSD-RSP-->	Receive DSD-RSP

2.13.8.5.3 Dynamic Service Deletion State Transition Diagrams

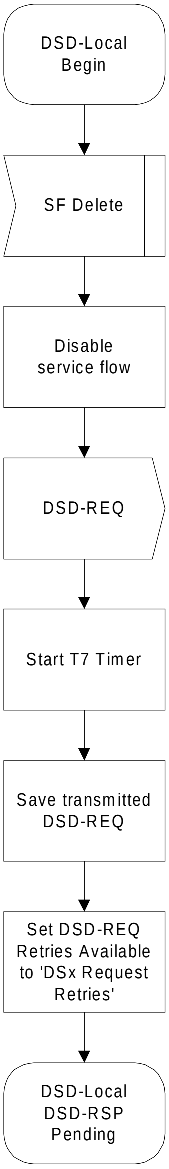


Figure 109—DSD - Locally Initiated Transaction Begin State Flow Diagram

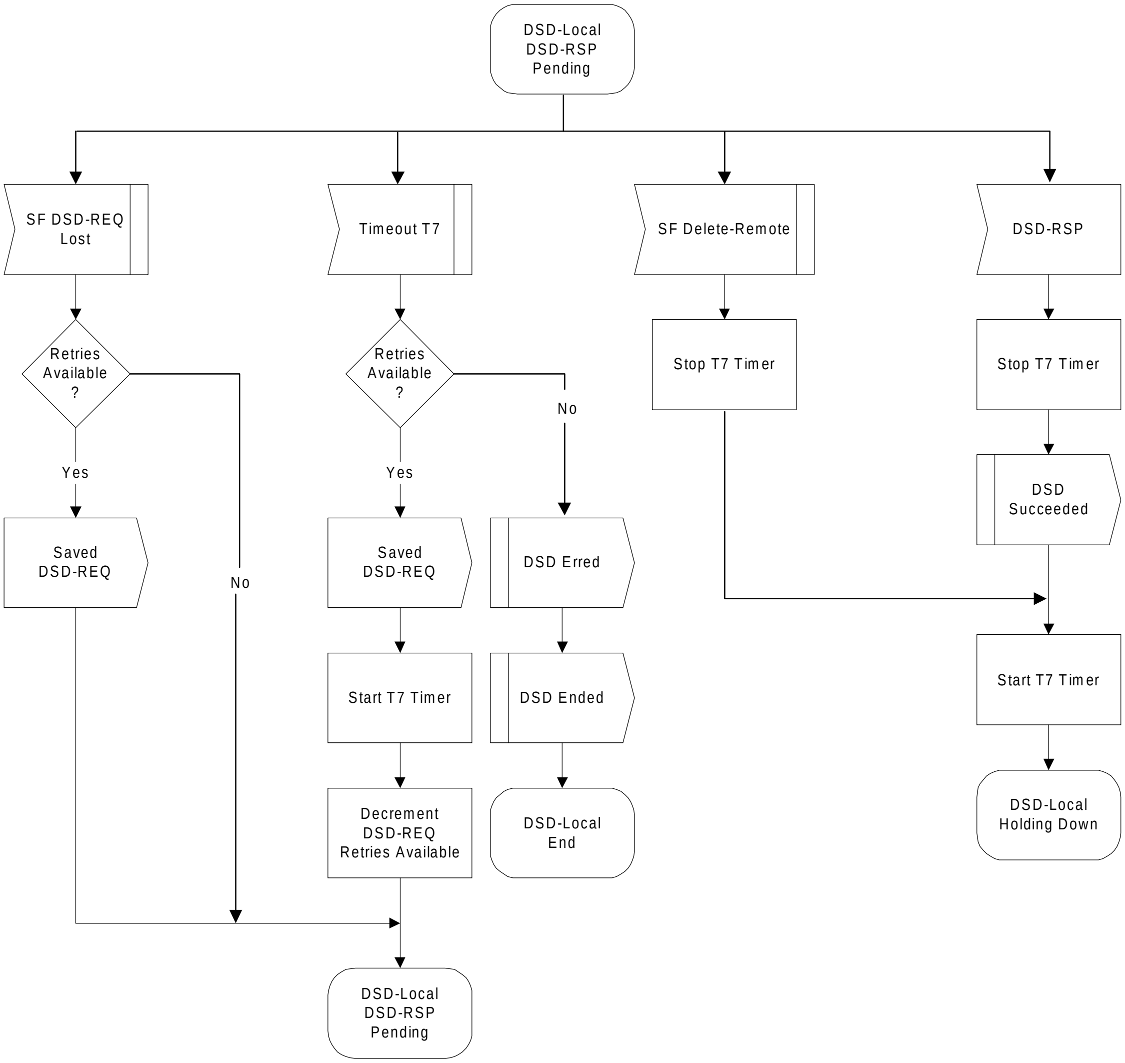


Figure 110—DSD - Locally Initiated Transaction DSD-RSP Pending State Flow Diagram

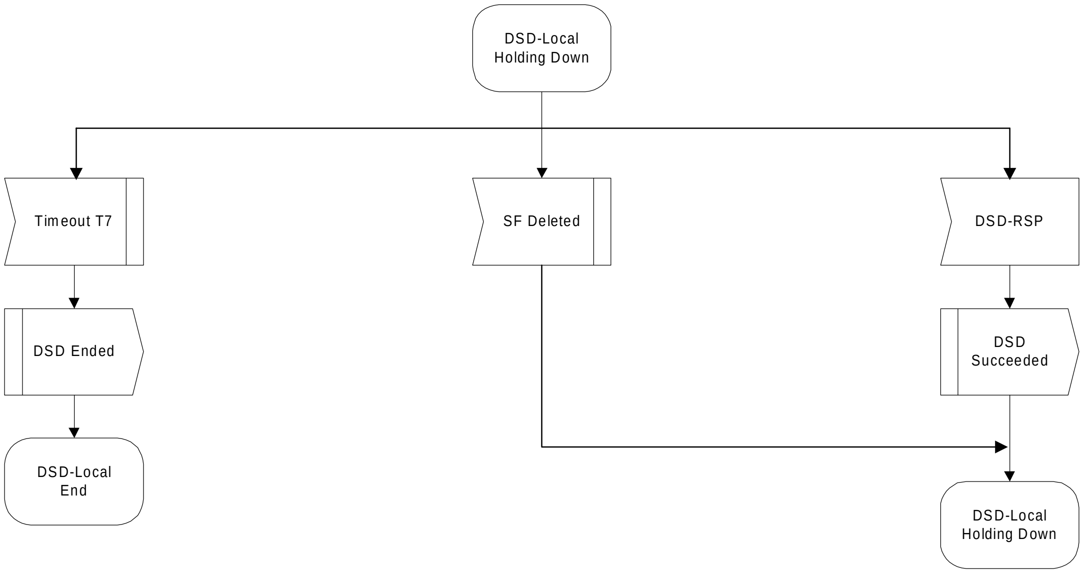


Figure 111—DSD - Locally Initiated Transaction Holding Down State Flow Diagram

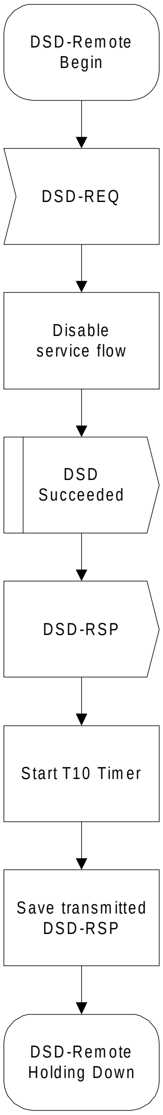


Figure 112—DSD - Remotely Initiated Transaction Begin State Flow Diagram

2.14 Authentication and Privacy

2.14.1 Privacy Overview

Privacy provides subscribers with privacy across the fixed broadband wireless network. It does this by encrypting connectionss between SS and BS.

In addition, Privacy provides operators with strong protection from theft of service. The BS protects against unauthorized access to these data transport services by enforcing encryption of the associated traffic flows across the network. Privacy employs an authenticated client/server key management protocol in which the

BS, the server, controls distribution of keying material to client SS. Additionally, the basic privacy mechanisms are strengthened by adding digital-certificate based SS authentication to its key management protocol.

2.14.2 Architectural Overview

Privacy has two component protocols:

An encapsulation protocol for encrypting packet data across the fixed broadband wireless access network. This protocol defines (1) a set of supported *cryptographic suites*, i.e., pairings of data encryption and authentication algorithms, and (2) the rules for applying those algorithms to a MAC header's payload.

A key management protocol (Privacy Key Management, or "PKM") providing the secure distribution of keying data from BS to SS. Through this key management protocol, SS and BS synchronize keying data; in addition, the BS uses the protocol to enforce conditional access to network services.

2.14.2.1 Packet Data Encryption

Encryption services are defined as a set of capabilities within the MAC sublayer. MAC Header information specific to encryption is allocated in the Generic MAC Header Formant.

This specification supports a single packet date encryption algorithm: the Cipher Block Chaining (CBC) mode of the US Data Encryption Standard (DES) algorithm [FIPS-46-1] [FIPS-81]. It does not pair DES CBC with any packet data authentication algorithm. Additional data encryption algorithms may be supported in future enhancements to the protocol specification, and these algorithms may be paired with data authentication algorithms.

Encryption is always applied to the MAC PDU payload; the Generic MAC Header is not encrypted. All MAC management messages shall be sent in the clear to facilitate registration, ranging, and normal operation of the MAC sublayer.

Section 2.15 specifies the format of MAC PDUs carrying encrypted packet data payloads.

2.14.2.2 Key Management Protocol

SS use the Privacy Key Management protocol to obtain authorization and traffic keying material from the BS, and to support periodic reauthorization and key refresh. The key management protocol uses X.509 digital certificates [ITU1], RSA [RSA, RSA1, RSA3] (a public-key encryption algorithm) and two-key triple DES to secure key exchanges between SS and BS.

The Privacy Key Management protocol adheres to a client/server model, where the SS, a PKM "client", requests keying material, and the BS, a PKM "server", responds to those requests, ensuring individual SS clients only receive keying material they are authorized for. The PKM protocol uses MAC management messaging.

Privacy uses public-key cryptography to establish a shared secret (i.e., an Authorization Key) between SS and BS. The shared secret is then used to secure subsequent PKM exchanges of traffic encryption keys. This two-tiered mechanism for key distribution permits refreshing of traffic encryption keys without incurring the overhead of computation-intensive public-key operations.

A BS authenticates a client SS during the initial authorization exchange. Each SS carries a unique X.509 digital certificate issued by the SS's manufacturer. The digital certificate contains the SS's Public Key along with other identifying information; i.e., SS MAC address, manufacturer ID and serial number. When requesting an Authorization Key, a SS presents it's digital certificate to a BS. The BS verifies the digital certificate, and then uses the verified Public Key to encrypt an Authorization Key, which the BS then sends back to the requesting SS.

The BS associates a SS’s authenticated identity to a paying subscriber, and hence to the data services that subscriber is authorized to access. Thus, with the Authorization Key exchange, the BS establishes an authenticated identity of a client SS, and the services (i.e., specific traffic encryption keys) the SS is authorized to access.

Since the BS authenticates SS, it can protect against an attacker employing a *cloned* SS, masquerading as a legitimate subscriber’s SS. The use of the X.509 certificates prevents cloned SSs from passing fake credentials onto a BS.

SS shall have factory-installed RSA private/public key pairs or provide an internal algorithm to generate such key pairs dynamically. If a SS relies on an internal algorithm to generate its RSA key pair, the SS shall generate the key pair prior to its first Privacy initialization, described in Section 2.14.3.1. SS with factory-installed RSA key pairs shall also have factory-installed X.509 certificates. SS that rely on internal algorithms to generate an RSA key pair shall support a mechanism for installing a manufacturer-issued X.509 certificate following key generation.

The PKM protocol is defined in detail in Section 2.16.

2.14.2.3 Security Associations

A *Security Association* (SA) is the set of security information a BS and one or more of its client SS share in order to support secure communications across the BWA network. Three types of Security Associations are defined: *Primary, Static*, and *Dynamic*. A Primary Security Association is related to the Basic CID that every SS establishes during registration. Static Security Associations are provisioned within the BS. Dynamic Security Associations are established and eliminated, on the fly, in response to the initiation and termination of specific traffic flows. Both Static and Dynamic SAs can by shared by multiple SS.

A Security Association’s shared information includes traffic encryption keys and CBC initialization vectors. In order to support, in future protocol enhancements, alternative data encryption and data authentication algorithms, Security Association parameters include a cryptographic suite identifier, indicating a the particular pairing of packet data encryption and packet data authentication algorithms employed by the security association. At the time of release of this specification, 56-bit DES is the only packet data encryption algorithms supported, and neither are paired with a PDU authentication algorithm.

Security Associations are identified using a SAID.

Each (Privacy enabled) SS establishes an exclusive Primary Security Association with its BS. All of a SS’s upstream traffic, and typically all downstream unicast traffic directed at SS device(s) behind the SS, are encrypted under the SS’s exclusive, Primary Security Association. (Selected downstream unicast traffic flows may be encrypted under Static or Dynamic SAs.) The CID corresponding to a SS’s Primary SA shall be equal to the SS’s Basic CID. Downstream traffic may be encrypted under any of the three types of SAs. A downstream multicast PDU, however, is typically intended for multiple SS and hence is more likely to be encrypted under Static or Dynamic SAs, which multiple SS can access, as opposed to a Primary SA, which is restricted to a single SS.

Using the PKM protocol, a SS requests from its BS a SA’s keying material. The BS ensures that each client SS only has access to the Security Associations it is authorized to access.

A SA's keying material (e.g., DES key and CBC Initialization Vector) has a limited lifetime. When the BS delivers SA keying material to a SS, it also provides the SS with that material's remaining lifetime. It is the responsibility of the SS to request new keying material from the BS before the set of keying material that the

SS currently holds expires at the BS. The PKM protocol specifies how SS and BS maintain key synchronization.

2.14.3 Operational Overview

2.14.3.1 SS Initialization

SS initialization is divided into the following sequence of tasks:

scan for downstream channel and establish synchronization with the BS
obtain transmit parameters
perform ranging
establish IP connectivity (DHCP)
establish time of day
transfer operational parameters (download parameter file via TFTP)
BS Registration

Privacy establishment follows BS registration.

If a SS is to run Privacy, its parameter file, downloaded during the transfer of operational parameters, shall include Privacy Configuration Settings. These additional configuration settings are defined in <TBD>.

Upon completing BS registration, the BS will have assigned one or more static CIDs to the registering SS that match the SS's static class-of-service provisioning. The first static CID assigned during the registration process is the Basic CID, and this CID will also serve as the SS's Privacy Basic SAID. If a SS is configured to run Privacy, BS registration is immediately followed by initialization of the SS's Privacy security functions.

Privacy initialization begins with the SS sending the BS an Authorization Request, containing:

data identifying the SS (e.g., MAC address),
the SS's RSA public key,
an X.509 certificate verifying the binding between the SS's identifying data and the SS's public key,
a list of the SS's security capabilities (i.e., the particular pairings of encryption and authentication algorithms the SS supports) and
the SS's Primary SAID.

If the BS determines the requesting SS is authorized for the Authorization Request's Basic SAID, the BS responds with an Authorization Reply containing an Authorization Key, from which SS and BS derive the keys needed to secure a SS's subsequent requests for traffic encryption keys and the BS's responses to these requests. The BS encrypts the Authorization Key with the receiving SS's public key.

The Authorization Reply also contains a list of security association descriptors, identifying the primary and static SAs the requesting SS is authorized to access. Each SA descriptor consists of a collection of SA parameters, including the SA's SAID, type and cryptographic. The list contains at least one entry: a descriptor describing the SS's primary security association. Additional entries are optional, and would describe any static SAs the SS was provisioned to access.

After successfully completing authentication and authorization with the BS, the SS sends key requests to the BS, requesting traffic encryption keys to use with each of its SAIDs. A SS's traffic key requests are authenticated using a keyed hash (the HMAC algorithm [RFC-2104]); the Message Authentication Key is derived from the Authorization Key obtained during the earlier authorization exchange. The BS responds with key replies, containing the Traffic Encryption Keys (TEKs); TEKs are triple DES encrypted with a key encryption key derived from the Authorization Key. Like the Key Requests, Key Replies are authenticated with a keyed hash, where the Message Authentication Key is derived from the Authorization Key.

2.14.3.2 SS Key Update Mechanism

The traffic encryption keys which the BS provides to client SS have a limited lifetime. The BS delivers a key's remaining lifetime, along with the key value, in the key replies it sends to its client SS. The BS controls which keys are current by flushing expired keys and generating new keys. It is the responsibility of individual SSs to insure the keys they are using match those the BS is using. SS do this by tracking when a particular SAID's key is scheduled to expire and issuing a new key request for the latest key prior to that expiration time.

In addition, SSs are required to periodically reauthorize with the BS; as is the case with Traffic Encryption Keys, an Authorization Key has a finite lifetime which the BS provides the SS along with the key value. It is the responsibility of each SS to reauthorize and obtain a fresh Authorization Key (and an up-to-date list of SA descriptors) before the BS expires the SS's current Authorization Key.

Privacy initialization and key update is implemented within the Privacy Key Management protocol, defined in detail in Section 2.16.

2.15 MAC PDU Formats

When operating with Privacy enabled, SS and BS encrypt the payload regions of particular MAC PDUs they transmit onto the FBWA network.

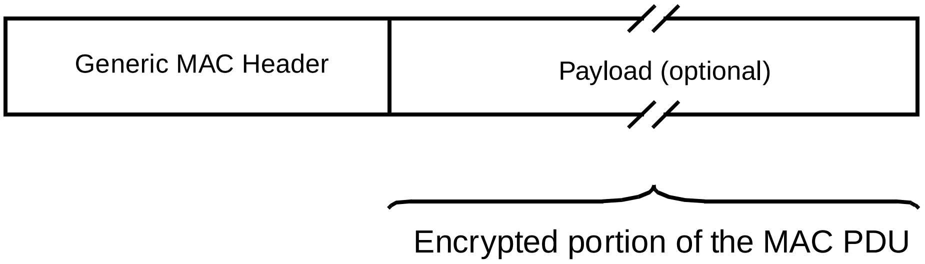


Figure 113—MAC PDU Encryption

The Generic MAC header shall not be encrypted. The Header contains all the Encryption information (Encryption Control Field, Encryption Key Sequence Field, and CID) needed to decrypt a Payload at the receiving station.

Four bits of a MAC Header contains a key sequence number. Recall that the keying material associated with a SA has a limited lifetime, and the BS periodically refreshes a SA's keying material. The BS manages a 4-bit key sequence number independently for each SA and distributes this key sequence number along with the SA's keying material to client SS. The BS increments the key sequence number with each new generation of keying material. The MAC Header includes this sequence number, along with the SAID, to identify the specific generation of that SA keying material being used to encrypt the attached payload. Being a 4-bit quantity, the sequence number wraps around to 0 when it reaches 15.

Comparing a received PDU’s key sequence number with what it believes to be the “current” key sequence number, a SS or BS can easily recognize a loss of key synchronization with its peer. A SS shall maintain the two most recent generations of keying material for each SA. Keeping on-hand the two most recent key generations is necessary for maintaining uninterrupted service during a SA’s key transition.

Encryption of the payload is indicated by the Encryption Control (EC) bit field. A value of 0 indicates the payload is encrypted and the EKS field contains meaningful data. A value of 1 indicates the payload is not encrypted and the EKS field is set to all zeros.

2.15.1 Fragmentation and Encryption

A fragment may have its payload encrypted. Encryption is applied after fragmentation. Likewise, decryption is applied before reassembly of the PDU fragments.

2.16 Privacy Key Management (PKM) Protocol

2.16.1 State Models

2.16.1.1 Introduction

The PKM protocol is specified by two separate, but interdependent, state models: an authorization state model (the Authorization state machine) and an operational service key state model (the Traffic Encryption Key, or *TEK* state machine). This section defines these two state models. The state models are for explanatory purposes only, and should not be construed as constraining an actual implementation.

SS authorization, controlled by the Authorization state machine, is the process of:

- the BS authenticating a client SS’s identity
- the BS providing the authenticated SS with an Authorization Key, from which a Key Encryption Key (KEK) and message authentication keys are derived
- the BS providing the authenticated SS with the identities (i.e., the SAIDs) and properties of primary and static security associations the SS is authorized to obtain keying information for

The KEK is a two-key triple DES encryption key that the BS uses to encrypt the Traffic Encryption Keys (TEKs) it sends to the SS. Traffic encryption keys are used for encrypting user data traffic. SS and BS use message authentication keys to authenticate, via a keyed message digest, the key requests and responses they exchange.

After achieving initial authorization, a SS periodically seeks re-authorization with the BS; reauthorization is also managed by the SS's Authorization state machine. A SS must maintain its authorization status with the BS in order to be able to refresh aging Traffic Encryption Keys. TEK state machines manage the refreshing of Traffic Encryption Keys.

A SS begins authorization by sending an Authentication Information message to its BS. The Authentication Information message contains the SS manufacturer’s X.509 certificate, issued by an external authority. The Authentication Information message is strictly informative, i.e., the BS may choose to ignore it; however it does provide a mechanism for a BS to learn the manufacturer certificates of its client SS.

The SS sends an Authorization Request message to its BS immediately after sending the Authentication Information message. This is a request for an Authorization Key, as well as for the SAIDs identifying any Static Security Associations the SS is authorized to participate in. The Authorization Request includes:

- the SS’s manufacturer ID and serial number

- the SS’s MAC address
- the SS's public key
- a manufacturer-issued X.509 certificate binding the SS’s public key to its other identifying information
- a description of the cryptographic algorithms the requesting SS supports; a SS’s cryptographic capabilities is presented to the BS as a list of cryptographic suite identifiers, each indicating a particular pairing of packet data encryption and packet data authentication algorithms the SS supports
- the SS’s Basic CID. The Basic CID is the first static CID the BS assigns to a SS during RF MAC registration -- the primary SAID is equal to the Basic CID

In response to an Authorization Request message, a BS validates the requesting SS’s identity, determines the encryption algorithm and protocol support it shares with the SS, activates an Authorization Key for the SS, encrypts it with the SS's public key, and sends it back to the SS in an Authorization Reply message. The authorization reply includes:

- an Authorization Key encrypted with the SS's public key
- a 4-bit key sequence number, used to distinguish between successive generations of Authorization Keys
- a key lifetime
- the identities (i.e., the SAIDs) and properties of the single primary and zero or more static security associations the SS is authorized to obtain keying information for

While the Authorization Reply may identify Static SAs in addition to the Primary SA whose SAID matches the requesting SS’s Basic CID, the Authorization Reply shall not identify any Dynamic SAs.

The BS, in responding to a SS’s Authorization Request, will determine whether the re-questing SS, whose identity can be verified via the X.509 digital certificate, is authorized for basic unicast services, and what additional statically provisioned services (i.e., Static SAIDs) the SS's user has subscribed for. Note that the protected services a BS makes available to a client SS can depend upon the particular cryptographic suites SS and BS share support for.

Upon achieving authorization, a SS starts a separate TEK state machine for each of the SAIDs identified in the Authorization Reply message. Each TEK state machine operating within the SS is responsible for managing the keying material associated with its respective SAID. TEK state machines periodically send Key Request messages to the BS, requesting a refresh of keying material for their respective SAIDs. A Key Request includes:

- identifying information unique to the SS, consisting of the manufacturer ID, serial number, MAC address and RSA Public Key
- the SAID whose keying material is being requested
- an HMAC keyed message digest, authenticating the Key Request

The BS responds to a Key Request with a Key Reply message, containing the BS’s active keying material for a specific SAID. This keying material includes:

- the triple-DES-encrypted traffic encryption key
- CBC initialization vector
- a key sequence number
- a key’s remaining lifetime
- an HMAC keyed message, authenticating the Key Reply

The traffic encryption key (TEK) in the Key Reply is triple DES (encrypt-decrypt-encrypt or EDE mode) encrypted, using a two-key, triple DES key encryption key (KEK) derived from the Authorization Key.

Note that at all times the BS maintains two active sets of keying material per SAID. The lifetimes of the two generations overlap such that each generation becomes active halfway through the life of it predecessor and expires halfway through the life of its successor. A BS includes in its Key Replies *both* of a SAID's active generations of keying material.

The Key Reply provides the requesting SS, in addition to the TEK and CBC initialization vector, the remaining lifetime of each of the two sets of keying material. The receiving SS uses these remaining lifetimes to estimate when the BS will invalidate a particular TEK, and therefore when to schedule future Key Requests such that the SS requests and receives new keying material before the BS expires the keying material the SS currently holds.

The operation of the TEK state machine's Key Request scheduling algorithm, combined with the BS's regimen for updating and using a SAID's keying material (see Section 2.18), insures that the SS will be able to continually exchange encrypted traffic with the BS.

A SS shall periodically refresh its Authorization Key by re-issuing an Authorization Request to the BS. Reauthorization is identical to authorization with the exception that the SS does not send Authentication Information messages during reauthorization cycles. Section 2.16.1.2's description of the authorization state machine clearly indicates when Authentication Information messages are sent.

To avoid service interruptions during reauthorization, successive generations of the SS's Authorization Keys have overlapping lifetimes. Both SS and BS shall be able to support up to two simultaneously active Authorization Keys during these transition periods. The operation of the Authorization state machine's Authorization Request scheduling algorithm, combined with the BS's regimen for updating and using a client SS's Authorization Keys (see Section 2.18), insures that SS will be able to refresh TEK keying information without interruption over the course of theSS's reauthorization periods.

A TEK state machine remains active as long as:

the SS is authorized to operate in the BS's security domain; i.e., it has a valid Authorization Key, and
the SS is authorized to participate in that particular Security Association; i.e. BS continues to provide fresh keying material during re-key cycles.

The parent Authorization state machine stops *all* of its child TEK state machines when the SS receives from the BS an Authorization Reject during a reauthorization cycle. Individual TEK state machines can be started or stopped during a reauthorization cycle if a SS's Static SAID authorizations changed between successive re-authorizations.

Communication between Authorization and TEK state machines occurs through the passing of events and protocol messaging. The Authorization state machine generates events (i.e., Stop, Authorized, Authorization Pending, and Authorization Complete events) that are targeted at its child TEK state machines. TEK state machines do not target events at their parent Authorization state machine. The TEK state machine affects the Authorization state machine indirectly through the messaging a BS sends in response to a SS's requests: a BS may respond to a TEK machine's Key Requests with a failure response (i.e., Authorization Invalid message) that will be handled by the Authorization state machine.

2.16.1.1.1 Preliminary Comment on Dynamic Security Associations and Dynamic SA Mapping

Section 2.14.2.3 introduced Dynamic SAs and mentioned how a BS can establish or eliminate a Dynamic SA in response to the initiation or termination of downstream traffic flows (e.g., a particular multicast group's traffic). In order for a SS to run a TEK state machine to obtain a Dynamic Security Association's keying material, the SS needs to know the corresponding SAID value. The BS, however, does not volunteer to client SS the existence of Dynamic SAs; instead, it is the responsibility of SS to request of the BS the mappings of traffic flow identifiers (e.g., an multicast address) to dynamic SAIDs.

The protocol defines a messaging exchange by which a SS learns the mapping of a downstream traffic flow to a Dynamic SA (all upstream traffic is encrypted under a SS's Primary SA). A SA Mapping state machine specifies how SSs manage the transmission of these mapping request messages. This is a forward-looking definition designed to support multicast traffic encryption.

The Authorization state machine controls the establishment and termination of TEK state machines associated with the Primary and any Static SAs; it does not, however, control the establishment and termination of TEK state machines associated with Dynamic SAs. SS shall implement the necessary logic to establish and terminate a Dynamic SA's TEK state machine. This interface specification, however, does not specify how SS should manage their Dynamic SA's TEK state machines.

A full description of the SA Mapping state model is deferred to Section 2.17.

2.16.1.1.2 Security Capabilities Selection

As part of their authorization exchange, the SS provides the BS with a list of all the cryptographic suites (pairing of data encryption and data authentication algorithms) the SS supports. The BS selects from this list a single cryptographic suite to employ with the requesting SS's primarySA. The Authorization Reply the BS sends back to the SS includes a primary SA descriptor which, among other things, identifies the cryptographic suite the BS selected to use for the SS's primary SA. A BS shall reject the authorization request if it determines that none of the offered cryptographic suites are satisfactory.

The Authorization Reply also contains an optional list of static SA descriptors; each static SA descriptor identifies the cryptographic suite employed within the SA. The selection of a static SA's cryptographic suite is typically made independent of the requesting SS's cryptographic capabilities. A BS may include in its Authorization Reply static SA descriptors identifying cryptographic suites the requesting SS does not support; if this is the case, the SS shall not start TEK state machines for static SAs whose cryptographic suites the SS does not support.

The above selection framework was incorporated in order to support future enhancements to MAC hardware and to the Privacy protocol. At the time of release of this specification, 56-bit DES and 40-bit DES are the only packet data encryption algorithms supported, and neither are paired with a packet data authentication algorithm.

2.16.1.2 Authorization State Machine

The Authorization state machine consists of six states and eight distinct events (including receipt of messages) that can trigger state transitions. The Authorization finite state machine (FSM) is presented below in a graphical format, as a state flow model (Figure 114), and in a tabular format, as a state transition matrix (Table 36).

The state flow diagram depicts the protocol messages transmitted and internal events generated for each of the model's state transitions; however, the diagram does not indicate additional internal actions, such as the clearing or starting of timers, that accompany the specific state transitions. Accompanying the state transition matrix is a detailed description of the specific actions accompanying each state transition; the state transition matrix shall be used as the definitive specification of protocol actions associated with each state transition.

The following legend applies to the Authorization State Machine flow diagram in depicted in Figure 114.

Ovals are states.

Events are in *italics*.

Messages are in normal font.

State transitions (i.e. the lines between states) are labeled with <what causes the transition>/<messages and events triggered by the transition>. So "*timeout*/Auth Request" means that the state received a "timeout" event and sent an Authorization Request ("Auth Request") message. If there are multiple events or messages before the slash "/" separated by a comma, *any* of them can cause a transition. If there are multiple events or messages listed after the slash, *all* of the specified actions must accompany the transition.

The Authorization state transition matrix presented in Table 36 lists the six Authorization machine states in the top-most row and the eight Authorization machine events (includes message receipts) in the left-most column. Any cell within the matrix represents a specific combination of state and event, with the next state (the state transitioned to) displayed within the cell. For example, cell 4-B represents the receipt of an Authorization Reply (Auth Reply) message when in the Authorize Wait (Auth Wait) state. Within cell 4-B is the name of the next state, "Authorized." Thus, when a SS's Authorization state machine is in the Authorize Wait state and an Authorization Reply message is received, the Authorization state machine will transition to the Authorized state. In conjunction with this state transition, several protocol actions must be taken; these are described in the listing of protocol actions, under the heading 4-B, in Section 2.16.1.2.5.

A shaded cell within the state transition matrix implies that either the specific event cannot or should not occur within that state, and if the event does occur, the state machine shall ignore it. For example, if an Authorization Reply message arrives when in the Authorized state, that message should be ignored (cell 4-C). The SS may, however, in response to an improper event, log its occurrence, generate an SNMP event, or take some other vendor-defined action. These actions, however, are not specified within the context of the Authorization state machine, which simply ignores improper events.

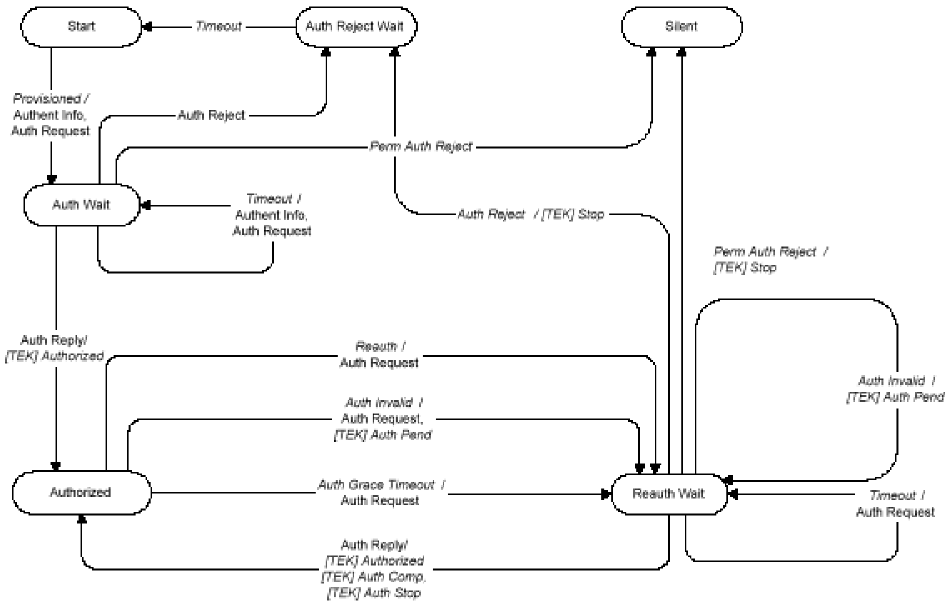


Figure 114—Authorization State Machine Flow Diagram

Table 36— Authorization FSM State Transition Matrix

State ***Event or Rcvd Message***	**(A)** **Start**	**(B)** **Auth Wait**	**(C)** **Authorized**	**(D)** **Reauth Wait**	**(E)** **Auth Reject Wait**	**(F)** **Silent**
(1) *Provisioned*	Auth Wait					
(2) Auth Reject		Auth Reject Wait		Auth Reject Wait		
(3) Perm Auth Reject		Silent		Silent		
(4) Auth Reply		Authorized		Authorized		
(5) Timeout		Auth Wait		Reauth Wait	Start	
(6) Auth Grace Timeout			Reauth Wait			
(7) Auth Invalid			Reauth Wait	Reauth Wait		
(8) Reauth			Reauth Wait			

2.16.1.2.1 States

Start

This is the initial state of the FSM. No resources are assigned to or used by the FSM in this state—e.g., all timers are off, and no processing is scheduled.

Authorize Wait (Auth Wait)

The SS has received the “Provisioned” event indicating that it has completed RF MAC registration with the BS. In response to receiving the event, the SS has sent both an Authentication Information and an Authorize Request message to the BS and is waiting for the reply.

Authorized

The SS has received an Authorization Reply message which contains a list of valid SAIDs for this SS. At this point, the SS has a valid Authorization Key and SAID list. Transition into this state triggers the creation of one TEK FSM for each of the SS’s privacy-enabled SAIDs.

Reauthorize Wait (Reauth Wait)

The SS has an outstanding re-authorization request. The SS was either about to time out its current authorization or received an indication (an Authorization Invalid message from the BS) that it's authorization was no longer valid. The SS sent an Authorization Request message to the BS and is waiting for a response.

Authorize Reject Wait (Auth RejectWait)

The SS received an Authorization Reject message in response to its last Authorization Request. The Authorization Reject's error code indicated the error was not of a permanent nature. In response to receiving this reject message, the SS set a timer and transitioned to the Authorize Reject Wait state. The SS remains in this state until the timer expires.

Silent

The SS received an Authorization Reject message in response to its last Authorization Request. The Authorization Reject's error code indicated the error was of a permanent nature. This triggers a transition to the Silent state, where the SS is not permitted to pass Subscriber traffic, but is able to respond to SNMP management requests arriving from across the cable network.

2.16.1.2.2 Messages

Note that the message formats are defined in detail in Section 2.16.2.

Authorization Request (Auth Request)

Request an Authorization Key and list of authorized SAIDs. Sent from SS to BS.

Authorization Reply (Auth Reply)

Receive an Authorization Key and list of authorized, static SAIDs. Sent from BS to SS. The Authorization Key is encrypted with the SS's public key.

Authorization Reject (Auth Reject)

Attempt to authorize was rejected. Sent from the BS to the SS.

Authorization Invalid (Auth Invalid)

The BS can send an Authorization Invalid message to a client SS as:

an unsolicited indication, or
a response to a message received from that SS

In either case, the Authorization Invalid message instructs the receiving SS to re-authorize with its BS.

The BS responds to a Key Request with an Authorization Invalid message if (1) the BS does not recognize the SS as being authorized (i.e., no valid Authorization Key associated with SS) or (2) verification of the Key Request's keyed message digest (in HMAC-Digest Attribute) failed. Note that the Authorization Invalid *event*, referenced in both the state flow diagram and the state transition matrix, signifies either the receipt of a Authorization Invalid message or an internally generated event.

Authentication Information (Authent Info)

The Authentication Information message contains the SS manufacturer’s X.509 Certificate, issued by an external authority. The Authent Info message is strictly an informative message the SS sends to the BS; with it, a BS may dynamically learn the manufacturer certificate of client SS. Alternatively, a BS may require out-of-band configuration of its list of manufacturer certificates.

2.16.1.2.3 Events

Provisioned

The Authorization state machine generates this event upon entering the Start state if the RF MAC has completed initialization, i.e., BS registration. If the RF MAC initialization is not complete, the SS sends a Provisioned event to the Authorization FSM upon completing BS registration. The Provisioned event triggers the SS to begin the process of getting its Authorization Key and TEKs.

Timeout

A retransmission or wait timer timed out. Generally a request is resent.

Authorization Grace Timeout (Auth Grace Timeout)

The Authorization Grace timer timed out. This timer fires a configurable amount of time (the Authorization Grace Time) before the current authorization is supposed to expire, signalling the SS to re-authorize before its authorization actually expires. The Authorization Grace Time is specified in a configuration setting within the TFTP-downloaded parameter file.

Reauthorize (Reauth)

SS's set of authorized static SAIDs may have changed. Event generated in response to an SNMP set, meant to trigger a reauthorization cycle.

Authorization Invalid (Auth Invalid)

This event can be internally generated by the SS when there is a failure authenticating a Key Reply or Key Reject message, or externally generated by the receipt of an Authorization Invalid message, sent from the BS to the SS. A BS responds to a Key Request with an Authorization Invalid if verification of the request’s message authentication code fails. Both cases indicate BS and SS have lost Authorization Key synchronization.

A BS may also send a SS an unsolicited Authorization Invalid message to a SS, forcing an Authorization Invalid event.

Permanent Authorization Reject (Perm Auth Reject)

The SS receives an Authorization Reject in response to an Authorization Request. The error code in the Authorization Reject indicates the error is of a permanent nature. What is interpreted as a permanent error is subject to administrative control within the BS. Authorization Request processing errors that can be interpreted as permanent error conditions include:

unknown manufacturer (do not have CA certificate of the issuer of the SS Certificate)
invalid signature on SS certificate
ASN.1 parsing failure
inconsistencies between data in the certificate and data in accompanying PKM data Attributes
incompatible security capabilities

When a SS receives an Authorization Reject indicating a permanent failure condition, the Authorization State machine moves into a Silent state where the SS is not permitted to pass Subscriber traffic, but is able to respond to SNMP management requests received across the cable network interface. SS shall issue an SNMP Trap upon entering the Silent state.

Authorization Reject (Auth Reject)

The SS receives an Authorization Reject in response to an Authorization Request. The error code in the Authorization Reject does not indicate the failure was due to a permanent error condition. As a result, the SS's Authorization state machine will set a wait timer and transition into the Authorization Reject Wait State. The SS remains in this state until the timer expires, at which time it will re-attempt authorization.

[Note: the following events are sent by an Authorization state machine to the TEK state machine.]

[TEK] Stop

Sent by the Authorization FSM to an active (non -START state) TEK FSM to terminate the FSM and remove the corresponding SAID's keying material from the SS's key table.

[TEK] Authorized

Sent by the Authorization FSM to a non-active (START state), but valid TEK FSM.

[TEK] Authorization Pending (Auth Pend)

Sent by the Authorization FSM to a specific TEK FSM to place that TEK FSM in a wait state until the Authorization FSM can complete its re-authorization operation.

[TEK] Authorization Complete (Auth Comp)

Sent by the Authorization FSM to a TEK FSM in the Operational Reauthorize Wait (Op Reauth Wait) or Rekey Reauthorize Wait (Rekey Reauth Wait) states to clear the wait state begun by a TEK FSM Authorization Pending event.

2.16.1.2.4 Parameters

All configuration parameter values are specified in the TFTP-downloaded parameter file (see 2.20: TFTP Configuration File Extensions).

Authorize Wait Timeout (Auth Wait Timeout)

Timeout period between sending Authorization Request messages from AuthorizeWait state. See 2.20.1.1.1.

Authorization Grace Time (Auth Grace Time)

Amount of time before authorization is scheduled to expire that the SS starts reauthorization. See .

Authorization Grace Time (Auth Grace Timeout)

Amount of time before authorization is scheduled to expire that the SS starts re-authorization. See 2.20.1.1.2.

Authorize Reject Wait Timeout (Auth Reject Wait Timeout)

Amount of time a SS's Authorization FSM remains in the Authorize Reject Wait state before transitioning to the Start state. See .

2.16.1.2.5 Actions

Actions taken in association with state transitions are listed by <event/rcvd message> - <state> below:

1-A Start (*Provisioned*) → Auth Wait

send Authentication Information message to BS
send Authorization Request message to BS
set Authorization Request retry timer to Authorize Wait Timeout

2-B Auth Wait (Auth Reject) → Auth Reject Wait

clear Authorization Request retry timer
set a wait timer to Authorize Reject Wait Timeout

2-D Reauth Wait (Auth Reject) → Auth Reject Wait

clear Authorization Request retry timer
generate TEK FSM Stop events for all active TEK state machines
set a wait timer to Authorize Reject Wait Timeout

3-B Auth Wait (Perm Auth Reject) → Silent

clear Authorization Request retry timer
disable all forwarding of SS traffic

3-D Reauth Wait (Perm Auth Reject) → Silent

clear Authorization Request retry timer
generate TEK FSM Stop events for all active TEK state machines
disable all forwarding of SS traffic

4-B Auth Wait (Auth Reply) → Authorized

clear Authorization Request retry timer
decrypt and record Authorization Key delivered with Authorization Reply
start TEK FSMs for all SAIDs listed in Authorization Reply (provided the SS supports the cryptographic suite that is associated with a SAID) and issue a TEK FSM Authorized event for each of the new TEK FSMs
set the Authorization Grace timer to go off "Authorization Grace Time" seconds prior to the supplied Authorization Key's scheduled expiration

4-D Reauth Wait (Auth Reply) → Authorized

clear Authorization Request retry timer
decrypt and record Authorization Key delivered with Authorization Reply

start TEK FSMs for any newly authorized SAIDs listed in Authorization Reply (provided the SS supports the cryptographic suite that is associated with the new SAID) and issue TEK FSM Authorized event for each of the new TEK FSMs

generate TEK FSM Authorization Complete events for any currently active TEK FSMs whose corresponding SAIDs were listed in Authorization Reply

generate TEK FSM Stop events for any currently active TEK FSMs whose corresponding SAIDs were not listed in Authorization Reply

set the Authorization Grace timer to go off “Authorization Grace Time” seconds prior to the supplied Authorization Key’s scheduled expiration

<u>5-B</u> Auth Wait (*Timeout*) → Auth Wait

send Authentication Information message to BS

send Authorization Request message to BS

set Authorization Request retry timer to Authorize Wait Timeout

<u>5-D</u> Reauth Wait (*Timeout*) → Reauth Wait

send Authorization Request message to BS

set Authorization Request retry timer to Reauthorize Wait Timeout

5-E Auth Reject Wait (*Timeout*) → Start

no protocol actions associated with state transition

<u>6-C</u> Authorized (*Auth Grace Timeout*) → Reauth Wait

send Authorization Request message to BS

set Authorization Request retry timer to Reauthorize Wait Timeout

<u>7-C</u> Authorized (*Auth Invalid*) → Reauth Wait

clear Authorization Grace timer

send Authorization Request message to BS

set Authorization Request retry timer to Reauthorize Wait Timeout

if the Authorization Invalid event is associated with a particular TEK FSM, generate a TEK FSM Authorization Pending event for the TEK state machine responsible for the Authorization Invalid event (i.e., the TEK FSM that either generated the event, or sent the Key Request message the BS responded to with an Authorization Invalid message)

<u>7-D</u> Reauth Wait (*Auth Invalid*) → Reauth Wait

if the Authorization Invalid event is associated with a particular TEK FSM, generate a TEK FSM Authorization Pending event for the TEK state machine responsible for the Authorization Invalid event (i.e., the TEK FSM that either generated the event, or sent the Key Request message the BS responded to with an Authorization Invalid message)

<u>8-C</u> Authorized (*Reauth*) → Reauth Wait

clear Authorization grace timer

send Authorization Request message to BS set Authorization Request retry timer to Reauthorize Wait Timeout

2.16.1.3 TEK State Machine

The TEK state machine consists of six states and nine events (including receipt of messages) that can trigger state transitions. Like the Authorization state machine, the TEK state machine is presented in both a state flow diagram and a state transition matrix. And as was the case for the Authorization state machine, the state transition matrix shall be used as the definitive specification of protocol actions associated with each state transition.

Shaded states in Figure 115 (Operational, Rekey Wait, and Rekey Reauthorize Wait) have valid keying material and encrypted traffic can be passed.

The Authorization state machine starts an independent TEK state machine for each of its authorized SAIDs.

As mentioned previously in Section 2.16.1.1, the BS maintains two active TEKs per SAID. The BS includes in its Key Replies both of these TEKs, along with their remaining lifetimes. The BS encrypts downstream traffic with the older of its two TEKs and decrypts upstream traffic with either the older or newer TEK, depending upon which of the two keys the SS was using at the time. The SS encrypts upstream traffic with the newer of its two TEKs and decrypts downstream traffic with either the older or newer TEK, depending upon which of the two keys the BS was using at the time. See Section 2.18 for details on SS and BS key usage requirements.

Through operation of a TEK state machine, the SS attempts to keep its copies of a SAID’s TEKs synchronized with those of its BS. A TEK state machine issues Key Requests to refresh copies of its SAID’s keying material soon after the scheduled expiration time of the older of its two TEKs and before the expiration of its newer TEK. To accommodate for SS/BS clock skew and other system processing and transmission delays, the SS schedules its Key Requests a configurable number of seconds before the newer TEK’s estimated expiration in the BS. With the receipt of the Key Reply, the SS shall always update its records with the TEK Parameters from both TEKs contained in the Key Reply Message. Figure 115 illustrates the SS’s scheduling of its key refreshes in conjunction with its management of a SA’s active TEKs.

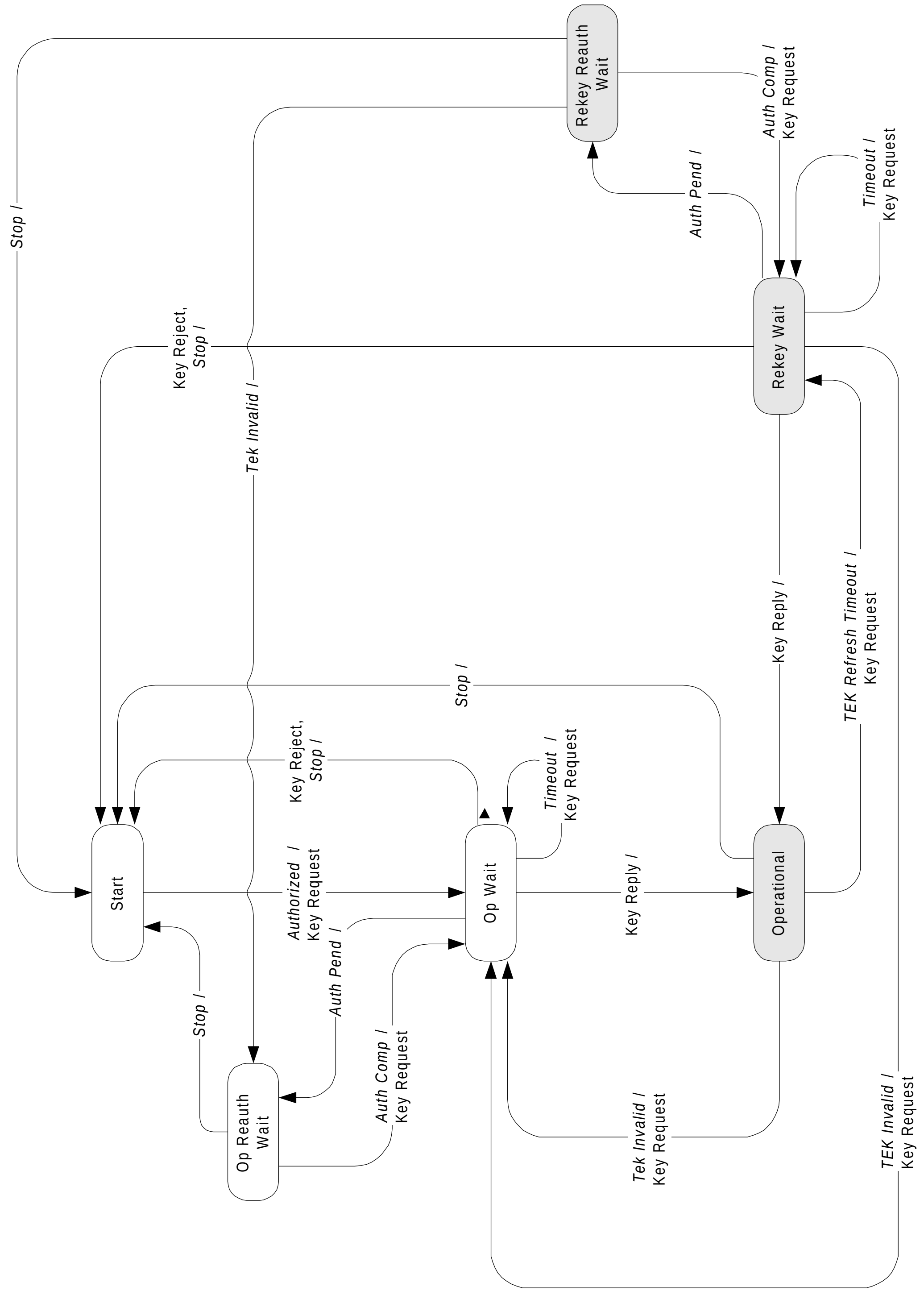


Figure 115—TEK State Machine Flow Diagram

Table 37—TEK FSM State Transition Matrix

State ***Event or Rcvd Message***	**(A)** **Start**	**(B)** **Op Wait**	**(C)** **Op Reauth Wait**	**(D)** **Op**	**(E)** **Rekey Wait**	**(F)** **Rekey Reauth Wait**
(1) *Stop*		Start	Start	Start	Start	Start
(2) *Authorized*	Op Wait					
(3) *Auth Pend*		Op Reauth Wait			Rekey Re-auth Wait	
(4) *Auth Comp*			Op Wait			Rekey Wait
(5) *TEK Invalid*				Op Wait	Op Wait	Op Reauth Wait
(6) *Timeout*		Op Wait			Rekey Wait	
(7) *TEK Refresh Timeout*				Rekey Wait		
(8) Key Reply		Operational			Operational	
(9) Key Reject		Start			Start	

2.16.1.3.1 States

Start

This is the initial state of the FSM. No resources are assigned to or used by the FSM in this state—e.g., all timers are off, and no processing is scheduled.

Operational Wait (Op Wait)

The TEK state machine has sent its initial request (Key Request) for its SAID’s keying material (traffic encryption key and CBC initialization vector), and is waiting for a reply from the BS.

Operational Reauthorize Wait (Op Reauth Wait)

The wait state the TEK state machine is placed in if it does not have valid keying material while the Authorization state machine is in the in the middle of a reauthorization cycle.

Operational

The SS has valid keying material for the associated SAID.

Rekey Wait

The TEK Refresh Timer has expired and the SS has requested a key update for this SAID. Note that the newer of its two TEKs has not expired and can still be used for both encrypting and decrypting data traffic.

Rekey Reauthorize Wait (Rekey ReauthWait)

The wait state the TEK state machine is placed in if the TEK state machine has valid traffic keying material, has an outstanding request for the latest keying material, and the Authorization state machine initiates a reauthorization cycle.

2.16.1.3.2 Messages

Note that the message formats are defined in detail in Section 2.16.2.

Key Request

Request a TEK for this SAID. Sent by the SS to the BS and authenticated with keyed message digest. The message authentication key is derived from the Authorization Key.

Key Reply

Response from the BS carrying the two active sets of traffic keying material for this SAID. Sent by the BS to the SS, it includes the SAID’s traffic encryption keys, triple DES encrypted with a key encryption key derived from the Authorization Key. The Key Reply message is authenticated with a keyed message digest; the authentication key is derived from the Authorization Key.

Key Reject

Response from the BS to the SS to indicate this SAID is no longer valid and no key will be sent. The Key Reject message is authenticated with a keyed message digest; the authentication key is derived from the Authorization Key

TEK Invalid

The BS sends a SS this message if it determines that the SS encrypted an upstream PDU with an invalid TEK; i.e., a SAID’s TEK key sequence number, contained within the received PDU’s MAC Header, is out of the BS’s range of known, valid sequence numbers for that SAID.

2.16.1.3.3 Events

Stop

Sent by the Authorization FSM to an active (non-START state) TEK FSM to terminate TEK FSM and remove the corresponding SAID’s keying material from the SS’s key table. See Section .

Authorized

Sent by the Authorization FSM to a non-active (START state) TEK FSM to notify TEK FSM of successful authorization. See Section .

Authorization Pending (Auth Pend)

Sent by the Authorization FSM to TEK FSM to place TEK FSM in a wait state while Authorization FSM completes re-authorization. See Section .

Authorization Complete (Auth Comp)

Sent by the Authorization FSM to a TEK FSM in the Operational Reauthorize Wait or Rekey Reauthorize Wait states to clear the wait state begun by the prior Authorization Pending event. See Section <TBD>.

TEK Invalid

This event can be triggered by either a SS's data packet decryption logic, or by the receipt of a TEK Invalid message from the BS.

A SS's data packet decryption logic triggers a TEK Invalid event if it recognizes a loss of TEK key synchronization between itself and the encrypting BS; i.e., a SAID's TEK key sequence number, contained within the received, downstream PDU's MAC Header, is out of the SS's range of known sequence numbers for that SAID.

A BS sends a SS a TEK Invalid message, triggering a TEK Invalid event within the SS, if the BS's decryption logic recognizes a loss of TEK key synchronization between itself and the SS.

Timeout

A retry timer timeout. Generally, the particular request is retransmitted.

TEK Refresh Timeout

The TEK refresh timer timed out. This timer event signals the TEK state machine to issue a new Key Request in order to refresh its keying material. The refresh timer is set to fire a configurable length of time (*TEK Grace Time*) before the expiration of the newer TEK the SS currently holds. This is configured via the BS to occur after the scheduled expiration of the older of the two TEKs.

2.16.1.3.4 Parameters

All configuration parameter values are specified in TFTP downloaded parameter file (see Section 2.20,: TFTP Configuration File Extensions).

Operational Wait Timeout

Timeout period between sending of Key Request messages from the Op Wait state. See Section 2.20.1.1.3.

Rekey Wait Timeout

Timeout period between sending of Key Request messages from the Rekey Wait state. See Section 2.20.1.1.4.

TEK Grace Time

Time interval, in seconds, before the estimated expiration of a TEK that the SS starts rekeying for a new TEK.

TEK Grace Time is specified in a configuration setting within the TFTP-downloaded parameter file, and is the same across all SAIDs. See Section 2.20.1.1.5.

2.16.1.3.5 Actions

1-B Op Wait (*Stop*) → Start

clear Key Request retry timer
terminate TEK FSM

1-C Op Reauth Wait (*Stop*) → Start

terminate TEK FSM

1-D Operational (*Stop*) → Start

clear TEK refresh timer, which is timer set to go off “*Tek Grace Time*” seconds prior to the TEK’s scheduled expiration time
terminate TEK FSM
remove SAID keying material from key table

1-E Rekey Wait(*Stop*) → Start

clear Key Request retry timer
terminate TEK FSM
remove SAID keying material from key table

1-F Rekey Reauth Wait(*Stop*) → Start

terminate TEK FSM
remove SAID keying material from key table

2-A Start (*Authorized*) → Op Wait

send Key Request Message to BS
set Key Request retry timer to Operational Wait Timeout

3-B Op Wait (*Auth Pend*) → Op Reauth Wait

clear Key Request retry timer

3-E Rekey Wait (*Auth Pend*) → Rekey Reauth Wait

clear Key Request retry timer

4-C Op Reauth Wait (*Auth Comp*) → Op Wait

send Key Request message to BS
set Key Request retry timer to Operational Wait Timeout

4-F Rekey Reauth Wait (*Auth Comp*) → Rekey Wait

send Key Request message to BS
set Key Request retry timer to Rekey Wait Timeout

5-D Operational (*TEK Invalid*) → Op Wait

clear TEK refresh timer
send Key Request message to BS
set Key Request retry timer to Operational Wait Timeout
remove SAID keying material from key table

5-E Rekey Wait (*TEK Invalid*) → Op Wait

clear Key Request retry timer
send Key Request message to BS
set Key Request retry timer to Operational Wait Timeout
remove SAID keying material from key table

5-F Rekey Reauth Wait (*TEK Invalid*) → Op Reauth Wait

remove SAID keying material from key table

6-B Op Wait (*Timeout*) → Op Wait

send Key Request message to BS
set Key Request retry timer to Operational Wait Timeout

6-E Rekey Wait (*Timeout*) → Rekey Wait

send Key Request message to BS
set Key Request retry timer to Rekey Wait Timeout

7-D Operational (*TEK Grace Timeout*) → Rekey Wait

send Key Request message to BS
set Key Request retry timer to Rekey Wait Timeout

8-B Op Wait (Key Reply) → Operational

(Note: Key Reply passed message authentication.)

clear Key Request retry timer
process contents of Key Reply message and incorporate new keying material into key database
set the TEK refresh timer to go off “TEK Grace Time” seconds prior to the key’s scheduled expiration

8-E Rekey Wait (Key Reply) → Operational

(Note: Key Reply passed message authentication.)

clear Key Request retry timer
process contents of Key Reply message and incorporate new keying material into key database
set the TEK refresh timer to go off “TEK Grace Time” seconds prior to the key’s scheduled expiration

9-B Op Wait (Key Reject) → Start

(Note: Key Reject passed message authentication.)

clear Key Request retry timer
terminate TEK FSM

9-E Rekey Wait (Key Reject) → Start

clear Key Request retry timer
terminate TEK FSM
remove CID keying material from key table

2.16.2 Key Management Message Formats

Privacy Key Management employs two MAC message types: PKM-REQ and PKM-RSP.

Table 38—Privacy Key Management MAC Messages

Type Value	Message Name	Message Description
9	PKM-REQ	Privacy Key Management Request [SS -> BS]
10	PKM-RSP	Privacy Key Management Response [BS -> SS]

While these two MAC management message types distinguish between PKM requests (SS to BS) and responses (BS to SS), more detailed information about message contents is encoded in the PKM messages themselves. This maintains a clean separation between privacy management functions and MAC bandwidth allocation, timing and synchronization.

2.16.2.1 Packet Formats

Exactly one PKM message is encapsulated in the Management Message Payload field of a MAC management message.

A summary of the PKM message format is shown below. The fields are transmitted from left to right.

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |     Code      |  Identifier   |            Length             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  Attributes ...
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-
```

Code

The Code field is one , and identifies the type of PKM packet. When a packet is received with an invalid Code field, it SHOULD be silently discarded.

PKM Codes (decimal) are assigned as follows:

Table 39—Privacy Key Management Message Codes

Code	PKM Message Type	MAC Management Message Name
0-3	Reserved	-
4	Auth Request	PKM-REQ
5	Auth Reply	PKM-RSP
6	Auth Reject	PKM-RSP
7	Key Request	PKM-REQ
8	Key Reply	PKM-RSP
9	Key Reject	PKM-RSP
10	Auth Invalid	PKM-RSP
11	TEK Invalid	PKM-RSP
12	Authent Info	PKM-REQ
13	Map Request	PKM-REQ
14	Map Reply	PKM-RSP
15	Map Reject	PKM-RSP
16-255	Reserved	-

Identifier

The Identifier field is one . A SS uses the identifier to match a BS's responses to the SS's requests.

The SS shall change (e.g., increment, wrapping around to 0 after reaching 255) the Identifier field whenever it issues a new PKM message. A "new" message is an Authorization Request, Key Request or SA Map Request that is not a retransmission being sent in response to a Timeout event. For retransmissions, the Identifier field shall remain unchanged.

The Identifier field in Authentication Information messages, which are informative and do not effect any response messaging, may be set to zero.

The Identifier field in a BS’s PKM response message shall match the Identifier field of the PKM Request message the BS is responding to. The Identifier field in TEK Invalid messages, which are not sent in response to PKM requests, shall be set to zero. The Identifier field in unsolicited Authorization Invalid messages shall be set to zero.

On reception of a PKM response message, the SS associates the message with a particular state machine (the Authorization state machine in the case of Authorization Replies, Authorization Rejects, and Authorization Invalids; a particular TEK state machine in the case of Key Replies, Key

Rejects and TEK Invalids; a particular SA Mapping state machine in the case of SA Map Replies and SA Map Rejects).

A SS may keep track of the Identifier of its latest, pending Authorization Request. The SS may silently discard Authorization Replies and Authorization Rejects whose Identifier fields do not match those of the pending requests.

A SS may keep track of the Identifier of its latest, pending Key Request. The SS may silently discard Key Replies and Key Rejects whose Identifier fields do not match those of the pending requests.

A SS may keep track of the Identifier of its latest, pending SA Map Request. The SS may silently discard SA Map Replies and SA Map Rejects whose Identifier fields do not match those of the pending requests.

Length

The Length field is two s. It indicates the length of the Attribute fields in s. The length field does not include the Code, Identifier and Length fields. s outside the range of the Length field shall be treated as padding and ignored on reception. If the packet is shorter than the Length field indicates, it SHOULD be silently discarded. The minimum length is 0 and maximum length is 1490.

Attributes

PKM Attributes carry the specific authentication, authorization and key management data exchanged between client and server. Each PKM packet type has its own set of required and optional Attributes. Unless explicitly stated, there are no requirements on the ordering of attributes within a PKM message.

The end of the list of Attributes is indicated by the Length of the PKM packet.

Attributes are type/length/value (TLV) encoded, as shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |            Length             | Value...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Packet formats for each of the PKM messages are described below. The descriptions list the PKM attributes contained within each PKM message type. The Attributes themselves are described in Section 2.16.2.2. Unknown attributes shall be ignored on receipt, and skipped over while scanning for recognized attributes.

The BS shall silently discard all requests that do not contain ALL required attributes. The SS shall silently discard all responses that do not contain ALL required attributes.

2.16.2.1.1 Authorization Request (Auth Request)

Code: 4

Attributes:

Table 40—Authorization Request Attributes

Attribute	Contents
SS-Identification	contains information used to identify SS to BS
SS-Certificate	contains the SS’s X.509 user certificate
Security-Capabilities	describes requesting SS’s security capabilities
SAID	SS’s primary SAID equal to the Basic CID

The SS-Identification attribute contains a set of data that identifies the requesting SS to the BS. Note that the BS is in all likelihood using only a single item in the SS-Identification attribute (e.g., SS MAC address) as a SS handle. While a specific item could be selected for inclusion in the Authorization Request message, including the entire SS-Identification attribute for client identification provides vendors with greater flexibility in the headend’s system design.

The SS-Certificate attribute contains an X.509 SS certificate issued by the SS’s manufacturer. The SS’s X.509 certificate is a public-key certificate which binds the SS’s identifying information to it’s RSA public key in a verifiable manner. The X.509 certificate is digitally signed by the SS’s manufacturer, and that signature can be verified by a BS that knows the manufacturer’s public key. The manufacturer’s public key is placed in an X.509 certification authority (CA) certificate, which in turn is signed by a higher level certification authority.

The Security-Capabilities attribute is a compound attribute describing the requesting SS’s security capabilities. This includes the data encryption algorithm(s) a SS supports and the data authentication algorithm(s) supported (of which there are currently none).

A SAID attribute contains a Privacy security association identifier, or SAID. In this case, the provided SAID is the SS’s Basic CID, which is equal to the Basic CID assigned the to SS during MAC registration.

2.16.2.1.2 Authorization Reply (Auth Reply)

Sent by the BS to a client SS in response to an Authorization Request, the Authorization Reply message contains an Authorization Key, the key’s lifetime, the key’s sequence number, and a list of SA-Descriptors identifying the Primary and Static Security Associations the requesting SS is authorized to access and their particular properties (e.g., type, cryptographic suite). The Authorization Key shall be encrypted with the SS’s public key. The SA-Descriptor list shall include a descriptor for the Basic CID reported to the BS in the corresponding Authorization Request. The SA-Descriptor list may include descriptors of Static SAIDs the SS is authorized to access.

Code field: 5

Attributes:

2.16.2.1.3 Authorization Reject (Auth Reject)

BS responds to a SS’s authorization request with an Authorization Reject message if the BS rejects the SS’s authorization request.

Code field: 6

Attributes:

Table 41—Authorization Reply Attributes

Attribute	Contents
AUTH-Key	Authorization (AUTH) Key, encrypted with the target client SS's public key
Key-Lifetime	Authorization key lifetime
Key-Sequence-Number	Authorization key sequence number
(one or more) SA-Descriptor	Each SA-Descriptor compound Attribute specifies a SAID and additional properties of the SA.

Table 42—Auth Rej Attributes

Attribute	Contents
Error-Code	Error code identifying reason for rejection of authorization request
Display-String (optional)	Display String providing reason for rejection of authorization request

The Error-Code and Display-String attributes describe to the requesting SS the reason for the authorization failure.

2.16.2.1.4 Key Request

Code: 7

Attributes:

Table 43—Key Request Attributes

Attribute	Contents
SS-Identification	Contains information used to identify SS to BS
Key-Sequence-Number	Authorization key sequence number
SAID	Security Association ID
HMAC-Digest	Keyed SHA message digest

The HMAC-Digest Attribute is a keyed message digest. The HMAC-Digest Attribute shall be the final Attribute in the Key Request's Attribute list. The message digest is performed over the PDU header and all of the Key Request's Attributes, other than the HMAC-Digest, in the order in which they appear within the packet.

Inclusion of the keyed digest allows the BS to authenticate the Key Request message. The HMAC-Digest's authentication key is derived from the Authorization Key. See Section 2.19, Cryptographic Methods, for details.

2.16.2.1.5 Key Reply

Code: 8

Attributes:

Table 44—Key Reply Attributes

Attribute	Contents
Key-Sequence-Number	Authorization key sequence number
SAID	Security Association ID
TEK-Parameters	“Older” generation of key parameters relevant to SAID
TEK-Parameters	“Newer” generation of key parameters relevant to SAID
HMAC-Digest	Keyed SHA message digest

The TEK-Parameters Attribute is a compound attribute containing all of the keying material corresponding to a particular generation of a SAID's TEK. This would include the TEK, the TEK’s remaining key lifetime, its key sequence number, and the CBC initialization vector. The TEK is encrypted. See Section 2.16.2.2.13 for details.

At all times the BS maintains two sets of active generations of keying material per SAID. (A set of keying material includes the a TEK and its corresponding CBC initialization vector.) One set corresponds to the “older” generation of keying material, the second set corresponds to the “newer” generation of keying material. The newer generation has a key sequence number one greater than (modulo 16) that of the older generation. Section 2.18.1 specifies BS requirements for maintaining and using a SAID’s two active generations of keying material.

The BS distributes to a client SS both generations of active keying material. Thus, the Key Reply message contains two TEK-Parameters Attributes, each containing the keying material for one of the SAIDs two active sets of keying material.

The HMAC-Digest Attribute is a keyed message digest. The HMAC-Digest Attribute shall be the final Attribute in the Key Reply’s Attribute list. The message digest is performed over the PKM message header (starting with the PKM Code field) and all of the Key Reply’s Attributes, other than the HMAC-Digest, in the order in which they appear within the packet.

Inclusion of the keyed digest allows the receiving client to authenticate the Key Reply message and ensure SS and BS have synchronized Authorization Keys. The HMAC-Digest’s authentication key is derived from the Authorization Key. See Section 2.19, Cryptographic Methods, for details.

2.16.2.1.6 Key Reject

Receipt of a Key Reject indicates the receiving client SS is no longer authorized for a particular SAID.

Code: 9

Attributes:

Table 45—Key Reject Attributes

Attribute	Contents
Key-Sequence-Number	Authorization key sequence number
SAID	Security Association ID
Error-Code	Error code identifying reason for rejection of Key Request
Display-String (optional)	Display string containing reason for Key Reject
HMAC-Digest	Keyed SHA message digest

The HMAC-Digest Attribute is a keyed message digest. The HMAC-Digest Attribute shall be the final Attribute in the Key Reject's Attribute list. The message digest is performed over the PKM message header (starting with the PKM Code field) and all of the Key Reject's Attributes, other than the HMAC-Digest, in the order in which they appear within the packet.

Inclusion of the keyed digest allows the receiving client to authenticate the Key Reject message and ensure SS and BS have synchronized Authorization Keys. The HMAC-Digest's authentication key is derived from the Authorization Key. See Section 2.19, Cryptographic Methods, for details.

2.16.2.1.7 Authorization Invalid

The BS can send an Authorization Invalid message to a client SS as:

an unsolicited indication, or
a response to a message received from that SS

In either case, the Authorization Invalid message instructs the receiving SS to re-authorize with its BS.

The BS sends an Authorization Invalid in response to a Key Request if (1) the BS does not recognize the SS as being authorized (i.e., no valid Authorization Key associated with the requesting SS) or (2) verification of the Key Request's keyed message digest (in HMAC-Digest Attribute) failed, indicating a loss of Authorization Key synchronization between SS and BS.

Code: 10

Attributes:

Table 46—Authorization Invalid Attributes

Attribute	Contents
Error-Code	Error code identifying reason for Authorization Invalid
Display-String (optional)	Display String describing failure condition

2.16.2.1.8 TEK Invalid

The BS sends a TEK Invalid message to a client SS if the BS determines that the SS encrypted an upstream PDU with an invalid TEK; i.e., a SAID's TEK key sequence number, contained within the received packet's MAC Header, is out of the BS's range of known, valid sequence numbers for that SAID.

Code: 11

Attributes:

Table 47—TEK Invalid Attributes

Attribute	Contents
Key-Sequence-Number	Authorization key sequence number
SAID	Security Association ID
Error-Code	Error code identifying reason for TEK Invalid message
Display-String (optional)	Display string containing vendor-defined in-formation
HMAC-Digest	Keyed SHA message digest

The HMAC-Digest Attribute is a keyed message digest. The HMAC-Digest Attribute shall be the final Attribute in the TEK Invalid's Attribute list. The message digest is performed over the PKM message header (starting with the PKM Code field) and all of the TEK Invalid's Attributes, other than the HMAC-Digest, in the order in which they appear within the packet.

Inclusion of the keyed digest allows the receiving client to authenticate the TEK Invalid message and ensure SS and BS have synchronized Authorization Keys. The HMAC-Digest's authentication key is derived from the Authorization Key. See Section 2.19, Cryptographic Methods, for details.

2.16.2.1.9 Authentication Information (Authent Info)

The Authentication Info message contains a single CA-Certificate Attribute, containing an X.509 CA certificate for the manufacturer of the SS. The SS's X.509 user certificate shall have been issued by the certification authority identified by the X.509 CA certificate. All X.509 CA certificates shall be issued by an external root certification authority.

Authentication Information messages are strictly informative: while the SS shall transmit Authent Info messages as indicated by the Authentication state model (Section 2.16.1.2), the BS may ignore them.

Code: 12

Attributes:

Table 48—Authentication Information Attributes

Attribute	Contents
CA-Certificate	certificate of manufacturer CA that issued SS certificate

The CA-certificate attribute contains an X.509 CA certificate for the CA that issued the SS's X.509 user certificate. The external certification authority issues these CA-certificates to SS manufacturers.

2.16.2.1.10 SA Map Request (MAP Request)

A SS sends SA Map Requests to its BS to request the mapping of a particular downstream traffic flow to a SA. Section 2.17 describes the SA Mapping state model which uses the message.

Code: 13

Attributes:

Table 49—SA Map Request Attributes

Attribute	Contents
SS-Identification	Contains information used to identify SS to BS
SA-Query	Contains addressing information identifying the downstream traffic flow SS is requesting an SA mapping for

2.16.2.1.11 SA Map Reply (Map Reply)

A BS sends an SA Map Reply as a positive response to a client SS's SA Map Request. The SA Map Reply informs the SS of a mapping between a queried address and a SA. Section 2.17 describes the SA Mapping state model which uses the message.

Code: 14

Attributes:

Table 50—SA Map Reply Attributes

Attribute	Contents
SA-Query	Contains addressing information identifying the downstream traffic flow SS is requested an SA mapping for
SA-Descriptor	SA-Descriptor compound Attribute specifies the mapped SA's SAID and other properties.

2.16.2.1.12 SAID Map Reject (Map Reject)

A BS sends SA Map Reject as a negative response to a client SS's SA Map Request. The SA Map Reject informs the SS that either (1) downstream traffic flow identified in the SA-Query Attribute is not being encrypted or (2) the requesting SS is not authorized to receive that traffic. The contents of an error code attribute distinguishes between the two cases. Section 2.17 describes the SA Mapping state model which uses the message.

Code: 15

Attributes:

Table 51—SA MAP Reject Attributes

Attribute	Contents
SA-Query	Contains addressing information identifying the downstream traffic flow SS requested an SA mapping for
Error-Code	Error code identifying reason for rejection of SA Map Request
Display-String (optional)	Display string containing reason for Map Reject

2.16.2.2 PKM Attributes

A summary of the Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |            Length             | Value...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

The Type field is one . Values of the PKM Type field are specified below. Note that Type values between 0 and 127 are defined within the Privacy Specification, values between 128 and 255 are vendor-assigned Attribute Types.

A PKM server shall ignore Attributes with an unknown Type.

A PKM client shall ignore Attributes with an unknown Type.

PKM client and server (i.e., SS and BS) may log receipt of unknown attribute types.

Length

The Length field is 2 s, and indicates the length of this Attribute’sValue field, in s. The length field *does not include* the Type and Length fields. The minimum Attribute Length is 0, the maximum Length is <TBD>.

Packets containing attributes with invalid lengths SHOULD be silently discarded.

Value

The Value field is zero or more s and contains information specific to the Attribute. The format and length of the Value field is determined by the Type and Length fields. All multi- integer quantities are in network-byte order, i.e., the containing the most-significant bits is the first transmitted on the wire.

Table 52—PKM Attribute Types

Type	BPKM Attribute
0	Reserved
1	Serial-Number
2	Manufacturer-ID
3	MAC-Address
4	RSA-Public-Key
5	SS-Identification
6	Display-String
7	AUTH-KEY
8	TEK
9	Key-Lifetime
10	Key-Sequence-Number
11	HMAC-Digest
12	SAID
13	TEK-Parameters
14	Reserved
15	CBC-IV
16	Error-Code
17	CA-Certificate
18	SS-Certificate
19	Security-Capabilities
20	Cryptographic-Suite
21	Cryptographic-Suite-List
22	Version
23	SA-Descriptor
24	SA-Type
25	SA-Query
26	SA-Query-Type
27	IP-Address
28-126	Reserved
127	Vendor-Defined
128-255	Vendor-assigned attribute types

Note that a “string” does not require termination by an ASCII NULL because the Attribute already has a length field.

The format of the value field is one of five data types.

Table 53—Attribute Value Data Types

string	0 – n s
uint8	8-bit unsigned integer
uint16	16-bit unsigned integer
uint32	32-bit unsigned integer
compound	collection of Attributes

2.16.2.2.1 Serial-Number

Description

This Attribute indicates the serial number assigned by the manufacturer to a SS device.

A summary of the Serial-Number Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type = 1  |            Length             | String...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

1 for Serial-Number

Length

>= 0 and =<255

String

The String field is zero or more s and contains a manufacturer-assigned serial number.

The manufacturer-assigned serial number shall be encoded in the ISO 8859-1 character encoding.

The characters employed shall be restricted to the following:

A-Z (0x41-0x5A)
a-z (0x61-0x7A)
0-9 (0x30-0x39)

"-" (0xD2)

2.16.2.2.2 Manufacturer-ID

Description

This Attribute identifies the manufacturer. The identifier is 3 s long and contains the 3- Organizationally Unique Identifier (OUI) assigned to applying organizations by the IEEE [IEEE802]. The first two bits of the 3- string are set to zero.

A summary of the Manufacturer-ID Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type = 2  |             Length              | String...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

2 for Manufacturer-ID

Length

3

String

The String field is three s and contains an IEEE OUI.

2.16.2.2.3 MAC-Address

Description

This Attribute identifies the IEEE MAC address assigned to the SS. Guaranteed to be unique, it is likely to be used as a SS handle/index at the BS.

A summary of the MAC-Address Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type = 3  |             Length              | String...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

3 for MAC-Address

Length

6

String

The String field contains a 6- MAC address.

2.16.2.2.4 RSA-Public-Key

Description

This Attribute is a string attribute containing a DER-encoded RSAPublicKey ASN.1 type, as defined in the RSA Encryption Standard PKCS #1 v2.0 [RSA3].

PKCS #1 v2.0 specifies that an RSA public key consists of both an RSA public modulus and an RSA public exponent; the RSAPublicKey type includes both of these as DER-encoded INTEGER types.

PKCS #1 v2.0 states that the RSA public exponent may be standardized in specific applications, and the document suggests values of 3 or 65537 (F4). The protocol standardizes on F4 for a public exponent and employs a 1024-bit modulus.

A summary of the Public-Key Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type = 4  |            Length             | String...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

4 for RSA-Public-Key

Length

140 (length of DER-encoding, using F4 as the public exponent, and a 1024-bit public modulus)

String

DER-encoded RSAPublicKey ASN.1 type

2.16.2.2.5 SS-Identification

Description

This Attribute is a compound attribute, consisting of a collection of sub-attributes. These sub-attributes contain information that can be used to uniquely identify a SS. Sub-attributes shall include:

Serial-Number
Manufacturer-ID

MAC-Address
RSA-Public-Key

The SS-Identification may also contain optional Vendor-Defined Attributes.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 5   |            Length             | Compound
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

5

Length

>= 126

2.16.2.2.6 Display-String

Description

This Attribute contains a textual message. It is typically used to explain a failure response, and might be logged by the receiver for later retrieval by an SNMP manager. Display strings shall be no longer than 128 bytes.

A summary of the Display-String Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 6   |            Length             | String...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

6 for Display String

Length

>=0 and <= 128

String

A string of characters. There is no requirement that the character string be null terminated; the length field always identifies the end of the string.

2.16.2.2.7 AUTH-Key

Description

The Authorization Key is an 20 byte quantity, from which a key encryption key, and two message authentication keys (one for upstream requests, and a second for downstream replies) are derived.

This Attribute contains either a 96 or a 128- quantity containing the Authorization Key RSA-encrypted with the SS's 1024-bit RSA public key. Details of the RSA encryption procedure are given in section 7.5. The ciphertext produced by the RSA algorithm will be the length of the RSA modulus, i.e., 128 s.

```
0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     Type = 7  |             Length            | String ...
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

7 for AUTH-Key

Length

96 or 128

String

96 or 128- quantity representing an RSA-encrypted Authorization Key.

2.16.2.2.8 TEK

Description

This Attribute contains an 8- quantity that is a TEK DES key, encrypted with a Key Encryption Key derived from the Authorization Key. TEK keys are encrypted using the Encrypt-Decrypt-Encrypt (EDE) mode of two-key triple DES. See Section 2.19, Cryptographic Methods, for details.

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |    Type = 8   |             Length            | String ...
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

8 for TEK

Length

8

String

64-bit quantity representing a (two-key triple DES EDE mode) encrypted traffic encryption key.

2.16.2.2.9 Key-Lifetime

Description

This Attribute contains the lifetime, in seconds, of an Authorization Key or TEK. It is a 32-bit unsigned quantity representing the number of remaining seconds that the associated key will be valid.

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Type = 9    |              Length           |    uint32 ... |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                  ... uint32                   |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

9 for Key-Lifetime

Length

4

uint32

32-bit quantity representing key lifetime

A key lifetime of zero indicates that the corresponding Authorization Key or traffic encryption key is not valid.

2.16.2.2.10 Key-Sequence-Number

Description

This Attribute contains a 4-bit sequence number for a TEK or Authorization Key. The 4-bit quantity, however, is stored in a single , with the high-order 4 bits set to 0.

A summary of the Key-Sequence-Number Attribute format is shown below. The fields are transmitted from left to right.

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |   Type = 10   |              Length           |    uint8      |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

10 for Key-Sequence-Number

Length

1

uint8

4-bit sequence number

2.16.2.2.11 HMAC-Digest

Description

This Attribute contains a keyed hash used for message authentication. The HMAC algorithm is defined in [RFC-2104]. The HMAC algorithm is specified using a generic cryptographic hash algorithm. Privacy uses a particular version of HMAC that employs the Secure Hash Algorithm (SHA-1), defined in [FIPS-180-1].

A summary of the HMAC-Digest Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 11  |             Length            |  String ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

11 for HMAC-Digest

Length

20-s

String

A 160-bit (20) keyed SHA hash

2.16.2.2.12 SAID

Description

This Attribute contains a 16-bit SAID (SAID) used by the Privacy Protocol as the security association identifier.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 12    |             Length            |    uint16 ... |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| ...uint16     |
+-+-+-+-+-+-+-+-+
```

Type

12 for SAID

Length

2

uint16

16-bit quantity representing a SAID

2.16.2.2.13 TEK-Parameters

Description

This Attribute is a compound attribute, consisting of a collection of sub-attributes. These sub-attributes represent all security parameters relevant to a particular generation of a SAID's TEK.

A summary of the TEK-Parameters Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Type = 13   |             Length            |   Compound...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

13 for TEK-Parameters

Length

33

Compound

The Compound field contains the following sub-Attributes:

2.16.2.2.14 CBC-IV

Description

Table 54—TEK-Parameters Sub-Attributes

Attribute	Contents
TEK	TEK, encrypted (two-key triple DES-EDE mode) with the KEK
Key-Lifetime	TEK Remaining Lifetime
Key-Sequence-Number	TEK Sequence Number
CBC-IV	Cipher Block Chaining (CBC) Initialization Vector

This Attribute contains a 64-bit (8-byte) value specifying a Cipher Block Chaining (CBC) Initialization Vector.

A summary of the HMAC-Digest Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Type = 15   |              Length           |   String ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

15 for CBC-IV

Length

8 s

String

A 64-bit quantity representing a DES-CBC initialization vector.

2.16.2.2.15 Error-Code

Description

This Attribute contains a one- error code providing further information about an Authorization Reject, Key Reject, Authorization Invalid, or TEK Invalid.

A summary of the Error-Code Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Type = 16   |              Length           |    uint8      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

16 for Error-Code

Length

1

uint8

1- error code

A BS shall include the Error-Code Attribute in all Authorization Reject, Authorization Invalid, Key Reject and TEK Invalid messages. Table 55 lists code values for use with this Attribute. The BS may employ the nonzero error codes (1-8) listed below; it may, however, return a code value of zero (0). Error code values other than those defined in Table 55 shall be ignored. Returning a code value of zero sends no additional failure information to the SS; for security reasons, this may be desirable.

Table 55—Error-Code Attribute Code Values

Error Code	Messages	Description
0	all	no information
1	Auth Reject, Auth Invalid	Unauthorized SS
2	Auth Reject, Key Reject	Unauthorized SAID
3	Auth Invalid	Unsolicited
4	Auth Invalid, TEK Invalid	Invalid Key Sequence Number
5	Auth Invalid	Message (Key Request) authentication failure
6	Auth Reject	Permanent Authorization Failure
7	Map Reject	not authorized for requested downstream traffic flow
8	Map Reject	downstream traffic flow not mapped to SAID

Error code 6, Permanent Authorization Failure, is used to indicate a number of different error conditions affecting the PKM authorization exchange. These include:

an unknown manufacturer; i.e., the BS does not have the CA certificate belonging to the issuer of a SS certificate
SS certificate has an invalid signature
ASN.1 parsing failure during verification of SS certificate
SS certificate is on the “hot list”
inconsistencies between certificate data and data in accompanying PKM attributes
SS and BS have incompatible security capabilities

Their common property is that the failure condition is considered permanent: any re-attempts at authorization would continue to result in Authorization Rejects. Details about the cause of a Permanent Authorization Failure may be reported to the SS in an optional Display-String Attribute that may accompany the Error-Code Attribute in Authorization Reject messages. Note that providing this additional detail to the SS should be administratively controlled within the BS. The BS may log these Authorization failures, or even trap then to an SNMP manager.

2.16.2.2.16 Vendor-Defined

The Vendor-Defined Attribute is a compound attribute whose first sub-attribute shall be the Manufacturer-ID Attribute. Subsequent Attribute(s) are user defined, with Type values as-signed by the vendor identified by the previous Manufacturer-ID Attribute.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 127   |              Length           |   Compound ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

1 27 for Vendor-Defined

Length

>= 6

Compound

The first sub-attribute shall be Manufacturer-ID. Subsequent attributes can include both universal Types (i.e., defined within this specification) and vendor-defined Types, specific to the vendor identified in the preceding Manufacturer-ID sub-attribute.

2.16.2.2.17 CA-Certificate

Description

This Attribute is a string attribute containing an X.509 CA Certificate, as defined in [X.509].

A summary of the CA-Certificate Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 17  |            Length             | String...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

17 for CA-Certificate

Length

Variable. Length shall not cause resulting MAC management message to exceed the maximum allowed size.

String

X.509 CA Certificate (DER-encoded ASN.1)

2.16.2.2.18 SS-Certificate

Description

This Attribute is a string attribute containing a SS's X.509 User Certificate, as defined in [X.509].

A summary of the SS-Certificate Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 18  |            Length             | String...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

18 for SS-Certificate

Length

Variable. Length shall not cause resulting MAC management message to exceed the maximum allowed size.

String

X.509 User Certificate (DER-encoded ASN.1)

2.16.2.2.19 Security-Capabilities

Description

The Security-Capabilities Attribute is a compound attribute whose sub-attributes identify the version of Privacy a SS supports and the cryptographic suite(s) a SS supports.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 19    |               Length          |   Compound ...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

19 for Security-Capabilities

Length

>=9

Compound

The Compound field contains the following sub-Attributes:

Table 56—Security-Capabilities Sub-Attributes

Attribute	Contents
Cryptographic-Suite-List	list of supported cryptographic suites
Version	version of Privacy supported

2.16.2.2.20 Cryptographic-Suite

Description

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  Type = 20    |               Length            |    uint16 ... |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | ...uint16     |
 +-+-+-+-+-+-+-+-+
```

Type

20 for Cryptographic-Suite

Length

2

Uint16

A 16-bit integer identifying a pairing of a data encryption algorithm (encoded in the left-most, most significant, byte) and a data authentication algorithm (encoded in the right-most, least significant, byte). Currently, 56-bit and 40-bit DES are the only algorithms specified for use within security, and neither are paired with a data authentication algorithm.

2.16.2.2.21 Cryptographic-Suite-List

Description

```
 0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |    Type = 21  |             Length              | String...
```

Table 57—Data Encryption Algorithm Identifiers

Value	Description
0	Reserved
1	CBC-Mode, 56-bit DES
2	CBC-Mode, 40-bit DES
3-255	Reserved

Table 58—Data Authentication Algorithm Identifiers

Value	Description
0	No Data Authentication
1-255	Reserved

Table 59—Cryptographic-Suite Attribute Values

Value	Description
256 (0x0100 hex)	CBC-Mode 56-bit DES & no data authentication
512 (0x0200 hex)	CBC-Mode 40-bit DES & no data authentication
all remaining values	Reserved

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

21 for Cryptographic-Suite-List

Length

2*n, where n=number of cryptographic suites listed

Uint8

A list of byte pairs identifying a collection of cryptographic suites. Each byte pair represents a supported cryptographic suite, with an encoding identical to the value field of the Cryptographic-Suite Attribute (Section 2.16.2.2.20). The BS shall not interpret the relative ordering of byte pairs in the list as a SS's preferences amongst the cryptographic suites it supports.

2.16.2.2.22 Version

Description

```
 0                   1                   2                   3
```

```
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |    Type = 22  |           Length              |     uint8     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

22 for Version

Length

1

Uint8

A 1- code identifying a version of Privacy security.

Table 60—Version Attribute Values

Value	Description
0	Reserved
1	Current Privacy
2-255	Reserved

2.16.2.2.23 SA-Descriptor

Description

The SA-Descriptor Attribute is a compound attribute whose sub-attributes describe the properties of a Security Association. These properties include the SAID, the SA type, and the cryptographic suite employed within the SA.

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |    Type = 23  |           Length              |  Compound...
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

23 for SA-Descriptor

Length

14

Compound

The Compound field contains the following sub-Attributes:

Table 61—SA-Descriptor Sub-Attributes

Attribute	Contents
SAID	Security Association ID
SA-Type	Type of SA
Cryptographic-Suite	pairing of data encryption and data authentication algorithms employed within the SA

2.16.2.2.24 SA-Type

Description

Identifies Type of SA. Privacy defines three SA types: Primary, Static, Dynamic.

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |    Type = 24  |            Length             |     uint8     |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

24 for SA-Type

Length

1

Uint8

A 1- code identifying the value of SA-type as defined in Table 62.

Table 62—SA-Type Attribute Values

Value	Description
0	Primary
1	Static
2	Dynamic
3-127	Reserved
128-255	Vendor-specific

2.16.2.2.25 SA-Query

Description

Compound Attribute used in SA Map Request to specify mapping query arguments. Query arguments include the query type and any addressing attributes particular to that query type - the addressing attributes identify a particular downstream traffic flow that a SA mapping is being requested for. Currently, the only query type specified is Multicast, and the addressing argument associated with that type is an IP group address.

```
   0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 25  |            Length              |  Compound...
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

25 for SA-Query

Length

11

Compound

The Compound field contains the following sub-Attributes:

Table 2-3. SA-Query Sub-Attributes

Attribute	Contents
SA-Query-Type	Type of Query
IP-Address	required if SA-Query-Type = IP-Multicast; contains an IP group address whose SA mapping is being requested.

2.16.3.2.26 SA-Query-Type

Description

This Attribute identifies an IP address used to identify an encrypted IP traffic flow. It is used, for example, to specify an IP multicast group address.

A summary of the IP-Address Attribute format is shown below. The fields are transmitted from left to right.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Type = 26  |            Length              |    uint8      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type

26 for SA-Query-Type

Length

1

Uint8

A 1- code identifying the value of SA-Query-Type as defined in Table 63.

Table 63—SA-Query-Type Attribute Values

Value	Description
0	Reserved
1	IP Multicast
2-127	Reserved
128-255	Vendor-specific

2.17 Dynamic SA Mapping

2.17.1 Introduction

Dynamic Security Associations (Dynamic SAs), introduced in Section 2.14.2.3, are SAs that a BS establishes and eliminates, dynamically, in response to its enabling and disabling of specific downstream traffic flows. These traffic flows may be initiated by the actions of:

a SS (Customer Premise Equipment) device attached to one of the BS's client SS,
an application server within the head end,
an OSS system, or
other unspecified mechanisms.

Regardless of what triggers the establishment of a Dynamic SA within the BS, client SS need a mechanism for learning the mapping of a particular Privacy-protected downstream traffic flow to that flow's dynamically assigned Security Association (and that SA's corresponding SAID).

The details of this mechanism and the associated requirements are TBD.

2.18 Key Usage

2.18.1 BS

After a SS completes MAC Registration, it initiates an Authorization exchange with its BS. The BS's first receipt of an Authorization Request message from the unauthorized SS initiates the activation of a new Authorization Key (AK), which the BS sends back to the requesting SS in an Authorization Reply message. This AK will remain active until it expires according to its predefined lifetime, *Authorization Key Lifetime*, a BS system configuration parameter (see Appendix A.2).

The BS shall use keying material derived from the SS's Authorization Key for:

verifying the HMAC-Digest in Key Requests received from that SS

encrypting (EDE mode two-key triple DES) the TEK in the Key Replies it sends to that SS (TEK is a sub-attribute of a Key Reply's TEK-Parameters Attribute)

calculating the HMAC-Digests it writes into Key Replies, Key Rejects and TEK Invalids sent to that SS

The BS must always be prepared to send a SS an AK upon request. The BS shall be able to support up to two simultaneously active AKs for each client SS. The BS has two active AKs during an Authorization Key transition period; the two active keys have overlapping lifetimes.

An Authorization Key transition period begins when the BS receives an Authorization Request from a SS and the BS has a single active AK for that SS. In response to this Authorization Request, the BS activates a second AK, which it sends back to the requesting SS in an Authorization Reply. The BS shall set the active lifetime of this second AK to be the remaining lifetime of the first AK, plus the predefined *Authorization Key Lifetime*; thus, the second, “newer” key will remain active for one *Authorization Key Lifetime* beyond the expiration of the first, “older” key. The key transition period will end with the expiration of the older key. This is depicted in the top half of Figure 6-1.

The Authorization Key lifetime a BS reports in a Authorization reply shall reflect, as accurately as an implementation permits, the remaining lifetimes of AK at the time the reply message is sent.

As long as the BS is in the midst of a SS's Authorization Key transition period, and thus is holding two active Authorization Keys for that SS, it will respond to Authorization Requests with the newer of the two active keys. Once the older key expires, an Authorization Request will trigger the activation of a new AK, and the start of a new key transition period.

If a SS fails to reauthorize before the expiration of its most current AK, the BS will hold no active Authorization keys for the SS and will consider the SS *unauthorized*. A BS shall remove from its keying tables all TEKs associated with an unauthorized SS's Primary SA.

A BS shall use a SS's active AK(s) to verify the HMAC-digest in Key Requests received from the SS. If a BS receives a Key Request while in an AK transition period, and the accompanying AK Key Sequence Number indicates the Request was authenticated with the newer of the two AKs, the BS identifies this as an *implicit acknowledgment* that the SS has obtained the newer of the SS's two active AKs.

A BS shall use an active AK when calculating HMAC-Digests in Key Replies and Key Rejects, and when encrypting the TEK in Key Replies. When sending Key Replies or Key Rejects within a key transition period (i.e., when two active AKs are available), if the newer key has been implicitly acknowledged, the BS shall use the newer of the two active AKs; if the newer key has not been implicitly acknowledged, the BS shall use the older of the two active AKs.

The upper half of Figure 6-1 illustrates the BS's policy regarding its use of AKs.

The BS shall maintain two sets of active traffic encryption keys (and their associated CBC initialization vectors) per SAID. They correspond to two successive generations of keying material, and have overlapping lifetimes. The newer TEK shall have a key sequence number one greater than (modulo 16) that of the older TEK. Each TEK becomes active half way through the lifetime of its predecessor, and expires half way through the lifetime of its successor. Once a TEK's lifetime expires, the TEK becomes inactive and shall no longer be used.

The BS transitions between the two active TEKs differently depending on whether the TEK is used for downstream or upstream traffic. For each of its SAIDs, the BS shall transition between active TEKs according to the following rules:

The BS shall use the older of the two active TEKs for encrypting downstream traffic. At expiration of the older TEK, the BS will immediately transition to using the newer TEK for encryption.

For decryption of upstream traffic, a transition period is defined that begins once the BS has sent the newer TEK to a SS within a Key Reply Message. The upstream transition period begins from the time the BS sends the newer TEK in a Key Reply Message and concludes once the older TEK expires. While in the transition period, the BS shall be able to decrypt upstream frames using either the older or newer TEK.

Note that the BS encrypts with a given TEK for only the second half of that TEK's total lifetime. The BS is able, however, to decrypt with a TEK for the TEK's entire lifetime.

The upper half of Figure 6-2 illustrates this BS's management of a Privacy Security Association's TEKs.

The BS is responsible for maintaining keying information for both primary and multicast SAIDs in the above manner. The Privacy Key Management protocol defined in this specification describes a mechanism for synchronizing this keying information between a BS and its client SS. It is the responsibility of the SS to update its keys in a timely fashion; the BS will transition to a new downstream encryption key regardless of whether a client SS has retrieved a copy of that TEK.

The Key Replies sent by a BS contain TEK parameters (the TEK itself, a key lifetime, a key sequence number and a CBC IV) for the two active TEKs. The key lifetimes a BS reports in a Key Reply shall reflect, as accurately as an implementation permits, the remaining lifetimes of these TEKs at the time the Key Reply message is sent.

2.18.2 SS

The SS is responsible for sustaining authorization with its BS and maintaining an active Authorization Key. A SS shall be prepared to use its two most recently obtained AKs.

AKs have a limited lifetime and must be periodically refreshed. A SS refreshes its Authorization Key by re-issuing an Authorization Request to the BS. The Authorization state machine (Section 2.16.1.2) manages the scheduling of Authorization Requests for refreshing AKs.

A SS's Authorization state machine schedules the beginning of reauthorization a configurable length of time (the *Authorization Grace Time*) before the SS's latest AK is scheduled to expire. The Authorization Grace Time is configured to provide a SS with an authorization retry period that is sufficiently long to allow for system delays and provide adequate time for the SS to successfully complete an Authorization exchange before the expiration of its most current AK.

Note that the BS does not require knowledge of the Authorization Grace Time. The BS, however, tracks the lifetime of its Authorization Keys and shall deactive a key once it has expired.

A SS shall use the newer of its two most recent Authorization Keys when calculating the HMAC-Digests it attaches to Key Requests. It shall be able to use either of its two most recent AKs to authenticate Key Replies or Key Rejects, and to decrypt a Key Keply's encrypted TEK. The SS uses the accompanying AK Key Sequence Number to determine which of the two AKs to use.

The lower half of Figure 6-1 illustrates a SS's maintenance and usage of its Authorization Keys.

A SS shall be capable of maintaining two successive sets of traffic keying material per authorized SAID. Through operation of its TEK state machines, a SS attempts to always maintain a SAID's two most recent sets of traffic keying material.

For each of its authorized SAIDs, the SS:

shall use the newer of its two TEKs to encrypt newly received upstream traffic. Traffic already queued up may use either TEK (in no specific order) for a brief period of time covering the transition from the old to the new key.

shall be able to decrypt downstream traffic encrypted with either of the TEKs

2.19 Cryptographic Methods

This section specifies cryptographic algorithms and key sizes protocol uses.

2.19.1 Packet Data Encryption

Privacy shall use the Cipher Block Chaining (CBC) mode of the US Data Encryption Standard (DES) algorithm [FIPS-46, FIPS-46-1, FIPS-74, FIPS-81] to encrypt the MAC PDU payloads.

Privacy implementations shall support 56-bit DES.

CBC shall be initialized with an initialization vector that is provided, along with other SAID key material, in a BS's Key Reply. Chaining is done block to block within a frame and reinitialized on a frame basis in order to make the system more robust to potential frame loss.

Residual termination block processing shall be used to encrypt the final block of plaintext when the final block is less than 64 bits. Given a final block having n bits, where n is less than 64, the next-to-last ciphertext block is DES encrypted a second time, using the ECB mode, and the least significant n bits of the result are exclusive ORed with the final n bits of the payload to generate the short final cipher block. In order for the receiver to decrypt the short final cipher block, the receiver DES encrypts the next-to-last ciphertext block, using the ECB mode, and exclusive ORs the left-most n bits with the short final cipher block in order to recover the short final cleartext block. This encryption procedure is depicted in Figure 9.4 (pg. 195) of [SCHNEIER].

In the special case when the frame's to-be-encrypted plaintext is less than 64 bits, the initialization vector shall be DES encrypted, and the left-most n bits of the resulting ciphertext corresponding to the number of bits of the payload shall be exclusive ORed with the n bits of the payload to generate the short cipher block.[12]

2.19.2 Encryption of TEK

The BS encrypts the value fields of the TEK in the Key Reply messages it sends to client SS. This field is encrypted using two-key triple DES in the encrypt-decrypt-encrypt (EDE) mode [SCHNEIER]:

encryption: $C = E_{k1}[D_{k2}[E_{k1}[P]]]$

decryption: $P = D_{k1}[E_{k2}[D_{k1}[C]]]$

P = Plaintext 64-bit TEK

C = Ciphertext 64-bit TEK

k1 = left-most 64 bits of the 128-bit KEK

k2 = right-most 64 bits of the 128-bit KEK

E[ ] = 56-bit DES ECB (electronic code book) mode encryption

[12] This method of encrypting short payloads is vulnerable to attack: EXORing two sets of ciphertext encrypted in the above manner under the same set of keying material will yield the EXOR of the corresponding sets of plaintext. Further investigation is required.

D[ ] = 56-bit DES ECB decryption

Section 2.19.4 below describes how the KEK is derived from the Authorization key.

2.19.3 HMAC-Digest Algorithm

The keyed hash employed by the HMAC-Digest Attribute shall use the HMAC message authentication method [RFC- 2104] with the SHA-1 hash algorithm [FIPS-180-1].

Upstream and downstream message authentication keys are derived from the Authorization Key (see Section 2.19.4 below for details).

2.19.4 Derivation of TEKs, KEKs and Message Authentication Keys

The BS generates Authorization Keys, TEKs and IVs. A random or pseudo-random number generator shall be used to generate Authorization Keys and TEKs. A random or pseudo-random number generator may also be used to generate IVs; regardless of how they are generated, IVs shall be unpredictable. [RFC-1750] provides recommended practices for generating random numbers for use within cryptographic systems.

[FIPS-81] defines DES keys as 8- (64-bit) quantities where the seven most significant bits (i.e., seven left-most bits) of each are the independent bits of a DES key, and the least significant bit (i.e., right-most bit) of each is a parity bit computed on the preceding seven independent bits and adjusted so that the has odd parity.

The keying material for two-key triple DES consists of two distinct (single) DES keys.

PKM does not require odd parity. The PKM protocol generates and distributes 8- DES keys of arbitrary parity, and it requires that implementations ignore the value of the least significant bit of each .

A key encryption key (KEK) and two message authentication keys are derived from a common Authorization Key. The following defines how these keys are derived:

KEK is the Key Encryption Key used to encrypt Traffic Encryption Keys.

HMAC_KEY_U is the message authentication key used in upstream Key Requests

HMAC_KEY_D is the message authentication key used in downstream Key Replies, Key Rejects and TEK Invalids.

SHA(x|y) denotes the result of applying the SHA function to the concatenated bit strings x and y.

Truncate(x,n) denotes the result of truncating x to its left-most n bits.

```
KEK = Truncate(SHA( K_PAD | AUTH_KEY ), 128)

HMAC_KEY_U = SHA( H_PAD_U | AUTH_KEY )

HMAC_KEY_D = SHA( H_PAD_D | AUTH_KEY )
```

Each _PAD_ is a 512 bit string:

K_PAD = 0x53 repeated 64 times.

H_PAD_U = 0x5C repeated 64 times.

H_PAD_D = 0x3A repeated 64 times.

2.19.5 Public-Key Encryption of Authorization Key

Authorization keys in Authorization Reply messages shall be RSA public-key encrypted, using the SS's public key. The protocol uses F4 (65537 decimal, or equivalently, 010001 hexadecimal) as its public exponent and a modulus length of 1024 bits. The protocol employs the RSAES-OAEP encryption scheme specified in version 2.0 of the PKCS#1 standard [RSA3]. RSAES-OAEP requires the selection of: a hash function; a mask-generation function; and an encoding parameter string. The default selections specified in [RSA3] shall be used when encrypting the authorization key. These default selections are: SHA-1 for the hash function; MGF1 with SHA-1 for the mask-generation function; and the empty string for the encoding parameter string.

2.19.6 Digital Signatures

The Protocol employs the RSA Signature Algorithm [RSA3] with SHA-1 [FIPS186] for all three of its certificate types.

As with its RSA encryption keys, Privacy uses F4 (65537 decimal, 010001 hexadecimal) as the public exponent for its signing operation. The external authority Root CA will employ a modulus length of 2048 bits (256 s) for signing the Manufacturer CA certificates it issues. Manufacturer CAs shall employ signature key modulus lengths of at least 1024 bits, and no greater than 2048 bits.

2.19.7 Supporting Alternative Algorithms

The current specification requires the use of 56-bit DES for encrypting packet data, two-key triple DES for encrypting traffic encryption keys, 1024-bit RSA for encrypting Authorization keys, and 1024-to-2048-bit RSA for signing Privacy X.509 certificates. The choice of key lengths and algorithms, while appropriate for current threat models and hardware capabilities, may be inappropriate in the future.

For example, it is generally agreed that DES is approaching the end of its practical usefulness as the industry standard for symmetric encryption. NIST is currently overseeing the development and adoption of a new standard encryption algorithm, commonly referred to as the Advanced Encryption Standard, or AES. Given the nature of the security services, the protocol is being asked to support (basic privacy at a level better than or equal to that possible over dedicated wires, and conditional access to RF data transport services) as well as the protocol's flexible key management policy (i.e., setting of key lifetimes), service providers will be justified in the continued reliance on DES for, at least, the next five years. Nevertheless, at some future date, SSs will need to adopt a stronger traffic encryption algorithm, possibly AES.

2.20 TFTP Configuration File Extensions

All of a SS's Privacy configuration parameter values are specified in the configuration file TFTP-downloaded by the SS during RF MAC initialization. Privacy configuration setting fields are included in both the SS MIC and BS MIC calculations, and in a SS's registration requests.

2.20.1 Privacy Configuration Setting Encodings

The following type/length/value encodings for Privacy configuration settings shall be used in both the configuration file and in MAC SS registration requests.

The Privacy Enable configuration setting controls whether Privacy is enabled or disabled in a SS. If Privacy is enabled, the Privacy Configuration Setting shall also be present. The Privacy Configuration setting may be present if Privacy is disabled. The separate Privacy Enable parameter allows an operator to disable or re-enable Privacy by toggling a single configuration parameter, thus not requiring the removal or re-insertion of the larger set of Privacy Configuration parameters.

This field defines the parameters associated with Privacy operation. It is composed of a number of encapsulated type/length/value fields. The type fields defined are only valid within the encapsulated Baseline Privacy configuration setting string.

type	length	value
P_CFG	n	

2.20.1.1 Internal Baseline Privacy Encodings

2.20.1.1.1 Authorize Wait Timeout

The value of the field specifies retransmission interval, in seconds, of Authorization Request messages from the Authorize Wait state.

sub-type	length	value
1	4	

Valid Range: 1 - 30

Reauthorize Wait Timeout

The value of the field specifies retransmission interval, in seconds, of Authorization Request messages from the Authorize Wait state.

sub-type	length	value
2	4	

Valid Range: 1 - 30

2.20.1.1.2 Authorization Grace Time

The value of this field specifies the grace period for re-authorization, in seconds.

sub-type	length	value
3	4	

Valid Range: 1 - 6,047,999

2.20.1.1.3 Operational Wait Timeout

The value of this field specifies the retransmission interval, in seconds, of Key Requests from the Operational Wait state.

sub-type	length	value

4	4	

Valid Range: 1 - 10

2.20.1.1.4 Rekey Wait Timeout

The value of this field specifies the retransmission interval, in seconds, of Key Requests from the Rekey Wait state.

sub-type	length	value
5	4	

Valid Range: 1 - 10

2.20.1.1.5 TEK Grace Time

The value of this field specifies grace period, in seconds, for rekeying the TEK.

sub-type	length	value
6	4	

Valid Range: 1 - 302399

2.20.1.1.6 Authorize Reject Wait Timeout

The value of this field specifies how long a SS waits (seconds) in the Authorize Reject Wait state after receiving an Authorization Reject.

sub-type	length	value
7	4	

Valid Range: 1 - 600

2.20.1.1.7 SA Map Wait Timeout

The value of this field specifies the retransmission interval, in seconds, of SA Map Requests from the Map Wait state.

sub-type	length	value
8	4	

Valid Range: 1 - 10

2.20.1.1.8 SA Map Max Retries

The value of this field specifies the maximum number of Map Request retries allowed.

sub-type	length	value
9	4	

Valid Range: 0 - 10

2.20.1.2 Parameter Guidelines

Below are recommended ranges and values for Privacy's various configuration and operational parameters. These ranges and default values may change as service providers gain operational experience running Privacy.

Table 64—Recommended Operational Ranges for Privacy Configuration Parameters

System	Name	Description	Minimum Value	Default Value	Maximum Value
BS	Authorization Lifetime	Lifetime, in seconds, BS assigns to new Authorization Key	1 day (86,400 sec.)	7 days (604,800 sec.)	70 days (6,048000 sec.)
BS	TEK Lifetime	Lifetime, in seconds, BS assigns to new TEK	30 min. (1800 sec.)	12 hours (43,200 sec.)	7 days (604,800 sec.)
SS	Authorize Wait Timeout	Auth Req retransmission interval from Auth Wait state	2 sec.	10 sec.	30 sec.
SS	Reauthorize Wait Timeout	Auth Req retransmission interval from Reauth Wait state	2 sec.	10 sec.	30 sec.
SS	Authorization Grace Time	Time prior to Authorization expiration SS begins re-authorization	5 min. (300 sec.)	10 min. (600 sec.)	35 days (3,024,000 sec).
SS	Operational Wait Timeout	Key Req retransmission interval from Op Wait state	1 sec.	1 sec.	10 sec.
SS	Rekey Wait Timeout	Key Req retransmission interval from Rekey Wait state	1 sec.	1 sec.	10 sec.
SS	TEK Grace Time	Time prior to TEK expiration SS begins rekeying	5 min. (300 sec)	1 hour (3,600 sec.)	3.5 days (302,399 sec)
SS	Authorize Reject Wait	Delay before re-sending Auth Request after receiving Auth Reject	10 sec.	60 sec.	10 min. (600 sec.)
SS	SA Map Wait Timeout	Map Request retransmission interval from Map Wait state	1 sec.	1 sec.	10 sec.
SS	SA Map Max Retries	Maximum number of times SS retries SA Map Request before giving up	0	4	10

The valid range (vs. recommended operational range) for Authorization and TEK lifetimes are:

Authorization Lifetime Valid Range: 1 - 6,048,000 seconds
TEK Lifetime Valid Range: 1 - 604,800 seconds

Note that valid ranges defined for each of Privacy’s configuration parameters extend below the recommended operational ranges. For the purposes of protocol testing, it is useful to run the privacy protocol with timer values well below the low end of the recommended operational ranges. The shorter timer values "speed up" prviacy’s clock, causing privacy protocol state machine events to occur far more rapidly than they would under an "operational" configuration. While privacy implementations need not be designed to operate efficiently at this accelerated privacy pace, the protocol implementation should operate correctly under these shorter timer values. Table 65 provides a list of shortened parameter values which are likely to be employed in protocol conformance and certification testing.

Table 65—Shortened Privacy Parameter Values for Protocol Testing

Authorization Lifetime	**5 min. (300 sec.)**
TEK Lifetime	3 min. (180 sec.)
Authorization Grace Time	1 min. (60 sec.)
TEK Grace time	1 min. (60 sec.)

The TEK Grace Time shall be less than half the TEK lifetime.

3 Physical Layer

3.1 Overview

The following physical layer specification was designed to meet the functional requirements that have been defined for Broadband Wireless Access (BWA) systems. It incorporates many aspects of existing standards in order to leverage existing technology for reduced equipment cost and demonstrated robustness of implementation, with modifications to ensure reliable operation in the targeted 10-66 GHz frequency band. In addition, this physical layer was designed with a high degree of flexibility in order to allow service providers the ability to optimize system deployments with respect to cell planning, cost considerations, radio capabilities, offered services, and capacity requirements. Two modes of operation have been defined for the downstream channel, one targeted to support a continuous transmission stream and one targeted to support a burst transmission stream. Having this separation allows each to be optimized according to their respective design constraints, while resulting in a standard that supports various system requirements and deployment scenarios.

3.1.1 Multiplexing and Multiple Access Technique

The upstream physical layer is based on the use of a combination of time division multiple access (TDMA) and demand assigned multiple access (DAMA). In particular, the upstream channel is divided into a number of "time slots". The number of slots assigned for various uses (registration, contention, guard, or user traffic) is controlled by the MAC layer in the base station and can vary in time for optimal performance. The downstream channel can be either based upon time division multiplexing (TDM), where the information for each subscriber station is multiplexed onto the same stream of data and is received by all subscriber stations located within the same sector, or in an alternative method (defined for the burst mode of operation) which allows bursts to be transmitted to specific CPEs in a similar fashion to the TDMA upstream bursts.

3.1.2 Duplexing Technique

Several duplexing techniques are supported with this physical layer. The continuous transmission downstream mode that is defined supports frequency division duplexing (FDD) only, while the burst mode of operation supports FDD with adaptive modulation or time division duplexing (TDD). The primary difference between the continuous mode and burst mode of operation for supporting FDD is the coding gain and how higher order modulation formats are supported. The continuous downstream mode is based on a concatenated Reed-Solomon, interleaver, and convolutional code, and can support different orders of modulation on separate carriers. The burst mode supports the capability to have different modulation formats transmitted on the same carrier so that the modulation level can be chosen on a subscriber level basis (*i.e*., adaptive modulation). Note that adaptive modulation is supported with any of the duplexing techniques that use the burst mode of operation.

3.1.3 Physical Media Dependent (PMD) Sublayers

Two different downstream physical layers have been defined in this standard. A Mode A downstream physical layer has been designed for continuous transmission, while a Mode B physical layer has been designed to support a burst transmission format.

Mode A is based upon a continuous transmission stream supporting a concatenation of Reed Solomon coding, interleaving, and convolutional coding for use in an FDD only system. Mode B supports a burst format that allows systems to implement an adaptive modulation scheme for an FDD system as well as supporting TDD configurations.

This approach to standardization allows for service providers the ability to pick the format which best allows them to meet their system requirements. Standards compliant subscriber stations are required to support at least one of the downstream modes of operation as defined here.

A single upstream physical layer is also defined here to support a TDMA based burst upstream transmission.

3.1.3.1 Continuous Downstream PMD Sublayer (Mode A) Overview

The Mode A downstream physical layer first encapsulates MAC packets into a convergence layer frame as defined by the transmission convergence sublayer. Then, the data is randomized and encoded using a (204,188) Reed-Solomon code over GF(256). Following the outer block encoder, the data goes through a convolutional interleaver with a depth of I=12. Then, the data must either pass through an inner, constraint length 7, convolutional code with a rate of 1/2, 2/3, 3/4, 5/6, 7/8, or 1, or pass through a differential encoder (*i.e.*, bypassing the convolutional encoder) as defined in the following sections. Code bits are then mapped to a QPSK, 16-QAM (optional), or 64-QAM (optional) signal constellation with symbol mapping as described here. Elements that are identified as optional need not be implemented in order to be standards compliant. However, if these options are supported, they shall be supported in the manner defined in this standard. Finally, symbols are Nyquist filtered using a square-root raised cosine filter with a roll-off factor of 0.15, 0.25 or 0.35.

3.1.3.2 Burst Downstream PMD Sublayer (Mode B) Overview

The Mode B downstream physical layer has a framing mechanism associated with it that simplifies the support for TDD systems and half-duplex terminals. The frame can either be configured to support a TDM transmission format, which would typically be used in a TDD system or an FDD system supporting adaptive modulation/FEC groups (to be discussed later). One unique preamble is used to indicate the beginning of a frame, which is followed by the PHY/MAC control data. A PHY control map is used to indicate the beginning of different modulation/FEC groups, which will typically be in the order of QPSK followed by 16-QAM and 64-QAM with the FEC scheme chosen to meet each desired C/I requirements. In addition, the modulation/FEC group specifications can change with time in order to adjust to the changing channel conditions. Various frame configurations for FDD and TDD are supported, as was discussed in section Figure 2.6.4. All subscriber station data is FEC block encoded allowing for a shortening of the last codeword of a burst. The Mode B downstream physical layer also goes through a transmission convergence sublayer that inserts a pointer byte at the beginning of the payload information bytes to help the receiver identify the beginning of a MAC packet. Data bits coming from the transmission convergence layer are first randomized, encoded using the defined outer and possibly inner codes, and then mapped, along with the preambles, to a QPSK, 16-QAM, or 64-QAM (optional) signal constellation. The modulated symbols are then Nyquist filtered using a square-root raised cosine filter with a roll-off factor of 0.15, 0.25 or 0.35.

3.1.3.3 Upstream PMD Sublayer Overview

The upstream physical layer has been designed to support burst modulation for a TDMA based system. Since many of the specific upstream channel parameters can be programmed by MAC layer messaging coming from the base station, several parameters can be left unspecified and configured by the base station during the registration process in order to optimize performance for a particular deployment scenario. In this mode, each burst is designed to carry MAC messages of variable lengths. The transmitter first randomizes the incoming data, and then encodes the data using an outer code and possibly an inner code to be selected by the MAC messages. The length of the codeword and the error correction capability of the code are programmable by the MAC messages coming from the base station via a burst configuration message. Each burst also contains a variable length preamble and a variable length guard space at the end of the burst. The preamble and coded bits are mapped to QPSK, 16-QAM (optional), or 64-QAM (optional) constellations. Nyquist pulse shaping using a square-root raised cosine filter is also employed with a roll-off factor of 0.15, 0.25, or 0.35.

3.2 Downstream Physical Layer

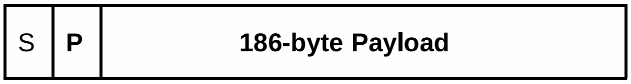
This section describes the two different downstream physical layers that have been adopted for use in this standard. A Mode A downstream physical layer has been designed for continuous transmission, while a Mode B physical layer has been designed to support a burst transmission format. Subscriber stations must support at least one of these physical layers.

3.2.1 Mode A: Continuous Downstream Transmission

This mode of operation has been designed for a continuous transmission stream, using a single modulation/coding combination on each carrier, in an FDD system (it is not applicable to FSDD or TDD operation). The physical media dependent sublayer uses a concatenated Reed-Solomon, interleaver, and convolutional code Forward Error Correction coding scheme, and has no explicit frame structure. Where spectrum resources allow, multiple carriers may be deployed, each using different modulation/coding methods defined here.

3.2.1.1 Mode A Downstream Transmission Convergence (TC) Sublayer

The downstream bitstream is defined as a continuous series of 188-byte packets. These packets consist of a one-byte synchronization pattern (Byte 1) and a one-byte pointer (Byte 2) followed by 186 bytes of payload (Bytes 3-188). The synchronization byte shall be set to hex 47 and shall be inverted to hex B8 every eight packets in order to reset the randomization function. The pointer field identifies the byte number in the packet which indicates either the beginning of the first MAC frame to start in the packet, or indicates the beginning of any stuff bytes that precede the next MAC frame. For reference, the first byte in the packet is refered to as byte number 1. If no MAC frame begins in the packet, then the pointer byte is set to 0. When no data is available to transmit, a stuff_byte pattern having a value (0xFF) must be used within the payload to fill any gaps between the 802.16 MAC frames. This value is chosen as an unused value for the first byte of the 802.16 MAC frame, which is designed to NEVER have this value. The following figure illustrates the format of the packet leaving the convergence layer.



P = 1 byte pointer field
S = 1 byte synch. pattern

Figure 116—Format of the Convergence Layer Packet

3.2.1.2 Mode A Physical Media Dependent (PMD) Sublayer

The encoding and decoding functions for the Mode A downstream physical layer are summarized in the following block diagram:

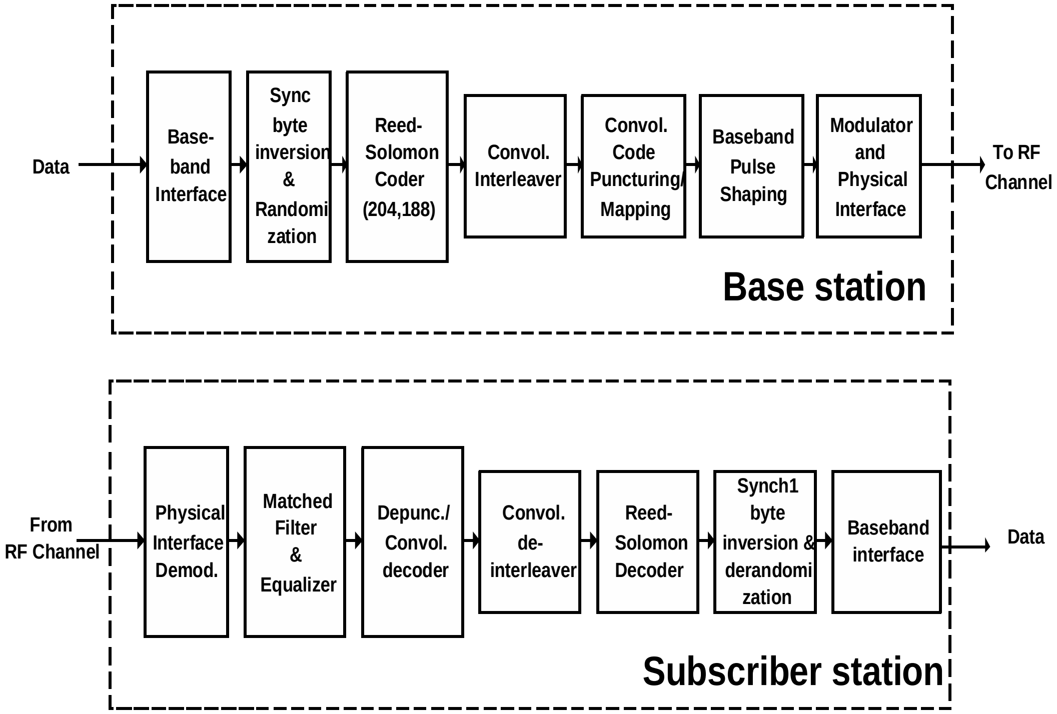

Data
Base-band Interface
Sync byte inversion & Randomization
Reed-Solomon Coder (204,188)
Convol. Interleaver
Convol. Code Puncturing/ Mapping
Baseband Pulse Shaping
Modulator and Physical Interface
To RF Channel
Base station
From RF Channel
Physical Interface Demod.
Matched Filter & Equalizer
Depunc./ Convol. decoder
Convol. de-interleaver
Reed-Solomon Decoder
Synch1 byte inversion & derandomization
Baseband interface
Data
Subscriber station

Figure 117— Conceptual Block diagram of the Mode A Downstream Physical Layer

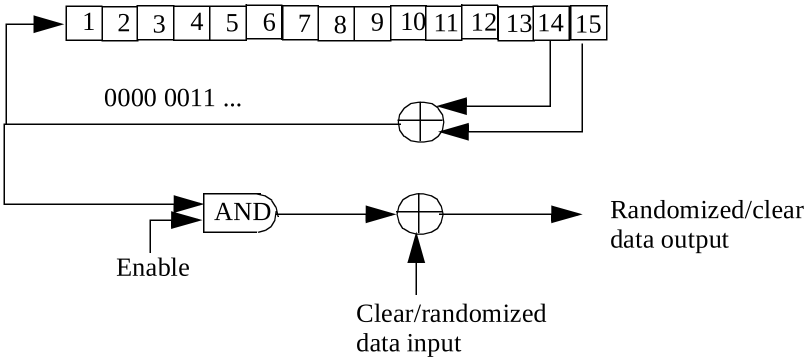
3.2.1.2.1 Baseband interfacing

This unit shall adapt the data structure coming from the MAC layer to the format defined by the transmission convergence sublayer defined above.

3.2.1.2.2 Synch. byte inversion and randomization

This unit shall invert the synch. byte according to the transmission convergence sublayer function, and randomizes the data stream for spectrum shaping purposes. Randomization shall be employed to minimize the possibility of transmission of an unmodulated carrier and to ensure adequate numbers of bit transitions to support clock recovery.

The stream of uncoded downstream packets, excluding synch. bytes, shall be randomized by modulo-2 addition of the data with the output of the pseudo random binary stream (PRBS) generator, as illustrated in the following diagram.

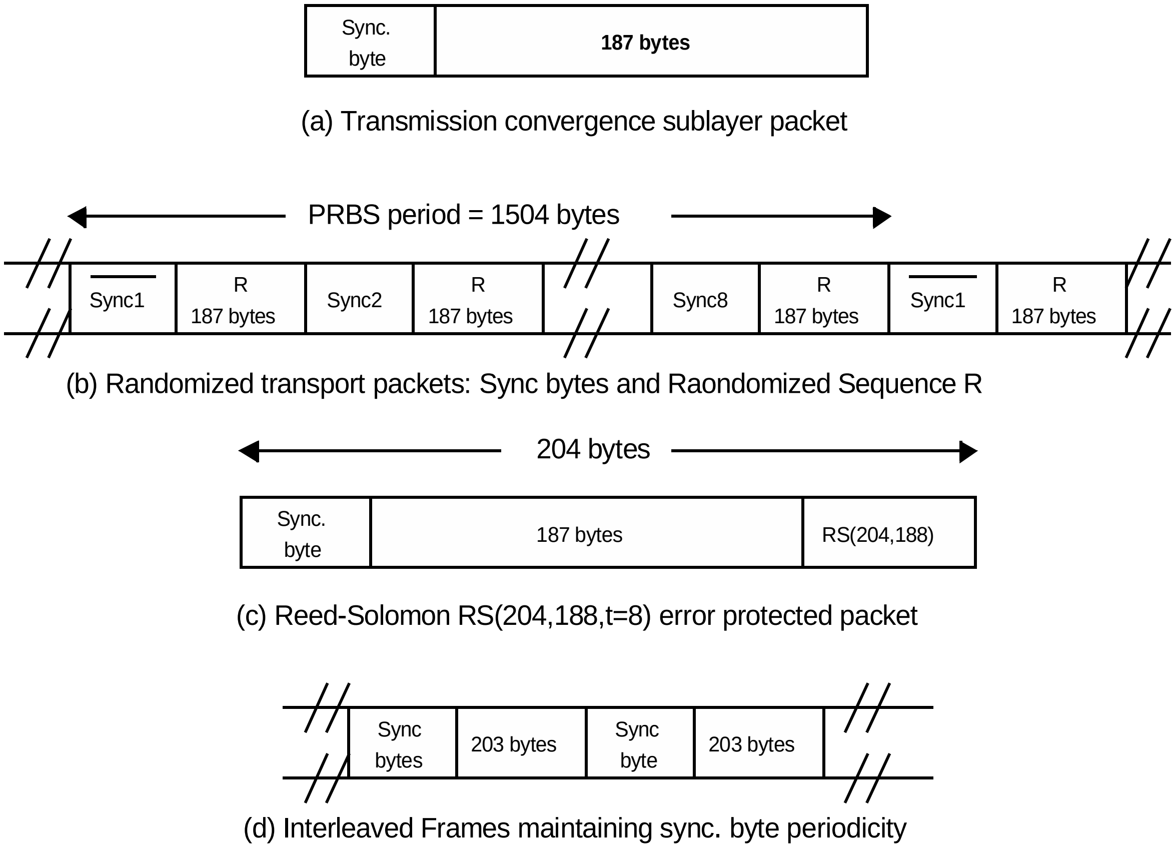


Data input (MSB first): 1 0 1 1 | 1 0 0 0 | x x x x | x x x x ....
PRBS sequence: | | 0 0 0 0 | 0 0 1 1 ....

Figure 118—Randomizer logic diagram

The PRBS shall be initialized at each inverted sync byte by the sequence 100101010000000 in the manner depicted in the figure. The synch. byte (hex 47) shall be inverted (hex B8) every eight packets, starting at the beginning base station powerup.

The generator polynomial for the PRBS shall be c(x) = $x^{15} + x^{14} + 1$. Following initialization, the first PRBS generator output bit shall be added to the first bit following the inverted synch. byte. Over subsequent synch. bytes, the PRBS generator shall continue to step its internal shift register state but the PRBS output addition to the synch. byte bits shall be disabled. Thus, the period of the PRBS sequence shall be 1504 bytes. The following diagram illustrates the framing structure of the transport stream.



(a) Transmission convergence sublayer packet

(b) Randomized transport packets: Sync bytes and Raondomized Sequence R

(c) Reed-Solomon RS(204,188,t=8) error protected packet

(d) Interleaved Frames maintaining sync. byte periodicity

$\overline{\text{Sync1}}$ = not randomized complemented sync byte

Sync n = not randomized sync byte, n=2...8

Figure 119— Framing structure based on transmission convergence sublayer.

3.2.1.2.3 Reed Solomon Coding

Following the energy dispersal randomization process, systematic shortened Reed-Solomon encoding shall be performed on each randomized transport packet, with T =8. This means that 8 erroneous bytes per transport packet can be corrected. This process adds 16 parity bytes to the transport packet to give a 204 byte codeword. RS coding shall also be applied to the packet synch byte, either non-inverted (i.e .47hex) or inverted (i.e. B8hex).

The Reed-Solomon code shall have the following generator polynomials:

Code Generator Polynomial: $g(x) = (x+\mu^0)(x+\mu^1)(x+\mu^2)...(x+\mu^{2T-1})$where μ= 02hex

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

The shortened Reed-Solomon code shall be implemented by adding 51 bytes, all set to zero, before the information bytes at the input of a (255,239) encoder; after the coding procedure these bytes are discarded.

3.2.1.2.4 Convolutional interleaving

The convolutional interleaving process shall be based on the Forney approach, with a depth of I=12. The interleaved frame shall be composed of overlapping error protected packets and shall be delimited by synch. bytes (preserving the periodicity of 204 bytes).

The interleaver is composed of I branches, cyclically connected to the input byte-stream by the input switch. Each branch shall be a First In First Out (FIFO) shift register, with depth (M) cells (where M =N/I, N =2 0 4 =error protected frame length, I =12 = maximum interleaving depth, j = branch index). The cells of the FIFO shall contain 1 byte, and the input and output switches shall be synchronized, as shown in the diagram below.

For synchronization purposes, the sync bytes and the inverted sync bytes shall be always routed into the branch "0" of the interleaver (corresponding to a null delay).

The deinterleaver is similar, in principle, to the interleaver, but the branch indexes are reversed (i.e . j=0 corresponds to the largest delay). The de-interleaver synchronization is achieved by routing the first recognized sync byte into the "0" branch.

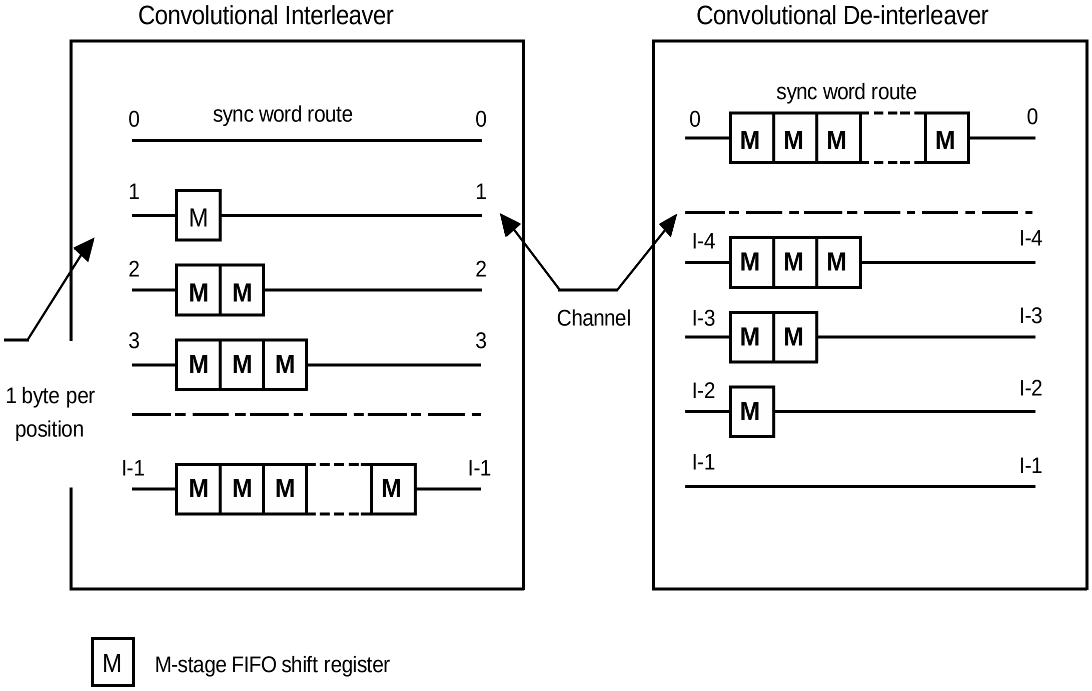


Figure 120— Conceptual diagram of the convolutional interleaver and de-interleaver.

3.2.1.2.5 Convolutional Coding with QPSK Modulation

When convolutional encoding is employed, the convolutional code shall be chosen from the following table of code rates, which are obtained by puncturing a rate 1/2 constraint length 7 code having the following generator vectors G, and puncturing patterns P (0 denotes punctured (deleted) bit).

Table 66—Convolutional Code Puncture Patterns

		1/2		2/3		3/4		5/6		7/8	
G_1	G_2	P	D_f	P	D_f	P	D_f	P	D_f	P	D_f
171 oct	133 oct	X=1 Y=1 $I=X_1$ $Q=Y_1$	10	X=10 Y=11 $I=X_1Y_2Y_3$ $Q=Y_1X_3Y_4$	6	X=101 Y=110 $I=X_1Y_2$ $Q=Y_1X_3$	5	X=10101 Y=11010 $I=X_1Y_2Y_4$ $Q=Y_1X_3X_5$	4	X=1000101 Y=1111010 $I=X_1Y_2Y_4Y_6$ $Q=Y_1Y_3X_5X_7$	3

The QPSK symbols will use gray-coded direct mapping of (I,Q) from bit pairs out of the convolutional encoder as follows:

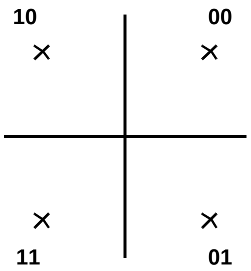


Figure 121— QPSK symbol mapping

3.2.1.2.6 Convolutional Coding with 16-QAM Modulation (optional)

16-QAM shall be supported using a rate 3/4 or 7/8 punctured convolutional code with the inner coding and constellation mapping as described in [xxx].

3.2.1.2.7 Differential encoding with QPSK or 16-QAM Modulation (16-QAM is optional)

In this mode, the inner convolutional code is disabled, and the mapping of bits to symbols shall use the following differential encoder and mapper as defined in ITU-T J.83 Annex A. The two most significant bits (MSBs) of each symbol shall be differentially coded in order to obtain a π/2 rotation-invariant QAM constellation. The differential encoding of the two MSBs shall be given by the following Boolean expression:

$$I_k = (\overline{A_k \oplus B_k}) \cdot (A_k \oplus I_{k-1}) + (A_k \oplus B_k) \cdot (A_k \oplus Q_{k-1})$$

$$Q_k = (\overline{A_k \oplus B_k}) \cdot (B_k \oplus Q_{k-1}) + (A_k \oplus B_k) \cdot (B_k \oplus I_{k-1})$$

Note: For the above Boolean expressio $a \oplus b$ "" denotes the EXOR function, $a + b$ "" denotes the logical OR function, "$a \cdot b$" denotes the logical AND function and the overstrike denotes inversion.

The following figure gives an example of implementation of byte-to-symbol conversion.

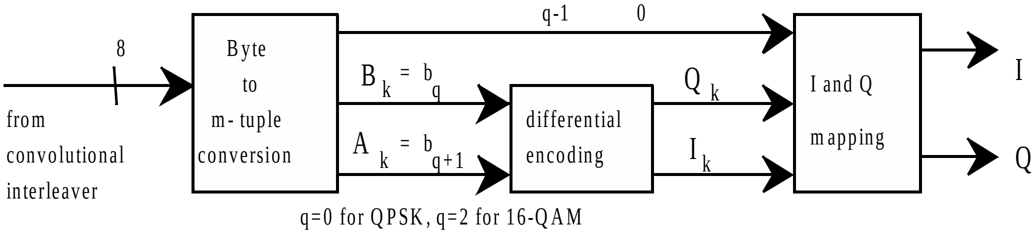


Figure 122— Example implementation of the byte to m-tuple conversion and the differential encoding of the two MSBs.

For QPSK, the output of the differential encoder shall map directly to the QPSK signal constellation based on the Quadrant to MSB mapping shown in the following table. The mapping of bits to symbols for 16-QAM, when implemented as an option, is given by the following figure.

Table 67— Conversion of constellation of quadrant 1 to other quadrants of the constellation diagrams given in the following diagrams.

Quadrant	MSBs	LSBs rotation
1	00	0
2	10	+π/2
3	11	+ π
4	01	+ 3π/2

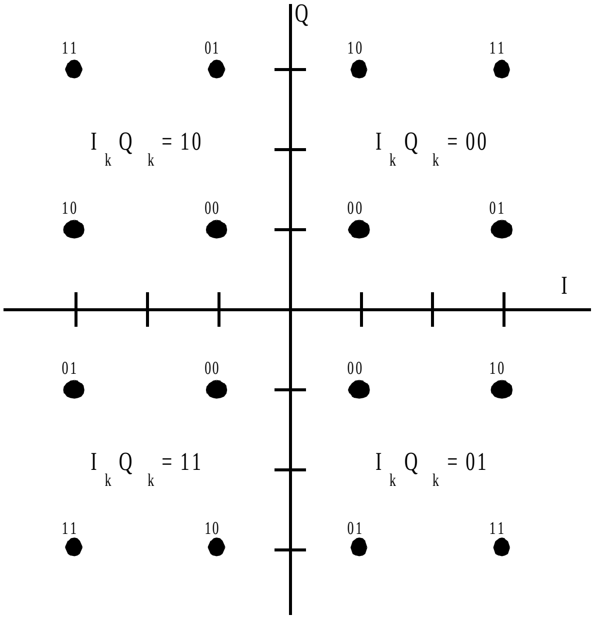


Figure 123—16-QAM Constellation Diagram

3.2.1.2.8 Differential encoding with 64-QAM Modulation (optional)

64-QAM modulation shall be optionally supported in this specification in order to allow for the future support for higher capacity links. This option uses the same differential encoding structure described above, with q=4 in the differential encoder, and the following mapping of bits to symbols.

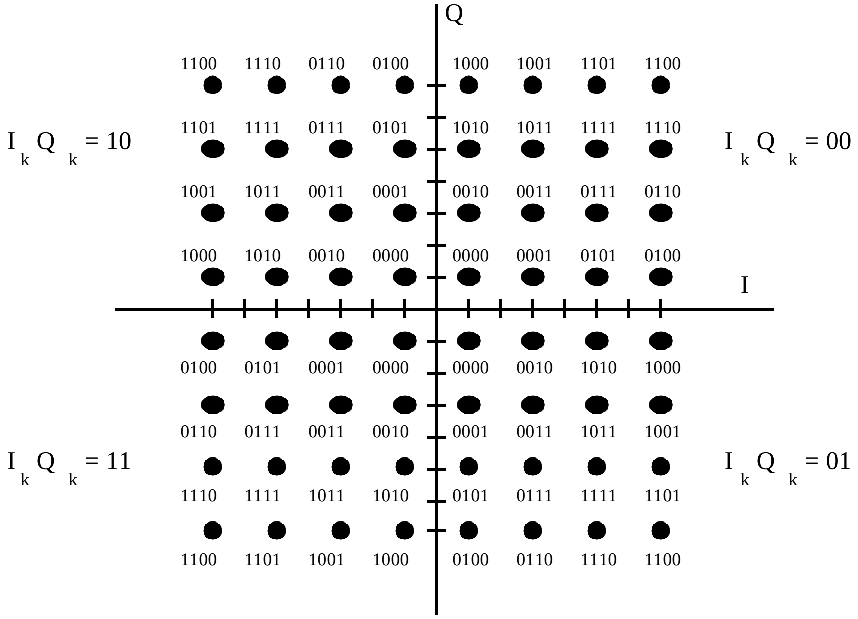


Figure 124—64-QAM Constellation Diagram

3.2.1.2.9 Baseband Pulse Shaping

Prior to modulation, the I and Q signals shall be filtered by square-root raised cosine filters. The excess bandwidth factor α shall be either 0.15, 0.25 or 0.35. The ideal square-root raised cosine filter is defined by the following transfer function H:

$$(H(f) = 1) \qquad \text{for } (|f| < f_N(1-\alpha))$$

$$\left(H(f) = \left\{\frac{1}{2} + \frac{1}{2}\sin\frac{\pi}{2f_N}\left[\frac{f_N - |f|}{\alpha}\right]\right\}^{\frac{1}{2}}\right) \text{ for } ((f_N(1-\alpha)) \le |f| \le (f_N(1+\alpha)))$$

$$(H(f) = 0) \qquad \text{for } (|f| > f_N(1+\alpha))$$

where $f_N = \frac{1}{2T_S} = \frac{R_S}{2}$ is the Nyquist frequency.

3.2.1.2.10 Summary of Mode A Downstream Physical Layer Parameters

Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000
Reed-Solomon Coding	(204,188) with T=8 byte errors corrected
Interleaving	Convolutional with depth I=12.
Convolutional coding	Selectable: rate 1/2, 2/3, 3/4, 5/6, 7/8,or 1 (disabled)
Modulation	QPSK, 16-QAM (optional), or 64-QAM (optional)
Differential encoding	enabled/disabled (enabled only when convolutional coding is not employed)
Spectral shaping	α=0.15, 0.25 or 0.35
Spectral inversion	inverted or non-inverted

3.2.2 Mode B: Burst Downstream Transmission

This mode of operation has been designed to support burst transmission in the downstream channel. In particular, this mode is applicable for systems using adaptive modulation in an FDD system or for systems using TDD, both of which require a burst capability in the downstream channel. Operating with a burst capability puts some constraints on several aspects of the physical layer, primarily with respect to phase recovery and allowable codeword lengths, which are taken into account in this mode of operation. In order to simplify phase recovery and channel tracking, a fixed frame time is used. At the beginning of every frame, a preamble is transmitted in order to allow for phase recover and equalization training. A description of the framing mechanism and the structure of the frame is further described in Section Section 2.6.4.

3.2.2.1 Mode B Downstream Transmission Convergence (TC) Sublayer

First, the downstream payload is segmented into blocks of data designed to fit into the proper codeword size after the convergence layer bytes are added. Note that the payload length may vary, depending on whether shortening of codewords is allowed or not for this burst type. A pointer byte is then added to each payload segment, as shown in the following figure:

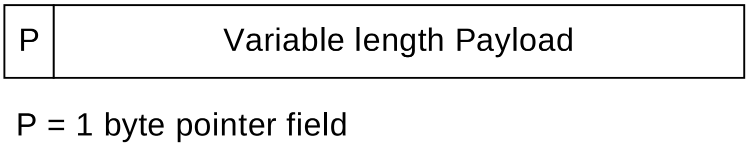


Figure 125— Format of the Convergence Layer Packet

The pointer field identifies the byte number in the packet which indicates either the beginning of the first MAC frame to start in the packet, or indicates the beginning of any stuff bytes that precede the next MAC frame. For reference, the first byte in the packet is refered to as byte number 1. If no MAC frame begins in the packet, then the pointer byte is set to 0. When no data is available to transmit, a stuff_byte pattern having a value (0xFF) must be used within the payload to fill any gaps between the 802.16 MAC frames. This value is chosen as an unused value for the first byte of the 802.16 MAC frame, which is designed to NEVER have this value.

3.2.2.2 Mode B Physical Media Dependent (PMD) Sublayer

The downstream physical layer coding and modulation for this mode is summarized in the block diagram shown below.

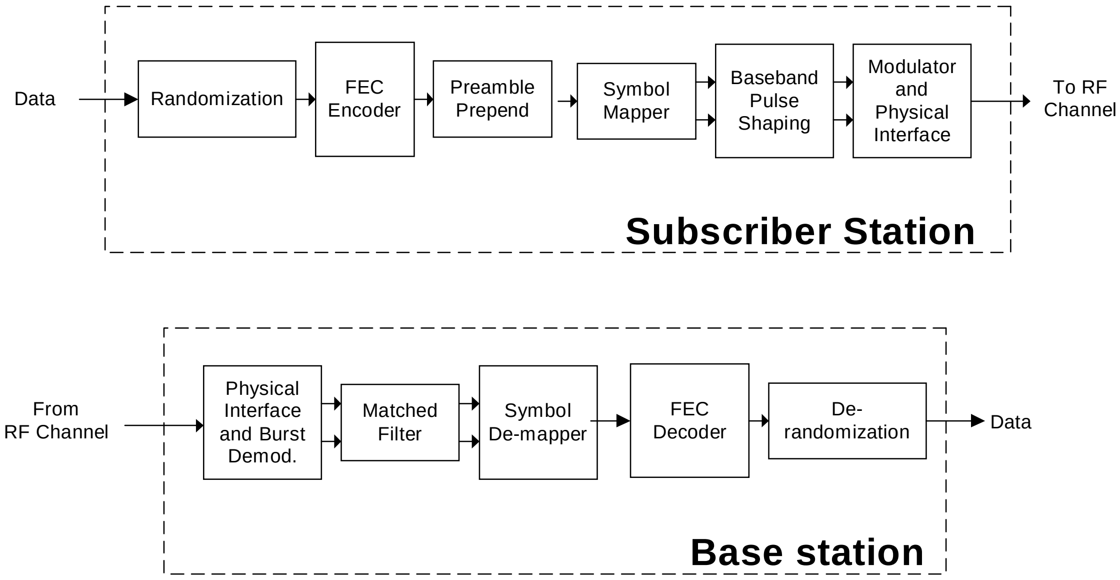


Figure 126—Conceptual Block diagram of the Mode B Downstream Physical Layer

3.2.2.2.1 Modulation/FEC Group Definitions

The downstream channel supports flexible modulation types and FEC coding on the user data portion of the frame. Up to 16 modulation/FEC groups can be defined, each having the following parameters that are communicated to the subscriber stations via MAC messages during the control portion of the downstream frame, which immediately follows the frame start preamble (see framing discussion from Section Section 2.6.4). Note that the control portion of the frame has a fixed modulation (QPSK) and FEC scheme in order to allow the subscriber stations to detect the MAC messages required to complete the registration process. After registration and authorization by the base station, the subscriber station shall be assigned a particular modulation type and FEC type to be used for its user data. The downstream channel and burst profiles are communicated to the CPEs via the MAC messages described in Section 2.5.2.2.

3.2.2.2.2 Downstream Physical Layer Terminal Capability Set Parameters

Since there exists some optional modulation and FEC schemes that can be implemented at the subscriber station, there must exist some method for identifying the capability to the base station (i.e., including the highest order modulatoin supported, the optional FEC coding schemes supported, interleaving type supported, and the minimum shortened last codeword length supported). This information shall be communicated to the base station during the subscriber registration period using the Registration Request and Response MAC messages described in Sections 2.5.7 and 2.5.8.

3.2.2.2.3 Randomization

Randomization shall be employed to minimize the possibility of transmission of an unmodulated carrier and to ensure adequate numbers of bit transitions to support clock recovery. The stream of downstream packets shall be randomized by modulo-2 addition of the data with the output of the pseudo random binary stream (PRBS) generator, as illustrated in the following diagram.

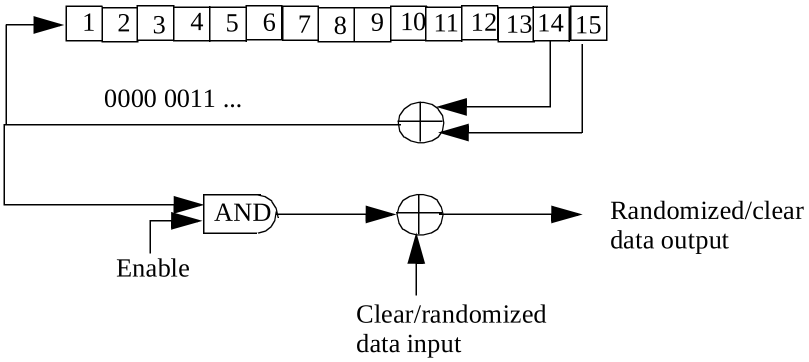


Figure 127—Randomizer logic diagram.

At the beginning of each burst, the PRBS register is cleared and the seed value of 100101010000000 is loaded. Note that a burst corresponds either to a TDM burst starting with a frame start preamble (Preamble 1 in the next section) or a TDMA burst starting with a shortened preamble (Preamble 2 in the next section). The seed value must be used to calculate the randomization bit, which is combined in an XOR with the first bit of data of each burst.

3.2.2.2.4 Forward Error Correction (FEC)

The forward error correction schemes for the Mode B downstream channel are selectable from the following types:

Table 68—FEC CodeTypes for Burst Downstream (Mode B)

Code Type	Outer Code	Inner Code
1	Reed Solomon over GF(256)	None
2	Reed Solomon over GF(256)	(24,16) Block convolutional code
3(Optional)	Reed Solomon over GF(256)	(9,8) Parity check code
4 (Optional)	Block Turbo Code	---

Note that the first two code types MUST be implemented by all subscriber stations, while code types 3 and 4 are optional.

Following is a summary of the four coding options:

(1) Reed-Solomon only: This case is useful either for a large data block or when high coding rate is required. The protection could vary between t=1 to t=16.

(2) Reed-Solomon + Block convolutional code (soft decodable): This case is useful for low to moderate coding rates providing good C/N enhancements. The coding rate is 2/3.

(3) Reed-Solomon + Parity check: This optional code his useful for moderate to high coding rates with small to medium size blocks (i.e., K=16, 53 or 128). The code itself is a simple bit wise parity check operating on byte (8 bit) level.

(4) Block Turbo Code: This optional code is used to significantly lower the required C/I level needed for reliable communication, and can be used to either extend the range of a base station or increase the code rate for greater throughput.

3.2.2.2.5 Reed Solomon Encoding (for code types 1-3)

The outer block code for code types 1-3 shall be a shortened, systematic Reed-Solomon code generated from GF(256) with information block lengths (K) variable from 6-255 bytes and error correction capability able to correct up to 16 byte errors. The specified code generator polynomials are given by

Code Generator Polynomial: $g(x) = (x+\mu^0)(x+\mu^1)(x+\mu^2)\ \ldots\ (x+\mu^{2T-1})$, where μ= 02hex

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

The specified code has a block length of 255 bytes, and shall be configured as a RS(255,255-R) code with information bytes preceded by (255-N) zero symbols, where N is the codeword length and R the number of redundancy bytes R=0 to 32. In the case of code type 3, R should be chosen odd if K is odd and should be chosen even if K is even in order to ensure an even number of bytes in the codeword.

When the number of bytes entering the FEC process M is less than K bytes, the following operation is performed:

(1) (K-M) zero bytes are added to the M byte block as a prefix

(2) RS Encoding is performed

(3) If inner code is either of type 1 or 2 or if the code type 3 with (M+R) even, then

All of the (K-M) zero RS symbols not associated with the original data are discarded

(4) If inner code is code type 3 with (M+R) odd, then

The first (K-M-1) zero RS symbols not associated with the original data are discarded

(5) Inner coding is performed on remaining symbols

(6) The resulting byte block is converted to bit block

When the number of bytes entering the FEC process M is greater than K bytes, the following operation is performed:

(1) Encode K bytes

(2) Subtract K from M, meaning Let M=M-K

(3) If M<K then go to (4), otherwise go to (1)

(4) Shortened FEC is applied to the remaining bytes as described above.

It is expected that the receiver, having knowledge of the expected data length, would properly zero pad the received block and decode it afterwards.

3.2.2.2.6 Code 2: Rate 2/3 Block Convolutional Code

The inner code in this concatenated coding scheme consists of short block codes derived from a 4-state, nonsystematic, punctured convolutional code $(7,5)_8$. The trellis shall use the tail-biting method, where the last 2 bits of the block are used to initialize the encoder memory, in order to avoid the overhead required for trellis termination.

For this concatenated coding scheme, the inner code message block is selected to be 16 bits. The puncturing pattern is described in the following table for the (24,16) case.

Table 69—The Parameters of the Inner Codes for the Block Convolutional Code

Inner Code Rate	Puncture pattern G1 = 7, G2 = 5
2/3	11, 10

3.2.2.2.7 Code 3: Parity Check (Optional)

For the code type 3, a parity check bit is added to each RS symbol individually and inserted as the MSB of the resulting 9-bit word. The parity is an exclusive-or operation on all 8 bits within the symbol. The result is a 9(K+R) block of bits, LSB first.

3.2.2.2.8 Code 4: BlockTurbo Code (Optional)

The Block Turbo Code (BTC) is a Turbo decoded Product Code (TPC). The idea of this coding scheme is to use extended Hamming block codes in a two dimensional matrix. The two-dimensional code block is depicted in Figure 128. The k_x information bits in the rows are encoded into n_x bits, by using an extended Hamming binary block (n_x,k_x) code. Likewise, k_y information bits in the columns are encoded into n_y bits, by using the same or possibly different extended Hamming binary block (n_y,k_y) code. The resultant code block is comprised of multiple rows and columns of the constituent extended Hamming block codes.

Because extended Hamming codes are linear codes, it does not matter whether the rows or columns are encoded first. For this standard, the rows shall be encoded first. After encoding the rows, the columns are encoded using another block code (n_y,k_y), where the check bits of the first code are also encoded. The overall block size of such a product code is $n = n_x$ x n_y, the total number of information bits k_x x k_y, the code rate is $R = R_x$ x R_y, where $R_i = k_i/n_i$ and i=x or y.

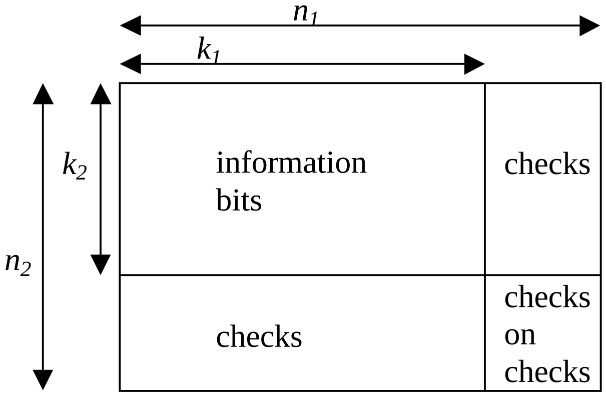


Figure 128—Two-dimensional product code matrix.

Table 70 provides the generator polynomials of the constituent Hamming codes used in this specification.

Table 70—Hamming Code Generator Polynomials

n	k	Generator Polynomial
31	26	$x^5 + x^2 + 1$
63	57	$x^6 + x + 1$

The composite extended Hamming code specified requires addition of an overall even parity check bit at the end of each codeword.

The encoder for a Block Turbo Code (BTCs) is composed of linear feedback shift registers (LFSRs), storage elements, and control logic. An example row (or column) encoder is shown here for clarification. The order of transmission is important since the decoder must match for proper decoding. This specification mandates that the resultant code block be transmitted row by row, left to right, top to bottom, for the case when no interleaving is used (Interleaver Type 1 described below).

Figure 129 shows an example LFSR based on a $x^4 + x + 1$ Hamming code polynomial to encode a (15,11) Hamming code. Also shown is an even parity computation register that results in an extended Hamming code. Note that encoders for the required (64,57) and (32,26) codes follow the same design concept. This figure is shown for clarification of the BTC encoder design and does not depict an actual design implementation.

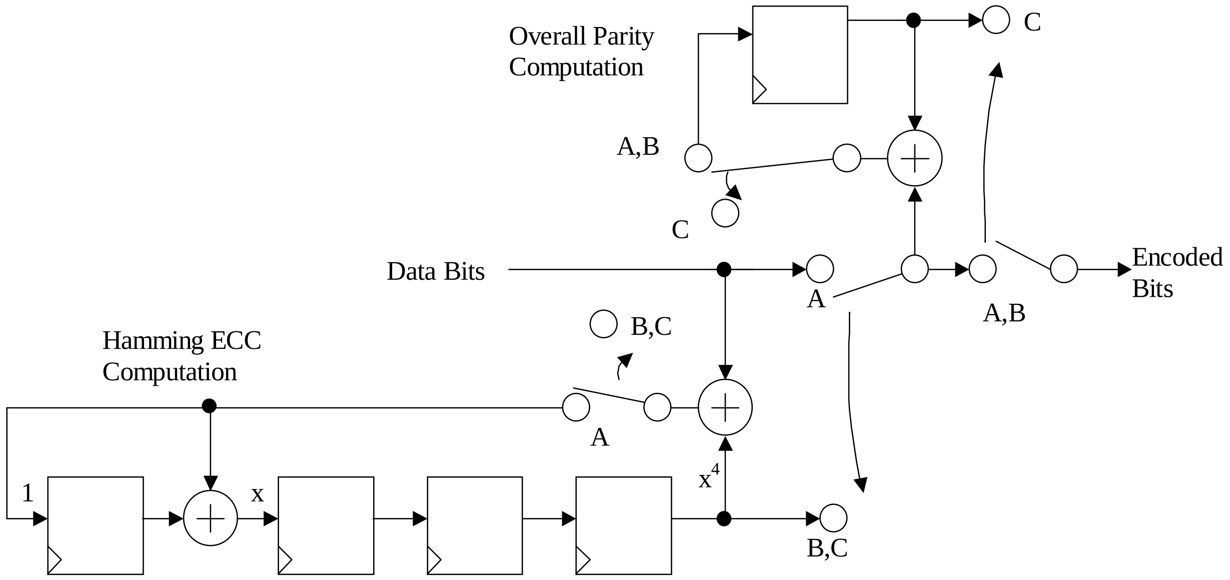


Figure 129—Example Encoder for a (16,11) Extended Hamming Code

The example circuit begins with all toggle switches in position A. Data to be encoded is fed as input one bit per clock (LSB first) to both the Hamming error correction code (ECC) computation logic and the overall even parity computation logic. Extended Hamming codes are systematic codes, so this data is also fed through as output on the encoded bit output. After all k bits are input, the toggle switches are moved to position B. At this point, data from the Hamming ECC logic is shifted out on the encoded bits bus. Finally, the overall parity bit is shifted out when the output select switch is moved to position C.

In order to encode the product code, each data bit is fed as input both into a row LFSR and a column LFSR. Note that only one row LFSR is necessary for the entire block, since data is written as input in row order. However, each column of the array must be encoded with a separate LFSR. Each column LFSR is clocked for only one bit of the row, so a more efficient method of column encoding is to store the column LFSR states in a k_x x (n_y-k_y) storage memory. A single LFSR can then be used for all columns of the array. With each bit input, the appropriate column LFSR state is read from the memory, clocked, and written back to the memory.

The encoding process will be demonstrated with an example. Assume a two-dimensional (8,4)x(8,4) extended Hamming Product code is to be encoded. This block has 16 data bits, and 64 total encoded bits. Table 71 shows the original 16 data bits denoted by D_{yx}, where y corresponds to a column and x corresponds to a row.

Table 71—Original Data for Encoding

D_{11}	D_{21}	D_{31}	D_{41}
D_{12}	D_{22}	D_{32}	D_{42}
D_{13}	D_{23}	D_{33}	D_{43}
D_{14}	D_{24}	D_{34}	D_{44}

The first four bits of the array are fed into the row encoder input in the order D_{11}, D_{21}, D_{31}, D_{41}. Each bit is also fed as input into a unique column encoder. Again, a single column encoder may be used, with the state of each column stored in a memory. After the fourth bit is fed into the input, the first row encoder ECC bits are shifted out.

This process continues for all four rows of data. At this point, 32 bits have been taken as output from the encoder, and the four column encoders are ready to shift out the column ECC bits. This data is shifted out at the end of the row. This continues from the remaining 3 rows of the array. Table 72 shows the final encoded block with the 48 generated ECC bits denoted by E_{yx}.

Table 72—Encoded Block

D_{11}	D_{21}	D_{31}	D_{41}	E_{51}	E_{61}	E_{71}	E_{81}
D_{12}	D_{22}	D_{32}	D_{42}	E_{52}	E_{62}	E_{72}	E_{82}
D_{13}	D_{23}	D_{33}	D_{43}	E_{53}	E_{63}	E_{73}	E_{83}
D_{14}	D_{24}	D_{34}	D_{44}	E_{54}	E_{64}	E_{74}	E_{84}
E_{15}	E_{25}	E_{35}	E_{45}	E_{55}	E_{65}	E_{75}	E_{85}
E_{16}	E_{26}	E_{36}	E_{46}	E_{56}	E_{66}	E_{76}	E_{86}
E_{17}	E_{27}	E_{37}	E_{47}	E_{57}	E_{67}	E_{77}	E_{87}
E_{18}	E_{28}	E_{38}	E_{48}	E_{58}	E_{68}	E_{78}	E_{88}

Transmission of the block over the channel occurs in a linear manner; all bits of the first row are transmitted left to right, followed by the second row, etc. This allows for the construction of a near zero-latency encoder, since the data bits can be sent immediately over the channel, with the ECC bits inserted as necessary. For the (8,4)x(8,4) example, the output order for the 64 encoded bits is D_{11}, D_{21}, D_{31}, D_{41}, E_{51}, E_{61}, E_{71}, E_{81}, D_{12}, D_{22}, … E_{88}.

For easier readability, the following notation is used:

1. The codes defined for the rows (x-axis) are binary (n_x,k_x) block codes.

2. The codes defined for the columns (y-axis) are binary (n_y,k_y) block codes.

3. Data bits are noted D_{yx} and parity bits are noted E_{yx}.

Shortened BTC

To match packet sizes, removing symbols from the array shortens a product code. Either rows or columns can be removed until the appropriate size is reached. Note that parity bits are removed as part of the shortening process, helping to keep the code rate high. Shortening is accomplished by removing entire rows and/or columns from the array. This is equivalent to shortening the constituent codes that make up the product code. This method enables a coarse granularity on shortening, and at the same time maintains the highest code rate possible by removing both data and parity symbols.

Shortened Two -Dimensional BTC example

For example, the 128 byte BTC code in this specification is composed of (64,57) constituent codes in the two dimensional array, which has been shortened by 25 rows and columns to form a (39,32) x (39,32) array. This code block has 32 x 32 = 1024 data bits, which results in the desired 128 byte information block. Figure 138 shows the structure of the resultant block.

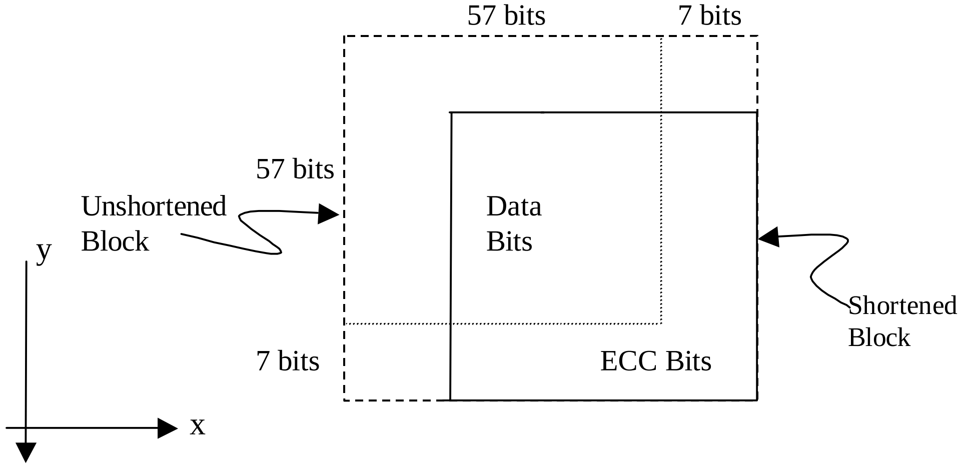


Figure 130—Structure of Shortened 2 D Block

Modifications to the encoder to support shortening are minimal. Since shortened bits are always zero, and zeros input to the encoder LFSR result in a zero state, the shortened bits can simply be ignored for the purposes of encoding. The encoder simply needs to know how many bits per row to input to the row LFSR before shifting out the result. Similarly, it must know the number of columns to input to the column encoders.

Transmission of the resultant code block must start with the first data bit in the first row, proceed left to right and then row by row from top to bottom.

Table 73—Required Block Codes for the BTC Option for the Downlink Channel

Table 3-1:

Code	**(39,32)x(39,32)**	**(63,56)x(63,56)**
Aggregate Code Rate	0.673	0.790
Uplink/Downlink/ Both	Downlink	Downlink
Block size (payload bits)	1024 (128 bytes)	3136 (392 bytes)

Interleaving

When using the Block Turbo Coding, two modes of bit interleaving shall be supported. The interleaver mechanism shall be implemented by writing information bits into the encoder memory and reading out the encoded bits as follows:

1. **Interleaver type 1**: No interleaver.

In this mode the encoded bits are read from the encoder row by row, in the order that they were written.

2. **Interleaver type 2**: Block interleaver.

In this mode the encoded bits are read from the encoder, only after all first k_2 rows were written into the encoder memory. The bits are read column-by-column, proceeding from the top position in the first column.

3. **Interleaver type 3**: Reserved.

It is expected that other interleaving methods may yield better performance in some cases. So, this Interleaver type 3 has been reserved for future definition.

Block mapping to the signal constellation

The first encoded bit out shall be the LSB, which is the first bit written into the encoder.

Method for determining codes for payload size different than the listed examples

The following text describes a method for performing additional codeword shortening when the input block of data does not match exactly the codeword information size.

1 Take the required payload as specified in bytes and convert it to bits (i.e., multiple by 8).

2 Take the square root of the resultant number.

3 Round the result up to the next highest integer.

4 Select the smallest base constituent code from the available list that has a k value equal to or greater than the value determined in step 3.

5 Subtract the value determined in step 3 from the k value selected in step 4. This value represents the number of rows and columns that need to be shortened from the base constituent code selected in step 4.

This method will generally result in a code block whose payload is slightly larger than required in step 1. In order to address the residual bits, the column dimension (n_y,k_y) should be shortened as needed as well as stuffing zero bits as needed into the last bits of the last row of the resulting code matrix. The zero bits in the last row should be discarded at the receiver.

Example: If a 20 byte payload code is desired, a (32,26) x (32,26) code is shortened by 13 rows and by 13 columns, which results in a (19,13) x (19,13) code. There are 9 bits left over which are stuffed with zeros. Data input to the defined encoder is 160 data bits followed by 9 zero bits. The code block is transmitted starting with the bit in row 1 column 1 (the LSB), then left to right, and then row by row.

3.2.2.2.9 Coding for the PHY/MAC control message portion of the frame

The PHY/MAC control portion of the downstream frame shall be encoded with a fixed set of parameters in order to ensure that all subscriber stations can read the information. The modulation shall be QPSK, and the PHY/MAC control portion of the frame shall be encoded with an outer (40,20) Reed-Solomon code and an inner (24,16) convolutional code. There must be a minimum of 2 codewords per control portion of the frame when a downstream allocation map is present.

3.2.2.2.10 Burst Preambles

Tables 74 through 76 define the preambles for the different downstream burst types. These preamble are based upon CAZAC sequences. The frame start preamble is always at the first part of a downstream frame and consists of a 32 symbol preamble (Burst Preamble 1), which is generated by repeating twice a CAZAC sequence of length 16 symbols. In the case of the TDMA mode on a downstream, user bursts are transmitted with a shortened preamble of 16 symbols (Burst Preamble 2), which is generated with a single length 16 CAZAC sequence. Note that these sequences have been shifted by +45 degrees in order to result in the same QPSK data symbol constellations.

Table 74— Burst Preamble Types

Burst type	Preamble Type	Modulation Type
Downstream burst, Frame begin	1	QPSK
Downstream TDMA burst	2	QPSK

Table 75 defines the bit sequence for burst preamble 1.

Table 75— Burst Preamble 1

Symbol	I	Q	B(1)	B(2)
1	1	1	0	0
2	-1	1	1	0
3	-1	-1	1	1
4	1	-1	0	1

5	1	1	0	0
6	-1	-1	1	1
7	1	1	0	0
8	-1	-1	1	1
9	1	1	0	0
10	1	-1	0	1
11	-1	-1	1	1
12	-1	1	1	0
13	1	1	0	0
14	1	1	0	0
15	1	1	0	0
16	1	1	0	0
17	1	1	0	0
18	-1	1	1	0
19	-1	-1	1	1
20	1	-1	0	1
21	1	1	0	0
22	-1	-1	1	1
23	1	1	0	0
24	-1	-1	1	1
25	1	1	0	0
26	1	-1	0	1
27	-1	-1	1	1
28	-1	1	1	0
29	1	1	0	0
30	1	1	0	0
31	1	1	0	0
32	1	1	0	0

Table 76 defines the bit sequence for burst preamble 2.

Table 76—Burst Preamble 2

Symbol	I	Q	B(1)	B(2)
1	1	-1	0	1
2	-1	-1	1	1
3	1	1	0	0
4	1	1	0	0
5	1	1	0	0
6	-1	1	1	0
7	1	1	0	0
8	-1	-1	1	1
9	-1	1	1	0
10	1	1	0	0
11	1	1	0	0
12	1	1	0	0
13	-1	-1	1	1
14	1	-1	0	1
15	1	1	0	0
16	-1	-1	1	1

3.2.2.2.11 Modulation

To maximize utilization of the air-link, the physical layer uses a multi-level modulation scheme. The modulation constellation can be selected based on the quality of the RF channel per subscriber. If link conditions permit, then a more complex modulation scheme can be utilized hence maximizing air-link throughput while still allowing reliable data transfer. If the air-link degrades over time, possibly due to environmental factors, the system can revert to the less complex constellations to allow more reliable data transfer.

The modulation used by the BS in the downstream shall be QPSK, 16-QAM, (both mandatory) and 64-QAM.

The sequence of modulation bits shall be mapped onto a sequence of modulation symbols S(k), where k is the corresponding symbol number. The number of bits per symbol is a result from the modulation type, for QPSK n=2, for 16-QAM n=4, for 64-QAM n=6. B(m) denotes the modulation bit of a sequence to be transmitted, where m is the bit number (m=1..n). In particular, B(1) corresponds to the first bit entering the modulator, B(2) corresponds to the second bit entering the modulation, and so on.

The complex modulation symbol S(k) shall take the value I +jQ. The following subsections apply to the base-band part of the transmitter.

Figure 131 and Table 77 describe the bit mapping for QPSK modulation.

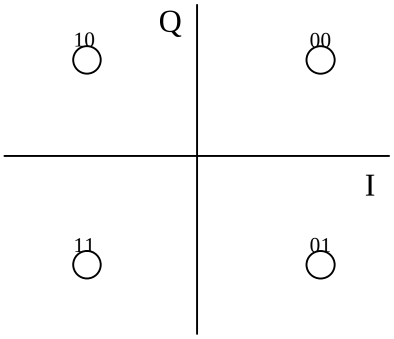


Figure 131— QPSK Constellation

Table 77— QPSK Bits to Symbol Mapping

B(1)	B(2)	I	Q
0	0	1	1
0	1	1	-1
1	0	-1	1
1	1	-1	-1

Figure 132 and Table 78 describe the bit mapping for 16-QAM modulation.

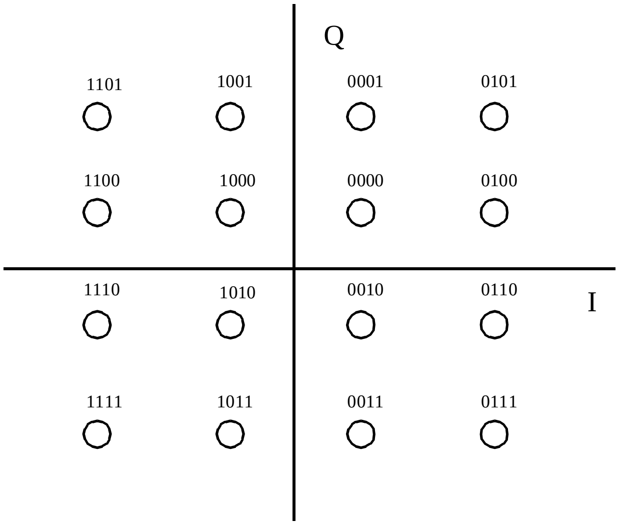


Figure 132— 16-QAM Constellation

Table 78— 16-QAM Bits to Symbol Mapping

B(1)	B(2)	B(3)	B(4)	I	Q
0	1	0	1	3	3
0	1	0	0	3	1
0	1	1	0	3	-1
0	1	1	1	3	-3
0	0	0	1	1	3
0	0	0	0	1	1
0	0	1	0	1	-1
0	0	1	1	1	-3
1	0	0	1	-1	3
1	0	0	0	-1	1
1	0	1	0	-1	-1
1	0	1	1	-1	-3
1	1	0	1	-3	3
1	1	0	0	-3	1
1	1	1	0	-3	-1
1	1	1	1	-3	-3

Figure 133 and Table 79 describe the bit mapping for 64-QAM modulation.

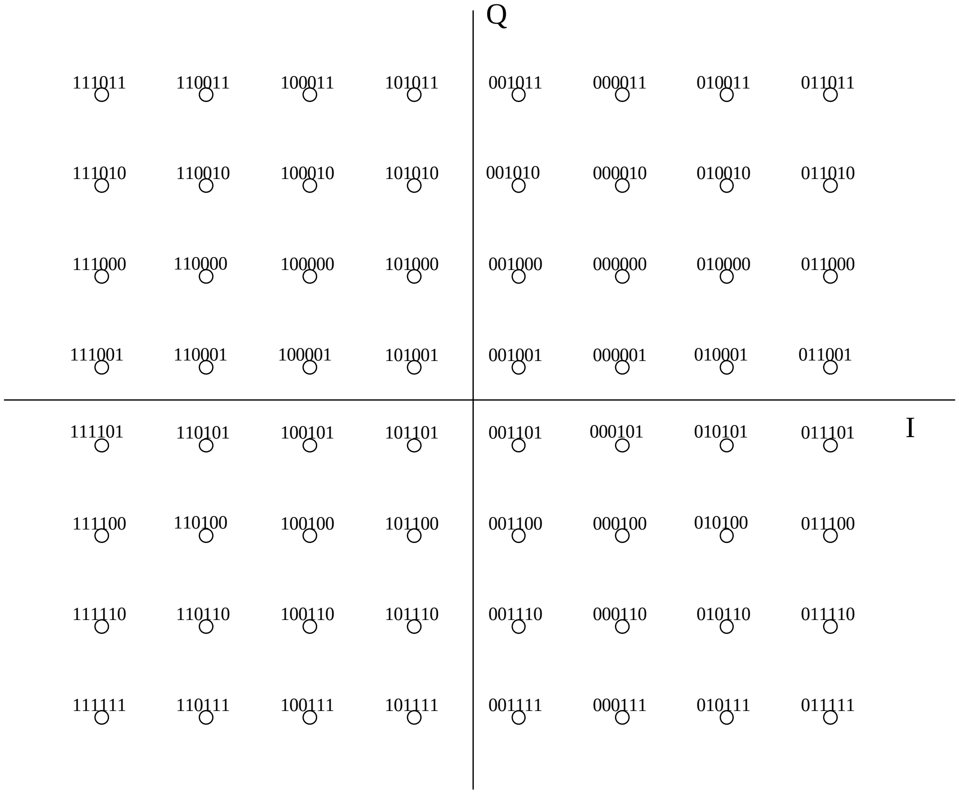


Figure 133— 64-QAM Constellation

Table 79— 64-QAM Bits to Symbol Mapping

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)	I	Q
0	1	1	0	1	1	7	7
0	1	1	0	1	0	7	5
0	1	1	0	0	0	7	3
0	1	1	0	0	1	7	1
0	1	1	1	0	1	7	-1
0	1	1	1	0	0	7	-3
0	1	1	1	1	0	7	-5
0	1	1	1	1	1	7	-7
0	1	0	0	1	1	5	7
0	1	0	0	1	0	5	5
0	1	0	0	0	0	5	3
0	1	0	0	0	1	5	1

0	1	0	1	0	1	5	-1
0	1	0	1	0	0	5	-3
0	1	0	1	1	0	5	-5
0	1	0	1	1	1	5	-7
0	0	0	0	1	1	3	7
0	0	0	0	1	0	3	5
0	0	0	0	0	0	3	3
0	0	0	0	0	1	3	1
0	0	0	1	0	1	3	-1
0	0	0	1	0	0	3	-3
0	0	0	1	1	0	3	-5
0	0	0	1	1	1	3	-7
0	0	1	0	1	1	1	7
0	0	1	0	1	0	1	5
0	0	1	0	0	0	1	3
0	0	1	0	0	1	1	1
0	0	1	1	0	1	1	-1
0	0	1	1	0	0	1	-3
0	0	1	1	1	0	1	-5
0	0	1	1	1	1	1	-7
1	0	1	0	1	1	-1	7
1	0	1	0	1	0	-1	5
1	0	1	0	0	0	-1	3
1	0	1	0	0	1	-1	1
1	0	1	1	0	1	-1	-1
1	0	1	1	0	0	-1	-3
1	0	1	1	1	0	-1	-5
1	0	1	1	1	1	-1	-7
1	0	0	0	1	1	-3	7
1	0	0	0	1	0	-3	5
1	0	0	0	0	0	-3	3
1	0	0	0	0	1	-3	1
1	0	0	1	0	1	-3	-1

1	0	0	1	0	0	-3	-3
1	0	0	1	1	0	-3	-5
1	0	0	1	1	1	-3	-7
1	1	0	0	1	1	-5	7
1	1	0	0	1	0	-5	5
1	1	0	0	0	0	-5	3
1	1	0	0	0	1	-5	1
1	1	0	1	0	1	-5	-1
1	1	0	1	0	0	-5	-3
1	1	0	1	1	0	-5	-5
1	1	0	1	1	1	-5	-7
1	1	1	0	1	1	-7	7
1	1	1	0	1	0	-7	5
1	1	1	0	0	0	-7	3
1	1	1	0	0	1	-7	1
1	1	1	1	0	1	-7	-1
1	1	1	1	0	0	-7	-3
1	1	1	1	1	0	-7	-5
1	1	1	1	1	1	-7	-7

3.2.2.2.12 Baseband Pulse Shaping

Prior to modulation, the I and Q signals shall be filtered by square-root raised cosine filters. The excess bandwidth factor α shall be either 0.15, 0.25 or 0.35. The ideal square-root raised cosine filter is defined by the following transfer function H:

$$(H(f) = 1) \qquad \text{for } (|f| < f_N(1-\alpha))$$

$$\left(H(f) = \left\{\frac{1}{2} + \frac{1}{2}\sin\frac{\pi}{2f_N}\left[\frac{f_N - |f|}{\alpha}\right]\right\}^{\frac{1}{2}}\right) \text{ for } ((f_N(1-\alpha)) \le |f| \le (f_N(1+\alpha)))$$

$$(H(f) = 0) \qquad \text{for } (|f| > f_N(1+\alpha))$$

where $f_N = \frac{1}{2T_S} = \frac{R_S}{2}$ is the Nyquist frequency.

3.2.2.2.13 Summary of Mode B Downstream Physical Layer Parameters

Table 80—Summary of Mode B Downstream Physical Layer Parameters

Transmission convergence layer	Includes 1 pointer byte
Outer Coding	Reed Solomon over GF(256) Information byte lengths: 6-255 bytes Error correction capability R=0-32 (T=0-16) Block Turbo Code (optional) (Note: There is no inner code selected in this case.)
Inner Coding	Selectable from the following options: None (24,16) block convolutional code (9,8) parity check code (optional)
Randomization	$1 + X^{14} + X^{15}$ Initialization: 100101010000000 at the beginning of each burst
Preamble	32 symbol Frame Start Preamble 16 symbol preamble for TDMA case
Modulation	QPSK, 16-QAM, or 64-QAM (optional)
Spectral shaping	α=0.15, 0.25, or 0.35

3.3 Upstream Physical Layer

3.3.1 Upstream Channel and Burst Descriptions

Since subscriber stations cannot transmit in the upstream channel until they have received some minimal configuration information from the base station, it is possible to support several different configurations that can be adjusted on an upstream channel basis or on a burst-by-burst basis. These parameters, and their ranges, are supported through MAC layer signaling, as described in Section 2.5.2.1.

3.3.2 Upstream Transmission Convergence (TC) Sublayer

When the transmission convergence layer is disabled, MAC packets are carried directly within upstream bursts. When the transmission convergence layer is enabled, the payload shall be partitioned in the following manner. First, the upstream payload is segmented into blocks of data designed to fit into the proper codeword size after the convergence layer bytes are added. Note that the payload length may vary, depending on whether shortening of codewords is allowed or not for this burst type. A pointer byte is then added to each payload segment. The pointer field identifies the byte number in the packet which indicates either the beginning of the first MAC PDU to start in the packet, or indicates the beginning of any stuff bytes that precede the next MAC PDU. For reference, the first byte in the packet is refered to as byte number 1. If no MAC frame begins in the packet, then the pointer byte is set to 0. When no data is available to transmit, a stuff_byte pattern having a value (0xFF) must be used within the payload to fill any gaps between the 802.16 MAC frames. This value is chosen as an unused value for the first byte of the 802.16 MAC frame, which is designed to NEVER have this value. The following figure illustrates the format of the packet leaving the convergence layer:

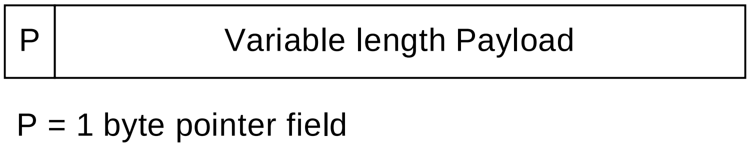


Figure 134— Format of the Convergence Layer Packet

3.3.3 Upstream Physical Media Dependent (PMD) sublayer

The upstream physical layer coding and modulation are summarized in the block diagram shown below.

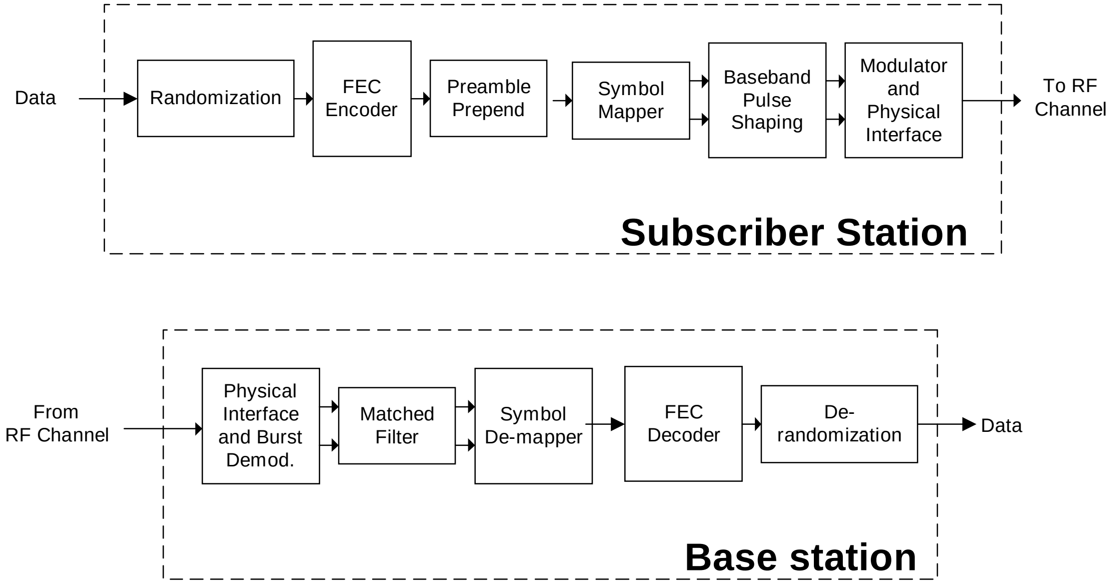


Figure 135— Conceptual Block diagram of the 802.16 Burst Transmission Upstream Physical Layer

3.3.3.1 Randomization for spectrum shaping

The upstream modulator must implement a randomizer using the polynomial $x^{15}+x^{14}+1$ with a 15-bit programmable seed. At the beginning of each burst, the register is cleared and the seed value is loaded. The seed value must be used to calculate the scrambler bit, which is combined in an XOR with the first bit of data of each burst (which is the MSB of the first symbol following the last symbol of the preamble).

3.3.3.2 Forward Error Correction

The forward error correction scheme for the upstream channel are selectable from the following types:

Table 81—FEC Code Types for the Upstream Channel

Code Type	Outer Code	Inner Code
1	Reed Solomon over GF(256)	None
2	Reed Solomon over GF(256)	(24,16) Block convolutional code
3 (Optional)	Reed Solomon over GF(256)	(9,8) Parity check code
4 (Optional)	Block Turbo Code	---

Note that the first two code types MUST be implemented by all subscriber stations, while code types 3 and 4 are optional.

Following is a summary of the four coding options:

(1) Reed-Solomon only: This case is useful either for a large data block or when high coding rate is required. The protection could vary between t=1 to t=16.

(2) Reed-Solomon + Block convolutional code (soft decodable): This case is useful for low to moderate coding rates providing good C/N enhancements. The coding rate is 2/3.

(3) Reed-Solomon + Parity check: This optional code is useful for moderate to high coding rates with small to medium size blocks (i.e., K=16, 53 or 128). The code itself is a simple bit wise parity check operating on byte (8 bit) level.

(4) Block Turbo Code: This optional code is used to significantly lower the required C/I level needed for reliable communication, and can be used to either extend the range of a base station or increase the code rate for greater throughput.

3.3.3.2.1 Reed Solomon Encoding (for code types 1-3)

The outer block code for code types 1-3 shall be a shortened, systematic Reed-Solomon code generated from GF(256) with information block lengths (K) variable from 6-255 bytes and error correction capability able to correct up to 16 byte errors. The specified code generator polynomials are given by

Code Generator Polynomial: $g(x) = (x+\mu^0)(x+\mu^1)(x+\mu^2) \ldots (x+\mu^{2T-1})$, where μ= 02hex

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

The specified code has a block length of 255 bytes, and shall be configured as a RS(255,255-R) code with information bytes preceded by (255-N) zero symbols, where N is the codeword length and R the number of redundancy bytes R=0 to 32. In the case of code type 3, R should be chosen odd if K is odd and should be chosen even if K is even.

When the number of bytes entering the FEC process M is less than K bytes, the following operation is performed:

(1) (K-M) zero bytes are added to the M byte block as a prefix

(2) RS Encoding is performed

(3) If inner code is either of type 1 or 2 or if the code type 3 with (M+R) even, then

All of the (K-M) zero RS symbols not associated with the original data are discarded

(4) If inner code is code type 3 with (M+R) odd, then

The first (K-M-1) zero RS symbols not associated with the original data are discarded

(5) Inner coding is performed on remaining symbols

(6) The resulting byte block is converted to bit block

When the number of bytes entering the FEC process M is greater than K bytes, the following operation is performed:

(1) Encode K bytes

(2) Subtract K from M, meaning Let M=M-K

(3) If M<K then go to (4), otherwise go to (1)

(4) Shortened FEC is applied to the remaining bytes as described above.

It is expected that the receiver, having knowledge of the expected data length, would properly zero pad the received block and decode it afterwards.

3.3.3.2.2 Code 2: Rate 2/3 Block Convolutional Code

The inner code in this concatenated coding scheme consists of short block codes derived from 4-state, nonsystematic, punctured convolutional code $(7,5)_8$. The trellis shall use the tail-biting method, where the last 2 bits of the block are used to initialize the encoder memory, in order to avoid the overhead required for trellis termination.

For this concatenated coding scheme, the inner code message block is selected to be 16 bits. The puncturing pattern is described in the following table for the (24,16) case.

Table 82—The Parameters of the Inner Codes for the Block Convolutional Code

Inner Code Rate	**Puncture pattern** **G1 = 7, G2 = 5**
2/3	11, 10

3.3.3.2.3 Code 3: Parity Check (Optional)

For the code type 3, a parity check bit is added to each RS symbol individually and inserted as the MSB of the resulting 9-bit word. The parity is an exclusive-or operation on all 8 bits within the symbol. The result is a 9(K+R) block of bits, LSB first.

3.3.3.2.4 Code 4: BlockTurbo Code (Optional)

The Block Turbo Code (BTC) is a Turbo decoded Product Code (TPC). The idea of this coding scheme is to use extended Hamming block codes in a two dimensional matrix. The two-dimensional code block is depicted in Figure 136. The k_x information bits in the rows are encoded into n_x bits, by using an extended Hamming binary block (n_x,k_x) code. Likewise, k_y information bits in the columns are encoded into n_y bits, by using the same or possibly different extended Hamming binary block (n_y,k_y) code. The resultant code block is comprised of multiple rows and columns of the constituent extended Hamming block codes.

Because extended Hamming codes are linear codes, it does not matter whether the rows or columns are encoded first. For this standard, the rows shall be encoded first. After encoding the rows, the columns are encoded using another block code (n_y,k_y), where the check bits of the first code are also encoded. The overall block size of such a product code is n = n_x x n_y, the total number of information bits k_x x k_y, the code rate is R = R_x x R_y, where R_i = k_i/n_i and i=x or y.

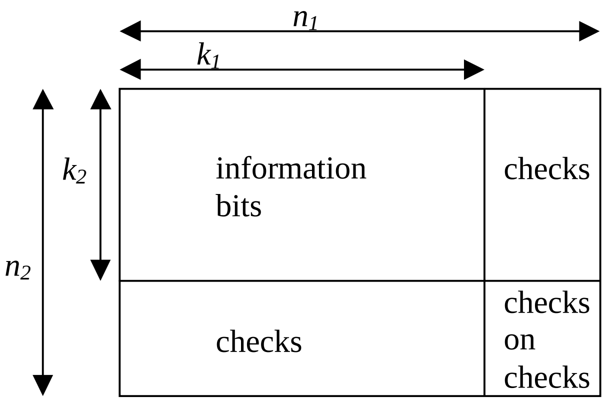


Figure 136—Two-dimensional product code matrix.

Table 83 provides the generator polynomials of the constituent Hamming codes used in this specification.

Table 83—Hamming Code Generator Polynomials

n	k	Generator Polynomial
31	26	$x^5 + x^2 + 1$
63	57	$x^6 + x + 1$

The composite extended Hamming code specified requires addition of an overall even parity check bit at the end of each codeword.

The encoder for a Block Turbo Code (BTCs) is composed of linear feedback shift registers (LFSRs), storage elements, and control logic. An example row (or column) encoder is shown here for clarification. The order of transmission is important since the decoder must match for proper decoding. This specification mandates that the resultant code block be transmitted row by row, left to right, top to bottom, for the case when no interleaving is used (Interleaver Type 1 described below).

Figure 137 shows an example LFSR based on a $x^4 + x + 1$ Hamming code polynomial to encode a (15,11) Hamming code. Also shown is an even parity computation register that results in an extended Hamming code. Note that encoders for the required (64,57) and (32,26) codes can follow the same design concept. This figure is shown for clarification of the BTC encoder design and does not depict an actual design implementation.

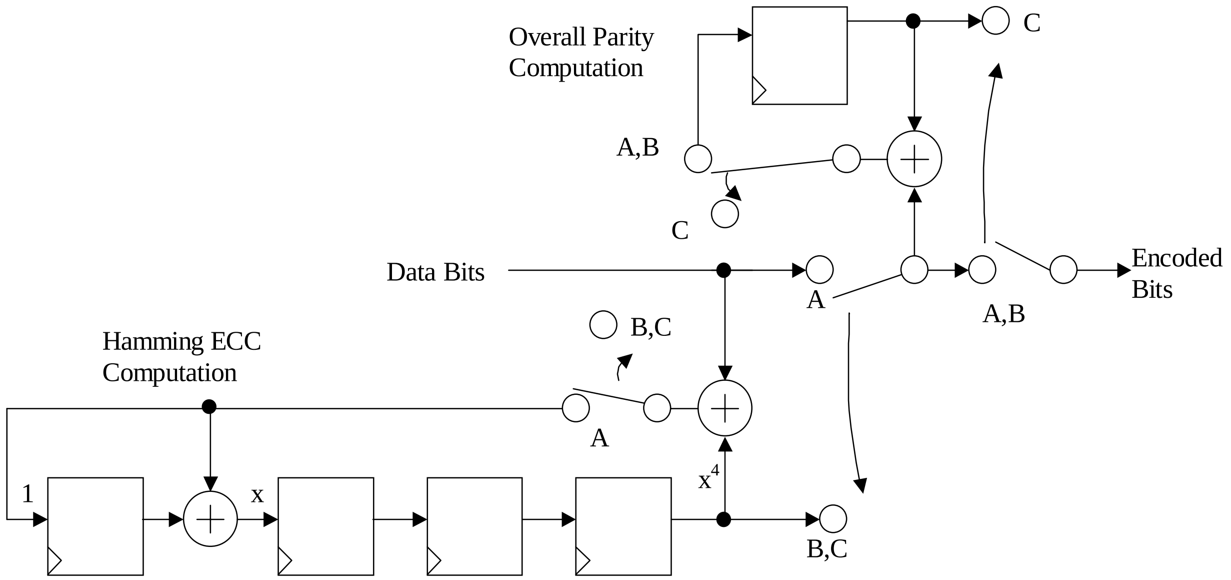


Figure 137—Example Encoder for a (16,11) Extended Hamming Code

This example circuit begins with all toggle switches in position A. Data to be encoded is fed as input one bit per clock (LSB first) to both the Hamming error correction code (ECC) computation logic and the overall even parity computation logic. Extended Hamming codes are systematic codes, so this data is also fed through as output on the encoded bit output. After all k bits are input, the toggle switches are moved to position B. At this point, data from the Hamming ECC logic is shifted out on the encoded bits bus. Finally, the overall parity bit is shifted out when the output select switch is moved to position C.

In order to encode the product code, each data bit is fed as input both into a row LFSR and a column LFSR. Note that only one row LFSR is necessary for the entire block, since data is written as input in row order. However, each column of the array must be encoded with a separate LFSR. Each column LFSR is clocked for only one bit of the row, so a more efficient method of column encoding is to store the column LFSR states in a k_x x $(n_y\text{-}k_y)$ storage memory. A single LFSR can then be used for all columns of the array. With each bit input, the appropriate column LFSR state is read from the memory, clocked, and written back to the memory.

The encoding process will be demonstrated with an example. Assume a two-dimensional (8,4)x(8,4) extended Hamming Product code is to be encoded. This block has 16 data bits, and 64 total encoded bits. Table 84 shows the original 16 data bits denoted by D_{yx}, where y corresponds to a column and x corresponds to a row.

Table 84—Original Data for Encoding

D_{11}	D_{21}	D_{31}	D_{41}
D_{12}	D_{22}	D_{32}	D_{42}
D_{13}	D_{23}	D_{33}	D_{43}
D_{14}	D_{24}	D_{34}	D_{44}

The first four bits of the array are fed into the row encoder input in the order D_{11}, D_{21}, D_{31}, D_{41}. Each bit is also fed as input into a unique column encoder. Again, a single column encoder may be used, with the state of each column stored in a memory. After the fourth bit is fed into the input, the first row encoder ECC bits are shifted out.

This process continues for all four rows of data. At this point, 32 bits have been taken as output from the encoder, and the four column encoders are ready to shift out the column ECC bits. This data is shifted out at the end of the row. This continues from the remaining 3 rows of the array. Table 85 shows the final encoded block with the 48 generated ECC bits denoted by E_{yx}.

Table 85—Encoded Block

D_{11}	D_{21}	D_{31}	D_{41}	E_{51}	E_{61}	E_{71}	E_{81}
D_{12}	D_{22}	D_{32}	D_{42}	E_{52}	E_{62}	E_{72}	E_{82}
D_{13}	D_{23}	D_{33}	D_{43}	E_{53}	E_{63}	E_{73}	E_{83}
D_{14}	D_{24}	D_{34}	D_{44}	E_{54}	E_{64}	E_{74}	E_{84}
E_{15}	E_{25}	E_{35}	E_{45}	E_{55}	E_{65}	E_{75}	E_{85}
E_{16}	E_{26}	E_{36}	E_{46}	E_{56}	E_{66}	E_{76}	E_{86}
E_{17}	E_{27}	E_{37}	E_{47}	E_{57}	E_{67}	E_{77}	E_{87}
E_{18}	E_{28}	E_{38}	E_{48}	E_{58}	E_{68}	E_{78}	E_{88}

Transmission of the block over the channel occurs in a linear manner; all bits of the first row are transmitted left to right, followed by the second row, etc. This allows for the construction of a near zero-latency encoder, since the data bits can be sent immediately over the channel, with the ECC bits inserted as necessary. For the (8,4)x(8,4) example, the output order for the 64 encoded bits is D_{11}, D_{21}, D_{31}, D_{41}, E_{51}, E_{61}, E_{71}, E_{81}, D_{12}, D_{22}, … E_{88}.

For easier readability, the following notation is used:

1. The codes defined for the rows (x-axis) are binary (n_x,k_x) block codes.

2. The codes defined for the columns (y-axis) are binary (n_y,k_y) block codes.

3. Data bits are noted D_{yx} and parity bits are noted E_{yx}.

Shortened BTC

To match packet sizes, removing symbols from the array shortens a product code. Either rows or columns can be removed until the appropriate size is reached. Note that parity bits are removed as part of the shortening process, helping to keep the code rate high. Shortening is accomplished by removing entire rows and/or columns from the array. This is equivalent to shortening the constituent codes that make up the product code. This method enables a coarse granularity on shortening, and at the same time maintains the highest code rate possible by removing both data and parity symbols.

Shortened Two -Dimensional BTC example

For example, the 128 byte BTC code in this specification is composed of (64,57) constituent codes in the two dimensional array, which has been shortened by 25 rows and columns to form a (39,32) x (39,32) array. This code block has 32 x 32 = 1024 data bits, which results in the desired 128 byte information block. Figure 138 shows the structure of the resultant block.

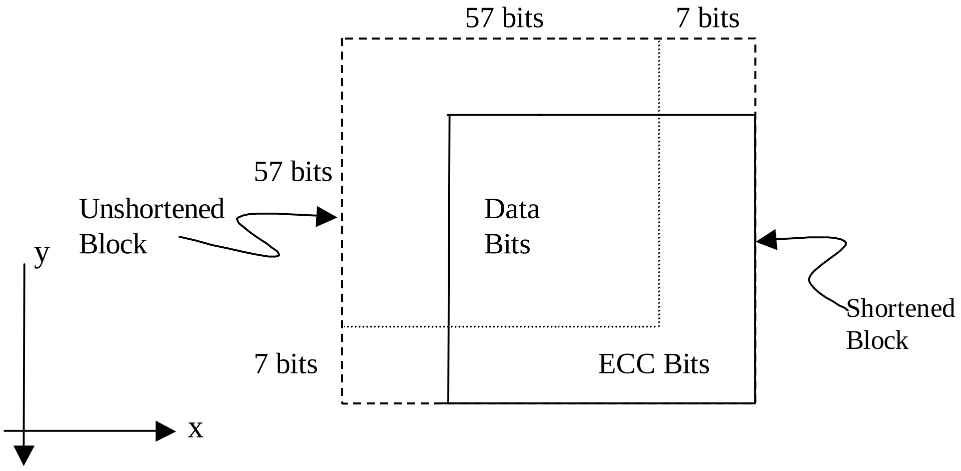


Figure 138—Structure of Shortened 2 D Block

Modifications to the encoder to support shortening are minimal. Since shortened bits are always zero, and zeros input to the encoder LFSR result in a zero state, the shortened bits can simply be ignored for the purposes of encoding. The encoder simply needs to know how many bits per row to input to the row LFSR before shifting out the result. Similarly, it must know the number of columns to input to the column encoders.

Transmission of the resultant code block must start with the first data bit in the first row, proceed left to right and then row by row from top to bottom.

Table 86—Required Block Codes for the BTC Option for the Uplink Channel

Code	**(32,24)x(25,19)**
Aggregate Code Rate	0.608
Uplink/Downlink/ Both	Uplink
Block size (payload bits)	456 (57 bytes)

Interleaving

When using the Block Turbo Coding, two modes of bit interleaving shall be supported. The interleaver mechanism shall be implemented by writing information bits into the encoder memory and reading out the encoded bits as follows:

1. **Interleaver type 1**: No interleaver.

In this mode the encoded bits are read from the encoder row by row, in the order that they were written.

2. **Interleaver type 2**: Block interleaver.

In this mode the encoded bits are read from the encoder, only after all first k_2 rows were written into the encoder memory. The bits are read column-by-column, proceeding from the top position in the first column.

3. **Interleaver type 3**: Reserved.

It is expected that other interleaving methods may yield better performance in some cases. So, this Interleaver type 3 has been reserved for future definition.

Block mapping to the signal constellation

The first encoded bit out shall be the LSB, which is the first bit written into the encoder.

Method for determining codes for payload size different than the listed examples

The following text describes a method for performing additional codeword shortening when the input block of data does not match exactly the codeword information size.

1 Take the required payload as specified in bytes and convert it to bits (i.e., multiple by 8).

2 Take the square root of the resultant number.

3 Round the result up to the next highest integer.

4 Select the smallest base constituent code from the available list that has a k value equal to or greater than the value determined in step 3.

5 Subtract the value determined in step 3 from the k value selected in step 4. This value represents the number of rows and columns that need to be shortened from the base constituent code selected in step 4.

This method will generally result in a code block whose payload is slightly larger than required in step 1. In order to address the residual bits, the column dimension (n_y,k_y) should be shortened as needed as well as stuffing zero bits as needed into the last bits of the last row of the resulting code matrix. The zero bits in the last row should be discarded at the receiver.

Example: If a 20 byte payload code is desired, a (32,26) x (32,26) code is shortened by 13 rows and by 13 columns, which results in a (19,13) x (19,13) code. There are 9 bits left over which are stuffed with zeros. Data input to the defined encoder is 160 data bits followed by 9 zero bits. The code block is transmitted starting with the bit in row 1 column 1 (the LSB), then left to right, and then row by row.

3.3.3.3 Preamble

The preamble shall be programmable and set by the base station based upon an integer number of repetitions of the following length 16 CAZAC sequence. Table 86a defines the bit sequence for the base preamble.

3.3.3.4 Modulation

The modulation used on the upstream channel shall be variable and set by the base station. QPSK must be supported, while 16-QAM and 64-QAM are optional, with the following mappings of bits to symbols. The sequence of modulation bits shall be mapped onto a sequence of modulation symbols S(k), where k is the corresponding symbol number. The number of bits per symbol is a result from the modulation type, for QPSK n=2, for 16-QAM n=4, for 64-QAM n=6. B(m) denotes the modulation bit of a sequence to be transmitted, where m is the bit number (m=1..n). In particular, B(1) corresponds to the first bit entering the modulator, B(2) corresponds to the second bit entering the modulation, and so on.

Table 86a—Upstream Base Preamble Sequence

Symbol	I	Q	B(1)	B(2)
1	1	1	0	0
2	1	1	0	0
3	1	-1	0	1
4	-1	-1	1	1
5	-1	-1	1	1
6	1	1	0	0
7	1	1	0	0
8	-1	1	1	0
9	1	1	0	0
10	1	1	0	0
11	-1	1	1	0
12	1	1	0	0
13	-1	-1	1	1
14	1	1	0	0
15	-1	-1	1	1
16	1	-1	0	1

The complex modulation symbol S(k) shall take the value I +jQ. The following subsections apply to the base-band part of the transmitter.

3.3.3.4.1 QPSK Symbol Mapping

The following mapping of bits to symbols shall be support for QPSK modulation:

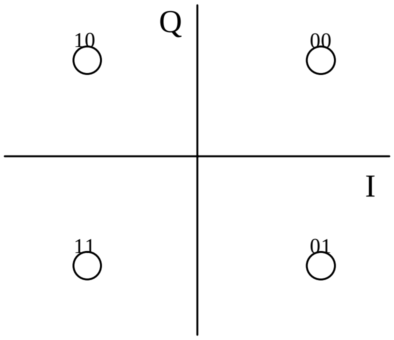


Figure 139— QPSK constellation mapping

Table 87—QPSK Bits to Symbol Mapping

B(1)	B(2)	I	Q
0	0	1	1
0	1	1	-1
1	0	-1	1
1	1	-1	-1

3.3.3.4.2 Gray-coded 16-QAM (Optional)

Figure 140 and Table 88 describe the bit mapping for 16-QAM modulation.

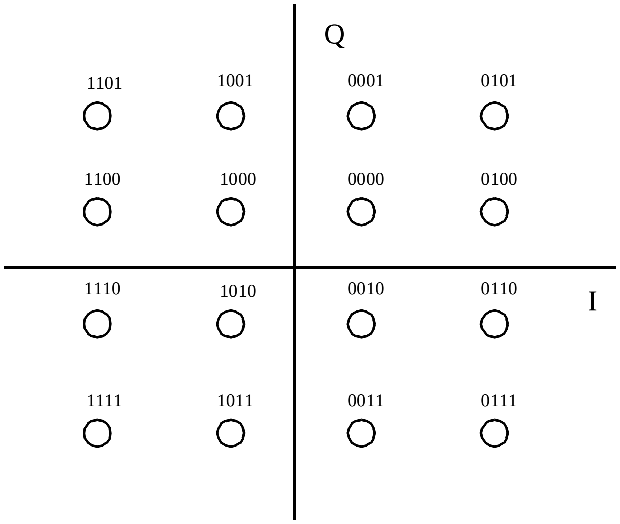


Figure 140— 16-QAM Constellation

Table 88— 16-QAM Bits to Symbol Mapping

B(1)	B(2)	B(3)	B(4)	I	Q
0	1	0	1	3	3
0	1	0	0	3	1
0	1	1	0	3	-1
0	1	1	1	3	-3
0	0	0	1	1	3
0	0	0	0	1	1
0	0	1	0	1	-1
0	0	1	1	1	-3
1	0	0	1	-1	3
1	0	0	0	-1	1
1	0	1	0	-1	-1
1	0	1	1	-1	-3
1	1	0	1	-3	3
1	1	0	0	-3	1
1	1	1	0	-3	-1
1	1	1	1	-3	-3

3.3.3.4.3 Gray-coded 64-QAM (Optional)

Figure 141 and Table 89 describe the bit mapping for 64-QAM modulation.

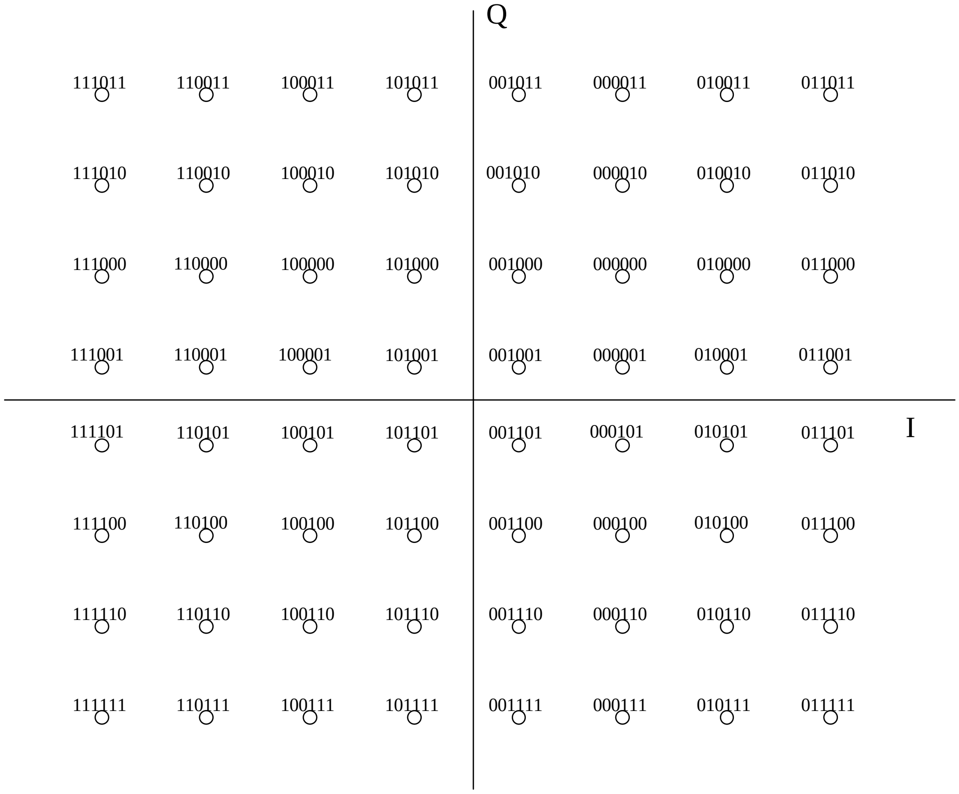


Figure 141— 64-QAM Constellation

Table 89—64-QAM Bits to Symbol Mapping

B(1)	B(2)	B(3)	B(4)	B(5)	B(6)	I	Q
0	1	1	0	1	1	7	7
0	1	1	0	1	0	7	5
0	1	1	0	0	0	7	3
0	1	1	0	0	1	7	1
0	1	1	1	0	1	7	-1
0	1	1	1	0	0	7	-3
0	1	1	1	1	0	7	-5
0	1	1	1	1	1	7	-7
0	1	0	0	1	1	5	7
0	1	0	0	1	0	5	5

0	1	0	0	0	0	5	3
0	1	0	0	0	1	5	1
0	1	0	1	0	1	5	-1
0	1	0	1	0	0	5	-3
0	1	0	1	1	0	5	-5
0	1	0	1	1	1	5	-7
0	0	0	0	1	1	3	7
0	0	0	0	1	0	3	5
0	0	0	0	0	0	3	3
0	0	0	0	0	1	3	1
0	0	0	1	0	1	3	-1
0	0	0	1	0	0	3	-3
0	0	0	1	1	0	3	-5
0	0	0	1	1	1	3	-7
0	0	1	0	1	1	1	7
0	0	1	0	1	0	1	5
0	0	1	0	0	0	1	3
0	0	1	0	0	1	1	1
0	0	1	1	0	1	1	-1
0	0	1	1	0	0	1	-3
0	0	1	1	1	0	1	-5
0	0	1	1	1	1	1	-7
1	0	1	0	1	1	-1	7
1	0	1	0	1	0	-1	5
1	0	1	0	0	0	-1	3
1	0	1	0	0	1	-1	1
1	0	1	1	0	1	-1	-1
1	0	1	1	0	0	-1	-3
1	0	1	1	1	0	-1	-5
1	0	1	1	1	1	-1	-7
1	0	0	0	1	1	-3	7
1	0	0	0	1	0	-3	5
1	0	0	0	0	0	-3	3

1	0	0	0	0	1	-3	1
1	0	0	1	0	1	-3	-1
1	0	0	1	0	0	-3	-3
1	0	0	1	1	0	-3	-5
1	0	0	1	1	1	-3	-7
1	1	0	0	1	1	-5	7
1	1	0	0	1	0	-5	5
1	1	0	0	0	0	-5	3
1	1	0	0	0	1	-5	1
1	1	0	1	0	1	-5	-1
1	1	0	1	0	0	-5	-3
1	1	0	1	1	0	-5	-5
1	1	0	1	1	1	-5	-7
1	1	1	0	1	1	-7	7
1	1	1	0	1	0	-7	5
1	1	1	0	0	0	-7	3
1	1	1	0	0	1	-7	1
1	1	1	1	0	1	-7	-1
1	1	1	1	0	0	-7	-3
1	1	1	1	1	0	-7	-5
1	1	1	1	1	1	-7	-7

3.3.3.5 Baseband Pulse Shaping

Prior to modulation, the I and Q signals shall be filtered by square-root raised cosine filters. The excess roll-off factor α shall be either 0.15, 0.25, or 0.35. The ideal square-root raised cosine filter is defined by the following transfer function H:

$$(H(f) = 1) \qquad \text{for } (|f| < f_N(1-\alpha))$$

$$\left(H(f) = \left\{\frac{1}{2} + \frac{1}{2}\sin\frac{\pi}{2f_N}\left[\frac{f_N - |f|}{\alpha}\right]\right\}^{\frac{1}{2}}\right) \text{ for } ((f_N(1-\alpha)) \le |f| \le (f_N(1+\alpha)))$$

$$(H(f) = 0) \qquad \text{for } (|f| > f_N(1+\alpha))$$

where $f_N = \frac{1}{2T_S} = \frac{R_S}{2}$ is the Nyquist frequency.

3.3.3.6 Summary of Upstream Physical Layer Parameters

Table 90—Summary of Upstream Physical Layer Parameters

Transmission convergence layer	Selectable on/off. When enable, the TC layer
Outer Coding	Reed Solomon over GF(256) Information byte lengths: 6-255 bytes Error correction capability R=0-32 (T=0-16) Block Turbo Code (optional) (Note: There is no inner code selected in this case.)
Inner Coding	Selectable from the following options: None (24,16) block convolutional code (9,8) parity check code (optional)
Randomization	$x^{15}+x^{14}+1$ Initialization seed: 15-bit programmable
Preamble	Programmable length: 0-1024 bits Based on repetition of 16 symbol defined sequence
Modulation	QPSK, 16-QAM (optional), or 64-QAM (optional)
Spectral shaping	α=0.15, 0.25, or 0.35

3.4 Baud Rates and Channel Bandwidths

Due to the large amount of spectrum available in the 10-66 GHz region for point-to-multipoint operation, and the different regulatory requirements in various countries around the world, the baud rates and RF channel bandwidths have been left somewhat flexible in order to allow service providers the ability to maximize capacity for a given spectrum allocation.

The following tables recommend modem baud rates and channel sizes that should be implemented in order to allow for interoperable equipment. It is recommended that subscriber station equipment generally support baud rates in the range of 10-32 MBaud, while other vendor specific channel sizes and baud rates may also be implemented that are not currently listed here. However, in order to limit the range of variable system parameters for implementation and testing reasons, only a few channel sizes are defined here, which are expected to meet the majority of these system deployments. The pulse shapes being used in these tables is a Nyquist Root-Raised Cosine with a roll-off factor of 0.15, 0.25, and 0.35.

Table 91—Recommended Baud rates for a roll-off factor of 0.15

Channel Size(MHz)	**Baud rates (MBaud)**	**Recommended Frame Size (msec)**	**Number of PSs/ Frame**
12.5	10.8	2	5400
14	12	2	6000
20	17.2	1	4300
25	21.6	1	5400
28	24.2	1	6050
36	31.2	0.5	3900
40	34.6	0.5	4325
50	43.4	0.5	5425

Table 92—Recommended Baud rates for a roll-off factor of 0.25

Channel Size (MHz)	Baud rates (MBaud)	Recommended Frame Size (msec)	Number of PSs/ Frame
12.5	10	2	5000
14	11.2	2	5600
20	16	1	4000
25	20	1	5000
28	22.4	1	5600
36	28.8	0.5	3600
40	32	0.5	4000
50	40	0.5	5000

Table 93—Recommended Baud rates for a roll-off factor of 0.35

Channel Size (MHz)	Baud rates (MBaud)	Recommended Frame Size (msec)	Number of PSs/ Frame
12.5	9.2	2	4600
14	10.2	2	5100
20	14.8	1	3700
25	18.4	1	4600
28	20.6	1	5150
36	26.6	0.5	3325
40	29.6	0.5	3700
50	37	0.5	4625

3.5 Radio Sub-system Control

3.5.1 Synchronization Technique (Frame and Slot)

In order to satisfy timing requirements for telephony or other CBR applications (T1/E1), the downstream demodulator should provide an output reference clock that is derived from the downstream symbol clock. This reference can then be used by the subscriber station to provide timing for rate critical interfaces when the downstream clock is locked to an accurate reference at the base station. A time-stamp based method could be used if the desired clock accuracy is sufficient for the services provided, but it should at least be an option to choose to derive subscriber station timing from the downstream symbol clock or an internal oscillator with time stamps coming from the MAC layer at the base station. Accurate upstream time slot synchronization is supported through a ranging calibration procedure defined by the MAC layer to ensure that upstream transmissions by multiple users do not interfere with each other. Therefore, the physical layer needs to support accurate timing estimates at the base station, and the flexibility to finely modify the timing at the subscriber station according to the transmitter characteristics specified in table below.

3.5.2 Frequency Control

Frequency control is also a critical component of the physical layer. Due to the large carrier frequencies proposed for Broadband Wireless Access systems, frequency errors will exist in the radio units, and will vary with age and temperature. In order to allow for cost effective radio units at the subscriber station, the upstream and downstream RF sources should reference each other. Note that there also exists an initial ranging process for frequency and power calibration. After the initial frequency has been calibrated, it is expected that periodic measurements of the frequency offset value at the basestation will be made by the physical layer and sent to the subscriber station via a MAC message, enabling low cost frequency references to be used in the radio units.

3.5.3 Power Control

As with frequency control, a power control algorithm should be supported for the upstream channel with both an initial calibration and periodic adjustment procedure without loss of data. The base station should be able to provide accurate power measurements of the received burst signal. This value can then be compared against a reference level, and the resulting error can be fed back to the subscriber station in a calibration message coming from the MAC layer.

The power control algorithm should be designed to support power attenuation due to distance loss or power fluctuations at rates of at most 10 dB/second with depths of at least 40 dB.

3.6 Minimum Performance

This section details the minimum performance requirements for proper operation of the system for the LMDS A Band frequencies. The values listed in this section apply over the operational environmental ranges of the system equipment and measured per Subsection xxx.

Basestation transmitter	
Max. Tx phase noise	Integrated phase noise <= 1.3 degrees for 16-QAM (assuming a receiver tracking loop bandwidth of 1 % of the symbol rate) Integrated phase noise <= 0.6 degrees for 64-QAM (assuming a receiver tracking loop bandwidth of 1 % of the symbol rate)
Tx symbol Timing accuracy	Peak-to-peak symbol jitter, referenced to the previous symbol zero crossing, of the transmitted waveform, MUST be less than 0.02 of the nominal symbol duration over a 2-sec. period. The peak-to-peak cumulative phase error, referenced to the first symbol time and with any fixed symbol frequency offset factored out, MUST be less than 0.04 of the nominal symbol duration over a 0.1 sec period.
Tx RF frequency/accuracy	10-66 GHz/ +- 5 ppm (including aging and temperature variations)
Spectral Mask (OOB)	Per relevant local regulatory requirements
Spurious	Per relevant local regulatory requirements
Composite Group delay variation	< 20% of symbol period for 16-QAM < 10% of symbol period for 64-QAM
Composite Amplitude ripple	1.0 dB peak-to-peak over the signal baud rate bandwidth (fc +/- baud rate/2)
Base station receiver	
Dynamic range	70 dB above receiver noise floor
Receiver equivalent noise floor (including noise floor for a 1 MHz noise bandwidth, noise figure, and other implementation losses)	-105 dBm
Maximum input 1 dB compression point	-25 dBm
Adjacent channel interference	
Subscriber Station transmitter	
Tx Dynamic range	40 dB

Min. Tx power level at Max. power level setting (1 dB compression point)	-26 dBW/MBaud (*i.e.*, -13 dBW = 17 dBm for 20 MBaud)
Tx power level adjustment steps and accuracy	The subscriber station shall adjust its Tx power level, based on feedback from the basestation via MAC messaging, in steps of [0.5] dB +/- TBD[0.2] dB in a monotonic fashion.
Max. Tx phase noise	TBD at a later date.
Tx symbol timing jitter	Peak-to-peak symbol jitter, referenced to the previous symbol zero crossing, of the transmitted waveform, MUST be less than 0.02 of the nominal symbol duration over a 2-sec. period. The peak-to-peak cumulative phase error, referenced to the first symbol time and with any fixed symbol frequency offset factored out, MUST be less than 0.04 of the nominal symbol duration over a 0.1 sec period."
Tx burst timing accuracy	Must implement corrections to burst timing with an accuracy of +- 1/2 of a symbol and a resolution of +- 1/4 of a symbol
Tx RF frequency/accuracy	10-60 GHz/ +- TBD ppm
Tx frequency range	TBD at a later date.
Spectral Mask (OOB)	TBD by Coexistence group.
Spectral mask (in-band)	TBD at a later date.
Filter distortion	
Group delay variation	TBD at a later date.
Amplitude ripple	TBD at a later date.
Adjacent channel interference	TBD by Coexistence group.
Co-channel interference	TBD by Coexistence group.
Spurious	TBD by Coexistence group.

Table 94— PHY Layer Requirements

PHY Layer Requirement	Specifica-tion Section
Reference Test Planes	
Transmitter Minimum Requirements	
- Introduction	.1
- Tap-Gain Process Types	.2
- Propagation Models	.3
Transmitter Minimum Requirements	
– Output Power	.1
– Emission Spectrum	.2
- Unwanted Conducted Emissions	.3
- Unwanted Radiated Emissions	.4
- RF Tolerance	.5
- Required Oscillator Performance	.5.1
- Frequency Stability	.5.2
- Power Stability	.6
- RF Output Power Time Mask	.7
- Intermodulation attenuation	.8
- CPE Channel Switching Time	.9
- Tx / Rx Carrier Switching Time	.10
- Off to On Carrier Switching Time	.11
- On to Off Carrier Release Time	.12
– Special Co-Location Requirements - Transmitter	.13
Receiver Minimum Requirements	
- Blocking Characteristics	.1
– Spurious Response Rejection	.2
- Intermodulation Response Rejection	.3
- Unwanted Conducted Emissions	.4
- Unwanted Radiated Emissions	.5

- Received Signal Strength Indication	.6
- Special Co-Location Requirements - Receiver	.7
Transmitter / Receiver Performance	
- Modulation Accuracy	.1
– Receiver Performance	.2
- Nominal Error Rates	.2.1
- Static Reference Sensitivity Performance	.2.2
- Dynamic Reference Sensitivity Performance	.2.3
- Reference Interference Performance	.2.4
- CPE receiver performance for synchronization acquisition	.2.5

3.6.1 Reference test planes

TBD

3.6.2 Propagation Conditions

Line of sight radio propagation conditions between base station and subscriber stations are required, to achieve high quality and availability service. Also, the subscriber stations need highly directional antennas, which minimize the number of multipaths and interference from unexpected sources. The intersymbol interference may occur as a consequence of multipaths.

3.6.2.1 Propagation Models

In this subsection, the propagation models that are referred to in this PHY Specification are defined.

Table 95— Propagation Models

Propagation model	**Tap number**	**Relative delay ((s)**	**Average relative power (dB)**	**Tap-gain process**
Static				
Dynamic				

3.6.3 Transmitter characteristics

Unless stated otherwise, the transmitter requirements are referenced to the antenna output port and apply with the transmitter tuned to any channel.

3.6.3.1 Output Power

In the following subsections, power is defined as the average power, measured through the square root raised cosine filter over the scrambled bits of one transmitted burst.

The power at which CPEs or BSs may operate are specified in the following subsections.

3.6.3.1.1 BS

The BS transmitter maximum output power shall be as defined in .

Table 96— Maximum BS Transmitter Power

Power class	Maximum power per carrier
1	

The output power shall be adjustable over the range +20 dBm to -30 dBm via a configurable software parameter.

3.6.3.1.2 CPE

The CPE maximum power shall be as defined in

TBD

Table 97— CPE Power Control Levels

Step Level	Power
0	
1	
2	
* * *	
98	
99	
100	

Table 98—Emissions Spectrum

TBD

3.6.3.2 Unwanted Conducted Emissions

TBD

3.6.3.3 Unwanted radiated emissions

TBD

3.6.3.4 Intermodulation Attenuation

TBD

3.6.3.5 Power Stability

TBD

3.6.3.6 RF Output Power Time Mask

TBD

3.6.3.7 Tx / Rx Carrier Switching Time Requirements

TBD

3.6.3.8 CPE Channel Switching Time

TBD

3.6.3.9 .3.10. Special Co-Location Requirements – Transmitter

TBD

3.6.4 Receiver Characteristic

TBD

3.6.4.1 Blocking Characteristics

TBD

3.6.4.2 Spurious Response Rejection

TBD

3.6.4.3 Intermodulation Response Rejection

TBD

3.6.4.4 Unwanted Conducted Emissions

TBD

3.6.4.5 Unwanted Radiated Emissions

TBD

3.6.4.6 Received Signal Strength Indication (RSSI)

TBD

3.6.4.7 Special Co-Location Requirements – Receiver

TBD

3.6.5 Transmitter / Receiver Performance

TBD

3.6.5.1 Modulation Accuracy

TBD

3.6.5.2 Receiver Performance

TBD

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