Project	**IEEE 802.16 Broadband Wireless Access Working Group**	
Title	**Changes between 802.16.1 Functional Requirements (IEEE 802.16s-99/00r1) and 802.16.3 Functional Requirements (Proposed) (IEEE 802.16.3-00/02r0)**	
Date Submitted	**2000-03-27**	
Source	Brian Petry 3Com 12230 World Trade Dr San Diego, CA	Voice: (858) 674-8533 Fax: E-mail:brian_petry@3com.com
Re:	At 802.16 Session #6, the sub-10 study group authorized Brian Petry to create a document that specified the differences between the 802.16.1 Functional Requirements and George Fishel's "first cut" at 802.16.3 Functional Requirements.	
Abstract	The document is the output from MS-Word's "Compare Documents" feature, that automatically created red-lined differences between the two documents.	
Purpose	This document is meant to assist 802.16.3 Functional Requirements reviewers to see exactly what changes George made to the 802.16.1 Functional Requirements.	
Notice	This document has been prepared to assist the IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.	
Release	The contributor acknowledges and accepts that this contribution may be made public by 802.16.	
IEEE Patent Policy	The contributor is familiar with the IEEE Patent Policy, which is set forth in the IEEE-SA Standards Board Bylaws <http://standards.ieee.org/guides/bylaws> and includes the statement: "IEEE standards may include the known use of patent(s), including patent applications, if there is technical justification in the opinion of the standards-developing committee and provided the IEEE receives assurance from the patent holder that it will license applicants under reasonable terms and conditions for the purpose of implementing the standard."	

Proposed Functional Requirements Draft Document for Sub 10 GHz Study Group

George Fishel

~~Imed Frigui~~

~~Marianna Goldhammer~~

~~Hossein Izadpanah~~

~~David Jarrett~~

~~Leland Langston~~

~~John Liebetreu~~

~~Willie Lu~~

~~Scott Marin~~

~~James Mollenauer~~

~~William Myers~~

~~Asif Rahman~~

~~Margarete Ralston~~

~~Gene Robinson~~

~~Michael Stewart~~

~~Jung Yee~~

Table of Contents

1 Introduction

This document provides functional requirements that are guidelines for developing an interoperable 802.16.3 air interface for the licensed microwave frequency bands between 12 and 101 GHz enabling Point to Multipoint (P-MP) Broadband Wireless Access (BWA) for Line of Sight (LOS) and Near Line of Sight (NLOS) ~~802.16.1 air interface. The 802.16.1~~applications. The BWA system is intended to provide packet and other non-fixed rate services with statistical multiplexing over the air interface for spectrum efficiency. The core MAC protocol is based on DOCSIS1.1 and extended to serve the needs of the wireless PHY. The 802.16.3 committee desired to reach an understanding and consensus for functional requirements before proceeding with developing standards for ~~802.16.1~~802.16.3 MAC and PHY protocols and thus formed a System Requirements Task Group to produce this document.

While this standard is developed specifically for the licensed frequency bands between 1 and 10 GHz, this does not prohibit the use of the standard for unlicensed bands in cases where the standard interface is compatible with the requirements imposed by the particular national communications commissions.

~~Please note t~~That ~~t~~his document provides guidelines for the 802.16 working group. Its purpose is to formulate and facilitate consensus on some general issues prior to plunging into MAC and PHY details. As such, the functional requirements are subject to change as the 802.16 working group debates the issues, makes revisions, and approves this document as a basis for starting the “Interoperability Standard” [20].

The Functional Requirements will not be published or sold by the IEEE. The requirements, with possible future amendments, are binding to the future development of ~~802.16.1~~802.16.3 air interface protocols. This means that the forthcoming air interface standard MUST comply with the functional requirements.

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..

"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 truly optional. One implementation may include the item because the target marketplace requires it or because it enhances the product, for example; another implementation may omit the same item.

1.1 Scope

For the purposes of this document, a "system" ~~constitutes: an 802.16.1 MAC and PHY implementation,~~constitutes an 802.16.3 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. So, "functional requirements" describes the properties of typical systems in terms of how they affect requirements of interoperable ~~802.16.1~~802.16.3 MAC and PHY protocols. The functional requirements describe ~~802.16.1~~802.16.3 systems and requirements in broad terms: *what* they are, but not *how* they work. The *how* part is left to the forthcoming ~~802.16.1~~802.16.3 interoperability standard [20], which will describe in detail the interfaces and procedures of the MAC and PHY protocols.

~~Since many BWA *systems* are conceivable, with many possible interconnections, inter-working functions [17] and parameters, t~~This document ~~does not specify them all, but~~ focuses on the~~bearer~~ services that an ~~802.16.1~~802.16.3 system is required to transport. These~~*bearer*~~ *services* have a direct impact on the requirements of the ~~802.16.1~~802.16.3 MAC and PHY protocols. When the 802.16 working group produces an interoperable air interface standard that meets these functional requirements, resulting ~~802.16.1~~802.16.3 systems provide the services required to neatly interface into many conceivable BWA systems. ~~See section 1.2.~~

Other goals of this document are to formulate reference models and terminology for both network topology and protocol stacks that help the 802.16 working group to discuss and develop the MAC and PHY protocols.

The ~~802.16.1~~802.16.3 air interface interoperability standard SHALL be part of a family of standards for local ~~and,~~ metropolitan ~~area~~ and wide area networks. The ~~802.16.1~~802.16.3 protocols relate to other 802 standards and to the OSI model as shown in ~~Figure 1.~~ Figure 1.

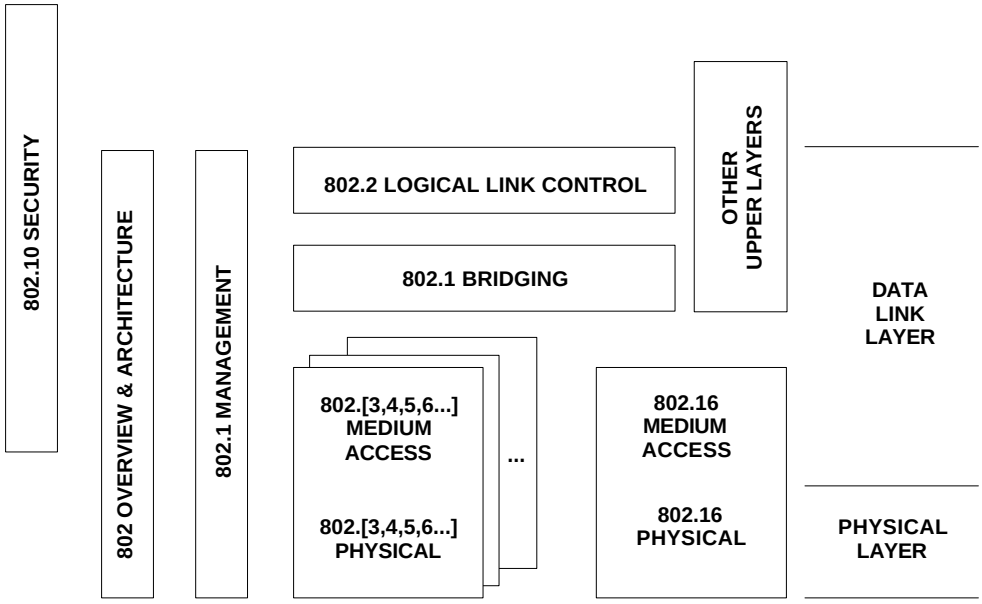


Figure 1: Relationship between ~~802.16.1~~802.16.3 and other Protocol Standards (the numbers in the figure refer to IEEE standard numbers)

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. This standard provides an overview to the family of IEEE 802 Standards. This document forms part of the 802.1 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)

1.2 Target Markets

The target markets described in this section are not an exhaustive set, but serve as guidelines and examples that suffice for meeting the broad applicability goals set forth by the air interface “Five Criteria” ~~[20a].~~

A broadband wireless access (BWA) system based on ~~802.16.1~~802.16.3 protocols is expected to address markets similar to wired broadband access technologies such as:

- Copper digital subscriber line (xDSL) technologies
- Digital cable TV hybrid fiber/coax (HFC) networks
- Integrated Services Digital Network (ISDN)

~~– Legacy TDM digital transmission systems (e.g., Full and Fractional T1, E1, ISDN PRI etc.)~~

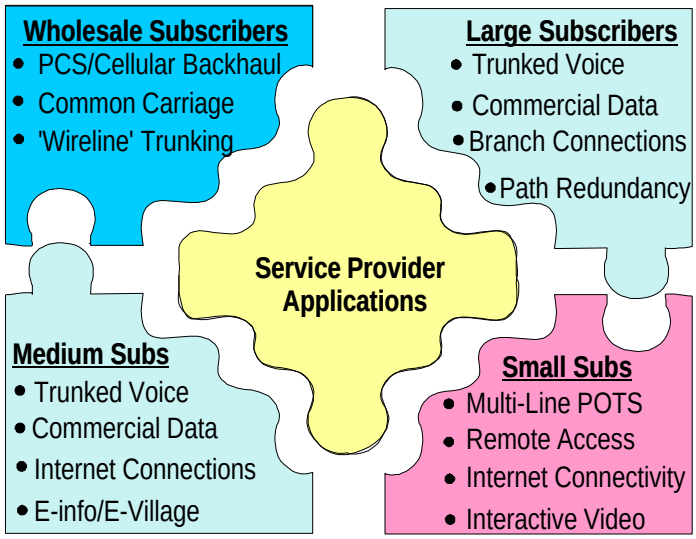
- The services that such legacy systems carry: data, voice and audio/video [8].

The ~~initial~~ target markets to be addressed by the ~~802.16.1~~802.16.3 protocols in BWA networks are ~~small to large businesses, and~~single family residential, SOHO, and ssmall businesses and multi-tenant dwellings. Future growth will include ~~multi-tenant dwellings such as high rise~~

~~buildings. 802.16.1 protocols in BWA networks may address the target market for single-family residences.~~

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 access system generally provides access to an external network, and by itself is not intended to form an end-to-end communication system. 802.16.1 systems are fixed.~~
802.16.3 access system generally provides access to an external network, and by itself is not intended to form an end-to-end communication system. 802.16.3 systems serve fixed position
~~Sometimes, the word *subscriber* is associated with a single customer that is billed for a service. But it is important to note that a BWA system SHOULD support more than one paying customer at a single access point to a subscriber BWA radio. In other words, the subscriber access point is for "wholesale" connection of multiple "retail" subscribers [14]. For instance, an office building may be well served by a single BWA radio, but house many tenants who are billed separately. This requirement may for instance affect multiplexing in the MAC layer, security (see section 8), and accounting (see section 7.3).~~

~~The target markets can be further described by Figure 1-2 and Figure 1-3.~~



~~Figure 1-2: Summary of 802.16.1 Example Applications and Services~~

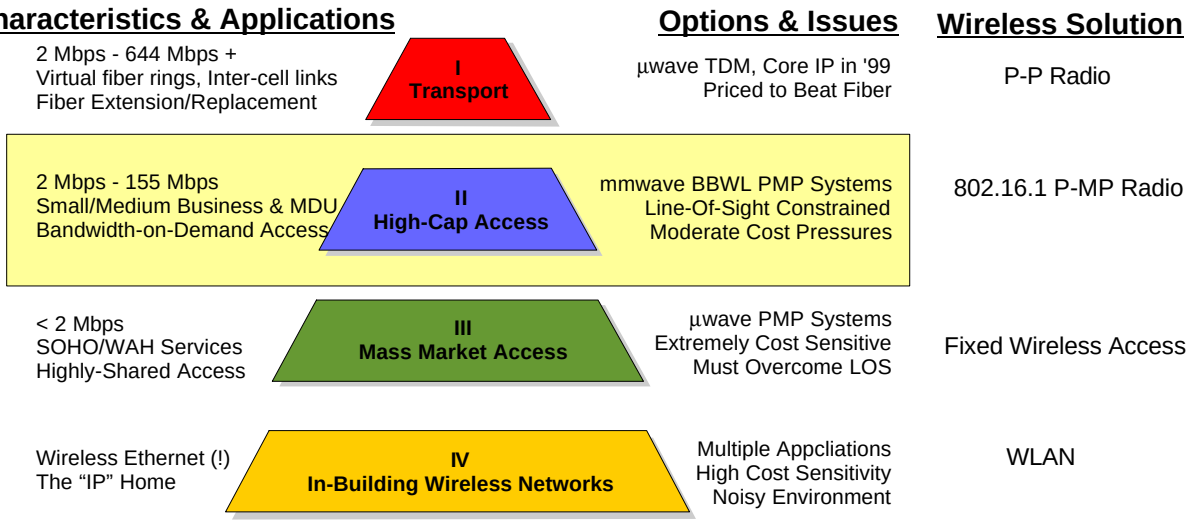


Figure 1-3: A Multi-Tier Perspective of Wireless Transmission and Distribution Systems

2802.16.1 System Model

This section presents a high level description of a system model to be used as a framework for developing 802.16.1 protocol standards. The model describes some of the main features of an 802.16.1 system, and the terminology to be used by the 802.16 working group in the creation of the standards.

As mentioned in section 1.1, an 802.16.1 "system" constitutes: an 802.16.1 MAC and PHY implementation, in which at least one subscriber station communicates with a base station via a radio air interface (an 802.16.1 system), and services transported by the MAC and PHY protocols. An 802.16.1 system employs point-to-multipoint (P-MP) radios operating in the vicinity of 30 GHz, but generally in the range from 10 GHz to 66 GHz, to connect a base station to one or more subscriber stations [4][9]. Radio communications in the above range require line-of-sight (LOS) between a base station and subscriber station. LOS blocked by foliage also contributes heavily to signal attenuation. Figure 2-1 and Figure 2-2 [13] depict some typical 802.16.1 systems. 802.16.1 systems SHALL be multiple-cell frequency reuse systems. The range of 802.16.1 radios varies with transmit power, LOS blockage, availability requirement, and atmospheric conditions.

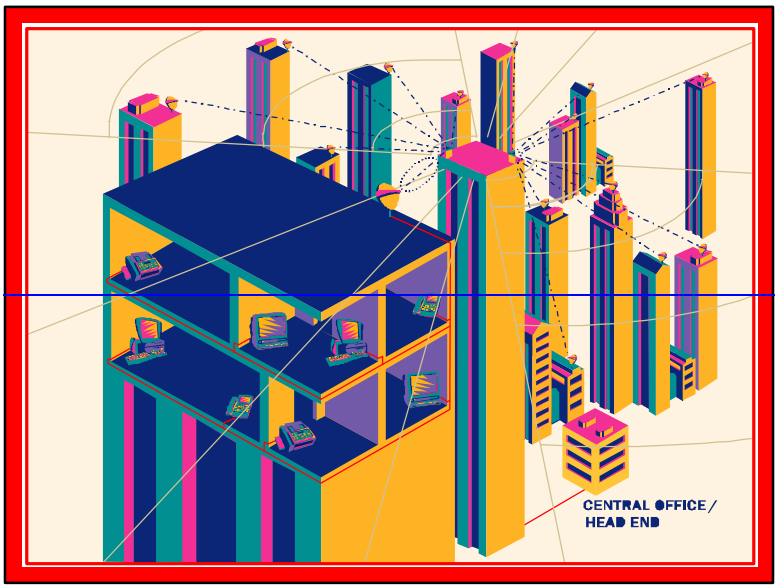
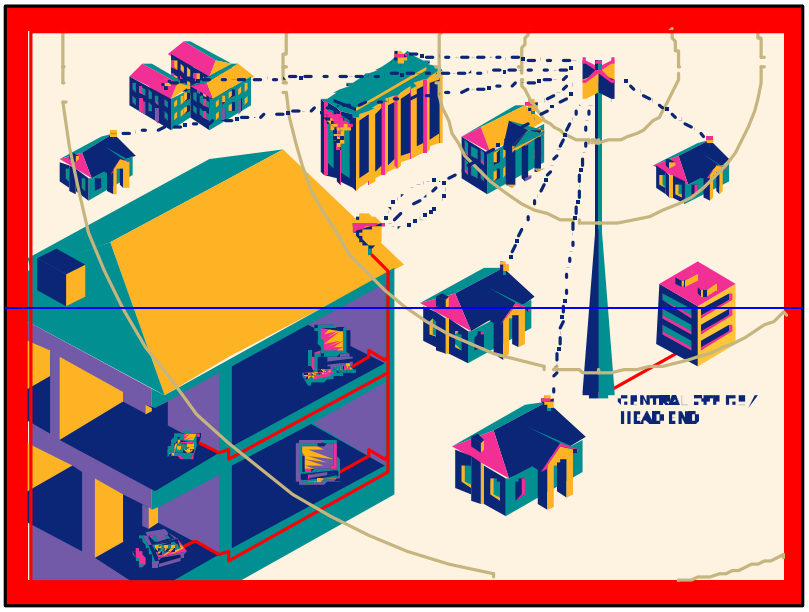


Figure 2-1: System Showing a Base Station Mounted on a Tall Bulding



~~Figure 2-2: System Showing a Base Station Mounted on a Tower~~

~~Note that, in concern for simple terminology, 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 base station radio SHOULD~~customers.

The word *subscriber* is associated with a single customer that is billed for a service. A Small Business customer is a subscriber with multiple users behind the CPE. [14]. This requirement may affect multiplexing in the MAC layer, security (see section), and accounting (see section). Editor's note: Need contribution on subscriber. Multi-subscriber capability from a single radio is a must for this air interface.

2 802.16.3 System Model

This section presents a high level description of a system model to be used as a framework for developing 802.16.3 protocol standards. The model describes some of the main features of an 802.16.3 system, and the terminology to be used by the 802.16 working.16-working group in the creation of the standards.

As mentioned in section, an 802.16.3 “system” constitutes: an 802.16.3MAC and PHY implementation, in which at least one subscriber station communicates with a base station via a radio air interface (an 802.16.3 system), and services transported by the MAC and PHY protocols. Specific applications of the 802.16.3 point-to-multipoint (P-MP) radios include 2.1 to3.5 GHz, but the standard in more generally applicable to the range from 1 GHz to 10 GHz. The standard is used to connect a base station to one or more subscriber stations [4][9]. Radio communications in the above range require near line-of-sight (NLOS) between a base station and subscriber station. NLOS operation may include partial blockage by foliage which contributes to signal attenuation and multipath effects. Figure 2.1 depicts a typical 802.16.3 systems. 802.16.3 systems SHALL be deployable in multiple-cell frequency reuse systems and single cell (super

cell) frequency reuse systems. The range of 802.16.3 radios varies with transmit power, NLOS blockage, availability requirement, and atmospheric conditions.

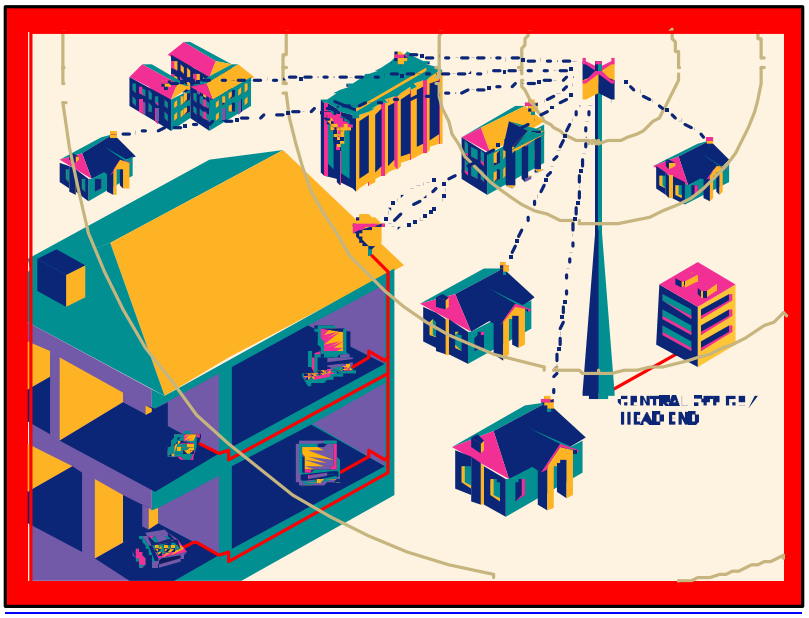


Figure 2-1: System Showing a Base Station Mounted on a Tower

Note , in concern for simple terminology, an 802.16.3 *system* consists of one base station radio and one or more subscribers. Thus, an 802.16.3 system also defines 802.16.3 base station and subscriber station radios that communicate using the 802.16.3 MAC and PHY protocols. The base station radio SHALL be P-MP, radiating its *downstream* signal with a shaped sector antenna achieving broad azimuthal beam width to "cover" a prospective number of subscribers. . An isolated omnidirectional antenna should be treated as the degenerative version of the sectored operation. Each subscriber station employs a highly directional radio pointed at the base station. Note that with this arrangement, direct radio communications between subscriber stations is not possible. Furthermore, the ~~802.16.1~~802.16.3 system does not define radio communications between base stations. Since the base station radios are "sector oriented," multiple base station radios will likely, in practice, be co-~~co-~~located (subject to frequency re-use requirements), and even share physical hardware.

The frequency bands used by ~~802.16.1~~802.16.3 systems vary among governed geographies [19].

2.1 System Reference Model

~~Figure 2-3~~Figure 2-2 shows the ~~802.16.1~~802.16.3 system reference points, depicting the relevant elements between a subscriber network and the "core" network (the network to which ~~802.16.1~~802.16.3 is providing *access*).~~The air interface MUST NOT preclude repeaters or reflectors to bypass obstructions and extend cell coverage.~~ A greater system encompassing user terminals, base station interconnection networks, network management facilities, etc. [1] may be envisaged, but the ~~802.16.1~~802.16.3 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. However, The description of~~possible~~ separation and protocols of base station and subscriber station into indoor and outdoor units is beyond the scope of this document. One addition to this model to be considered are security systems (see section ~~8~~). Two key interfaces "to the outside world" 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 from section 1.2 that the SNI may support multiple paying subscribers, such as within a multi-tenant office building or dwelling.~~ residential networks: voice, data and video, etc. A base station interfaces ~~to~~may support one or more core networks through one or more BNIs. For the purposes of ~~802.16.1~~,802.16.3, the SNI and BNI are abstract concepts. The details of these interfaces, which are sometimes called inter-working functions (IWFs), are beyond the scope of this document and are not specified by the forthcoming interoperability standard [20] [17]. 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 ~~3.1~~) on the requirements of ~~802.16.1~~802.16.3 protocols by drawing focus to the air interface and the immediate requirements imposed by the surrounding networks. The standard (e.g., MAC/PHY protocols) SHALL describe common access protocol(s) and comm on modulation technique(s).

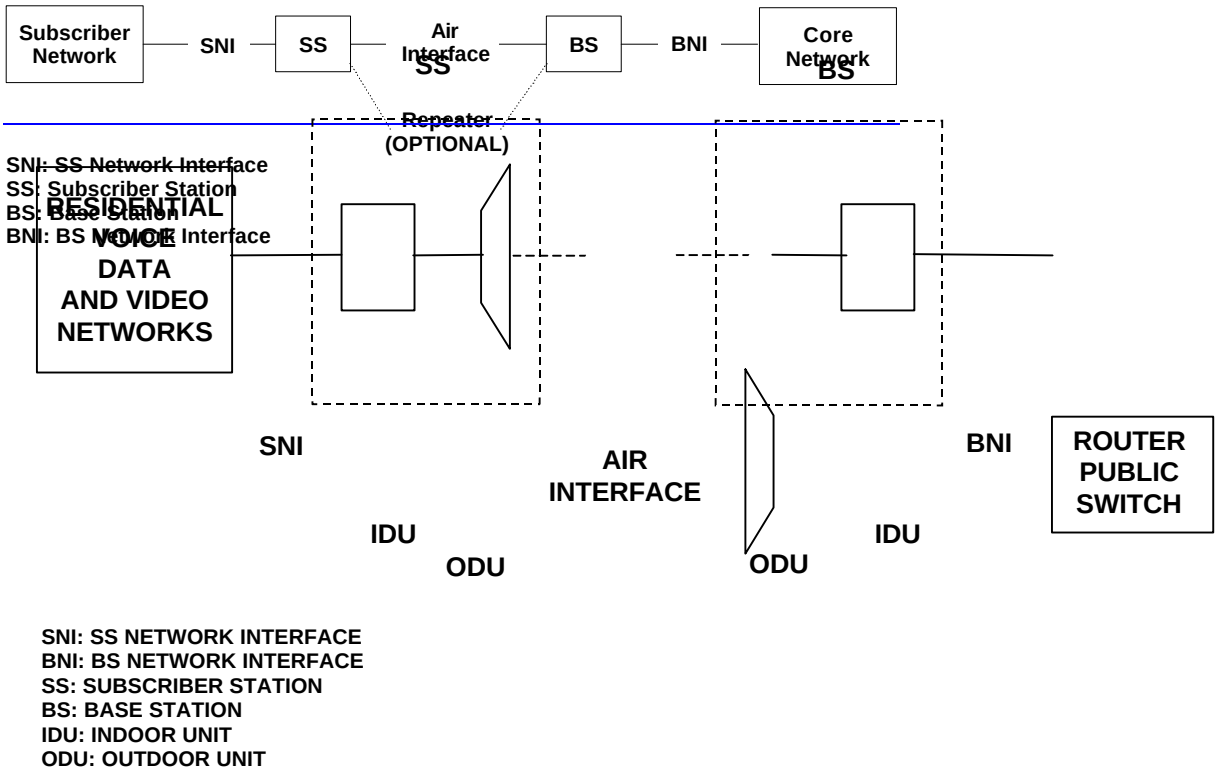


Figure 2~~-3:~~-2: System Reference Points

2.2 Topology

Since all data traffic in a single cell of an ~~802.16.1~~802.16.3 network MUST go through the base station, that station SHALL serve as a radio resource supervisor [10]. The subscriber stations may request bandwidth to achieve QoS objectives (see section ~~6~~), but it may be convenient for the base station to implement the “smarts” of bandwidth allocation.

In the downstream direction, within a channel, the network topology is similar to a contention-less broadcast bus, since all transmissions are transmitted by the base station, and more than one

subscriber station could share a downstream channel. In the upstream direction, if subscriber stations share a channel, the topology is similar to a contention-oriented bus, ~~802.16.1~~802.16.3 protocols MUST provide the means to multiplex traffic from multiple subscriber stations in the downstream direction, and provide for a means to resolve contention and allocate bandwidth in the upstream direction.

3 Supported Services

This section describes the~~bearer~~ services that an ~~802.16.1~~802.16.3 system at least SHOULD support (some services MUST be supported). ~~First, typical~~Both the target markets ~~are described, then the particular~~and the associated bearer services~~which an 802.16.1 system is expected to transport.~~

are described. It may be difficult to comprehend services the system supports without first understanding the system model. Please refer to section ~~2~~ if necessary.

3.1 ~~Bearer~~ Services

This section describes typical services, transported by an ~~802.16.1~~802.16.3 system. In this document,~~*bearer*~~ *services* 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~~802.16.3-based BWA networks. [12] [54].

The MAC and PHY protocols may not have explicit support for each and every~~bearer~~ service, since they SHOULD be handled as data streams in a generic fashion. But it is important to consider all the~~bearer~~ services for any particular requirements they may have and extract the "common denominators" that result as generic parameters of -MAC and PHY protocols.

~~3.1.1Digital Audio/Video Multicast~~

~~802.16.1 protocols SHOULD efficiently transport digital audio/video streams to subscribers. This form of digital transport MAY bypass the MAC protocol layer. The streams flow in the direction of the infrastructure network to subscriber(s) only, and do not originate from subscribers. Digital Audio/Video Multicast service is thus similar to digital video capabilities of digital broadcast cable TV, and digital satellite television service.~~

~~3.1.2~~3.1.1 ~~Digital Telephony~~Voice Services

~~802.16.1 systems SHOULD support supplying telephony "pipes"~~802.16.3 systems SHALL support "telephony" to subscribers in a way that eases the migration of legacy telephony 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~~802.16.3 systems. The access transport will be packet based (as opposed to circuit switched) and voice services will be recovered ~~digital telephony service hierarchies: Synchronous Digital Hierarchy (SDH) or Plesiochronous Digital Hierarchy (PDH) (please see the glossary entries in appendix B).~~

~~Note that many forms of digital telephony are possible:~~from the packets. The consumer service level will be in the following form:

~~—~~Narrow band/Voice Frequency Telephony - POTS (supporting FAX services)~~, Centrex, ISDN BRI~~
~~— NxDSO Trunking - Fractional DS1/E1 to PBXs and/or data equipment, ISDN PRI~~
~~— Full DS1/E1 - transparent mapping including all framing information~~
~~— Voice Over IP, Voice Over Frame Relay, Voice and Telephony over ATM (VTOA), and similar services~~

~~802.16.1~~802.16.3 systems and protocols MUST support the QoS requirements of these services, as defined in Section ~~6~~.

3.1.1.1 Telephony Service Properties

The relevant properties of telephony services are [12] [54]:

- Bandwidth – in general, the codings used in these services require bandwidths in the range of 64 Kbps or less per ~~call (one exception is ISDN BRI service with both B channels and the D channel active, which uses 144 Kbps). There are also some~~call. Voice connectivity will be provided via a VoIP protocol and may involve low rate vocoding. There are subjective quality metrics for the clarity of the encoded speech signals, that can vary based on the quality of the services sold to the end user (e.g., residential vs. business).

- Low delay – as apparent to the end users, the amount of delay between a user speaking and another user hearing the speech MUST be kept below a certain level to support two-way conversation. Again, the specific amount of delay can vary based on the quality of the service sold to the end user.

~~- Timing - (Fractional) DS1/E1 services require timing to be delivered from the network to the end user's equipment, whether the timing is synchronous with the network (i.e., based on the serving network's clock) or asynchronous with the network (based on a clock other than the serving network's clock).~~

BWA protocols MUST support efficient transport of encoded voice data in terms of bandwidth, reliability and delay. ~~Other properties are managed by digital signaling protocols (see section 3.1.2.2).~~

~~3.1.2.2Signaling Systems and Protocols~~

~~Telephony and video conferencing signaling protocols may place specific requirements on 802.16.1 protocols. Some relevant telephony signaling protocols are: Bellcore TR-008, V5.X, Q.931, Q.2931, H.225, H.245, H.323, MGCP, Bellcore GR-303, , MFC R2, E&M, Q.sig, IETF SIP, etc. [12] [17] [61] [editor's note: protocol references not cited].~~

~~In digital telephony hierarchies, periodic bits in the time-division-multiplexed data stream, sometimes "robbed" from encoded voice streams, are used to transport signaling and troubleshooting information [12]. Other signaling protocols (such as those used in ISDN and B-ISDN/ATM) are message-oriented and do not utilize periodic bits in a TDM data stream. The 802.16.1 protocols MUST meet the transport requirements of such telephony signaling, whether TDM- or message-oriented.~~

~~3.1.3ATM Cell Relay Service~~

~~ATM standards define a rich set of quality of service (QoS) guarantees for various service categories [8].~~

~~802.16.1 protocols SHOULD be defined such that an 802.16.1 system can efficiently transport ATM cell relay service and preserve its QoS features (see section 6).~~

~~Also note that, since ATM cell relay service is circuit based, it employs message based signaling protocols (Q.2931) 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 (see also section 3.1.2.2).~~

~~802.16.1 SHOULD provide a means to utilize ATM addresses such as ITU-T E.164 [74]. For instance, 802.16.1 MAY provide a direct ATM addressing mode for 802.16.1 nodes, or MAY provide a means to translate ATM addresses to 802 addresses [10].~~

3.1.1 Internet Protocol Service

The ~~802.16.1~~802.16.3 system MUST directly transport variable length IP datagrams efficiently. Both IP version 4 and 6 MUST be supported. For efficient transport of IPv6, TCP/IP header compression over the air interface SHOULD be supported.

The ~~802.16.1~~802.16.3 IP service MUST provide support for real-time and non-real-time services. It SHOULD be possible to support the emerging IP Quality of Service (QoS) efforts: Differentiated Services [43, 44] and Integrated Services [42].

~~1.1.2~~3.1.2 Bridged LAN Service

The ~~802.16.1~~802.16.3 protocols MAY support bridged LAN services, whether directly or indirectly.

~~1.1.3~~3.1.3 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.~~may be added. These services ~~do not~~SHALL NOT place any special requirements on ~~802.16.1~~802.16.3 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 [9]. In the example system described in [9], 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. PPP-over-802.16.1 is not expected to place any additional requirements on 802.16.1 protocols, and is expected to be similar to IP or bridged LAN service.~~

~~**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 (Q.933) and in use. Frame Relay also defines a management protocol. [3] [12].~~

~~The 802.16.1 protocols SHOULD not preclude the transport of the above mentioned services.~~

4 802.16. Protocols

Protocols are the heart of the ~~802.16.1~~802.16.3 standard that, when described well, result in interoperability of multiple vendors' equipment. Protocol interoperability occurs at each level in

the protocol "stack" [16]. IEEE 802 protocols reside at layer 1 and 2 and consist primarily of Logical Link Control (802.2) [67] and the various MAC and PHY layers for each LAN or MAN standard. The IEEE Std 802-1990 *Overview and Architecture* [21] describes these layers as follows (excerpt from 802-1990~~)~~ :

"The LLC Sublayer (sublayer of layer 2) describes three types of operation for data communication between service access points: unacknowledged connectionless (type 1), connection-oriented (type 2), and acknowledged connectionless (type 3).

With type 1 operation, information frames are exchanged between LLC entities without the need for the prior establishment of a logical link between peers. These LLC frames are not acknowledged, nor are there any flow control or error recovery procedures.

With type 2 operation, a logical link is established between pairs of LLC entities prior to any exchange of information frames. In the data transfer phase of operation, information frames are transmitted and delivered in sequence. Error recovery and flow control are provided.

With type 3 operation, information frames are exchanged between LLC entities without the need for the prior establishment of a logical link between peers. However, the frames are acknowledged to allow error recovery and proper ordering. Further, type 3 operation allows one station to poll another for data."

"The MAC Sublayer performs access control functions for the shared medium in support of the LLC Sublayer. For different applications, different MAC options may be required. The MAC Sublayer performs the addressing and recognition of frames in support of LLC. MAC also performs other functions, such as frame check sequence generation and checking, and LLC protocol data unit (PDU) delimiting."

"The Physical Layer provides the capability of transmitting and receiving bits between Physical Layer Entities. A pair of Physical Layer Entities identifies the peer-to-peer unit exchange of bits between to MAC users. The Physical Layer provides the capability of transmitting and receiving modulated signals assigned to specific frequency channels, in the case of broadband, or to a~~single~~ single-channel band, in the case of baseband."

The ~~802.16.1~~802.16.3 protocol stack reference diagram is shown in ~~Figure 4-1.~~figure 4-1. In addition to the LLC, MAC and PHY layers suggested by the generic 802 architectures [21] [22] [23], ~~802.16.1~~802.16.3 protocols transport other categories of "upper protocols" that correspond to the requirements of the~~bearer~~ services described in section ~~3.1~~.

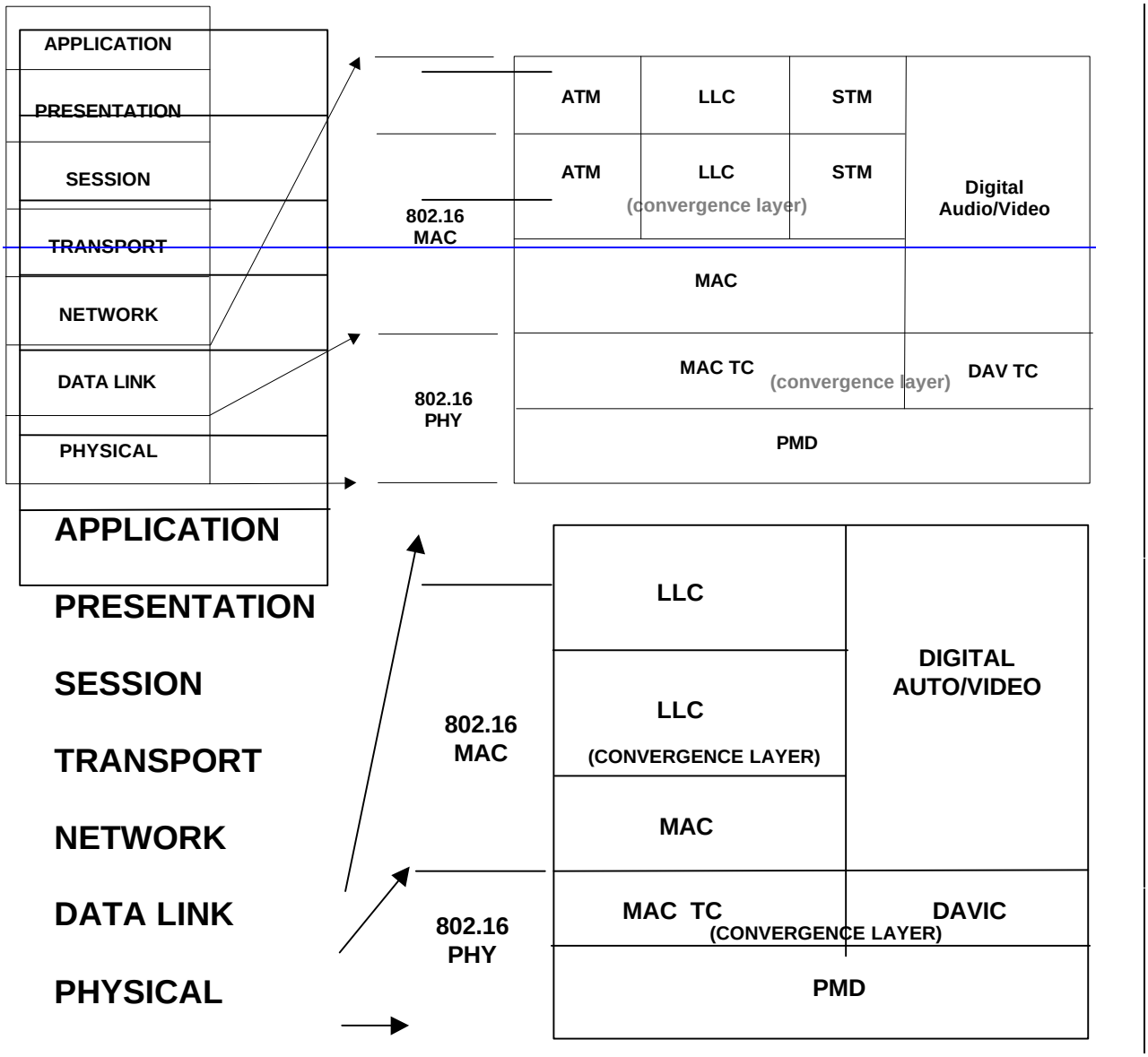


Figure 4-1: Protocol Stack Reference Model

This protocol stack reference model is intended to help develop terminology, and possibly protocol architecture. Each of the "special" protocols above the MAC and PHY are given "convergence sub-layers.". The convergence sub-layers [2] [17] may be necessary to:

- Encapsulate PDU framing of upper layers into the native ~~802.16.1~~802.16.3 MAC/PHY PDUs. [17]
- Map an upper layer's addresses into ~~802.16.1~~802.16.3 addresses
- Translate upper layer CoS/QoS parameters into native ~~802.16.1~~802.16.3 MAC constructs
- Adapt the asynchronous, synchronous or isochronous data pattern of the upper layer into the equivalent MAC service
- Reduce the need for complex inter-working functions (IWFs) [17]

~~For instance, in the ATM world a Transmission Convergence (TC) layer is defined for each link type that carries ATM cells. The purpose of this layer is to delimit cells using the particular link technology, and to signal idle time,~~

~~or insert idle ATM cells on the link. 802.16.1 borrows this terminology to accommodate "special" requirements of the multiple upper layer protocols.~~

~~Another assumption made in the diagram is that digital audio/video (DAV) service bypasses the MAC protocol layer and accesses the PHY layer directly. This assumption is made because the DAV multicast bearer service (see section 3.1.1) is transmitted in the downstream direction only, and does not require the main service of the MAC: channel contention (access control).~~

The central purpose of the MAC protocol layer in ~~802.16.1~~802.16.3 is sharing of radio channel resources. The MAC protocol defines how and when a base station 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 MUST define interfaces and procedures to provide guaranteed service to the upper layers. In the downstream direction, since only one base station is present, and controls its own transmission, the MAC protocol is simple. But in the upstream direction, if one radio channel is allocated to more than one subscriber station, the MAC protocol MUST efficiently resolve contention and bandwidth allocation. Note that the function of the MAC layer is not to provide error correction by retransmission, or automatic repeat request (ARQ). In the 802 model, those functions if necessary, are provided by the LLC layer

The PHY layer is similarly subdivided between a convergence layer and a physical medium-dependent (PMD) layer. The PMD is the "main" part of the PHY. Like the MAC convergence layers, the PHY convergence layers adapt/map the "special" needs of the MAC and DAV services to generic PMD services.~~For instance, tobest support DAV services, the PHY MAY provide TDM-based encapsulation of DAV streams in TDM MPEG-II frames [14].~~

Further details, and finalization of the protocol reference model, SHALL be worked out by the ~~802.16.1~~802.16.3 MAC and PHY task groups while developing the air interface interoperability standard.

5 Performance and Capacity

This section addresses some issues regarding ~~802.16.1~~802.16.3 system performance and capacity. Specifying protocols such that an ~~802.16.1~~802.16.3 system can maintain a specified/mandated performance level in the face of rapidly changing channel ~~characteristics (e.g., due to rain)~~characteristics(e.g., due to multipath) will be a difficult problem for the ~~802.16.1~~802.16.3 working group. This section specifies the target performance levels. ~~Given the target performance levels, planning and provisioning an 802.16.1 system instance is also a difficult problem. The 802.16.1~~The 802.16.3 system capacity at the target performance levels for all subscribers, given geographically local LOS obstruction and atmospheric conditions will also be difficult. This section also outlines some of the issues for ~~802.16.1~~802.16.3 capacity planning.

Note that ITU-R (WP 9A) has presented several questions regarding the need for performance objectives for fixed wireless access radio systems. [16]

~~1.1~~5.1 Scalability

The ~~802.16.1~~802.16.3 protocols SHOULD allow for different "scales" of capacity and performance for ~~802.16.1~~802.16.3 system instances.

~~1.2~~5.2 Delivered Bandwidth

~~802.16.1~~802.16.3 protocols SHALL be optimized to provide the peak capacity from 2 to ~~155 Mbps~~10Mbps to a subscriber station ~~sufficiently close to~~within the specified distance from the base station. The ~~802.16.1~~802.16.3 MAC protocol SHOULD allow the upper range of delivered bandwidth to scale beyond ~~155~~10 Mbps. ~~However, 802.16.1 protocols SHALL not preclude the ability of an 802.16.1 system to deliver less than 2 Mbps peak per-user capacity.~~

~~1.3~~5.3 Flexible Asymmetry

~~802.16.1~~802.16.3 protocols SHOULD allow for flexibility between delivered upstream and downstream bandwidth and CoS/QoS. Some target markets utilize naturally asymmetrical bandwidth, such as for generic Internet access where most of the bandwidth is consumed in the downstream direction. Some markets utilize asymmetrical bandwidth, using more in the upstream direction, such as a video multicast from a corporate or distance-learning source. Other markets and applications require symmetrical bandwidth, such as telephony and video conferencing [17].

A high degree of flexibility may be achieved by utilizing the MAC protocol to arbitrate channel bandwidth in either direction, upstream or downstream.

~~1.4~~5.4 Radio Link Availability

An ~~802.16.1~~802.16.3 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%~~99.94% of the time [2, 11] , assuming that the system and radios receive adequate mains 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~~802.16.3 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 (cite G.826).

- 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 typified as data block containing an error detection code for service performance monitoring. An errored block is a block in which one or more bits are in error.

It is expected that the highest contributor to ~~802.16.1~~802.16.3 system outage will be excessive attenuation ~~due to atmospheric conditions (e.g., rain rate, droplet size and other factors) [50] [51] [52] [53] [72].~~ ~~802.16.1~~and multipath due to varying path impediment such as foliage.802.16.3 MAC and PHY protocols MUST accommodate ~~atmospheric~~these conditions, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements. Since statistical atmospheric and path conditions vary widely in geography, the ~~802.16.1~~802.16.3 protocols MUST be flexible in consumed radio bandwidth (spectral efficiency), cell radius, and transmit~~power to accommodate a rain allowance that varies with geography [11].~~power.

Bandwidth and cell radius are critical components of system/cell capacity planning (also see section ~~5.7~~).

~~802.16.1~~802.16.3 MAC and PHY protocols SHOULD specify functions and procedures to adjust transmitter power, modulation, or other parameters to accommodate rapid changes in channel characteristics ~~due to atmospheric conditions~~.

5.5 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 SHALL meet IEEE 802 functional requirements: The bit error ratio (BER) is 10E-9. Note that this BER of the recovered payload applies to a BWA system which is only one component of a network's end-to-end BER. ~~Additionally, each block of data delivered by the PHY to the MAC MUST allow for detection of errors by the MAC (e.g., by CRC) with 1, 2 or 3 errored bits (a Hamming Distance of 4) [7].~~ Note that the size of the data block is TBD.

5.6 Delay

Variation of delay, or jitter, is important to consider. For example, a high variation of delay can severely impact telephony services. ~~But~~However, 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 [15] [17] [75].

The budget for ~~802.16.1~~802.16.3 system transit delay and access delay MUST be derived. [15] [17]. The MAC layer may have different requirements for each direction, upstream and downstream. In the upstream direction, time MUST be budgeted for requesting bandwidth and contending among nodes. The budget for ~~802.16.1~~802.16.3 transit delay is suggested to be less than 19.5 ms [15] for "stringent QoS" services.

ITU I.356 [73] 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 [17]. It is suggested that the budget for ~~802.16.1~~802.16.3 systems be 1.5ms [15] for "stringent QoS" services.

Please refer to section ~~6.2~~, descriptions of QoS parameters.

5.7 Capacity Issues

~~802.16.1~~802.16.3 system capacity requirement is defined as the product of the number of subscribers, their peak bandwidth requirements and load factor based on quality of service guarantees. The delivered capacity can vary depending on attenuation due to atmospheric conditions, LOS blockage, transmit power, etc. In a given ~~802.16.1~~802.16.3 system instance, capacity MUST be carefully planned to ensure that subscribers' quality of service guarantees and minimum error rates are met. Given the atmospheric conditions statistics in a geographic area, and the development of a channel link budget [11], the following parameters of an ~~802.16.1~~802.16.3 system SHOULD be addressed by the MAC and PHY protocols [11]:

- Radio range (shaped sector radius)
- Width of the sector
- Upstream/downstream channels' data rates
- Allocation of prospective subscriber data rate to channels. Note: the MAC and PHY standards MAY allow subscribers to hop between channels
- Types of modulation

The MAC and PHY protocols MUST accommodate channel capacity issues and changes in channel capacity to meet contracted service levels with customers. For example, flexible modulation types, power level adjustment, and bandwidth reservation schemes MAY be employed. Also, as subscribers are added to ~~802.16.1~~802.16.3 systems, the protocols MUST accommodate them in an automated fashion.

The time-variant ~~impairments, rain fade and multi-path interference, are~~impairments (multi-path interference) is expected to be the most significant contributor~~s~~ to channel impairments and complexity in cell capacity planning [7] [37] [38] [39] [40] [11] [50] [51] [52] [53]. Common metrics, such as dispersive fade margin (DFM) [7] for frequency-selective fading environments, may be employed to compare the performance of ~~802.16.1~~802.16.3 equipment (e.g., radios and modems).

6 Class of Service and Quality of Service

This section describes the classes of service and quality of service for ~~802.16.1~~802.16.3 systems. Terminology is borrowed from the~~ATM Forum and~~ Internet Engineering Task Force (IETF) world~~s~~.

~~802.16.1~~802.16.3 protocols MUST support classes of service (CoS) with various quality of service (QoS) guarantees to support the~~bearer~~ services (see section **Error! Bookmark not defined.**~~8) that an 802.16.1~~7) that an 802.16.3 system MUST transport.~~Each bearer service defines guarantees that they "expect" to be preserved by an 802.16.1 system.~~ Thus, ~~802.16.1~~802.16.3 protocol standards MUST define interfaces and procedures that accommodate the needs of the~~bearer~~ services with respect to allocation of prioritization of bandwidth. Additionally, ~~802.16.1~~802.16.3 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements [2] (see ~~section 7.1). **Error! Reference source not found.**~~section). Table 1 provides a summary of the QoS requirements that the PHY and MAC SHALL provide. Note that delay in the table refers to the transmission delay from the MAC input from the upper layer at the transmit station to the MAC output to the upper layer the receiving station for information transmission. It does not include setup time, link acquisition, etc.

~~The 802.16.1 protocols MUST be capable of dedicating constant-rate, provisioned, bandwidth for bearer services such as SDH/PDH. For instance, the MAC layer MAY employ TDM allocation of bandwidth within a channel for these services. TDM bandwidth allocation may be performed dynamically to allow for both 1) turning up fixed-bandwidth Permanent Virtual Circuits (PVCs) and 2) for dynamically changing bandwidth of a virtual circuit once it has been established.~~

For QoS-based, connectionless, but not circuit-based,~~bearer~~ services, the ~~802.16.1~~802.16.3 protocols MUST support bandwidth negotiation "on-demand" [9]. 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-~~ 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~~However, the 802.16.3 MAC layer interface MAY provide a connection-less service interface that requires a 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.

Table 1: Services and QoS Requirements

~~Bearer Service~~	~~MAC Payload Rate~~	~~Maximum Ratio~~	~~Maximum Delay (One way)~~
Service	MAC Payload Rate	Maximum Ratio	Maximum Delay (One way)
Circuit-Based			
High Quality Narrowband/Voice Frequency Telephony (Vocoder MOS ≥ 4.0)	32 kbps – 64 kbps	10^{-6} BER	5 msec
~~Trunking~~	~~<=155 Mbps~~	~~10^{-6} BER~~	~~5 msec~~
Lower Quality Narrowband/Voice Frequency Telephony (Vocoder MOS < 4.0)	6 kbps – 16 kbps	10^{-4} BER	10 ms
Variable Packet [71]			
Time Critical Packet Services	4-13 kbps (voice) and 32-1.5 Mbps (video)	BER 10^{-6}	10ms
~~Non- Time Critical Services: IP, IPX, FR… Audio/video streaming, Bulk data transfer etc..~~	~~<= 155 Mbps~~	~~BER 10^{-8}~~	~~N/A~~
Non- Time Critical Services: IP, IPX, FR… Audio/video streaming, Bulk data transfer etc..	<= 10 Mbps	BER 10^{-8}	N/A
~~MPEG video~~	~~<=8 Mbps~~	~~BER 10^{-11}~~	~~TBD~~
~~Fixed-length Cell/Packet [73]~~			
~~ATM Cell Relay - CBR~~	~~16 kbps – 155 Mbps~~	~~CLR $3*10^{-7}$ CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}~~	~~10 ms~~
~~ATM Cell Relay - rt VBR~~	~~Same as CBR above~~	~~CLR 10^{-5} CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}~~	~~10 ms~~
~~ATM Cell Relay – other~~	~~<= 155 Mbps~~	~~CLR 10^{-5} CER $4*10^{-6}$ CMR 1/day SECBR 10^{-4}~~	~~N.A.~~

6.1 Types and Classes of Service

The fundamental direction for the QoS model that will be exported to the BWA endpoints will be IP based and conform to IETF DiffServ QoS model in conjunction with other IP based protocols. The DiffServ QoS model defines traffic for all services ~~is roughly categorized as follows [2] [8] [4] (using ATM terminology):~~as follows:

- ~~Constant Bit Rate (CBR). The bearer service~~Expedited forwarding (EF) EF 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 demand (VoD), and other "multimedia" applications.
- ~~Variable Bit Rate: Non-Real-Time (VBR-nrt). The~~Assured Forwarding (AF): In AF 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.~~
- category. 'Assured Forwarding' service allows the traffic to be divided into different classes. Using this service, an ISP can offer an "Olympic" service model, which provides three tiers of services: gold, silver and bronze with decreasing quality (i.e, the gold level of service receives a higher share of resources than silver during times of congestion). This service model would support, for example, the ability to provide preferential treatment to subscribers willing to pay a "premium" price for better service. Or it would support more granular priorities such as giving preference to VoIP traffic over other traffic e.g., HTTP).
- ~~Available Bit Rate (ABR).~~Best Effort Service (BES). The bandwidth varies within a wide range, and is allowed to burst up to the maximum link bandwidth when ~~CBR~~EF and ~~VBR~~AF traffic are not using bandwidth. The bandwidth and delay requirements may or may not be specified. Higher variations of delay may be tolerable since applications that fall into this category allow for priority traffic to preempt their bandwidth consumption.
- ~~Unspecified Bit Rate (UBR). The bandwidth and delay requirements are not specified.~~ Bandwidth is delivered on a "best effort" basis. Current Internet service is an example of this type of operation.

6.2 Parameters

~~ATM standards describe service categories (see section 6.1) in terms of traffic descriptors [9] [12] [54]:~~

- ~~Peak Cell Rate (PCR). The maximum rate at which cells will be transmitted.~~
- ~~Sustainable Cell Rate (SCR). The cell rate which could be sustained for a certain length of time.~~
- ~~Maximum Burst Size (MBS). The maximum number of cells that could be transmitted "back-to-back."~~
- ~~Minimum Cell Rate (MCR). The minimum cell rate supported by a connection (applies to ABR service only).~~

~~Other ATM QoS parameters are:~~

- ~~Cell Loss Ratio (CLR)~~
- ~~Maximum Cell Transfer Delay (MCTD)~~
- ~~Cell Delay Variation Tolerance (CDVT)~~

~~802.16.1~~802.16.3 protocols SHALL define a set of parameters that preserve the intent of QoS parameters for~~both ATM- and~~ IP-based services.

6.3 ~~Bearer~~ Service QoS Mappings

The classes of service and QoS parameters of~~bearer~~ services SHALL be 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 MUST participate in signaling protocols to set up QoS~~ 802.16.3.
~~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. The IWF MUST participate in the ATM signaling protocol that sets up the circuit. It also MUST utilize 802.16.1 interface primitives (e.g., MAC layer user interface primitives) to request QoS.~~

~~Similarly, a~~A QoS-based IP network may employ the Resource Reservation Protocol (RSVP) [70] to "signal" the allocation of resources along a routed IP path. If ~~802.16.1~~802.16.3 is to be a "link" in the IP network, an IWF MUST interface with ~~802.16.1~~802.16.3 to negotiate resource allocation.

~~The specification of how IWFs operate is outside the scope of this document and the forthcoming 802.16.1 interoperable air interface standard [20] [20a]. However, the QoS parameters for 802.16.1 MUST be chosen and interface primitives defined that allow for bearer services' IWFs to negotiate QoS "through" an 802.16.1 system.~~

The basic mechanism available within ~~802.16.1~~802.16.3 systems for supporting QoS requirements is to allocate bandwidth to various services. ~~802.16.1~~802.16.3 protocols SHOULD include a mechanism that can support dynamically-variable-bandwidth channels and paths (such as those defined for~~ATM and~~ IP environments).

7 Management

As outlined in IEEE Std 802-1990 [21], 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 (FCAPS):

- Fault management
- Configuration management
- Accounting management
- Performance management (see also ~~5~~)
- Security (see also section ~~8~~)

The 802 standards define a framework for LAN/MAN management in ISO/IEC 15802-2: 1995(E) [24]. The framework contains guidelines for managed objects, management protocol, and the relationship to ITU management protocols (CMIP/CMIS).

7.1 Service Level Agreements

The ~~802.16.1~~802.16.3 protocols MUST permit operators to enforce service level agreements (SLAs) with subscribers by restricting access to the air link, discarding data, dynamically controlling bandwidth available to a user or other appropriate means [3]. The ~~802.16.1~~802.16.3 protocols MUST also permit subscribers to monitor performance service levels of the ~~802.16.1~~802.16.3 services being provided at the delivery point.

7.2 Malfunctioning Subscriber Station or Base Station

The operator MUST have means to shut down a subscriber station if necessary, remote from the subscriber station, in the face of a malfunction. The operator also MUST have the means to shut down a base station remotely. The ~~802.16.1~~802.16.3 protocols SHOULD support a function that

automatically shuts down transmission from a subscriber station or base station in case of malfunction (e.g., power limits exceeded).

7.3 Accounting and Auditing

The ~~802.16.1~~802.16.3 system management framework, architecture, protocols and managed objects MUST allow for operators to effectively administer accounting and auditing. An operator MUST be able to account for time- and bandwidth-utilization and the various QoS parameters for each subscriber. Also recall from Section~~1.2~~ that a single subscriber station can interface to multiple subscribers that an operator could bill separately.

8 Security

The ~~802.16.1~~802.16.3 system SHALL enforce security procedures described in this section.

The security system chosen by ~~802.16.1~~802.16.3 SHALL be added to the protocol stack~~(Figure 4-1)~~ and reference points~~(Figure 2-3)~~ to include security protocols, and "database" servers for authentication, authorization, key management, etc. [29] [30]

8.1 Authentication

There are two levels of authentication for an ~~802.16.1~~802.16.3 system. The first level of authentication is when the subscriber station authenticates itself with the base station at the subscriber station's network entry. This initial authentication MUST be very strong in order to prevent "enemy" subscriber station from entering the network or an "enemy" base station from emulating a real base station. Once the initial authentication at this level is complete, future authentication at this level can be a little more relaxed. This level of authentication MUST be supported by the ~~802.16.1~~802.16.3 MAC layer.

The second level of authentication is between the subscriber and the BWA system. This may or may not be the responsibility of the ~~802.16.1~~802.16.3 protocols. It MAY be handled by higher layer protocols.

An additional level of authentication may exist between the other two. This additional layer is the authentication of the subscriber with the subscriber station. This is beyond the scope of the ~~802.16.1~~802.16.3 protocols.

The authentication mechanisms MUST be secure so that an "enemy" subscriber station is not able to gain access to an ~~802.16.1~~802.16.3 system, or to the core network beyond. Passwords and secrets MUST NOT be passed "in the clear" through the air interface.

8.2 Authorization

Authorization is a security process that determines what services an authenticated subscriber is permitted to invoke. Each subscriber has a set of credentials that describe what the subscriber is "allowed" to do. The ~~802.16.1~~802.16.3 standard SHALL identify a standard set of credentials and allow for vendors to extend the defined credentials with non-standard credentials. Some possible credentials are:

- Permission to access the ~~802.16.1~~802.16.3 system

- Permission to request up to a defined QoS profile (bandwidth, delay, etc.)

—

- Permission to operate certain~~bearer~~ services (~~ATM,~~ IP, Remote Bridging, Digital Audio/Video, etc.)

Subscriber authorization requests and responses MUST be transacted securely.

8.3 Privacy

Privacy is a security concept that protects transmitted data from being intercepted and understood by third parties (e.g., an "enemy" subscriber station, base station or passively "listening" radio). Wire-equivalent privacy (WEP) [10] and shared private key [10] privacy have been suggested as minimum required privacy levels for ~~802.16.1~~802.16.3 systems.

~~802.16.1~~802.16.3 standards SHOULD allow a strong cryptographic algorithm to be employed that is internationally applicable. Facilities SHOULD also be 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.

9 802 Conformance

As mentioned in some earlier sections of this document, ~~802.16.1~~802.16.3 SHOULD strive to fit into the 802 system model. Some particulars with the 802 model (see *IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture* (IEEE Std 802-1990) [21]) are:

- The ~~802.16.1~~802.16.3 MAC supports 802 "universal" 48 bit addresses.

- An ~~802.16.1~~802.16.3 system supports MAC multicast. Note that ~~802.16.1~~802.16.3 protocols support multicast in the downstream direction only, not upstream.

- The ~~802.16.1~~802.16.3 protocols support 802.1 bridging services and protocols, including support of the 802.1q virtual LAN tag and 802.1D priority ID [25] [26] [28].

- The ~~802.16.1~~802.16.3 protocols support encapsulation of 802.2 (LLC) [67] 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 ~~7~~) [27].

- Provide a MAC service interface that complies to 802 conventions [22].

Appendix

Requirements Summary

This section contains tabular summaries or requirements found in the text of this document. Requirements are separated into three categories: required, recommended and optional.

Each requirement is numbered for easy reference. Future revisions of this document will keep the requirement reference numbers intact such that the number for a requirement will not change from revision to revision.

To better discern the meaning and intent of a requirement, please refer to the text.

Editor's note: As additional information for 802.16 task groups, the areas of the standard which a requirement is most likely to affect are also given: MAC, PHY, Management (MGMT), and Security (SEC). This additional information, selected by the editor, is meant as a guideline only: task groups should examine the impact of *all* requirements.

Mandatory

It is mandatory that the ~~802.16.1~~802.16.3 standard support or specify the items in ~~Table 2.~~Table 2.

Table 2: Mandatory Requirements

#	Section	Requirement	Affects Mostly
M1	1	The forthcoming air interface standard MUST comply with the system requirements.	All
~~M2~~	~~1.1~~	~~The 802.16.1 air interface interoperability standard SHALL be part of a family of standards for local and metropolitan area networks.~~	~~All~~
M2	1.1	The 802.16.3 air interface interoperability standard SHALL be part of a family of standards for metropolitan area networks.	All
~~M3~~	~~2~~	~~802.16.1 systems SHALL be multiple-cell frequency reuse systems.~~	~~MAC PHY~~
M3	2	802.16.3 systems SHALL be deployable in multiple-cell frequency reuse system configuration and in single super cell frequency reuse system configuration.	MAC PHY
~~M4~~	~~2.1~~	~~The air interface MUST NOT preclude repeaters or reflectors to bypass obstructions and extend cell coverage.~~	~~PHY~~
M4	2	The 802.16.3 system SHALL be deployable as a Point-to-Multi-point system.	MAC PHY
M5	2.1	The standard (e.g., MAC/PHY protocols) SHALL describe common access protocol(s) and common modulation technique(s).	MAC PHY
~~M6~~	~~2.2~~	~~All data traffic in a single cell of an 802.16.1 network MUST go through the base station.~~	~~MAC~~
M6	2.2	All data traffic in a single cell of an 802.16.3 network MUST go through the base station.	MAC
M7	2.2	The base station SHALL serve as a radio resource supervisor.	MAC
~~M8~~	~~2.2~~	~~802.16.1 protocols MUST provide the means to multiplex traffic from multiple subscriber stations in the downstream direction, and provide for a means to resolve contention and allocate bandwidth in~~	~~MAC~~

		~~the upstream direction.~~	
M8	2.2	802.16.3 protocols MUST provide the means to multiplex traffic from multiple subscriber stations in the downstream direction, and provide for a means to resolve contention and allocate bandwidth in the upstream direction.	MAC
~~M9~~	~~3.1.2~~	~~802.16.1 systems and protocols MUST support the QoS requirements of the services:~~ ~~Narrowband/Voice Frequency Telephony - POTS (supporting FAX services), Centrex, ISDN BRI 35~~ ~~NxDSO Trunking - Fractional DS1/E1 to PBXs and/or data equipment, ISDN PRI 36~~ ~~Full DS1/E1 - transparent mapping including all framing information~~ ~~Voice Over IP, Voice Over Frame Relay, Voice and Telephony over ATM (VToA), and similar services~~	~~MAC~~
M9	3.1.2	802.16.3 systems and protocols MUST support the QoS requirements of the telephony services: • POTS via Voice Over IP • NxDS0 via Voice over IP • FT1/FE1 reconfigured from NxDS0 at the CPE.	MAC
M10	3.1.2.1	The amount of delay between a user speaking and another user hearing the speech MUST be kept below a certain level to support two-way conversation.	MAC PHY
M11	3.1.2.1	BWA protocols MUST support efficient transport of encoded voice data in terms of bandwidth, reliability and delay.	MAC PHY
~~M12~~	~~3.1.2.2~~	~~MUST meet the transport requirements of telephony signaling, whether TDM- or message-oriented.~~	~~MAC~~
M12	3.1.2.2	MUST meet the pass through requirements of telephony signaling, whether TDM- or message-oriented.(For further study)	MAC
M13	3.1.4	802.16 MUST directly transport variable length IP datagrams efficiently.	MAC
M14	3.1.4	Both IP version 4 and 6 MUST be supported.	MAC
~~M15~~	~~3.1.4~~	~~The 802.16.1 IP service MUST provide support for real-time and non-real-time services.~~	~~MAC~~
M15	3.1.4	The 802.16.3 IP service MUST provide support for real-time and non-real-time services.	MAC
M16	4	The MAC protocol MUST define interfaces and procedures to provide guaranteed service to the upper layers.	MAC
M17	4	The MAC protocol MUST efficiently resolve contention and bandwidth allocation.	MAC

~~M18~~	~~4~~	~~Further details, and finalization of the protocol reference model, SHALL be worked out by the 802.16.1 MAC and PHY task groups while developing the air interface interoperability standard.~~	~~All~~
M18	4	Further details, and finalization of the protocol reference model, SHALL be worked out by the 802.16.3 MAC and PHY task groups while developing the air interface interoperability standard.	All
~~M19~~	~~5.2~~	~~802.16.1 protocols SHALL be optimized to provide the peak capacity from 2 to 155 Mbps to a subscriber station sufficiently close to the base station.~~	~~MAC PHY~~
~~M20~~	~~5.2~~	~~802.16.1 protocols SHALL NOT preclude the ability of an 802.16.1 system to deliver less than 2 Mbps peak per-user capacity.~~	~~MAC PHY~~
M19	5.2	802.16.3 protocols SHALL be optimized to provide the peak capacity up to 2 and enable up to 10 Mbps	MAC PHY
~~M21~~	~~5.4~~	~~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.~~	~~PHY~~
M21	5.4	The 802.16.3 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.	PHY
~~M22~~	~~5.4~~	~~802.16.1 MAC and PHY protocols MUST accommodate atmospheric conditions, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements.~~	~~MAC PHY MGMT~~
M22	5.4	802.16.3 MAC and PHY protocols MUST accommodate atmospheric conditions, perhaps consuming more radio bandwidth and/or requiring smaller radio propagation distance (radius) to meet the availability requirements.	MAC PHY MGMT
~~M23~~	~~5.4~~	~~Since statistical atmospheric conditions vary widely in geography, the 802.16.1 protocols MUST be flexible in consumed radio bandwidth (spectral efficiency), cell radius, and transmit power to accommodate a rain allowance that varies with geography.~~	~~MAC PHY MGMT~~
M23	5.4	Since statistical atmospheric conditions vary widely in geography, the 802.16.3 protocols MUST be flexible in consumed radio bandwidth (spectral efficiency), cell radius, and transmit power to accommodate a rain allowance that varies with geography.	MAC PHY MGMT
M24	5.5	The error rate, after application of the appropriate error correction mechanism (e.g., FEC), delivered by the PHY layer to the MAC layer SHALL meet IEEE 802 functional requirements: The bit error rate (BER) is 10E-9.	MAC PHY
~~M25~~	~~5.5~~	~~Each block of data delivered by the PHY to the MAC layer MUST allow for detection of errors by the MAC (e.g., by CRC) with 1, 2 or 3 errored bits (a Hamming Distance of 4).~~	~~PHY~~
~~M26~~	~~5.6~~	~~The budget for the 802.16.1 system transit delay and access delay~~	~~MAC~~

		~~MUST be derived. The MAC layer may have different requirements for each direction, upstream and downstream.~~	~~PHY~~
M26	5.6	The budget for the 802.16.3 system transit delay and access delay MUST be derived. The MAC layer may have different requirements for each direction, upstream and downstream.	MAC PHY
M27	5.6	In the upstream direction, time MUST be budgeted for requesting bandwidth and contending among nodes.	MAC
~~M28~~	~~5.7~~	~~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.~~	~~MGMT~~
M28	5.7	In a given 802.16.3 system instance, capacity MUST be carefully planned to ensure that subscribers' quality of service guarantees and maximum error rates are met.	MGMT
M29	5.7	The MAC and PHY protocols MUST accommodate channel capacity issues and changes in channel capacity to meet contracted service levels with customers.	MAC PHY MGMT
~~M30~~	~~5.7~~	~~As subscribers are added to 802.16.1 systems, the protocols MUST accommodate them in an automated fashion.~~	~~MAC MGMT~~
M30	5.7	As subscribers are added to 802.16.3 systems, the protocols MUST accommodate them in an automated fashion.	MAC MGMT
~~M31~~	~~6~~	~~802.16.1 protocols MUST support classes of service (CoS) with various quality of service (QoS) guarantees to support the bearer services that an 802.16.1 system MUST transport.~~	~~MAC~~
M31	6	802.16.3 protocols MUST support classes of service (CoS) with various quality of service (QoS) guarantees to support the services that that support IP protocol.	MAC
~~M32~~	~~6~~	~~802.16.1 protocol standards MUST define interfaces and procedures that accommodate the needs of the bearer services with respect to allocation of prioritization of bandwidth.~~	~~MAC~~
M32	6	802.16.3 protocol standards MUST define interfaces and procedures that accommodate the needs of the services with respect to allocation of prioritization of bandwidth.	MAC
~~M33~~	~~6~~	~~802.16.1 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements.~~	~~MAC MGMT~~
M33	6	802.16.3 protocols MUST provide the means to enforce QoS contracts and Service Level Agreements.	MAC MGMT
~~M34~~	~~6~~	~~The 802.16.1 protocols MUST be capable of dedicating constant-rate, provisioned, bandwidth for bearer services such as SDH/PDH.~~	~~MAC~~
~~M35~~	~~6~~	~~For QoS-based, connectionless, but not circuit-based, bearer services, the 802.16.1 protocols MUST support bandwidth negotiation "on-demand."~~	~~MAC~~
~~M36~~	~~6~~	~~Table 1 provides a summary of the QoS requirements that the PHY~~	~~MAC~~

		~~and MAC SHALL provide.~~	~~PHY~~
~~M37~~	~~6.2~~	~~802.16.1 protocols SHALL define a set of parameters that preserve the intent of QoS parameters for both ATM- and IP-based services.~~	~~MAC~~
M35	6	For QoS-based, connectionlessthe 802.16.3 protocols MUST support guaranteed bandwidth in provisioning process of the system	MAC
~~M38~~	~~6.3~~	~~The classes of service and QoS parameters of bearer services SHALL be translated into a common set of parameters defined by 802.16.1.~~	~~MAC~~
~~M39~~	~~6.3~~	~~A network node that serves as an inter-working function (IWF) between a QoS-capable LAN or WAN and an 802.16.1 system MUST participate in signaling protocols to set up QoS parameters for connection-oriented services.~~	~~MAC~~
~~M40~~	~~6.3~~	~~The IWF MUST participate in the ATM signaling protocol that sets up the circuit.~~	~~MAC~~
~~M41~~	~~6.3~~	~~The IWF also MUST utilize 802.16.1 interface primitives (e.g., MAC layer user interface primitives) to request QoS.~~	~~MAC~~
~~M42~~	~~6.3~~	~~If 802.16.1 is to be a "link" in the IP network, an IWF MUST interface with 802.16.1 to negotiate resource allocation.~~	~~MAC~~
~~M43~~	~~6.3~~	~~The QoS parameters for 802.16.1 MUST be chosen and interface primitives defined that allow for bearer services' IWFs to negotiate QoS "through" an 802.16.1 system.~~	~~MAC~~
M37	6.2	802.16.3 protocols SHALL define a set of parameters that preserve the intent of QoS parameters for IP-based services.	MAC
~~M44~~	~~7.1~~	~~The 802.16.1 protocol MUST permit operators to enforce service level agreements (SLAs) with subscribers by restricting access to the air link, discarding data, dynamically controlling bandwidth available to a user or other appropriate means.~~	~~MAC MGMT~~
M44	7.1	The 802.16.3 protocol MUST permit operators to enforce service level agreements (SLAs) with subscribers by restricting access to the air link, discarding data, dynamically controlling bandwidth available to a user or other appropriate means.	MAC MGMT
~~M45~~	~~7.1~~	~~The 802.16.1 protocols MUST permit subscribers to monitor performance service levels of the 802.16.1 services being provided at the delivery point.~~	~~MAC PHY MGMT~~
M45	7.1	The 802.16.3 protocols MUST permit subscribers to monitor performance service levels of the 802.16.3 services being provided at the delivery point.	MAC PHY MGMT
~~M46~~	~~7.2~~	~~The operator MUST have means to shut down a subscriber station if necessary, remote from the subscriber station, in the face of a malfunction.~~	~~MAC PHY MGMT~~
~~M47~~	~~7.2~~	~~The operator MUST have the means to shut down a BTS remotely.~~	~~MAC PHY~~

			~~MGMT~~
M46	7.2	The operator MUST have means to shut down a subscriber station if necessary, remote from the subscriber station, in the face of a malfunction. This is a part od DOCSIS provisioning	MAC PHY MGMT
~~M48~~	~~7.3~~	~~The 802.16.1 system management framework, architecture, protocols and managed objects MUST allow for operators to effectively administer accounting and auditing.~~	~~MAC MGMT~~
M48	7.3	The 802.16.3 system management framework, architecture, protocols and managed objects MUST allow for operators to effectively administer accounting and auditing via the SNMP protocol.	MAC MGMT
M49	7.3	An operator MUST be able to account for time- and bandwidth-utilization and the various QoS parameters for each subscriber.	MAC
~~M50~~	~~8~~	~~The 802.16.1 system SHALL enforce security procedures described in section 8.~~	~~MAC SEC~~
M50	8	The 802.16.3 system SHALL enforce security procedures described in section This will be implemented with the Baseline Privacy Interface (BPI) specification currently available with the IP centric solutions available today.	MAC SEC
~~M51~~	~~8~~	~~The security system chosen by 802.16.1 SHALL be added to the protocol stack (Figure 4-1) and reference points (Figure 2-3) to include security protocols, and "database" servers for authentication, authorization, key management, etc.~~	~~SEC~~
M51	8	The security system chosen by 802.16.3 SHALL be added to the protocol stack) and reference points to include security protocols, and "database" servers for authentication, authorization, key management, etc.	SEC
~~M52~~	~~8.1~~	~~This initial authentication MUST be very strong in order to prevent an "enemy" subscriber station from entering the network or an "enemy" base station from emulating a real base station.~~	~~MAC SEC~~
M52	8.1	This initial authentication MUST be very strong in order to prevent an "enemy" subscriber station from entering the network or an "enemy" base station from emulating a real base station.	MAC SEC
~~M53~~	~~8.1~~	~~Initial authentication MUST be supported by the 802.16.1 MAC layer.~~	~~MAC SEC~~
M53	8.1	Initial authentication MUST be supported by the 802.16.3 MAC layer.	MAC SEC
~~M54~~	~~8.1~~	~~The authentication mechanisms MUST be secure so that an "enemy" subscriber station is not able to gain access to an 802.16.1 system, or to the core network beyond.~~	~~MAC SEC~~
M54	8.1	The authentication mechanisms MUST be secure so that an "enemy" subscriber station is not able to gain access to an 802.16.3 system, or to the core network beyond.	MAC SEC

M55	8.1	Passwords and secrets MUST NOT be passed “in the clear” through the air interface.	MAC SEC
~~M56~~	~~8.2~~	~~The 802.16.1 standard SHALL identify a standard set of credentials and allow for vendors to extend the defined credentials with non-standard credentials.~~	~~MAC SEC MGMT~~
M56	8.2	The 802.16.3 standard SHALL identify a standard set of credentials and allow for vendors to extend the defined credentials with non-standard credentials.	MAC SEC MGMT
~~M57~~	~~8.2~~	~~Subscriber authorization requests and responses MUST be transacted securely.~~	~~MAC SEC~~
M57	8.2	Subscriber authorization requests and responses MUST be transacted securely. Protocol to support link layer encryption between the CPE and the BS,	MAC SEC

Recommended (R)

It is recommended that the ~~802.16.1~~802.16.3 standard support or specify the items in ~~Table 3.~~ Table 3 “Recommended” means that there may exist valid reasons in particular circumstances to ignore an item, but the full implications should be understood and the case carefully weighed before choosing a different course.

Table 3: Recommended Requirements

#	Section	Requirement	Affects Mostly
~~R1~~	~~1.2~~	~~802.16.1 SHOULD support more than one paying customer at a single access point to a subscriber BWA radio.~~	~~MAC MGMT SEC~~
R1	1.2	802.16.3 SHOULD support more than one paying customer at a single access point to a subscriber BWA radio.	MAC MGMT SEC
~~R2~~	~~2~~	~~The base station radio SHOULD be P-MP.~~	~~MAC PHY~~
~~R3~~	~~3~~	~~An 802.16.1 system SHOULD support the services described in section 3~~	~~MAC PHY MGMT~~
R3	3	An 802.16.3 system SHOULD support the services described in section	MAC PHY MGMT
~~R4~~	~~3.1~~	~~The MAC and PHY protocols may not have explicit support for each and every bearer service, since they SHOULD be handled as data streams in a generic fashion.~~	~~MAC PHY~~
R4	3.1	The MAC and PHY protocols may not have explicit support for	MAC

		each and every service, since they SHOULD be handled as data streams in a generic fashion.	PHY
~~R5~~	~~3.1.1~~	~~802.16.1 SHOULD efficiently transport digital audio/video streams to subscribers.~~	~~MAC PHY~~
R5	3.1.1	802.16.3 SHOULD efficiently transport digital audio/video streams to subscribers.	MAC PHY
~~R6~~	~~3.1.2~~	~~802.16.1 systems SHOULD support supplying telephony "pipes" to subscribers in a way that eases the migration of legacy telephony equipment and public switched telephone network (PSTN) access technologies to 802.16.1 systems.~~	~~MAC PHY MGMT~~
R6	3.1.2	802.16.3 systems SHOULD support supplying telephony to subscribers in a way that eases the migration of legacy telephony equipment and public switched telephone network (PSTN) access technologies to 802.16.3 systems.	MAC PHY MGMT
~~R7~~	~~3.1.3~~	~~802.16.1 protocols SHOULD be defined such that an 802.16.1 system can efficiently transport ATM cell relay service and preserve its QoS features.~~	~~MAC~~
~~R8~~	~~3.1.3~~	~~Provide a means to utilize ATM addresses such as ITU-T E.164.~~	~~MAC~~
R9	3.1.4	For efficient transport of IPv6, TCP/IP header compression over the air interface SHOULD be supported.	MAC
R10	3.1.4	It SHOULD be possible to support the emerging IP Quality of Service (QoS) efforts: Differentiated Services and Integrated Services.	MAC
~~R11~~	~~3.1.6~~	~~The 802.16.1 protocols SHOULD NOT preclude the transport of the following services:~~ ~~Back-haul service~~ ~~Virtual point-to-point connections~~ ~~Frame Relay Service~~	~~MAC~~
R11	3.1.6	The 802.16.3 protocols SHOULD NOT preclude the transport of the following services: • Back-haul service • Virtual point-to-point connections • Frame Relay Service	MAC
~~R12~~	~~5.1~~	~~The 802.16.1 protocols SHOULD allow for different "scales" of capacity and performance for 802.16.1 system instances.~~	~~MAC PHY~~
R12	5.1	The 802.16.3 protocols SHOULD allow for different "scales" of capacity and performance for 802.16.3 system instances.	MAC PHY
~~R13~~	~~5.2~~	~~802.16.1 MAC protocol SHOULD allow the upper range of delivered bandwidth to scale beyond 155 Mbps.~~	~~MAC PHY~~

R13	5.2	802.16.3 MAC protocol SHOULD allow the upper range of delivered bandwidth to scale beyond 10 Mbps.	MAC PHY
~~R14~~	~~5.3~~	~~802.16.1 protocols SHOULD allow for flexibility between delivered upstream and downstream bandwidth and CoS/QoS.~~	~~MAC PHY~~
R14	5.3	802.16.3 protocols SHOULD allow for flexibility between delivered upstream and downstream bandwidth and CoS/QoS.	MAC PHY
~~R15~~	~~5.4~~	~~An 802.16.1 system SHOULD be available to transport all services at better than their required maximum error rates 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.~~	~~PHY~~
R15	5.4	An 802.16.3 system SHOULD be available to transport all services at better than their required maximum error rates from about 99.9 to 99.94% of the time, assuming that the system and radios receive adequate power 100% of the time and not counting equipment availability.	PHY
~~R16~~	~~5.4~~	~~802.16.1 MAC and PHY protocols SHOULD specify functions and procedures to adjust power, modulation, or other parameters to accommodate rapid changes in channel characteristics due to atmospheric conditions.~~	~~MAC PHY MGMT~~
R16	5.4	802.16.3 MAC and PHY protocols SHOULD specify functions and procedures to adjust power, modulation, or other parameters to accommodate rapid changes in channel characteristics due to atmospheric conditions.	MAC PHY MGMT
~~R17~~	~~5.6~~	~~In a telephony network, for example, the maximum acceptable end-to-end delay for the longest path is RECOMMENDED to be less than 300ms.~~	~~MAC PHY~~
R17	5.6	In a telephony network, the maximum acceptable end-to-end delay for the longest path is RECOMMENDED to be less than 300ms.	MAC PHY
~~R18~~	~~5.7~~	~~The following parameters of an 802.16.1 system SHOULD be addressed by the MAC and PHY protocols:~~ ~~Radio range (shaped sector radius)~~ ~~Width of the sector~~ ~~Upstream/downstream channels' data rates~~ ~~Allocation of prospective subscriber data rate to channels. Note: the MAC and PHY standards may allow subscribers to hop between channels~~ ~~Types of modulation~~	~~MAC PHY MGMT~~
R18	5.7	The following parameters of an 802.16.3 system SHOULD be addressed by the MAC and PHY protocols: • Radio range (shaped sector radius)	MAC PHY MGMT

		• Width of the sector • Upstream/downstream channels' data rates • Allocation of prospective subscriber data rate to channels. Note: the MAC and PHY standards may allow subscribers to hop between channels • Types of modulation	
~~R19~~	~~6.3~~	~~802.16.1 protocols SHOULD include a mechanism that can support dynamically-variable-bandwidth channels and paths (such as those defined for ATM and IP environments).~~	~~MAC~~
R19	6.3	802.16.3 protocols SHOULD include a mechanism that can support dynamically-variable-bandwidth channels and paths as defined for IP environments.	MAC
~~R20~~	~~7.2~~	~~The 802.16.1 protocols SHOULD support a function that automatically shuts down transmission from a subscriber station or base station in case of malfunction (e.g., power limits exceeded).~~	~~MAC PHY MGMT~~
R20	7.2	The 802.16.3 protocols SHOULD support a function that automatically shuts down transmission from a subscriber station or base station in case of malfunction (e.g., power limits exceeded).	MAC PHY MGMT
R21	8.3	Allow for a strong cryptographic algorithm to be employed that is internationally applicable.	SEC
R22	8.3	Facilities SHOULD also be 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.	SEC
~~R23~~	~~9~~	~~802.16.1 SHOULD strive to fit into the 802 system model.~~	~~All~~
R23	9	802.16.3 SHOULD strive to fit into the 802 system model.	All

Optional (O)

It is optional that the ~~802.16.1~~802.16.3 standard support or specify the items in ~~Table 4.~~Table 4.

Table 4: Optional Requirements

#	Section	Requirement	Affects Mostly
~~O1~~	~~3.1.1~~	~~Digital audio/video transport MAY bypass the MAC protocol layer.~~	~~MAC PHY~~
~~O2~~	~~3.1.2~~	~~802.16.1 protocols MAY transport any layer in the nationally- and internationally-defined digital telephony service hierarchies.~~	~~MAC~~
~~O3~~	~~3.1.3~~	~~802.16.1 MAY provide a direct ATM addressing mode for 802.16.1 nodes, or MAY provide a means to translate ATM addresses to 802 addresses.~~	~~MAC~~
~~O4~~	~~3.1.5~~	~~The 802.16.1 protocols MAY support bridged LAN services, whether directly or indirectly.~~	~~MAC~~
O4	3.1.5	The 802.16.3 protocols MAY support bridged LAN services, whether directly or indirectly.	MAC
~~O5~~	~~4~~	~~To best support DAV services, the PHY MAY provide TDM-based encapsulation of DAV streams in TDM MPEG-II frames~~	~~PHY~~
O6	5.7	The MAC and PHY standards MAY allow subscribers to hop between channels.	MAC PHY
O7	5.7	Flexible modulation types, power level adjustment, and bandwidth reservation schemes MAY be employed.	MAC PHY
~~O8~~	~~6~~	~~The MAC layer MAY employ TDM allocation of bandwidth within a channel for SDH/PDH services.~~	~~MAC~~
~~O9~~	~~6~~	~~The MAC protocol MAY allocate bursts of time slots to bearer services that require changes in bandwidth allocation.~~	~~MAC~~
O9	6	The MAC protocol MAY allocate bursts of time slots to services that require changes in bandwidth allocation.	MAC
O10	8.1	The second level of authentication, between the subscriber and the BWA system, MAY be handled by higher layer protocols.	MAC SEC

Vocabulary of Terms

Term	Definition	Reference
Access	End-user connection(s) to core networks NOTE 1 - Core networks include, for example, PSTN, ISDN, PLMN, PSDN, Internet, WAN/LAN, CATV, etc. NOTE 2 - The end-user may be a single user or a user accessing the services on behalf of multiple users.	Based on Rec. ITU-R F.1399
Accounting	A function which apportions the revenue obtained by the service providers to network operators in line with commercial arrangements.	Rec. ITU-R M.1224
Air interface	The common boundary between the subscriber station and the radio equipment in the network, defined by functional characteristics, common radio (physical) interconnection characteristics, and other characteristics, as appropriate. NOTE 1 – An interface standard specifies the bi-directional interconnection between both sides of the interface at once. The specification includes the type, quantity and function of the interconnecting means and the type, form and sequencing order of the signals to be interchanged by those means.	Based on Rec. ITU-R M.1224
~~Asynchronous transfer mode~~	~~A transfer mode in which the information is transferred within labeled cells; it is asynchronous in the sense that the recurrence of cells containing information from an individual user is not necessarily periodic.~~	~~ITU-T Rec. I.113~~
Authentication	The process of verifying the identity of a user, terminal, or service provider.	Rec. ITU-R M.1224
Authorization	A property by which the rights to resources are established and enforced.	Rec. ITU-R M.1224
~~Available bit rate~~	~~The ATM layer service category for which the limiting ATM layer transfer characteristics provided by the network may change subsequent to connection establishment.~~	~~ATM Forum~~
Backhaul service	Transport of aggregate communication signals from base stations to the core network.	IEEE 802.16
Bandwidth; communication	The bandwidth of the information payload capacity of a communication channel available to a user for	

channel bandwidth	services (expressed in bit/s or multiples thereof).	
Bandwidth; RF channel bandwidth	The bandwidth of a specified portion of the RF spectrum capable of carrying information over the radio interface (expressed in Hz or multiples thereof).	
Bandwidth; transmission channel bandwidth	The frequency spectrum bandwidth required for the transmission of a specified signal (expressed in Hz or multiples thereof).	
Base station	The common name for all the radio equipment located at one and the same place used for serving one or several cells. (See also “station”).	ITU-R Rec. M.1224
Bearer service	A type of telecommunication service that provides the capability for the transmission of signals between user-network interfaces.	ITU-T Rec. I.112
Broadband wireless access	wireless access in which the connection(s) capabilities are higher than the primary rate.	Rec. ITU-R F.1399
Cell	The radio coverage area of a base station, or of a subsystem (e.g. sector antenna) of that base station corresponding to a specific logical identification on the radio path, whichever is smaller.	Based on Rec. ITU-R M.1224
Cell	A block of fixed length which is identified by a label at the asynchronous transfer mode layer of the B-ISDN protocol reference model.	ITU-T Rec. I.113
Cell delay variation	A component of cell transfer delay, induced by buffering and cell scheduling.	ATM Forum
Cell loss ratio	The proportion of lost cells over the total number of transmitted cells for a connection.	ATM Forum
Channel; communication channel	A specific portion of the information payload capacity, available to the user for services.	ITU-T Rec. I.113
Channel; radio-frequency (RF) channel	A specified portion of the RF spectrum with a defined bandwidth and a carrier frequency and is capable of carrying information over the radio interface.	Rec. ITU-R M.1224
Channel; transmission channel	A means of unidirectional transmission of signals between two points.	ITU-T Rec. I.112
~~Constant bit rate~~	~~An ATM service category which supports a guaranteed rate to transport services such as video or voice as well as circuit emulation which requires rigorous timing control and performance~~	~~ATM Forum~~

	~~parameters.~~	
Core network	Core networks include, for example, PSTN, ISDN, PLMN, PSDN, Internet, WAN/LAN, CATV, etc.	Based on Rec. ITU-R F.1399
Customer premises equipment/network	The equipment/network administered by the user.	Based on ITU-T Rec. H.310
Downstream	The direction from base station to subscriber station(s).	IEEE 802.16
Dynamically variable bandwidth	A capability of a system to be able to change the bandwidth of the information payload capacity of a communication channel available to a user for services according to negotiated user requirements.	
Fixed wireless access	Wireless access application in which the base station and the subscriber station are fixed.	Based on Rec. ITU-R F.1399
Frequency Division Duplex	Separation of upstream and downstream transmission in the frequency domain at the same time.	IEEE 802.16
Internet protocol	Networking protocol defined by IETF standards.	IETF
Interoperability	The ability of multiple entities in different networks or systems to operate together without the need for additional conversion or mapping of states and protocols.	Rec. ITU-R M.1124
Inter-working	The means of supporting communications interactions between entities in different networks or systems.	Rec. ITU-R M.1124
Inter-working function	Mechanism which masks the differences in physical, link, and network technologies by converting or mapping states and protocols into consistent network and user services.	Rec. ITU-R M.1124
~~Maximum burst size~~	~~The number of cells that may be transmitted at the peak rate and still be in conformance with the GCRA.~~	~~ATM Forum~~
~~Minimum cell rate~~	~~An ABR service traffic descriptor, in cells/sec, that is the rate at which the source is always allowed to send.~~	~~ATM Forum~~
~~Maximum cell transfer delay~~	~~The sum of the fixed delay component across the link or node and MCDV.~~	~~ATM Forum~~
Network	A set of nodes and links that provides connections between two or more defined points to facilitate telecommunication between them.	Rec. ITU-R M.1224
Nomadic wireless	Wireless access application in which the subscriber	Based on ITU-R Rec.

access	station may be in different places but must be stationary while in use.	F.1399
~~Peak cell rate~~	~~The limit, in cell/sec, for source transmission.~~	~~ATM Forum~~
plesiochronous mode	A mode where the essential characteristic of time scales or signals such that their corresponding significant instants occur at nominally the same rate, any variation in rate being constrained within specified limits.	ITU-T Rec. G.810 (96), 4.3.5
Point-to-multipoint system	a system that establishes connections between a single specified point and more than one other specified points.	ITU-R Rec. F.1399
Privacy	The provision of capabilities to prevent access of information by unauthorized parties.	ANSI T1.702-1995
Quality of service	The collective effect of service performance which determine the degree of satisfaction of a user of the service. NOTE 1 - The quality of service is characterized by the combined aspects of service support performance, service operability performance, serveability performance, service security performance and other factors specific to each service. NOTE 2 - The term "quality of service" is not used to express a degree of excellence in a comparative sense nor is it used in a quantitative sense for technical evaluations. In these cases a qualifying adjective (modifier) should be used.	ITU-T Rec. E.800 (94), 2101
Radio interface	See air interface	Rec. ITU-R M.1224
Real-Time (adjective)	Pertaining to the processing or transmission of data according to defined time requirements .	Based on ITU-T Rec. Q.9 (88), 6103
Security	The protection of information availability, integrity and confidentiality, as well as authentication and authorization.	Based on Rec. ITU-R M.1224
Service	A set of functions offered to a user by an organization.	Recs. ITU-R M.1224, M.1308
Station	the common name for all the radio equipment at one and the same place. NOTE - The term "station" may refer to any end-user radio equipment (“subscriber station”) or network radio equipment (“base station”).	Rec. ITU-R M.1224
Subscriber	A person or other entity that has a contractual relationship with a service provider on behalf of one or more users. (A subscriber is responsible for	Rec. ITU-R M.1224

	the payment of charges due to that service provider.)	
Subscriber station	the common name for all the radio equipment at one and the same place serving one or more users. (See also “station”).	Based on Rec. ITU-R M.1224
Supplementary service	A service which modifies or supplements a basic telecommunication service. Consequently, it can not be offered to a customer as a standalone service, rather, it must be offered together with or in association with a basic telecommunication service. The same supplementary service may be common to a number of telecommunication services.	Rec. ITU-R M.1224
~~Sustainable cell rate~~	~~The cell rate which could be sustained for a certain length of time.~~ ~~An upper bound on the conforming average rate of an ATM connection over time scales which are long relative to those for which the PCR is defined.~~	~~IEEE 802.16~~ ~~ATM Forum~~
Synchronous transfer mode	A transfer mode which offers periodically to each connection a fixed-length block.	Based on ITU-T Rec. I.113
System	A regularly interacting or interdependent group of items forming a unified whole technology.	Recs. ITU-R M.1224, M.1308
Time Division Duplex	Separation of upstream and downstream transmission in the time domain using the same frequency.	IEEE 802.16
~~Unspecified bit rate~~	~~UBR is an ATM service category which does not specify~~ ~~traffic related service guarantees. Specifically, UBR does not include the~~ ~~notion of a per-connection negotiated bandwidth. No numerical commitments~~ ~~are made with respect to the cell loss ratio experienced by a UBR~~ ~~connection, or as to the cell transfer delay experienced by cells on the~~ ~~connection.~~	~~ATM Forum~~
Upstream	The direction from subscriber station(s) to base station.	IEEE 802.16
User	Any entity external to the network which utilizes connections through the network for communication.	ITU-T Rec. E.600

~~Variable bit rate~~	~~An ATM Forum defined service category which supports traffic with average and peak traffic parameters.~~	~~ATM Forum~~
~~Variable Bit Rate: Non-Real-Time~~	~~An ATM Forum defined service category which supports bursty traffic, and is characterized in terms of a PCR, SCR, and MBS.~~	~~ATM Forum~~
~~Variable Bit rate: Real-Time~~	~~An ATM Forum defined service category which supports traffic requiring tightly constrained delay and delay variation, as would be appropriate for voice and video applications.~~	~~ATM Forum~~
Virtual point-to-point connections	Providing a point-to-point connection to a subscriber using a point to multipoint system.	IEEE 802.16
Wireless access	end-user radio connection(s) to core networks. NOTE 1 - Core networks include, for example, PSTN, ISDN, PLMN, PSDN, Internet, WAN/LAN, CATV, etc. NOTE 2 - The end-user may be a single user or a user accessing the services on behalf of multiple users.	Rec. ITU-R F.1399

Acronyms and Abbreviations

Acronym/Abbreviation	**Definition**
~~ABR~~	~~Available bit-rate~~
~~ATM~~	~~Asynchronous transfer mode~~
BBER	Background block error ratio
BER	Bit Error Ratio
B-ISDN	Broadband aspects of ISDN
BNI	Base station network interface
BWA	Broadband Wireless Access
~~CBR~~	~~Constant bit rate~~
CDVT	Cell delay variation tolerance
CLR	Cell loss ratio
CPE	Customer premises equipment
DSL	Digital Subscriber Line
FDD	Frequency Division Duplex
HFC	Hybrid fiber coax
IP	Internet protocol
ISDN	Integrated Services Digital Network
IWF	Inter-working function
LAN	Local area network
LLC	Logical link control
MAC	Medium Access Control
MAN	Metropolitan area network
MBS	Maximum burst size
MCR	Maximum cell rate
MCTD	Maximum cell transfer delay
OSI	Open Systems Interconnection
PBX	Private Branch Exchange

PCR	Peak cell rate
PDH	Plesiochronous Digital Hierarchy
PDU	Protocol Data Unit
PHY	Physical layer
P-MP	Point-to-multipoint
PSTN	Public Switched Telephone Network
QoS	Quality of service
SCR	Suitable cell rate
SDH	Synchronous Digital Hierarchy
SNI	Subscriber station network interface
TC	Transmission convergence
TDD	Time Division Duplex
UBR	Unspecified bit rate
~~VBR~~	~~Variable bit rate~~
~~VBR-nrt~~	~~Variable Bit rate: Non-Real-Time rate~~
~~VBR-rt~~	~~Variable Bit rate: Real-Time~~

References

[Editor's note: these references are not in a particular order. Some of these references are not cited in the text of this document.]

~~[1] Margarete Ralston, 802.16sc-99/3, 802.16sc-99/4 Reference Diagram and Notes.~~

[2] James Mollenauer, 802.16sc-99/5 Functional Requirements for Broadband Wireless Access Networks.

[3] Jim Mollenauer, 802.16sc-99/7 Functional Requirements for the 802.16 Standard.

[4] Brian Petry, 802.16sc-99/8 System Requirements Agenda and On-the-fly Notes from 5/99 Boulder Meeting.

[5] Brian Petry, 802.16sc-99/9 ITU-R 9B/134E (cable modem over BWA) Requirements.

~~[6] Hossein Izadpanah, 802.16sc-99/10 LMDS Technologies For Broadband Wireless Local Loop Applications.~~

[7] John Liebetreu, 802.16sc-99/13 Dispersive Fade Margin: A Physical Layer Performance Metric.

~~[8] Jung Yee, 802.16sc-99/14 A Multi-Service LMDS System.~~

~~[9] Willie Lu, 802.16sc-99/15 System Reference Model and Protocol Stack for Broadband Wireless Access.~~

[10] Marianna Goldhammer, 802.16sc-99/16 MAC Services.

~~[11] Robert Duhamel, 802.16sc-99/17 LMDS Cell Sizing and Availability.~~

~~[12] David Jarrett, 802.16sc-99/18 Definition of Bearer Services and Teleservices, and Services.~~

[13] Scott Marin, 802.16sc-99/19 The Network Topology of Point to Multipoint Radio Systems.

[14] Scott Marin, 802.16sc-99/20 802.16 Services and Applications.

[15] Scott Marin, 802.16sc-99/21 Quality of Service.

[16] George Fishel, 802.16sc-99/22 Interface to MAC and LLC Protocols.

[17] Imed Frigui, 802.16sc-99/23 Services and Performance requirements for Broadband Fixed Wireless Access.

~~[18] XXX James F Mollenauer, 802.16sc-99/24 Supporting STM in the IEEE 802.16 Standard.~~

[19] Doug Gray, 802.16cc-99/04 WW Spectrum Allocations for BWA.

[20] 802.16 PAR: Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Air Interface for Fixed Broadband Wireless Access Systems.

[20] 802.16 Rationale for a Broadband Wireless Access Air Interface Standard: Meeting the Five Criteria.

[21] IEEE Std 802-1990 "IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture. IEEE 1990.

[22] ISO/IEC 10039: 1991. Information technology -- Open Systems Interconnection -- Local area networks -- MAC service definition.

[23] ISO 7498-1:1984. Information technology -- Open Systems Interconnection -- Basic Reference Model.

[24] ISO/IEC 15802-2:1995. Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Common specifications -- Part 2: LAN/MAN management.

[25] ISO 15802-3:1998. Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Common specifications -- Part 3: Media Access Control (MAC) bridging.

[26] ISO/IEC 15802-5:1998. Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Common specifications -- Part 5: Remote Media Access Control (MAC) bridging.

[27] IEEE 802.1F-1993. IEEE Standards for Local and Metropolitan Area Networks: Common Definitions and Procedures for IEEE 802 Management Information.

[28] IEEE 802.1Q-1998. IEEE Standards for Local and Metropolitan Area Networks: Virtual Bridged Local Area Networks.

[29] IEEE 802.10-1998. IEEE Standards for Local and Metropolitan Area Networks: Standard for Interoperable LAN/MAN Security (SILS).

[30] IEEE 802.10c-1998. IEEE Standards for Local and Metropolitan Area Networks: Supplement to Standard for Interoperable LAN/MAN Security (SILS) -- Key Management (Clause 3).

[31] J. Costa ITU-R 9B/134E Broadband Wireless Access Draft New Recommendation ITU-R F.BWA Radio Transmission Systems for Fixed Broadband Wireless Access (BWA) Based on Cable Modem Standards" Apr. 1999.

~~[32] D. Gray, "A Broadband Wireless Access System at 28 GHz" IEEE Radio and Wireless Conference, Boulder, CO, pp. 1-7, Aug. 1997.~~

[33] H. D. Graves, "A Detailed Analysis of MMDS and LMDS", February 23-26, 1997 IEEE MTT-S Wireless Technology Symposium, Vancouver, Canada, pp. 7-10, Feb 1997.

~~[34] H. Izadpanah, "LMDS: A Broadband Wireless Access Technology: An Overview", The 3rd IAA Annual Conference on "Computers and Communications", The City University of New York, New York, Sept. 1998.~~

[35] H. Izadpanah, D. Gregoire, J. Schaffner, and HP Hsu, "MM-Wave Wireless Access Technology For The Wideband Wireless Local Loop Applications", 1998 IEEE Radio and Wireless Conference (RAWCON'98) Colorado Springs, CO, pp. ,Aug., 1998.

[36] J. Schaffner, H. Izadpanah, and HP Hsu, "MM-Wave Wireless Technology and Testbed Development for Wideband Infrastructure Access", WCC'98, San Diego, CA, Nov. 1998.

[37] C.W. Lundgren and W.D. Rummler, "Digital radio outage due to selective fading observation vs. prediction from laboratory simulation," Bell System Technical Journal, pp.1073-1100, May-June 1979.

[38] M. Emshwiller, "Characterization on the performance of PSK digital radio transmission in the presence of multipath fading," ICC'78 Conference Record, Toronto, Ontario, CANADA, Paper 47.3.

[39] Microwave digital radio systems criteria, Bellcore Technical Reference TR-TSY-000752, October 1989.

[40] W.D. Rummler, R.P. Coutts, and M. Linger, "Multipath fading channel models for microwave digital radio," IEEE Communications Magazine, November 1986, pp.30-42.

~~[41] M. Taylor, "LAN emulation over ATM", Computer Commun., Vol. 20, No. 1, January 1997.~~

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

[43] S. Blake et al, "An Architecture for Differentiated Services", RFC 2475, December, 1998.

[44] S. Blake et al, "A Framework for Differentiated Services", Internet Draft, October, 1998.

[45] "Broadband Radio Access Networks (BRAN); Requirements and architectures for broadband fixed radio access networks (HIPERACCESS)", ETSI Technical Report TR 101 177 V1.1.1 (1998-05).

[46] A. Azcorra et al., "IP/ATM Integrated Services over Broadband Access Copper Technologies" IEEE Communications, pp. 90-97, Vol. 37, No. 5, May 1999.

[47] Proc. Of 1999 IMT-2000 3rd Generation Wireless Technology Conference. Feb 10-12, 1999. New Orleans, USA.

[48] Lou Dellaverson, Evolution of a Global Standard on WATM. ATM Forum, 1999.

[49] Proceedings of 1999 Wireless Symposium. Feb. 22-26, 1999. San Jose, USA.

[50] R. K. Crane, "Prediction of Attenuation by Rain" IEEE, 1980.

[51] ITU-T G.826: Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate (2/99).

[52] ITU-R F.1189-1 Error performance objectives for constant bit rate digital paths at or above the primary rate carried by digital radio-relay systems which may form part or all of the national portion of a 27500 km hypothetical reference path. (1995-1997).

[53] CCIR Recommendation 749, Radio-Frequency channels arrangements for radio-relay systems operating in the 36.0 to 40.5 GHz band. (1992).

[54] ITU-T Recommendation I.210 (1993) - "ISDN Service Capabilities Principles of Telecommunications Services Supported by an ISDN and the Means to Describe Them".

[55] W. Stallings, Data and Computer Communications, 5th ed., Prentice Hall, 1996.

[56] G. Almes et. al. "A One-way Delay Metric for IPPM". Internet Draft, May 1999.

[57] G. Almes et. al. "A Round-trip Delay Metric for IPPM". Internet Draft, May 1999.

[58] G. Almes et. al. "A One-way Packet Loss Metric for IPPM". Internet Draft, May 1999.

[59] ITU-T Recommendation I.35IP. Internet Protocol Data Communication Service IP Packet Transfer Performance Parameters.

[60] C. Demichelis. "Packet Delay Variation: Comparison between ITU-T and IETF draft definitions". Draft, carlo.demichelis@cselt.it.

[61] M. Hamdi et. al. "Voice Service Interworking for PSTN and IP Networks". IEEE Comm. Magazine, Vol. 37 No. 5, May 1999.

[62] J. Russell. "Multimedia Networking Performance Requirements". ATM Networks, I. Viniotis and R. O. Onvural, Eds., New York; Plenum, 1993, pp. 187-198.

[63] A. Dutta-Roy. "Cable it's not just for TV". IEEE Spectrum, Vol. 36 No. 5, May 1999.

[64] K. Dubose and H.S. Kim. "An Effective Bit Rate/Table Lookup Based Admission Control Algorithm for the ATM B-ISDN." In: Proc of the 17 th IEEE Conf. On Local Computer Networks, Sept. 1992.

[65] L. P. Bermejo et. al. "Service Characteristic and Traffic Models in Broadband ISDN". Electrical Communication, Vol. 64-2/3, 1990, pp.132-138.

[66] G. Galassi et. al. "Resource Management and Dimensioning in ATM Networks". IEEE Network Magazine, May 1990, pp. 8-17.

[67] ISO/IEC 8802-2:1998. Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Common specifications -- Part 2: Logical Link Control.

[68] IEEE P802.14/a Draft 3 Revision 3, Cable-TV access method and physical layer specification Oct. 1998. (unpublished draft)

[69] Data-Over-Cable Service Interface Specifications. Radio Frequency Interface Specification V1.1 SP-RFI-104-980724, Cable Television Labs, 1998.

[70] RFC-2205 Resource ReSerVation Protocol (RSVP) -- Version 1 Functional Specification. R. Braden, Ed., L. Zhang, S. Berson, S. Herzog, S. Jamin. September 1997. Status: PROPOSED STANDARD.

[71] Recommendation ITU-R M.1079 (June 1999). Performance and Quality of Service (QoS) Requirements for International Mobile Telecommunications-2000 (IMT-2000).

[72] Recommendation ITU-R PN530. Propagation of Data and Prediction Methods for Design of Terrestrial Line of Sight Systems.

[73] Recommendation ITU-T I.356 (October 1996) - B-ISDN ATM layer cell transfer performance.

[74] Summary of Recommendation ITU-T E.164 (05/97).

~~[75] Recommendation ITU-T G.114 (02/96) - One-way transmission time.~~