Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**The Draft IEEE 802.16m System Description Document**
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Re:	The Draft SDD
Abstract	This version is a revised version of IEEE 802.16m-08/003r4. The revision is based on comment resolution captured in the IEEE 802.16m-08/035r5.
Purpose	Draft for further development of the IEEE 802.16m SDD
Notice	
Release	
Patent Policy	

The Draft IEEE 802.16m System Description Document

Table of Contents

1 Scope

The IEEE 802.16m amendment shall be developed in accordance with the P802.16 project authorization request (PAR), as approved on 6 December 2006 [1], and with the Five Criteria Statement in IEEE 802.16-06/055r3 [2]. According to the PAR, the standard shall be developed as an amendment to IEEE Std 802.16 [3][4]. The resulting standard shall fit within the following scope:

> *This standard amends the IEEE 802.16 WirelessMAN-OFDMA specification to provide an advanced air interface for operation in licensed bands. It meets the cellular layer requirements of IMT-Advanced next generation mobile networks. This amendment provides continuing support for legacy WirelessMAN-OFDMA equipment.*

And the standard will address the following purpose:

> *The purpose of this standard is to provide performance improvements necessary to support future advanced services and applications, such as those described by the ITU in Report ITU-R M.2072.*

The standard is intended to be a candidate for consideration in the IMT-Advanced evaluation process being conducted by the International Telecommunications Union– Radio Communications Sector (ITU-R) [5][6][7]. This document represents the system description document for the IEEE 802.16m amendment. It describes the system level description of the IEEE 802.16m system based on the SRD developed by the IEEE 802.16 TGm[8]. All content included in any draft of the IEEE 802.16m amendment shall be in accordance with the system level description in this document as well as in compliance with the requirements in the SRD. This document, however, shall be maintained and may evolve. The system described herein is defined to ensure competitiveness of the evolved air interface with respect to other mobile broadband radio access technologies as well as to ensure support and satisfactory performance for emerging services and applications.

2 References

[1] IEEE 802.16m PAR, December 2006, http://standards.ieee.org/board/nes/projects/802-16m.pdf

[2] IEEE 802.16 WG, "Five Criteria Statement for PIEEE 802.16m PAR Proposal," IEEE 802.16-06/55r3, November 2006, http://ieee802.org/16/docs/06/80216-06_055r3.pdf

[3] IEEE Std 802.16-2004: Part 16: IEEE Standard for Local and metropolitan area networks: Air Interface for Fixed Broadband Wireless Access Systems, June 2004

[4] IEEE Std. IEEE 802.16e-2005, IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, and IEEE Std. 802.16-2004/Cor1-2005, Corrigendum 1, December 2005

[5] Recommendation ITU-R M.1645: Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000, January 2003

[6] ITU-R Document 8F/TEMP/568: Guidelines for evaluation of radio interface technologies for IMT-Advanced, May 2007

[7] ITU-R Document 8F/TEMP/574: Requirements related to technical system performance for IMT-Advanced radio interface(s) [IMT.TECH] , May 2007

[8] IEEE 802.16m System Requirements, IEEE 802.16m-07/002r4

[9] The WiMAX Forum Network Architecture Stage 2 - 3: Release 1, Version 1.2 http://www.wimaxforum.org/technology/documents/WiMAX_End-to-End_Network_Systems_Architecture_Stage_2-3_Release_1.1.2.zip

3 Definitions, Symbols, Abbreviations

3.1 Definitions

1. **WirelessMAN-OFDMA Reference System**: as defined in IEEE 802.16m SRD[8]
2. **Legacy MS (16e MS)**: as defined in IEEE 802.16m SRD[8]
3. **Legacy RS (16j RS)**: A relay station (RS) compliant with the IEEE 802.16 WirelessMAN OFDMA specification specified by IEEE 802.16-2004 and amended by IEEE 802.16e-2005, IEEE 802.16Cor2/D3 and IEEE 802.16j
4. **Legacy BS (16e BS)**: as defined in IEEE 802.16m SRD[8]
5. **Legacy MR-BS (16j BS)**: A base station (BS) compliant with the IEEE 802.16 WirelessMAN OFDMA specification specified by IEEE 802.16-2004 and amended by IEEE 802.16e-2005, IEEE 802.16Cor2/D3 and IEEE 802.16j
6. **IEEE 802.16m MS (16m MS)**: as defined in IEEE 802.16m SRD[8]
7. **IEEE 802.16m RS (16m RS)**: A relay station (RS) compliant with the IEEE 802.16 WirelessMAN OFDMA specification specified by IEEE 802.16-2004 and amended by IEEE 802.16e-2005, IEEE 802.16Cor2/D3 and IEEE 802.16m
8. **IEEE 802.16m BS (16m BS)**: as defined in IEEE 802.16m SRD[8]
9. **Legacy Zone (16e/16j zone):** A positive integer number of consecutive subframes where IEEE 802.16m BS communicates with legacy RS or legacy MS, and where IEEE 802.16m RS communicates with a legacy MS
10. **IEEE 802.16m Zone (16m zone):** A positive integer number of consecutive subframes where IEEE 802.16m BS communicates with IEEE 802.16m RS or IEEE 802.16m MS, and where IEEE 802.16m RS communicates with other IEEE 802.16m entities (i.e. IEEE 802.16m BS, IEEE 802.16m RS or IEEE 802.16mMS)

3.2 Abbreviations

DRU	Distributed Resource Unit
E-MBS	Enhanced Multcast Broadcast Service
FA	Frequency Assignment
FDD	Frequency Division Duplex
HFDD	Half-duplex Frequency Division Duplex
LBS	Location Base Service
LRU	Logical Resource Unit
LDRU	Logical Distributed Resource Unit
LLRU	Logical Localized Resource Unit
MAC	Medium Access Control
MBS	Multicast Broadcast Service
MC	Multi Carrier
MCS	Modulation Coding Scheme
OFDMA	Orthogonal Frequency Division Multiple Access
PRU	Physical Resource Unit
RU	Resource Unit
RS	Relay Station
TDD	Time Division Duplex

4 Overall Network Architecture

<Editor’s Note: This section will describe the overall network architecture applicable to IEEE 802.16m.>

The Network Reference Model (NRM) is a logical representation of the network architecture. The NRM identifies functional entities and reference points over which interoperability is achieved between functional entities. Figure 1 illustrates the NRM, consisting of the following functional entities: Mobile Station (MS), Access Service Network (ASN), and Connectivity Service Network (CSN). The existing network reference model is defined in WiMAX Network Architecture [9].

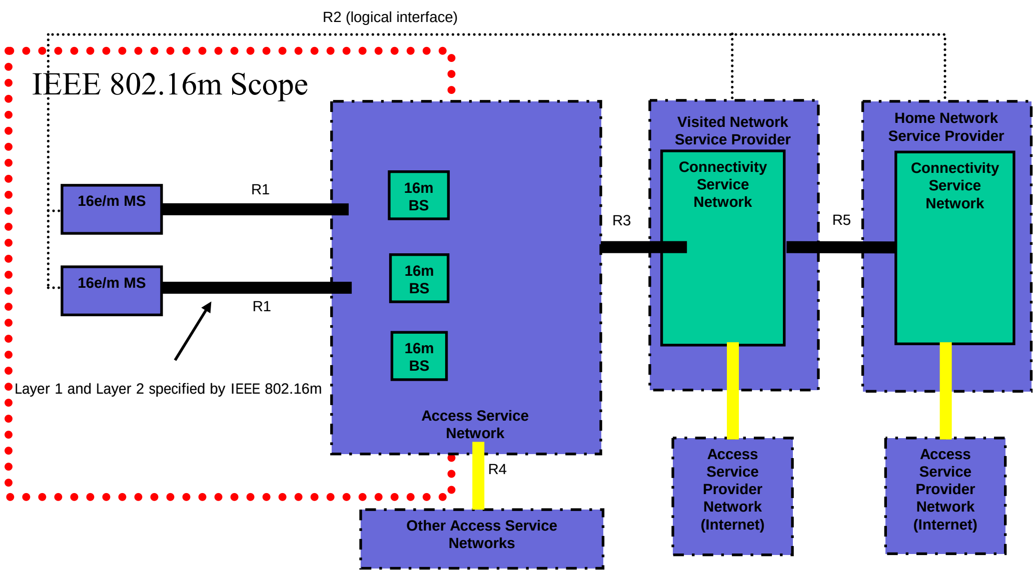

Figure 1 Example of overall network architecture

The ASN is defined as a complete set of network functions needed to provide radio access to an IEEE 802.16e/m subscriber. The ASN provides at least the following functions:

- IEEE 802.16e/m Layer-1 (L1) and Layer-2 (L2) connectivity with IEEE 802.16e/m MS
- Transfer of AAA messages to IEEE 802.16e/m subscriber’s Home Network Service Provider (H-NSP) for authentication, authorization and session accounting for subscriber sessions
- Network discovery and selection of the IEEE 802.16e/m subscriber’s preferred NSP
- Relay functionality for establishing Layer-3 (L3) connectivity with an IEEE 802.16e/m MS (i.e. IP address allocation)
- Radio Resource Management

In addition to the above functions, for a portable and mobile environment, an ASN further supports the following functions:

- ASN anchored mobility
- CSN anchored mobility
- Paging

- ASN-CSN tunneling

The ASN comprises network elements such as one or more Base Station(s), and one or more ASN Gateway(s). An ASN may be shared by more than one CSN. The CSN is defined as a set of network functions that provide IP connectivity services to the IEEE 802.16e/m subscriber(s). A CSN may provide the following functions:

- MS IP address and endpoint parameter allocation for user sessions
- AAA proxy or server
- Policy and Admission Control based on user subscription profiles
- ASN-CSN tunneling support,
- IEEE 802.16e/m subscriber billing and inter-operator settlement
- Inter-CSN tunneling for roaming
- Inter-ASN mobility

The IEEE 802.16e/m CSN provides services such as location based services, connectivity for peer-to-peer services, provisioning, authorization and/or connectivity to IP multimedia services.

CSN may further comprise network elements such as routers, AAA proxy/servers, user databases, Interworking gateway MSs. A CSN may be deployed as part of a IEEE 802.16m NSP or as part of an incumbent IEEE 802.16e NSP.

Relay Stations (RSs) may be deployed to provide improved coverage and/or capacity.

A IEEE 802.16m BS that is capable of supporting a 16j RS, shall communicate with the 16j RS in the "legacy zone". The IEEE 802.16m BS is not required to provide 16j protocol support in the "16m zone". [The design of 16m relay protocols should be based on the design of 16j wherever possible, although 16m relay protocols used in the "16m zone" may be different from 16j protocols used in the "legacy zone".]

Figure 2 and Table 1, show the IEEE 802.16m relay related interfaces that are to be supported and those which are not required to be supported in the 802.16 specification. Only the interfaces involving RSs (IEEE 802.16m and legacy RS) are shown.

Figure 2 and Table 1 also indicate the specific 802.16 protocol that is to be used for supporting the particular connection.

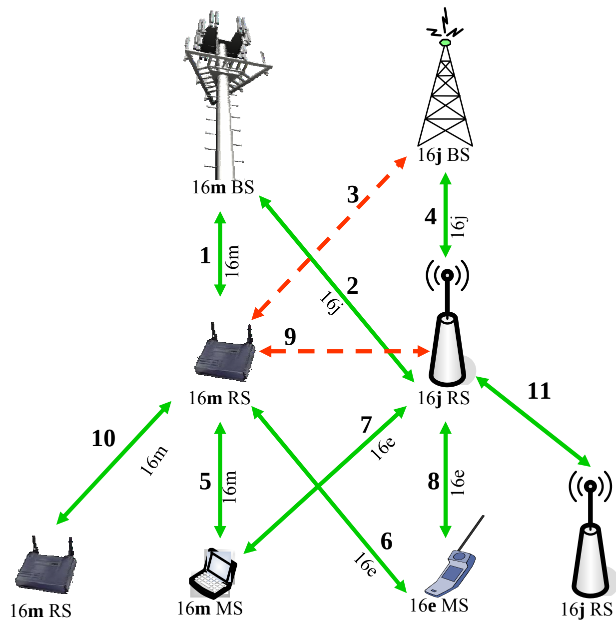

Figure 2 Diagram showing the relay-related connections.

The entities shown in Figure 2 and referred to in Table 1 are defined as follows:

- IEEE 802.16m BS – A base station that supports the base station functionality specified in the IEEE 802.16m draft amendment including the optional relay functionality.
- 16j BS – A base station that supports the base station functionality specified in the IEEE 802.16j draft amendment. This type of base station is referred to as an MR-BS in the IEEE 16j draft amendment.
- IEEE 802.16m RS – A relay station that supports the relay station functionality specified in the IEEE 802.16m draft amendment.
- 16j RS – A relay station that supports the relay station functionality specified in the IEEE 802.16j draft amendment.
- IEEE 802.16m MS – An MS which supports the mobile station functionality specified in the IEEE 802.16m draft amendment.
- 16e MS – An MS which supports the mobile station functionality compliant with the WirelessMAN-OFDMA Reference System, as specified in IEEE 802.16m System Requirements [8].

Connection #	Connected Entities	Protocol used	Supported (Y/N)
1	16m BS -16m RS	16m	Y
2	16m BS - 16j RS	16j	Y
3	16m RS – 16j BS	N/A	N
4	16j BS - 16j RS	16j	Y
5	16m RS - 16m MS	16m	Y
6	16m RS - 16e MS	16e	Y
7	16m MS – 16j RS	16e	Y
8	16j RS - 16e MS	16e	Y
9	16m RS – 16j RS	N/A	N
10	16m RS – 16m RS	16m	Y
11	16j RS – 16j RS	16j	Y

Table 1 Interconnections between the entities shown in Figure 2 and the protocol used.

Figure 2 and Table 1 capture the interfaces which may exist between the IEEE 802.16m and legacy stations. The figure and table are not intended to specify any constraints on the usage of these interfaces. For example, the figure and table do not provide rules for which interfaces a particular station can utilize at the same time, or how many connections a station can have over each of the specified interfaces.

The usage of the interfaces described in Figure 2 and Table 1 is constrained as follows: A IEEE 802.16m MS may connect to a 16m BS either directly or via one or more IEEE 802.16m RSs. The number of hops between the IEEE 802.16m BS and a IEEE 802.16m MS can be two or greater than two. The topology between the IEEE 802.16m BS and the subordinate IEEE 802.16m RSs within a IEEE 802.16m BS cell shall be restricted to a tree topology. A 16e MS may connect to a IEEE 802.16m BS either directly or via one or more IEEE 802.16m RSs. Furthermore a 16e MS may connect to a IEEE 802.16m BS via one or more 16j RSs. The topology between the IEEE 802.16m BS and the subordinate 16j RSs within a IEEE 802.16m BS cell is specified in the IEEE 802.16j draft amendment.

Connection 10 indicates a connection between a IEEE 802.16m RS and another directly connected IEEE 802.16m RS. Such connections exist in order to support topologies in which the number of hops between the IEEE 802.16m BS and an MS is greater than two hops.

Connection 11 indicates a connection between a 16j RS and another directly connected 16j RS. Such connections exist in order to support topologies in which the number of hops between the 16j MR-BS and an MS is greater than two hops.

5 IEEE 802.16m System Reference Model

<Editor's Note: This section describes system reference model in for those functions introduced in the IEEE 802.16m air interface>

As shown in the following Figure 3, the proposed reference model for IEEE 802.16m is very similar to that of IEEE 802.16e with the exception of soft classification of MAC common part sub-layer into radio resource control and management functions and medium access control functions (i.e., no SAP is required between the two classes of functions).

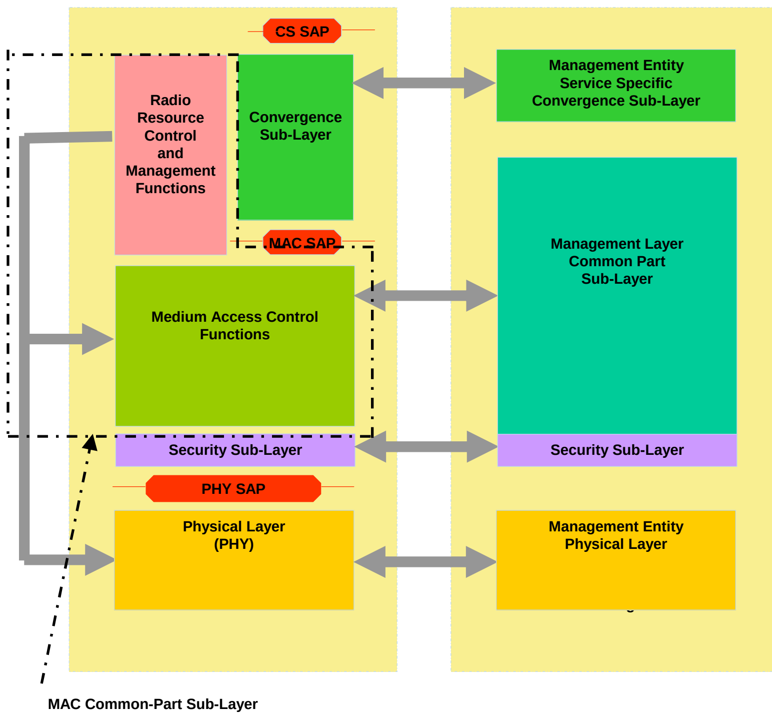

Figure 3 System Reference Model

6 IEEE 802.16m Mobile Station State Diagrams

<Editor's Note: To capture only the top level states of the mobile stations, base stations. Detailed feature specific state diagrams will be captured elsewhere in the respective sections.>

The Figure 4 illustrates the mobile station state transition diagram for IEEEIEEE 802.16m MS. Mobile Station state diagram for IEEEIEEE 802.16m systems consists of 4 states, Initialization state, Access state, Connected state and Idle state.

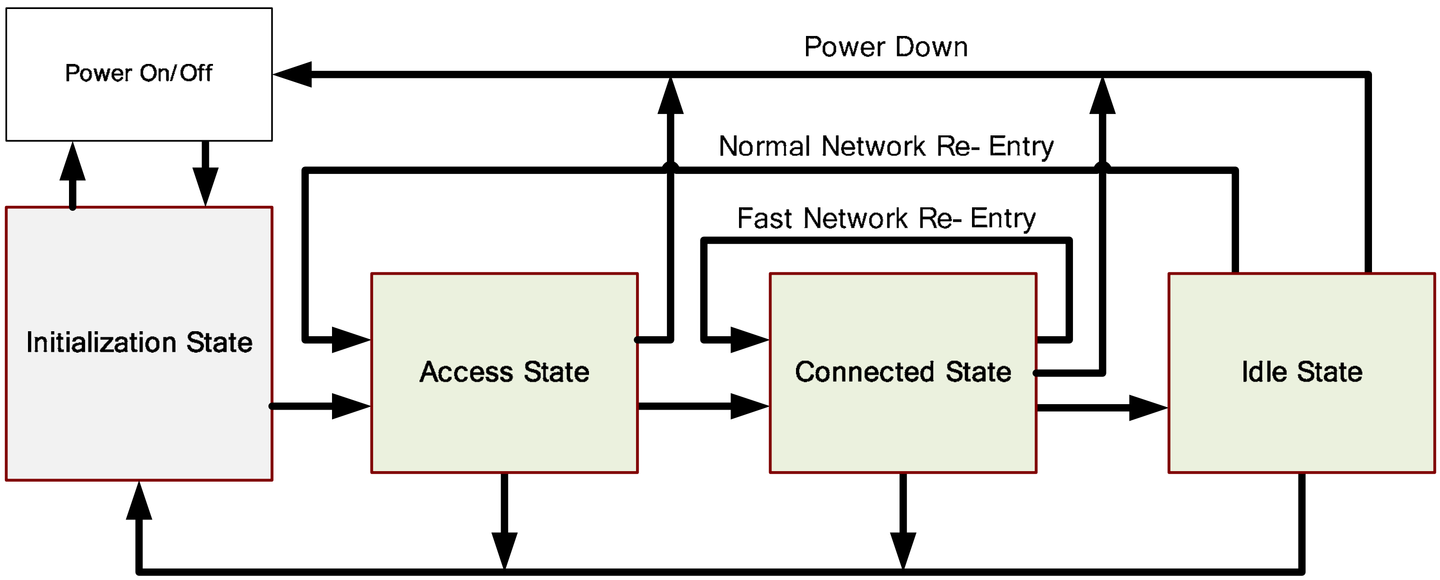

Figure 4 Mobile Station State Transition Diagram of IEEEIEEE 802.16m

6.1 *Initialization State*

In the initialization state, the MS performs cell selection by scanning and synchronizing to a BS SCH, and acquiring the system configuration information through BCH before entering Access State.

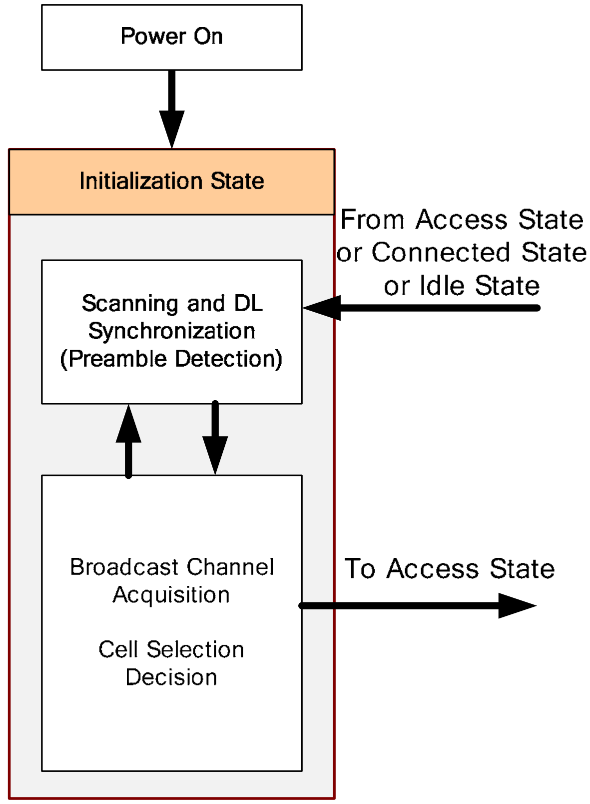

Figure 5 Initialization State Transition Diagram

During this state, if the MS cannot properly perform the BCH information decoding and cell selection, it should return to perform scanning and DL synchronization. If the MS successfully decodes BCH information and selects one target BS, it transitions to the Access State. The MS can transit from any state to the initialization state under abnormal conditions..

6.2 Access State

Access State is where the MS performs network entry to the selected BS by going through several processes. The MS performs the ranging process (initial ranging code and RNG-REQ/RSP MAC message is used in the Reference System) in order to obtain UL synchronization. Next, the MS performs basic capability negotiation with the BS (SBC-REQ/RSP MAC message is used in the Reference System). The MS then performs the authentication and authorization process. Next, the MS performs the registration process (REG-REQ/RSP MAC message is used in the Reference System). MS receives the IEEE 802.16m Station Identifier as part of Access State procedures. The MS establishes at least one connection using MAC signaling,(DSx procedures in the Reference System) and transitions to the Connected state. IP address assignment may follow using appropriate procedures.

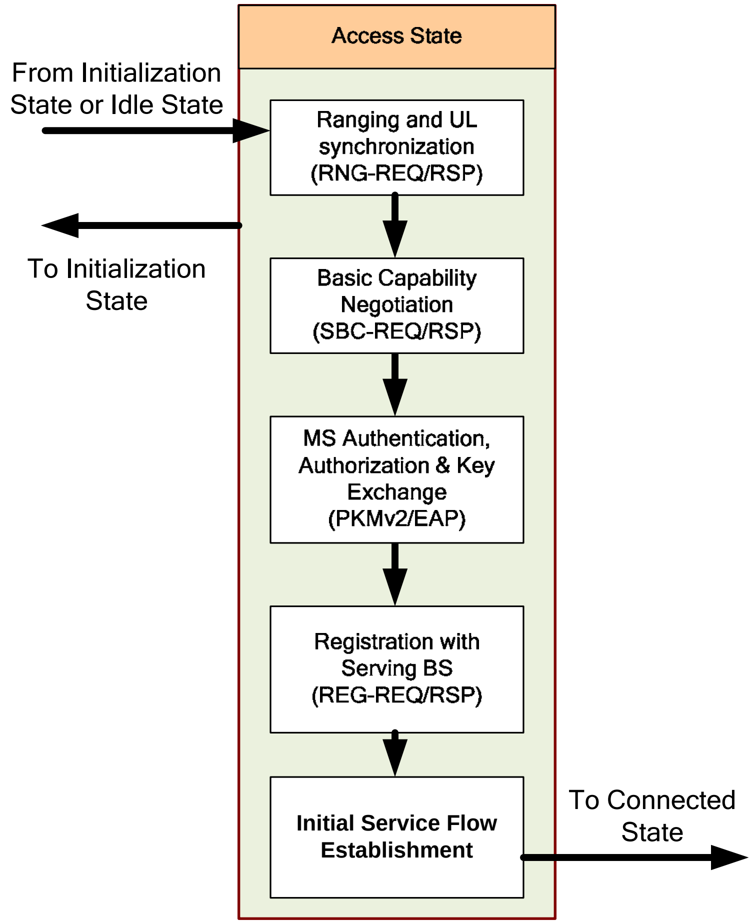

Figure 6 Access State Transition Diagram

<Editor's note: This figure identifies the access state transitions consistent with IEEE 802.16e. These procedures may be modified for IEEE 802.16m. Further updates are likely necessary. In addition the names of the messages in the parenthesis are the ones used in the Reference System>

Upon successfully performing the Access State operation, the MS goes to the Connected State. Otherwise, in case of abnormal operation, the MS goes back to the Initialization State.

6.3 Connected State

The Connected State consists of 3 modes; Sleep Mode, Active Mode and Scanning Mode. During Connected State, the MS maintains at least one connection as established during Access State, while MS and BS may establish additional transport connections. In addition, to reduce power consumption of the MS during user data exchange, the MS or BS can request a transition to sleep mode. And also, MS can scan neighbor cell's signal to reselect a cell which provides robust and reliable services.

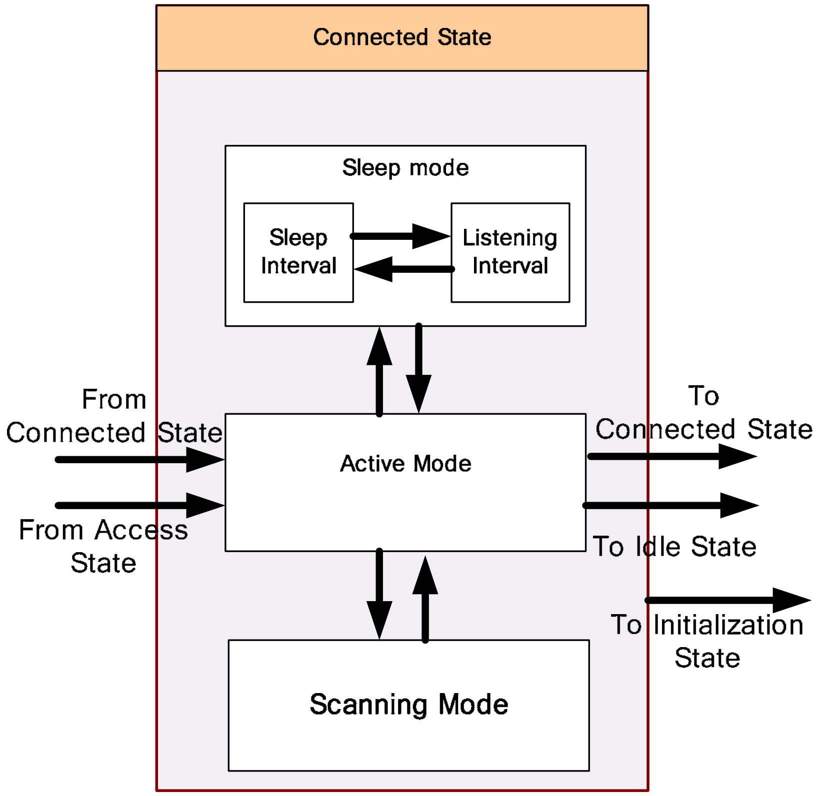

Figure 7 Connected State Transition Diagram

6.3.1 Active mode

During Active Mode, the MS and BS perform normal operations to exchange the DL/UL traffic transaction between the MS and BS. MS can perform the Fast network re-entry procedures after handover: while in handover, MS maintains station identifier and flow identifier IEEE 802.16mand its IP address in accordance with upper layer protocols. Without going through Access State, MS may remain in Connected State with target BS.

6.3.2 Sleep mode

During Sleep mode, MS may enable power saving techniques. MS in Active mode transitions to sleep mode through sleep mode MAC signaling management messages(MOB_SLP-REQ/RSP message is used in the Reference System). The MS neither transmits nor receives any traffic to or from its BS during the sleep interval. An MS can receive an indication message (MOB_TRF-IND message is used in the Reference System) during listening interval and then based on the message content to decide whether it should transit to active mode or stay in sleep mode. During the sleep interval, MS may choose to transit to active mode.

6.3.3 Scanning mode

During scanning mode, the MS performs scanning operation and may be temporarily unavailable to the serving BS. While in active mode, MS transitions to scanning mode via explicit MAC signaling (MOB_SCN-REQ/RSP message is used in the Reference System) or implicitly without scanning management messages generation. In scanning intervals, MS is unavailable to the serving BS.

6.4 Idle State

The Idle state consists of 2 separated modes, paging available mode and paging unavailable mode based on its operation and MAC message generation._During Idle State, the MS may perform power saving by switching between Paging available mode and Paging Unavailable mode

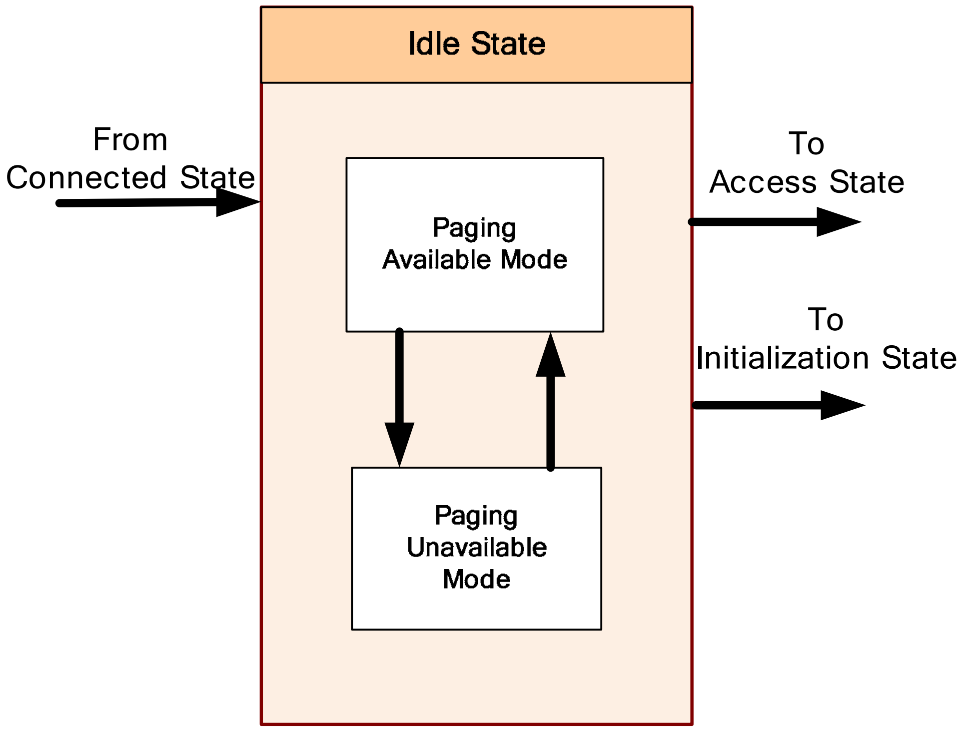

Figure 8 Idle State Transition Diagram

6.4.1 Paging Available Mode

The MS may be paged by the BS (MOB_PAG-ADV message is used in the Reference System) while it is in the paging available mode. If the MS is paged, it shall transition to the Access State for its network re-entry. MS may perform location update procedure during idle state.

6.4.2 Paging Unavailable Mode

During paging unavailable mode, MS does not need to monitor the downlink channel in order to reduce its power consumption. While in this mode, MS can also transition to Access State if required.

7 Frequency Bands

<Editor's Note: This section will describe the frequency bands that are applicable to the IEEE 802.16m system>

IEEE 802.16m systems can operate in RF frequencies less than 6 GHz and are deployable in licensed spectrum allocated to the mobile and fixed broadband services. The following frequency bands have been identified for IMT and/or IMT-2000 by WARC-92, WRC-2000 and WRC-07

- 450-470 MHz
- 698-960 MHz
- 1710-2025 MHz
- 2110-2200 MHz
- 2300-2400 MHz
- 2500-2690 MHz
- 3400-3600 MHz

ITU-R has developed frequency arrangements for the bands identified by WARC-92 and WRC-2000, which are described in Recommendation ITU-R M.1036-3. For the frequency bands that were identified at WRC-07, further work on the frequency arrangements is ongoing within the framework of ITU-R.

8 IEEE 802.16m Air-Interface Protocol Structure

8.1 The IEEE 802.16m Protocol Structure

The IEEE 802.16m MAC is divided into two sublayers:

- Convergence sublayer (CS)
- Common Part sublayer (CPS)

MAC Common Part Sublayer is further classified in to Radio Resource Control and Management (RRCM) functions and Medium Access Control (MAC) functions. The RRCM sublayer includes several functional blocks that are related with radio resource functions such as:

- Radio Resource Management
- Mobility Management
- Network-entry Management
- Location Management
- Idle Mode Management
- Security Management
- System Configuration Management
- MBS
- Connection Management
- Relay functions
- Self Organization
- Multi-Carrier

The functional block definitions captured in section 8.1 apply to the BS and MS. Definitions of functional blocks for the RS are captured in section 8.2.

The Radio Resource Management block adjusts radio network parameters based on traffic load, and also includes function of load control (load balancing), admission control and interference control.

Mobility Management block supports functions related to Intra-RAT/ Inter-RAT handover. Mobility Management block handles the Intra-RAT/ Inter-RAT Network topology acquisition which includes the advertisement and measurement, manages candidate neighbor target BSs/RSs and also decides whether MS performs Intra-RAT/Inter-RAT handover operation.

Network-entry Management block is in charge of initialization and access procedures. Network-entry Management block may generate management messages which are needed during access procedures, i.e., ranging (this does not mean physical ranging, but ranging message in order to identification, authentication, and CID allocation), basic capability negotiation, registration, and so on.

Location Management block is in charge of supporting location based service (LBS). Location Management block may generate messages including the LBS information.

The Idle Mode Management block manages location update operation during idle mode. Idle Mode Management block controls idle mode operation, and generates the paging advertisement message based on paging message from paging controller in the core network side.

Security Management block is in charge of authentication/authorization and key management for secure communication.

System Configuration Management block manages system configuration parameters, and system parameters and system configuration information for transmission to the MS.

MBS (Multicast and Broadcasting Service) block controls management messages and data associated with broadcasting and/or multicasting service.

Service Flow and Connection Management block allocates station identifier and flow identifiers during access/handover/ service flow creation procedures. Connection Management block interacts with convergence sublayer to classify MAC Service Data Unit (MSDU) from upper layer, and maps MSDU onto a particular transport connection.

Relay Functions block includes functions to support multi-hop relay mechanisms. The functions include procedures to maintain relay paths between BS and an access RS.

Self Organization block performs functions to support self configuration and self optimization mechanisms. The functions include procedures to request RSs/MSs to report measurements for self configuration and self optimization and receive the measurements from the RSs/MSs.

Multi-carrier (MC) block enables a common MAC entity to control a PHY spanning over multiple frequency channels. The channels may be of different bandwidths (e.g. 5, 10 and 20 MHz), be non-contiguous or belong to different frequency bands. The channels may be of the same or different duplexing modes, e.g. FDD, TDD, or a mix of bidirectional and broadcast only carriers. For contiguous frequency channels, the overlapped guard sub-carriers shall be aligned in frequency domain in order to be used for data transmission.

The Medium Access Control (MAC) includes function blocks which are related to the physical layer and link controls such as:

- PHY Control
- Control Signaling
- Sleep Mode Management
- QoS
- Scheduling and Resource Multiplexing
- ARQ
- Fragmentation/Packing
- MAC PDU formation
- Multi-Radio Coexistence
- Data forwarding
- Interference Management
- Inter-BS coordination

PHY Control block handles PHY signaling such as ranging, measurement/feedback (CQI), and HARQ ACK/NACK. Based on CQI and HARQ ACK/NACK, the PHY Control block estimates channel quality as seen by the MS, and performs link adaptation via adjusting modulation and coding scheme (MCS), and/or power level. In the ranging procedure, PHY contol block does UL synchronization with power adjustment, frequency offset and timing offset estimation.

Control Signaling block generates resource allocation messages.

Sleep Mode Management block handles sleep mode operation. Sleep Mode Management block may also generate MAC signaling related to sleep operation, and may communicate with Scheduler and Resource Multiplexing block in order to operate properly according to sleep period.

QoS block handles QoS management based on QoS parameters input from Connection Management function for each connection, and scheduler shall operate based on the input from QoS block in order to meet QoS requirement.

Scheduling and Resource Multiplexing block schedules and multiplexes packets based on properties of connections. In order to reflect properties of connections Scheduling and Resource and Multiplexing block receives QoS information from QoS block for each connection.

ARQ block handles MAC ARQ function. For ARQ-enabled connections, ARQ block logically splits MAC SDU to ARQ blocks, and numbers to each logical ARQ block. ARQ block may also generate ARQ management messages such as feedback message (ACK/NACK information).

Fragmentation/Packing block performs fragmenting or packing MSDUs based on scheduling results from Scheduler block.

MAC PDU formation block constructs MAC protocol data unit (PDU) so that BS/MS can transmit user traffic or management messages into PHY channel. MAC PDU formation block adds MAC header and may add sub-headers. MAC PDU formation block may also add MAC CRC if necessary.

Multi-Radio Coexistence block performs functions to support concurrent operations of IEEE 802.16m and non-IEEE 802.16m radios collocated on the same mobile station.

The Data Forwarding block performs forwarding functions when RSs are present on the path between BS and MS. The Data Forwarding block may cooperate with other blocks such as Scheduling and Resource Multiplexing block and MAC PDU formation block.

Interference Management block performs functions to manage the inter-cell/sector interference. The operations may include:

- MAC layer operation
  - Interference measurement/assessment report sent via MAC signaling
  - Interference mitigation by scheduling and flexible frequency reuse
- PHY layer operation
  - Transmit power control
  - Interference randomization
  - Interference cancellation
  - Interference measurement
  - Tx beamforming/precoding

Inter-BS coordination block performs functions to coordinate the actions of multiple BSs by exchanging information, e.g., interference management. The functions include procedures to exchange information for e.g., interference management between the BSs by backbone signaling and by MS MAC messaging. The information may include interference characteristics, e.g. interference measurement results, etc.

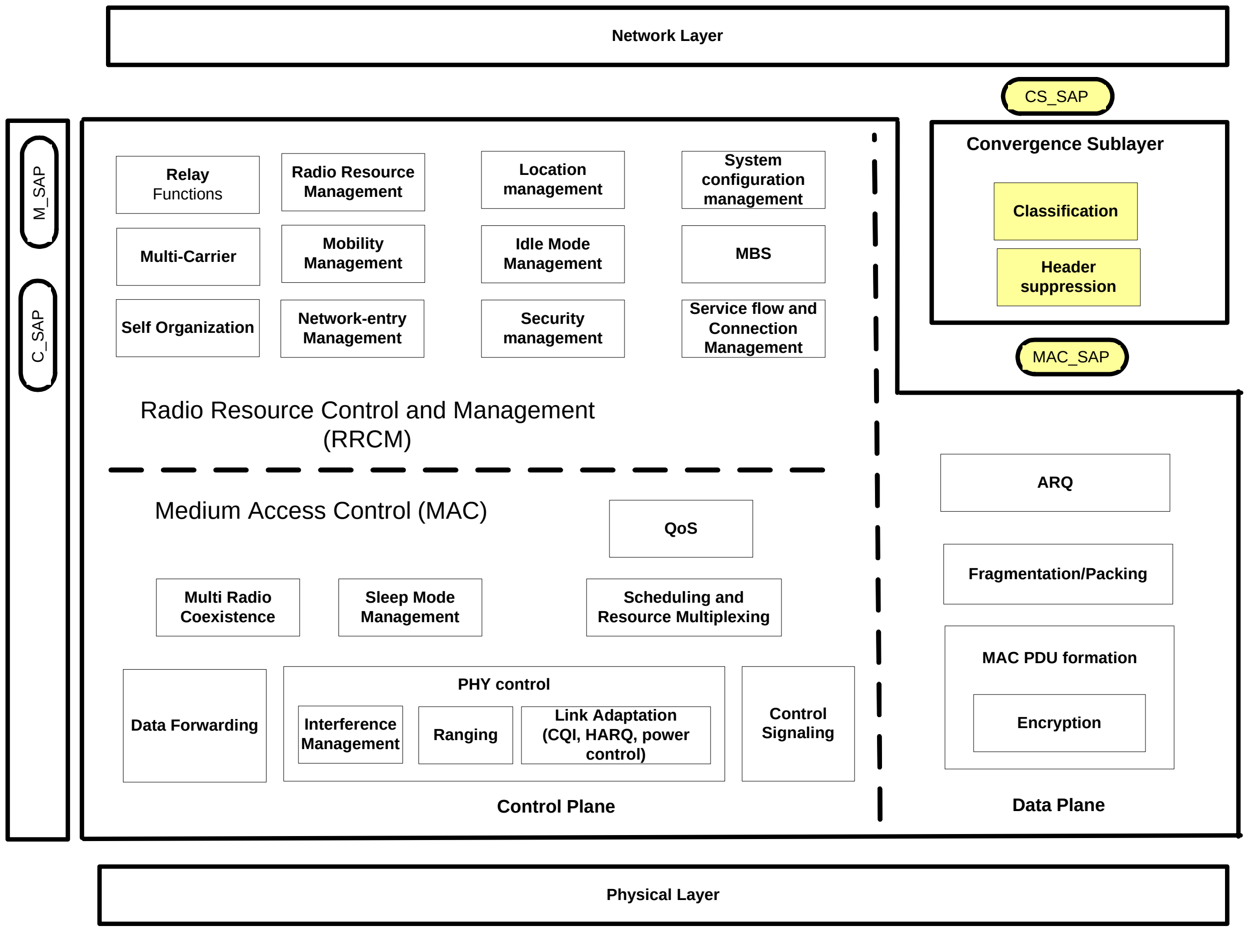

Figure 9 The IEEE 802.16m Protocol Structure

8.1.1 The IEEE 802.16m MS/BS Data Plane Processing Flow

Figure 10 shows the user traffic data flow and processing at the BS and the MS. The red arrows show the user traffic data flow from the network layer to the physical layer and vice versa. On the transmit side, a network layer packet is processed by the convergence sublayer, the ARQ function (if present), the fragmentation/packing function and the MAC PDU formation function, to form MAC PDU(s) to be sent to the physical layer. On the receive side, a physical layer SDU is processed by MAC PDU formation function, the fragmentation/packet function, the ARQ function (if present) and the convergence sublayer function, to form the network layer packets. The black arrows show the control primitives among the MAC CPS functions and between the MAC CPS and PHY that are related to the processing of user traffic data.

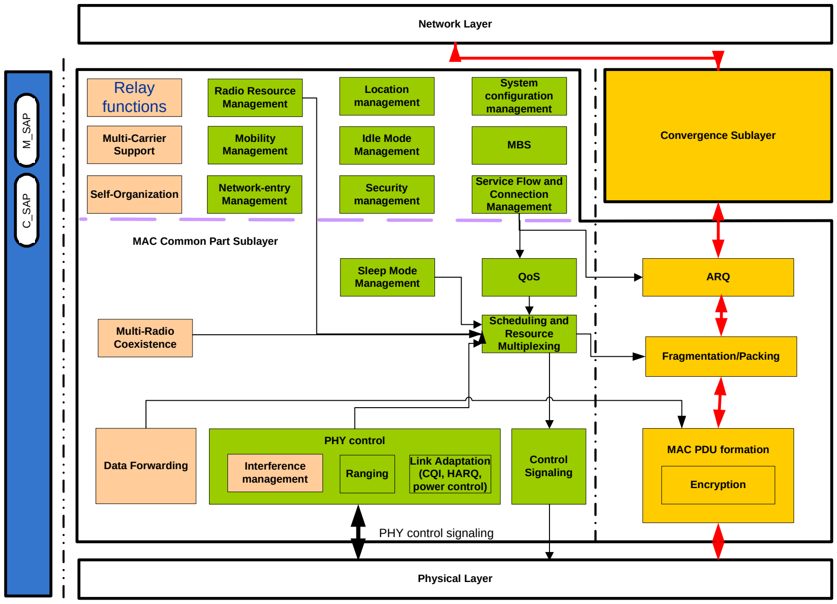

Figure 10 The IEEE 802.16m MS/BS Data Plane Processing Flow Note: The MS may not utilize all the blocks shown in this figure.

8.1.2 The IEEE 802.16m MS/BS Control Plane Processing Flow

The following figure shows the MAC CPS control plane signaling flow and processing at the BS and the MS. On the transmit side, the blue arrows show the flow of control plane signaling from the control plane functions to the data plane functions and the processing of the control plane signaling by the data plane functions to form the corresponding MAC signaling (e.g. MAC management messages, MAC header/sub-header) to be transmitted over the air. On the receive side, the blue arrows show the processing of the received over-the-air MAC signaling by the data plane functions and the reception of the corresponding control plane signaling by the control plane functions. The black arrows show the control primitives among the MAC CPS functions and between the MAC CPS and PHY that are related to the processing of control plane signaling. The black arrows between M_SAP/C_SAP and MAC functional blocks show the control and management primitives to/from Network Control and Management Service (NCMS). The primitives to/from M_SAP/C_SAP define the network involved functionalities such as inter-BS interference management, inter/intra RAT mobility management, etc, and management related functionalities such as location management, system configuration etc.

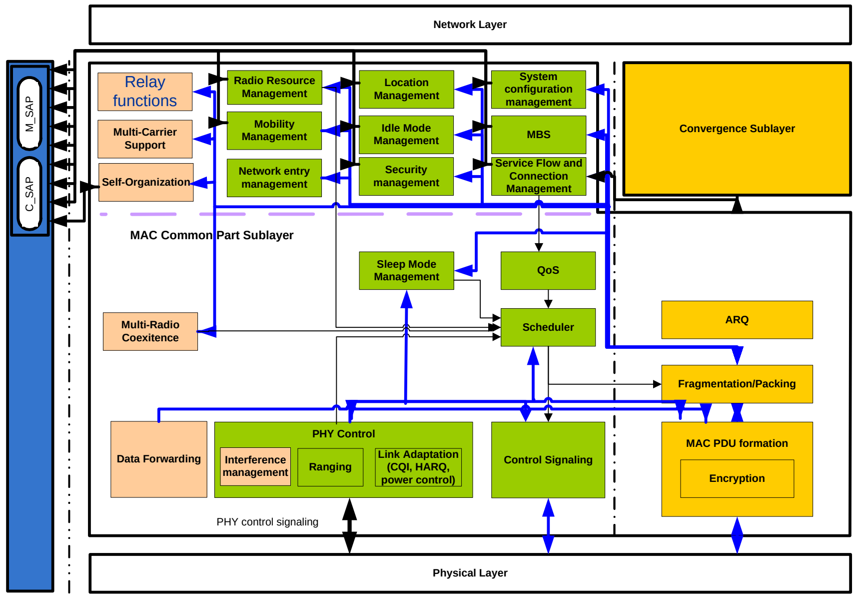

Figure 11 The IEEE 802.16m MS/BS Control Plane Processing Flow Note: The MS may not utilize all the blocks shown in this figure.

8.1.3 Multicarrier Support Protocol Structure

Generic protocol architecture to support multicarrier system is illustrated in Figure 12. A common MAC entity may control a PHY spanning over multiple frequency channels. Some MAC messages sent on one carrier may also apply to other carriers. The channels may be of different bandwidths (e.g. 5, 10 and 20 MHz), be non-contiguous or belong to different frequency bands. The channels may be of different duplexing modes, e.g. FDD, TDD, or a mix of bidirectional and broadcast only carriers.

The MAC entity may support simultaneous presence of MSs with different capabilities, such as operation over one channel at a time only or aggregation across contiguous or non-contiguous channels.

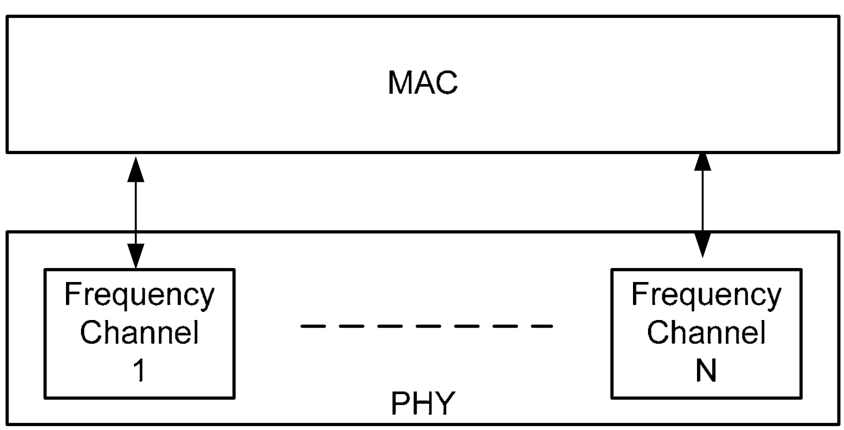

Figure 12 Multicarrier support protocol structure

8.1.4 Multi-Radio Coexistence Support Protocol Structure

Figure 13 shows an example of multi-radio device with co-located IEEE 802.16m MS, IEEE 802.11 STA, and IEEE 802.15.1 device. The multi-radio coexistence functional block of the IEEE 802.16m MS obtains the information about other co-located radio's activities, such as time characteristics, via inter-radio interface, which is internal to multi-radio device and out of the scope of IEEE 802.16m.

IEEE 802.16m provides protocols for the multi-radio coexistence functional blocks of MS and BS to communicate with each other via air interface. MS generates management messages to report the information about its co-located radio activities obtained from inter-radio interface, and BS generates management messages to respond with the corresponding actions to support multi-radio coexistence operation. Furthermore, the multi-radio coexistence functional block at BS communicates with the scheduler functional block to operate properly according to the reported co-located coexistence activities. The multi-radio coexistence function can be used independently from sleep mode operation to enable optimal power efficiency with a high level of coexistence support. However, when sleep mode provides sufficient co-located coexistence support, the multi-radio coexistence function may not be used.

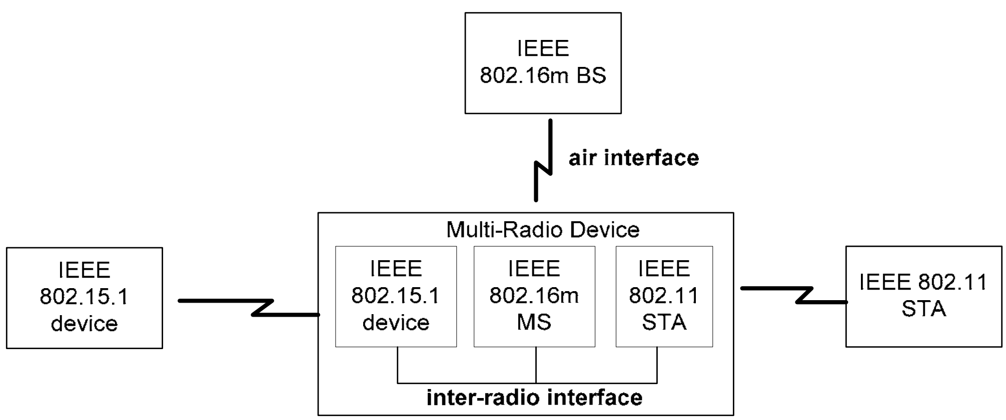

Figure 13 Example of Multi-Radio Device with Co-Located IEEE 802.16m MS, IEEE 802.11 STA, and IEEE 802.15.1 device

8.2 Relay Protocol Structure

The protocol partitioning for the BS and MS is shown in Figure 9 and the data plane and control plane processing flow is described in sub-clauses 8.1.1 and 8.1.2, respectively.

Figure 14 shows the proposed protocol functions for an RS. An RS may consist of a subset of the protocol functions shown in Figure 14. The subset of functions will depend on the type or category of the RS.

The functional blocks and the definitions in this section do not imply that these functional blocks shall be supported in all RS implementations.

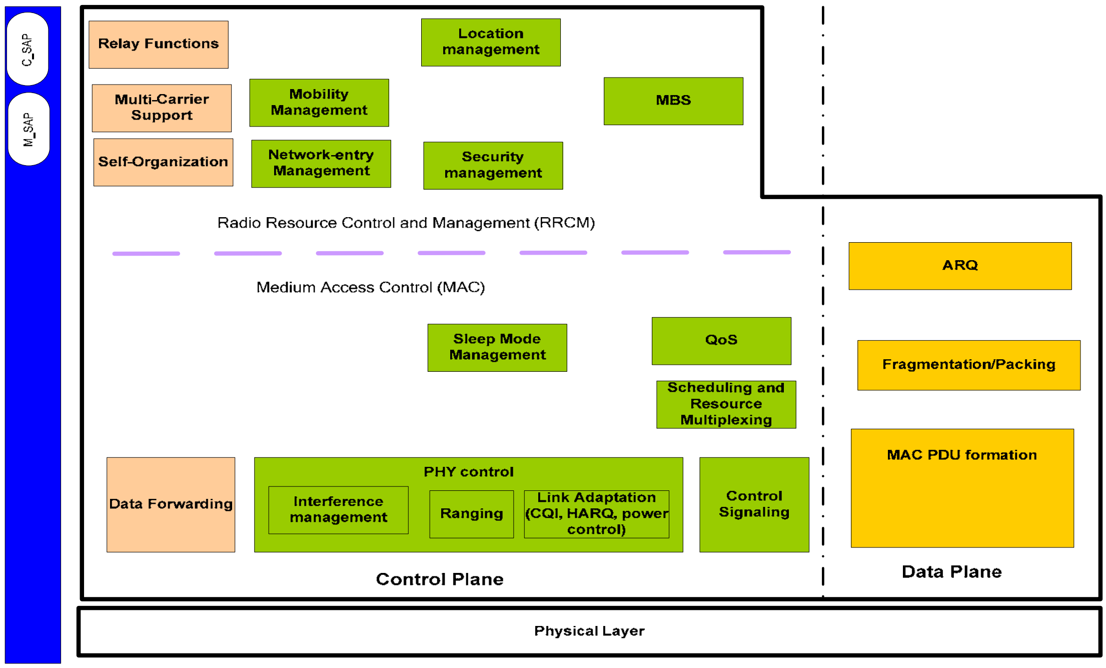

Figure 14 Protocol Functions of RS

The IEEE 802.16m RS MAC is divided into two sublayers:

- Radio Resource Control and Management (RRCM) sublayer
- Medium Access Control (MAC) sublayer

The IEEE 802.16m RS RRCM sublayer includes the following functional blocks that are related with RS radio resource functions:

- Mobility Management
- Network-entry Management
- Location Management
- Security Management
- MBS
- Path Management functions
- Self Organization
- Multi-Carrier

The Mobility Management block supports MS handover operations in cooperation with the BS.

The Network-entry Management block is in charge of RS/MS initialization procedures and performing RS network entry procedure to the BS. Network-entry Management block may generate management messages

needed during RS/MS initialization procedures and performing the network entry.
The Location Management block is in charge of supporting location based service (LBS), including positioning data, at the RS and reporting location information to the BS. Location Management block may generate messages for the LBS information including positioning data.
The Security Management block handles the key management for the RS.

The MBS (Multicast and Broadcasting Service) block coordinates with the BS to schedule the transmission of MBS data.

The Path Management Functions block includes procedures to maintain relay paths.
The Self Organization block performs functions to support RS self configuration and RS self optimization mechanisms coordinated by BS. The functions include procedures to request RSs/MSs to report measurements for self configuration and self optimization and receive measurements from the RSs/MSs, and report measurements to BS. The functions also include procedures to adjust RS parameters and configurations for self configuration / optimization with / without the coordination with BS.

The Multi-carrier (MC) block enables a common MAC entity to control a PHY spanning over multiple frequency channels at the RS.

The IEEE 802.16m RS Medium Access Control (MAC) sublayer includes the following function blocks which are related to the physical layer and link controls:

- PHY Control
- Control Signaling
- Sleep Mode Management
- QoS
- Scheduling and Resource Multiplexing
- ARQ
- Fragmentation/Packing
- MAC PDU formation
- Data forwarding
- Interference Management

The PHY Control block handles PHY signaling such as ranging, measurement/feedback (CQI), and HARQ ACK/NACK at the RS. Based on CQI and HARQ ACK/NACK, PHY Control block estimates channel environment of RS/MS, and performs link adaptation via adjusting modulation and coding scheme (MCS) or power level.

The Control Signaling block generates RS resource allocation messages such as MAP as well as specific control signaling messages.

The Sleep Mode Management block handles sleep mode operation of its MSs in coordination with the BS.

The QoS block handles rate control based on QoS parameters based on inputs from TBD functional blocks.

The Scheduling and Resource Multiplexing block schedules the transmission of MPDUs. The Scheduling and Resource Multiplexing block is present in the RS in order to support distributed scheduling.

The ARQ block assists MAC ARQ function between BS, RS and MS.

The Fragmentation/Packing block performs fragmenting or packing MSDUs based on scheduling results from Scheduler block. The Fragmentation/Packing block in an RS includes the unpacking and repacking of fragments that have been received for relaying in order to adapt the size of MPDUs to the expected channel quality of the outgoing link.

The MAC PDU formation block constructs MAC protocol data units (PDUs) which contain user traffic or management messages. User traffic is assumed to have originated at either the BS or MS. The MAC PDU formation block may add or modify MPDU control information (e.g., MAC header).

The Data Forwarding block performs forwarding functions on the path between BS and RS/MS. The Data Forwarding block may cooperate with other blocks such as Scheduling and Resource Multiplexing block and MAC PDU formation block.

The Interference Management block performs functions at the RS to manage the inter-cell/sector and inter-RS interference among RS and BS. This includes the collection of interference level measurements and selection of transmission mode used for individual MSs attached to the RS.

Control functions can be divided among the BS and RSs using a centralized model or a distributed model. In a centralized model, the BS makes control decisions and the RSs relay control information between the BS and MS. In a distributed model the RS makes control decisions for MSs attached to it as appropriate, and optionally communicates those decisions to the BS. The determination of whether a particular control function should be centralized or distributed is made independently for each control function. The classification of specific control functions as centralized or distributed is for further study.

9 Convergence Sub-Layer

10 Medium Access Control Sub-Layer

10.1 MAC Addressing

The MS has a global address and logical addresses that identify the MS and connections during operation.

10.1.1 IEEE 802 MAC Address

The 48-bit globally-unique IEEE 802 MAC address uniquely identifies the MS.

10.1.2 Logical Identifiers

The following logical identifiers are defined:

10.1.2.1 "Station Identifier"

The BS assigns a "Station Identifier" to the MS during network entry, and, in some cases, network re-entry, that uniquely identifies the MS within the domain of the BS. Each MS registered in the network has an assigned "Station Identifier". Some specific "Station Identifiers" are reserved, for example, for broadcast, multicast, and ranging.

10.1.2.2 "Flow Identifier"

Each MS connection is assigned a "Flow Identifier" that uniquely identifies the connection within the MS. "Flow Identifiers" identify management connections and transport connections. Some specific "Flow Identifiers" may be pre-assigned by default.

10.2 HARQ Functions

HARQ is supported in downlink and uplink packet (re)transmissions in both BS and MS to improve robustness and performance.

The HARQ operation relies on N-process (multi-channel) stop-and-wait protocol.

10.2.1 HARQ in the Downlink

10.2.1.1 HARQ Timing and Protocol

IEEE 802.16m uses asynchronous HARQ scheme in the downlink.

The following HARQ parameters and their associated values are defined:

- Maximum retransmission delay.: FFS
- Maximum number of retransmissions: FFS
- Maximum number of HARQ processes FFS
- ACK/NACK delay: FFS

[Placeholder for figures illustrating the choice of HARQ scheme(s) in Downlink]

The HARQ ACK/NACK delay is defined for FDD and for each TDD DL/UL ratio and for each mixed mode scenarios

10.2.1.2 HARQ Operation with Persistent Allocation

<Editor's note: This section is provided as place holder. This section will be filled when details of HARQ operation for persistent allocation is presented and discussed>

10.2.1.3 HARQ Re-transmissions

<Editor's note: the working assumption will depend on decision taken w.r.t. section 10.x.1.1>

For asynchronous HARQ, IEEE 802.16m uses an adaptive HARQ scheme in the downlink. In adaptive asynchronous HARQ, the resource allocation and transmission format for the HARQ retransmissions may be different from the initial transmission. In case of retransmission, control signaling is required to indicate the resource allocation and transmission format along with other HARQ necessary parameters.

10.2.2 HARQ in the Uplink

10.2.2.1 HARQ Timing and Protocol

IEEE 802.16m uses synchronous HARQ scheme in the uplink.

The following HARQ parameters and their associated values are defined:

- Maximum retransmission delay: FFS
- Maximum number of retransmissions: FFS
- Maximum number of HARQ processes FFS
- ACK/NACK delay: FFS

[Placeholder for figures illustrating the choice of HARQ scheme(s) in Uplink]

10.2.2.2 HARQ Operation with Persistent Allocation

<Editor's note: This section is provided as place holder. This section will be filled when details of HARQ operation for persistent allocation is presented and discussed>

10.2.2.3 HARQ Re-transmissions

For synchronous HARQ, resource at the retransmissions in the uplink can be fixed or adaptive according to control signaling.

10.2.3 HARQ and ARQ Interactions

<Editor's note: This section is provided as place holder. This section will be filled when details of HARQ and ARQ interactions is presented and discussed>

10.3 Handover

The following 4 cases are considered for handover in IEEE 802.16m

Case-1: IEEE 802.16m MS handover from legacy serving BS to legacy target BS
Case-2: IEEE 802.16m MS handover from IEEE 802.16m serving BS to legacy target BS
Case-3: IEEE 802.16m MS handover from legacy serving BS to IEEE 802.16m target BS
Case-4: IEEE 802.16m MS handover from IEEE 802.16m serving BS to IEEE 802.16m target BS

The IEEE 802.16m network and mobile station uses legacy handover procedures for case-1. Solutions for cases 2, 3 and 4 are FFS.

10.3.1 Network topology acquisition

10.3.1.1 Network topology advertisement

A BS periodically broadcasts the system information of the neighboring BSs using MOB_NBR-ADV message. The BS formats MOB_NBR-ADV message based on the cell types of neighbor cells, in order to achieve overhead reduction and facilitate scanning priority for MS. MOB_NBR-ADV message does not include information of neighbor femto cells. Special handling of neighbor information of femto cell is described in section 10.3.4

A serving BS may unicast the MOB_NBR-ADV message to a MS.

10.3.1.2 Scanning Procedure

The scanning procedure provides the opportunity for the MS to perform measurement of the neighboring cells for handover decision. The MS may use current or negotiate new unavailable intervals to perform scanning. In addition, the MS may perform scanning procedure during its active cycle without interrupting its communication with the serving BS if the MS supports such capability.

MS selects the scanning candidate BSs by information obtained from MOB_NBR-ADV or information cached in the MS, or instructed by BS. The BS or MS may prioritize the neighbor BSs to be scanned based on various metrics, such as cell type, loading, RSSI and location.

MS measures the selected scanning candidate BSs and reports the measurement result back to the serving BS. The serving BS defines triggering conditions and rules for MS sending scanning report.

10.3.2 Handover Process

10.3.2.1 HO Framework

The handover algorithm is a network-controlled, MS-assisted handover. Although handover procedure may be initiated by either MS or BS, the final HO decision and target BS(s) selection are performed by the serving BS or the network. MS executes the HO as directed by the BS or cancels the HO procedure through HO cancellation message. The network re-entry procedure with the target BS may be optimized by target BS possession of MS information obtained from serving BS over the backbone network. MS may also maintain communication with serving BS while performing network re-entry at target BS as directed by serving BS. Figure 15 shows a general call flow for handover.

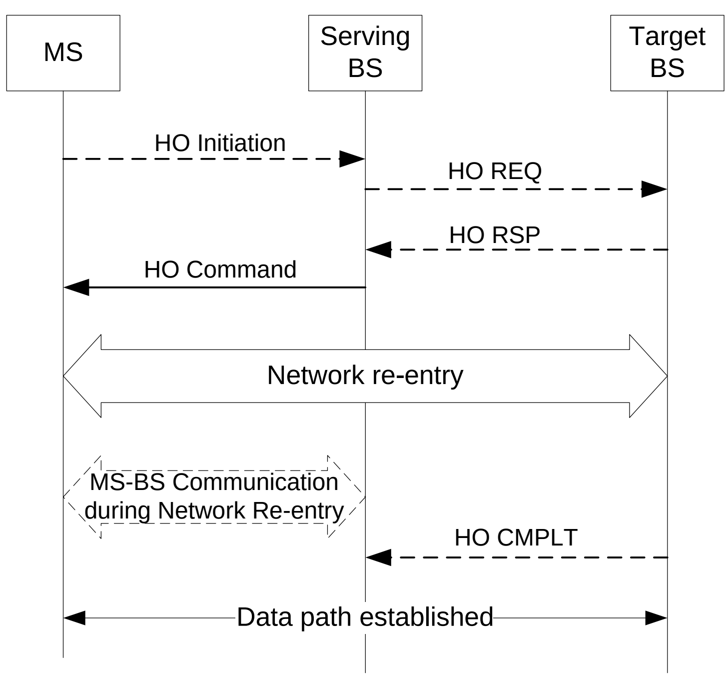

Figure 15 A general call flow for HO

The handover procedures are divided into three phrases, namely, HO initialization, HO preparation and HO execution. When HO execution is complete, the MS is ready to perform Network re-entry procedures at target BS. In addition, HO cancellation procedure is defined to allow MS cancel a HO procedure.

10.3.2.2 HO Procedure

10.3.2.2.1 HO initiation

Handover procedure may be initiated by either MS or BS and controlled by the BS. When handover is initiated by the MS, the serving BS defines the triggers and conditions based on which the MS initiates a handover. When multiple triggers and conditions are defined, the serving BS may use combination of multiple conditions to trigger HO. When HO is initiated by MS, a HO Initiation control signaling is sent by the MS to start the HO procedure. In case of BS initiated HO, HO initiation and HO preparation phases are carried out together.

10.3.2.2.2 HO preparation

During HO preparation phase, the serving BS selects communicate with target BS(s) for HO. The target BS may obtain MS information from the serving BS via backbone network for HO optimization. Ranging with target BS prior or during HO preparation is FFS. If ranging with target BS not performed prior to or during HO preparation, dedicated ranging resource (e.g. code, channel, etc.) at target BS may be reserved for the MS to facilitate non-contention-based HO ranging. Information regarding MS identity (e.g. TEK, STID, FIDs, etc.), may be pre-updated during HO preparation. Any mismatched system information between MS and the target BS, if detected, may be provided to the MS by the Serving BS during HO preparation.

HO preparation phase completes when serving BS informs the MS of its handover decision via a HO Command control signaling. The control signaling may include dedicate ranging resource allocation and resource pre-allocations for MS at target BS for optimized network re-entry. The control signaling includes an action time for the MS to start network re-entry at the target BS and an indication whether MS should maintain communication with serving BS during network re-entry.

10.3.2.2.3 HO execution

At the action time specified in the HO command control signaling, the MS performs network re-entry at the target BS. If communication is not maintained between MS and serving BS during network re-entry at the target BS, serving BS stops allocating resources to MS for transmission at action time.
If directed by serving BS via HO Command control signaling, the MS performs network re-entry with the target BS at action time while continuously communicates with serving BS. However, the MS stops communication with serving BS after network re-entry at target BS is completed. In addition, MS cannot exchange data with target BS prior to completion of network re-entry. Multiplexing of network re-entry signaling with target BS and communications with serving BS is FFS.

10.3.2.2.4 HO cancellation

After HO is initiated, the MS may cancel HO at any phase during HO procedure by sending a HO cancellation message to the serving BS. After the HO cancellation message is processed, the MS and serving BS resume their normal operation. The dedicated ranging code assignment for transmitting HO cancellation message is

FFS.

10.3.2.3 Network Re-entry

10.3.2.3.1 CDMA-based HO Ranging procedure

If a dedicated ranging code is assigned to the MS by target BS, the MS transmits the dedicated ranging code to the target BS during network re-entry. If a ranging channel is scheduled by the target BS for handover purpose only, the MS should use that ranging channel in order to avoid excessive multiple access interference. MS authentication through CDMA-based HO ranging is FFS. For CDMA-based HO ranging without MS authentication, upon reception of the dedicated ranging code, the target BS should allocate uplinks resources for RNG-REQ message and UL data if needed.

CDMA-based HO ranging with target BS prior to network re-entry is FFS. When the MS handovers to the target BS, CDMA-based HO ranging may be omitted if the ranging parameters are valid.

10.3.2.3.2 Network Re-entry Procedure

The network re-entry procedure is carried out as specified in IEEE P802.16Rev2 procedure unless otherwise specified in this section. Enhancement to the authentication mechanism at the target BS is FFS..

10.3.3 Handover support for Femto BS

[Editor's Note: This section is only related to intra-RAT IEEE 802.16m to IEEE 802.16m HO. The text proposed in C80216m-MAC-08_022r2 is included with some modification.]

The network provides the mapping between femto BS and corresponding overlay (macro/micro) BS as well as certain system information such as carrier frequency of the femto cell to MS for supporting handover between (macro/micro) BS and femto BS. MS may cache this information for future handover to the specific femto cell. At the time of handover preparation, the system information of a target femto cell may be unicast or multicast to the MS upon MS request/network trigger or obtained by the MS monitoring the femto cell.

The HO procedure between femto BS and macro BS is FFS.

10.3.4 Handover Process supporting Legacy system

[Editor's Note: This section is only related to intra-RAT 16e/IEEE 802.16m HO.]

10.3.4.1 Network topology acquisition

10.3.4.2 Handover from 16e to IEEE 802.16m

10.3.4.3 Handover from IEEE 802.16m to 16e

10.4 Power Management

IEEE 802.16m provides MS power management functions including sleep mode and idle mode to alleviate MS battery consumption.

10.4.1 Sleep Mode

10.4.1.1 Introduction

Sleep mode is a state in which an MS conducts pre-negotiated periods of absence from the serving BS air interface. Per MS, a single power saving class is managed in order to handle all the active connections of the MS. Sleep mode may be activated when an MS is in the connected state. When Sleep Mode is active, the MS is provided with a series of alternate listening window and sleep windows**.** The listening window is the time in which MS is available to receive and send signaling and/or data from and to the BS.
The IEEE 802.16m provides a framework for dynamically adjusting the duration of sleep windows and listening windows within a sleep cycle based on changing traffic patterns and HARQ operations.
Sleep windows and listening windows can be dynamically adjusted for the purpose of transport data as well as MAC control signaling transmission. MS can send and receive transport data and MAC control signaling without deactivating the sleep mode.

10.4.1.2 Sleep mode entry

Sleep mode activation/entry is initiated either by a MS or a BS. When MS is in Active mode, sleep parameters are negotiated between MS and BS. BS makes the final decision and instructs the MS to enter sleep mode. MAC control signaling can be used for sleep mode request/response signaling.

10.4.1.3 Sleep Mode Operations

10.4.1.3.1 Sleep cycle operation

The period of the sleep cycle is measured in units of frames or superframes. A sleep cycle is the sum of a sleep window and a listening window. MS or BS may request change of sleep cycle through explicit MAC control signaling. Also, sleep mode may change implicitly. BS keeps synchronized with MS on the sleep/listening windows' boundary. The synchronization could be done either implicitly by following pre-determined procedure, or explicitly by using proper signaling mechanism.

10.4.1.3.2 Sleep Window Operation

During the sleep window, the MS is unavailable to receive any DL data and MAC control signaling from the serving BS. IEEE 802.16m provides a framework for dynamically adjusting the duration of the sleep windows. If MS has data or MAC control signaling to transmit to BS during the sleep window, MS can interrupt the sleep window and request bandwidth for UL transmission with or without deactivating sleep mode based on sleep mode configuration.

10.4.1.3.3 Listening window operation

During the listening window the MS can receive DL data and MAC control signaling from BS. MS can also send data if any uplink data is scheduled for transmission. Listening window is measured in units of subframes or frames**.** After termination (by explicit signaling or implicit method) of a listening window, the MS may go back to sleep for the remainder of the current sleep cycle.

10.4.1.3.3.1 Traffic Indication

During the MS listening window, BS may transmit the traffic indication message intended for one or multiple MSs. It indicates whether or not there is traffic addressed to one or multiple MSs. The traffic indication message transmission is carried out in two steps: an indicator followed by a traffic indication message. Traffic indication message is transmitted when the indicator is positive. The indicator and the traffic indication message are transmitted at pre-defined location. Upon receiving negative traffic indication in the traffic indication message, the MS can go to sleep for the rest of the current sleep cycle.

10.4.1.3.3.2 Listening Window Extension

The listening window duration can be dynamically adjusted based on traffic availability or control signaling in MS or BS. The listening window can be extended through explicit signaling or implicit method. The maximum length of the extension is to the end of the current sleep cycle in which case there is no sleep window during the current sleep cycle.

10.4.1.3.4 Sleep Mode Exit

Sleep mode termination/deactivation is initiated either by MS or BS. BS makes the final decision and instructs the MS to de-activate sleep mode by using explicit signaling. MAC control signaling are used for sleep mode request/response signaling.

10.4.2 Idle mode

Idle mode is intended as a mechanism to provide efficient power saving for the MS by allowing the MS to become periodically available for DL broadcast traffic messaging (e.g. Paging message) without registration at a specific BS.

The network assigns idle mode MS to a paging group during idle mode entry or location update. The design shall allow the network to minimizes the number of location updates performed by the MS and the paging signaling overhead caused to the BSs. The idle mode operation considers user mobility.

The MS monitors the paging message at MS's paging listening interval. The start of the MS's paging listening interval shall be derived based on paging cycle and paging offset. Paging offset and paging cycle are defined in terms of number of super-frames.

The MSs are divided into logical groups to offer a scalable paging load-balancing distribution. The criteria of load balancing are FFS.

10.4.2.1 Paging Procedure

BS transmits the list of PGIDs at the pre-determined location <u>of the beginning of the paging listening interval</u>. Paging mechanism in 802.16m may use the two-step paging procedure that includes the paging indication followed by the full paging message.

10.4.2.1.1 Paging Indication

Paging indications, if present, are transmitted at the pre-determined location. When paging indications are transmitted, BS transmits the list of PG IDs and associated paging indicator flag The exact format of paging indicator is TBD indicating the presence of full paging messages for the corresponding PGIDs.

10.4.2.1.2 BS Broadcast Paging message

The number of times the paging messages are transmitted in a super frame is FFS. Methods used to determine the frame/sub-frame (within a super-frame) that contains the paging message/uplink access for one or group of idle mode MSs is FFS.
Paging message includes identification of the MSs to be notified of DL traffic pending or location update.'

10.4.2.1.3 Operation during paging unavailable interval

BS should not transmit any DL traffic or paging advertisement to MS during MS's paging unavailable interval. During paging unavailable interval, the MS may power down, scan neighbor BSs, reselect a preferred BS, conduct ranging, or perform other activities for which the MS will not guarantee availability to any BS for DL traffic.

10.4.2.1.4 Operation during paging listening interval

The MS derives the start of the paging listening interval based on the paging cycle and paging offset. At the beginning of paging listening interval, the MS scans and synchronizes on the SCH of its preferred BS. The MS decodes the BCH. The MS shall confirm whether it exists in the same paging group as it has most recently belonged by getting PG ID information.

During paging listening interval, MS monitors BCH. If BCH indicates change in system broadcast information (e.g. change in system configuration count) then MS should acquire the latest system broadcast information at the pre-determined time when the system information is broadcast by the BS.
Additionally, if paging indicators are present, MS also monitors the paging indicators. If the paging indicator flag associated with its own PGID is set then MS will subsequently decode the full paging message at the predetermined location otherwise MS will return to paging unavailable interval.
If paging indicators are not present, MS decodes the full paging message at the predetermined location.
If the MS decodes a paging message that contains its identification, the MS performs network re-entry or location update depending on the notification indicated in the paging message. Otherwise, MS returns to paging unavailable interval.

10.4.2.2 Idle Mode Entry/Exit Procedure

10.4.2.2.1 Idle mode initiation

In order to reduce signaling overheads and provide location privacy, the paging controller may assign temporary identifier to uniquely identify the MSs in the idle mode in a particular paging group. The MS's temporary identifier remains valid as long as MS stays in the same paging group. The temporary identifier assignment may happen during idle mode entry or during location update due to paging group change. Temporary identifier may be used in paging messages or during MS's network re-entry procedure from idle mode as response to paging.

10.4.2.2.2 Idle mode termination

For termination of idle mode, MS shall perform network reentry with its preferred BS. The network reentry procedure can be shortened by the BS possession of MS information obtained from network management entity.

10.4.2.3 Location Update

10.4.2.3.1 Location update trigger condition

An MS in idle mode shall perform a location update process operation if any of the following location update trigger condition is met.

- Paging group location update
- Timer based location update
- Power down location update

During paging group location update or timer based location update, MS may update paging cycle and paging offset.

10.4.2.3.2 Location update procedure

If an MS determines or elects to update its location, depending on the security association the MS shares with its preferred BS, the MS shall use one of two processes: secure location update process or unsecure location update process.

Location update comprises condition evaluation and location update signaling.

10.4.2.3.2.1 Paging group location update

The MS performs the Location Update process when the MS detects a change in paging group. The MS detects the change of paging group by monitoring the Paging Group IDs, which are transmitted by the BS.

10.4.2.3.2.2 Timer based location update

MS shall periodically perform location update process prior to the expiration of idle mode timer. At every location update including paging group location update, idle mode timer is reset to 0 and restart.

10.4.2.3.2.3 Power down location update

The MS attempts to complete a location update once as part of its orderly power down procedure.

10.5 Security

11 Physical Layer

11.1 Duplex modes

IEEE 802.16m supports TDD and FDD duplex modes, including H-FDD MS operation, in accordance with the IEEE 802.16m system requirements document [8]. Unless otherwise specified, the frame structure attributes and baseband processing are common for all duplex modes.

11.2 Downlink and Uplink Multiple Access Schemes

IEEE 802.16m uses OFDMA as the multiple access scheme in the downlink and uplink.

11.3 OFDMA Parameters

The OFDMA parameters for the IEEE 802.16m are specified as follows:

Nominal Channel Bandwidth (MHz)		5	7	8.75	10	20
Over-sampling Factor		28/25	8/7	8/7	28/25	28/25
Sampling Frequency (MHz)		5.6	8	10	11.2	22.4
FFT Size		512	1024	1024	1024	2048
Sub-Carrier Spacing (kHz)		10.937500	7.812500	9.765625	10.937500	10.937500
Useful Symbol Time T_u (μs)		91.429	128	102.4	91.429	91.429
Cyclic Prefix (CP) T_g=1/8 T_u	Symbol Time T_s (μs)	102.857	144	115.2	102.857	102.857
	Number of OFDM symbols per Frame	48	34	43	48	48
	Idle time (μs)	62.86	104	46.40	62.86	62.86
Cyclic Prefix (CP) T_g=1/16 T_u	Symbol Time T_s (μs)	97.143			97.143	97.143
	Number of OFDM symbols per Frame	51			51	51
	Idle time (μs)	45.71			45.71	45.71

Table 2 OFDMA parameters for IEEE 802.16m

A CP size longer than 1/8 is used in channels with long delay spread.

11.4 Frame structure

11.4.1 Basic Frame structure

The IEEE 802.16m basic frame structure is illustrated in Figure 16. Each 20 ms superframe is divided into four equally-sized 5 ms radio frames. When using the same OFDMA parameters as in Table 2 with the channel bandwidth of 5 MHz, 10 MHz, or 20 MHz, each 5 ms radio frame further consists of eight subframes. A subframe shall be assigned for either DL or UL transmission. There are two types of subframes depending on the size of cyclic prefix: 1) the type-1 subframe which consists of six OFDMA symbols and 2) the type-2 subframe that consists of seven OFDMA symbols. In both subframe types, some of symbols may be idle symbols.

The basic frame structure is applied to FDD and TDD duplexing schemes, including H-FDD MS operation. The number of switching points in each radio frame in TDD systems is either two or four, where a switching point is defined as a change of directionality, i.e., from DL to UL or from UL to DL.

When H-FDD mobile stations are included in an FDD system, the frame structure from the point of view of the H-FDD mobile station is similar to the TDD frame structure; however, the DL and UL transmissions occur in two separate frequency bands. The transmission gaps between DL and UL (and vice versa) are required to allow switching the TX and RX circuitry.

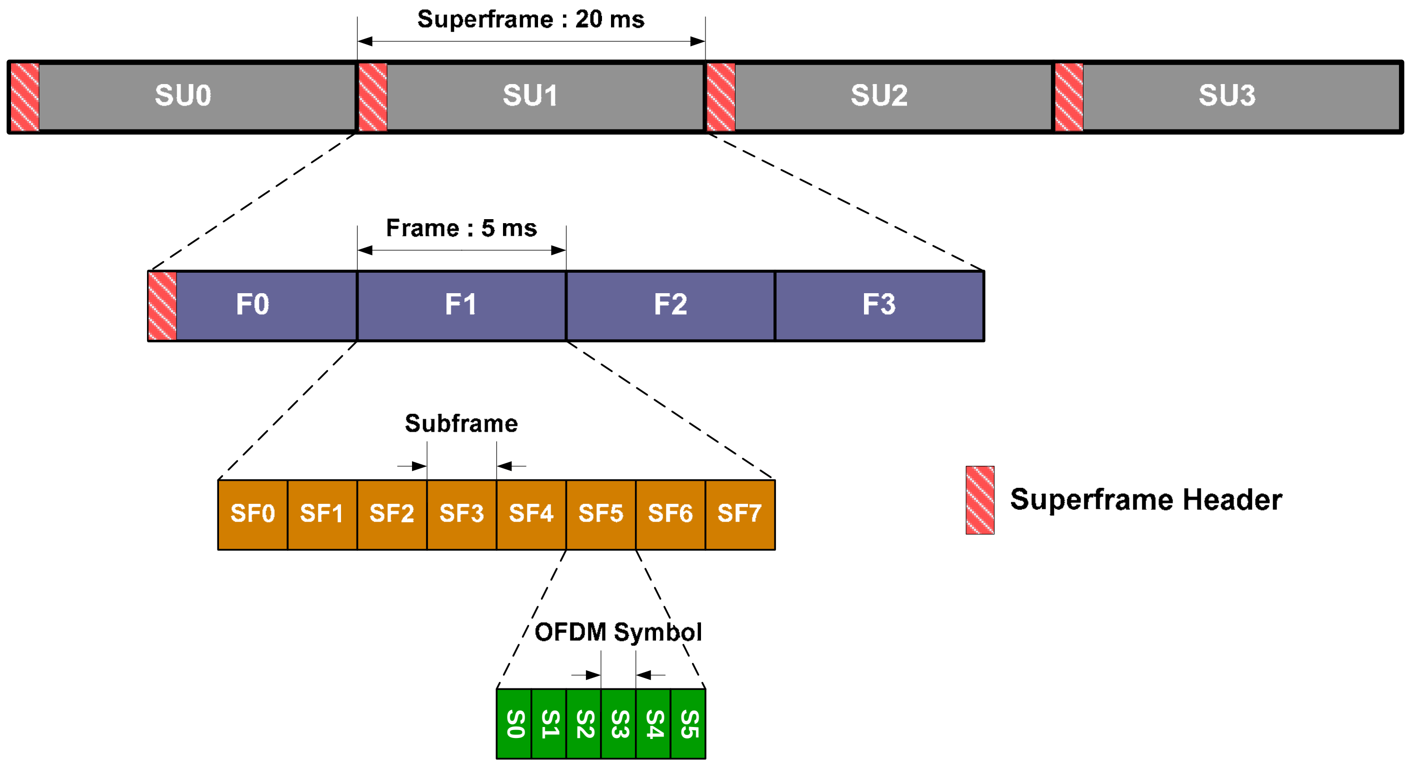

Figure 16 Basic frame structure

11.4.1.1 Frame Structure for CP=1/8 T_u

Figure 17 illustrates an example TDD frame structure with DL to UL ratio of 5:3. Assuming OFDMA symbol duration of 102.857µs and a CP length of 1/8 T_u, the length of type-1 subframe is 0.617 ms. In Figure 17, the last DL subframe, i.e., DL SF4, is a type-1 short subframe whose last OFDMA symbol is an idle symbol to accommodate the gap required to switch from DL to UL. Other numerologies may result in different number of subframes per frame and symbols within the subframes. Figure 18 shows an example of a frame structure in FDD mode.

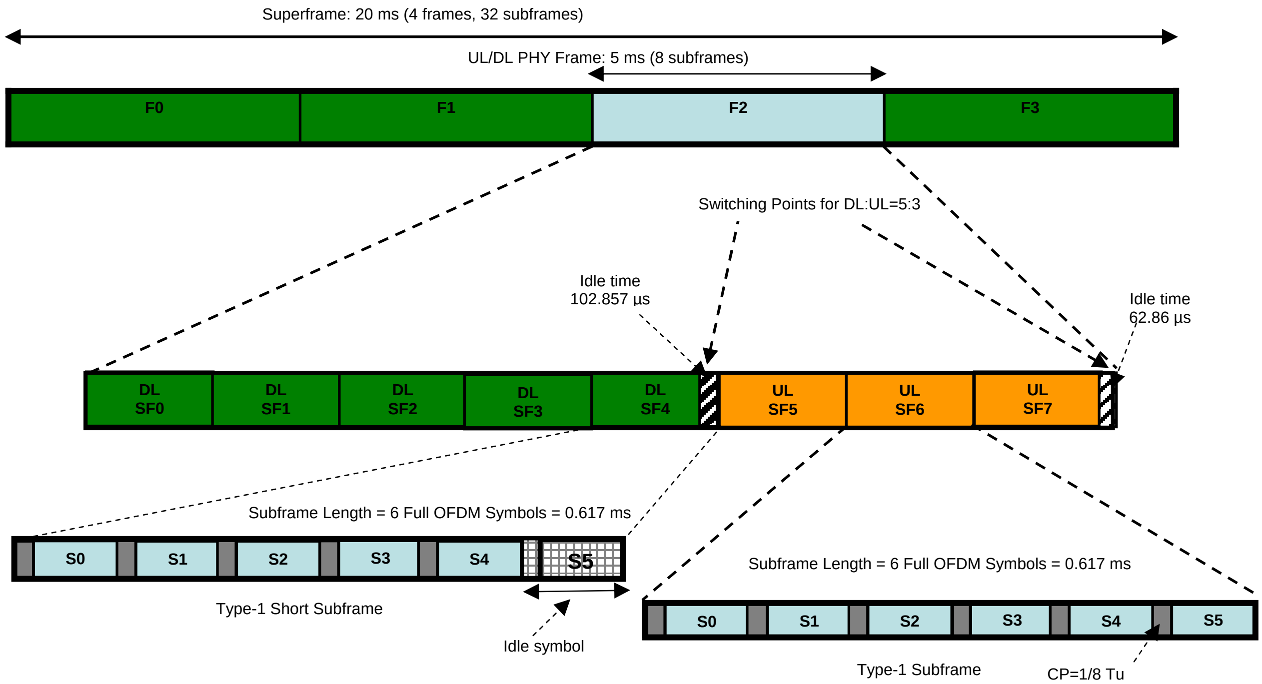

Figure 17 Frame structure with type-1 subframe in TDD duplex mode (CP=1/8 T_u)

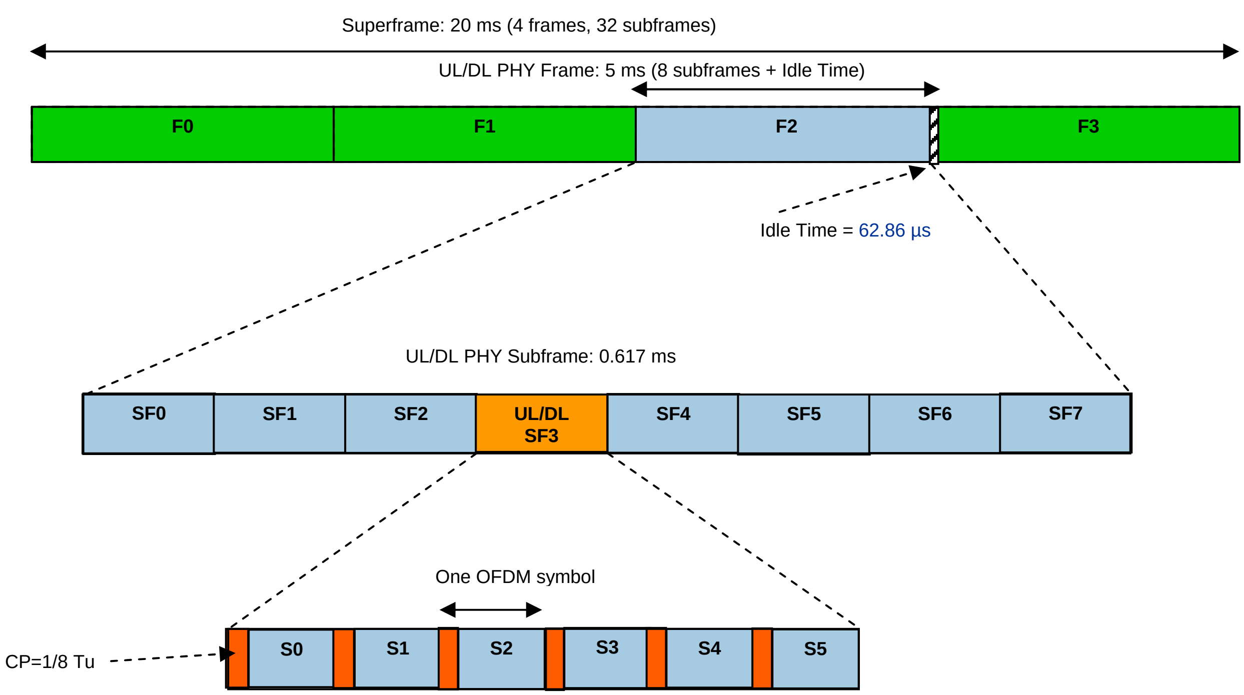

Figure 18 Frame structure with type-1 subframe in FDD duplex mode (CP=1/8 T_u)

11.4.1.2 Frame Structure for CP=1/16 T_u

Figure 19 illustrates an example of TDD and FDD frame structure with a CP of 1/16 T_u. Assuming OFDMA symbol duration of 97.143 µs and a CP length of 1/16 T_u, the length of type-1 and type-2 subframes are 0.583 ms and 0.680 ms, respectively. Other numerologies may result in different number of subframes per frame and symbols within the subframes.

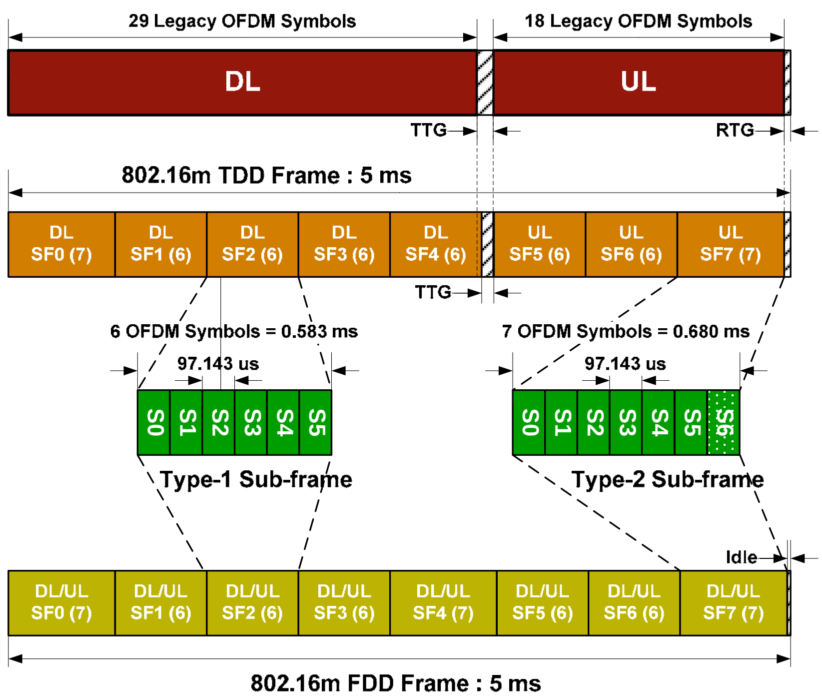

Figure 19 TDD and FDD Frame Structure with a CP of 1/16 T_u (DL to UL ratio of 5:3)

11.4.1.3 Superframe Header

As shown in Figure 16, each superframe begins with a DL subframe that contains a superframe header.

11.4.1.4 Transmission Time Interval

The transmission time interval (TTI) is the duration of the transmission of the physical layer encoded packet over the radio air interface and is equal to an integer number of subframes, default one subframe. The default TTI is 1 subframe.

11.4.2 Frame Structure Supporting Legacy Frames

The legacy and IEEE 802.16m frames are offset by a fixed number of subframes to accommodate new features such as the IEEE 802.16m synchronization channel (preamble), broadcast channel (system configuration information), and control channels, as shown in Figure 20. The FRAME_OFFSET shown in Figure 20 is for illustration. It is an offset between the start of the legacy frame and the start of the IEEE 802.16m frame carrying the superframe header, defined in a unit of subframes. In the case where IEEE 802.16m BSs coexist with legacy BSs, two switching points shall be selected in each TDD radio frame.

For UL transmissions both TDM and FDM approaches are supported for multiplexing of legacy and IEEE 802.16m mobiles.

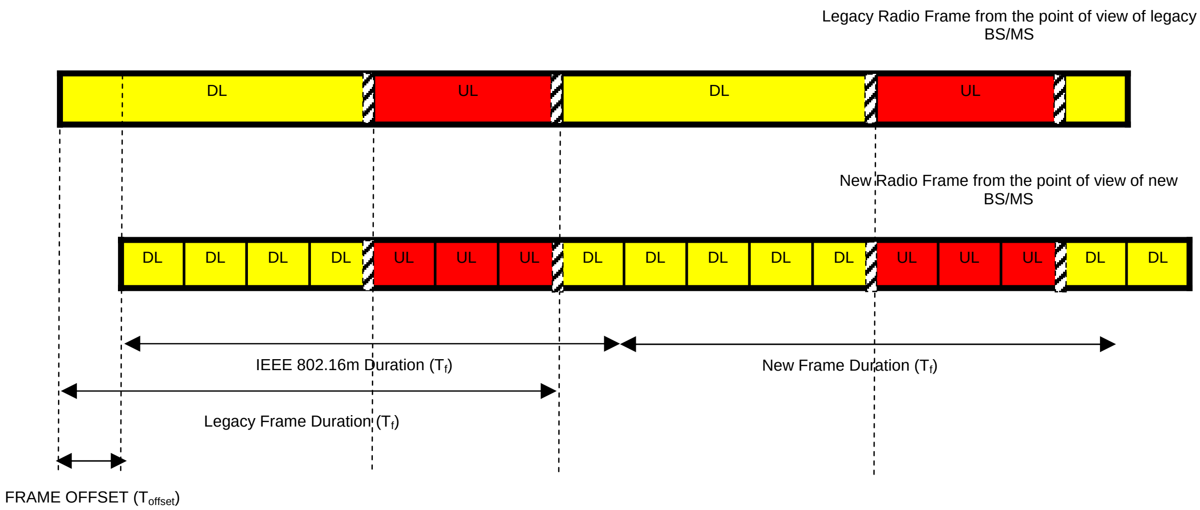

Figure 20 Relative position of the IEEE 802.16m and IEEE 802.16e radio frames (example TDD duplex mode)

11.4.2.1 The Concept of Time Zones

The time zone is defined as an integer number (greater than 0) of consecutive subframes. The concept of time zones is introduced that is equally applied to TDD and FDD systems. The IEEE 802.16m and IEEE 802.16e time zones are time-multiplexed (TDM) across time domain for the downlink. For UL transmissions both TDM and FDM approaches are supported for multiplexing of IEEE 802.16e and IEEE 802.16m terminals. Note that DL/UL traffic for the IEEE 802.16m MS can be scheduled in both zones whereas the DL/UL traffic for the IEEE 802.16e MS can only be scheduled in the IEEE 802.16e zones.

In the absence of any IEEE 802.16e system, the IEEE 802.16e zones will disappear and the entire frame will be allocated to the IEEE 802.16m zones and thereby new systems.

11.4.2.1.1 Time Zones in TDD

In a mixed deployment of IEEE 802.16e terminals and new IEEE 802.16m terminals, the allocation of time zones in the TDD mode is as shown in Figure 21 and Figure 22, which are examples for the two and four switching point case respectively. The duration of the zones may vary. Every frame shall start with a preamble and the MAP followed by IEEE 802.16e DL zone since IEEE 802.16e terminals/relays expect IEEE 802.16e zones in this region. Similarly, in a mixed deployment of IEEE 802.16e terminals and new IEEE 802.16m terminals, the UL portion shall start with IEEE 802.16e UL zone since IEEE 802.16e BS/terminals/relays expect IEEE 802.16e UL control information be sent in this region. Here the coexistence is defined as a deployment where IEEE 802.16e and IEEE 802.16m BSs co-exist on the same frequency band and in the same or neighboring geographical areas and in this case, four switching points should not be used. In a green-field deployment where no IEEE 802.16e terminal exists, the IEEE 802.16e zones can be removed.

Switching points should be synchronized across network to reduce inter-cell interference.

The switching points would require use of idle symbols to accommodate the gaps. In case of TDD operation with the generic frame structure, the last symbol in the slot immediately preceding a downlink-to-uplink/uplink-to-downlink switching point may be reserved for guard time and consequently not transmitted.

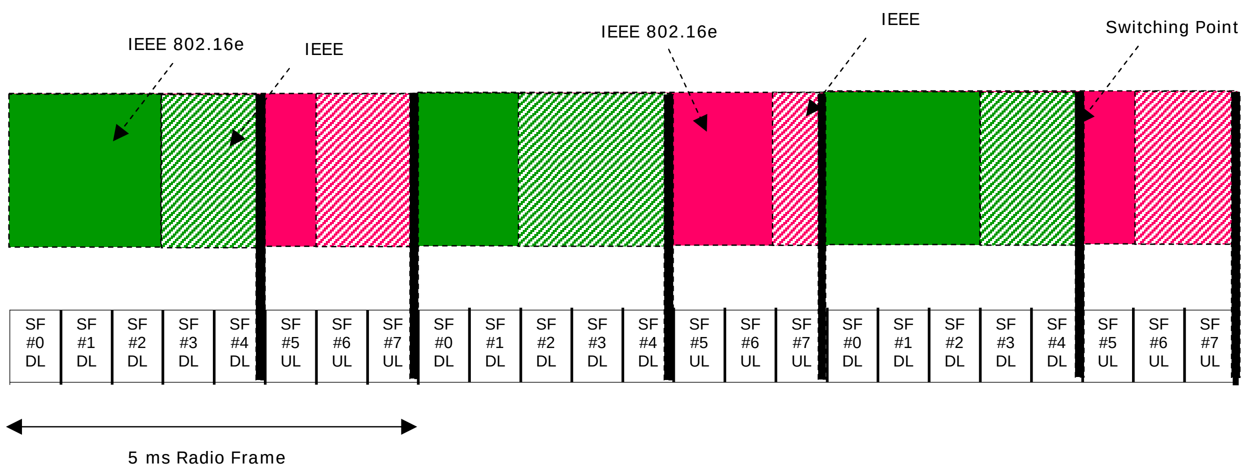

Figure 21 Example of Time zones in TDD mode

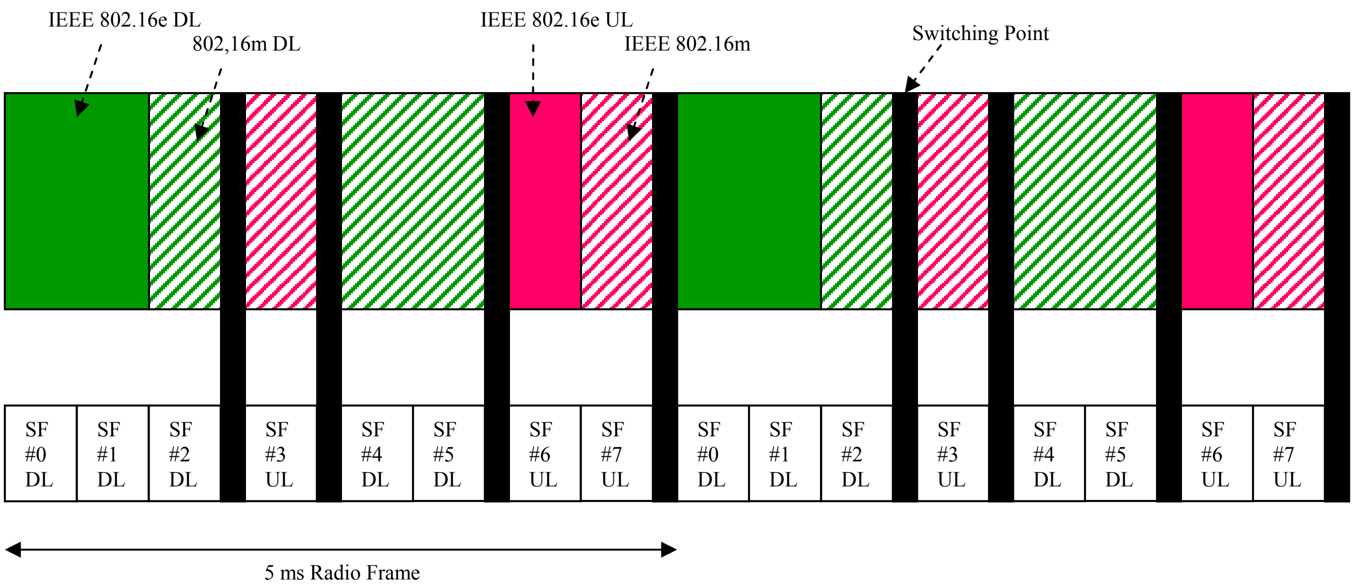

Figure 22 Example of Time zones in a TDD system with four switching points per radio frame.

11.4.2.1.2 Time Zones in FDD

In a mixed deployment of legacy terminals and new IEEE 802.16m terminals, an example of the allocation of time zones in the FDD mode is shown in Figure 23.

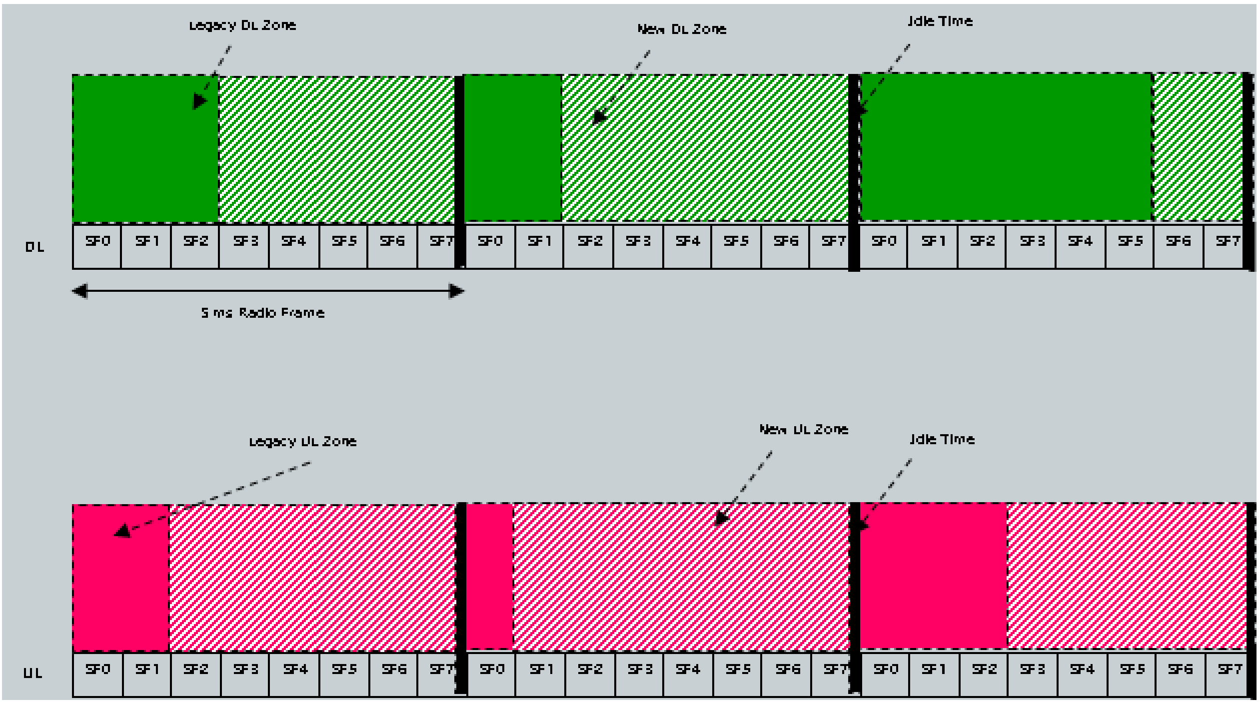

Figure 23 Example of Time zones in FDD mode

11.4.3 Frame Structure Supporting Legacy Frames in IEEE 802.16m Systems with Wider Channel Bandwidths

Figure 24 shows an example for the IEEE 802.16m frame structure supporting legacy frame in a wider channel. A number of narrow bandwidth carriers of the IEEE 802.16m can be aggregated to support wide bandwidth operation of IEEE 802.16m MSs. One or multiple of the narrowband carriers can be designated as the legacy carrier(s). When the center carrier spacing between two adjacent carriers is an integer multiple of subcarrier spacing, there is no necessity to reserve guard subcarriers for the IEEE 802.16m carriers. Different number of usable guard sub-carriers can be allocated on both sides of the carrier.

For UL transmissions both TDM and FDM approaches should be supported for multiplexing of legacy and IEEE 802.16m MSs in the legacy and IEEE 802.16m mixed carrier. The TDM in the figure is only for example.

In the case when the edge carrier is a legacy carrier, the impact of the small guard bandwidth on the edge of the wider channel on the filter requirements is FFS.

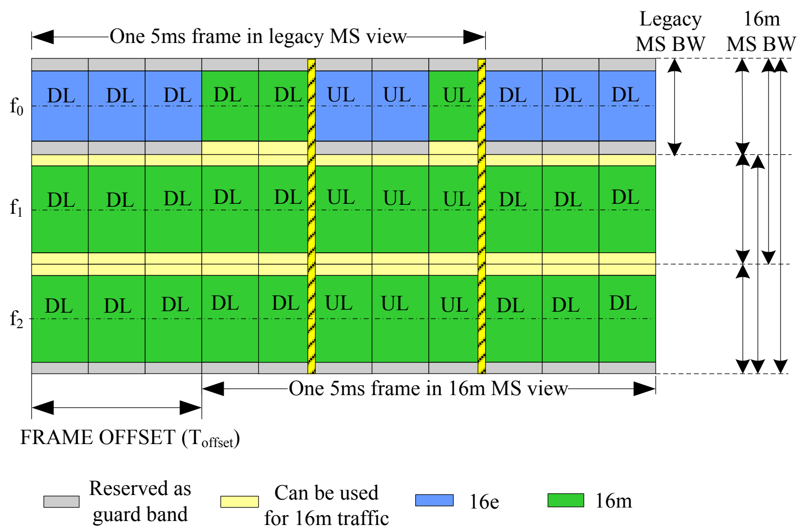

Figure 24 Illustration of frame structure supporting legacy frames with a wider channel

11.4.4 Relay Support in Frame Structure

A IEEE 802.16m BS that supports IEEE 802.16m relay stations shall communicate with the IEEE 802.16m RS in the IEEE 802.16m zone. The IEEE 802.16m BS shall multiplex the legacy zone and the IEEE 802.16m zone using TDM in the DL. In the UL, the IEEE 802.16m BS can support TDM as well as FDM for multiplexing legacy zone and the IEEE 802.16m zone. The IEEE 802.16m specification shall not alter the legacy zone operation. The access link and the relay link communications in the legacy zone shall be multiplexed in accordance with the IEEE 802.16j specifications.

A IEEE 802.16m RS shall communicate with the 16e MS in the "legacy zone".

The start of the legacy zone and IEEE 802.16m zone of the BS and all the subordinate RSs associated with the BS shall be time aligned. The duration of the legacy zone of the BS and the RS may be different.

- Legacy Zone
  - where IEEE 802.16m BS communicates with 16j RS or 16e MS, and where IEEE 802.16m RS communicates with a 16e MS.
- 16e Access Zone
  - where IEEE 802.16m BS, a 16j RS or a IEEE 802.16m RS communicates with a 16e MS.
- 16j Relay Zone
  - where IEEE 802.16m BS communicates with a 16j RS.
- IEEE 802.16m Zone
  - where IEEE 802.16m BS communicates with IEEE 802.16m RS or IEEE 802.16m MS, and where IEEE 802.16m RS communicates with other IEEE 802.16m entities (i.e. IEEE 802.16m BS, IEEE 802.16m RS or 16mMS).

There are two options for the Relay frame structure. These are captured in Figure 25 and Figure 26. Further study is required to distill a single frame structure from among these two options.

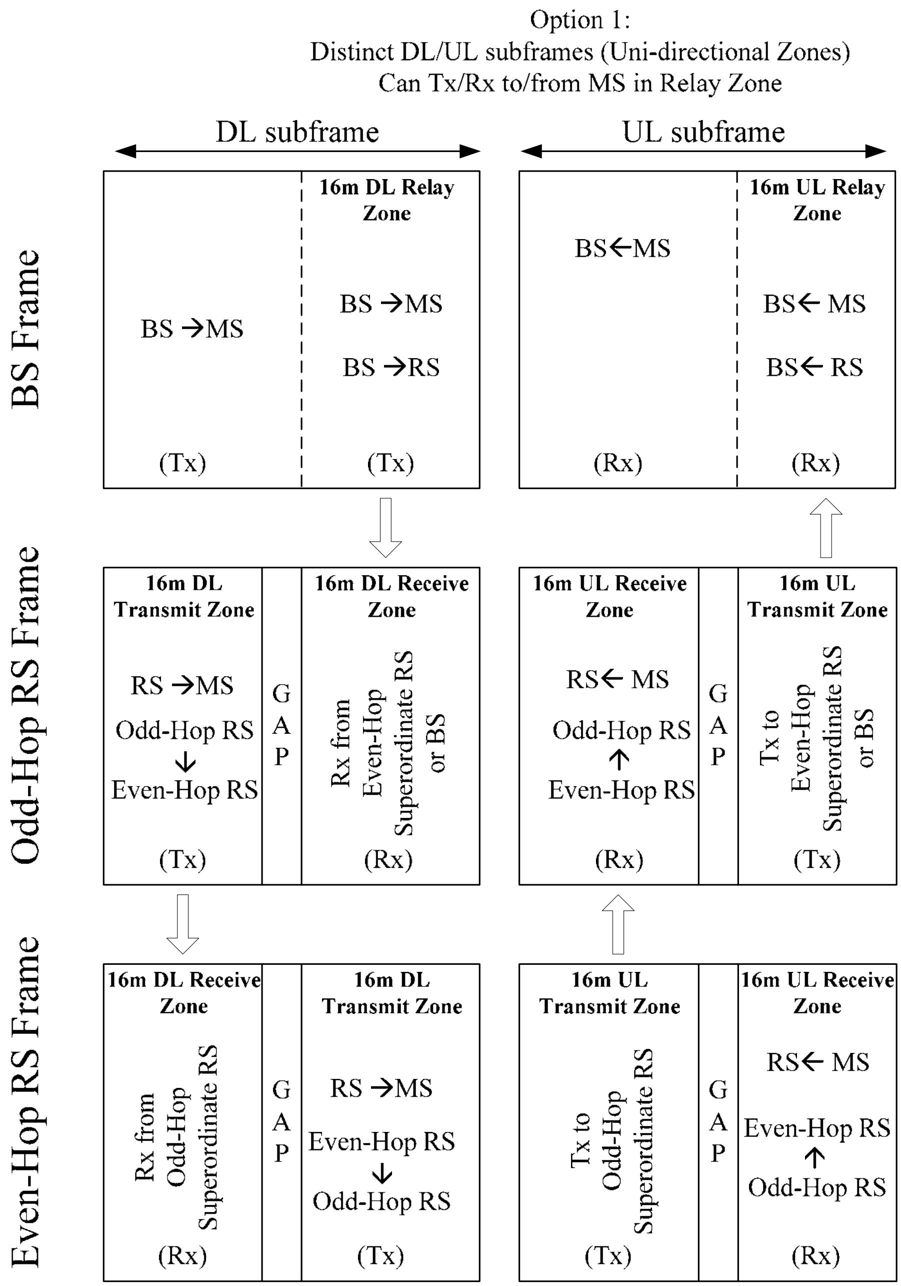

Figure 25 ***Relay Frame structure option 1***

Definitions corresponding to Option 1 shown in Figure 25

- 16m DL Access Zone: An integer multiple of subframes located in the 16m zone of the BS frame, where a 16m BS can transmit to the 16m MSs.
- 16m UL Access Zone: An integer multiple of subframes located in the 16m zone of the BS frame, where a 16m BS can receive from the 16m MSs.
- DL Relay Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the DL of the BS frame, where a IEEE 802.16m BS can transmit to the IEEE 802.16m RSs and the IEEE 802.16m

MSs.

- UL Relay Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the UL of the IEEE 802.16m BS frame, where a IEEE 802.16m BS can receive from the IEEE 802.16m RSs and the IEEE 802.16m MSs.
- DL Transmit Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the DL of the IEEE 802.16m RS frame, where a IEEE 802.16m RS can transmit to subordinate IEEE 802.16m RSs and the IEEE 802.16m MSs.
- DL Receive Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the DL of the IEEE 802.16m RS frame, where a IEEE 802.16m RS can receive from its superordinate station.
- UL Transmit Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the UL of the IEEE 802.16m RS frame, where a IEEE 802.16m RS can transmit to its superordinate station.
- UL Receive Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the UL of the IEEE 802.16m RS frame, , where a IEEE 802.16m RS can receive from its subordinate IEEE 802.16m RSs and the IEEE 802.16m MSs.

Option 2:
Bi-Directional Zones
Distinct DL/UL Access Zone

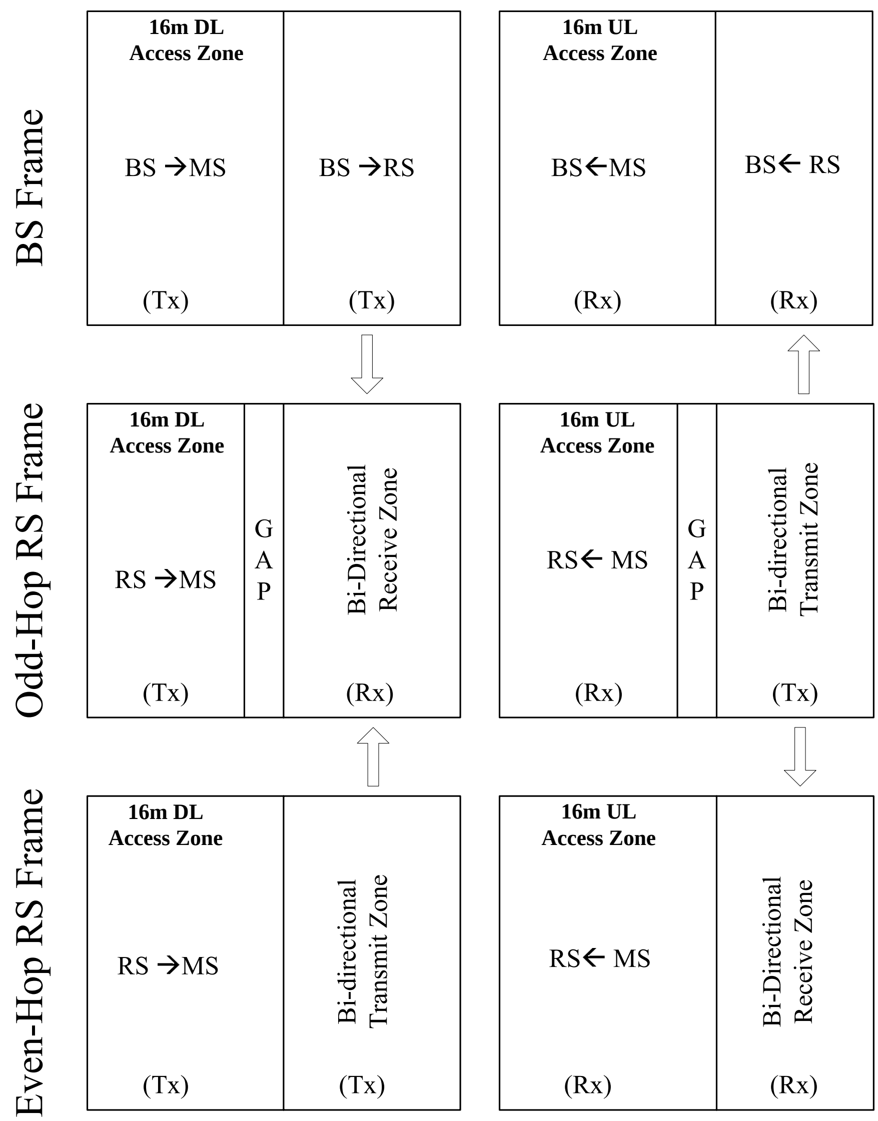

Figure 26 ***Relay Frame structure option 2***

Notes related to Figure 26: An explicit access zone may or may not be present.

Definitions corresponding to Option 2 shown in Figure 26

- Bi-directional Transmit Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the RS frame where transmission to superordinate as well as subordinate station takes place.
- Bi-directional Receive Zone: An integer multiple of subframes located in the IEEE 802.16m zone of the RS frame where reception from superordinate as well as subordinate station takes place.
- IEEE 802.16m DL Access Zone: An integer multiple of subframes in the IEEE 802.16m zone where IEEE 802.16m BS or a IEEE 802.16m RS transmits to the IEEE 802.16m MSs.

- IEEE 802.16m UL Access Zone: An integer multiple of subframes in the IEEE 802.16m zone where BS or an RS receives from the MSs.

11.4.5 Coexistence Support in Frame Structure

IEEE 802.16m downlink radio frame shall be time aligned with reference timing signal as defined in section 21.1 and should support symbol puncturing to minimize the inter-system interference.

11.4.5.1 Adjacent Channel Coexistence with E-UTRA (LTE-TDD)

Coexistence between IEEE 802.16m and E-UTRA in TDD mode may be facilitated by inserting either idle symbols within the IEEE 802.16m frame or idle subframes, for certain E-UTRA TDD configurations. An operator configurable delay or offset between the beginning of an IEEE 802.16m frame and an E-UTRA TDD frame can be applied in some configurations to minimize allows the time allocated to idle symbols or idle subframes to be minimized.IEEE 802.16mIEEE 802.16m Figure 27 shows two examples using frame offset to support coexistence with E-UTRA TDD in order to support minimization of the number of punctured symbols within the IEEE 802.16m frame.

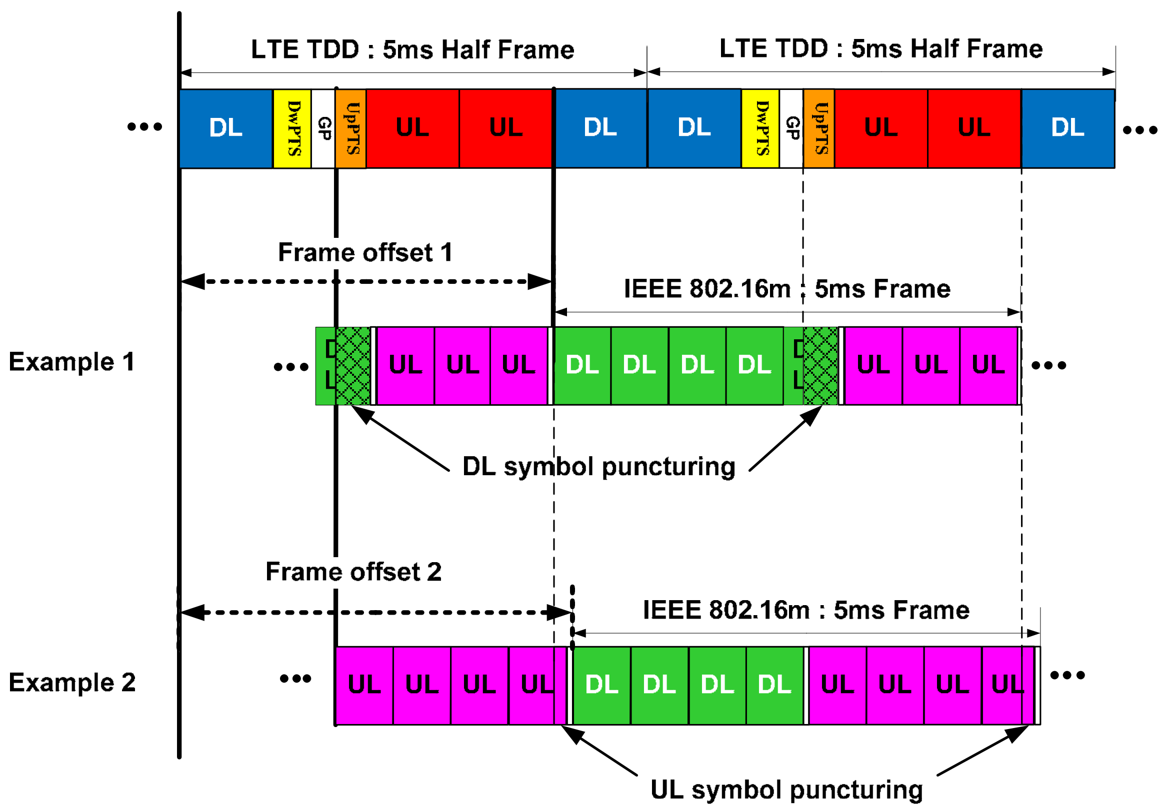

Figure 27 Alignment of IEEE 802.16m frame and E-UTRA frame in TDD mode

11.4.5.2 Adjacent Channel Coexistence with UTRA LCR-TDD (TD-SCDMA)

Coexistence between IEEE 802.16m and UTRA LCR-TDD may be facilitated by inserting either idle symbols within the IEEE 802.16m frame or idle subframes. An operator configurable delay or offset between the beginning of an IEEE 802.16m frame and an UTRA LCR-TDD frame can be applied in some configurations to minimize allows the time allocated to idle symbols or idle subframes to be minimized.IEEE 802.16mIEEE 802.16m Figure 28 demonstrates how coexistence between IEEEIEEE 802.16m and UTRA LCR-TDD can be achieved to minimize the inter-system interference.

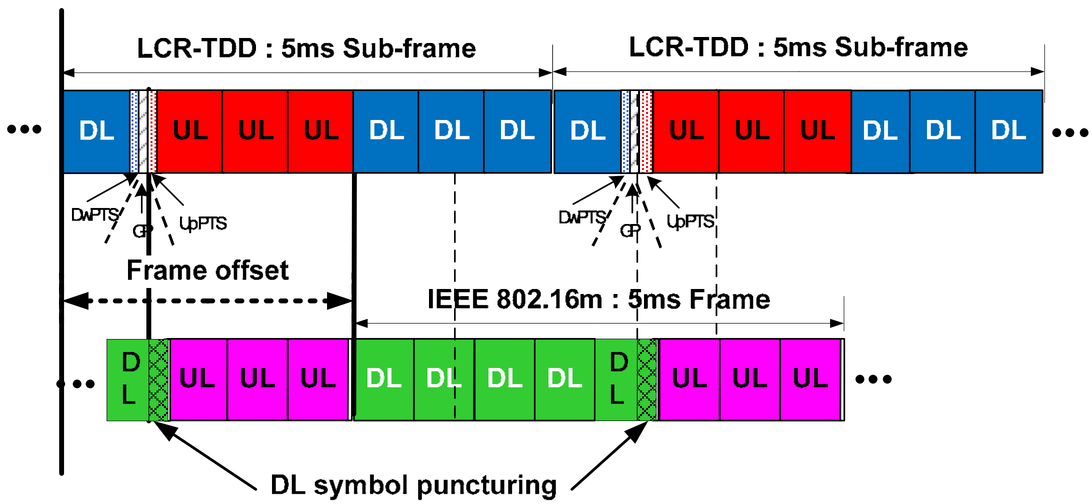

Figure 28 Alignment of IEEE 802.16m frame with UTRA LCR-TDD frame in TDD mode

11.4.6 Frame Structure to support multi-carrier operation

The support for multiple RF carriers can be accommodated with the same frame structure used for single carrier support, however, some considerations in the design of protocol and channel structure may be needed to efficiently support this feature.

In general, each MS operating under IEEE 802.16m standard is controlled by one RF carrier, herein referred to as the primary RF carrier. When multi-carrier operation feature is supported, the system may define and utilize additional RF carriers to improve the user experience and QoS, or provide services through additional RF carriers configured or optimized for specific services.

Figure 29 shows that the same frame structure would be applicable to both single carrier and multicarrier mode of operation. A number of narrow BW carriers can be aggregated to support effectively wider BW operation. Each carrier may have its own synchronization channel and superframe header. Further, some carriers may have only part of superframe header.

The multiple carriers involved in multi-carrier operation may be in a contiguous or non-contiguous spectrum. When carriers are in the same spectrum and adjacent and when the separation of center frequency between two adjacent carriers is multiples of subcarrier spacing, no guard subcarriers are necessary between adjacent carriers.

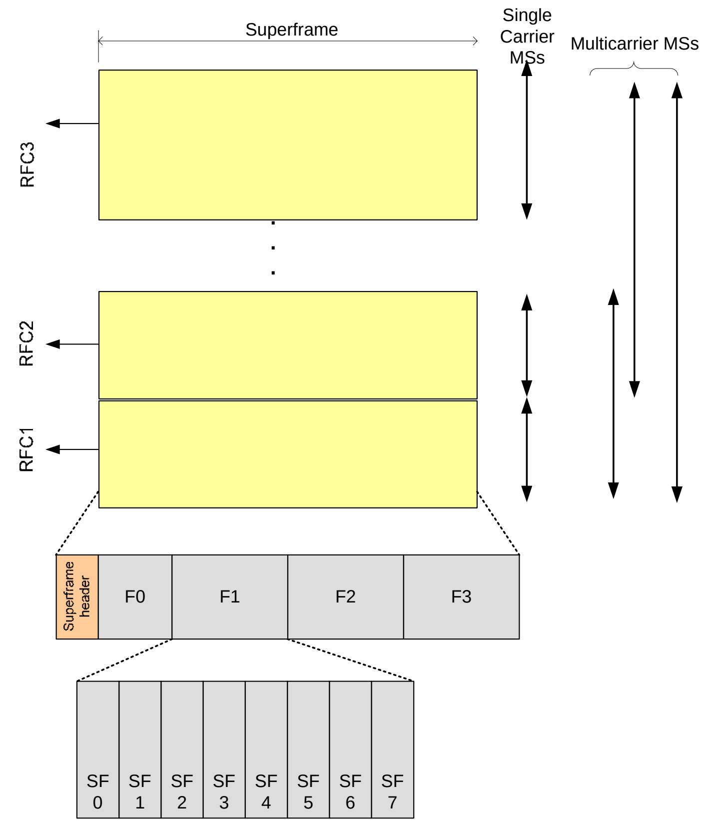

Figure 29 Example of the proposed frame structure to support multi-carrier operation

11.5 Downlink Physical Structure

Each downlink subframe is divided into a number of frequency partitions, where each partition consists of a set of physical resource units across the total number of OFDMA symbols available in the subframe. Each frequency partition can include contiguous (localized) and/or non-contiguous (distributed) physical resource units. Each frequency partition can be used for different purposes such as fractional frequency reuse (FFR) or multicast and broadcast services (MBS). Figure 30 illustrates the downlink physical structure in the example of two frequency partitions with frequency partition 2 including both localized and distributed resource allocations.

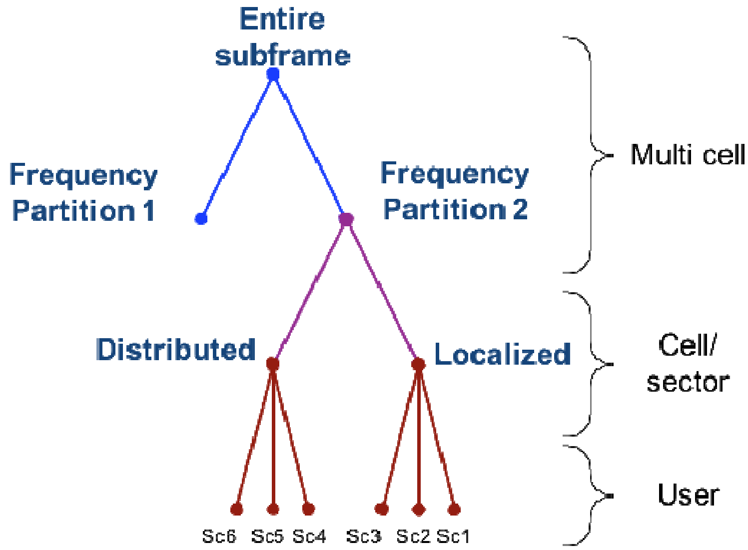

Figure 30 **Hierarchical representation of the downlink physical structure**

11.5.1 Physical and Logical Resource Unit

A physical resource unit (PRU) is the basic physical unit for resource allocation that comprises P_{sc} consecutive subcarriers by N_{sym} consecutive OFDMA symbols. P_{sc} is 18 subcarriers and N_{sym} is 6 OFDMA symbols for type-1 subframes, and N_{sym} is 7 OFDM symbols for type-2 sub frames. A logical resource unit (LRU) is the basic logical unit for distributed and localized resource allocations. A LRU is P_{sc}*N_{sym} subcarriers for type-1 subframes and type-2 subframes. Note that the LRU includes the pilots that are used in a PRU. So, the effective number of subcarriers in an LRU depends on the number of allocated pilots.

11.5.1.1 Distributed resource unit

The logical distributed resource unit (LDRU) can be used to achieve frequency diversity gain. The LDRU contains a group of subcarriers which are spread across the distributed resource allocations within a frequency partition. The size of the LDRU equals the size of PRU, i.e., P_{sc} subcarriers by N_{sym} OFDMA symbols. The minimum unit for forming the LDRU is equal to one subcarrier.

11.5.1.2 Localized resource unit

The logical localized resource unit (LLRU) can be used to achieve frequency-selective scheduling gain. The LLRU contains a group of subcarriers which are contiguous across the localized resource allocations. The size of the LLRU equals the size of the PRU, i.e., P_{sc} subcarriers by N_{sym} OFDMA symbols.

11.5.2 Subchannelization and Resource mapping

11.5.2.1 Basic Symbol Structure

The subcarriers of an OFDMA symbol are partitioned into $N_{g,left}$ left guard subcarriers, $N_{g,right}$ right guard subcarriers, and N_{used} used subcarriers. The DC subcarrier is not loaded. The N_{used} subcarriers are divided into PRUs. Each PRU contains pilot and data subcarriers. The number of used pilot and data subcarriers depends on MIMO mode, rank and number of multiplexed MS as well as the type of the subframe, i.e., type-1 or type-2.

11.5.2.2 Downlink subcarrier to resource unit mapping

The DL subcarrier to resource unit mapping process is defined as follows and illustrated in the Figure 31:

1. First-level or outer permutation is applied to the PRUs in the units of N1 and N2 PRUs, where N1=4 (TBD) and N2 =1 or 2 depending on system bandwidth (TBD). Direct mapping of outer permutation can be supported only for LLRU.
2. Distributing (TBD) the reordered PRUs into frequency partitions.
3. The frequency partition is divided into localized(LLRU) and/or distributed(LDRU) resources for each resource group. Sector specific permutation can be supported and direct mapping of the resources can be supported for localized resources. The sizes of the distributed/localized resources are flexibly configured per sector (TBD). Adjacent sectors do not need to have same configuration of localized and distributed resources;
4. The localized and distributed groups are further mapped into LRUs (by direct mapping of LLRU and by “Subcarrier permutation” on DRUs) as shown in the following figure.

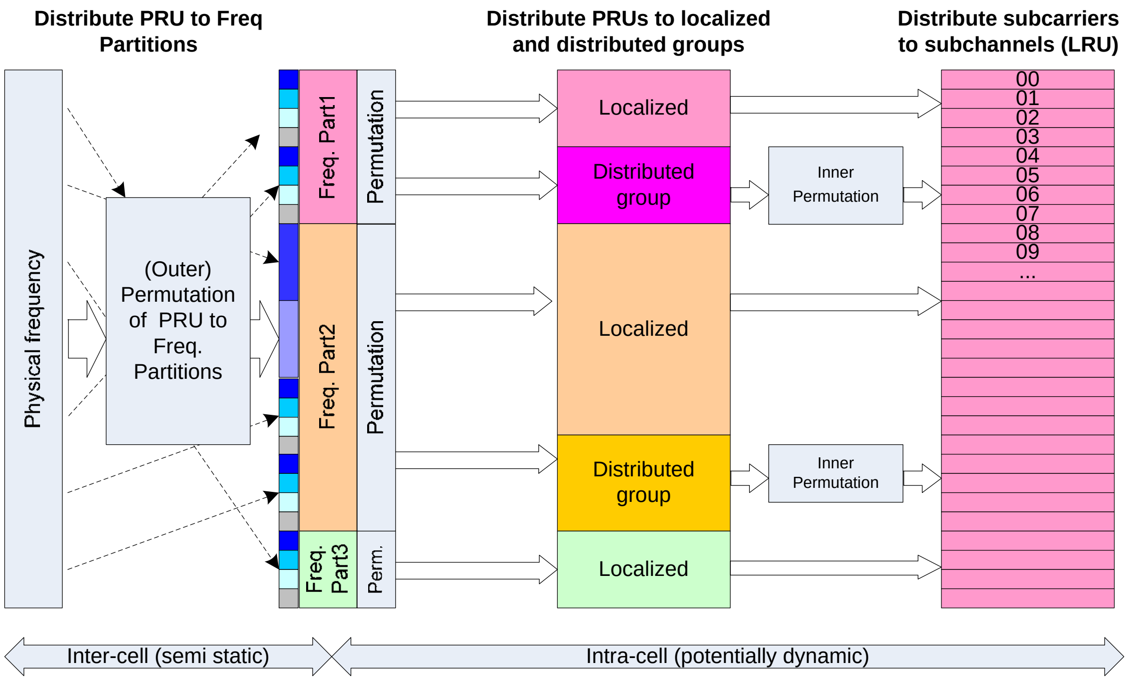

Figure 31 Illustration of the downlink subcarrier to resource unit mapping

11.5.2.3 Subchannelization for DL distributed resource

The inner permutation defined for the DL distributed resource allocations within a frequency partition spreads the subcarrriers of the LDRU across the whole distributed resource allocations . The granularity of the inner permutation is equal to the minimum unit for forming a LDRU according to 11.5.1.1.

Suppose that there are N_{RU} LRUs in a distributed group. A permutation sequence P (TBD) for the distributed group is provided. The subchannelization for DL distributed resource spreads the subcarriers of LRUs into the whole available bandwidth of distributed resource, as indicated in the following procedure:

- Let n_k denote the number of pilot tones in each OFDMA symbol within a PRU, and N_{RU} be the number of LRUs within the distributed resource .
- For each k-th OFDMA symbol in the subframe
  1. Allocate the n_k pilots in each OFDMA symbol within each PRU;
  2. Renumber the remaining N_{RU} * (P_{sc} - n_k) data subcarriers in order, from 0 to N_{RU} * (P_{sc} - n_k)-1 subcarriers. Apply the permutation sequence P (TBD) to form the permuted subcarriers 0 to N_{RU} * (P_{sc} - n_k)-1. The contiguous renumbered subcarriers are grouped into pairs/clusters before applying permutation, for example, to support Space Frequency Block Code (SFBC), renumbered subcarriers 0 to N_{RU} * (P_{sc} - n_k)-1 are first paired into (N_{RU} * (P_{sc} - n_k)-1)/2 clusters.
  3. Map each set of logically contiguous (P_{sc} - n_k) subcarriers into distributed LRUs (i.e. subchannels) and form a total of N_{RU} distributed LRUs.

11.5.2.4 Subchannelization for DL localized resource

There is no inner permutation defined for the DL localized resource allocations. The PRUs are directly mapped to LLRUs within each frequency partition defined in 11.5.

11.5.3 Pilot Structure

The transmission of pilot subcarriers in the downlink is necessary for enabling channel estimation, measurements of channel quality indicators such as the SINR, frequency offset estimation, etc. To optimize the system performance in different propagation environments and applications, IEEE 802.16m supports both common and dedicated pilot structures. The categorization in common and dedicated pilots is done with respect to their usage. The common pilots can be used by all MSs. Dedicated pilots can be used with both localized and distributed allocations. Pilot subcarrriers that can be used only by a group of MSs is a special case of common pilots and are termed shared pilots. The dedicated pilots are associated with a specific resource allocation, can be only used by the MSs allocated to said specific resource allocation, and therefore can be precoded or beamformed in the same way as the data subcarriers of the resource allocation. The pilot structure is defined for up to four transmission (Tx) streams and there is a unifiedpilot pattern design for common and dedicated pilots. There is equal pilot density per Tx stream, while there is not necessarily equal pilot density per OFDMA symbol of the downlink subframe. Further, there is equal number of pilots for each PRU of a data burst assigned to one MS.

The pilots can be used for channel estimation, measurements (CQI and interference mitigation/cancellation), frequency offset estimation and time offset estimation. Pilot patterns are proposed for efficiency and performance. Pattern A is used for 1 and 2 DL data streams dedicated and common pilot scenarios.

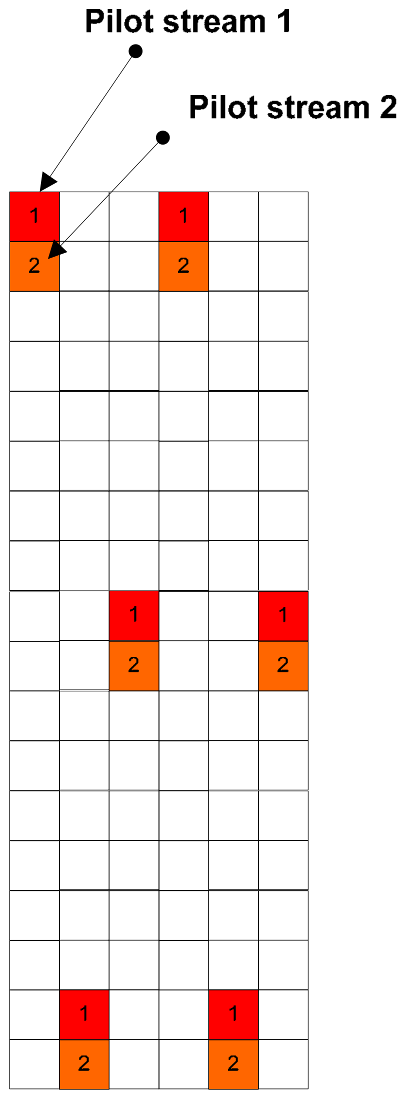

Figure 32 Pattern A for 1/2 pilot streams.

<u>For the subframe consisting of 5 or 7 OFDMA symbols, one of OFDMA symbols is deleted or added.</u>

The interlaced pilot patterns can be generated by cyclic shifting the base pilot pattern. The interlaced pilot patterns are shown in Figure 33 and can be optionally used by different BSs. The use of interlaced pilot pattern is FFS. Pattern B is used for 4 data streams DL dedicated and common pilot pattern.

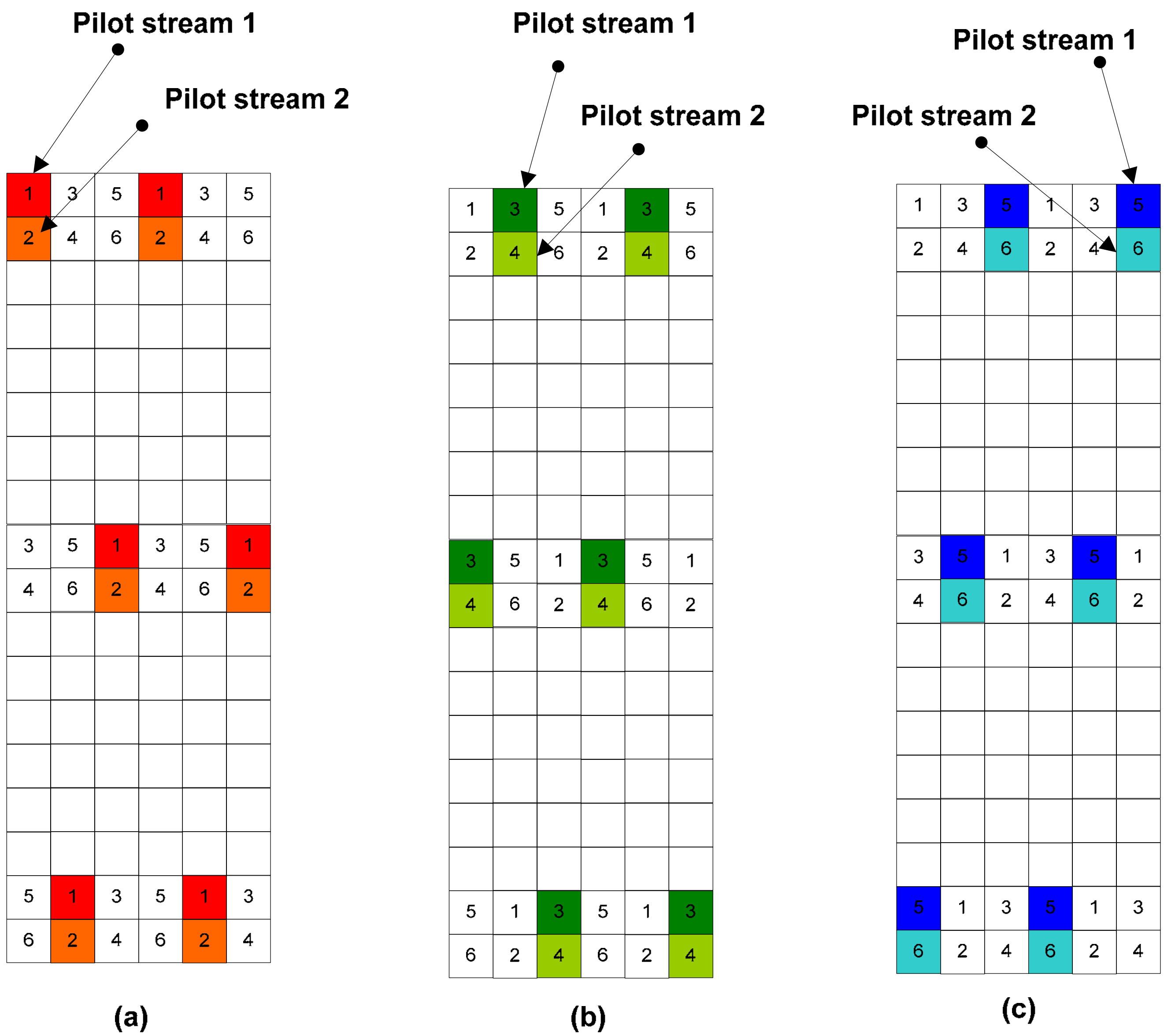

Figure 33 Interlaced Pattern A for 1/2 pilot streams.

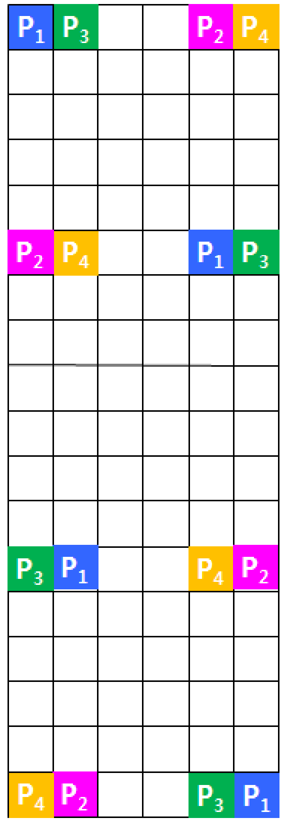

Figure 34 Pilot Pattern B for 4 stream pilots, pilot k denotes pilot for transmit antenna k.

For the subframe consisting of 5 OFDMA symbols, the third or fourth OFDMA symbol is deleted. For the subframe consisting of 7 OFDMA symbols, the third or fourth OFDMA symbol is added in the end of the subframe.

11.5.3.1 11.5.3.1 Common pilot structure

11.5.3.2 11.5.3.2 Dedicated pilot structure

11.6 Uplink Physical Structure

Each UL subframe is divided into a number of frequency partitions, where each partition consists of a set of physical resource units across the total number of OFDMA symbols available in the subframe. Each frequency partition can include contiguous (localized) and/or non-contiguous (distributed) physical resource units. Each frequency partition can be used for different purposes such as fractional frequency reuse (FFR). Figure 35 illustrates the uplink physical structure in the example of two FFR groups with FFR group 2 including both localized and distributed resource allocations.

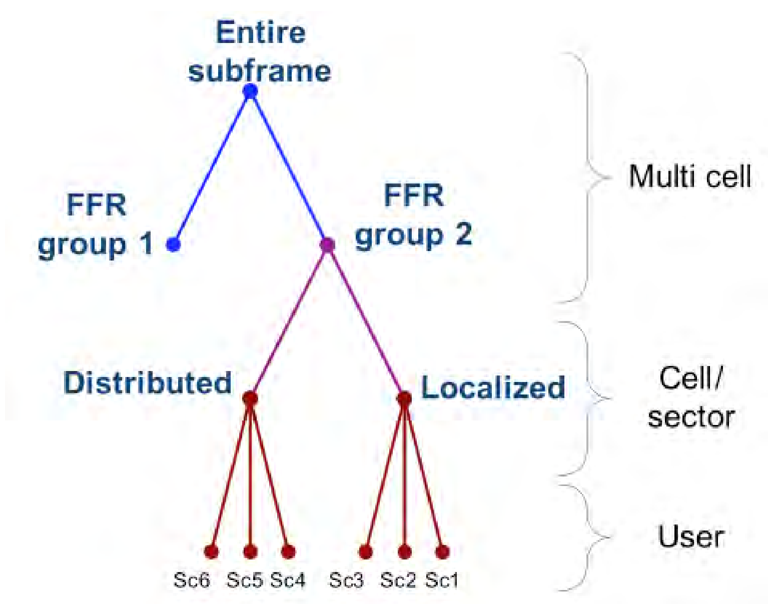

Figure 35 Example of uplink physical structure

11.6.1 Physical and Logical Resource Unit

A physical resource unit (PRU) is the basic physical unit for resource allocation that comprises Psc consecutive subcarriers by Nsym consecutive OFDMA symbols. Psc is 18 subcarriers and Nsym is the number of OFDMA symbols depending on the subframe type. A logical resource unit (LRU) is the basic logical unit for distributed and localized resource allocations and its size is Psc*Nsym subcarriers for data transmission. For control channel/message transmission, the size of LRU should be the same as that of data transmission and multiple users are allowed to share one control LRU. The LRU includes in its numerology the number of pilots that are used in a PRU, and may include control information. So, the effective number of data subcarriers in an LRU depends on the number of allocated pilots and control channel presence.

11.6.1.1 Distributed Resource unit

The distributed resource unit (LDRU) can be used to achieve frequency diversity gain. The LDRU contains a group of subcarriers which are spread across the distributed resource allocations. The size of the LDRU equals the size of the LRU for distributed allocations. The minimum unit for forming the LDRU is a tile. *T* different types of tiles are defined, where *T* is 1. The UL tile sizes are $6xN_{sym}$, where N_{sym} depends on the subframe type. 18x2 for UL transmit power optimized distributed allocation and other tile sizes are FFS. Details of the UL transmit power optimized distributed allocation are FFS.

11.6.1.2 Localized Resource unit

The logical localized resource unit (LLRU) can be used to achieve frequency-selective scheduling gain. The LLRU contains a group of subcarriers which are contiguous across the localized resource allocations. The size of the LLRU equals the size of the LRU for localized allocations, i.e., Psc subcarriers by Nsym OFDMA symbols.

11.6.2 Subchannelization and Resource mapping

11.6.2.1 Basic Symbol Structure

The subcarriers of an OFDMA symbol are partitioned into $N_{g,left}$ left guard subcarriers, $N_{g,right}$ right guard subcarriers, and N_{used} used subcarriers. The DC subcarrier is not loaded. The N_{used} subcarriers are divided into PRUs. Each PRU contains pilot and data subcarriers. The number of used pilot and data subcarriers depends on MIMO mode, rank and number of multiplexed MS and the type of resource allocation, i.e., distributed or localized resource allocations as well as the type of the subframe, i.e., type-1 or type-2.

11.6.2.2 Uplink Subcarrier to Resource Unit Mapping

The main features of resource mapping include:

1. Support of localized resource unit (LLRU) and distributed resource unit (LDRU) in an FDM manner.
2. DRUs comprise multiple tiles which are spread across the distributed resource allocations to get diversity gain.
3. FFR can be applied in UL.

Based on the main design concepts above, the UL subcarriers to resource unit mapping process is defined as follows and illustrated in Figure 36:

1. First-level or outer permutation is applied to the PRUs in the units of N1 and N2 PRUs, where N1=4 (TBD) and N2=1 (TBD). Direct mapping of outer permutation can be supported.
2. Distributing the reordered PRUs into frequency partitions.
3. The frequency partition is divided into localized (LLRU) and/or distributed (LDRU) resource allocations. Using sector specific permutation can be supported; directly mapping of the resources can be supported for localized resource. The sizes of the distributed/localized resources are flexibly configured per sector. Adjacent sectors do not need to have same configuration of localized and diversity resources.
4. The localized and distributed groups resources are further mapped into LRUs. For the LLRU resources, the mapping is direct. For the LDRU resources, a tile or hopping permutation is carried out for permuting or hopping the tiles of the distributed groups.

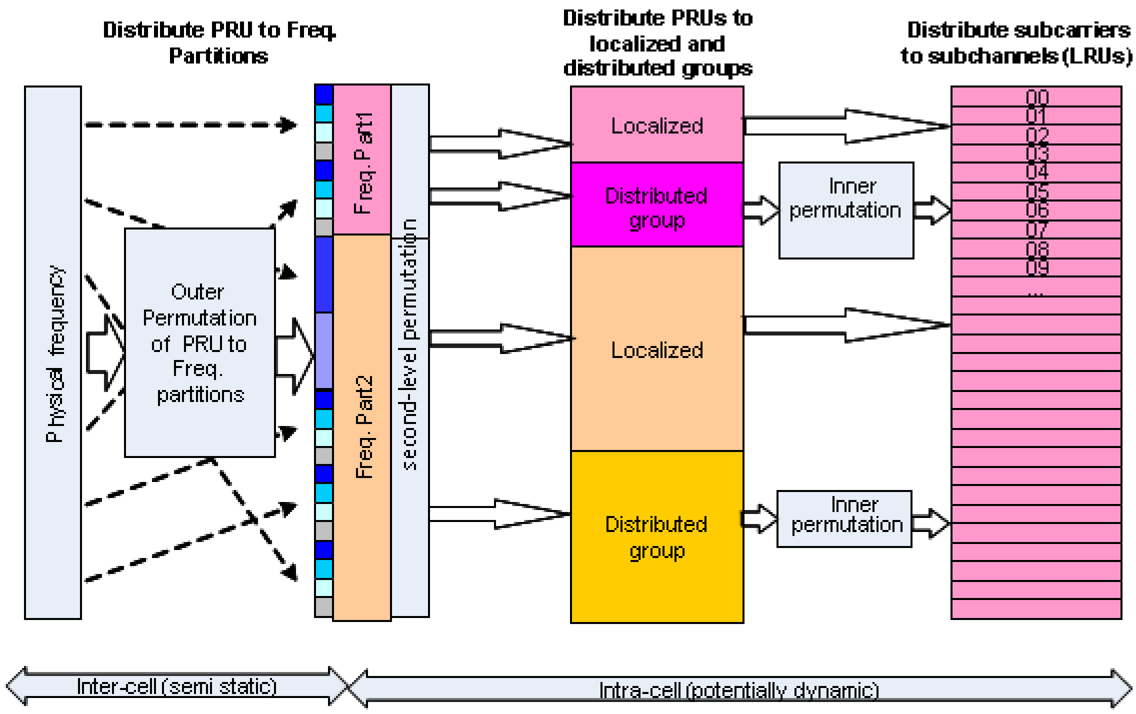

Figure 36 Illustration of the uplink subcarrier to resource unit mapping

11.6.2.3 Subchannelization for UL Distributed Resource

An inner permutation permutes PRUs within a frequency partition. The localized resource could be directly mapped. The tile permutation defined for the uplink distributed resource allocations spreads the tiles of the LDRU across the whole allocated distributed resource allocations frequency band.

Two kinds of distributed resource allocation are used for UL distributed subchannelization, (1) regular distributed allocation (2) UL transmit power optimized distributed allocation. The UL transmit power optimized distributed resource is allocated first. The rest of the frequency resource is then allocated for regular distributed allocation. A hopping/permutation sequence (TBD) is defined for the power optimized allocation that spreads the hopping units across frequency. The second-level or inner permutation defined for the UL regular distributed resource allocations spreads the tiles of the LDRU across the frequency band. The granularity of the inner permutation is equal to the tile size for forming a LDRU according to section 11.6.1.1.

11.6.2.4 Subchannelization for UL Localized Resource

Localized subchannels contain subcarriers which are contiguous in frequency. There is no inner permutation defined for the UL localized resource allocations. The LLRU is directly mapped to localized LRU within each frequency partition. Precoding and/or boosting applied to the data subcarriers will also be applied to the pilot subcarriers.

11.6.3 Pilot Structure

The transmission of pilot subcarriers in the uplink is necessary for enabling channel estimation, measurement of channel quality indicators such as SINR, frequency offset and timing offset estimation, etc. The uplink pilots are dedicated to localized and distributed resource units and are precoded using the same precoding as the data subcarriers of the resource allocation. The pilot structure is defined for up to 4 Tx streams with orthogonal patterns.

The pilot pattern may support variable pilot boosting. When pilots are boosted, each data subcarrier should have the same Tx power across all OFDM symbols in a resource block. The boosting values are TBD.

The DL 18x6 pilot patterns defined in Section 11.5.3 are used for UL 18x6 pilots, which include pilots up to 4 TX streams.

For 6-by-6 UL tile, the UL pilot pattern for DRU is shown in Figure 37

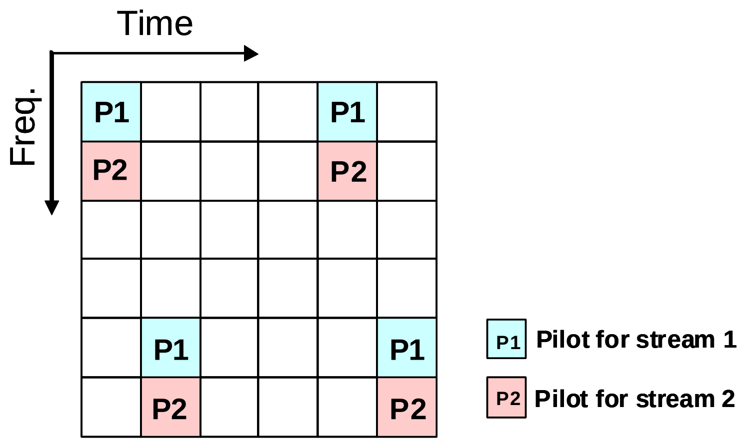

Figure 37 UL DRU tile structure.

11.6.4 Uplink Physical Structure for Legacy Support

The IEEE 802.16m uplink physical structure supports both FDM (frequency division multiplexing) and TDM (time division multiplexing) with the legacy system. When the legacy system operates in the PUSC mode, then the type of multiplexing is FDM or TDM. If the legacy system operates in the AMC mode, then the uplink resources for the legacy and the IEEE 802.16m system are multiplexed using FDM or TDM.
When the legacy system operates in the PUSC mode, a symbol structure according to 16m PUSC should be used in order to provide FDM-based legacy support.

11.6.4.1 Distributed Resource Unit for 16m PUSC

Unlike a DRU structure defined in 11.6.1.1, a DRU in 16m PUSC contains six tiles which size is 4xNsym where Nsym depends on the subframe type. Figure 38 shows a tile structure when a subframe has 6 symbols. Pilot pattern is TBD.

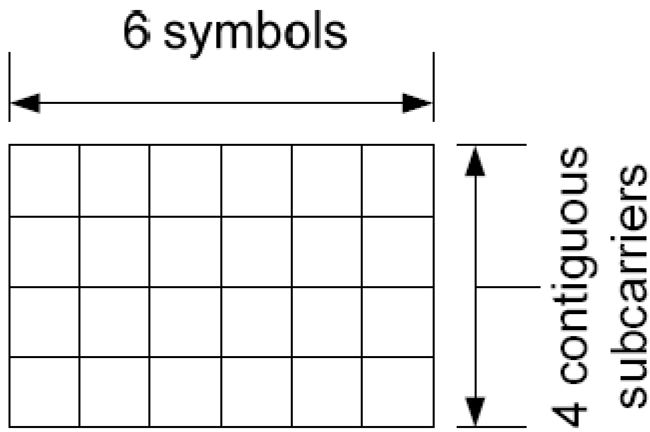

Figure 38 Tile structure in 16m PUSC

11.6.4.2 Subchannelization for 16m PUSC

A subchannelization for 16m PUSC is identical to legacy uplink PUSC [2]. For a given system bandwidth, total usable subcarriers are allocated to form tiles (four contiguous subcarriers) and every tiles are permuted according to permutation defined in uplink PUSC [2]. Once subchannelization is done, every subchannel is assigned to either legacy system or 16m system. Figure 39 shows the uplink frame which is divided in frequency domain into two logical region – one is for legacy PUSC subchannels and the other is for 16m PUSC DRUs.

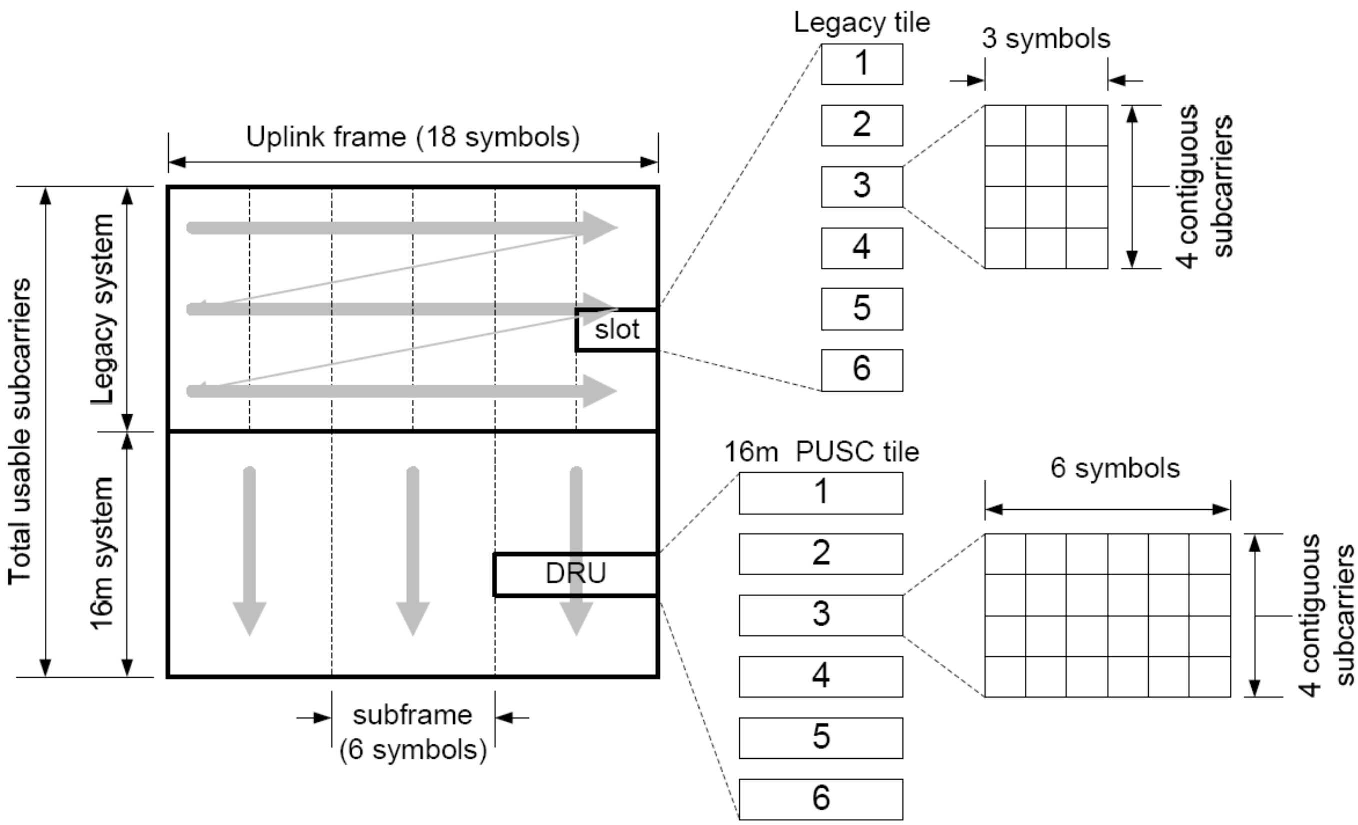

Figure 39 Subchannelization of 16m PUSC and DRU structure

11.7 DL Control Structure

DL control channels are needed to convey information essential for system operation. In order to reduce the overhead and network entry latency, and improve robustness of the DL control channel, information is transmitted hierarchically over different time scales from the superframe level to the subframe level. Broadly speaking, control information related to system parameters and system configuration is transmitted at the superframe level, while control and signaling related to traffic transmission and reception is transmitted at the frame/subframe level.

In mixed mode operation (legacy/IEEE 802.16m), an IEEE 802.16m MS can access the system without decoding legacy FCH and legacy MAP messages.

Details of the DL control structure are described in the following sections.

11.7.1 DL Control Information Classification

Information carried in the DL control channels is classified as follows.

11.7.1.1 Synchronization information

This type of control information is necessary for synchronization and system acquisition.

11.7.1.2 Essential system parameters and system configuration information

This includes a minimal set of time critical system configuration information and parameters needed for the mobile station (MS) to complete access in a power efficient manner, including the following three types:

11.7.1.2.1 Deployment-wide common information

Deployment-wide common information and parameters such as downlink/uplink system bandwidth, TDD downlink/uplink ratio, and number of switching points.

11.7.1.2.2 Downlink sector-specific information

Downlink sector-specific essential information and parameters to enable MS to further receive downlink extended broadcast information, control signaling and data. Examples of such information include antenna configuration, DL resource allocation configuration, pilot configuration.

11.7.1.2.3 Uplink sector-specific information

Uplink sector-specific essential information and parameters that are needed for the MS to perform access on the uplink. Examples include UL resource allocation configuration, system configuration for initial ranging, UL channel parameters, UL power control parameters.

11.7.1.3 Extended system parameters and system configuration information

This category includes additional system configuration parameters and information not critical for access, but needed and used by all MSs after system acquisition. Examples of this class include information required for handover such as handover trigger, neighbor BS information, etc.

11.7.1.4 Control and signaling for DL notifications

Control and signaling information may be transmitted in the DL to provide network notifications to a single user or a group of users in the idle mode and sleep mode. Example of such notification is paging, etc.

11.7.1.5 Control and signaling for traffic

The control and signaling information transmitted in the DL for resource allocation to a single user or a group of users in active or sleep modes is included in this category. This class of information also includes feedback information such as power control and DL acknowledgement signaling related to traffic transmission/reception.

11.7.2 Transmission of DL Control Information

11.7.2.1 Synchronization Channel (SCH)

The synchronization channel (SCH) is a DL physical channel which provides a reference signal for time, frequency, and frame synchronization, RSSI estimation, channel estimation, and BS identification.

11.7.2.1.1 Synchronization channel requirements (Informative)

DEFINITIONS

Convergence time	Time interval for the probability of error in SCH index detection to be less than 1 % under non-ideal assumptions on the timing and carrier synchronization, measured from the start of the acquisition process.
Correct detection	Choose a BS among the co-channel BS's whose received powers averaged over the convergence time are within 3 dB of the BS with the highest received power
Coverage area	Area where the false detection probability is less than 1 % within the convergence time
Overhead	Total radio resources (time and frequency) per superframe that can not be used for other purpose because of SCH
Cell ID set	The cell ID set is the set of unique SCH symbols for differentiating between macrocell/femtocell/sector/relay transmitters
Multi-bandwidth support	Design of SCH for different bandwidths as specified in Table 2
Multi-carrier support	Design of SCH to support functionality described in sections 8.1.3 and 11.4.6

11.7.2.1.1.1 Overhead

Mixed mode with legacy system

In mixed mode operation the SCH overhead shall be less than or equal to 4 % per superframe including the legacy preamble, where the 4% is calculated based on the ratio of SCH resource and that of usable resource for transmitting data.

IEEE 802.16m only mode

In IEEE 802.16m only mode operation the SCH overhead shall be less than or equal to 2.6 % per superframe, where the 2.6% is calculated based on the ratio of SCH resource and that of usable resource for transmitting data.

11.7.2.1.1.2 Synchronization

The SCH will provide synchronization for:

- Time, including frame and superframe
- Frequency

Synchronization performance must at least match that of IEEE 802.16e.

IEEE 802.16m SCH must enable system acquisition without knowledge of the full channel bandwidth.

The IEEE 802.16m SCH shall not cause degradation of synchronization for coexisting legacy systems. Synchronization shall be robust for the full range of required mobile velocities as defined in the SRD (i.e. up to 350km/hr).

11.7.2.1.1.3 Coverage

The coverage area of IEEE 802.16m SCH shall not be worse than the minimum of the required coverage for broadcasting channel, control channel and unicast data channel at channel conditions under considerations.

11.7.2.1.1.4 Cell IDs

The cell ID shall be obtained from the SCH. To support femto-cell deployments, the number of unique cell IDs conveyed by the SCH shall be greater than or equal to 512

11.7.2.1.1.5 MIMO support and channel estimation

IEEEIEEE 802.16m SCH may support multi-antenna transmissions. The number of supported antennas is FFS.

Channel estimation supported from the SCH is FFS.

11.7.2.1.1.6 Multi-carrier Multi-bandwidth support

IEEE 802.16m SCH shall support multi-bandwidth and multi-carrier operations as defined in the latest revision of the SDD.

11.7.2.1.1.7 Measurement Support

IEEE 802.16m SCH shall support noise power estimation.

11.7.2.1.1.8 Sequence requirements

The PAPR and peak power shall be no larger than those of the downlink signal (excluding SCH).

11.7.2.1.2 Synchronization channel architecture

11.7.2.1.2.1 Overview

11.7.2.1.2.1.1 Hierarchy

Two levels of synchronization hierarchy exist. These are called the primary synchronization channel (P-SCH) and secondary synchronization channel (S-SCH). The P-SCH is used for initial acquisition, superframe synchronization and sending additional information. The use of P-SCH for LBS is FFS.The S-SCH is used for fine synchronization, and cell/sector identification (ID).

11.7.2.1.2.1.2 Multiplexing

P-SCH and S-SCH are TDM

11.7.2.1.2.1.3 Number of symbols in SCH

A complete instance of the SCH exists within a superframe. Multiple symbols within the superframe may comprise the SCH.

In mixed deployments, the presence of the IEEE 802.16e preamble is implicit.

11.7.2.1.2.1.4 Location of synchronization symbols

In mixed deployments, the presence of the 16e preamble in the first symbol of the 16e frame is implicit. The location of the SCH symbol(s) is fixed within the superframe.

The location of SCH is FFS.

11.7.2.1.2.1.5 Properties of P-SCH & S-SCH

The P-SCH has these properties:

- Common to a group of sectors/cells
- Supports limited signaling (e.g. mode, bandwidth, repeat part of cell ID, etc)
- Fixed bandwidth (5MHz)
- Support LBS(FFS)

The S-SCH has these properties:

- [Same bandwidth as P-SCH | Full bandwidth]
- Carries cell ID information

11.7.2.1.2.2 Description of legacy support/reuse

IEEE 802.16m system will exist in both greenfield and mixed (coexisting 16e and IEEE 802.16m equipment) deployments. In mixed deployments the 16e preamble will be always present. As discussed in the requirements, the IEEE 802.16m SCH is not to degrade the performance of legacy acquisition.

The IEEE 802.16m SCH shall enable IEEE 802.16m MSs to synchronize in frequency and time without requiring the IEEE 802.16e preamble.

11.7.2.1.2.3 Cell ID support

The number of IDs is at least 512.

Sectors are distinguished by the synchronization channel.

11.7.2.1.2.4 Multicarrier and multi-bandwidth support

The location of the SCH in frequency is FFS

11.7.2.1.2.5 MIMO support and channel estimation

Where employed, MIMO support is achieved by transmitting SCH subcarriers from known antennas. Antennas are:

(a) Cyclic delay diversity (with antenna specific delay values

(b) Interleaved either within a symbol (multiple antennas can transmit within a single symbol but on distinct subcarriers) or the different SCH sequences are transmitted from multi-antennas

(c) Across frames (only one antenna transmits in each symbol)

(d) Or some combination – actual approach is FFS.

The number of BS antennas supported for MIMO channel measurements is FFS, depending on the requirements of other IEEE 802.16m SDD content, such as DL MIMO and interference mitigation.

11.7.2.1.3 Synchronization channel Sequence Design Properties

The SCH enables timing synchronization by autocorrelation.

The power of synchronization channel can be boosted

The P-SCH is mapping with every other subcarrier on the frequency domain. Frequency reuse of 1 is applied to P-SCH.

Frequency reuse of [TBD] is applied to S-SCH.

11.7.2.2 Broadcast Channel (BCH)

The Broadcast Channel (BCH) carries essential system parameters and system configuration information. The BCH is divided into two parts: Primary Broadcast Channel (PBCH) and Secondary Broadcast Channel (SBCH).

11.7.2.2.1 Primary Broadcast Channel (PBCH) and Secondary Broadcast Channel (SBCH)

The Primary Broadcast Channel (PBCH) and the Secondary Broadcast Channel (SBCH) carry essential system parameters and system configuration information. The The PBCH is transmitted every superframe. The SBCH may also be transmitted. When present, SBCH may be transmitted over one or more superframes. The information contents of PBCH and SBCH is FFS

11.7.2.2.2 Location of the BCH

The SFH includes PBCH and the SBCH, and is located in the first subframe within a superframe.

11.7.2.2.3 Multiplexing of the PBCH and SBCHwith other control channels and data channels

The PBCH/SBCH is TDM with the SCH.

If SFH occupies narrower BW than system BW, the PBCH and SBCH in SFH are FDM with data within the same subframe.

11.7.2.2.4 Transmission format

The PBCH and SBCH are transmitted using predetermined modulation and coding schemes.

The modulation and coding rate for PBCH and the modulation and coding rate for SBCH are TBD.

Multiple antenna schemes for transmission of the PBCH/SBCH are supported. The PBCH is transmitted as a single stream. The MS is not required to know the antenna configuration prior to decoding the PBCH.

If needed, signaling of the multiple antenna scheme used to transmit the PBCH/SBCH is TBD.

11.7.2.2.5 Resource allocation (physical to logical mapping, pilots, block size)

<Editors' Notes: This section depends on SDD text included in the DL PHY Structure.>

11.7.2.3 Unicast Service Control Channels

11.7.2.3.1 Unicast service control information/content

Unicast service control information consists of both user-specific control information and non-user-specific control information.

11.7.2.3.1.1 Non-user-specific control information

Non-user-specific control information consists of information that is not dedicated to a specific user or a specific group of users. It includes information required to decode the user-specific control. Non-user-specific control information that is not carried in the BCH may be included in this category. Details of non-user specific control information are FFS.

11.7.2.3.1.2 User-specific control information

User specific control information consists of information intended for one user or more users. It includes scheduling assignment, power control information, HARQ ACK/NACK information.

Resources can be allocated persistently to MSs. The periodicity of the allocation may be configured.

A group control information is used to allocate resources and/or configure resources to one or multiple mobile stations within a user group. Each group is associated with a set of resources. VoIP is an example of the subclass of services that use group messages.

11.7.2.3.2 Multiplexing scheme for data and unicast service control

Within a sub-frame, control and data channels are multiplexed using FDM. Both control and data channels are transmitted on logical resource units (LRU) that span all OFDM symbols in a sub-frame.

11.7.2.3.3 Location of control blocks

The first IEEE 802.16m DL sub-frame of each frame contains user-specific control information.

Control blocks for user specific control information are located 'n' IEEE 802.16m subframes apart. If a unicast service control channel (USCCH) is allocated in subframe N, the next USCCH is in subframe N+n of the same frame. DL data allocations corresponding to the USCCH can correspond to resources in any subframes between successive USCCH. The values of n can be 1 or 2. Other values of n (3 and 4) are FFS. For example, for n=2, USCCH in subframe N can point to resource allocation in subframe N or N+1 and the next USCCH is in subframe N+2.IEEE 802.16m If a USCCH is allocated in subframe N and contains the specification for UL data allocations, the corresponding UL data allocations occur in subframe TBD.

In the FDD mode, the first IEEE 802.16m DL subframe of each frame contains user-specific control information. In the TDD mode, the first IEEE 802.16m DL subframe after each UL to DL transition contains user-specific control information.

The location of control blocks for non-user specific control information is TBD.

11.7.2.3.4 Transmission format

A unicast service control information element is defined as the basic element of unicast service control. A unicast service control information element may be addressed to one user using a unicast ID or to multiple users using a multicast/broadcast ID. It may contain information related to resource allocation, HARQ, transmission mode etc.

If each unicast service control information element is coded separately, this type of coding is referred to as “separate coding”, whereas if multiple unicast service control information elements are coded jointly, this type of coding is referred to as “joint coding”.

A coded control block is the output of separate coding or joint coding. The MCS of each coded control block may be controlled individually. Coded control blocks may all be transmitted at the same MCS and this transmission scheme is referred to as “fixed MCS”. If each coded block may be transmitted at a different MCS, this scheme is referred to as “variable MCS”.

Coding of multiple unicast service control information elements may therefore either be joint coding or separate coding.

MCS of coded control blocks may either be with a fixed MCS or a variable MCS.

Non-user-specific control information is encoded separately from the user-specific control information.

For user-specific control information intended for a single user, multiple information elements are coded separately. The modulation and coding scheme (fixed/variable) is FFS.

The transmission format (joint/separate and fixed/variable MCS) for non-user-specific control information is FFS

11.7.2.3.5 Resource allocation (physical to logical mapping, pilots, block size)

<Editors’ Notes: This section depends on SDD text included in the DL PHY Structure.>

11.7.2.3.5.1 Pilot structure for unicast service control channels

<Editors’ Notes: This section depends on SDD text included in the DL PHY Structure.>

11.7.2.4 Multicast Service Control Channels

<Editors’ Notes:This section is a placeholder for text to be developed based on SDD text that will be added to Section 15 of the SDD (Support for Enhanced Multicast Broadcast Service). >

11.7.2.4.1 Multicast service control information/content

11.7.2.4.2 Multiplexing scheme of data and multicast service control and (e.g. TDM, FDM, Hybrid TDM/FDM)

11.7.2.4.3 Location of control blocks within a frame/subframe

11.7.2.4.4 Transmission format (e.g. modulation, coding, multiple antenna schemes)

11.7.2.4.5 Resource allocation (physical to logical mapping, pilots, block size)

11.7.2.5 Transmission of Additional Broadcast information

Examples of additional broadcast information include system descriptors, neighbor BS information and paging information. The indication of the presence of additional broadcast information is FFS.

MAC management messages may be used to transmit additional broadcast information.

11.7.3 Mapping information to DL control channels

Information		Channel	Location
Synchronization information		Synchronization Channel (SCH)	FFS
Essential system parameters and system configuration information		Primary Broadcast Channel (PBCH) and Secondary Broadcast Channel (SBCH)	Inside of SFH
Extended system parameters and system configuration information		FFS	Outside of SFH
Control and signaling for DL notifications		FFS	FFS
Control and signaling for traffic		Unicast Service Control Channel	Outside of SFH

Table 3 Mapping information to DL control channels

11.7.4 Multi-carrier Control Structure

<Editors’ Notes:This section is a placeholders for text to be developed based on SDD text that will be added to Section 19 of the SDD (Support for Multi-carrier Operation). >

The carriers involved in a multi-carrier system, from one MS point of view, can be divided into two types:

- A Primary carrier is the carrier used by the BS and the MS to exchange traffic and PHY/MAC control information defined in IEEE 802.16m specification. Further, the primary carrier is used for control functions for proper MS operation, such as network entry. Each MS shall have only one carrier it considers to be its primary carrier in a cell.
- A Secondary carrier is an additional carrier which the MS may use for traffic, only per BS’s specific allocation commands and rules, typically received on the primary carrier. The secondary carrier may

also include control signaling to support multi-carrier operation.

Based on the primary and/or secondary usage, the carriers of a multi-carriers system may be configured differently as follows:

- Fully configured carrier: A carrier for which all control channels including synchronization, broadcast, multicast and unicast control signaling are configured. Further, information and parameters regarding multi-carrier operation and the other carriers can also be included in the control channels. Fully configured carrier shall support both single carrier MS and multicarrier MS.
- Partially configured carrier: A carrier with only essential control channel configuration to support traffic exchanges during multi-carrier operation.

A primary carrier shall be fully configured while a secondary carrier may be fully or partially configured depending on usage and deployment model.

11.8 DL MIMO Transmission Scheme

11.8.1 DL MIMO Architecture and Data Processing

The architecture of downlink MIMO on the transmitter side is shown in the Figure 40.
In SU-MIMO, only one user is scheduled in one Resource Unit (RU). In MU-MIMO, multiple users can be scheduled in one RU.
If vertical encoding is utilized, there is only one encoder block (one “layer”). If horizontal encoding is utilized, there are multiple encoders (multiple “layers”). A “layer” is defined as a coding / modulation path fed to the MIMO encoder as an input, and a “stream” is defined as each output of the MIMO encoder that is passed to the beamformer / precoder.

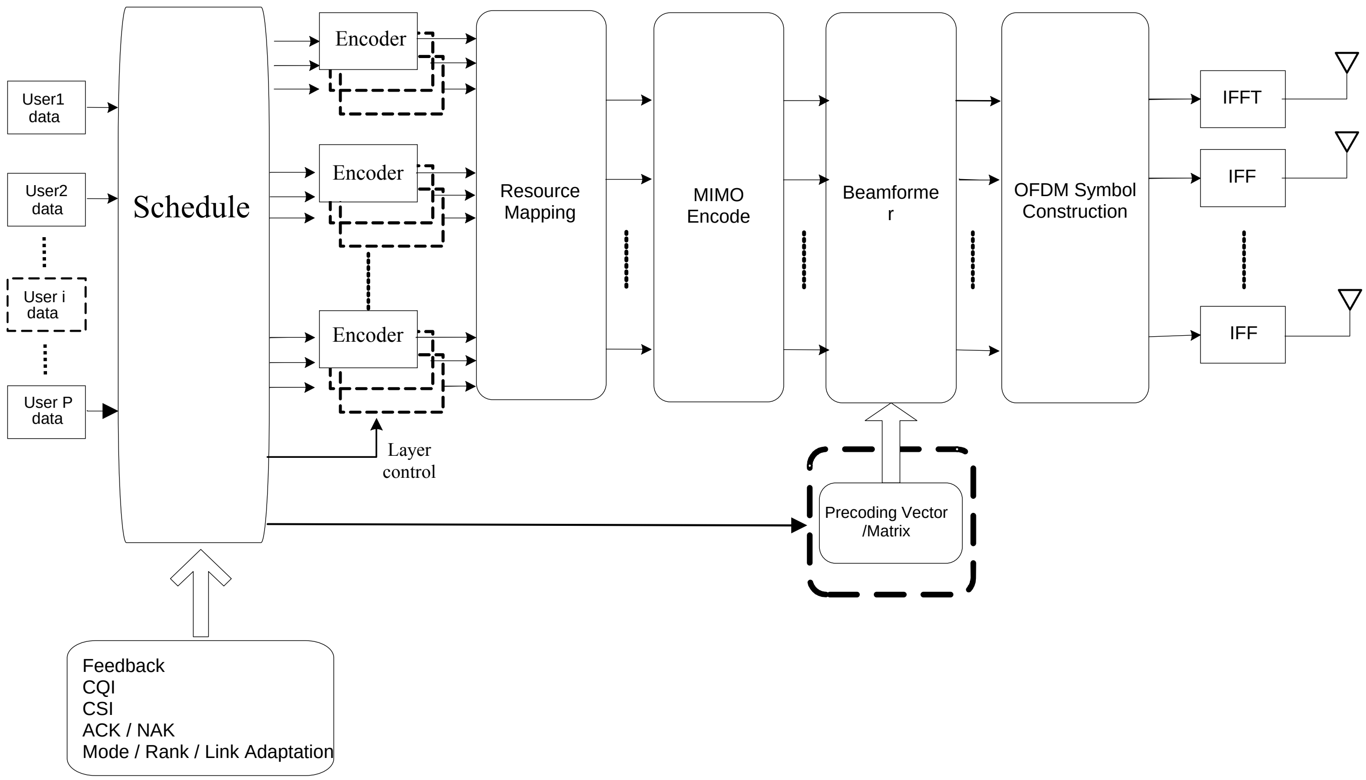

Figure 40 MIMO Architecture

The encoder block contains the channel encoder, interleaver, rate-matcher, and modulator for each layer.

The Resource Mapping block maps the modulated symbols to the corresponding time-frequency resources in the allocated resource units (RUs).

The MIMO encoder block maps L (≥1) layers onto N_S (≥L) streams, which are fed to the Beamformer/Precoder block.

The Beamformer/Precoder block maps streams to antennas by generating the antenna-specific data symbols according to the selected MIMO mode.

The OFDM symbol construction block maps antenna-specific data to the OFDM symbol.

The feedback block contains feedback information such as CQI and CSI from the MS.

The scheduler block will schedule users to resource blocks and decide their MCS level, MIMO parameters (MIMO mode, rank). This block is responsible for making a number of decisions with regards to each resource allocation, including:

- ***Allocation type***: Whether the allocation in question should be transmitted with a distributed or localized allocation
- ***Single-user (SU) versus multi-user (MU) MIMO***: Whether the resource allocation should support a single user or more than one user

- ***MIMO Mode***: Which open-loop (OL) or closed-loop (CL) transmission scheme should be used for the user(s) assigned to the resource allocation.
- ***User grouping***: For MU-MIMO, which users should be transmitted to on the Resource Unit (RU)
- ***Rank selection***: For the spatial multiplexing modes in SU-MIMO, the number of streams to be used for the user allocated to the Resource Unit (RU).
- ***MCS level per layer***: The modulation and coding rate on each layer must be determined.
- ***Boosting***: The power boosting values to be used on the data and pilot subcarriers.
- ***Band selection***: If localized resource allocation is used, where in the frequency band should the localized allocation be placed.

11.8.1.1 Antenna Configuration

The BS employs a minimum of two transmit antennas. The MS employs a minimum of two receive antennas. The antenna configurations are (N_T, N_R) = (2, 2), (4, 2), (4, 4), (8, 2), (8, 4), and (8,8) where N_T denotes the number of BS transmit antennas and N_R denotes the number of MS receive antennas.

11.8.1.2 Layer to Stream Mapping

For open-loop spatial multiplexing and closed-loop SU-MIMO, the number of streams, $N_S \le \min(N_T, N_R)$, where N_S is no more than 4 (8 streams are FFS). For open-loop transmit diversity modes, N_S depends on the STC schemes employed by the MIMO encoder. MU-MIMO can have up to 2 streams with 2 Tx antennas, and up to 4 streams for 4 Tx antennas and 8Tx antennas.

For SU-MIMO, Vertical encoding (SCW) is employed. For SU-MIMO, transmit diversity MIMO mode employs SCW. [The support of horizontal encoding (MCW) for SU-MIMO is FFS]. For MU-MIMO, MCW (or horizontal) encoding is employed at the base-station while only one stream is transmitted to each mobile station.

11.8.1.3 Stream to Antenna Mapping

The stream to antenna mapping depends on the MIMO scheme used. The mapping can be defined using the following equation

$$\mathbf{y} = \mathbf{P} \times \mathbf{S}(\mathbf{x}), \text{ Equation 1}$$

where $\mathbf{y}$ is the output of the precoder/beamformer, $\mathbf{P}$ is a pre-coding matrix, $\mathbf{S}(\mathbf{x})$ is an STC matrix, and $\mathbf{x}$ is the input layer vector.

11.8.1.4 Resource mapping

The following table illustrates the MIMO mode permutation for various MIMO schemes.

MIMO Scheme	Resource Mapping

Open-loop SU-MIMO	Distributed or Localized
Closed-loop SU-MIMO	Distributed or Localized
MU-MIMO	Distributed or Localized

Table 4 Supported resource channels in MIMO

11.8.1.5 Pilots

11.8.1.6 Signaling support for MIMO

11.8.1.6.1 Signaling support for SU MIMO

11.8.1.6.2 Signaling support for MU MIMO

In the downlink MU-MIMO, the precoding matrix shall be signaled via explicit signaling if common demodulation pilots are used, or via dedicated pilots.

11.8.2 Transmission for Data Channels

11.8.2.1 Single-user MIMO

Single-user MIMO schemes are used to improve per-link performance.

Both open-loop single-user MIMO and closed-loop single-user MIMO are supported for the antenna configurations specified in Section 11.8.1.1.

For open-loop single-user MIMO, both spatial multiplexing and transmit diversity schemes are supported. Note that in the case of open-loop single-user MIMO, CQI and rank feedback may still be transmitted to assist the base station's decision of rank adaptation, transmission mode switching, and rate adaptation. Note that CQI, and rank feedback may or may not be frequency dependent.

For closed-loop single-user MIMO, codebook based precoding is supported for both TDD and FDD systems. CQI, PMI, and rank feedback can be transmitted by the mobile station to assist the base station's scheduling, resource allocation, and rate adaptation decisions. Note that the CQI, PMI, and rank feedback may or may not be frequency dependent.

For closed-loop single-user MIMO, sounding based precoding is supported for TDD systems.

As described in section 11.8.1, the overall structure of MIMO processing has two parts. The first part is the MIMO encoder and second part is the precoder.

The MIMO encoder is a batch processor that operates on M input symbols at a time. The input to the MIMO encoder is represented by an $M \times 1$ vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_M \end{bmatrix}, \text{Equation 2}$$

where s_i is the i-th input symbol within a batch. The output of the MIMO encoder is an $N_S \times N_F$ MIMO STC matrix $\mathbf{z} = \mathbf{S}(\mathbf{x})$, which serves as the input to the precoder. The output of the precoder is denoted by a matrix $N_T \times N_F$ matrix

$$\mathbf{y} = \begin{bmatrix} y_{1,1} & y_{1,2} & \cdots & y_{1,N_F} \\ y_{2,1} & y_{2,2} & \cdots & y_{2,N_F} \\ \vdots & \vdots & \ddots & \vdots \\ y_{N_T,1} & y_{N_T,2} & \cdots & y_{N_T,N_F} \end{bmatrix}, \text{Equation 3}$$

where $y_{i,j}$ is the output symbol to be transmitted via the *i*-th physical antenna on the *j*-th subcarrier/symbol. Note N_F is the number of subcarriers or symbols used to transmit the MIMO signals derived from the input vector **x**. For open-loop SU-MIMO, the rate of a mode is defined as $R = M / N_F$.

11.8.2.1.1 Open-loop SU-MIMO

A number of antenna configurations and transmission rates are supported in open-loop SU-MIMO. Among them, 2Tx, 4Tx, and 8Tx antennas with rate 1 transmission are defined as Transmit Diversity modes. The operation of these modes is specified in Section 11.8.2.1.1.1. The other modes, including 2Tx, 4Tx, and 8Tx antennas with rate 2 transmission, 4Tx and 8Tx antennas with rate 3 transmission, 4Tx and 8Tx antennas with rate 4 transmission, and 8Tx antennas with transmission up to rate 8, are defined as Spatial Multiplexing modes. The operation of these modes is specified in Section 11.8.2.1.1.2. The dimensions of the vectors and matrices for open-loop SU-MIMO are shown in the following table:

N_T	Rate	M	N_F
2	1	1	1
2	1	2	2
4	1	1	1
4	1	2	2
8	1	1	1
8	1	2	2
2	2	2	1
4	2	2	1
8	2	2	1
4	3	3	1
8	3	3	1
4	4	4	1
8	4	4	1

Table 5 Matrix dimensions for open-loop SU-MIMO modes

On a given subcarrier k, the precoding matrix **P** can be defined using the following equation:

$$\mathbf{P}(k) = \mathbf{W}(k), \text{ Equation 4}$$

The precoder is composed of two matrices. The first matrix $\mathbf{W}(k)$ is an $N_T \times N_S$ matrix, where N_T is the number of transmit antennas and N_S is the numbers of streams. The matrix $\mathbf{W}(k)$ is selected from a predefined unitary codebook, and changes every *u* subcarriers, and/or *v* OFDM symbols. A codebook is a unitary codebook if each of its matrices consists of columns of a unitary matrix. [The detailed unitary codebook, and the parameter u and v are FFS.]

For OL SU-MIMO, the following schemes are FFS: 4Tx rate-1 SFBC + Antenna hopping, 4Tx rate-2 Double SFBC + Antenna hopping, 4Tx rate-2 SM + Antenna hopping, 4Tx rate-3 SM + Antenna hopping, 4Tx rate-3 hybrid SM + SFBC + Antenna hopping.

11.8.2.1.1.1 Transmit Diversity

The following transmit diversity modes are supported for open-loop single-user MIMO:

- 2Tx rate-1: STBC/SFBC, and rank-1 precoder
- 4Tx rate-1: STBC/SFBC with precoder, and rank-1 precoder
- 8Tx rate-1: STBC/SFBC with precoder, and rank-1 precoder

For the transmit diversity modes with M=1, the input to MIMO encoder is x=s1, and the output of the MIMO encoder is a scalar, z=x.

- The output of the rank-1 precoder for NT = 2, 4, and 8 Tx antennas is a NT × 1 matrix y=W × z, where W may be frequency and/or time dependent as described in section 11.8.2.1.1.
- For the transmit diversity modes with M=2, the input to the MIMO encoder is represented a 2 × 1 vector. The MIMO encoder generates 2Tx SFBC, and then multiplied by NT × 2 matrix as described in section 11.8.2.1.1.

For the transmit diversity modes, the input to the MIMO encoder is represented a 2 × 1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}, \text{ Equation 5}$$

The output of the MIMO encoder is a 2 × 2 matrix

$$\mathbf{z} = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix}, \text{ Equation 6}$$

For the 2Tx rate-1 mode, the output of the precoder is a 2 × 2 matrix

$$\mathbf{y} = \mathbf{z}, \text{ Equation 7}$$

For the 4Tx rate-1, the output of the precoder is a 4 × 2 matrix

$$\mathbf{y} = \mathbf{W} \times \mathbf{z}, \text{ Equation 8}$$

where **W** is a 4 × 2 precoder. Note that **W** may be frequency and/ or time dependent as described in section 11.8.2.1.1.

For the 8Tx rate-1, the output of the precoder is a 8 × 2 matrix

$$\mathbf{y} = \mathbf{W} \times \mathbf{z}\text{, Equation 9}$$

where **W** is a 8 × 2 precoder. Note that **W** may be frequency and/ or time dependent as described in section 11.8.2.1.1.

11.8.2.1.1.2 Spatial Multiplexing

The following spatial multiplexing modes are supported for open-loop single-user MIMO:

- Rate-2 spatial multiplexing modes:
  - 2Tx rate-2: rate 2 SM
  - 4Tx rate-2: rate 2 SM with precoding
  - 8Tx rate-2: rate 2 SM with precoding
- Rate-3 spatial multiplexing modes:
  - 4Tx rate-3: rate 3 SM with precoding
  - 8Tx rate-3: rate 3 SM with precoding
- Rate-4 spatial multiplexing modes:
  - 4Tx rate-4: rate 4 SM
  - 8Tx rate-4: rate 4 SM with precoding

For the rate-2 spatial multiplexing modes, the input to the MIMO encoder is represented as a 2 × 1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}\text{, Equation 10}$$

The output of the MIMO encoder is a 2 × 1 vector

$$\mathbf{z} = \mathbf{x}\text{, Equation 11}$$

For the 2Tx rate-2 mode, the output of the precoder is a 2 × 1 vector

$$\mathbf{y} = \mathbf{z}\text{. Equation 12}$$

For the 4Tx rate-2 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{W} \times \mathbf{z}\text{ Equation 13}$$

where **W** is a 4 × 2 precoder. Note that **W** may be frequency and/ or time dependent as described in section 11.8.2.1.1.

For the 8Tx rate-2 mode, the output of the precoder is a 8 × 1 vector

$$\mathbf{y} = \mathbf{W} \times \mathbf{z}\text{, Equation 14}$$

where **W** is a 8 × 2 precoder. Note that **W** may be frequency and/ or time dependent as described in section 11.8.2.1.1.

For the rate-3 spatial multiplexing modes, the input to the MIMO encoder is represented as a 3 × 1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix}, \text{ Equation 15}$$

The output of the MIMO encoder is a 3 × 1 vector

$$\mathbf{z} = \mathbf{x}, \text{ Equation 16}$$

For the 4Tx rate-3 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{W} \times \mathbf{z}, \text{ Equation 17}$$

where **W** is a 4 × 3 precoder. Note that **W** may be frequency and/ or time dependent as described in section 11.8.2.1.1.

For the 8Tx rate-3 mode, the output of the precoder is a 8 × 1 vector

$$\mathbf{y} = \mathbf{W} \times \mathbf{z}, \text{ Equation 18}$$

where **W** is a 8 × 3 precoder. Note that **W** may be frequency and/ or time dependent as described in section 11.8.2.1.1.

For the rate-4 spatial multiplexing modes, the input to the MIMO encoder is represented as a 4×1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix}, \text{ Equation 19}$$

The output of the MIMO encoder is a 4 × 1 vector

$$\mathbf{z} = \mathbf{x}, \text{ Equation 20}$$

For the 4Tx rate-4 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{z}, \text{ Equation 21}$$

For the 8Tx rate-4 mode, the output of the precoder is a 8 × 1 vector

$$\mathbf{y} = \mathbf{W} \times \mathbf{z}, \text{ Equation 22}$$

where **W** is a 8 × 4 precoder. Note that **W** may be frequency and/ or time dependent as described in section 11.8.2.1.1.

11.8.2.1.2 Closed-loop SU-MIMO

11.8.2.1.2.1 Precoding technique

In FDD and TDD systems, unitary codebook based precoding is supported.

In TDD systems, sounding based precoding is supported.
For codebook based precoding, the codebook will be a .16e-based and/or DFT-based codebook.

11.8.2.1.3 Feedback for SU-MIMO

In FDD systems and TDD systems, a mobile station may feedback some of the following information in Closed loop SU-MIMO mode:

- Rank (Wideband or sub-band)
- Sub-band selection
- CQI (Wideband or sub-band, per layer)
- PMI (Wideband or sub-band for serving cell and/or neighboring cell)
- Long-term CS

For codebook based precoding, two different feedback modes for the PMI are supported:

- The standard mode: the feedback from a mobile station shall be based on the same codebook as used by base station for transmission, and it shall be sufficient for the base station to determine a new precoder.
- The differential mode: the feedback from a mobile station provides a differential knowledge which represents information that is used along with other feedback information known at the base station for determining a new precoder.

Mobile station shall support the standard mode and may support the differential mode.
For codebook based precoding, the feedback from a mobile station shall be based on the same codebook as used by base station for transmission.

The feedback information may be transmitted via a physical layer control channel or via a higher layer signaling message.

In TDD systems, a mobile station may transmit a sounding signal on the uplink.

11.8.2.2 Multi-user MIMO

Multi-user MIMO schemes are used to enable a resource allocation to communicate data to two or more MSs. IEEE 802.16m uses Multi-user MIMO to boost system throughput.

Multi-user transmission with one stream per user is supported for MU-MIMO. MU-MIMO includes the MIMO configuration of 2Tx antennas to support up to 2 users, and 4Tx or 8Tx antennas to support up to 4 users.

11.8.2.2.1 Precoding technique

The precoding for MU-MIMO can be either standardized or vendor-specific. Up to four MSs can be assigned to each resource allocation. Both unitary and non-unitary MU MIMO are supported in IEEE 802.16m.
The standardized codebook will be a .16e-based and/or DFT-based codebook.

In MU-MIMO systems, the received signal of the f-th subcarrier in the i-th MS (without considering co-channel interference) can be described as:

$$\mathbf{y}_{i,f} = \mathbf{H}_{i,f} \sum_{j=1}^{K} \mathbf{v}_{j,f} \mathbf{x}_{j,f} + \mathbf{n}_{i,f} \text{, Equation 23}$$

where K is the number of the allocated users, $\mathbf{v}_{j,f}$ is the precoding vector of the f-th subcarrier for the transmit signal to the j-th MS, $\mathbf{x}_{j,f}$ is the transmit signal of the f-th subcarrier to the j-th MS and $\mathbf{n}_{i,f}$ is the noise of the f-th subcarrier in the j-th MS.

If dedicated pilots are used, the form and derivation of the assembled precoding matrix, $\mathbf{V}_f = [\mathbf{v}_{1,f} ... \mathbf{v}_{K,f}]$, can be either standardized or vendor-specific. If the columns of the assembled precoding matrix are orthogonal to each other, it is defined as unitary MU-MIMO. Otherwise, it is defined as non-unitary MU-MIMO. Note that beamforming is enabled with this precoding mechanism. Non-linear precoding is FFS.

11.8.2.2.2 Unification with SU

Predefined and flexible adaptation between SU-MIMO and MU-MIMO are supported. The adaptation between SU MIMO rank 1 and MU MIMO is dynamic by using the same feedback information.
The adaptation between feedback for SU MIMO rank 2 (or more) and feedback for MU MIMO is semi-static.

11.8.2.2.3 Feedback for MU-MIMO

11.8.2.2.3.1 CQI feedback

For CQI feedback, the mobile station measures the downlink pilot channel, computes the channel quality information (CQI), and reports the CQI on the uplink feedback channel. Both wideband CQI and subband CQI may be transmitted by a mobile station. Wideband CQI is the average CQI of a wide frequency band. In contrast, sub-band CQI is the CQI of a localized sub-band. The CQI is calculated at the mobile station assuming that the interfering users are scheduled by the serving base station using precoders orthogonal to each other and orthogonal to the reported PMI.

11.8.2.2.3.2 CSI feedback

Channel state information feedback may be employed for MU-MIMO. Codebook-based feedback is supported in both FDD and TDD. Sounding-based feedback is supported in TDD.
For codebook based precoding, two different feedback modes for the PMI are supported:

- The standard mode: the feedback from a mobile station shall be based on the same codebook as used by base station, and it shall be sufficient for the base station to determine a new precoder.
- The differential mode: the feedback from a mobile station provides a differential knowledge which represents information that is used along with other feedback information known at the base station for determining a new precoder.

Mobile station shall support the standard mode and may support the differential mode.
The unified codebook for SU and MU is employed. The codebook is a subset (including full set) of SU-MIMO codebook. BS indicates which codebook subset will be used.
An enhanced UL sounding channel is used to feedback CSI-related information by the MS to facilitate vendor-specific adaptive closed-loop MIMO precoding. For sounding-based precoding, the enhanced UL sounding

channel can be configured to carry a known pilot signal from one or more MS antennas to enable the BS to compute its precoding/beamforming weights by leveraging TDD reciprocity. The sounding waveform can be configured to occupy portions of the frequency bandwidth in a manner similar to the sounding waveform used in the legacy system. To facilitate analog-feedback-based precoding, the enhanced UL sounding channel can be configured to carry unquantized CSI-related information (e.g., an unquantized encoding of the DL spatial covariance matrix or an unquantized encoding of the eigenvectors of the DL spatial covariance matrix). The unquanitized CSI-related information can be specific to a particular specified portion of the band (narrowband feedback) or specific to the entire bandwidth (wideband feedback).

11.8.2.3 Rank and Mode Adaptation

To support the numerous radio environments for IEEE 802.16m systems, both MIMO mode and rank adaptation are supported. BSs and MSs may adaptively switch between DL MIMO techniques depending on parameters such as antenna configurations and channel conditions. Parameters selected for mode adaptation may have slowly or fast varying dynamics. By switching between DL MIMO techniques an IEEE 802.16m system can dynamically optimize throughput or coverage for a specific radio environment.

The MIMO modes include open-loop MIMO like transmit diversity, spatial multiplexing, and closed-loop MIMO, etc. The adaptation of these modes is related with the system load, the channel information, MS speed and average CINR. Switching between SU-MIMO and MU-MIMO is also supported.

Both dynamic and semi-static adaptation mechanisms are supported in 16m. For dynamic adaptation, the mode/rank may be changed frame by frame. For semi-static adaptation, MS may request adaptation. The decision of rank and mode adaptation is made by the BS. The adaptation occurs slowly, and feedback overhead is less.

11.8.3 Transmission for Control Channel

11.8.3.1 Transmission for Broadcast Control Channel

A SU open-loop technique that provides diversity gain will be used for the Broadcast Control Channel. The detailed transmit diversity scheme for the Broadcast Control Channel is FFS.

11.8.3.2 Transmission for Unicast Control Channel

A SU technique that provides diversity or beamforming gain will be used for the Unicast Control Channel. The detailed transmit diversity scheme for Unicast Control Channels is FFS.

11.8.4 Advanced Features

11.8.4.1 Multi-cell MIMO

Multi-BS MIMO techniques are supported for improving sector throughput and cell-edge throughput through multi-BS collaborative precoding, network coordinated beamforming, or inter-cell interference nulling. Both open-loop and closed-loop multi-BS MIMO techniques can be considered. For closed-loop multi-BS MIMO, CSI feedback via codebook based feedback or sounding channel will be used. The feedback information may be shared by neighboring base stations via network interface. Mode adaptation between single-cell MIMO and multi-BS MIMO is utilized.

11.8.4.2 MIMO for Multi-cast Broadcast Services

Open-loop spatial multiplexing schemes as described in Section 11.8.2.1.1.2 are used for MBS.

11.9 UL Control Structure

Details of the UL control structure are described in the following sections.

11.9.1 UL Control Information Classification

The UL control channels carry multiple types of control information to support air interface procedures. Information carried in the control channels is classified as follows.

<Editors' Notes: Text included in this section depends on SDD text being developed by other Rapporteur Groups (MIMO, HARQ).>

11.9.1.1 Channel quality feedback

Channel quality feedback provides information about channel conditions as seen by the MS. This information is used by the BS for link adaptation, resource allocation, power control etc. Channel quality measurement includes narrowband and wideband measurements. CQI feedback overhead reduction is supported through differential feedback or other compression techniques. Examples of CQI include Physical CINR, Effective CINR, band selection, etc. Channel sounding can also be used to measure uplink channel quality.

11.9.1.2 MIMO feedback

MIMO feedback provides spatial characteristics of the channel that are required for MIMO operation. The precoder matrix index, rank adaptation, channel covariance matrix elements, power loading factor, eigenvectors and channel sounding are examples of MIMO feedback information.

11.9.1.3 HARQ feedback

HARQ feedback (ACK/NACK) is used to acknowledge DL transmissions. Multiple codewords can be acknowledged in a single ACK/NACK transmission.

11.9.1.4 Synchronization

Uplink synchronization signals are needed to acquire uplink synchronization during initial access or handover and also to periodically maintain synchronization. This includes reference signals for measuring and adjusting the uplink timing offset.

11.9.1.5 Bandwidth request

Bandwidth requests are used to provide information about the needed uplink bandwidth to the BS. Bandwidth requests are transmitted through indicators or messages. Bandwidth request messages can include information about the status of queued traffic at the MS such as buffer size and quality of service, including QoS identifiers.

11.9.1.6 E-MBS feedback

<Editors' Notes : This section is a placeholder for text to be developed based on SDD text that will be added to Section 15 of the SDD (Support for Enhanced Multicast Broadcast Service). >

E-MBS feedback provides information for DL MBS transmission to one or multiple cells. Details are TBD.

11.9.2 UL Control Channels

<Editors' Notes: Text included in this section depends on SDD text being developed by other Rapporteur Groups (MIMO, HARQ).>

11.9.2.1 UL Fast Feedback Channel

The UL fast feedback channel carries channel quality feedback and MIMO feedback. Transmission of other feedback information on the UL fast feedback channel is FFS.

The mapping of UL fast feedback information into physical channels is described in Section 11.9.2.1.2. .

11.9.2.1.1 Multiplexing with other control channels and data channels

The UL fast feedback channel is FDM with other UL control and data channels.

The UL fast feedback channel starts at a pre-determined location, with the size defined in a DL broadcast control message. Fast feedback allocations to an MS can be periodic and the allocations are configurable. For periodic allocations, the specific type of feedback information carried on each fast feedback opportunity can be different.

The UL fast feedback channel carries one or more types of fast feedback information. The use of TDM/FDM or CDM to multiplex fast feedback channels from one or more users is FFS.

11.9.2.1.2 PHY structure

Transmission on the fast feedback channel can be event-driven. The transmission format of the fast feedback channel can be adaptive.

The structure of the resource blocks, pilots and resource mapping for the UL fast feedback channel are TBD.

11.9.2.2 UL HARQ Feedback Channel

This channel is used to carry HARQ feedback information.

11.9.2.2.1 Multiplexing with other control channels and data channels

The UL HARQ feedback channel starts at a pre-determined offset with respect to the corresponding DL transmission.

The UL HARQ feedback channel is FDM with other control and data channels.

Orthogonal signaling is used to multiplex multiple HARQ feedback channels.

11.9.2.2.2 PHY structure

The structure of UL HARQ feedback channel resource blocks, pilots and resource mapping are TBD.

11.9.2.3 UL Sounding Channel

The UL sounding channel is used by an MS to send a sounding signal for MIMO feedback, channel quality feedback and acquiring UL channel information at the BS.

11.9.2.3.1 Multiplexing with other control information and data

The BS can configure an MS to transmit an UL sounding signal on specific UL sub-bands. The sounding signal is transmitted over predefined subcarriers within the intended sub-bands. The periodicity of the sounding signal for each MS is configurable.

The UL sounding channel is FDM with other control and data channels.

11.9.2.3.2 PHY structure

Sounding from single or multiple antennas and multiple users are supported to provide full MIMO channel information for DL transmission. Power allocation, sounding sequence design and mapping to subcarriers is TBD.

11.9.2.4 Ranging Channel for Non-Synchronized Mobile Stations

The UL ranging channel is used for UL synchronization. The UL ranging channel can be further classified into ranging channel for non-synchronized mobile stations and synchronized mobiles stations. A random access procedure, which can be contention based or non-contention based is used for ranging. Contention-based random access is used for initial ranging, periodic ranging and handover. Non-contention based random access is used for periodic ranging and handover.

11.9.2.4.1 Multiplexing with other control channels and data channels

The ranging channel for non-synchronized MSs is used for initial access and handover.

11.9.2.4.1.1 Multiplexing with other control channels and data channels

The UL ranging channel for non-synchronized MSs starts at a configurable location with the configuration defined in a DL broadcast control message.

The UL ranging channel for non-synchronized MSs is FDM with other UL control channels and data channels.

11.9.2.4.2 PHY structure

The physical ranging channel for non-synchronized mobile stations consists of three parts: 1) cyclic prefix (CP), 2) ranging preamble (RP) and 3) guard time (GT). The length of CP shall not be shorter than the sum of the maximum channel delay spread and round trip delay (RTD) of supported cell size. The length of GT shall not be also shorter than the RTD of supported cell size. The length of ranging preamble shall be equal to or longer than CP length of ranging channel. The details on the length of each part and its configurations are FFS.
The physical resource of ranging channel for non-synchronized mobile stations is consecutive Nr_{sc} ranging subcarriers (BW_{RCH-NS} Hz corresponding to continuous Nr_{ru} LLRUs) and Nr_{sym} OFDMA symbols (T_{RCH-NS} sec). As a default configuration, Nr_{sc} and Nr_{sym} are equal to [TBD] ranging subcarriers and [TBD] OFDMA symbols, respectively. The guard subcarriers shall be reserved at the edge of non-synchronized ranging channel(s) physical resource. The details of the ranging structure within the localized resource are FFS.

11.9.2.4.3 The additional ranging structure for TDD mode is FFS.Ranging Channel for synchronized mobile stations

The ranging channel for synchronized MSs is used for periodic ranging. The use of the ranging channel for synchronized MSs for handover is FFS.

11.9.2.4.3.1 Multiplexing with other control channels and data channels

The UL ranging channel for synchronized MSs starts at a configurable location with the configuration defined in a DL broadcast control message.

The UL ranging channel for synchronized MSs is FDM with other UL control channels and data channels.

11.9.2.4.3.2 PHY structure

The ranging sequence design and mapping to subcarriers are TBD.

11.9.2.5 Bandwidth Request Channel

Contention based or non-contention based random access is used to transmit a bandwidth request indicator on this control channel. To support different levels of QoS, the bandwidth request channel provides a mechanism for prioritized bandwidth requests quality of service including QoS identifiers. Inclusion of addition information in a bandwidth request indicator such as bandwidth request size, Station Identifierflow identifier, and quality of service including QoS identifiers is FFS.

The random access bandwidth request procedure is described in Figure 41. A 5-step regular procedure (step 1 to 5) or an optional quick access procedure (step 1,4 and 5) may be supported concurrently. Step 2 and 3 are used only in 5-step regular procedure. In step 1, MS sends a bandwidth request indicator that may indicate information such as MS addressing and/or request size (FFS) and/or uplink transmit power report (FFS), and the BS may allocate uplink grant based on certain policy. The 5-step regular procedure is used independently or as fallback mode for quick access procedure. The MS may piggyback additional BW-REQ information along with user data during uplink transmission (step 5). In step 2 and step 4, BS may send message to acknowledge the reception status.

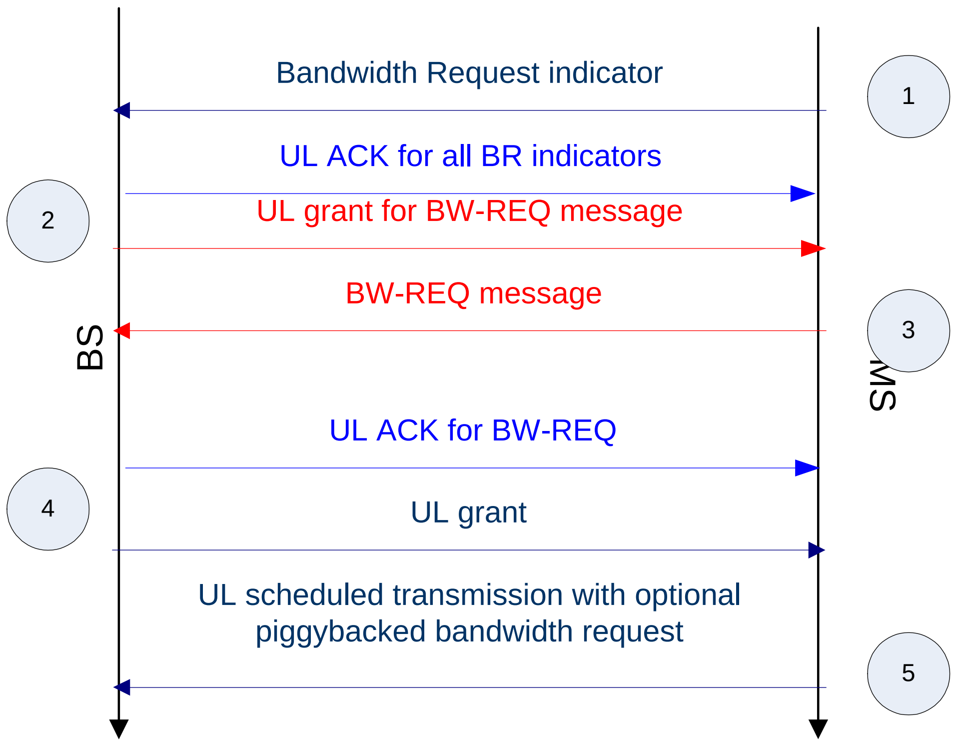

Figure 41 Bandwidth Request Procedure

11.9.2.5.1 Multiplexing with other control channels and data channels

The bandwidth request channel starts at a configurable location with the configuration defined in a DL broadcast control message. The bandwidth request channel is FDM with other UL control and data channels.

11.9.2.5.2 PHY structure

The structure of bandwidth request channel resource blocks, pilots and resource mapping are TBD. The ranging sequence design and mapping to subcarriers are TBD. The bandwidth request (BW-REQ) channel contains resources for the MS to send in BW-REQ access sequence and optional message for quick access at thestep-1 of bandwidth request procedure shown in Figure 41.

11.9.3 UL Inband Control Signaling

Uplink control information can be multiplexed with data on the UL data channels as MAC headers or MAC management messages. Inband control signaling can contain information such as uplink bandwidth requests or bandwidth assignment updates.

11.9.4 Mapping of UL control information to UL control channels

<Editors’ Notes: This table needs to be updated as the mapping of UL control information to UL control channels is developed.>

Information	Channel

Channel quality feedback	UL Fast Feedback Channel
MIMO feedback	UL Fast Feedback Channel
HARQ feedback	UL HARQ Feedback Channel
Sounding	UL Sounding Channel
Synchronization	UL Ranging Channel
Bandwidth request	Bandwidth Request Channel
	UL Inband Control Signaling
	UL Fast Feedback Channel
E-MBS feedback	FFS

11.10 Power Control

The power control scheme shall be supported for DL and UL based on the frame structure, DL/UL control structures, and fractional frequency reuse (FFR). Two power control modes, namely open-loop power control and closed-loop power control should be supported to maintain the quality of the radio link between the MS and the BS and to control the overall system interference.

11.10.1 Downlink Power Control

The BS should be capable of controlling the transmit power per sub-frame and per each user. This is useful for self-organization/optimization networks (e.g., pico-cell, femto-cell and relay networks). With downlink power control, each user-specific information or control information would reach to the MS with the required power level. DL user specific control channel (USCCH) should be power controlled based on MS UL channel quality feedback.

The per pilot tone power and the per data tone power can jointly be adjusted for adaptive downlink power control. In the case of dedicated pilots this is done on a per user basis and in the case of common pilots jointly for the users sharing the pilots.

Power Control in DL supports Single-User MIMO and Multi-User MIMO applications.

11.10.2 Uplink Power Control

Uplink power control shall be supported to compensate the pathloss, shadowing, fast fading and implementation loss. Uplink power control should also be used to control inter-cell and intra-cell interference level. Uplink power control should also consider optimization of overall system performance and the reduction of battery consumption. Uplink power control consists of two different modes: open-loop power control (OLPC) and closed-loop power control (CLPC). BS can transmit necessary information through control channel or message to MSs to support uplink power control. The parameters of power control algorithm are optimized on system-wide basis by the BS, and broadcast periodically or trigged by events.

MS can transmit necessary information through control channel or message to the BS to support uplink power control. BS can exchange necessary information with neighbor BSs through backbone network to support uplink power control.

In high mobility scenarios, power control scheme may not be able to compensate the fast fading channel effect because of the very dynamic changes of the channel response. As a result, the power control shall be used to compensate the distance-dependent path loss, shadowing and implementation loss only.

Uplink power control should consider the transmission mode depending on the single- or multi-user support in the same allocated resource at the same time.

11.10.2.1 Open-loop Power Control (OLPC)

The OLPC compensates the channel variations and implementation loss without frequently interacting with BS. The MS can determine the transmit power based on the transmission parameters sent by the BS, downlink channel state information and interference knowledge obtained from downlink. Mobile stations use uplink open loop power control applying channel and interference knowledge to operate at optimum power settings.

Open-loop power control could provide a coarse initial power setting of the terminal at the beginning of a connection.

As for mitigating inter-cell interference, power control may consider serving BS link target SINR and/or target Interference to other cells/sectors. In order to achieve target SINR, the serving BS path-loss can be fully or partially compensated for a tradeoff between overall system throughput and cell edge performance. When considering target interference to other cells/sectors, mobile station TX power is controlled to generate less interference than the target interference levels. The compensation factor and interference targets are determined and broadcasted by BS, with considerations including FFR pattern, cell loading and etc. More details can be referred to section 20.3.

11.10.2.2 Closed-loop Power Control (CLPC)

The CLPC compensates channel variation with power control command from BS. Base station measures uplink channel state information and interference information using uplink data and/or control channel transmissions and sends power control command to MSs while minimizing signaling overhead.

According to the power control command from BS, MS adjust its UL transmission power. The adjustment step of CLPC is FFS.

11.10.2.3 Coupling of Open Loop and Closed Loop Power Control

OLPC and CLPC can be combined into a unified power control procedure that uses both MS measurements and BS corrections for efficient operations. Closed loop power control is active during data transmission. Close loop power control measures uplink power using uplink data and/or control channel transmissions and sends control command. Moreover, the fast-moving MS could request to change the power control mode from open-loop to closed-loop and vice versa. The BS could also send the unsolicited power control mode change command to the MS.

11.11 Link Adaptation

This section introduces the Link Adaption schemes which will adaptively adjust radio link transmission formats in response to change of radio channel for both downlink and uplink.

11.11.1 DL Link Adaptation

11.11.1.1 Adaptive modulation and channel coding scheme

IEEE 802.16m shall support the adaptive modulation and channel coding (AMC) scheme for DL transmission. The serving BS can adapt the modulation and coding scheme (MCS) level based on the DL channel quality indicator (CQI) reported from MS. The definition of CQI is FFS. DL control channel transmit power should also be adapted based on DL channel quality indicator (CQI) reported from MS.

11.11.2 UL Link Adaptation

11.11.2.1 Adaptive modulation and channel coding scheme

IEEE 802.16m shall support the adaptive modulation and channel coding (AMC) scheme for UL transmission. The serving BS can adapt the modulation and coding scheme (MCS) level based on the UL channel quality estimation and the maximum transmission power by MS. The definition of UL channel indicator is FFS. Note that the UL AMC may be integrated with UL power control and interference mitigation schemes to further achieve higher spectral efficiency. UL control channel (excluding initial ranging channel) transmit power should also be adapted based on UL power control.

11.11.3 Transmission Format

[Note: The content of this section shall not contradict with the transmission format determined by HARQ RG and PHY text RG]

IEEE 802.16m system should support the transmission format used in legacy system for the purpose of legacy support. IEEE 802.16m can have transmission format independent of legacy transmission format, and IEEE 802.16m transmission format is FFS.

11.12 UL MIMO Transmission Scheme

11.12.1 UL MIMO Architecture and Data Processing

The architecture of uplink MIMO on the transmitter side is illustrated in Figure 42.

In SU-MIMO, only one user is scheduled in one Resource Unit (RU). In MU-MIMO, multiple users can be scheduled in one RU.

If vertical encoding is utilized, there is only one encoder/modulator block (one “layer”). If horizontal encoding is utilized, there are multiple encoders / modulators (multiple “layers”). A “layer” is defined as a coding / modulation path fed to the MIMO encoder as an input, and a “stream” is defined as each output of the MIMO encoder that is passed to the beamformer / precoder.

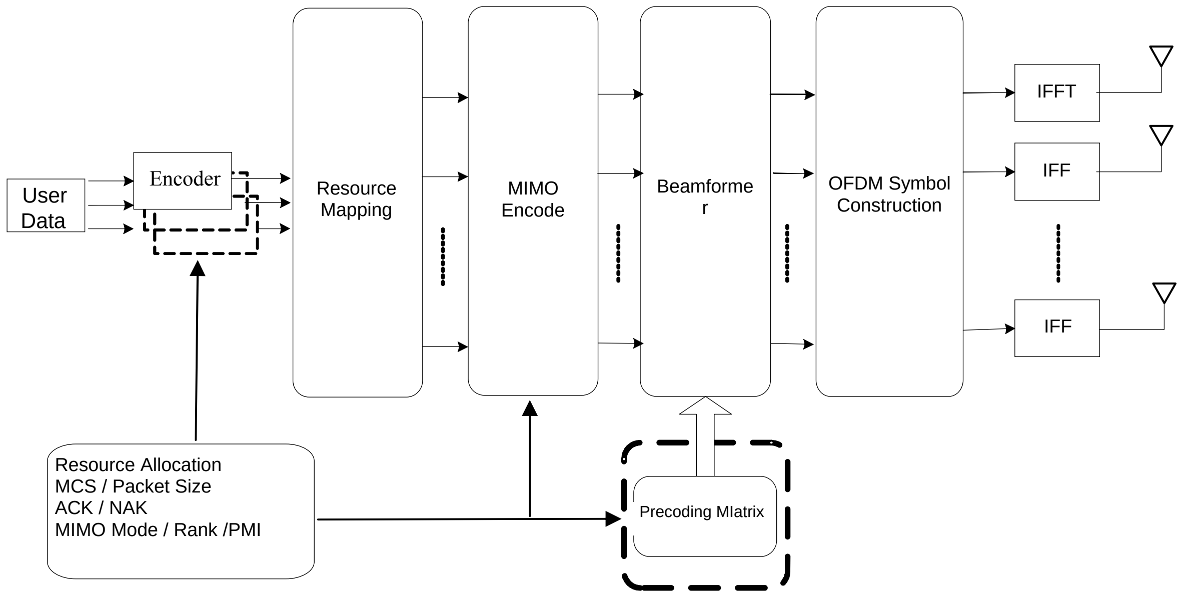

Figure 42 MIMO Architecture

The encoder block contains the channel encoder, interleaver, rate-matcher, and modulator for each layer.

The Resource Mapping block maps the modulation symbols to the corresponding time-frequency resources in the allocated resource units (RUs).

The MIMO encoder block maps L ($\geq$1) layers onto N_S ($\geq$L) streams, which are fed to the precoding block.

The precoding block maps streams to antennas by generating the antenna-specific data symbols according to the selected MIMO mode.

The OFDM symbol construction block maps antenna-specific data to the OFDM symbol.

If only one transmit antenna is used, the codeword to stream mapping, MIMO encoding and precoder are removed in Figure 1.

The base station (BS) will schedule users to resource blocks and decides their MCS level, MIMO parameters (MIMO mode, rank). PMI may be calculated at the BS or MS.

Decisions with regards to each resource allocation include:

- ***Allocation type***: Whether the allocation in question should be transmitted with a distributed or localized allocation
- ***Single-user (SU) versus multi-user (MU) MIMO***: Whether the resource allocation should support a single user or more than one user
- ***MIMO Mode***: Which open-loop (OL) or closed-loop (CL) transmission scheme should be used for the user(s) assigned to the resource allocation.
- ***User grouping***: For MU-MIMO, which users are allocated to the resource allocation
- ***Rank selection***: For the spatial multiplexing modes in SU-MIMO, the number of streams to be used for the user allocated to the resource allocation.
- ***MCS level per layer***: The modulation and coding rate on each layer must be determined.

- ***Boosting***: The power boosting values to be used on the data and pilot subcarriers.
- ***Band selection***: If localized resource allocation is used, the frequency band location.

11.12.1.1 Antenna Configuration

The antenna configurations are denoted by (N_T, N_R) where N_T denotes the number of MS transmit antennas and N_R denotes the number of BS receive antennas. The supported antenna configurations are N_T = 1, 2, or 4 and N_R ≥ 2. Support of N_T = 3 is FFS.

11.12.1.2 Layer to Stream Mapping

For open-loop spatial multiplexing and closed-loop SU-MIMO, the number of streams, $N_S \le \min(N_T, N_R)$. For open-loop transmit diversity modes, N_S depends on the STC schemes employed by the MIMO encoder and its value is specified in Table 11.10.2.1.1-1. For SU-MIMO and MU-MIMO, Vertical encoding (SCW) is employed [Support for MCW is FFS pending decisions in DL MIMO].

11.12.1.3 Stream to Antenna Mapping

The stream to antenna mapping depends on the MIMO scheme used. The mapping can be defined using the following equation

$\mathbf{y} = \mathbf{P} \times \mathbf{S}(\mathbf{x})$, Equation 24

where **P** is a pre-coding matrix, **S**(**x**) is an STC matrix, and **x** is the input layer vector.

11.12.1.4 Resource mapping

The following table illustrates the MIMO mode permutation for various MIMO schemes.

Table 6 Supported resource channels in MIMO

MIMO Scheme	Resource Mapping
Open-loop SU-MIMO	Distributed or Localized
Open-loop MU-MIMO	Distributed or Localized
Closed-loop SU-MIMO	Distributed or Localized
Closed-loop MU-MIMO	Distributed or Localized

11.12.1.5 Signaling support for MIMO

One or both of the following approaches for TDD and FDD will be supported:

1. Downlink reference signals. These reference signals (e.g. Common Pilots or a Midamble) shall support measurements at the MS of the channel from the physical antennas of the BS.
2. A downlink control channel may carry one or more of the following information computed based on uplink reference signals. Such information can include but is not limited to the following:
    a. MIMO mode
    b. Precoding matrix index (PMI)

In FDD systems and TDD systems, a base station may transmit the following uplink MIMO transmission parameters in the uplink closed-loop SU-MIMO mode:

- Rank
- Sub-band selection
- MCS / packet size
- PMI

The uplink MIMO transmission parameters may be transmitted via a physical layer control channel or via a higher layer signaling message.

11.12.2 Transmission for Data Channels

11.12.2.1 Single-user MIMO

Single-user MIMO schemes are used to improve per-link performance in the uplink.

Both open-loop single-user MIMO and closed-loop single-user MIMO are supported for the antenna configurations specified in Section 11.12.1.1.

For open-loop single-user MIMO, both spatial multiplexing and transmit diversity schemes are supported.

For closed-loop single-user MIMO, codebook based precoding is supported for both TDD and FDD systems.

For closed-loop single-user MIMO, downlink pilot based precoding is supported for TDD systems.

As described in section 11.12.1, the overall structure of MIMO processing has two parts. The first part is the MIMO encoder and second part is the precoder.

The MIMO encoder is a batch processor that operates on M input symbols at a time. The input to the MIMO encoder is represented by an $M \times 1$ vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_M \end{bmatrix}$$, Equation 25

where s_i is the i-th input symbol within a batch. The output of the MIMO encoder is an $N_S \times N_F$ MIMO STC matrix $\mathbf{z} = \mathbf{S}(\mathbf{x})$, which serves as the input to the precoder. The output of the precoder is denoted by a matrix $N_T \times N_F$ matrix

$$\mathbf{y} = \begin{bmatrix} y_{1,1} & y_{1,2} & \cdots & y_{1,N_F} \\ y_{2,1} & y_{2,2} & \cdots & y_{2,N_F} \\ \vdots & \vdots & \ddots & \vdots \\ y_{N_T,1} & y_{N_T,2} & \cdots & y_{N_T,N_F} \end{bmatrix}$$, Equation 26

where $y_{i,j}$ is the output symbol to be transmitted via the i-th physical antenna on the j-th subcarrier/symbol. Note N_F is the number of subcarriers or symbols used to transmit the MIMO signals derived from the input vector **x**.

For open-loop SU-MIMO, the rate of a mode is defined as $R = M / N_F$.

11.12.2.1.1 Open-loop SU-MIMO

A number of antenna configurations and transmission rates are supported in uplink open-loop SU-MIMO. Among them, 2Tx and 4Tx antennas with rate 1 transmission are defined as Transmit Diversity modes. The operation of these modes is specified in Section 11.12.2.1.1.1. The other modes, including 2Tx and 4Tx antennas with rate 2 transmission, 4Tx antennas with rate 3 transmission, and 4Tx antennas with rate 4 transmission, are defined as Spatial Multiplexing modes. The operation of these modes is specified in Section 11.12.2.1.1.2. The dimensions of the vectors and matrices for open-loop SU-MIMO are shown in the following table:

Table 7 Matrix dimensions for open-loop SU-MIMO modes

N_T	Rate	M	N_S	N_F
2	1	1	1	1
2	1	2	2	2
4	1	1	1	1
4	1	2	2	2
2	2	2	2	1
4	2	2	2	1
4	3	3	3	1
4	4	4	4	1

On a given frequency resource k [size is FFS], the precoding matrix **P** can be defined using the following equation:

$\mathbf{P}(k) = \mathbf{D}(k)\mathbf{W}(k)$, Equation 27

The precoder is composed of two matrices. The first matrix $\mathbf{W}(k)$ is an $N_T \times N_S$ matrix, where N_T is the number of transmit antennas and N_S is the number of streams. The matrix $\mathbf{W}(k)$ is selected from a predefined unitary codebook, and changes every u subcarriers. A codebook is a unitary codebook if each of its matrices consists of columns of a unitary matrix. [The detailed unitary codebook, and the parameter u are FFS.] The second matrix $\mathbf{D}(k)$ is an $N_T \times N_T$ diagonal matrix as follows,

$$\mathbf{D}(k) = \begin{bmatrix} e^{j\theta_0 k} & 0 & \cdots & 0 \\ 0 & e^{j\theta_1 k} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & e^{j\theta_{(N_T-1)} k} \end{bmatrix}, \text{ Equation 28}$$

where k denotes frequency resource index and $\theta_i, i = 0, 1, 2, ..., N_T - 1$ denotes the phase shift for the i-th transmit antenna across two adjacent frequency resources. [The value of θ_i is FFS.]

For OL SU-MIMO, the following schemes are FFS: rate-1 STBC/SFBC and rate-2 Double STBC/SFBC, 2-D POD for rate-1 and rate-2, rate-3 hybrid SM+STBC/SFBC, differential STBC/SFBC, Antenna hopping, and SM+Antenna hopping.

11.12.2.1.1.1 Transmit Diversity

The following transmit diversity modes are supported for open-loop single-user MIMO:

- 2Tx rate-1: STBC/SFBC, and rank-1 precoder
- 4Tx rate-1: STBC/SFBC with precoder, and rank-1 precoder

In Transmit Diversity mode, the MIMO encoder generates 2Tx STBC/SFBC, and then multiplied by $N_T \times 2$ matrix and $N_T \times N_T$ diagonal matrix as described in section 11.12.1.1.

For the transmit diversity modes, for M=1, the input to MIMO encoder is

$$\mathbf{x} = s_1,$$

and the output of the MIMO encoder is a scalar

$$\mathbf{z} = \mathbf{x}.$$

The output of the rank-1 precoder for $N_T = 2$, and 4 Tx antennas is a $N_T \times 1$ matrix

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z}$$

where **W** and **D** may be frequency and/or time dependent as described in section 11.12.2.1.1.

For the transmit diversity modes, the input to the MIMO encoder is represented a 2×1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix},$$ Equation 29

The output of the MIMO encoder is a 2×2 matrix

$$\mathbf{z} = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix},$$ Equation 30

For the 2Tx rate-1 mode, the output of the precoder is a 2×2 matrix

$$\mathbf{y} = \mathbf{z},$$ Equation 31

For the 4Tx rate-1, the output of the precoder is a 4×2 matrix

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$ Equation 32

where **W** is a 4×2 precoder and **D** is a 4×4 diagonal phase matrix. Note that **W** and **D** may be frequency dependent as described in section 11.12.2.1.1.

11.12.2.1.1.2 Spatial Multiplexing

The following spatial multiplexing modes are supported for open-loop single-user MIMO:

- Rate-2 spatial multiplexing modes:
  - 2Tx rate-2: rate 2 SM
  - 4Tx rate-2: rate 2 SM with precoding
- Rate-3 spatial multiplexing modes:
  - 4Tx rate-3: rate 3 SM with precoding
- Rate-4 spatial multiplexing modes:
  - 4Tx rate-4: rate 4 SM

For the rate-2 spatial multiplexing modes, the input to the MIMO encoder is represented as a 2 × 1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}$$, Equation 33

The output of the MIMO encoder is a 2 × 1 vector

$$\mathbf{z} = \mathbf{x}$$, Equation 34

For the 2Tx rate-2 mode, the output of the precoder is a 2 × 1 vector

$$\mathbf{y} = \mathbf{z}$$, Equation 35

For the 4Tx rate-2 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z}$$, Equation 36

where **W** is a 4 × 2 precoder and **D** is a 4 × 4 diagonal phase matrix. Note that **W** and **D** may be frequency dependent as described in section 11.12.2.1.1.

For the rate-3 spatial multiplexing modes, the input to the MIMO encoder is represented as a 3 × 1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix}$$, Equation 37

The output of the MIMO encoder is a 3 × 1 vector

$$\mathbf{z} = \mathbf{x}$$, Equation 38

For the 4Tx rate-3 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z}$$, Equation 39

where **W** is a 4 × 3 precoder and **D** is a 4 × 4 diagonal phase matrix. Note that **W** and **D** may be frequency dependent as described in section 11.12.2.1.1.

For the rate-4 spatial multiplexing modes, the input to the MIMO encoder is represented as a 4×1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix}$$, Equation 40

The output of the MIMO encoder is a 4 × 1 vector

$$\mathbf{z} = \mathbf{x}$$, Equation 41

For the 4Tx rate-4 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{z}$$, Equation 42

11.12.2.1.2 Closed-loop SU-MIMO

11.12.2.1.2.1 Precoding technique

In FDD and TDD systems, unitary codebook based precoding is supported. In this mode, a mobile station transmits a sounding pilot in the uplink to assist the uplink scheduling and precoder selection in the base station. The base station signals the resource allocation, MCS, rank, preferred precoder index, and packet size to the mobile station. The codebook on the uplink shall be the same or a subset of the SU-MIMO codebook in the downlink. The uplink codebook shall be constant modulus.

In TDD systems, downlink pilot based precoding is supported. In this mode, a mobile station transmits a sounding pilot in the uplink to assist the uplink scheduling in the base station. The base station signals the resource allocation, MCS, rank, and packet size to the mobile station. The mobile station chooses the precoder based on the downlink CQI measurement pilot. The precoder is vendor-specific. It is FFS whether the mobile station will feedback the rank and MCS to assist the uplink scheduling in the base station.

The support of transmit antenna selection is FFS.

11.12.2.1.3 Uplink overhead channels for uplink SU-MIMO

In FDD systems and TDD systems, a mobile station may transmit a sounding signal on the uplink.

11.12.2.2 Multi-user MIMO

Uplink Multi-user MIMO is supported to enable multiple MSs spatially multiplexed on the same radio resources (e.g. the same time and the same frequency allocation) for uplink transmission.

Both open-loop and closed-loop MU-MIMO are supported.

MS precoding and/or beamforming is supported.

11.12.2.2.1 Precoding techniques

In MU-MIMO systems, the received signal of the *f*-th subcarrier at the BS can be represents as follows.

$$\mathbf{y}_f = \sum_{j=1}^{K} \mathbf{H}_{j,f} \mathbf{V}_{j,f} \mathbf{x}_{j,f} + \mathbf{n}_f$$

, Equation 43

where K is the number of the allocated users on one resource unit, $H_{j,f}$ is the uplink channel response of the f-th subcarrier from the j-th MS to the BS; $\mathbf{V}_{j,f}$ is the precoding matrix of the f-th subcarrier from the j-th MS; $\mathbf{x}_{j,f}$ is the transmit signal of the f-th subcarrier from the j-th MS; and $\mathbf{n}_f$ is the noise of the f-th subcarrier received at the BS.

In FDD and TDD systems, unitary codebook based precoding is supported. In TDD systems, downlink pilot based precoding is supported and the precoder is vendor-specific. The number of MSs or streams to support on the same time-frequency resource is also vendor/implementation specific. Different pilot patterns may be employed on different streams. Specific pilot patterns are FFS. The maximum number of pilot streams is limited to 4.

11.12.2.2.2 Open-loop MU-MIMO

MSs with single transmit antenna are supported in open-loop MU-MIMO transmissions. MSs with multiple transmit antennas are also supported in open-loop MU-MIMO transmissions. All uplink open-loop SU-MIMO modes are supported in open loop MU-MIMO for MSs with more than one transmit antenna.

11.12.2.2.3 Closed-loop MU-MIMO

Unitary codebook based precoding is supported for both TDD and FDD. In this case, the MS shall follow indication of PMI from the BS in a downlink control channel and perform codebook based precoding. Downlink pilot based precoding is supported in TDD systems. In this case, the precoder may be vendor-dependent.

Non-unitary precoding is FFS.

11.12.2.2.4 Unification with SU-MIMO

Unified codebook for SU and MU may be supported.

11.12.2.2.5 Feedback for MU-MIMO

Feedback with an uplink sounding signal is supported.

11.13 Channel coding and HARQ

11.13.1 Channel coding

11.13.1.1 Block diagram

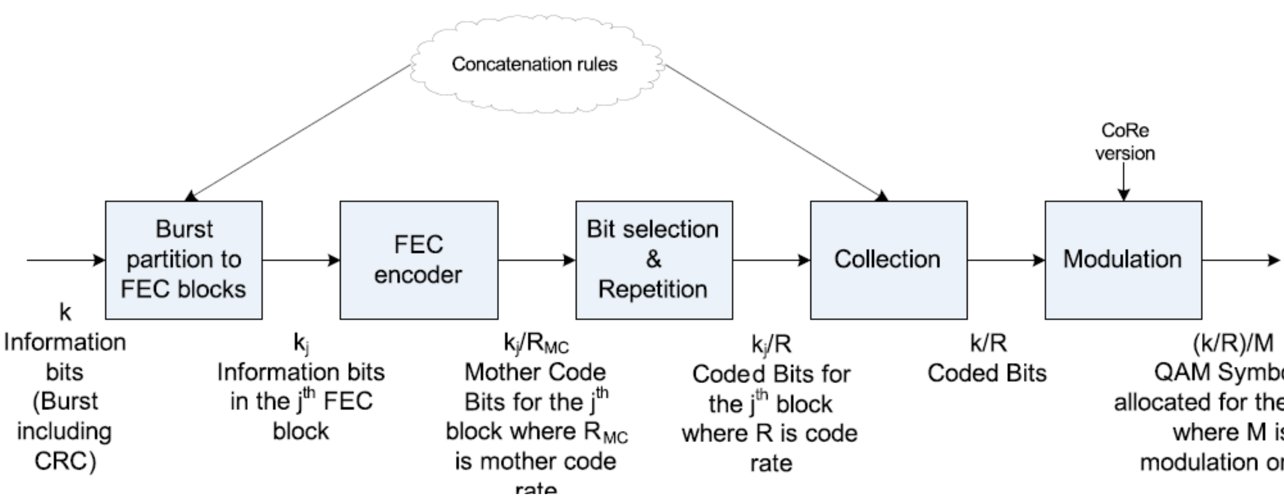

Figure 43 Channel coding block diagram

11.13.1.2 Partition into FEC blocks

When the burst size exceeds the maximum FEC block size, the burst is partitioned into a number of smaller blocks, each of which is encoded separately. The maximum FEC block size is TBD. Concatenation rules are based on the number of information bits and do not depend on the structure of the resource allocation (number of LRUs and their size). The concatenation rules are FFS. Error detection is provided at the end of the burst by appending a Cyclic Redundancy Check (CRC).

11.13.1.3 FEC encoding

IEEE 802.16m uses the CTC (convolutional turbo code) of code rate 1/3 defined in the IEEE 802.16e standard.

The code rate of the "FEC Encoder" block in Figure 43 is termed mother code rate (RMC). The use of other coding schemes like CC and LDPC are FFS.
The CTC scheme is extended to support additional FEC block sizes. FEC block sizes larger than the legacy ones
are supported. The FEC block sizes are FFS and they are independent of the transmission format, including code rate, modulation order, and resource allocation. Further, the FEC block sizes are regularly increased with pre-determined block size resolutions. The FEC block sizes which are multiple of 7 shall be removed for the tail-biting encoding structure with the detailed mechanism being FFS.
The encoder block depicted in Figure 43 includes the sub-block interleavers. The interleaving details are FFS.

11.13.1.4 Bit selection and repetition

Bit selection and repetition are used in 802.16m to achieve rate matching. Bit selection adapts the number of coded bits to the size of the resource allocation (in QAM symbols) which may vary depending on the LRU and subframe type. The Mother Code Bits after the FEC are considered as a circular buffer. Repetition is performed when the number of transmitted bits is larger than the number of Mother Code Bits (total number of information and parity bits generated by FEC encoder). The selection of coded bits is done cyclically over the buffer.

11.13.1.5 Modulation

Modulation constellations of QPSK, 16 QAM, and 64 QAM are supported as defined for the legacy system. The
mapping of bits to the constellation point depends on the constellation-rearrangement (CoRe) version used for HARQ re-transmission as described in Section 11.x.1.2.2 and may depend on the MIMO stream. QAM Symbols are mapped to the input of the MIMO encoder. The use of Hierarchical Modulation is FFS.

11.13.2 HARQ

11.13.2.1 HARQ type

Incremental redundancy Hybrid-ARQ (HARQ IR) is used in 802.16m by determining the starting position of the bit selection for HARQ retransmissions. The rule for determining the starting position is FFS.

11.13.2.2 Constellation re-arrangement

Constellation re-arrangement (Co-Re) is supported in 802.16m. For each transmitted bit, the CoRe-version is selected by the transmission number of this bit. The specific selection mechanism is FFS.

11.13.2.3 Adaptive HARQ

The resource allocation in each retransmission in both downlink and uplink can be fixed or adaptive according to control signaling. The support of adaptive HARQ and the specific mechanism for adaptive HARQ are FFS, while the reduction of signaling overhead should be considered as an important criterion for those studies.

11.13.2.4 Exploitation of frequency diversity

In HARQ re-transmissions, the bits or symbols are transmitted in a different order to exploit the frequency diversity of the channel. The mechanism is FFS.

11.13.2.5 MIMO HARQ

For HARQ subpacket retransmission, the mapping of bits or modulated symbols to spatial streams may be applied to exploit spatial diversity with given mapping pattern, depending on the type of IR. In this case, the predefined set of mapping patterns should be known to both transmitter and receiver. The specific mechanism is FFS and it should be determined with the consideration of MIMO architecture and data processing for IEEE

11.13.2.6 HARQ feedback

A basic ACK/NAK channel to transmit 1-bit feedback is supported.
An enhanced ACK/NAK control channel with some additional information is FFS.

12 Inter-Radio Access Technology Functions

13 Support for Location Based Services

14 Support for Enhanced Multicast Broadcast Service

15 Support for multi-hop relay

16 Solutions for Co-deployment and Co-existence

17 Support for Femtocell

18 Support for Self-organization

19 Support for Multi-carrier Operation

19.1 Multi-carrier operation Principles

The following is common in all modes of multi-carrier operation:

- The system defines N standalone fully configured RF carriers as defined in section 11.7.4, each fully configured with all synchronization, broadcast, multicast and unicast control signaling channels. Each MS in the cell is connected to and its state is controlled through only one of the fully configured carriers as its primary carrier.
- The system defines M (M >= 0) partially configured RF carriers as defined in section 11.7.4, each configured with the essential control channel configuration to support traffic exchanges during multicarrier operation.
- In the multicarrier operation a common MAC can utilize radio resources in one or more of the secondary carriers, while maintaining full control of MS mobility, state and context through the primary carrier.
- Some information about the secondary carriers including their presence and location shall be made available to the MS through the primary carriers. The primary carrier may also provide MS the information about the configuration of the secondary carrier.
- The resource allocation to a MS can span across a primary and multiple secondary RF carriers. Link adaptation feedback mechanisms should incorporate measurements relevant to both primary and secondary carriers.
- A multi-carrier system may assign secondary carriers to an MS in the downlink and/or uplink

asymmetrically based on system load (i.e., for static/dynamic load balancing), peak data rate, or QoS demand.

- In addition to its primary RF carrier data transfer between a BS and itself, an MS may dynamically utilize resources across multiple secondary RF carriers. Multiple MS, each with a different primary RF carrier may also share the same secondary carrier.
- The multiple carriers may be in different parts of the same spectrum block or in non-contiguous spectrum blocks. The use of non-contiguous spectrum blocks may require additional control information on the secondary carriers.
- Each MS will consider only one fully configured RF carrier to be its primary carrier in a cell. A secondary carrier for an MS, if fully configured, may serve as primary carrier for other MS's.

There are two scenarios to multicarrier deployment.

Scenario 1: All carriers in the system are fully configured to operate standalone and may support some users as their primary carrier and others as their secondary carrier. MS can, in addition, access on secondary channels for throughput improvement, etc.

Scenario 2: In addition to fully configured and standalone RF carriers the system also utilizes additional partially configured supplementary radio carriers optimized as data pipes for certain services or traffic types using limited control signaling capability. Such supplementary carriers may be used only in conjunction with a primary carrier and cannot operate standalone to offer IEEE 802.16m services for a MS.

In multi-carrier operation, an MS can access multiple carriers. The following multi-carrier operations are identified:

- Carrier aggregation
  - MS shall always maintain its physical layer connection and monitor the control information on the primary carrier.
- Carrier switching
  - MS can switch its physical layer connection from the primary to the secondary carrier per BS' instruction. When the MS is connected to the secondary carrier, the MS doesn't need to maintain its physical layer connection to the primary carrier.
  - This mode may be used for the cases of single radio MS.

19.2 Subcarrier Alignment for Utilization of Guard Subcarriers of Adjacent Frequency Channels

When multiple contiguous frequency channels are available, the guard sub-carriers between contiguous frequency channels can be utilized for data transmission only if the sub-carriers from adjacent frequency channels are well aligned. In order to align those sub-carriers from adjacent frequency channel, a frequency offset ($\Delta f'$) can be applied to its FA. The basic idea is shown by the example in Figure 44.

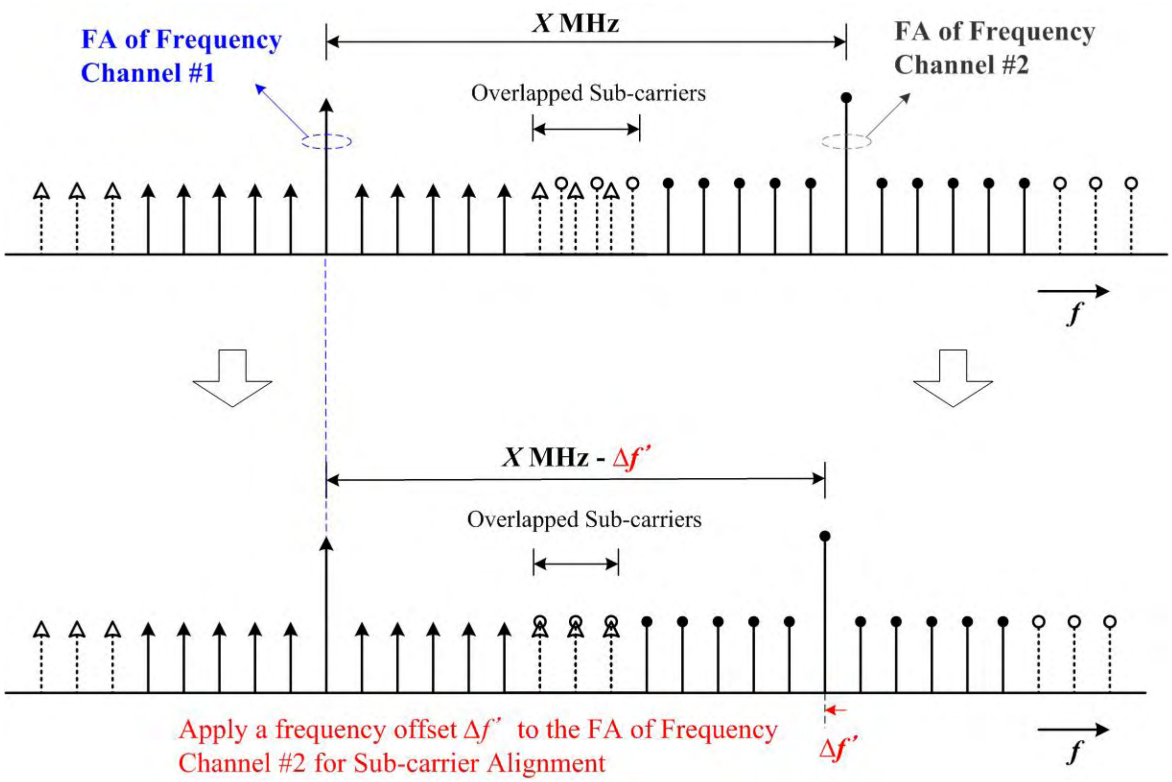

Figure 44 Sub-carrier alignment by applying a fraction of sub-carrier spacing to the FA of adjacent frequency channel

In order to utilize the guard sub-carrier for data transmission, the information of the available guard sub-carriers eligible for data transmission shall be sent to MS. This information shall include the numbers of available sub-carriers in upper side and in lower side with respect to the DC sub-carrier of carrier.

20 Support for Interference Mitigation

This section introduces the interference mitigation schemes by using fractional frequency reuse (FFR), advanced antenna technology, power control and scheduling.

20.1 Interference Mitigation using Fractional Frequency Reuse (FFR)

IEEE 802.16m shall support the fractional frequency reuse (FFR) to allow different frequency reuse factors to be applied over different frequency partitions during the designated period for both DL and UL transmissions, note that the frequency partition is defined in 11.5.2.2 and in 11.6.2.2 for DL and UL respectively. The operation of FFR is usually integrated with other functions like power control or antenna technologies for adaptive control and joint optimization. The basic concept of FFR is introduced by the example in Figure 45.

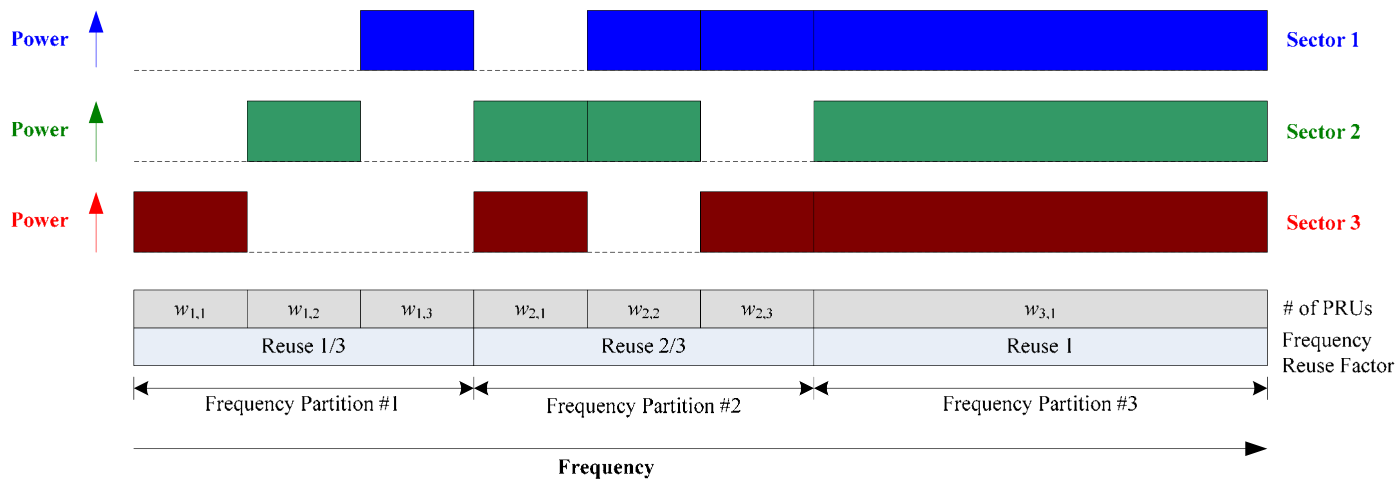

Figure 45 Basic Concept of Fractional Frequency Reuse (FFR)

In basic FFR concept, subcarriers across the whole frequency band are grouped into frequency partitions with different reuse factors. In general, the received signal quality can be improved by serving MSs in the frequency partitions with lower frequency reuse factor, due to lower interference levels. This will be helpful for the MSs located around cell boundary or for the MSs suffer severe inter-cell interference. On the other hand, BS may apply higher frequency reuse factor for some frequency partitions to serve the MSs which does not experience significant inter-cell interference. This will be helpful for BS to serve more MSs and achieve better spectral efficiency.

Resource allocation in an FFR system takes several factors into consideration such as reuse factor in partition, power at partition, available multi-antenna technologies, as well as interference-based measurements taken at MS.

20.1.1 Downlink (DL) FFR

20.1.1.1 Interference Measurement and Signaling Support

For DL FFR, the MSs shall be capable of reporting the interference information to serving BS. The serving BS can instruct MS to perform interference measurement over the designated radio resource region in solicited/unsolicited manner, or the MS may perform the autonomous interference measurement without the instruction by BS. Examples of interference measurement include SINR, SIR, interference power, RSSI, etc. The MS can also recommend the preferred frequency partition to serving BS based on considerations such as interference measurements, resource metric of each partition, etc.. The measurement results can then be reported by message and/or feedback channel.

The BS can transmit necessary information through a signaling channel or message to facilitate the measurement by MS. The information includes the frequency reuse parameters of each frequency partitions, the corresponding power levels and associated metric for each partition. Resource metric of each FFR partition is the measure of the overall system resource usage by the partition (such as effective bandwidth due to reuse, transmission power, multi-antennas, and interference to other cells and so on). The use of resource metric is

FFS.

20.1.1.2 Inter-BS Coordination

In order to support FFR, the BSs shall be capable of reporting interference statistics and exchanging its FFR configuration parameters which may include FFR partitions, power levels of each partition, associated metric of each partition with each other or with some control element in the backhaul network. Note that some of the coordination may be achieved by signaling over air-interface and the configuration format for FFR coordination is FFS.

The Figure 46 shows an example to integrate FFR with DL power control. This allows the system to adaptively designate different DL power boosting over different PRUs in each frequency partition. The power allocation of each PRU may be higher or lower than normal level, it should be well coordinated from system-wide consideration.

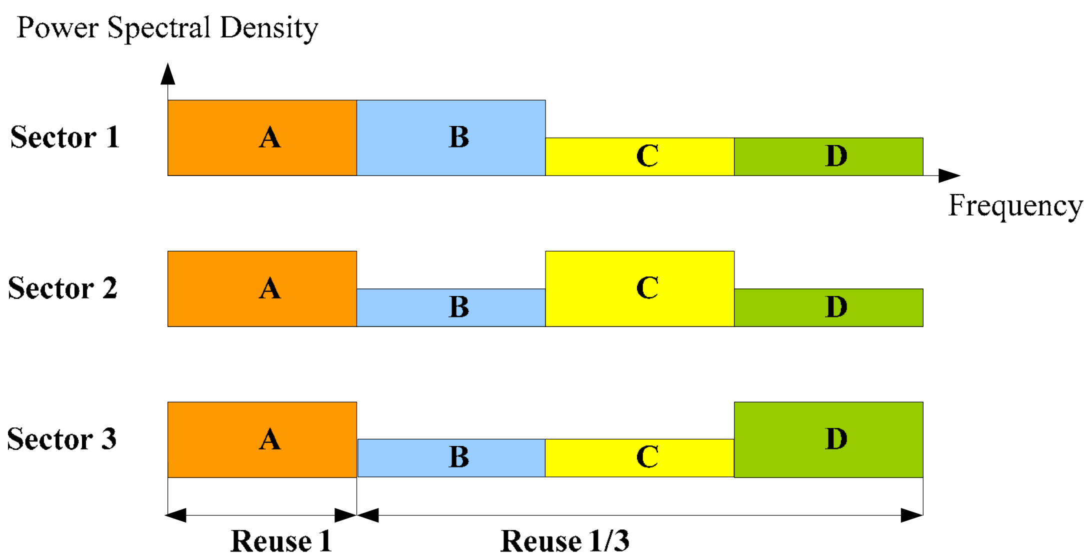

Figure 46 Example to integrate FFR and DL power control

20.1.2 Uplink (UL) FFR

20.1.2.1 Interference Measurement and Signaling Support

For UL FFR, the BSs shall be capable to estimate the interference statistics over each frequency partitions. In order to support UL FFR, the BS can transmit necessary information through a feedback channel or message to the MS. The information can include the frequency reuse parameters of each frequency partitions and the corresponding UL power control target.

20.1.2.2 Inter-BS Coordination

In order to support UL FFR, the BSs shall be capable of reporting its interference statistics and to exchange its FFR configuration and corresponding UL power control target with each other or with some control element in the backhaul network. Note that some of the coordination may be achieved by signaling over air-interface and the configuration format for FFR coordination is FFS.

The Figure 47 (a,b) shows examples of integration of FFR with UL power control (Section 11.x). In Figure 47(a), system adaptively designates different IoT targets for UL power control over different PRUs in each frequency partition. A MS assigned for a partition needs to do power control properly considering the target IoT level of other cells for that partition. If the target IoT level of other cells for a partition is low, for example, a MS assigned for that partition should transmit with lower power not to interfere other cell users. If the target IoT level of other cells for a partition is high, then a user assigned for that partition may transmit with a higher power. To control system-wide interference, the BS can adjust the frequency partitions and the corresponding target IoT level in coordination with other BSs.

Another example for SINR based UL power control is given in Figure 47(b), where different target SINR level may be designated for different frequency partitions.

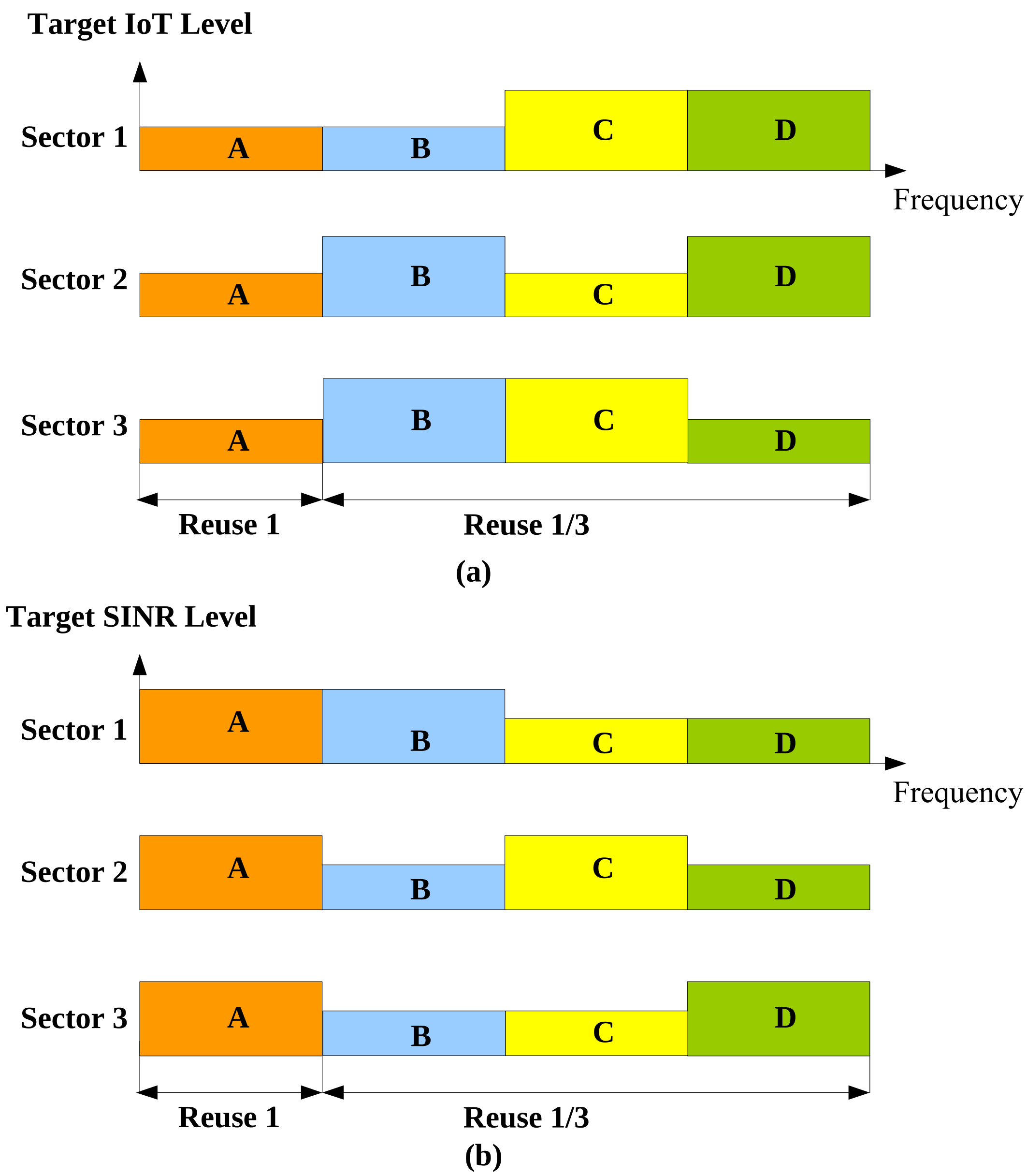

Figure 47 Example to integrate FFR and UL power control

20.2 Interference Mitigation using Advanced Antenna Technologies

[Note: The content of this section shall not contradict with the content of "11.8.4.1 Multi-cell MIMO" in IEEE 802.16m-08/003r4]

IEEE 802.16 should support the advanced antenna technologies to mitigate inter-cell interference.

20.2.1 Single Cell Antenna Processing with Multi-cell Coordination

The details of single cell antenna processing are defined in "11.8 DL MIMO Transmission Scheme". This sub-section introduces the interference mitigation techniques based on the MIMO schemes defined in Section 11 with extended inter-BS coordination mechanisms and interference measurement support. Note that the inter-BS coordination mechanisms in this sub-section do not require data forwarding between different cells, i.e. different BS will not transmit the same data to a MS.

When precoding technique is applied in neighboring cells, the inter-cell interference can be mitigated by coordinating the PMIs (Precoding Matrix Indexes) applied in neighboring cells. For example, the MS can estimate which PMIs in neighboring cell will result in severe interference level and report the PMI restriction or recommendation to the serving BS. The serving BS can then forward this information to recommend its neighboring BSs a subset of PMIs to use or not to use. Based on this information, the neighboring BS can configure the codebook and broadcast it.

In addition, the PMI coordination can also be applied in UL. One example is that the neighboring BSs can estimate the sounding signal transmitted by specific MS and identify which PMIs may result in significant interference. By forwarding this information over the backhaul network, the serving BS can instruct the MS to choose the proper PMI or the combination of PMIs for maximizing SINR to its own cell and minimizing the interference to neighboring cells.

Precoding with interference nulling can also be used to mitigate the inter-cell interference. For example, additional degrees of spatial freedom at a BS can be exploited to null its interference to neighboring cells.

20.2.1.1 Inter-BS Coordination

In order to support PMI coordination to mitigate inter-cell interference, the BSs shall be capable to exchange the interference measurement results like recommended PMI subset to be restricted or to be applied in neighboring cells with each other or with some control element in the backhaul network. For UL PMI coordination, this subset is estimated by BS through estimating the sounding signals transmitted by specific MSs. In order to facilitate the PMI coordination and interfering PMIs estimation, the information on the PMI and the associated resource allocation applied in each cell should also be exchanged.

In order to support precoding with interference nulling, the associated resource allocation and some control element should be exchanged between neighboring BSs.

Note that the PMI coordination may also be integrated with the FFR defined in 20.1. For example, the BS may apply FFR to isolate some of the interference sources if the PMIs restrictions recommended by different MSs are contradicted with each other.

20.2.1.2 Interference Measurement

In order to support DL PMI coordination to mitigate inter-cell interference, the MS shall be capable to measure the channel from the interfering BS, calculates the worst or least interfering PMIs, and feedbacks the restricted or recommended PMIs to the serving BS together with the associated BS IDs or information assisting in determining the associated BS IDs. The measurement can be performed over the region implicitly known to MS or explicitly designated by BS. The PMIs can then be reported to BS by UL control channel and/or MAC layer messaging in solicited/unsolicited manner.

For UL PMI coordination, the BS shall be capable to measure the channel from the interfering MS using sounding signals. Neighboring BS should calculate the PMIs with least interference and forward it to the serving BS. The mechanism to identify the interfering MS is FFS.

The priority of selection of PMIs forwarded from neighboring BS is set in DL/UL. For priority of selection of PMIs, measurements such as SINR, normalized interference power, or IoT for each resource unit (e.g., a subchannel, a fraction of PRU) is required, and it should be forwarded from neighboring BS. The measured CINR should provide an accurate prediction of the CINR when the transmission happens with coordinated DL closed loop transmission. In order to mitigate UL interference, corresponding to each sub-band, or RB(s), BSs may send an indication to neighbor base stations if the IoT is above the thresholds.

In addition to PMIs, additional interference measurements may need to be reported to resolve conflicting requests from different MSs. More details are FFS.

In order to support precoding with interference nulling to mitigate inter-cell interference, a BS shall be capable to measure the channel from an interfering MS.

20.2.2 Multi-cell Joint Antenna Processing

This sub-section introduces the techniques to use joint MIMO transmission or reception across multiple BSs for interference mitigation and for possible macro diversity gain, and the Collaborative MIMO (Co-MIMO) and the Closed-Loop Macro Diversity (CL-MD) techniques are examples of the possible options. For downlink Co-MIMO, multiple BSs perform joint MIMO transmission to multiple MSs located in different cells. Each BS performs multi-user precoding towards multiple MSs, and each MS is benefited from Co-MIMO by receiving multiple streams from multiple BSs. For downlink CL-MD, each group of antennas of one BS performs narrow-band or wide-band single-user precoding with up to two streams independently, and multiple BSs transmit the same or different streams to one MS. Sounding based Co-MIMO and CL-MD are supported for TDD, and codebook based ones are supported for both TDD and FDD.

20.2.2.1 Closed-loop Multi-cell MIMO

For the uplink, macro-diversity combining, cooperative beamforming and interference cancellation can be used across multiple base stations to mitigate inter-cell interference.

20.2.2.1.1 Inter-BS Coordination

For macro-diversity combining, soft decision information in the form of log-likelihood ratios is generated at different base stations and combined. This will require the exchange of non-persistent allocations of scheduling information and soft-decision information across base stations.

For cooperative beamforming, joint multi-antenna processing is carried out across multiple base stations. This will require the exchange of non-persistent allocations of channel state information, scheduling information and quantized versions of received signals across base stations.

For interference cancellation, a BS that is unable to decode data for a particular user may request a neighboring BS to exchange the decoded data of the interfering users along with scheduling and transmission format related information. The information exchanged may be used in conjunction with channel state information for the purpose of interference cancellation.

Cooperative cells can have same permutation for resource allocation.

For all of these uplink multi-cell MIMO techniques, channel state information can be derived either through different pilots or sounding channels per sector or cell.

The BSs can coordinate transmission of their beams, so that interference from neighboring cells can be almost completely eliminated. Furthermore, if BSs cannot coordinate, then the sequence in which beams are served can be chosen randomly and independently at each BS.

In order to support CL-MD, the associated resource allocation and some control element should also be exchanged between neighboring BSs. For codebook-based cases, the MSs involved in coordination determines precoding matrix index (PMI) for each coordinating BS, and reports them to the serving BS, which in turn forwards the corresponding PMI to the relevant BS via the network interface. For sounding based cases, the BSs involved in coordination obtain precoding matrix based on uplink sounding.

Note that the CL-MD may also be integrated with the FFR defined in 20.1.

In order to support Co-MIMO, the associated resource allocation and some control element should also be exchanged among coordinating BSs. For codebook-based cases, the MS involved in coordination determines narrow precoding matrix index (PMI) for each coordinating BS, and reports these to the serving BS, which in turn forwards the corresponding PMI to the relevant BS via the network interface. For sounding based cases, the BS involved in coordination estimates the channel state information (CSI) using uplink sounding for all MSs involved in coordination, and calculates multiuser precoding matrixes for these users.

20.2.2.1.2 Measurement Support

A BS that senses high levels of interference may send a request for inter-cell interference reduction to a neighboring BS along with identification of dominant interfering MSs. Once a neighboring BS with dominant interfering MSs accepts the inter-cell interference reduction request, the measurement process will be started. The measurement process requires estimation of channel state information for MSs involved in multi-cell joint antenna processing.

BS can request multiple uplink sounding signals per MS during a Frame to enable the measurement of CQI on a per beam basis.

In order to support codebook based CL-MD, the MS shall be capable to measure the channel from the interfering BS, and calculate the PMI for it. In order to support sounding based CL-MD, the BS shall be capable to measure the channel from an interfering MS, and calculates the precoding matrix for it.

In order to support codebook based Co-MIMO, the MS shall be capable to measure the channel from the all BSs involved in coordination, and calculates the PMIs for them. In order to support sounding based Co-MIMO, the BS shall be capable to measure the channel from all MSs involved in coordination, and calculates the precoding matrixes for these users.

20.3 Interference Mitigation using Power Control and Scheduling

BS may use various techniques to mitigate the interference experienced by MS or to reduce the interference to other cells. The techniques may include sub-channels scheduling, dynamic transmit power control, dynamic antenna patterns adjustment, and dynamic modulation and coding scheme. As an example, BS may allocate different modulation and coding schemes (MCS) to mobiles through UL scheduling which indirectly controls mobile transmit power and the corresponding UL interference to other cells. BS can exchange information related to UL power control schemes with other neighbor BSs. MS may use interference information and its downlink measurements to control the uplink interference it causes to adjacent cells.

Using interference information BS may attempt intra-BS techniques such as alternative traffic scheduling, adjustment of MCS to avoid interference and BS may also use inter-BS techniques such as the examples depicted in sections 20.1 and 20.2.

DL interference mitigation may be achieved by allocating different DL power boosting over different sub-channels, while the UL interference mitigation may also be achieved by setting different power control schemes (Section 11.x). Both the UL and DL power control techniques may be further cooperated with the FFR (20.1) and the advanced antenna technologies (20.2) for better performances.

BS can schedule MSs with high mutual interference potential on different subchannels or frequency partitions, e.g. by exchanging scheduling constraints between coordinating BSs. The necessary interference prediction may be based on the interference measurement mechanisms defined in 20.1 and 20.2.

20.4 Interference Mitigation to Support Co-deployment with other Networks

This sub-section addresses the coexistence problems which may appear between wireless networks deployed by different operators. IEEE 802.16m deployment addresses the licensed spectrum allocations, which generally enjoy low interference levels. Problems may arise in the case of co-deployment of FDD and TDD networks or of un-synchronized TDD networks.

In order to resolve the potential interference due to the coexistence between wireless networks, the technique of Coordinated Coexistence Frame (CXCF) may be applied.

- When enabling the CXCF technique, the following allocations will be identified:

A. Protected allocations, having as scope to protect the receive operation of MS, BS or a combination of them; in some cases such allocations involve the creation of the silence intervals, during which there are no transmissions.

B. Un-protected allocations, during which the interference is not mitigated by especial measures. The existing licensed operation is based on this approach.

- Synchronization by using GPS or similar synchronization sources in order to achieve the absolute time synchronization of the Coordinated Coexistence Frame

- Scheduling among wireless communications to reduce the experienced interference

The Coordinated Coexistence Frame period is based on the IEEE 802.16m superframe structure, further including frames and sub-frames. The CXCF duration and structure depends on the air-interfaces deployed by other wireless networks.

21 RF Requirements

22 Inter-BS Synchronization

22.1 Network synchronization

For TDD and FDD realizations, it is recommended that all BSs be time synchronized to a common timing signal. In the event of the loss of the network timing signal, BSs shall continue to operate and shall automatically resynchronize to the network timing signal when it is recovered. The synchronizing reference shall be a 1 pps timing pulse and a 10 MHz frequency reference. These signals are typically provided by a GPS receiver but can be derived from any other source which has the required stability and accuracy. For both FDD and TDD realizations, frequency references derived from the timing reference may be used to control the frequency accuracy of BSs provided that they meet the frequency accuracy requirements of [tbd]. This applies during normal operation and during loss of timing reference.

22.2 Downlink frame synchronization

At the BS, the transmitted downlink radio frame shall be time-aligned with the 1pps timing pulse with a possible delay shift of n micro-seconds (n being between 0 and 4999). The start of the preamble symbol, excluding the CP duration, shall be time aligned with 1pps plus the delay of n micro-seconds timing pulse when measured at the antenna port.

Appendix 1 IEEE 802.16e Protocol Structure

Figure 48 shows the protocol architecture of IEEE 802.16e which will be used as reference system. The MAC layer is composed of two sub-layers: Convergence Sublayer (CS) and MAC Common Part Sublayer (MAC CPS).

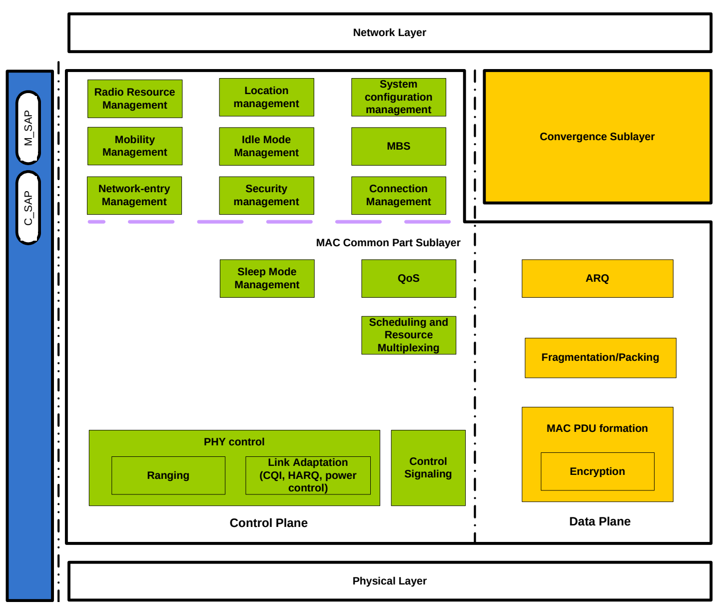

Figure 48 The IEEE 802.16e protocol architecture

For convenience, the MAC CPS functions are classified into two groups based on their characteristics. The upper one is named as resource control and management functions group, and the lower one is named as medium access control functions. Also the control plane functions and data plane functions are also separately classified.

The resource control and management functional group includes several functional blocks that are related with radio resource functions such as:

- Radio Resource Management
- Mobility Management
- Network-entry Management
- Location Management
- Idle Mode Management
- Security Management
- System Configuration Management
- MBS
- Connection Management

Radio Resource Management block adjusts radio network parameters related to the traffic load, and also includes function of load control (load balancing), admission control and interference control.

Mobility Management block handles related to handover procedure. Mobility Management block manages candidate neighbor target BSs based on some criteria, e.g. PHY signaling report, loading, etc. and also decides whether MS performs handover operation.

Network-entry Management block is in charge of initialization procedures. Network-entry Management block may generate management messages which needs during initialization procedures, i.e., ranging (this does not mean physical ranging, but ranging message in order to identification, authentication, and CID allocation), basic capability, registration, and so on.

Location Management block is in charge of supporting location based service (LBS). Location Management block may generate messages including the LBS information. The Idle Mode Management block manages location update operation during idle mode.

Idle Mode Management block controls idle mode operation, and generates the paging advertisement message based on paging message from paging controller in the core network side.

Security Management block is in charge of key management for secure communication. Using managed key, traffic encryption/decryption and authentication are performed.

System Configuration Management block manages system configuration parameters, and generates broadcast control messages such as downlink/uplink channel descriptor (DCD/UCD).

MBS (Multicast and Broadcasting Service) block controls management messages and data associated with broadcasting and/or multicasting service.

Connection Management block allocates connection identifiers (CIDs) during initialization/handover/ service flow creation procedures. Connection Management block interacts with convergence sublayer to classify MAC Service Data Unit (MSDU) from upper layer, and maps MSDU onto a particular transport connection.

The medium access control functional group includes function blocks which are related with physical layer and link controls such as:

- PHY Control
- Control Signaling
- Sleep Mode Management
- QoS
- Scheduling and Resource Multiplexing
- ARQ
- Fragmentation/Packing
- MAC PDU formation

PHY Control block handles PHY signaling such as ranging, measurement/feedback (CQI), and HARQ ACK/NACK. Based on CQI and HARQ ACK/NACK, PHY Control block estimates channel environment of MS, and performs link adaptation via adjusting modulation and coding scheme (MCS) or power level.

Control Signaling block generates resource allocation messages such as DL/UL-MAP as well as specific control signaling messages, and also generates other signaling messages not in the form of general MAC messages (e.g., DL frame prefix also known as FCH).

Sleep Mode Management block handles sleep mode operation. Sleep Mode Management block may also generate management messages related to sleep operation, and may communicate with Scheduler block in order to operate properly according to sleep period.

QoS block handles rate control based on QoS parameters input from Connection Management function for each connection, and scheduler shall operate based on the input from QoS block in order to meet QoS requirement.

Scheduling and Resource and Multiplexing block schedules and multiplexes packets based on properties of connections. In order to reflect properties of connections Scheduling and Resource and Multiplexing block receives QoS information from QoS block for each connection.

ARQ block handles MAC ARQ function. For ARQ-enabled connections, ARQ block logically splits MAC SDU to ARQ blocks, and numbers to each logical ARQ block. ARQ block may also generate ARQ management messages such as feedback message (ACK/NACK information).

Fragmentation/Packing block performs fragmenting or packing MSDUs based on scheduling results from Scheduler block.

MAC PDU formation block constructs MAC protocol data unit (PDU) so that BS/MS can transmit user traffic or management messages into PHY channel. MAC PDU formation block may add sub-headers or extended sub-headers. MAC PDU formation block may also add MAC CRC if necessary, and add generic MAC header.

A1.1 The IEEE 802.16e MS/BS Data Plane Processing Flow

The following figure describes data transmission flow in the IEEE 802.16e. On the transmitter side, after a packet arrives from higher layer, Convergence Sublayer classifies a packet according to classification rules, and maps a packet onto a particular transport connection. If a packet is associated with ARQ connection, then ARQ block logically splits a packet into ARQ blocks. After scheduling, a packet may be fragmented or packed, and add sub-header if necessary. A packet including sub-headers may be encrypted if negotiated. MAC PDU formation block adds generic MAC header, then MAC Protocol Data Unit (MPDU) is constructed. Several MPDUs may be concatenated according to the size of the data burst.

On the receiver side, after a packet arrives from physical layer, MAC PDU formation block constructs MPDU, and Fragmentation/Packing block defragments/unpacks MPDU to make MSDU. After reconstituted in Convergence Sublayer, MSDU is transferred to higher layer.

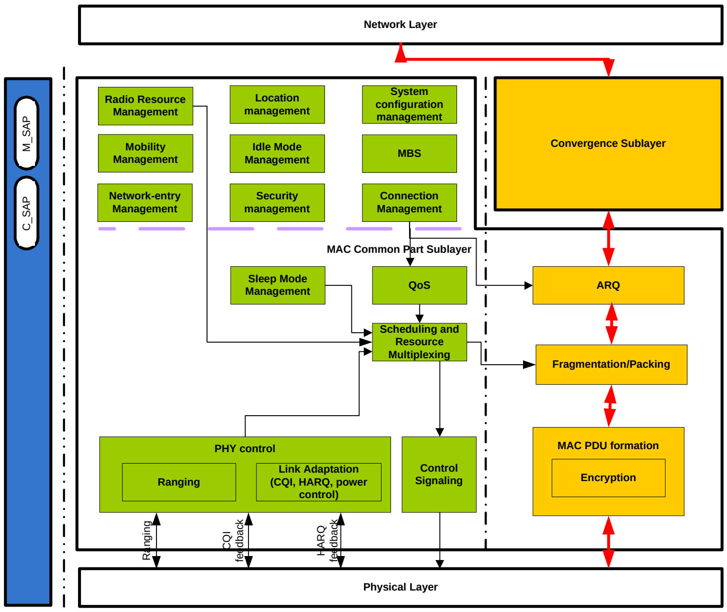

Figure 49 The IEEE 802.16e MS/BS Data Plane Processing Flow

A1.2 The IEEE 802.16e MS/BS Control Plane Processing Flow

Figure 50 describes the MAC message transmission flow in IEEE 802.16e. Most of the MAC functional block generates its own management messages, and these messages are transported to Fragmentation/Packing block. Basically the MAC management message does not use ARQ block (Management messages will be operated in request-and-response manner, that is, if there is no response, sender retransmits request. Therefore additional ARQ operation is not required). Management message may be fragmented or packed, and authentication information (e.g., CMAC/HMAC in IEEE 802.16e) may be appended to the management message if necessary. Some of MAC message may be transmitted via Control Signaling block in the form of control message (e.g., MAP). On the receiver side, most of MAC functional block also receives and handles MAC management messages from the MAC functional block of the opposite side (MS to BS, BS to MS).

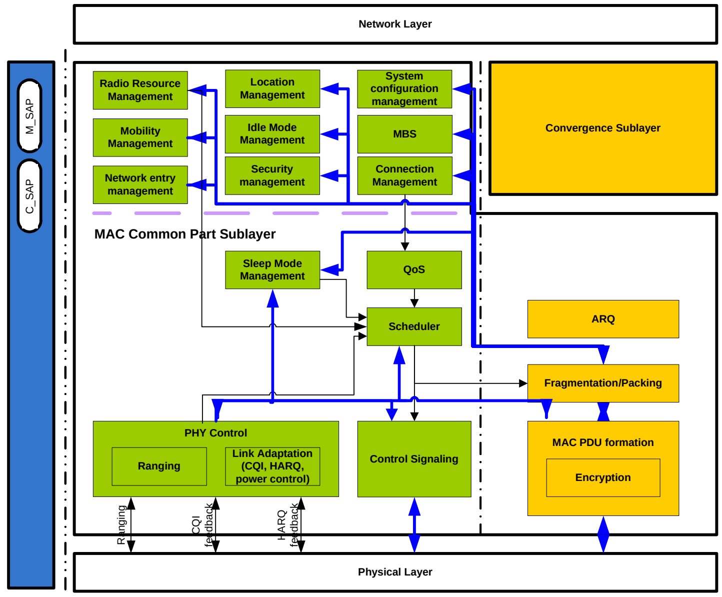

Figure 50 The IEEE 802.16e MS/BS Control Plane Processing Flow

<Editor note: the following text has been generated based on minority opinion and the TBD responses from a large number of members to latency attributes of the frame structure in the Excel Sheet [CIEEE 802.16m-08/096r10] and the necessity to demonstrate the frame structure compliance with the IEEE 802.16m SRD [8]. The content of the following tables will be updated based on the ultimate decisions that will be made in the group on the frame structure parameters.>

Appendix 2. Data Plane and Control Plane Access Latencies

[In order to justify the choice of parameters for the proposed frame structure, it is imperative to demonstrate that the frame structure and associated parameters satisfy the IEEE 802.16m system requirements. In the following sections, the break down of the data and control planes access latencies is provided for the reference and the IEEE 802.16m systems.

A2.1 Data Plane Access Latency

The break down of the components of data plane access latency is shown in Table 8. The access latency with 30% frame error rate over the airlink is 4.67 ms which is less than 10 ms limit specified by the IEEE 802.16m SRD.

Step	Description	IEEE 802.16e Value	IEEE 802.16m Value
0	MS wakeup time	Implementation Dependent	Implementation Dependent
1	MS Processing Delay	2.5 ms	1.23 ms
2	Frame Alignment	2.5 ms	0.31 ms
3	TTI for UL DATA PACKET (Piggy back scheduling information)	5 ms	0.617 ms
4	H-ARQ Retransmission (FER = 30%)	0.3*20 ms	0.3* 4.3 ms
5	BS Processing Delay	2.5 ms	1.23 ms
6	R6 Transfer delay	T_{R6}	T_{R6}
7	ASN-GW Processing delay	T_{ASN_GW}	T'_{ASN_GW}
	Total one way access delay	18.50 ms + T_{ASN_GW}+T_{R6}	4.67 ms + T'_{ASN_GW}+T_{R6}

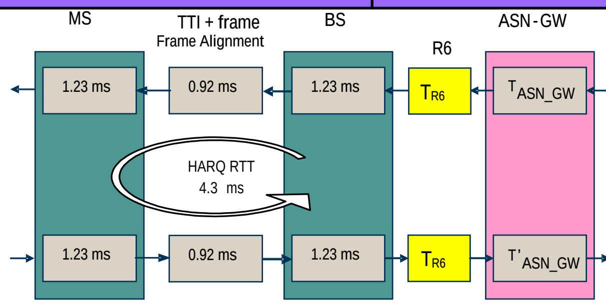

Table 8 Data plane access latency. The above processing time is FFS.

A2.2 Control Plane Access Latency

The break down of system entry procedure from DL scanning and synchronization to the point where the radio resource control (RRC) connection is established is shown in Table 9. Note that the use of superframe header, that encompasses the system configuration information, would significantly reduce the time spent in step 1. Also, since the probability of error required for transmission of some of the MAC control messages is typically 10^{-3}, H-ARQ is used to ensure more reliability. The use of shorter TTI and faster transmissions would enable shorter H-ARQ retransmission, consequently reducing the total time for IDLE_STATE to ACTIVE_STATE transition.

In addition, we assume that the base station, relay station, or mobile station processing time is approximately 2*TTI = 1.23 ms, that further reduces the total delay budget. It is shown that the IDLE_STATE to ACTIVE_STATE transition time of less than 80 ms is achievable through the use of proposed frame structure which is less the 100 ms value specified by the SRD.

It must be noted that some of the radio resource control and management messages require probability errors in the order of 10^{-6}; ARQ is used in conjunction with H-ARQ to achieve higher transmission reliability.

Step	Description	IEEE 802.16e Value	IEEE 802.16m Value
0	MS wakeup time	Implementation dependent	Implementation dependent
1	DL scanning and synchronization + DL MAP acquisition + DCD/UCD acquisition	> 300 ms (Assuming 0.5 s DCD/UCD interval)	20 ms
2	Random Access Procedure (UL CDMA Code + BS Processing + DL CDMA_ALLOC_IE)	> 15 ms	< 5 ms
3	Initial Ranging (RNG-REQ + BS Processing + RNG-RSP)	> 15 ms (0.3*20 ms for H-ARQ ReTX)	< 5 ms (0.3* 4.3 ms for H-ARQ
4	Capability Negotiation (SBC-REQ + BS Processing + SBC-RSP) + H-ARQ Retransmission @ 30%	> 15 ms (0.3*20 ms for H-ARQ ReTX)	< 5 ms (0.3* 4.3 ms for H-ARQ ReTX)
5	Authorization and Authentication/Key Exchange (PKM-REQ + BS Processing + PKM-RSP + …) +H-ARQ Retransmission @30%	> 15 ms (0.3*20 ms for H-ARQ ReTX)	< 5 ms (0.3* 4.3 ms for H-ARQ ReTX)
6	Registration (REG-REQ + BS/ASN-GW Processing + REG-RSP) + H-ARQ Retransmission @30%	> 15 ms (0.3*20 ms for H-ARQ ReTX)	< 5 ms (0.3* 4.3 ms for H-ARQ ReTX)
7	RRC Connection Establishment (DSA-REQ + BS Processing + DSA-RSP + DSA-ACK) + H-ARQ Retransmission @30%	> 15 ms (0.3*20 ms for H-ARQ ReTX)	< 5 ms (0.3* 4.3 ms for H-ARQ ReTX)
	Total C-plane connection establishment Delay	> 90 ms	< 30 ms
	Total IDLE_STATE –> ACTIVE_STATE Delay	> 390 ms	< 50 ms

Table 9 Control plane access latency. The above processing time is FFS.