Project	IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>
Title	**IEEE 802.16m System Description Document (SDD)**
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Re:	System Description Document for the P802.16m Advanced Air Interface
Abstract	This document is the approved baseline IEEE 802.16m System Description Document. As directed by TGm, this document is a revision to IEEE 802.16m-08/003r9a according to the comment resolution conducted by TGm in Session #62.
Purpose	System description for the P802.16m draft.
Notice	
Release	
Patent Policy	

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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 Task Group m[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.

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 P802.16m PAR Proposal," IEEE 802.16-06/055r3, November 2006, http://ieee802.org/16/docs/06/80216-06_055r3.pdf

[3] IEEE Std 802.16-2004: IEEE Standard for Local and metropolitan area networks – Part 16: 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] Report ITU-R M.2135: Guidelines for evaluation of radio interface technologies for IMT-Advanced (2008)

[7] New Report ITU-R M.2134: Requirements related to technical performance for IMT Advanced radio interface(s) (2008)

[8] IEEE 802.16m System Requirements, IEEE 802.16m-07/002 http://ieee802.org/16/tgm/#07_002

[9] WiMAX Forum™ Mobile System Profile, Release 1.0 Approved Specification (Revision 1.4.0: 2007-05-02), http://www.wimaxforum.org/technology/documents

[10] The WiMAX Forum Network Architecture Stage 2 - 3: Release 1, Version 1.2 http://www.wimaxforum.org/documents/documents/WiMAX_Forum_Network_Architecture_Stage_2-3_Rel_1v1.2.zip

[11] ITU-T Recommendation X.680: Information technology - Abstract Syntax Notation One (ASN.1): Specification of basic notation, July 2002.

[12] ITU-T Recommendation X.681: Information technology - Abstract Syntax Notation One (ASN.1): Information object specification, July 2002.

[13] ITU-T Recommendation X.682: Information technology - Abstract Syntax Notation One (ASN.1): Constraint specification, July 2002.

[14] ITU-T Recommendation X.683: Information technology - Abstract Syntax Notation One (ASN.1): Parameterization of ASN.1 specifications, July 2002.

[15] ITU-T Recommendation X.691: Information technology - ASN.1 encoding rules: Specification of Packed Encoding Rules (PER), July 2002.

[16] WiMAX Forum: WiMAX Network Protocols and Architecture for Location Based Services *Full Reference to be complete*

[17] Guidelines for use of a 48-bit Extended Unique Identifier (EUI-48™), http://standards.ieee.org/regauth/oui/tutorials/EUI48.html

[18] Wireless Priority Service for National Security/Emergency Preparedness: Algorithms for Public Use Reservation and Network Performance", August 2002, http://wireless.fcc.gov/releases/da051650PublicUse.pdf.

[19] Internet Draft "Transmission of IP over Ethernet over IEEE 802.16 Networks" http://tools.ietf.org/html/draft-ietf-16ng-ip-over-ethernet-over-802-dot-16-08

[20] Internet Draft "Transmission of IPv4 packets over IEEE 802.16's IP Convergence Sublayer" http://tools.ietf.org/html/draft-ietf-16ng-ipv4-over-802-dot-16-ipcs-04

3 Definitions, Symbols, Abbreviations

3.1 Definitions

1. **WirelessMAN-OFDMA Reference System**: A system compliant with a subset of the WirelessMAN-OFDMA capabilities specified by IEEE 802.16-2004 and amended by IEEE 802.16e-2005 and IEEE 802.16Cor2/D3, where the subset is defined by WiMAX Forum Mobile System Profile, Release 1.0 (Revision 1.4.0: 2007-05-02) [9], excluding specific frequency ranges specified in the Section 4.1.1.2 (Band Class Index)
2. **Advanced WirelessMAN-OFDMA System**: A system compliant with the the features and functions defined in according to this document.
3. **YMS (Yardstick Mobile Station)**: A mobile station compliant with the WirelessMAN-OFDMA Reference System
4. **RS (Relay Station)**: A relay station 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
5. **YBS (Yardstick Base Station)**: A base station compliant with the WirelessMAN-OFDMA Reference System
6. **MRBS (Multihop Relay Base Station)**: A YBS implementing functionality to support RSs as defined in IEEE 802.16j
7. **AMS**: (Advanced Mobile Station) a mobile station capable of acting as a YMS and additionally implementing the protocol defined in IEEE 802.16m
8. **ARS**: A station implementing the relay station functionality defined in IEEE 802.16m
9. **ABS**: a base station capable of acting as a YBS and additionally implementing the protocol defined in IEEE 802.16m
10. **LZone**: A positive integer number of consecutive subframes where ABS communicates with RSs or YMSs, and where an ARS or an RS communicates with one or more YMSs.
11. **MZone**: A positive integer number of consecutive subframes where an ABS communicates with one or more ARSs or AMSs, and where an ARS communicates with one or more ARSs or AMSs.
12. **Location-Based Service (LBS)**: A service provided to a subscriber based on the current geographic location of the MS.
13. **LBS Application**: The virtual entity that controls and runs the location based service, including location determination, and information presentation to the users.
14. **Location Server (LS)**: A server which determines and distributes the location of the MS in the WiMAX network. It may reside in the WiMAX network CSN, as defined by [15].
15. **Location Controller (LC)**: A controller which is responsible for coordinating the location measurements of the MS. It may reside in the WiMAX network ASN, as defined by [15].
16. **Location Agent (LA)**: An agent which is responsible for the making measurements or optionally collecting and reporting of location related data to LC. LA function could reside entirely in the BS, in the MS or both, as defined by [15].
17. **LBS Zone**: A configurable amount of consecutive resource units which are reserved for LBS purposes.
18. **LBS Pilots**: A set of pilots which are periodically broadcasted by involved BSs for LBS purposes.
19. **Time difference of arrival (TDOA)**: The measurement of the difference in arrival time of received signals.
20. **Time of arrival (TOA)** : The time of arrival of a signal received by an MS or BS
21. **Angle of arrival (AOA)**: The angle of arrival of a received signal relative to the boresight of the antenna.
22. **Spatial Channel Information**: Generalized set of measurements from the antennas (spatial channel estimation or a set of AOA's), which can be used for location estimation
23. **Round trip delay (RTD)**: The time required for a signal or packet to transfer from a MS to a BS and back again.
24. **Relative delay (RD)**: The delay of neighbor DL signals relative to the serving/attached BS.
25. **Separate coding**: Each unicast service control information element is coded separately
26. **Joint coding**: Multiple unicast service control information elements are coded jointly
27. **E-MBS Zone**: An E-MBS zone is a group of ABSs transmitting the same E-MBS content.
28. **E-MBS Region**: An E-MBS region is a time/frequency region within a frame where E-MBS data is

transmitted.

29. **Multicast Service**: A Multicast Service is a service where users may dynamically join and leave a Multicast session. The network may monitor the number of users at each E-MBS Zone to decide on data transmission and its mode.
30. **Dynamic Multicast Service**: In the Dynamic Multicast Service, the membership of the multicast group changes in time. Users may join and leave groups at any time. The transmission of the content may be turned on or off based on the number of users in the group.
31. **Static Multicast Service**: In the Static Multicast Service, the content is always transmitted through one or more broadcast channel(s) irrespective of the number of users in the group. The broadcast channel(s) normally pre-established prior to the user(s) join and leave a Multicast session at each Multicast service area.
32. **Broadcast Service**: The Broadcast Service is a special type of E-MBS service for which the content is always transmitted through broadcast channels by the access network without considering the number of users receiving the transmission.
33. **Subordinate link**: a link between the ABS or ARS and its subordinate stations (ARSs or AMS)
34. **Superordinate link**: a link between the ARS or AMS and its superordinate station (ABS or ARS)
35. **Time-division transmit and receive (TTR) relaying**: a relay mechanism where transmission to subordinate station(s) and reception from the superordinate station, or transmission to the superordinate station and reception from subordinate station(s) is separated in time.
36. **Transparent ARS**: a relay station that does not transmit A-PREAMBLE, SFH, A-MAP.
37. **Non-transparent ARS**: a relay station that transmits A-PREAMBLE, SFH, A-MAP.
38. **Access station**: A station (ARS or ABS) that provides a point of access into the network for an AMS or ARS.
39. **Access ARS**: A relay station which serves as an access station.
40. **Centralized security mode**: This mode is based on authentication and key management between AMS and ABS, without involving the access ARS.
41. **Distributed security mode**: This mode is based on authentication and key management between AMS and an access ARS, and between the access ARS and the ABS.
42. **CSG (Closed Subscriber Group) Femtocell BS**: A CSG Femtocell BS is accessible only to the MSs, which are member of the CSG, except for emergency services.
43. **OSG (Open Subscriber Group) Femtocell BS**: An OSG Femtocell BS is accessible to any MSs

3.2 Abbreviations

Unless otherwise specified here, abbreviations and acronyms are as defined in [4].

ABS	Advanced Base Station (see definitions)
A-MAP	Advanced MAP
AMC	Adaptive modulation and coding
AMS	Advanced mobile station (see definitions)
AOA	Angle of Arrival
A-PREAMBLE	Advanced Preamble
ARQ	Automatic Repeat reQuest
ARS	Advanced Relay Station (see definitions)
ASN	Access Service Network
BR	Bandwidth Request
BS	Base Station
BW	Bandwidth (abbreviation used only in equations, tables, and figures)
CC	Confirmation Code
CID	Connection Identifier
CINR	Carrier-to-Interference-and-Noise Ratio
CLPC	Closed-Loop Power Control
CMAC	Cipher-based Message Authentication Code
CoCL-MD	Closed-Loop Macro Diversity
Co-MIMO	Collaboration MIMO
Co-Re	Constellation Re-Arrangement

CP	Cyclic Prefix
CPS	Common Part Sublayer
CQI	Channel Quality Information
CRC	Cyclic Redundancy Check
CRU	Contiguous Resource Unit
CS	Convergence Sublayer
CSI	Channel State Information
CSN	Connectivity Service Network
CXCF	Coordinated Coexistence Frame
DCD	Downlink Channel Descriptor
DL	Downlink
DRU	Distributed Resource Unit
E-MBS	Enhanced Multicast Broadcast Service
FA	Frequency Assignment
FCH	Frame Control Header
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FFR	Fractional Frequency Re-Use
FFS	For Further Study
FFT	Fast Fourier Transform
FID	Flow Identifier
FUSC	Full Usage of Subchannels
GPCS	Generic Packet Convergence Sublayer
GPS	Global Positioning System
GT	Guard Time
HARQ	Hybrid Automatic Repeat reQuest
HFDD	Half-duplex Frequency Division Duplex
HMAC	Hashed Message Authentication Code
HO	Handover
IoT	Interference Over Thermal noise
IP	Internet Protocol
IPCS	IP Convergence Sublayer
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radiocommunication sector
LBS	Location Based Service
LDPC	Low-Density Parity Check
LRU	Logical Resource Unit
MAC	Medium Access Control
MBS	Multicast Broadcast Service
MC	Multi Carrier
MCS	Modulation Coding Scheme
MIMO	Multiple Input Multiple Output
MS	Mobile Station
MSDU	MAC Service Data Unit
MU-MIMO:	Multiple Use-MIMO
NRM	Network Reference Model
NSP	Network Service Provider
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OLPC	Open-Loop Power Control
PAPR	Peak to Average Power Ratio
PA-PREAMBLE	Primary Advanced Preamble
PBCH	Primary Broadcast Channel
PDU	Protocol Data Unit
PHY	Physical Layer
PMI	Precoding Matrix Index

PRU	Physical Resource Unit
P-SFH	Primary Superframe Header
PUSC	Partial Usage of Subchannels
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase-shift Keying
RAT	Radio Access Technology
REQ	Request
RNG	Ranging
RRCM	Radio Resource Controller and Management
RS	Relay Station
RSP	Response
RSSI	Receive Signal Strength Indicator
RTD	Round Trip Delay
RU	Resource Unit
Rx	Receive (abbreviation not used as verb)
SAP	Service Access Point
SA-PREAMBLE	Secondary Advanced Preamble
SDU	Service Data Unit
SFBC	Space Frequency Block Code
SFC	Space Frequency Coding
SFH	Superframe Header
SM	Spatial Multiplexing
S-SFH	Secondary Superframe Header
STID	Station Identifier
SU-MIMO	Single User-MIMO
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDOA	Time Difference of Arrival
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
TOA	Time of Arrival
Tx	Transmit (abbreviation not used as verb)
UCD	Uplink Channel Descriptor
UL	Uplink
UTRA	Universal Terrestrial Radio Access
WARC	World Administrative Radio Conference

4 Overall Network Architecture

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].

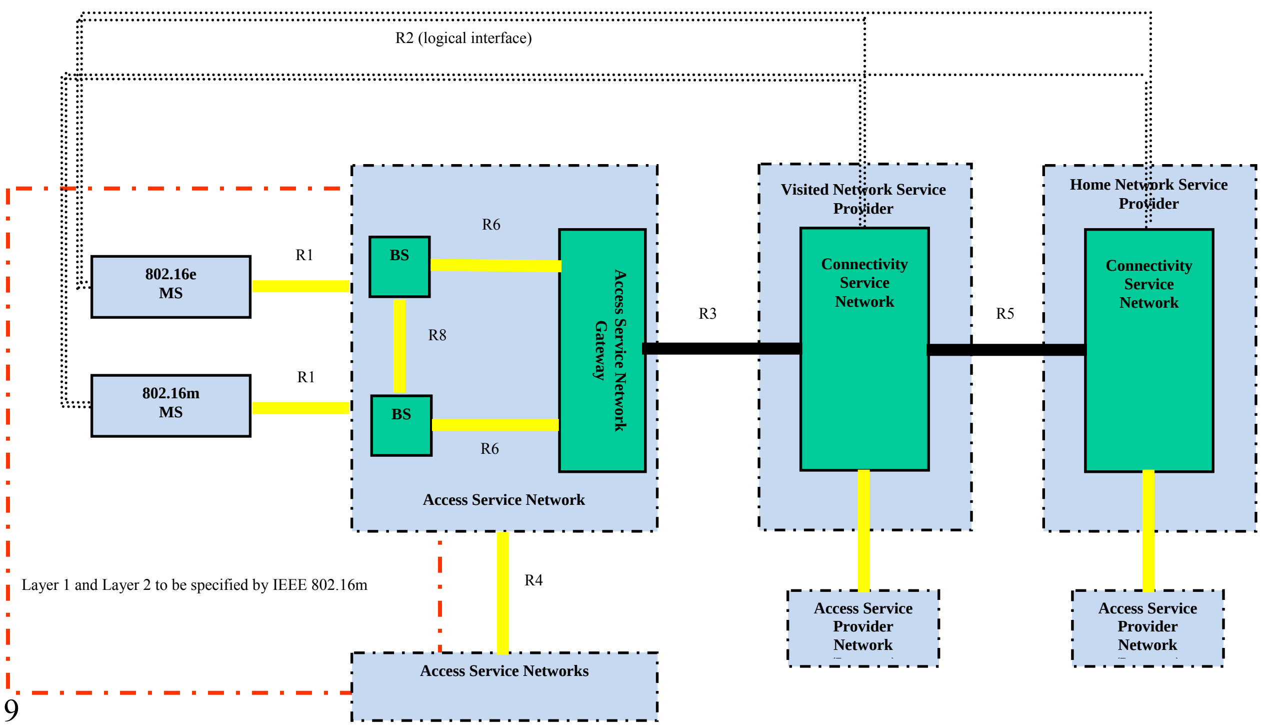

Figure 1: IEEE 802.16m Network Reference Model.

Note: The network reference model and the reference points Ri in Figure 1 are specified in [9]

The ASN is defined as a complete set of network functions needed to provide radio access to an IEEE Std 802.16-2009/ IEEE 802.16m subscriber. The ASN provides at least the following functions:

- IEEE Std 802.16-2009/ IEEE 802.16m Layer-1 (L1) and Layer-2 (L2) connectivity with IEEE Std 802.16-2009/ IEEE 802.16m MS
- Transfer of AAA messages to IEEE Std 802.16-2009/ IEEE 802.16m subscriber's Home Network Service Provider (H-NSP) for authentication, authorization and session accounting for subscriber sessions
- Network discovery and selection of the IEEE Std 802.16-2009/ IEEE 802.16m subscriber's preferred NSP
- Relay functionality for establishing Layer-3 (L3) connectivity with an IEEE Std 802.16-2009/ IEEE 802.16m 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 Std 802.16-2009/ IEEE 802.16m 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 Std 802.16-2009/ IEEE 802.16m subscriber billing and inter-operator settlement
- Inter-CSN tunneling for roaming
- Inter-ASN mobility

The IEEE Std 802.16-2009/ IEEE 802.16m 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 an IEEE 802.16m NSP or as part of an incumbent IEEE Std 802.16-2009 NSP.

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

An ABS that is capable of supporting the IEEE Std 802.16j-2009 RS, communicates with the IEEE Std 802.16j-2009 RS in the LZone. The ABS is not required to provide IEEE Std 802.16j-2009 protocol support in the "Mzone". The design of IEEE 802.16m relay protocols should be based on the design of IEEE Std 802.16j-2009 wherever possible, although IEEE 802.16m relay protocols used in the "Mzone" may be different from IEEE Std 802.16j-2009 protocols used in the LZone.

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 IEEE 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 IEEE 802.16 protocol that is to be used for supporting the particular interface.

Figure 2 and Table 1 illustrate 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: An AMS may connect to an ABS either directly or via one or more ARSs. The number of hops between the ABS and an AMS can be two or more. The topology between the ABS and the subordinate ARSs within an ABS cell is restricted to a tree topology. A YMS may connect to an ABS either directly or via one or more ARSs. Furthermore a YMS may connect to an ABS via one or more RSs. The topology between the ABS and the subordinate RSs within an ABS cell is specified in the IEEE Std 802.16j-2009 amendment.

Connection 10 indicates a connection between an ARS and another directly connected ARS. Such connections exist in order to support topologies in which the number of hops between the ABS and an AMS is greater than two hops.

Connection 11 indicates a connection between an RS and another directly connected RS. Such connections exist in order to support topologies in which the number of hops between the MRBS/ABS and an YMS/AMS is greater than two hops.

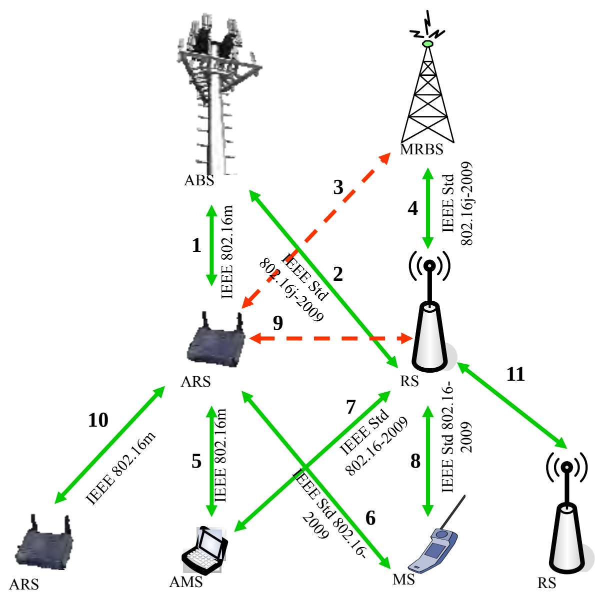

Figure 2: Relay related connections

Connection #	Connected Entities	Protocol used	Supported (Y/N)
1	AMS -ARS	IEEE 802.16m	Y
2	AMS - RS	IEEE Std 802.16j-2009	Y
3	ARS – MRBS	N/A	N
4	MRBS - RS	IEEE Std 802.16j-2009	Y
5	ARS – AMS	IEEE 802.16m	Y
6	ARS – YMS	IEEE Std 802.16-2009	Y
7	AMS – RS	IEEE Std 802.16-2009	Y
8	RS - YMS	IEEE Std 802.16-2009	Y
9	ARS – RS	N/A	N
10	ARS – ARS	IEEE 802.16m	Y
11	RS – RS	IEEE Std 802.16j-2009	Y

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

5 IEEE 802.16m System Reference Model

As shown in Figure 3, the reference model for IEEE 802.16m is very similar to that of the IEEE Std 802.16-2009 with the exception of soft classification (i.e., no SAP is required between the two classes of functions) of the MAC common part sublayer into radio resource control and management functions and medium access control.

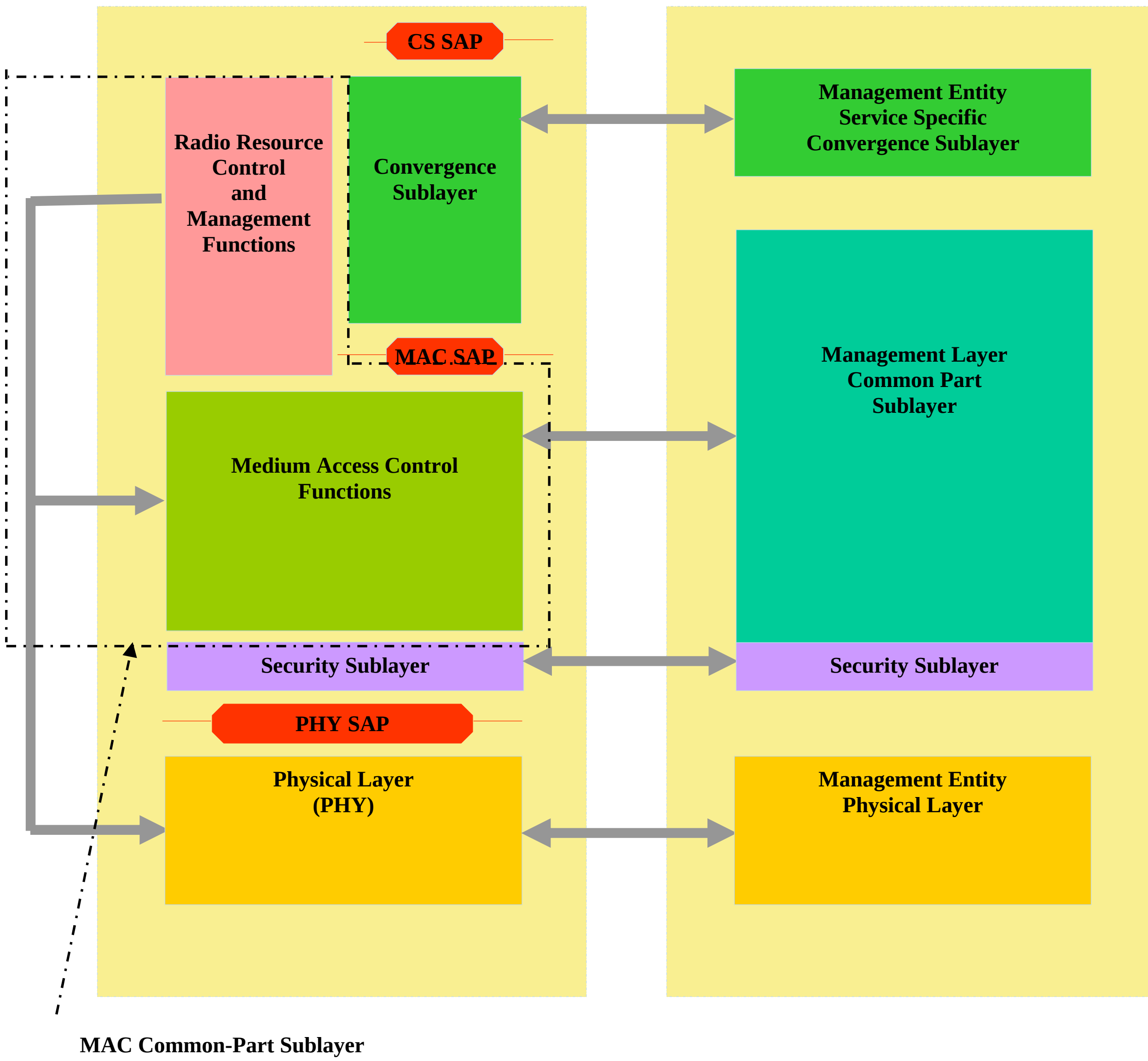

Figure 3: System Reference Model

The MAC and PHY functions can be classified into three categories namely data plane, control plane, and management plane. The data plane comprises functions in the data processing path such as header compression as well as MAC and PHY data packet processing functions. A set of layer-2 (L2) control functions is needed to support various radio resource configuration, coordination, signaling, and management. This set of functions is collectively referred to as control plane functions. A management plane is also defined for external management and system configuration. Therefore, all management entities fall into the management plane category.

6 Advanced Mobile Station State Diagrams

The Figure 4 illustrates the Mobile Station state transition diagram for an AMS. The state transition diagram consists of four states, Initialization State, Access State, Connected State and Idle State.

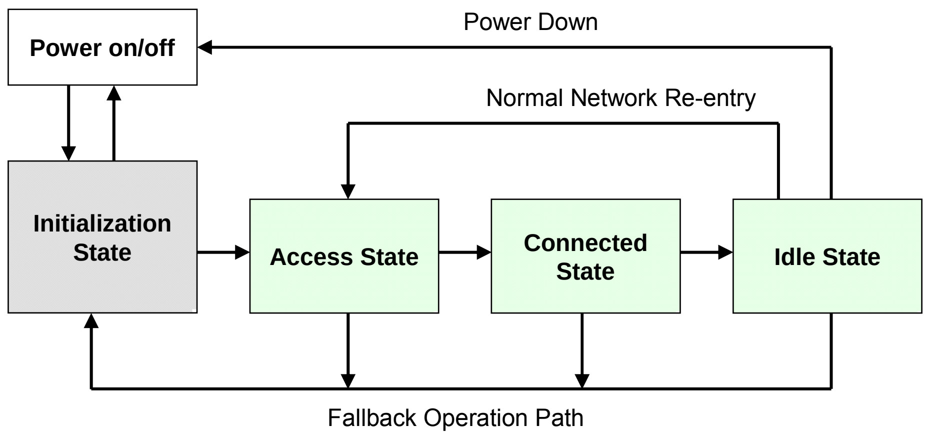

Figure 4: IEEE 802.16m Mobile Station State Transition Diagram

6.1 Initialization State

In the Initialization State, the AMS performs cell selection by scanning, synchronizing and acquiring the system configuration information before entering Access State.

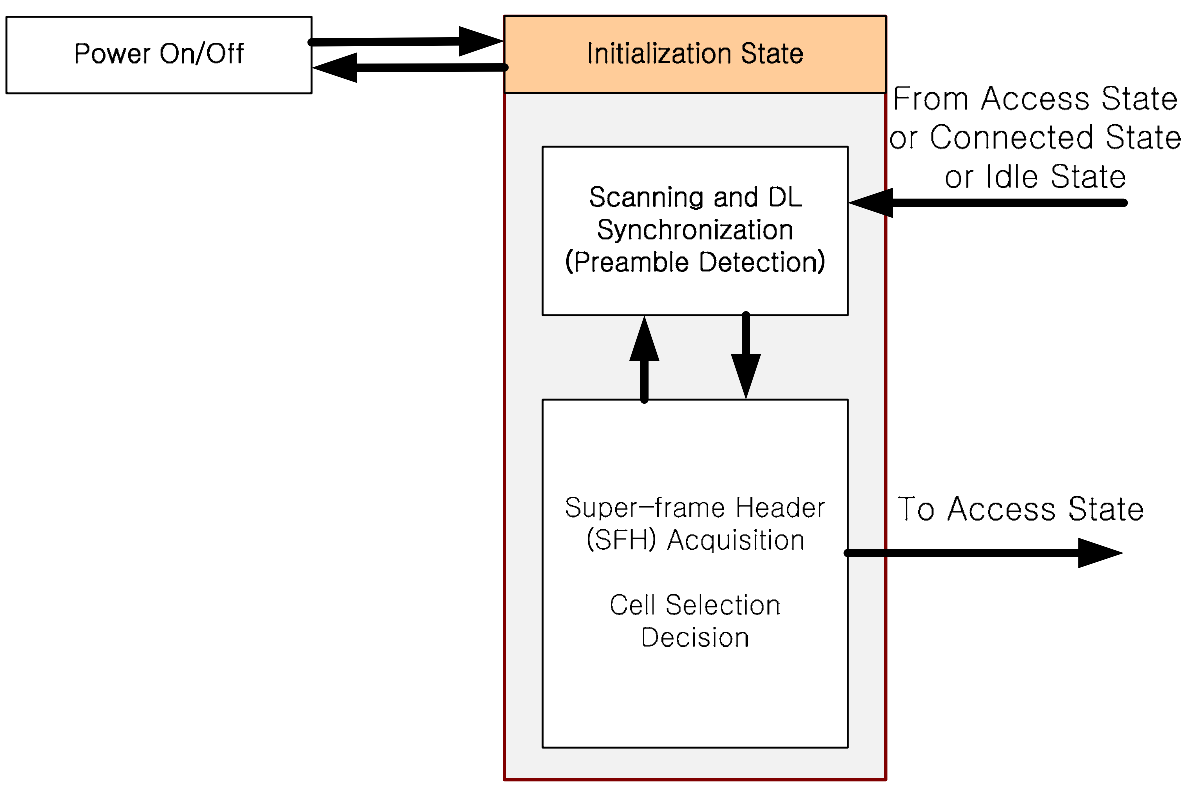

Figure 5: Initialization State Procedures

During this state, if the AMS cannot properly perform the system configuration information decoding and cell selection, it falls back to perform scanning and DL synchronization. If the AMS successfully decodes the system configuration information and selects a target ABS, it transitions to the Access State.

6.2 Access State

The AMS performs network entry with the target ABS while in the Access State. Network entry is a multi step process consisting of ranging, pre-authentication capability negotiation, authentication and authorization, capability exchange and registration. The AMS receives its Station ID and establishes at least one connection using and transitions to the Connected State. Upon failing to complete any one of the steps of network entry the AMS transitions to the Initialization State.

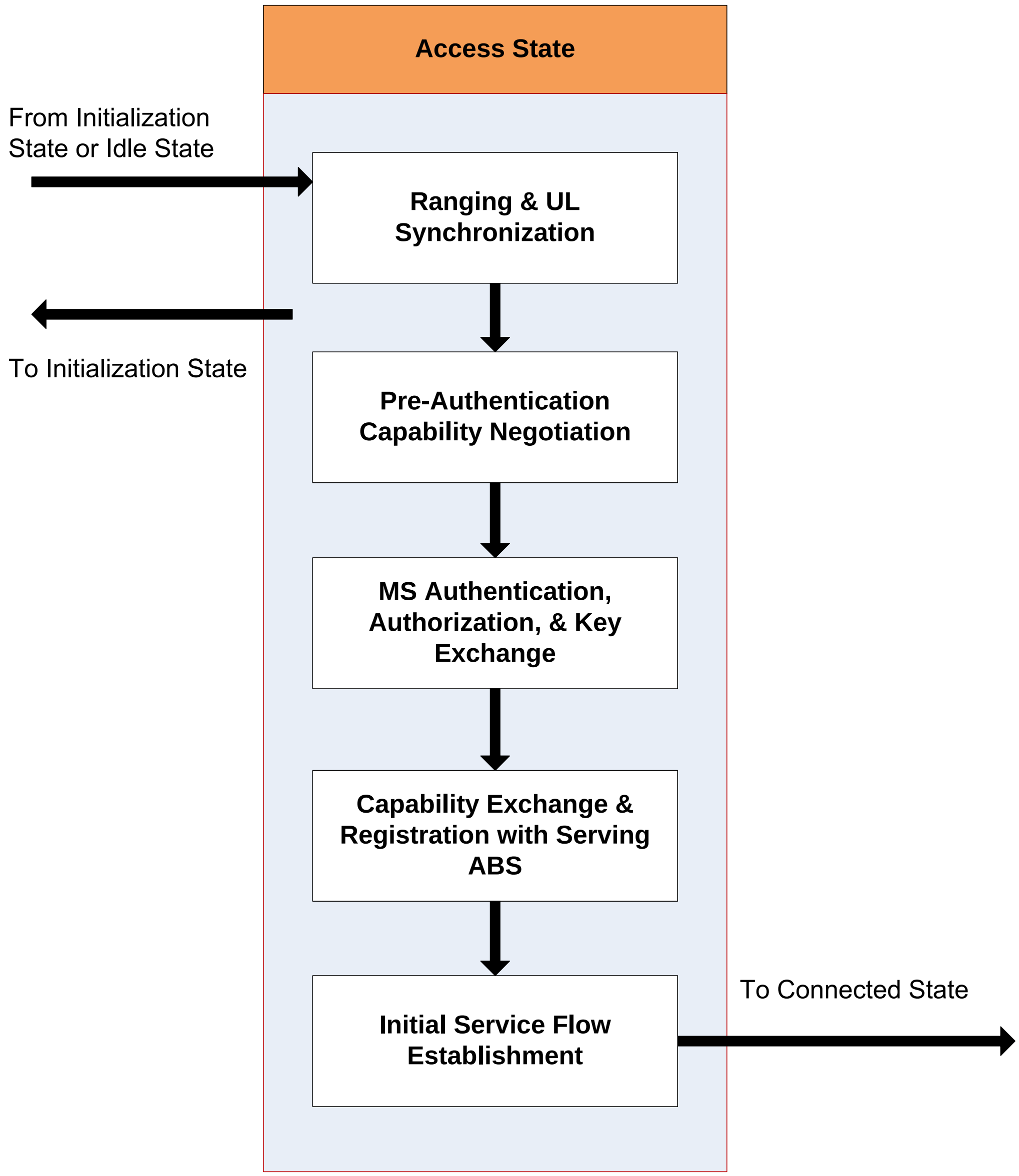

Figure 6: Access State Procedures

6.3 Connected State

When in the Connected State, an AMS operates in one of three modes; Sleep Mode, Active Mode and Scanning Mode. During Connected State, the AMS maintains two connections established during Access State. Additionally, the AMS and the ABS may establish additional transport connections. The AMS may remain in Connected State during a hand over. The AMS transitions from the Connected State to the Idle State based on a command from the ABS. Failure to maintain the connections prompts the AMS to transition to the Initialization State.

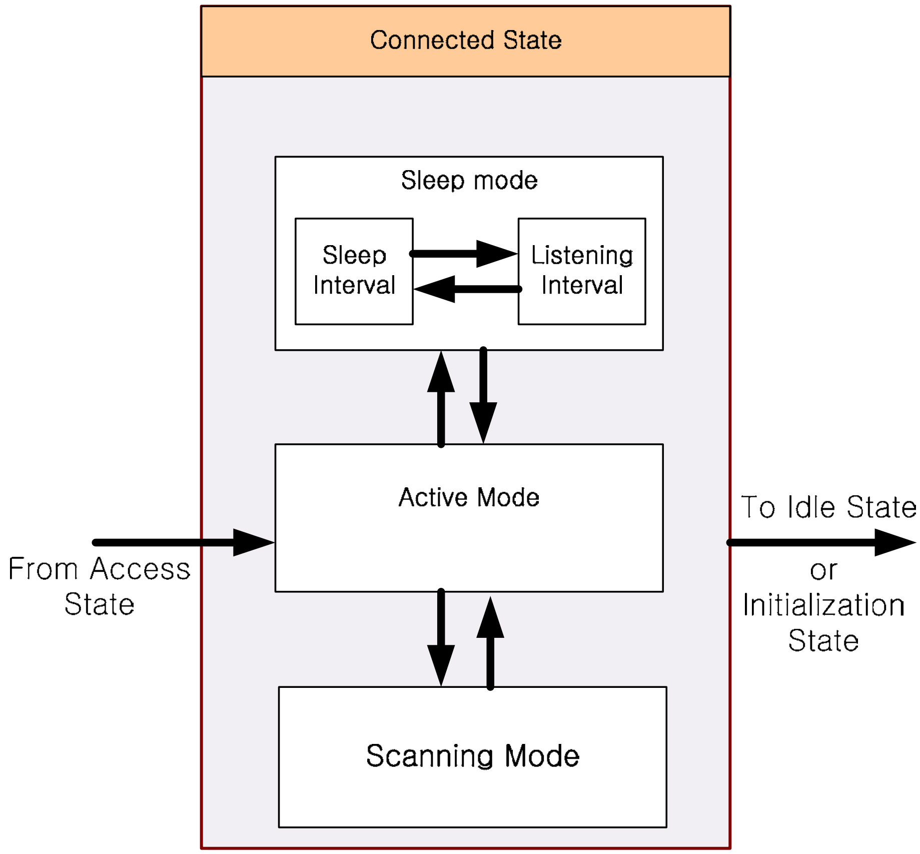

Figure 7: Connected State Procedures

6.3.1 Active Mode

When the AMS is in Active Mode, the serving ABS may schedule the AMS to transmit and receive at the earliest available opportunity provided by the protocol, i.e. the AMS is assumed to be 'available' to the ABS at all times. The AMS may request a transition to either Sleep or Scanning Mode from Active Mode. Transition to Sleep or Scanning Mode happens upon command from the serving ABS. The AMS may transition to Idle State from Active Mode of Connected State.

6.3.2 Sleep Mode

When in Sleep Mode, the AMS and ABS agree on the division of the radio frame in time into Sleep Windows and Listening Windows. The AMS is only expected to be capable of receiving transmissions from the ABS during the Listening Windows and any protocol exchange has to be initiated during that time. The AMS transition to Active Mode is prompted by control messages received from the ABS. The AMS may transition to Idle State from Sleep Mode of Connected State during Listening Intervals.

6.3.3 Scanning Mode

When in Scanning Mode, the AMS performs measurements as instructed by the serving ABS. The AMS is unavailable to the serving ABS while in scanning Mode. The AMS returns to Active Mode once the duration negotiated with the ABS for scanning expires.

6.4 Idle State

The Idle state consists of two separated modes, Paging Available Mode and Paging Unavailable Mode based on its operation and MAC message generation. During Idle State, the AMS may perform power saving by switching between Paging Available Mode and Paging Unavailable Mode.

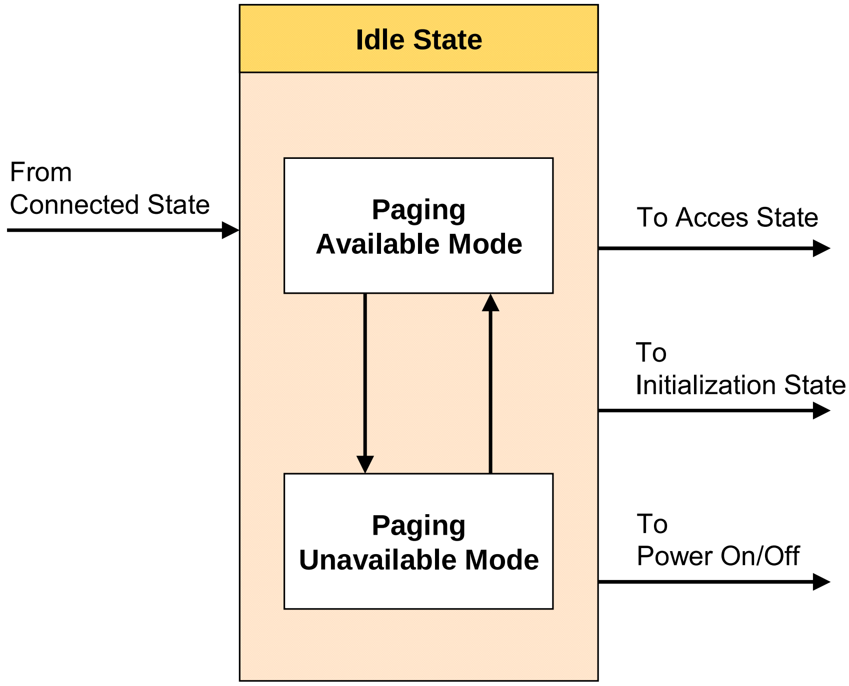

Figure 8: Idle State Procedures

6.4.1 Paging Available Mode

The AMS may be paged by the ABS while it is in the Paging Available Mode. If the AMS is paged with indication to return to the Connected State, the AMS transitions to the Access State for its network re-entry. The AMS may perform location update procedure during the Idle State.

6.4.2 Paging Unavailable Mode

During Paging Unavailable Mode, AMS does not need to monitor the downlink channel in order to reduce its power consumption.

7 Frequency Bands

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

The functional block definitions captured in Section 8.1 apply to the ABS and AMS. Definitions of functional blocks for the ARS are captured in Section 8.2.

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)

The MAC Common Part Sublayer is further classified into Radio Resource Control and Management (RRCM) functions and medium access control (MAC) functions. The RRCM functions fully reside on the control plane. The MAC functions reside on the control and data planes. The RRCM functions include 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
- Service Flow and Connection Management
- Relay Functions
- Self Organization
- Multi-Carrier

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.

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

The Network-entry Management block is in charge of initialization and access procedures. The Network-entry Management block may generate management messages which are needed during access procedures, i.e., ranging, basic capability negotiation, registration, and so on.

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

The Idle Mode Management block manages location update operation during Idle Mode. The 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.

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

The System Configuration Management block manages system configuration parameters, and transmits system configuration information to the AMS.

The E-MBS (Enhanced -Multicast Broadcast Service) block controls management messages and data associated with broadcasting and/or multicasting service.

The Service Flow and Connection Management block allocates STID and FIDs during access/handover/ service flow creation procedures.

The Relay Functional block includes functions to support multi-hop relay mechanisms. The functions include procedures to maintain relay paths between ABS and an access ARS.

The 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.

The 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) on contiguous or non-contiguous 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 are aligned in frequency domain in order to be used for data transmission.

The control plane part of the Medium Access Control (MAC) functional group includes functional 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
- Multi-Radio Coexistence
- Data Forwarding
- Interference Management
- Inter-ABS Coordination

The 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 AMS, and performs link adaptation via adjusting modulation and coding scheme (MCS), and/or power level. In the ranging procedure, PHY control block does UL synchronization with power adjustment, frequency offset and timing offset estimation.

The Control Signaling block generates resource allocation messages.

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

The QoS block handles QoS management based on QoS parameters input from Service Flow and Connection Management block for each connection.

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

The 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 ABS and AMS. 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 to manage the inter-cell/sector interference. The operations may include:

- MAC layer operation
    - Interference measurement/assessment report sent via MAC signaling

- o Interference mitigation by scheduling and flexible frequency reuse
- PHY layer operation
  - o Transmit power control
  - o Interference randomization
  - o Interference cancellation
  - o Interference measurement
  - o Tx beamforming/precoding

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

The data plane includes the following MAC functions:

- ARQ
- Fragmentation/Packing
- MAC PDU formation

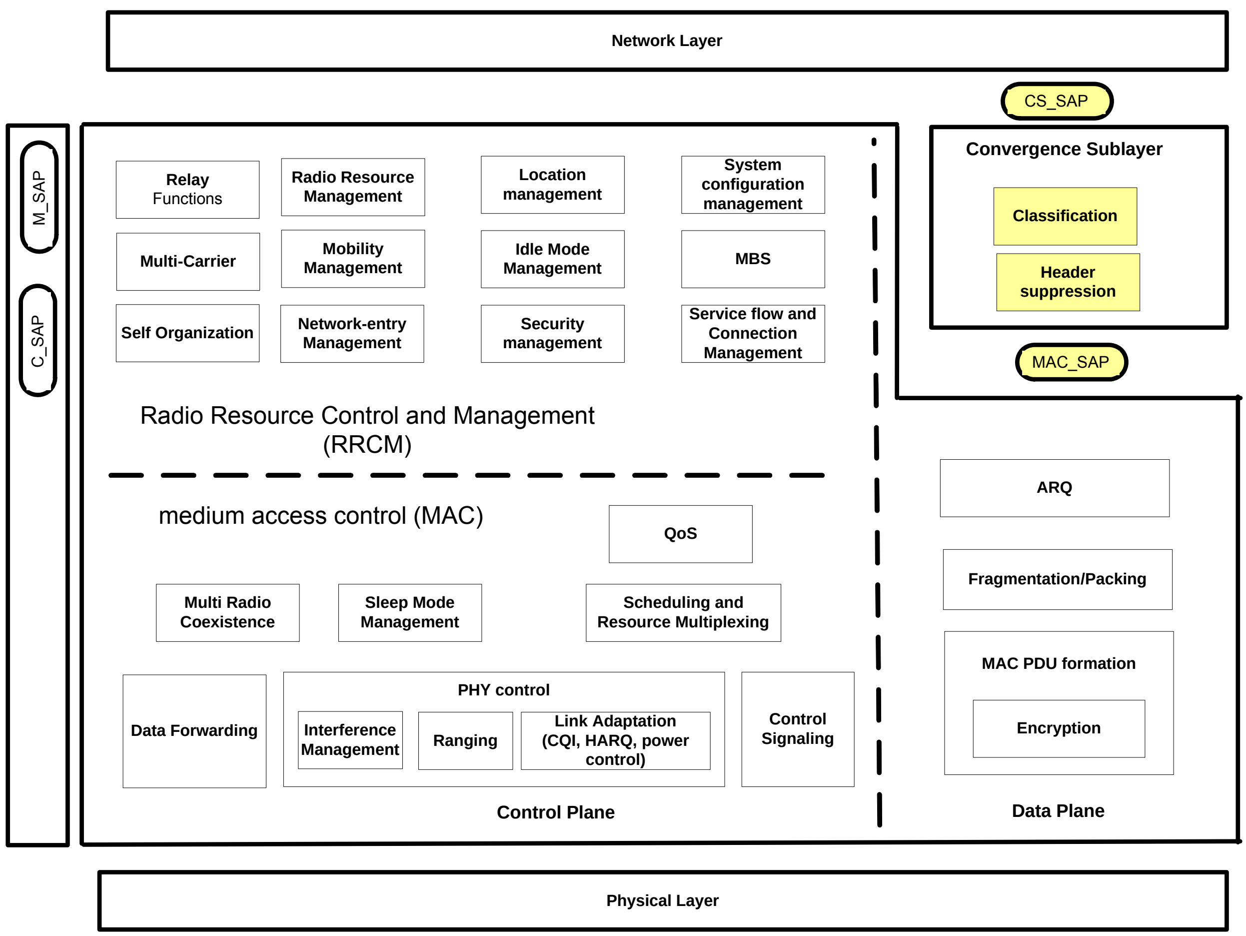

Figure 9: IEEE 802.16m Protocol Structure

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

The Fragmentation/Packing block performs fragmenting or packing MSDUs based on scheduling results from Scheduling and Resource Multiplexing block.

The MAC PDU formation block constructs MAC protocol data unit (PDU) so that ABS/AMS can transmit user traffic or management messages into PHY channel. MAC PDU formation block adds MAC header and may add sub-headers.

8.1.1 AMS/ABS Data Plane Processing Flow

Figure 10 shows the user traffic data flow and processing at the ABS and the AMS. 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 enabled), 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/packing function, the ARQ function (if enabled) and the convergence sublayer function, to form the network layer packets. The black arrows show the control primitives among the CPS functions and between the CPS and PHY that are related to the processing of user traffic data.

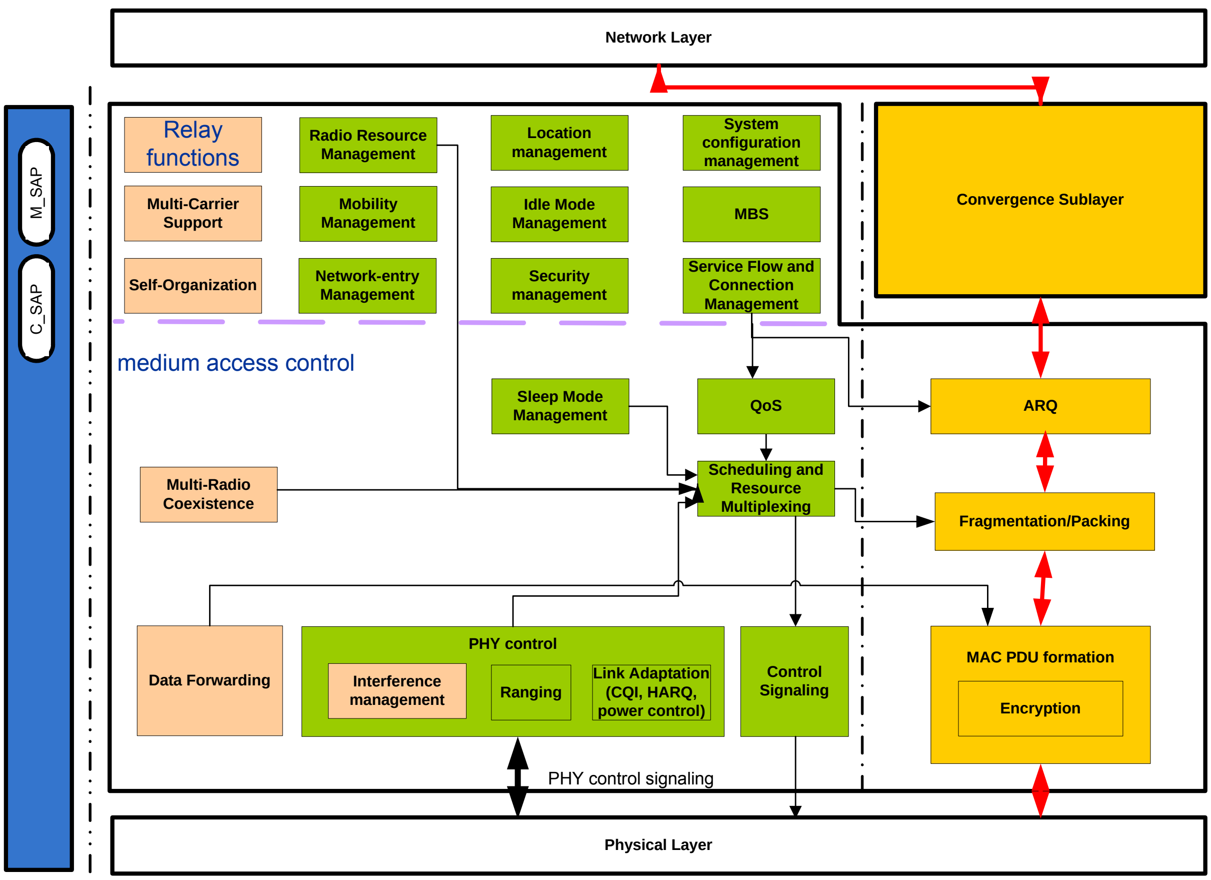

Figure 10: IEEE 802.16m AMS/ABS Data Plane Processing Flow

Note: The AMS may not utilize all the blocks shown in Figure 10

8.1.2 The AMS/ABS Control Plane Processing Flow

The following figure shows the MAC CPS control plane signaling flow and processing at the ABS and the AMS. 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 CPS functions and between the CPS and PHY that are related to the processing of control plane signaling. The black arrows between Management SAP (M_SAP)/ Control SAP (C_SAP) and MAC functional blocks show the control and management primitives to/from Network Control and Management System (NCMS). The primitives to/from M_SAP/C_SAP define the network involved functionalities such as inter-ABS interference management, inter/intra RAT mobility management, etc, and management related functionalities such as location management, system configuration etc. The Control SAP and Management SAP expose control plane and management plane functions to upper layers.

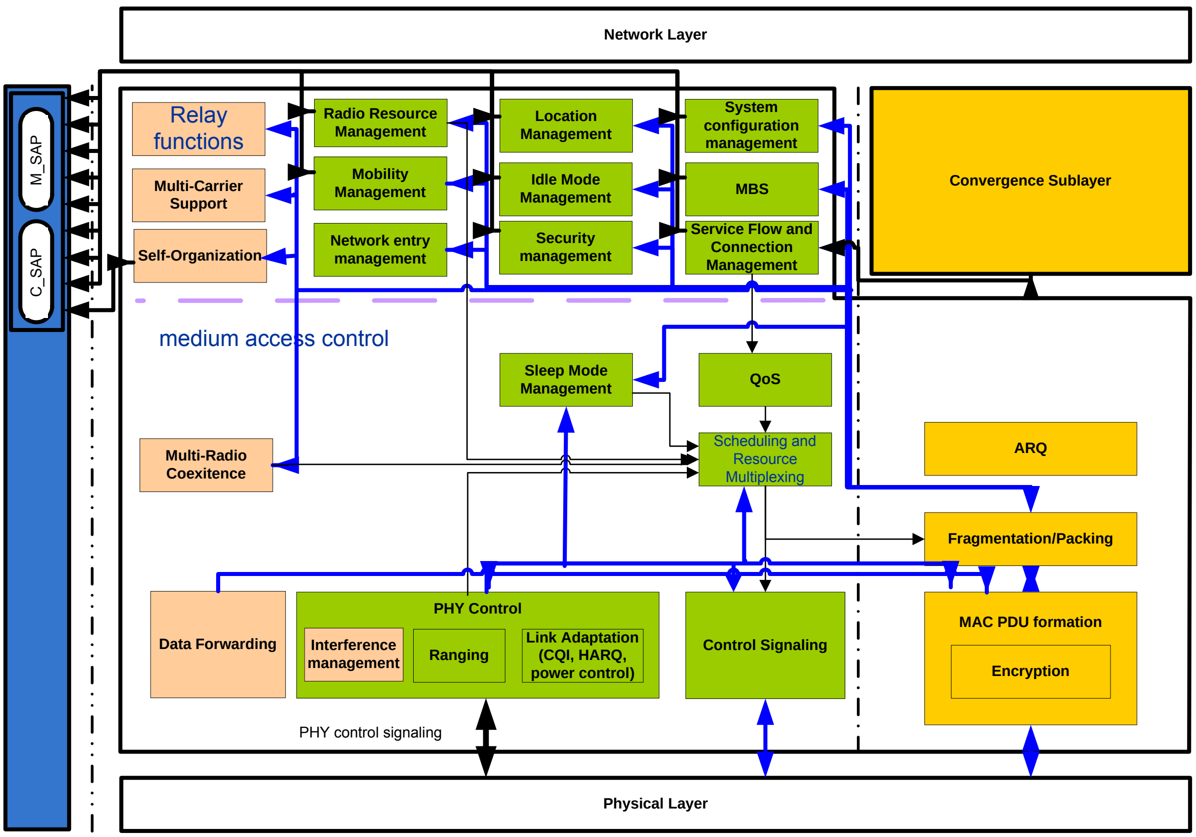

Figure 11: IEEE 802.16m AMS/ABS Control Plane Processing Flow

Note: The AMS may not utilize all the blocks shown in Figure 11

8.1.3 Multicarrier Support Protocol Structure

The 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) on contiguous or non-contiguous 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.

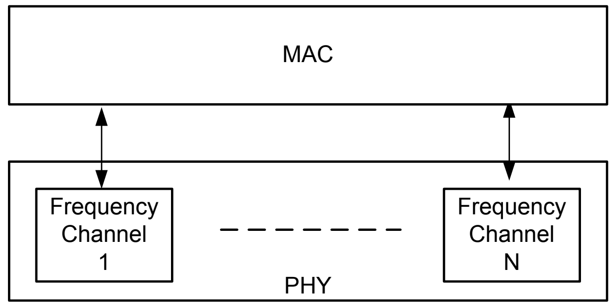

Figure 12: IEEE 802.16m multicarrier generic protocol structure

8.1.4 Multi-Radio Coexistence Support Protocol Structure

Figure 13 shows an example of multi-radio device with co-located AMS, IEEE 802.11 station, and IEEE 802.15.1 device. The multi-radio coexistence functional block of the AMS 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 the IEEE 802.16m standard.

IEEE 802.16m provides protocols for the multi-radio coexistence functional blocks of AMS and ABS or ARS to communicate with each other via air interface. The AMS generates management messages to report the information about its co-located radio activities obtained from inter-radio interface, and ABS or ARS generates management messages to respond with the corresponding actions to support multi-radio coexistence operation. Furthermore, the multi-radio coexistence functional block at ABS or ARS communicates with the Scheduling and Resource Multiplexing 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.

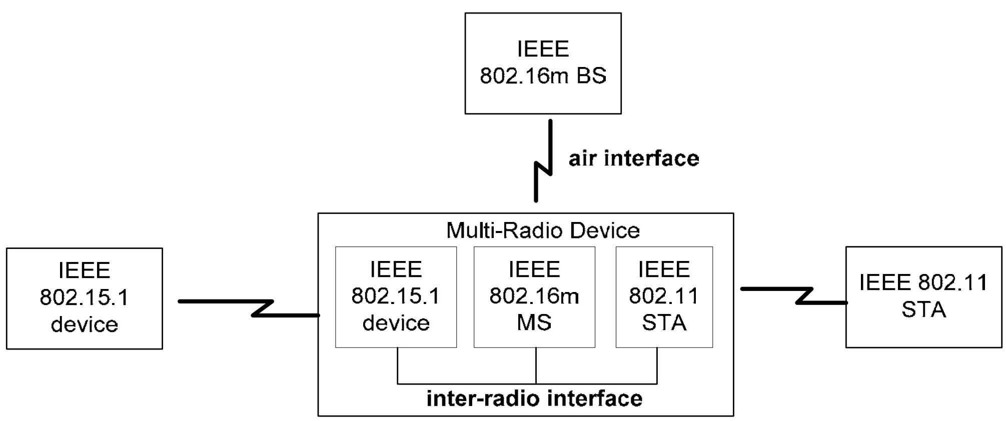

Figure 13: Example of multi-radio device with co-located IEEE 802.16m AMS, IEEE 802.11 STA, and IEEE 802.15.1 devices

8.2 Relay Protocol Structure

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

The functional blocks and the definitions in this section do not imply that these functional blocks are supported in all ARS implementations.

The ARS MAC is divided into two sublayers:

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

The ARS RRCM sublayer includes the following functional blocks that are related with ARS radio resource functions:

- Mobility Management
- Network-entry Management
- Location Management
- Security Management
- MBS
- Relay Functions
- Self Organization
- Multi-Carrier

The Mobility Management block supports AMS handover operations in cooperation with the ABS.

The Network-entry Management block is in charge of ARS/AMS initialization procedures and performing ARS network entry procedure to the ABS. Network-entry Management block may generate management messages needed during ARS/AMS initialization procedures and performing the network entry.

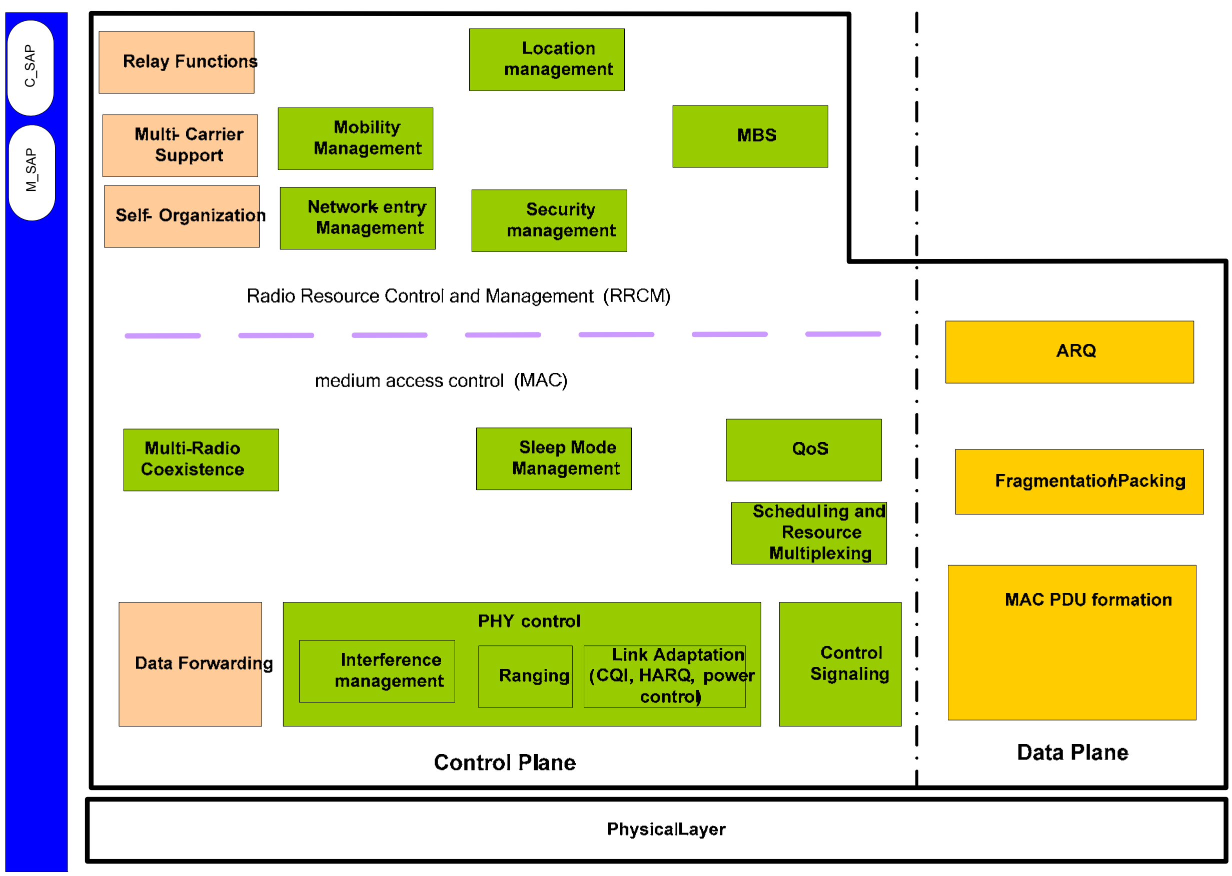

Figure 14: IEEE 802.16m ARS Protocol Structure

The Location Management block is in charge of supporting location based service (LBS), including positioning data, at the ARS and reporting location information to the ABS. Location Management block may generate messages for the LBS information including positioning data.

The Security Management block handles the key management for the ARS.

The E-MBS (Enhanced Multicast and Broadcast Service) block coordinates with the ABS to schedule the transmission of MBS data.

The Relay Functions block includes procedures to maintain relay paths.

The Self Organization block performs functions to support ARS self configuration and ARS self optimization mechanisms coordinated by ABS. The functions include procedures to request ARSs/AMSs to report measurements for self configuration and self optimization and receive measurements from the ARSs/AMSs, and report measurements to ABS. The functions also include procedures to adjust ARS parameters and configurations for self configuration / optimization with / without the coordination with ABS.

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

The ARS Medium Access Control (MAC) sublayer on the control plane 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
- Data Forwarding
- Multi-Radio Coexistence

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

The Control Signaling block generates ARS 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 ABS.

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

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

The Data Forwarding block performs forwarding functions on the path between ABS and ARS/AMS. 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 ARS to manage the inter-cell/sector and inter-ARS interference among ARS and ABS. This includes the collection of interference level measurements and selection of transmission mode used for individual MSs attached to the ARS.

Control functions can be divided among the ABS and ARSs using a centralized model or a distributed model. In a centralized model, the ABS makes control decisions and the RSs relay control information between the ABS and

AMS. In a distributed model the ARS makes control decisions for MSs attached to it as appropriate, and optionally communicates those decisions to the ABS. 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.

Multi-Radio Coexistence block within the RS handles multi-radio coexistence operation of its AMSs in coordination with the ABS.

The MAC functions on the data plane include the following:

- ARQ
- Fragmentation/Packing
- MAC PDU formation

The ARQ block assists MAC ARQ function between ABS, ARS and AMS.

The Fragmentation/Packing block performs fragmenting or packing MSDUs based on scheduling results from Scheduling and Resource Multiplexing block. The Fragmentation/Packing block in an ARS 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 ABS or AMS. The MAC PDU formation block may add or modify MPDU control information (e.g., MAC header).

8.3 E-MBS Protocol Structure

Enhanced Multicast and Broadcast Services (E-MBS) consists of MAC and PHY protocols that define interactions between the MSs and the BSs.

While the basic definitions are consistent with IEEE Std 802.16-2009 some enhancements and extensions are defined to provide improved functionality and performance.

The breakdown of E-MBS function (see Figure 9) into constituent sub-functions is shown in Figure 15. In the control plane, E-MBS MAC function operates in parallel with the unicast MAC functions. Unicast MAC functions could operate independently from E-MBS MAC function. E-MBS MAC function may operate differently depending on whether operating in Active Mode or Idle Mode.

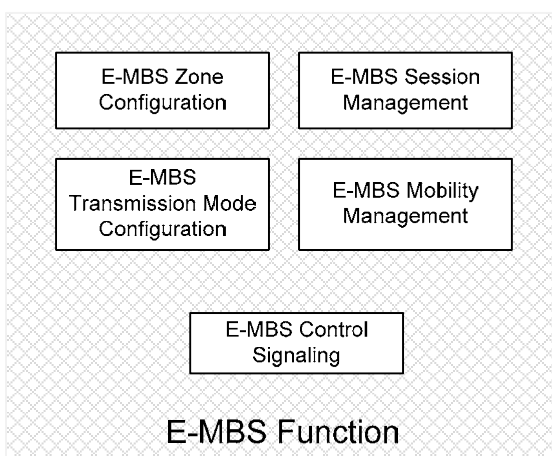

Figure 15: Breakdown of the E-MBS Function (Control Plane)

The E-MBS MAC function consists of the following functional blocks:

E-MBS Zone Configuration: This function manages the configuration advertisement of E-MBS zones. An ABS could belong to multiple E-MBS zones.

E-MBS Transmission Mode Configuration: This function describes the transmission mode in which E-MBS is delivered over air interface such as single-ABS and multi-ABS transmission.

E-MBS Session Management: This function manages E-MBS service registration / de-registration and session start / update / termination.

E-MBS Mobility Management: This block manages the zone update procedures when an AMS crosses the E-MBS zone boundary.

E-MBS Control Signaling: This block broadcasts the E-MBS scheduling and logical-to-physical channel mapping to facilitate E-MBS reception and support power saving.

9 Convergence Sublayer

The service-specific Convergence Sublayer (CS) resides on top of the MAC CPS and utilizes, via the MAC SAP, the services provided by the MAC CPS. The CS performs the following functions:

- Accepting higher layer protocol data units (PDUs) from the higher layer
- Performing classification of higher layer PDUs
- Processing (if required) the higher layer PDUs based on the classification
- Delivering CS PDUs to the appropriate MAC SAP
- Receiving CS PDUs from the peer entity

Internet Protocol CS or Generic Packet CS is used to transport packet data over the air interface. For GPCS the classification is assumed to take place on layers above the CS. Relevant information for performing classification is transparently transported during connection setup or change.

10 Medium Access Control Layer

10.1 Addressing

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

10.1.1 MAC Address

The AMS, ARS and ABS are identified by the globally unique 48-bit IEEE Extended Unique Identifier (EUI-48™) based on the 24-bit Organizationally Unique Identifier (OUI) value administered by the IEEE Registration Authority [16].

10.1.2 Logical Identifiers

The following logical identifiers are defined in the following subsections.

10.1.2.1 Station Identifier (STID)

The ABS assigns a 12 bit STID to the AMS during network entry, and, in some cases, network re-entry, that uniquely identifies the AMS within the domain of the ABS. Each AMS registered in the network has an assigned STID. Some specific “STIDs” are reserved, for example, for broadcast, multicast, and ranging.

10.1.2.2 Flow Identifier (FID)

Each AMS connection is assigned a 4 bit FID that uniquely identifies the connection within the AMS. FIDs identify management connections and transport connections. Some specific FIDs may be pre-assigned.

10.2 HARQ Functions

IEEE 802.16m always uses HARQ for unicast data traffic in both downlink and uplink. The IEEE 802.16m HARQ scheme is based on a stop-and-wait protocol. Both ABS and AMS are capable of maintaining multiple HARQ channels. The DL HARQ channels are identified by HARQ channel identifier (ACID), whereas the UL HARQ channels are identified by both ACID and the index of UL subframe in which UL HARQ data burst is transmitted. Multiple UL HARQ channels in the same UL subframe are identified by different ACIDs, and UL HARQ channels in different UL subframes is identified by the index of UL subframe when the same ACID is addressed to them.

Generation of the HARQ subpackets follows the channel coding procedures. The received subpackets are combined by the FEC decoder as part of the decoding process. The use of Incremental redundancy (IR) is mandatory, with Chase combining as a special case of IR. For IR, each subpacket contains the part of codeword determined by a subpacket identifier (SPID). The rule of subpacket transmission is as follows:

For the downlink,

a) In the first transmission, ABS sends the subpacket labeled 0b00.
b) ABS may send one among subpackets labeled 0b00, 0b01, 0b10 and 0b11 in any order.

For the uplink,

a) In the first transmission, AMS sends the subpacket labeled 0b00.
b) AMS shall send one among subpackets labeled 0b00, 0b01, 0b10 and 0b11 in sequential order.

In order to specify the start of a new transmission, a single-bit HARQ identifier sequence number (AI_SN) is toggled on every new HARQ transmission attempt on the same ACID. If the AI_SN changes, the receiver treats the corresponding HARQ attempt as belonging to a new encoder packet and discards previous HARQ attempt with the same ACID.

10.2.1 HARQ in the Downlink

10.2.1.1 HARQ Timing and Protocol

IEEE 802.16m uses adaptive asynchronous HARQ 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.

Upon receiving a DL Basic Assignment A-MAP IE, AMS attempts to receive and decode the data burst as allocated to it by the DL Basic Assignment A-MAP IE. If the decoding is successful, the AMS sends a positive acknowledgement to ABS; otherwise, AMS will send a negative acknowledgement to ABS.

The process of retransmissions is controlled by the ABS using the ACID and AI_SN fields in the DL Basic Assignment A-MAP IE. If the AI_SN field for the ACID remains same between two HARQ bursts allocation, it indicates retransmission. Through the DL Basic Assignment A-MAP IE for retransmission, the ABS may allocate different resource allocation and transmission format. If AI_SN field for the ACID is toggled, i.e. from 0 to 1 or vice versa, it indicates the transmission of a new HARQ burst. In the DL, the maximum number of total HARQ channels per AMS is 16. The delay between two consecutive HARQ transmissions of the same data burst does not exceed the maximum [T_ReTx_Interval]. The number of retransmissions of the same data burst does not exceed the maximum [N_MAX_ReTx].

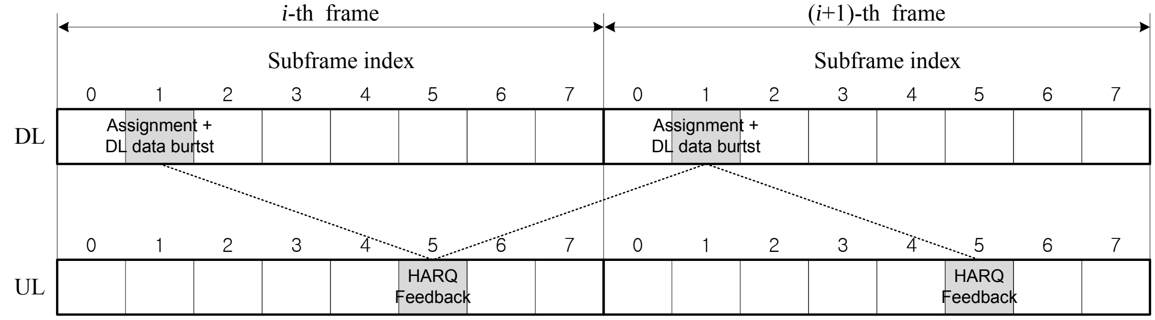

Figure 16: Example of FDD DL HARQ timing for 5, 10 and 20 MHz channel bandwidths

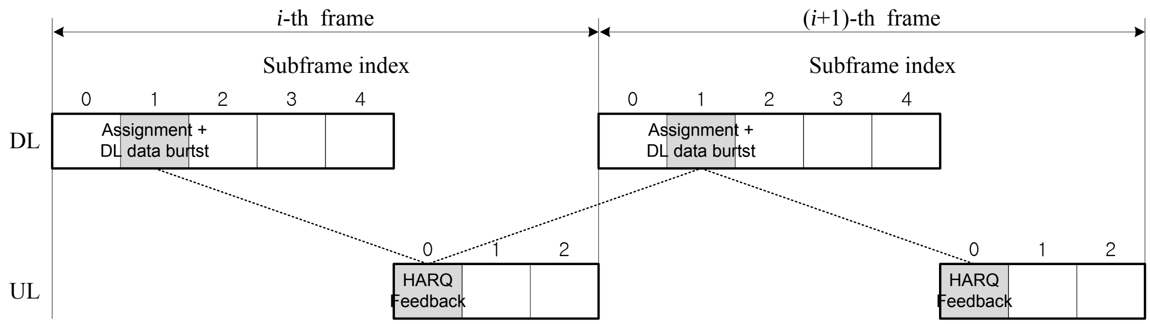

Figure 17: Example of TDD DL HARQ timing for 5, 10 and 20 MHz channel bandwidths

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

A failed HARQ burst should be retransmitted within maximum retransmission delay bound. An HARQ burst is discarded if a maximum number of retransmissions is reached.

10.2.1.2 HARQ Operation with Persistent and Group Allocation

When persistent allocation is applied to initial transmissions, HARQ retransmissions are supported in a non-persistent manner, i.e. resources are allocated dynamically for HARQ retransmissions. Asynchronous HARQ operation is supported.

With group resource allocation, the HARQ retransmissions are allocated individually in an asynchronous manner.

10.2.2 HARQ in the Uplink

10.2.2.1 HARQ Timing and Protocol

IEEE 802.16m uses synchronous HARQ in the uplink. For synchronous HARQ, resource allocation for the retransmissions in the uplink can be fixed or adaptive according to control signaling. The default operation mode of HARQ in the uplink is non-adaptive, i.e. the parameters and the resource for the retransmission are known a priori. The ABS can by means of signaling enable an adaptive UL HARQ mode. In adaptive HARQ the parameters of the retransmission are signaled explicitly.

Upon receiving a UL Basic Assignment A-MAP IE, the AMS transmits the subpacket of HARQ data burst in the resource assigned by the UL Basic Assignment A-MAP IE. The ABS attempts to decode the data burst. If the decoding is successful, the ABS sends a positive acknowledgement to the AMS; otherwise, the ABS will send a negative acknowledgement to AMS. Upon receiving the negative acknowledgement, AMS triggers retransmission procedure.

In the retransmission procedure, if AMS does not receive a UL Basic Assignment A-MAP IE for the HARQ data burst in failure, the AMS transmits the next subpacket through the resources assigned at the latest subpacket transmission with the same ACID. A UL Basic Assignment A-MAP IE may be sent to signal control information for retransmission with the corresponding ACID and AI_SN being not toggled. Upon receiving the UL Basic Assignment A-MAP IE, the AMS performs the HARQ retransmission as instructed in this UL Basic Assignment A-MAP IE.

In UL, the maximum number of total HARQ channels per AMS is 16. The number of retransmissions of the same data burst does not exceed the maximum [N_MAX_ReTx].

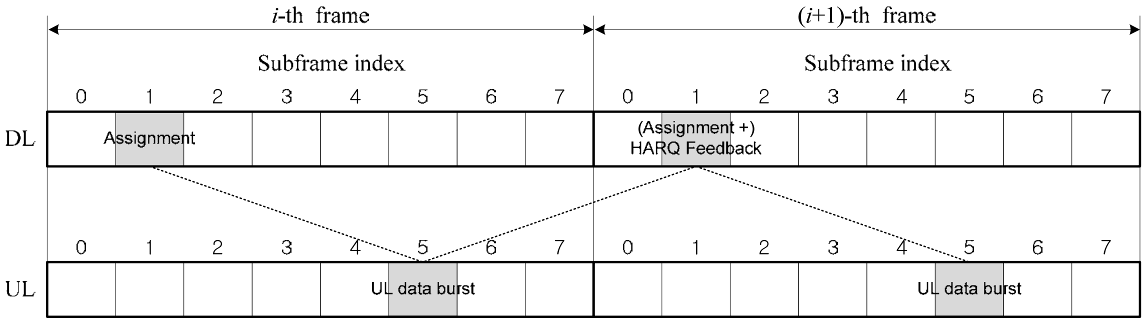

Figure 18: Example of FDD UL HARQ timing for 5, 10 and 20 MHz channel bandwidths

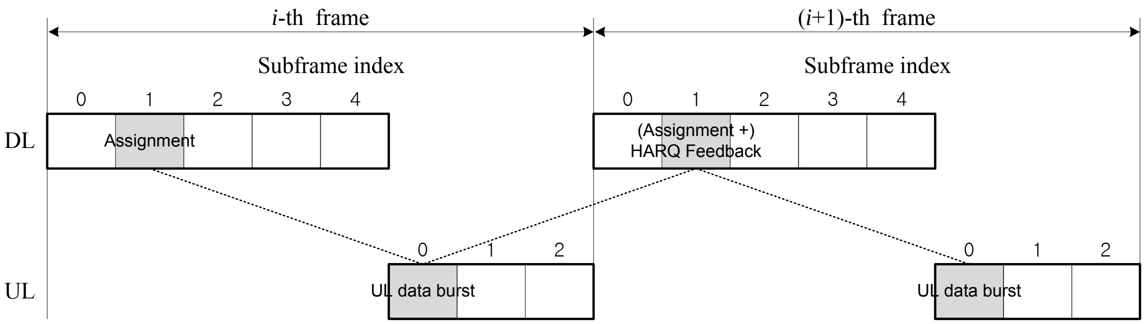

Figure 19: Example of TDD UL HARQ timing for 5, 10 and 20 MHz channel bandwidths

10.2.2.2 HARQ Operation with Persistent and Group Allocation

When persistent allocation is applied to initial transmissions, HARQ retransmissions are supported in a synchronous manner i.e., resources are allocated implicitly or explicitly.

With group resource allocation, the HARQ retransmissions are allocated individually in a synchronous manner.

10.2.3 HARQ and ARQ Interactions

When both ARQ and HARQ are applied for a flow, HARQ and ARQ interactions described here can be applied to the corresponding flow.

If the HARQ entity in the transmitter determines that the HARQ process was terminated with an unsuccessful outcome, the HARQ entity in the transmitter informs the ARQ entity in the transmitter about the failure of the HARQ burst. The ARQ entity in the transmitter can then initiate retransmission and re-segmentation of the ARQ blocks that correlate to the failed HARQ burst.

10.3 Handover

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

Case-1: AMS handover from serving YBS to target YBS
Case-2: AMS handover from serving ABS to target YBS
Case-3: AMS handover from serving YBS to target ABS
Case-4: AMS handover from serving ABS to target ABS

The IEEE 802.16m network and mobile station use legacy handover procedures for case-1.
Solutions for cases 2, 3 and 4 are described in Sections 10.3.3.3, 10.3.3.2 and 10.3.2 respectively.

10.3.1 Network Topology Acquisition

10.3.1.1 Network Topology Advertisement

An ABS periodically broadcasts the system information of the neighboring ABSs and/or YBS using Neighbor Advertisement message. The ABS formats Neighbor Advertisement message based on the cell types of neighbor cells, in order to achieve overhead reduction and facilitate scanning priority for AMS. A broadcast Neighbor Advertisement message does not include information of neighbor CSG femtocells. Special handling of neighbor information of femtocell BS is described in Section 15.7.

A serving ABS may unicast the Neighbor Advertisement message to an AMS. The Neighbor Advertisement message may include parameters required for cell selection e.g., cell load and cell type.

10.3.1.2 Scanning Procedure

The scanning procedure provides the opportunity for the AMS to perform measurement of the neighboring cells for handover decision. The AMS may use any interval not allocated by the serving ABS to perform autonomous scanning. In addition, the AMS may perform scanning procedure without interrupting its communication with the serving ABS if the AMS supports such capability.

AMS selects the scanning candidate ABSs by information obtained from the ABS or information cached in the AMS. The ABS or AMS may prioritize the neighbor ABSs to be scanned based on various metrics, such as cell type, loading, RSSI and location.

As part of the scanning procedure, AMS measures the selected scanning candidate ABSs and reports the measurement result back to the serving ABS. The measurements may be used by the AMS or the network to determine the correct target –ABS for the AMS to handover to. The measurements in the Advanced WirelessMAN-OFDMA Interface include the measurements specified as part of the WirelessMAN-OFDMA system as well as any other measurements defined in the Advanced WirelessMAN-OFDMA Interface. The serving ABS defines triggering conditions and rules for AMS sending scanning report.

10.3.2 Handover Process

10.3.2.1 HO Framework

The handover procedure may be initiated by either AMS or ABS. In the case of the AMS initiated HO, the AMS sends an HO initiation message to the serving ABS (S-ABS). The S-ABS responds to the HO initiation message by sending an HO command message to the AMS. In the case of the S-ABS initiated HO, the S-ABS sends an HO Command control message to the AMS. In both cases (HO initiated by AMS or S-ABS) the HO command message should include one or more target ABSs (T-ABSs). If the HO command message includes only one target ABS, the AMS should execute the HO as directed by the ABS. An AMS may send a HO indication message to the S-ABS before the expiration of disconnect time. The S-ABS stops sending DL data and providing UL allocations to the AMS after expiration of the disconnect time or after reception of HO-IND.

If the HO command message includes more than one target ABSs, the AMS selects one of these targets and informs the S-ABS of its selection by sending an HO indication message to the S-ABS before the expiration of disconnect time.

The network re-entry procedure with the target ABS may be optimized by target ABS possession of AMS information obtained from serving ABS over the backbone network. AMS may also maintain communication with serving ABS while performing network re-entry at target ABS as directed by serving ABS. Figure 20 shows a general call flow for handover.

The S-ABS defines error conditions based on which the AMS decides when a T-ABS among those that are included in HO command control signaling is unreachable. If all the target ABSs that are included in the HO command signaling are unreachable, the AMS signals the new T-ABS to the S-ABS by sending HO indication control signaling before the expiration of disconnect time, and the AMS performs network re-entry at the new T-ABS as indicated in the HO indication control signaling. The AMS also indicates the identity of its old S-ABS to the new T-ABS during network entry at the new T-ABS.

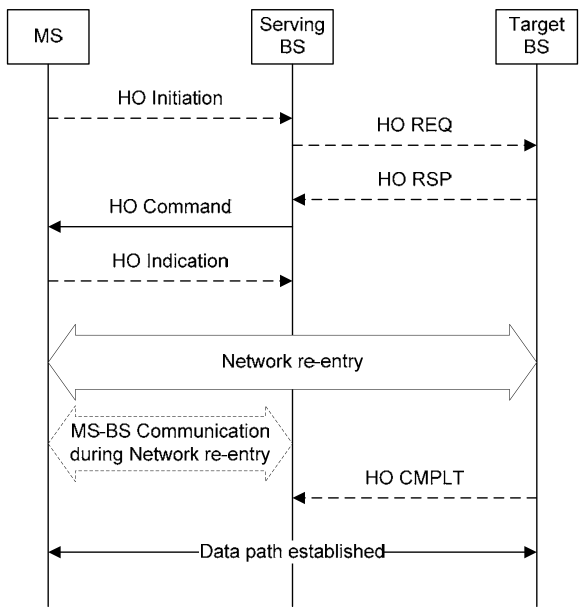

Figure 20: The general call flow for handover

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

10.3.2.2 HO Procedure

10.3.2.2.1 HO initiation

Handover procedure may be initiated by either AMS or ABS. When handover is initiated by the AMS, it is based on the triggers and conditions defined by the S-ABS. The HO trigger may consist of a combination of multiple conditions. When HO is initiated by AMS, a HO Initiation control signaling is sent by the AMS to start the HO procedure. In case of ABS 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 ABS communicates with target ABS(s) selected for HO. The target ABS may obtain AMS information from the serving ABS via backbone network for HO optimization. If ranging with target ABS not performed prior to or during HO preparation, dedicated ranging resource (e.g. code, channel, etc.) at target ABS may be reserved for the AMS to facilitate non-contention-based HO ranging. Information regarding AMS identity (e.g. TEK, STID, FIDs, etc.), may be pre-updated during HO preparation. Any mismatched system information between AMS and the target ABS, if detected, may be provided to the AMS by the Serving ABS during HO preparation.

When only one target ABS is included in the HO Command control signaling, the HO preparation phase completes when serving ABS informs the AMS of its handover decision via a HO Command control signaling. When multiple target ABSs are included in the HO Command control signaling, the HO preparation phase completes when the AMS informs the ABS of its target ABS selection via HO indication control signaling. The HO Command control signaling may include dedicated ranging resource allocation and resource pre-allocations for AMS at each target ABS for optimized network re-entry. The HO Command control signaling includes an action time for the AMS to start network re-entry at each target ABS and an indication whether AMS should maintain communication with serving ABS during network re-entry. The HO Command control signaling further includes a disconnect time, which indicates when the serving ABS will stop sending downlink data and stop providing any regularly scheduled unsolicited uplink allocations for the AMS. In the case that AMS maintains communication with serving ABS during network re-entry, the parameters associated with the scheme of multiplexing transmission with serving and target ABS are determined by serving ABS based on the AMS capability and negotiated between the serving and target ABSs.

The HO command control signaling indicates if the static and/or dynamic context and its components of the AMS is available at the target ABS.

10.3.2.2.3 HO Execution

At the action time specified in the HO command control signaling, the AMS performs network re-entry at the target ABS. If communication is not maintained between AMS and serving ABS during network re-entry at the target ABS, serving ABS stops allocating resources to AMS for transmission at disconnect time.

If directed by serving ABS via HO Command control signaling, the AMS performs network re-entry with the target ABS at action time while continuously communicating with the serving ABS. However, the AMS stops communication with serving ABS after network re-entry at target ABS is completed. In addition, AMS cannot exchange data with target ABS prior to completion of network re-entry. Multiplexing of network re-entry signaling with the target ABS and data communications with the serving ABS is done by negotiating with the serving ABS for some intervals for network re-entry signaling with the target ABS, and the remaining intervals for data communication with the serving ABS. If the negotiated interval is set to 0, the AMS communicates with the serving ABS continuously while concurrently performing network re-entry with the target ABS. In case of single radio AMS, the negotiated interval excludes the value 0.

10.3.2.2.4 HO Cancellation

After HO is initiated, the handover may be canceled by AMS at any phase during HO procedure. After the HO cancellation is processed, the AMS and serving ABS resume their normal operation.

The network can advertise HO cancellation trigger conditions. When one or more of these trigger conditions are met the MS cancels the HO.

10.3.2.3 Network Re-entry

The network re-entry procedure is performed as specified in the WirelessMAN OFDMA Reference System unless otherwise specified in this section.

If a dedicated ranging code is assigned to the AMS by target ABS, the AMS transmits the dedicated ranging code to the target ABS during network re-entry. If a ranging channel is scheduled by the target ABS for handover purpose only, the AMS should use that ranging channel in order to avoid excessive multiple access interference. Upon reception of the dedicated ranging code, the target ABS should allocate uplink resources for AMS to send RNG-REQ message and UL data if needed.

When the AMS performs handover to the target ABS, CDMA-based HO ranging may be omitted.

10.3.3 Handover Process Supporting WirelessMAN OFDMA Reference System

10.3.3.1 Network Topology Acquisition

The WirelessMAN-OFDMA Reference System/WirelessMAN-OFDMA Advanced System co-existing system consists of WirelessMAN-OFDMA Reference System and WirelessMAN-OFDMA Advanced System cells/sectors. An YBS advertises the system information for its neighbor YBSs and the LZones of its neighbor ABSs. An ABS advertises the system information for its neighbor YBSs in its both LZone and MZone. It advertises the LZone system information of its neighbor ABSs in its LZone. It also advertises the system information for its neighbor ABSs in its MZone.

The ABS may indicate its WirelessMAN-OFDMA Advanced capability and information in its LZone broadcast information (e.g. by the modified reserved bit of the FCH and the MAC version TLV).

10.3.3.2 Handover from YBS to ABS

When a handover from a WirelessMAN-OFDMA Reference System to a WirelessMAN-OFDMA Advanced System is triggered for a YMS, the YMS handover is from the serving YBS to the LZone of the target ABS using WirelessMAN-OFDMA Reference System handover signaling and procedures.

An AMS may handover from the serving YBS to the LZone of the target ABS using a WirelessMAN-OFDMA Reference System handover signaling and procedures, and switch to the MZone of the ABS after AMS entering LZone. The detailed procedure for zone switching is FFS.

An AMS may also handover from a YBS to a WirelessMAN-OFDMA-Advanced-System-only ABS or MZone of ABS directly if AMS is able to scan WirelessMAN-OFDMA-Advanced-System-only ABS or MZone prior to handover. The detailed procedure is FFS.

10.3.3.3 Handover from ABS to YBS

When a handover from the WirelessMAN-OFDMA Advanced System to the WirelessMAN-OFDMA Reference System is triggered for a YMS, the YMS handover is from LZone of the serving ABS to the target YBS using handover signaling and procedures as defined in WirelessMAN-OFDMA Reference System.

When a handover from the WirelessMAN-OFDMA Advanced System to the WirelessMAN-OFDMA Reference System is triggered for an AMS, the serving ABS and AMS perform handover execution using handover signaling and procedures as defined in the WirelessMAN-OFDMA Advanced System. The serving ABS performs context mapping and protocol inter-working from the WirelessMAN-OFDMA Advanced System to the WirelessMAN-OFDMA Reference System. Then the AMS perform network re-entry to target YBS using network re-entry signaling and procedures as defined in the WirelessMAN-OFDMA Reference System.

10.3.4 Inter-RAT Handover Procedure

10.3.4.1 Network Topology Acquisition

IEEE 802.16m systems advertise information about other RATs to assist the AMS with network discovery and selection. IEEE 802.16m systems provide a mechanism for AMS to obtain information about other access networks in the vicinity of the AMS from a ABS either by making a query or listening to system information broadcast. This mechanism can be used both before and after AMS authentication. IEEE 802.16m system may obtain the other access network information from an information server. The ABSs may indicate the boundary area of the IEEE 802.16m network by advertising a network boundary indication. Upon receiving the indication, the AMS may perform channel measurement to the non-IEEE 802.16m network.

10.3.4.2 Generic Inter-RAT HO procedure

IEEE 802.16m system provides mechanisms for conducting inter-RAT measurements and reporting. Further, IEEE 802.16m system forwards handover related messages with other access technologies such as IEEE 802.11, 3GPP and 3GPP2. The specifics of these handover messages may be defined elsewhere, e.g. IEEE 802.21.

10.3.4.3 Enhanced Inter-RAT HO procedure

10.3.4.3.1 Dual Transmitter/Dual Receiver Support

In addition to the HO procedures specified in Section 10.3.4.2, an AMS with dual RF may connect to both an ABS and a BS operating on other RAT simultaneously during handover. The second RF is enabled when inter-RAT handover is initiated. The network entry and connection setup processes with the target BS are all conducted over the secondary radio interface. The connection with the serving BS is kept alive until handover completes.

10.3.4.3.2 Single Transmitter/Single Receiver Support

An AMS with a single RF may connect to only one RAT at a time. The AMS will use the source RAT to prepare the target RAT system. Once target RAT preparation is complete the AMS may switch from source RF to target RF and complete network entry in target RAT. Only one RF is active at any time during the handover.

10.4 ARQ

An ARQ block is generated from one or multiple MAC SDU(s) or MAC SDU fragment(s) of the same flow. ARQ blocks can be variable in size. ARQ blocks are sequentially numbered.

Retransmission of a failed ARQ block can be performed with or without rearrangement. Transmitter may send ARQ feedback polling request to the receiver, to update the reception status of the transmitted ARQ blocks. Receiver sends an ARQ feedback when one of the following conditions is met:

- ARQ feedback polling request is received from the transmitter
- An ARQ block has been missing for a predetermined period

Cumulative and selective ACK types are used by the receiver for sending an ARQ feedback.

10.5 Power Management

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

10.5.1 Sleep Mode

10.5.1.1 Introduction

Sleep mode is a state in which an AMS conducts pre-negotiated periods of absence from the serving ABS air interface. Per AMS, a single power saving class is managed in order to handle all the active connections of the AMS. Sleep mode may be activated when an AMS is in the connected state. When Sleep Mode is active, the AMS is provided with a series of alternate listening window and sleep windows. The listening window is the time in which the AMS is available to exchange control signaling as well as data between itself and the ABS.

The Advanced WirelessMAN-OFDMA System provides a framework for dynamically adjusting the duration of sleep windows and listening windows based on changing traffic patterns and HARQ operations. The length of successive sleep windows may remain constant or may change based on traffic conditions.

Sleep windows and listening windows can be dynamically adjusted for the purpose of data transportation as well as MAC control signaling transmission. AMS can send and receive data and MAC control signaling without deactivating the sleep mode.

10.5.1.2 Sleep Mode Entry

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

10.5.1.3 Sleep Mode Operations

10.5.1.3.1 Sleep Cycle Operation

Unit of sleep cycle is expressed in frames. The start of the listening window is aligned at the frame boundary. The MS ensures that it has up-to-date system information for proper operation. If the AMS detects that the information it has is not up-to-date, then it does not transmit in the listening window until it receives the up-to-date system information. A sleep cycle is the sum of a sleep window and a listening window. AMS or ABS may request change of sleep cycle through explicit MAC control signaling. Also, sleep cycle may change implicitly. ABS keeps synchronizing with AMS 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.

10.5.1.3.2 Sleep Window Operation

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

10.5.1.3.3 Listening Window Operation

During the listening window, the AMS can receive DL data and MAC control signaling from ABS. AMS 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 AMS may go back to sleep for the remainder of the current sleep cycle.

10.5.1.3.3.1 Traffic Indication

During the AMS listening window, ABS may transmit the traffic indication message intended for one or multiple AMSs. It indicates whether or not there is traffic addressed to one or multiple AMSs. The traffic indication message is transmitted at pre-defined location. Upon receiving negative traffic indication in the traffic indication message, the AMS can go to sleep for the rest of the current sleep cycle.

10.5.1.3.3.2 Listening Window Extension

The listening window duration can be dynamically adjusted based on traffic availability or control signaling in AMS or ABS. The listening window can be extended through explicit signaling or implicit method. The listening window cannot be extended beyond the end of the current sleep cycle.

10.5.1.3.4 Sleep Mode Exit

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

10.5.2 Idle Mode

Idle mode provides efficient power saving for the AMS by allowing the AMS to become periodically available for DL broadcast traffic messaging (e.g. Paging message) without registration at a specific ABS.

The network assigns idle mode AMS to a paging group during idle mode entry or location update. The design allows the network to minimize the number of location updates performed by the AMS and the paging signaling overhead caused to the ABSs. The idle mode operation considers user mobility.

ABSs and Idle Mode AMSs may belong to one or multiple paging groups. Idle mode AMSs may be assigned paging groups of different sizes and shapes based on user mobility.

The AMS monitors the paging message at AMS's paging listening interval. The start of the AMS's paging listening interval is derived based on paging cycle and paging offset. Paging offset and paging cycle are defined in terms of number of superframes.

The AMSs may be divided into logical groups to offer a scalable paging load-balancing distribution.

10.5.2.1 Paging Procedure

ABS transmits the list of PGIDs at the pre-determined location. The PGID information should be received during AMS's paging listening interval.

Paging mechanism in 802.16m may use the two-step paging procedure that includes the paging indication followed by the full paging message.

10.5.2.1.1 Paging Indication

Paging indications, if present, are transmitted at the pre-determined location. When paging indications are transmitted, ABS transmits the list of PGIDs and associated paging indicator flag indicating the presence of full paging messages for the corresponding PGIDs.

10.5.2.1.2 ABS Broadcast Paging Message

Within a paging listening interval, the frame that contains the paging message for one or group of idle mode AMSs is known to idle mode AMSs and the paging ABSs. Paging message includes identification of the AMSs (i.e. temporary identifier) to be notified of DL traffic pending or location update.

10.5.2.1.3 Operation During Paging Unavailable Interval

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

10.5.2.1.4 Operation During Paging Listening Interval

The AMS derives the start of the paging listening interval based on the paging cycle and paging offset. At the beginning of paging listening interval, the AMS scans and synchronizes on the A-PREAMBLE of its preferred ABS. The AMS decodes the SFH. The AMS confirms whether it exists in the same paging group as it has most recently belonged by getting PGID information.

During paging listening interval, AMS monitors SFH. If SFH indicates change in system broadcast information (e.g. change in system configuration count) then AMS should acquire the latest system broadcast information at the pre-determined time when the system information is broadcasted by the ABS.

Additionally, if paging indicators are present, AMS also monitors the paging indicators. If the paging indicator associated with its own PGID is set then AMS will subsequently decode the full paging message at the pre-determined location; otherwise AMS will return to paging unavailable interval.

If paging indicators are not present, AMS decodes the full paging message at the predetermined location. If the AMS decodes a paging message that contains its identification, the AMS performs network re-entry or location update depending on the notification indicated in the paging message. Otherwise, AMS returns to paging unavailable interval.

10.5.2.2 Idle Mode Entry/Exit Procedure

10.5.2.2.1 Idle Mode Initiation

An AMS or serving ABS initiates idle mode using procedures defined in the WirelessMAN-OFDMA Reference system. In order to reduce signaling overhead and provide location privacy, a temporary identifier is assigned to uniquely identify the AMSs in the idle mode in a particular paging group. The AMS's temporary identifier remains valid as long as AMS 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 AMS's network re-entry procedure.

10.5.2.2.2 Idle Mode Termination

An AMS terminates idle mode operation using procedures defined in the WirelessMAN-OFDMA Reference system. For termination of idle mode, AMS performs network re-entry with its preferred ABS. The network re-entry procedure can be shortened by the ABS possession of AMS information.

10.5.2.3 Location Update

10.5.2.3.1 Location Update Trigger Condition

An AMS in idle mode performs 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
- MBS location update

During paging group location update, timer based location update, or MBS location update, AMS may update temporary identifier, paging cycle and paging offset.

10.5.2.3.2 Location Update Procedure

If an AMS determines or elects to update its location, depending on the security association the AMS shares with its preferred ABS, the AMS uses one of two processes: secure location update process or unsecure location update process.

Location update comprises conditional evaluation and location update signaling.

10.5.2.3.2.1 Paging Group Location Update

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

10.5.2.3.2.2 Timer Based Location Update

AMS periodically performs 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 restarted.

10.5.2.3.2.3 Power Down Location Update

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

10.5.2.3.2.4 MBS Location Update

For an AMS receiving MBS data in the Idle State, during MBS zone transition, the AMS may perform the MBS location update process to acquire the MBS zone information for continuous reception of MBS data

10.5.3 Power Management for the Connected Mode

Enhanced power savings when the MS is in connected mode and is actively transmitting to the network may be supported. In this mode, the base station optimizes resources and transmission parameters to optimize energy savings at the MS.

10.6 Security

10.6.1 Security Architecture

The security functions provide subscribers with privacy, authentication, and confidentiality across the WirelessMAN-OFDMA Advance System. It does this by applying cryptographic transforms to MAC PDUs carried across connections between AMS and ABS.

The security architecture of WirelessMAN-OFDMA Advance System consists of the following functional entities: the AMS, the ABS, and the Authenticator.

Figure 21 describes the protocol architecture of security services.

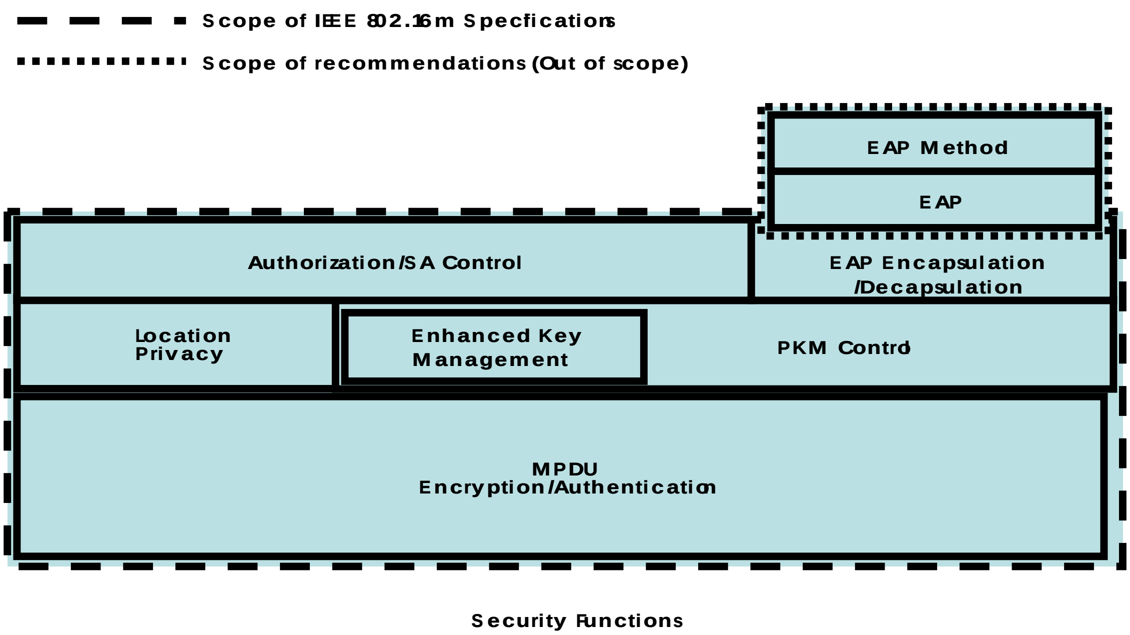

Figure 21: Functional blocks of IEEE 802.16m security architecture

Within AMS and ABS the security architecture is divided into two logical entities:

- Security management entity
- Encryption and integrity entity

Security management entity functions includes :

- Overall security management and control
- EAP encapsulation/decapsulation for authentication - see 10.6.2
- Privacy Key Management (PKM) control (e.g. key generation/derivation/distribution, key state management) - see 10.6.3
- Authentication and Security Association (SA) control - authentication is described in 10.6.2 and SA control in 10.6.4
- Location privacy - see 10.6.2.1

Encryption and integrity protection entity functions include:

- Transport data Encryption/Authentication Processing
- Management message authentication processing
- Management message Confidentiality Protection

10.6.2 Authentication

Pairwise mutual authentication of user and device identities takes place between AMS and ABS entities using EAP. The choice of EAP methods and selection of credentials that are used during EAP-based authentication are outside the scope of this specification.

.Authentication is executed during initial network entry after pre-authentication capability negotiation. Security capabilities, policies etc. are negotiated in this pre-authentication capability negotiation. The remaining AMS capability negotiation is performed together with registration after the successful completion of the authentication and the authorization.

Re-authentication should be made before lifetime of authentication materials/credentials expires. Data transmission may continue during re-authentication process, by providing AMS with two sets of authentication/keying material with overlapping lifetimes. Authentication procedure is controlled by authorization state machine, which defines allowed operations in specific states.

10.6.3 Key Management Protocol

WirelessMAN-OFDMA Advance System inherits the key hierarchies of theWirelessMAN-OFDMA Reference System. The WirelessMAN-OFDMA Advance System uses the PKM protocol to achieve:

- Transparent exchange of authentication and authorization messages (see 10.6.2)
- Key agreement (See 10.6.3.2)
- Security material exchange (Seer 10.6.3.2)

PKM protocol provides mutual authentication and establishes shared secret between the AMS and the ABS. The shared secret is then used to exchange or derive other keying material. This two-tiered mechanism allows frequent traffic key refreshing without incurring the overhead of computation intensive operations.

10.6.3.1 Key Derivation

All IEEE 802.16m security keys are derived directly / indirectly from the MSK by the ABS and the AMS.

The Pairwise Master Key (PMK) is derived from the MSK and then this PMK is used to derive the Authorization Key (AK).

The Authorization Key (AK) is used to derive other keys:

- Key Encryption Key (KEK)
- Transmission Encryption Key (TEK)
- Cipher-based Message Authentication Code (CMAC) key

After completing (re)authentication process and obtaining an AK, key agreement is performed to verify the newly created AK and exchange other required security parameters.

KEK derivation follows procedures as defined in the WirelessMAN-OFDMA Reference system..

TEK is derived at AMS and ABS by feeding identity parameters into a key derivation function. Parameters such as AK, Security Association ID (SAID), NONCE, KEY_COUNT, BSID, AMS MAC address can be used.
NONCE is generated by ABS and distributed to AMS. If more than one TEK is to be created for an SA, separate KEY_COUNTs are maintained for each TEK.

The CMAC key is derived locally by using the AK-and the KEY_COUNT.

The KEY_COUNT parameter of the SA, which is mapped to management connections, is shared between the CMAC and the TEK derivation.

TEK(s) are derived in the following situations:

- Initial authentication
- Re-authentication
- Key update procedure for unicast connection.
- Network re-entry to new ABS.

CMAC keys are derived in the following situations:

- Initial authentication

- Re-authentication
- Network re-entry to new ABS

In the last two cases, KEY_COUNT value is incremented prior derivation.

10.6.3.2 Key Exchange

The key exchange procedure is controlled by the security key state machine, which defines the allowed operations in the specific states. The key exchange state machine does not differ from reference system, except that instead of the exchanging the keys in reference system, a nonce is exchanged and used to derive keys locally.

In IEEE 802.16m, the nonce used to derive and update TEK is sent from ABS to AMS during authorization phase, during ranging procedure on NW reentry from idle mode, or when the AMS requests a nonce.

The Nonce can be exchanged with the following messages/procedures:

- Key Request / Reply
- Key Agreement
- Ranging

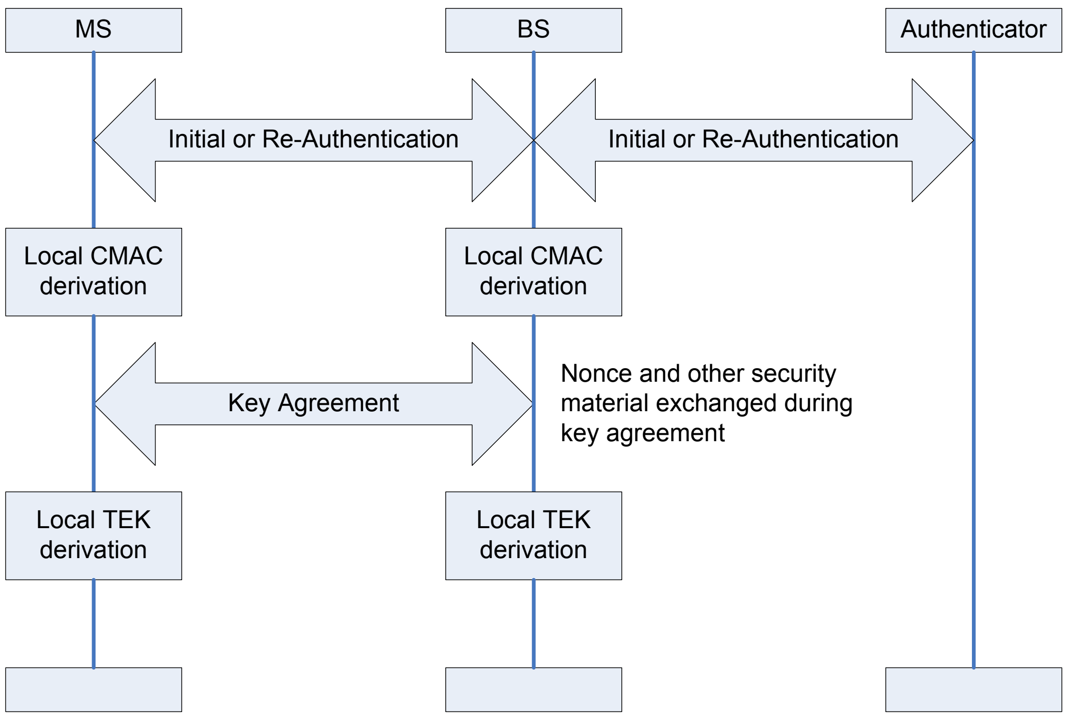

Figure 22: Initial or Re-authentication - Key Derivation and Exchange

10.6.3.3 Key Usage

The TEK usage does not differ from the reference system.

In encryption, used KEY_COUNT value is identified by the receiver (AMS or ABS). EKS field carries the 2-bit key sequence of associated TEK.

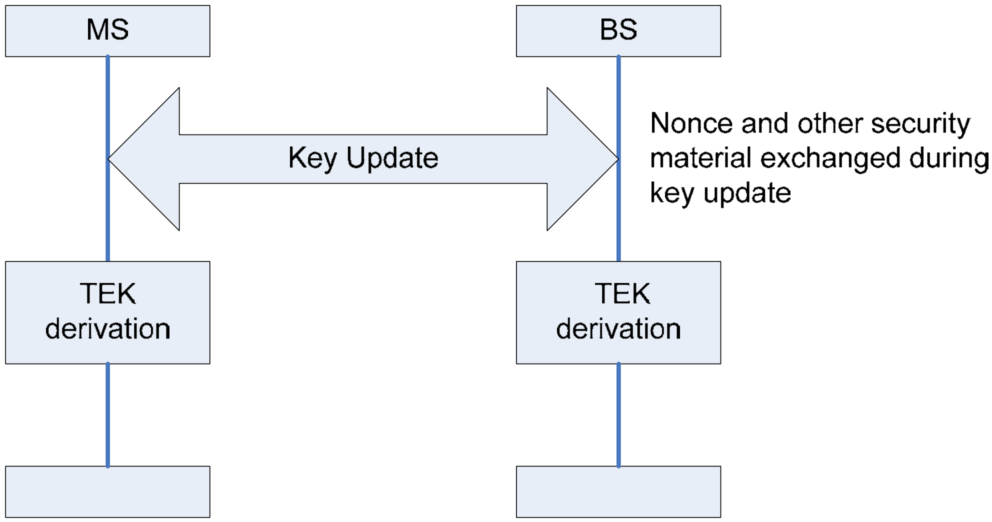

Figure 23: Key update procedure

10.6.4 Security Association Management

A security association (SA) is the set of information required for secure communication between ABS and AMS. SA is identified using an SA identifier (SAID). The SA is applied to the respective flows once an SA is established.

IEEE 802.16m supports Unicast SA (SA) only.

Unicast SA is used to provide keying material to unicast transport connections. The SA is applied to all the data exchanged within the connection. Multiple connections may be mapped to the same unicast SA. Unicast SA can be static or dynamic. Static SAs are assigned by the ABS during network (re-)entry. Dynamic SAs are established and eliminated dynamically. The ABS may map a transport connection to a dynamic SA.

The unicast SA is used to provide keying material for unicast management connections. However, SA is not equally applied to all the management messages within the same management connection. According to the value of MAC header fields, the SA is selectively applied to the management connections.

If AMS and ABS decide "No authorization" as their authorization policy, no SAs will be established. In this case, Null SAID is used as the target SAID field in service flow creation messages. If authorization is performed but the AMS and ABS decide to create an unprotected service flow, the Null SAID may be used as the target SAID field in service flow creation messages.

10.6.5 Cryptographic Methods

Cryptographic methods specify the algorithms used in 802.16m for the following functions:

- MAC PDU protection
- Key encryption/decryption

10.6.5.1 Data Encryption Methods

AMS and ABS may support encryption methods and algorithms for secure transmission of MPDUs. AES algorithm is the only supported cryptographic method in 802.16m. The following AES modes are defined in 802.16m:

- AES-CCM mode - provides also integrity protection
- AES-CTR mode

10.6.5.1.1 AES in CCM mode

AES-CCM mode is supported for unicast transport and management connections. The PN size is 22 bits.

10.6.5.1.2 AES in CTR mode

AES-CTR mode is supported for unicast transport connections. The PN size is 22 bits.

10.6.5.1.3 Multiplexing and Encryption of MPDUs

When some connections identified by flow ids are mapped to the same SA, their payloads can be multiplexed together into one MPDU. The multiplexed payloads are encrypted together. For exmaple , in Figure 24, payloads of Flow_x and Flow_y which are mapped to the same SA are encrypted together. The MAC header or extended headers provides the details of payloads which are multiplexed.

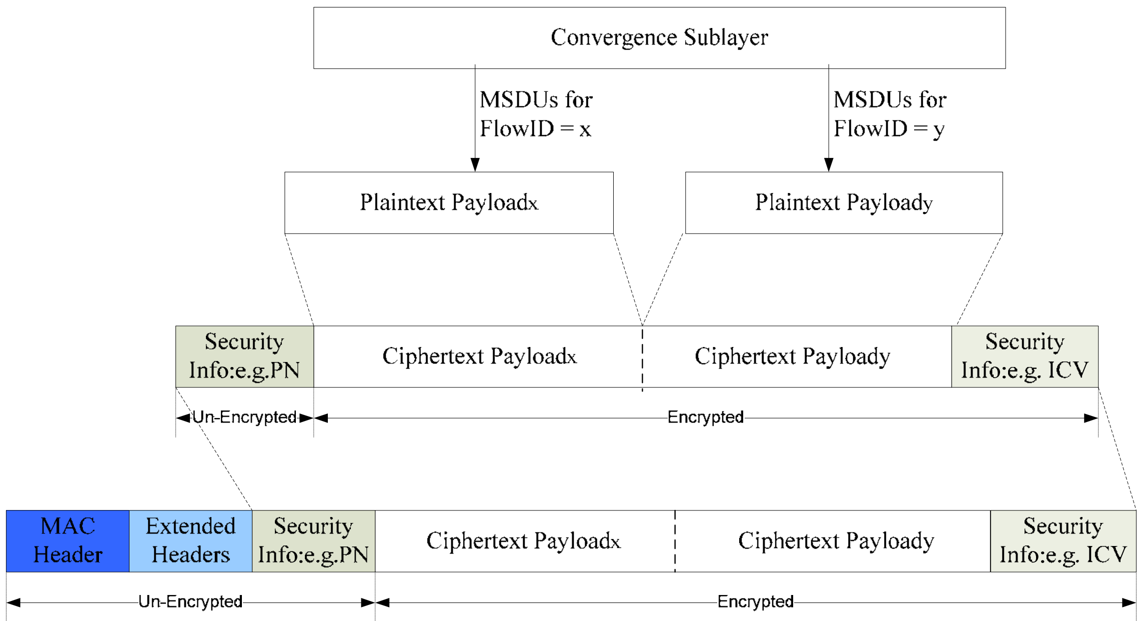

Figure 24: Multiplexed MAC PDU format

10.6.5.2 Control Plane Signaling Protection

10.6.5.2.1 Management Message Protection

IEEE 802.16m supports the selective confidentiality protection over MAC management messages. Through capability negotiation, AMS and ABS know whether the selective confidentiality protection is applied or not. If the selective confidentiality protection is activated, the negotiated keying materials and cipher suites are used to encrypt the management messages.

Figure 25 presents three levels of selective confidentiality protection over management messages in IEEE 802.16m.

- No protection: If AMS and ABS have no shared security context or protection is not required, then the management messages are neither encrypted nor authenticated. Management messages before the authorization phase also fall into this category.
- CMAC based integrity protection--: CMAC Tuple is included to the management message. CMAC integrity protects the entire MAC management message. Actual management message is plain text.
- AES-CCM based authenticated encryption-: ICV field is included after encrypted payload and this ICV integrity protects both payload and MAC header part.

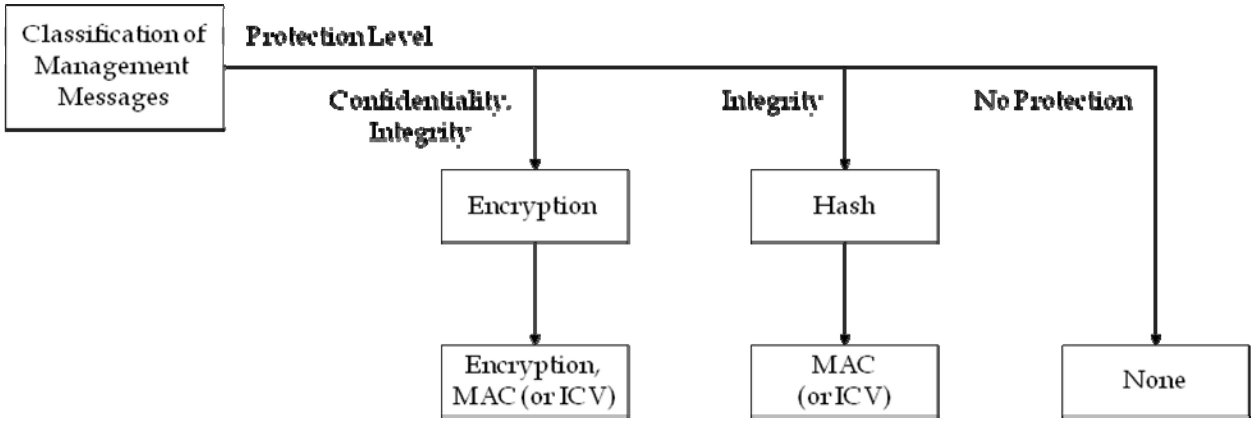

Figure 25: Flow of IEEE 802.16m management message protection

10.6.6 AMS Privacy

In order to protect the mapping between the STID and the AMS MAC Address, two types of STIDs are assigned to an AMS during network entry - temporary STID (TSTID) and (normal) STID.A TSTID is assigned during initial ranging process, and is used until the STID is allocated. The STID is assigned after the successful authentication process, and is encrypted during transmission. The TSTID is released after STID is assigned. The STID is used for all the remaining transactions.

10.7 Convergence Sublayer

IPCS or GPCS is used to transport packet data over the air interface. For GPCS the classification is assumed to take place on layers above the CS. Relevant information for performing classification are transparently transported during connection setup or change.

10.8 Network Entry

Network entry is the procedure by which an AMS finds and establishes a connection with the network. The network entry has the following steps:

- AMS synchronizes with the ABS via Advanced Preamble (A-PREAMBLE).
- AMS obtains necessary information e.g. ABS ID, NSP ID for initial network entry, and performs network selection.
- AMS starts ranging process.
- Pre-authentication capability negotiation.
- Authentication.
- Capability exchange and registration.
- AMS enters Advanced WirelessMAN-OFDMA network and sets up service flows.

Neighbor BSs search is based on the same downlink signals as initial network search (eg: preamble) except some information can be provided by serving ABS (eg: NBR-ADV). Network re-entry from such procedures as handover, idle mode exit and so on, is based on initial network entry procedure with certain optimization procedures.

The ABS responds to the AMS' initial ranging code transmission by broadcasting a status indication message (e.g.: Decoding Status Bitmap) in a following predefined DL frame/subframe. The initial ranging related messages (e.g.: RNG-RSP and BW Grant for RNG-REQ) can be linked to the corresponding bit of the status indication message to reduce overhead.

10.9 Connection Management

Connections are identified by the combination of STID and FID. Two types of connections are used – management connections and transport connections.

Management connections are used to carry MAC management messages. Transport connections are used to carry user data including upper layer signaling messages such as DHCP, etc and data plane signaling such as ARQ feedback.

Fragmentation is supported on transport connections. Fragmentation may be supported on unicast management connections.

10.9.1 Management Connections

Management connections are bi-directional. Default values of FIDs are reserved for unicast management connections. Management connections are automatically established after a STID is assigned to an AMS during AMS initial network entry.

10.9.2 Transport Connections

Transport connection is uni-directional and established with unique FID assigned during service flow establishment procedure. Each admitted/active service flow is uniquely mapped to a transport connection.

Transport connection is released when the associated service flow is removed. To reduce bandwidth usage, the ABS and AMS may establish/change/release multiple connections using a single message transaction on a management connection

Transport connections can be pre-provisioned or dynamically created. Pre-provisioned connections are those established by system for an AMS during the AMS network entry. On the other hand, ABS or AMS can create new connections dynamically if required. A connection can be created, changed, or torn down on demand.

10.9.3 Emergency Service Flows

For handling Emergency Telecommunications Service and E-911, emergency service flows will be given priority in admission control over the regular service flows.

Default service flow parameters are defined for emergency service flow. The ABS grants resources in response an emergency service notification from the AMS without going through the complete service flow setup procedure. The AMS can include an emergency service notification in initial ranging or service flow setup requests.

If a service provider wants to support National Security/emergency Preparedness (NS/EP) priority services, the ABS uses its own algorithm as defined by its local country regulation body. For example, in the US the algorithm to support NS/EP is defined by the FCC in Hard Public Use Reservation by Departure Allocation (H-PURDA) [28].

10.10 QoS

In order to provide QoS, IEEE 802.16m MAC associates uni-directional flows of packets which have a specific QoS requirement with a service flow. A service flow is mapped to one transport connection with one FID. ABS and AMS provide QoS according to the QoS parameter sets, which are pre-defined or negotiated between the ABS and the AMS during the service flow setup/change procedure. The QoS parameters can be used to schedule and police the traffic.

10.10.1 Adaptive Granting and Polling

IEEE 802.16m supports adaptation of service flow QoS parameters. One or more sets of QoS parameters are defined for one service flow. The AMS and ABS negotiate the supported QoS parameter sets during service flow setup procedure. When QoS requirement/traffic characteristics for UL traffic changes, the ABS may autonomously switch the service flow QoS parameters such as grant/polling interval or grant size based on predefined rules. In addition, the AMS may request the ABS to switch the service flow QoS parameter set with explicit signaling. The ABS then allocates resource according to the new service flow parameter set.

10.10.2 Scheduling Services

In addition to the scheduling services supported by the WirelessMAN OFDMA reference system, IEEE 802.16m provides a specific scheduling service to support realtime non-periodical applications such as on-line gaming.

10.11 MAC Management

To meet the latency requirements for aspects of network entry, handover, state transition, 802.16m supports fast and reliable transmission of MAC management messages.

To provide reliable transmission of MAC management messages, message timers for retransmission are defined for all the unicast MAC management messages. The message timers may be different for different MAC management messages. If HARQ is applied during the transmission of a MAC management message and if the HARQ process is terminated with an unsuccessful outcome before the expiration of the message timer, the MAC message management entity in the transmitter may initiate retransmission of the complete message or the message fragment of the failed HARQ burst.

The IEEE 802.16m MAC protocol peers communicate using a set of MAC Control Messages. These messages are defined using ASN.1 [10], [11], [12], [13]. The ASN.1 descriptions are written in way that provides future extension of the messages. The Packed Encoding Rules (PER) [14] are used to encode the messages for transmission over the air.

IEEE 802.16m provides a generic MAC management message at the L2 called L2_transfer that acts as a generic service carrier for various standards defined services including, but not limited to: Device provisioning bootstrap message to AMS, GPS assistance delivery to AMS, ABS(es) geo-location unicast delivery to AMS, 802.21 MIH transfer, etc.

10.12 MAC PDU Formats

Each MAC PDU contains a MAC header. The MAC PDU may contain payload. The MAC PDU may contain one or more extended headers.

Multiple MAC SDUs and/or SDU fragments from different unicast connections belonging to the same AMS can be multiplexed into a single MAC PDU.

10.12.1 MAC Header Formats

10.12.1.1 Generic MAC Header

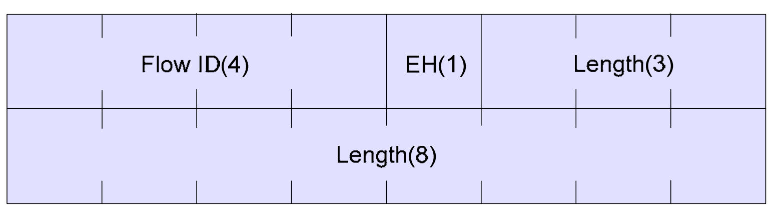

Figure 26: Generic MAC header format

- FlowID (Flow Identifier): This field indicates the service flow that is addressed.. This field is 4bits long.
- EH (Extended Header Presence Indicator): When set to ‘1”, this field indicates that an Extended Header is present following this GMH.
- Length: Length of the payload. This field is 11bits long

10.12.1.2 Compact Header

The compact header is used for connections with persistent allocation and group allocation.

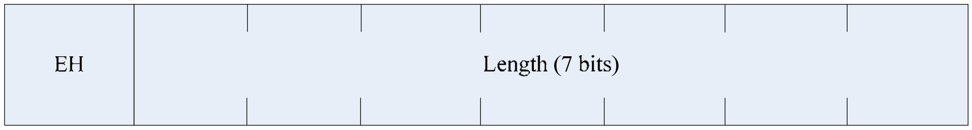

Figure 27: Compact header format

- EH (Extended Header Presence Indicator): When set to '1", this field indicates that an Extended Header is present following this header.
- Length (7): Length of the payload.

10.12.2 Extended Header

The inclusion of extended header is indicated by EH indicator bit in MAC Header. The EH format will be used unless specified otherwise.

- Last: When the "Last" bit is set, this extended header is the last one. If this bit is not set, another extended header will follow the current extended header.
- Type: indicates the type of extended header. The length is TBD.
- Body Contents: Type-dependent contents.

10.12.2.1 Fragmentation and Packing Extended Header for Transport Connections

This fragmentation and packing extended header is shown in Figure 28. This header shall be used when MAC PDU contains single transport connection payload. The location of this header exists after the last extended header (i.e., extended header with 'Last' = '1') if 'EH' in GMH set to '1' or after the GMH if 'EH' in GMH set to '0'.

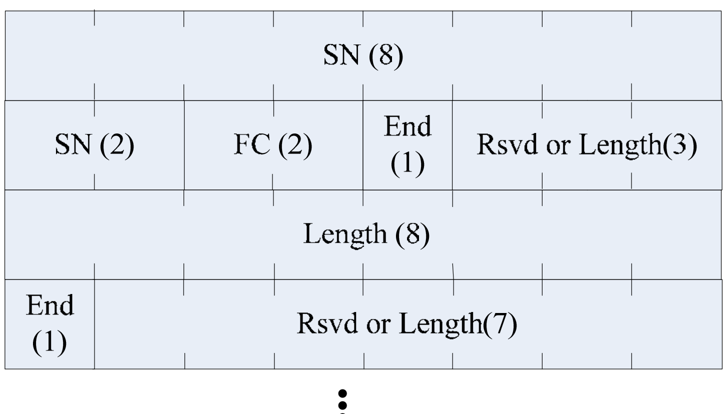

Figure 28: Fragmentation and packing extended header format for transport connection

- SN (10 bits): Payload sequence number
- FC (2 bits): Fragmentation control bits definition is given in Table 2.
- End (1 bit): If this bit set to '0', another 'Length' and 'End' field are followed. If this bit set to '1', reserved bits may follow for byte alignment
- Length (11bits): This field represents the length of SDU/SDU fragment. If a payload consists of 'N' SDU/SDU fragments, N-1 length fields are present in the header
- Rsvd: Reserved bits for byte alignment.

FC	Meaning	Examples
00	The first byte of data in the MPDU payload is the first byte of a MAC SDU. The last byte of data in the MPDU payload is the last byte of a MAC SDU.	One or Multiple Full SDUs packed in an MPDU
01	The first byte of data in the MPDU payload is the first byte of a MAC SDU. The last byte of data in the MPDU payload is not the last byte of a MAC SDU.	a) MPDU with only First fragment of an SDU b) MPDU with one or more unfragmented SDUs, followed by first fragment of subsequent SDU
10	The first byte of data in the MPDU payload is not the first byte of a MAC SDU. The last byte of data in the MPDU payload is the last byte of a MAC SDU.	a) MPDU with only Last fragment of an SDU b) MPDU with Last fragment of an SDU, followed by one or more unfragmented subsequent SDUs
11	The first byte of data in the MPDU payload is not the first byte of a MAC SDU. The last byte of data in the MPDU payload is not the last byte of a MAC SDU.	a) MPDU with only middle fragment of an SDU b) MPDU with Last fragment of an SDU, followed by zero or more unfragmented SDUs, followed by first fragment of a subsequent SDU

Table 2: Fragmentation control information

10.12.2.2 Fragmentation Extended Header for Management Connections

This fragmentation extended header is shown in Figure 29. This header shall be used when MAC PDU contains single management message payload

Figure 29: Fragmentation extended header format for management connection

- Last (1 bit): always set to '1'
- TYPE(TBD): Extended header type field
- SN (8 bits): Payload sequence number
- FC (2 bits): Fragmentation control bits definition is given in Table 2.
- Rsvd: Reserved bits for byte alignment.

10.12.2.3 Multiplexing Extended Header (MEH)

Multiplexing Extended Header (MEH) is used when SDUs or SDUs fragments from different connections are included in the same MPDU.

As shown in Figure 30, the Multiplexing Extended Header contains multiple Multiplexing Extended Header Blocks (MEHBs). The SDUs or SDU fragments belonging to the same connection are packed together and the information related to these SDUs or SDU fragments is included in one MEHB. The M bit in MEHB indicates if there is more MEHB followed. If the SDUs or SDU fragment(s) included belong to the same connection, only one MEHB is present.

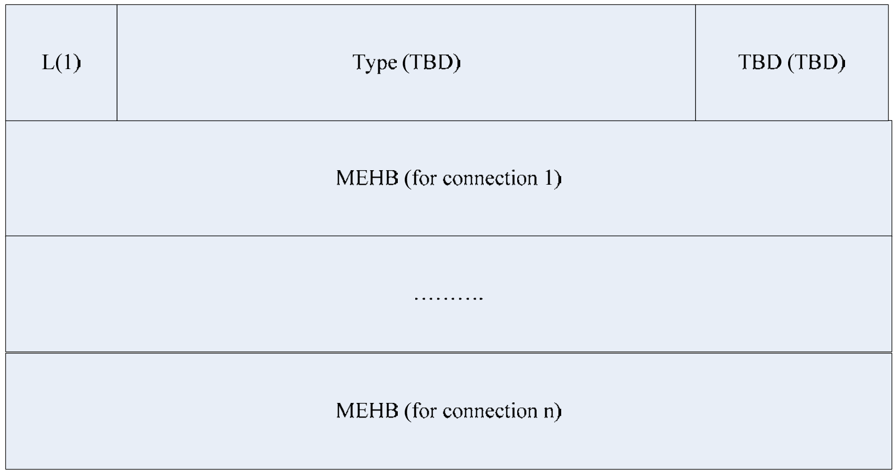

Figure 30: Format of Multiplexing Extended Header (MEH)

The format of MEHB is shown in Figure 31 except the first MEHB. The first MEHB doesn't contain the Flow ID and the length for the first SDU or SDU fragment associated with the Flow ID. The Flow ID and the Length fields in the generic MAC header represent the flow ID and the length of the first SDU or SDU fragment associated with the first MEHB.

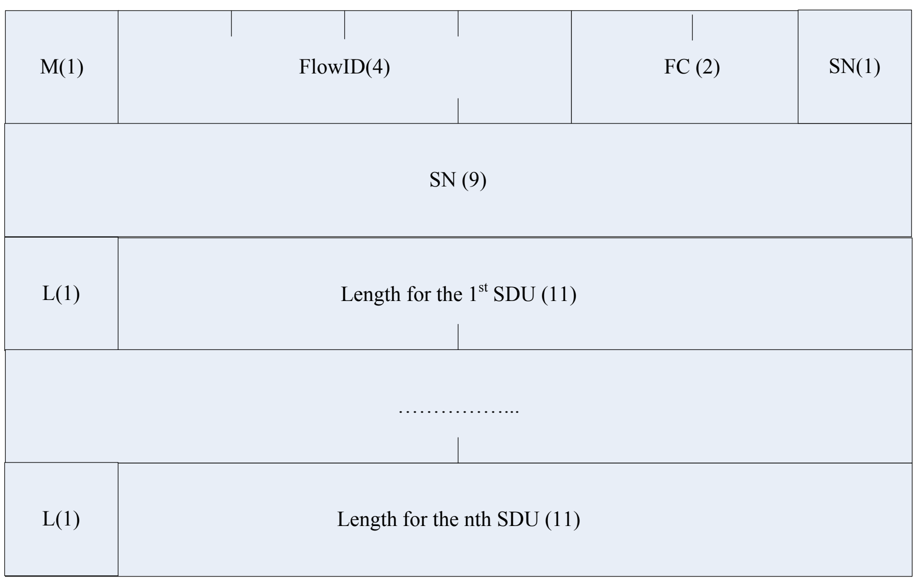

Figure 31: Format of Multiplexing Extended Header Block (MEHB)

M (1bit): indicate if there is more MEHB follows
Flow ID (4 bit): flow id of the SDUs/SDU fragments identified in the MEHB
SN (10): ARQ BSN for ARQ enabled connection or Fragment SN for non-ARQ enabled connection.
L (1bit): indicate if there is more length field follows
Length: length for each SDU identified in the MEHB
FC (2bit): Multiplexing Control Information.

10.13 Multi-Radio Coexistence

AMS conducts pre-negotiated periodic absences from the serving ABS to support concurrent operation of co-located non 802.16 radios, e.g. IEEE 802.11, IEEE 802.15.1, etc., and the time pattern of such periodic absence is referred by ABS and AMS as CLC class.

The following parameters are defined to support CLC class operation:

- CLC start time: the start time of a CLC class
- CLC active interval: the time duration of a CLC class designated for co-located non 802.16 radio activities.
- CLC active cycle: the time interval of the active pattern of a CLC class repeating
- CLC active ratio: the time ratio of CLC active intervals to CLC active cycle of a CLC class
- number of active CLC classes: the number of active CLC classes of the same type of an AMS

802.16m supports three types of CLC classes, and they differ from each other in terms of the time unit of CLC start time, active cycle and active interval, as shown in Table 3.

Type I CLC class is recommended for non 802.16 radio activity that is low duty cycle, and may not align with 802.16 frame boundary. Otherwise, Type II CLC class is recommended for better scheduling flexibility. Type III CLC class is recommended for continuous non-802.16 radio activity that lasts seconds, and has only one cycle.

	CLC active cycle	**CLC active interval**	**CLC start time**
Type I	Microsecond	Subframe	Subframe
Type II	Frame	Subframe	Frame
Type III	not applicable	Superframe	superframe

Table 3: Time Unit of CLC Class Parameters

AMS determines CLC active interval and cycle based on the activities of its co-located non 802.16 radios. AMS determines CLC start time only for Type I CLC class, and ABS determines CLC start time for Type II and III CLC class for better scheduling flexibility.

The serving ABS shall not schedule A-MAP, data, and HARQ feedback of the AMS's allocations in CLC active interval of an active CLC class. Whether only DL or only UL or both are prohibited depends on the configuration of the CLC class. The default is both DL and UL allocations are prohibited.

11 Physical Layer

11.1 Duplex Modes

IEEE 802.16m supports TDD and FDD duplex modes, including H-FDD AMS 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 employs OFDMA as the multiple access scheme in the downlink and uplink.

11.3 OFDMA Parameters

The OFDMA parameters for IEEE 802.16m are specified in Table 4.

Nominal channel bandwidth (MHz)			5	7	8.75	10	20
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
CP T_g=1/8 T_u	**Symbol time T_s (μs)**		102.857	144	115.2	102.857	102.857
	FDD	**Number of OFDM symbols per 5ms frame**	48	34	43	48	48
		Idle time (μs)	62.857	104	46.40	62.857	62.857
	TDD	**Number of OFDM symbols per 5ms frame**	47	33	42	47	47
		TTG + RTG (μs)	165.714	248	161.6	165.714	165.714
CP T_g=1/16 T_u	**Symbol time T_s (μs)**		97.143	136	108.8	97.143	97.143
	FDD	**Number of OFDM symbols per 5ms frame**	51	36	45	51	51
		Idle time (μs)	45.71	104	104	45.71	45.71
	TDD	**Number of OFDM symbols per 5ms frame**	50	35	44	50	50
		TTG + RTG (μs)	142.853	240	212.8	142.853	142.853
CP T_g=1/4 T_u	**Symbol Time T_s (μs)**		114.286	160	128	114.286	114.286
	FDD	**Number of OFDM symbols per 5ms frame**	43	31	39	43	43
		Idle time (μs)	85.694	40	8	85.694	85.694
	TDD	**Number of OFDM symbols per 5ms frame**	42	30	38	42	42
		TTG + RTG (μs)	199.98	200	136	199.98	199.98

Table 4: OFDMA parameters for IEEE 802.16m

Tone dropping at both edges of the frequency band based on 10 and 20 MHz systems can be used to support other bandwidths.

11.4 Frame Structure

11.4.1 Basic Frame Structure

The IEEE 802.16m basic frame structure is illustrated in Figure 32. Each 20 ms superframe is divided into four equally-sized 5 ms radio frames and begins with the superframe header (SFH). When using the same OFDMA parameters as in Table 4 with the channel bandwidth of 5 MHz, 10 MHz, or 20 MHz, each 5 ms radio frame further consists of eight subframes for CP sizes of 1/8 and 1/16. With the channel bandwidth of 8.75 and 7 MHz, each 5 ms radio frame further consists of seven and six subframes, respectively for CP sizes of 1/8 and 1/16.

A subframe is assigned for either DL or UL transmission. There are four types of subframes: 1) the type-1 subframe which consists of six OFDMA symbols, 2) the type-2 subframe which consists of seven OFDMA symbols, and 3) the type-3 subframe which consists of five OFDMA symbols, and 4) the type-4 subframe which consists of nine OFDMA symbols. This type is applied only to UL subframe for the 8.75MHz channel bandwidth when supporting the IEEE Std 802.16-2009 frames.

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 two, 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 MSs are included in an FDD system, the frame structure from the point of view of the H-FDD MS 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.

A data burst occupies either one subframe (i.e. the default TTI transmission) or multiple contiguous subframes (i.e. the long TTI transmission). The long TTI in FDD is equal to 4 subframes for both DL and UL. The long TTI in TDD is equal to the all the DL (UL) subframes in the DL (UL) in a frame.

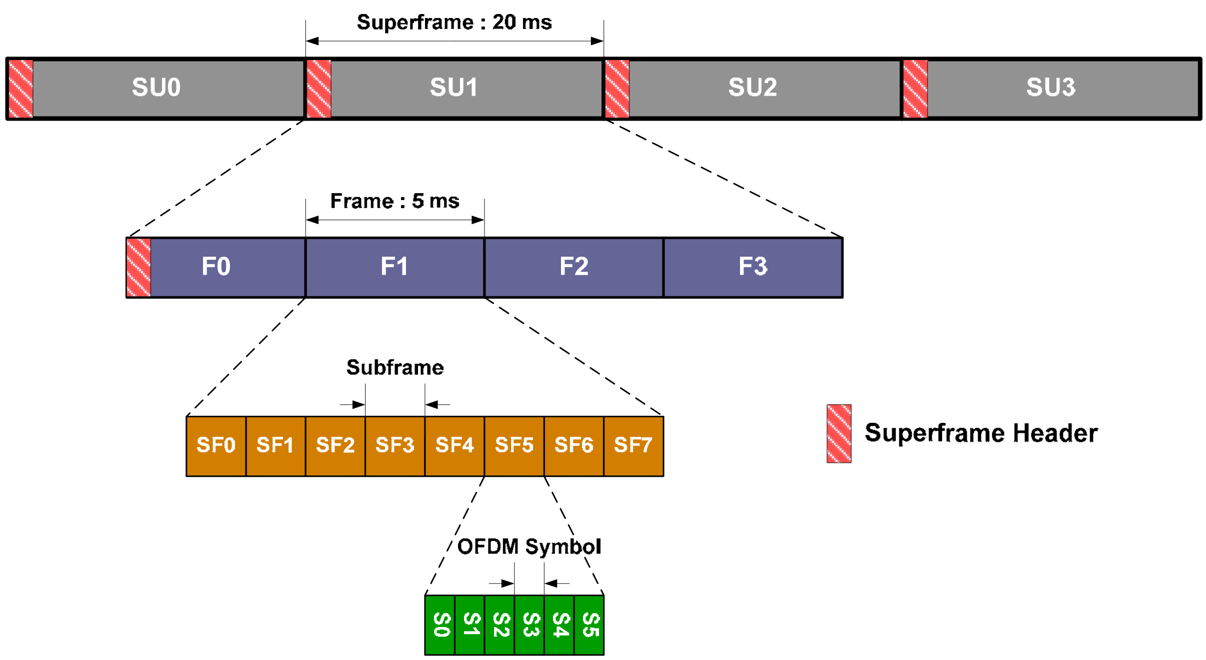

Figure 32: Basic frame structure for 5, 10, and 20 MHz channel bandwidths

11.4.1.1 Frame Structure for CP=1/8 T_u

For nominal channel bandwidths of 5, 10, and 20 MHz, an IEEE 802.16m frame for a CP of 1/8 Tu has eight type-1 subframes for FDD, and seven type-1 subframes and one type-2 subframes for TDD.

Figure 33 provides an example of the TDD and FDD frame structure for 5, 10, and 20 MHz channel bandwidth with a CP of 1/8 Tu. With OFDM symbol duration of 102.857 µs and a CP length of 1/8 Tu, the length of type-1 and type-3 subframes are 0.617 ms and 0.514 ms, respectively. TTG and RTG are 105.714 µs and 60 µs, respectively. Other numerologies may result in different number of subframes per frame and symbols within the subframes.

In FDD, the structure of a frame (number of subframes, their types etc.) has to be identical for the DL and UL for each specific frame.

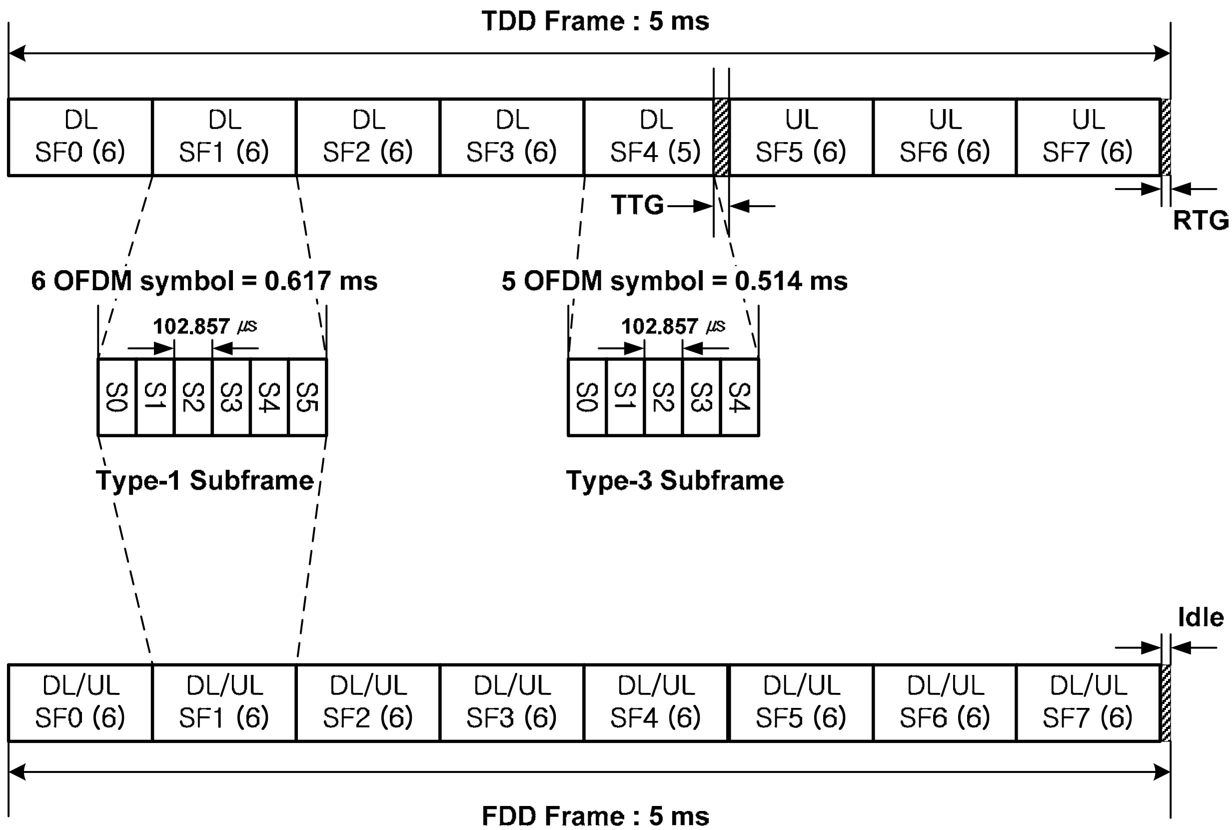

Figure 33: TDD and FDD Frame Structure with a CP of 1/8 T_u (DL to UL ratio of 5:3)

11.4.1.2 Frame Structure for CP=1/16 T_u

For nominal channel bandwidths of 5, 10, and 20 MHz, an IEEE 802.16m frame for a CP of 1/16 T_u has five type-1 subframes and three type-2 subframes for FDD, and six type-1 subframes and two type-2 subframes for TDD. The subframe preceding a DL to UL switching point is a type-1 subframe.

Figure 34 provides an example of the TDD and FDD frame structure for 5, 10, and 20 MHz channel bandwidths with a CP of 1/16 Tu. With an OFDM 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. TTG and RTG are 82.853 µs and 60 µs, respectively. Other numerologies may result in different number of subframes per frame and symbols within the subframes.

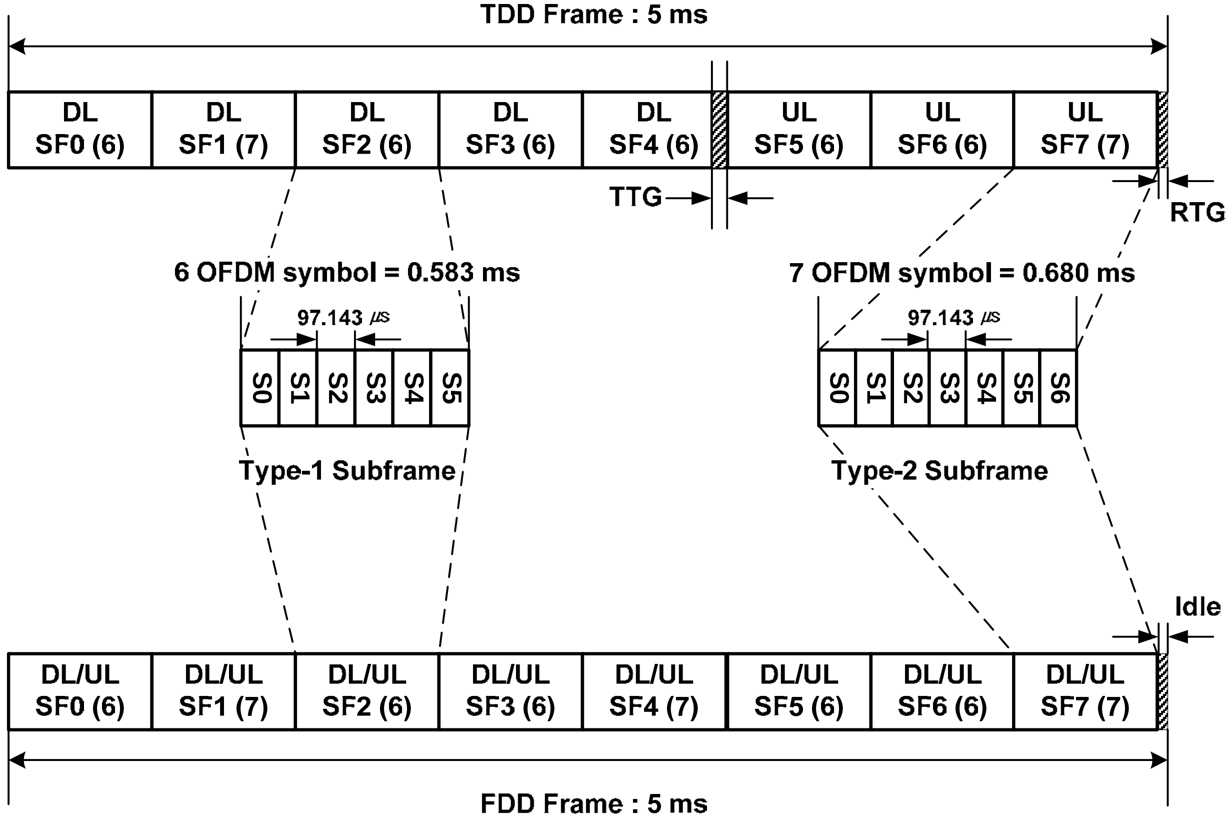

Figure 34: TDD and FDD frame structure with a CP of 1/16 T_u (DL to UL ratio of 5:3)

In FDD, the structure of a frame (number of subframes, their types etc.) has to be identical for the DL and UL for each specific frame.

11.4.2 Frame Structure Supporting Legacy Frames

The legacy and IEEE 802.16m frames are offset by an integer number of subframes to accommodate new features such as the IEEE 802.16m Advanced Preamble (preamble), Superframe Header (system configuration information), and control channels, as shown in Figure 35. The FRAME_OFFSET shown in Figure 35 is for illustration. It is an offset between the start of the legacy frame and the start of the IEEE 802.16m frame defined in a unit of subframes.

For UL transmissions both TDM and FDM approaches are supported for multiplexing of YMS and AMS.

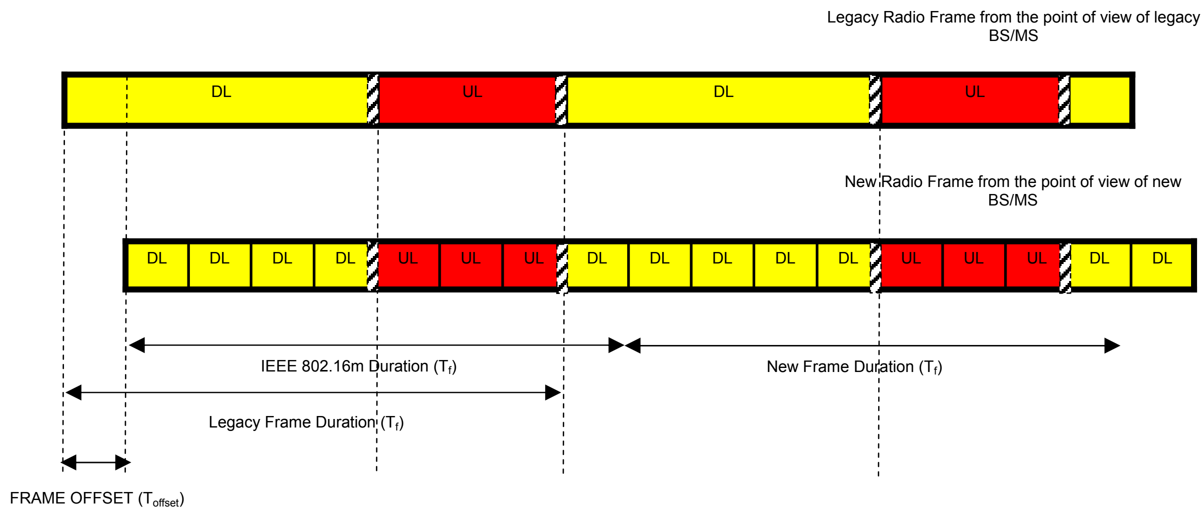

Figure 35: Relative position of the IEEE 802.16m and IEEE Std 802.16-2009 radio frames (example TDD duplex mode)

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 equally applied to TDD and FDD systems. The MZones and LZones are time-multiplexed (TDM) across time domain for the downlink. For UL transmissions both TDM and FDM approaches are supported for multiplexing of YMSs and AMSs. Note that DL/UL traffic for the AMS can be scheduled in either zone according to the mode (IEEE 802.16m or legacy IEEE Std 802.16-2009) with which AMS is connected to the ABS, but not in both zones at the same time, whereas the DL/UL traffic for the YMS can only be scheduled in the LZones.

In the absence of any IEEE Std 802.16-2009 system, the LZones will disappear and the entire frame will be allocated to the MZones and thereby new systems.

11.4.2.1.1 Time Zones in TDD

In a mixed deployment of YMSs and new AMSs, the allocation of time zones in the TDD mode is as shown in Figure 36. The duration of the zones may vary. Every frame starts with a preamble and the MAP followed by IEEE Std 802.16-2009 DL zone since YMSs/relays expect LZones in this region. Similarly, in a mixed deployment of YMSs and new AMSs, the UL portion starts with IEEE Std 802.16-2009 UL zone since YBS /YMS/RS expect IEEE Std 802.16-2009 UL control information be sent in this region. Here the coexistence is defined as a deployment where YBSs and ABSs co-exist on the same frequency band and in the same or neighboring geographical areas. In a green-field deployment where no YMS exists, the LZones can be removed.

The DL to UL and UL to DL 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.

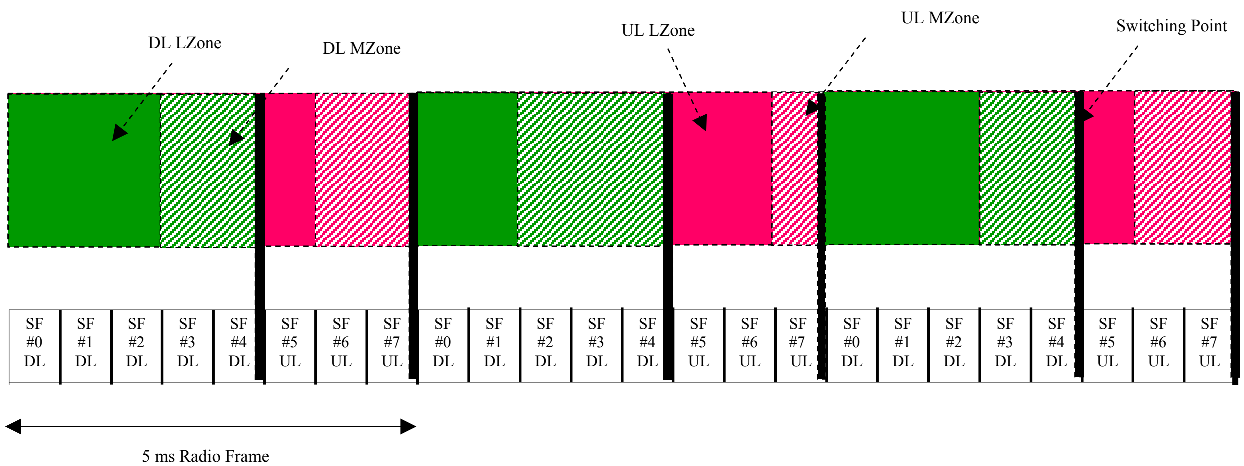

Figure 36: Example of time zones in TDD mode

11.4.2.1.2 Time Zones in FDD

In a mixed deployment of legacy terminals and new AMSs, an example of the allocation of time zones in the FDD mode is shown in Figure 37.

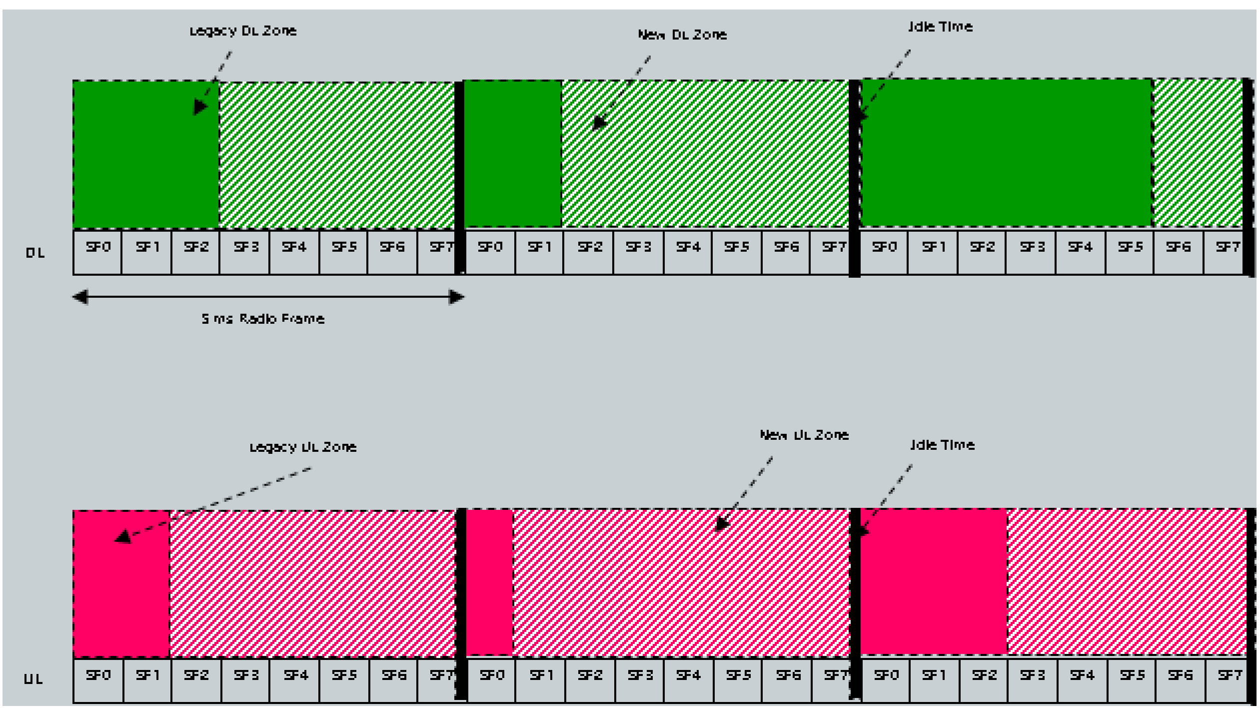

Figure 37: Example of time zones in FDD mode

11.4.3 Relay Support in Frame Structure

An ABS that supports ARSs communicates with the ARS in the MZone. The access link and the relay link communications in the LZone is multiplexed in accordance with the IEEE Std 802.16j specifications.

An RS radio frame may also define points where the RS switches from receive mode to transmit mode or from transmit mode to receive mode, where the receiving and transmitting operations are both performed on either DL or UL data. An ARS communicates with the YMS in the LZone.

The start of the LZone and MZone of the ABS and all the subordinate RSs/ARSs associated with the ABS are time aligned. The duration of the LZone of the ABS and the RS may be different.

- IEEE Std 802.16-2009 Access Zone
    - o where ABS, a RS or a ARS communicates with a 16e MS.
- IEEE Std 802.16j-2009 Relay Zone
    - o where ABS communicates with a RS.

The relay frame structure is illustrated in Figure 38.

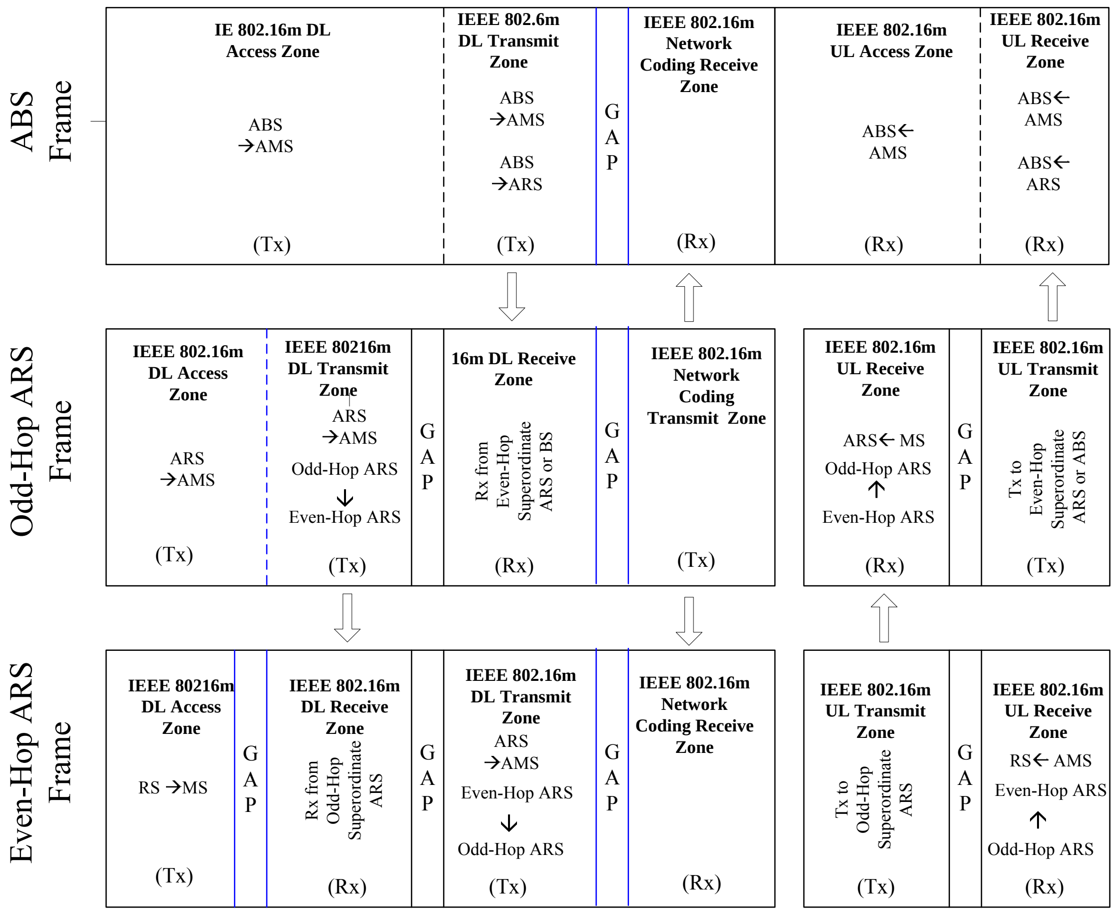

Figure 38: Relay frame structure

Definitions related to Figure 38:

- IEEE 802.16m DL Access Zone: An integer multiple of subframes located in the MZone of the ABS frame, where an ABS can transmit to the AMSs.
- IEEE 802.16m UL Access Zone: An integer multiple of subframes located in the MZone of the ABS frame, where an ABS can receive from the AMSs.
- DL Access Zone: An integer multiple of subframes located in the Mzone of the DL of the ABS frame or ARS frame, where a ABS or an ARS can transmit to the AMSs. A-PREAMBLE and SFH as well as unicast transmissions may be performed in this zone.
- UL Access Zone: An integer multiple of subframes located in the Mzone of the UL of the ABS frame, where an ABS can receive from the AMSs.

- DL Transmit Zone: An integer multiple of subframes located in the MZone of the DL of the ABS frame or ARS frame, where an ABS or ARS can transmit to subordinate ARSs and the AMSs.
- DL Receive Zone: An integer multiple of subframes located in the MZone of the DL of the ARS frame, where a ARS can receive from its superordinate station.
- UL Transmit Zone: An integer multiple of subframes located in the MZone of the UL of the ARS frame, where a ARS can transmit to its superordinate station.
- UL Receive Zone: An integer multiple of subframes located in the MZone of the UL of the ABS frame or ARS frame, where an ABS or ARS can receive from its subordinate ARSs and the AMSs.
- Network Coding Transmit Zone: An integer multiple of subframes located in the DL of the frame of the Odd Hop ARS which is directly attached to the ABS, where an Odd Hop ARS can transmit network coded transmissions to the ABS and Even Hop ARS. The transmissions to the AMS in this zone are being studied.
- Network Coding Receive Zone: An integer multiple of subframes located in the DL of the ABS or Even Hop ARS frame, where an ABS or Even Hop ARS can receive network coded transmissions from the ARS directly attached to the ABS.

If the ABS supports network coding, the presence of the aforementioned zones is determined by the ABS depending on the number of hops and the ARS capabilities. The Network Coding Transmit Zone may be present in an ARS frame if the ARS supports network coding. If the Network Coding Transmit Zone is present, it appears only in the frame of an ARS which is directly attached to the ABS. The Network Coding Receive Zone may be present only in the frames of the ABS and the even hop ARS that is two hops away from the ABS, if the ARS and the ABS support network coding.

11.4.4 Coexistence Support in Frame Structure

IEEE 802.16m downlink radio frame is time aligned with reference timing signal as defined in Section 20.1 and should support symbol puncturing to minimize the inter-system interference.

11.4.4.1 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 the time allocated to idle symbols or idle subframes. Figure 39 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.

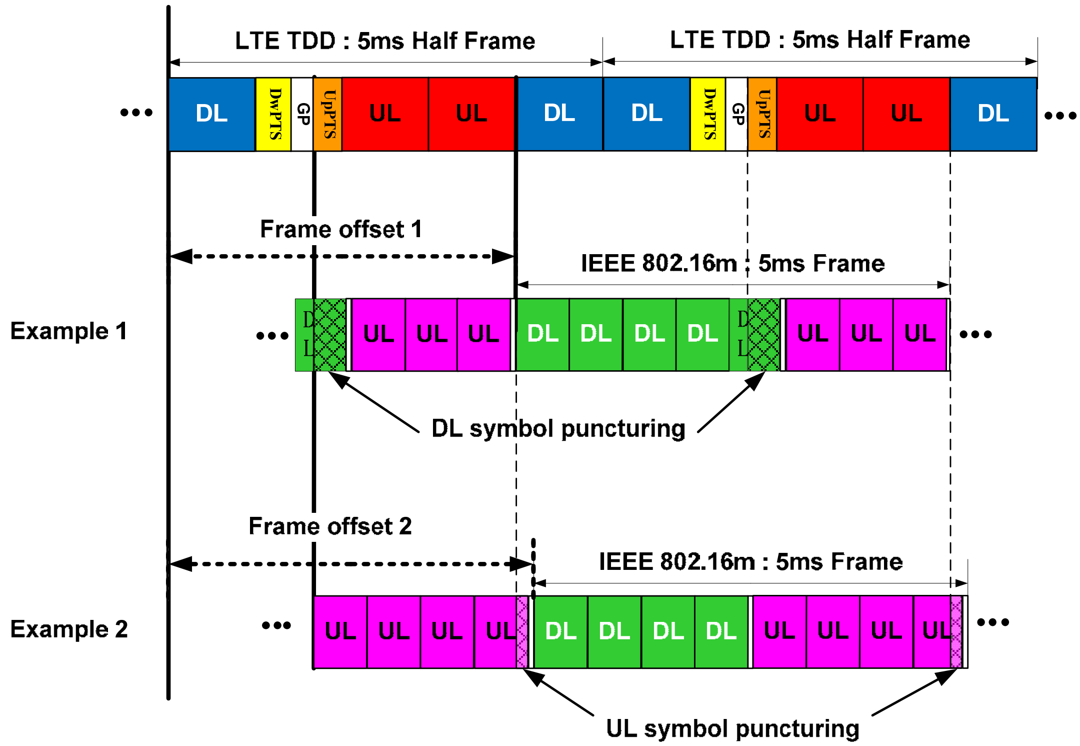

Figure 39: Alignment of IEEE 802.16m frame and E-UTRA frame in TDD mode

11.4.4.2 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 the time allocated to idle symbols or idle subframes. Figure 40 demonstrates how coexistence between IEEE 802.16m and UTRA LCR-TDD can be achieved to minimize the inter-system interference.

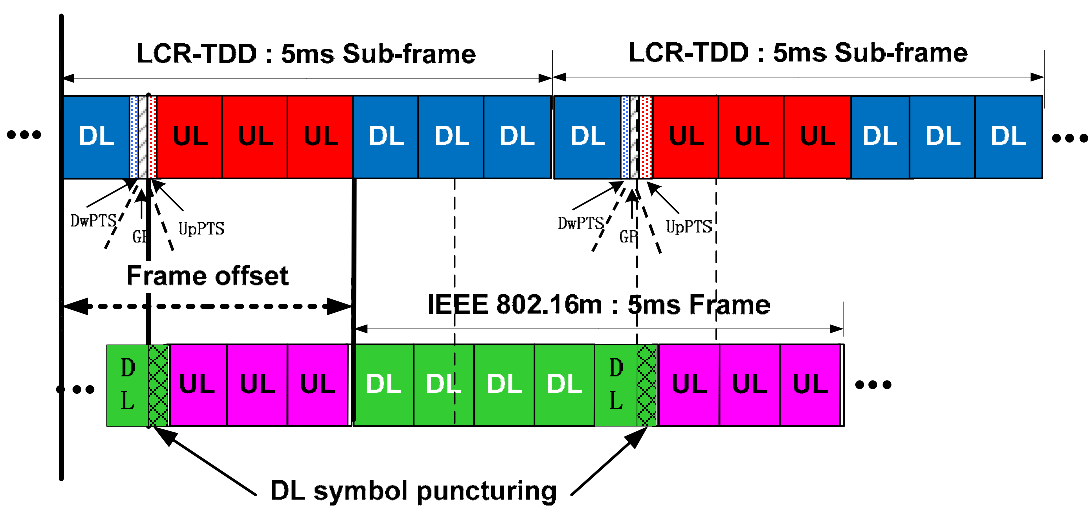

Figure 40: Alignment of IEEE 802.16m frame with UTRA LCR-TDD frame in TDD mode

11.5 Downlink Physical Structure

Each downlink subframe is divided into four or fewer 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). The example in Figure 41 illustrates the downlink physical structure with two frequency partitions. In the example shown, frequency partition 2 includes both localized and distributed resource allocations and *Sc* stands for subcarrier.

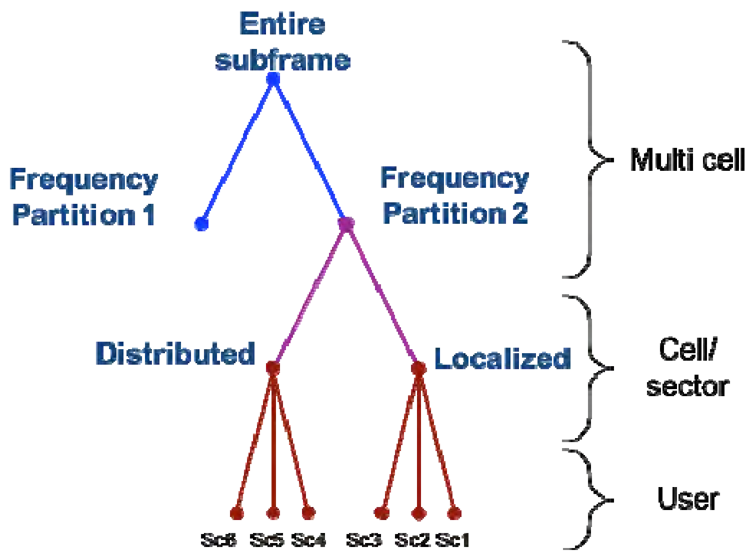

Figure 41: Example of the downlink physical structure

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, 7, and 5 OFDMA symbols for type-1, type-2, and type-3 subframes, respectively. A logical resource unit (LRU) is the basic logical unit for localized and distributed resource allocations. An LRU comprises $P_{sc} \cdot N_{sym}$ subcarriers and includes the pilots that are used in a PRU.

11.5.1.1 Distributed Resource Unit

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

11.5.1.2 Contiguous Resource Unit

The localized resource unit, also known as contiguous resource unit (CRU) can be used to achieve frequency-selective scheduling gain. The CRU contains a group of subcarriers which are contiguous across the localized resource allocations within a frequency partition. The size of the CRU 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 the MIMO mode, rank and number of multiplexed AMS as well as the type of the subframe, i.e., type-1, type-2, or type-3.

11.5.2.2 Downlink Resource Unit Mapping

The PRUs are first subdivided into subbands and minibands where a subband comprises N_1 adjacent PRUs and a miniband comprises N_2 adjacent PRUs, where N_1 =4 and N_2 =1. Subbands are suitable for frequency selective allocations as they provide a contiguous allocation of PRUs in frequency. Minibands are suitable for frequency diverse allocation and are permuted in frequency.

The downlink subcarrier to resource unit mapping process is defined as follows and illustrated in the Figure 42:

1. An outer permutation is applied to the PRUs in the units of N_1 and N_2 PRUs, where N_1 =4 and N_2 =1. Direct mapping of outer permutation can be supported only for CRUs.
2. The reordered PRUs are distributed into frequency partitions.
3. The frequency partition is divided into localized and/or distributed resource allocations. The sizes of the distributed/localized groups are flexibly configured per sector. Adjacent sectors do not need to have same configuration for the localized and distributed groups.
4. The localized and distributed resource units are further mapped into LRUs by direct mapping for CRUs and by “subcarrier permutation” for DRUs.

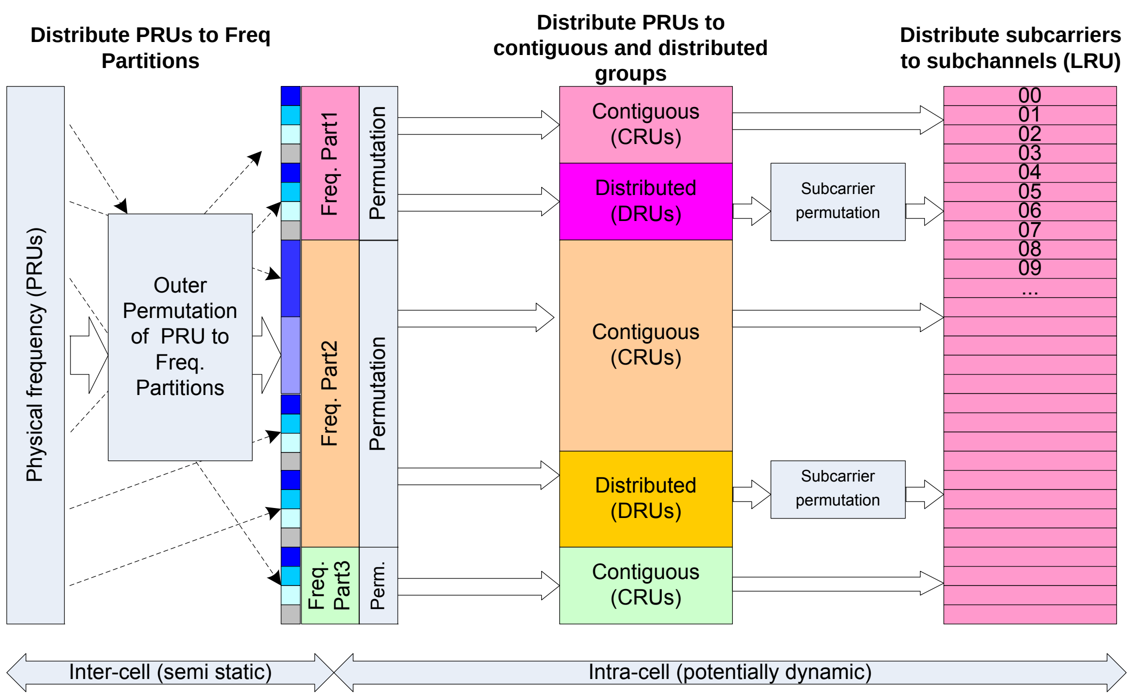

Figure 42: Illustration of the downlink resource unit mapping

11.5.2.3 Subchannelization for Downlink Distributed Resource Allocation

The subcarrier permutation defined for the downlink distributed resource allocations spreads the subcarriers of the DRU across all the distributed resource allocations within a frequency partition. After mapping all pilots, the remaining used subcarriers are used to define the DRUs. To allocate the LRUs, the remaining subcarriers are paired into contiguous subcarrier-pairs. Each LRU consists of a group of subcarrier-pairs.

Suppose that there are N_{RU} DRUs. A permutation sequence, P for the distributed group is provided and the subchannelization for downlink-distributed resource allocations is performed using the following procedure:

For every k^{th} OFDMA symbol in the subframe

1. Let n_k denote the number of pilot tones in the k^{th} OFDMA symbol within a PRU. Allocate the n_k pilots in the k^{th} OFDMA symbol within each PRU;
2. Let N_{RU} denote the number of DRUs within the frequency partition. Renumber the remaining $N_{RU} \cdot (P_{sc} - n_k)$ data subcarriers of the DRUs in order, from 0 to $N_{RU} \cdot (P_{sc} - n_k)-1$ subcarriers.
3. Group these contiguous and logically renumbered subcarriers into $N_{RU} \cdot (P_{sc} - n_k)/2$ pairs and renumber them from 0 to $N_{RU} \cdot (P_{sc} - n_k)/2-1$.
4. Apply the subcarrier permutation formula with the permutation sequence P or data subcarrier-pairs.
5. 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 (DLRU).

11.5.2.4 Subchannelization for Downlink Localized Resource

There is no subcarrier permutation defined for the downlink localized resource allocations. The CRUs are directly mapped to the subband and miniband LRUs within each frequency partition.

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 of common and dedicated pilots is done with respect to their usage. Common pilots can be used by all AMSs. Dedicated pilots can be used with both localized and distributed allocations. The dedicated pilots are associated with a specific resource allocation, and can be only used by the AMSs to which the specified resource is allocated. Therefore the dedicated pilots can be precoded or beamformed in the same way as the data subcarriers of the specified resource. The pilot structure is defined for up to eight transmission (Tx) streams and there is a unified pilot 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 symol of the downlink subframe. Further, within the same subframe there is equal number of pilots for each PRU of a data burst assigned to one AMS.

11.5.3.1 Pilot Patterns

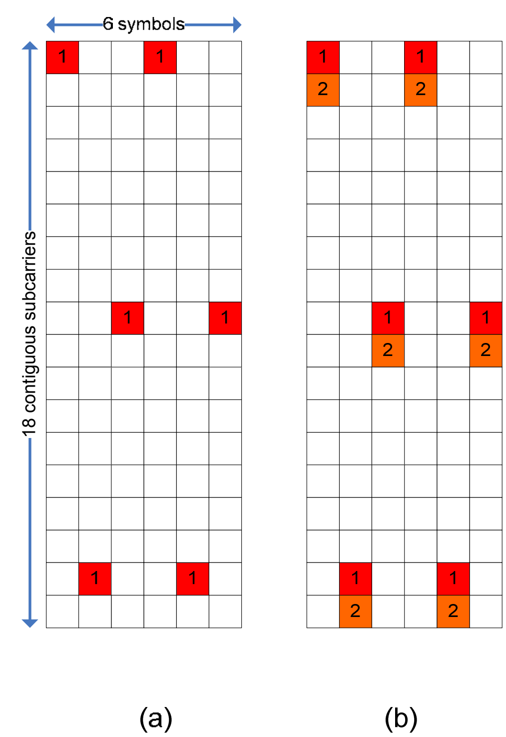

Figure 43: Pilot patterns used for one and two DL data streams.

Pilot patterns are specified within a PRU. Base pilot patterns used for one and two DL data streams in dedicated and common pilot scenarios are shown in Figure 43 with the sub-carrier index increasing from top to bottom and the OFDMA symbol index increasing from left to right. The numbers on the pilot locations indicate the stream that they correspond to.

The pilot pattern of the type-3 subframe is obtained by deleting the last OFDMA symbol of the type-1 subframe. The pilot pattern of the type-2 subframe is obtained by adding the first OFDMA symbol of the type-1 subframe to the end of the type-1 subframe.

Interlaced pilot patterns are generated by cyclic shifting the base pilot pattern and are used by different BSs for one and two Tx streams. The interlaced pilot patterns for one and two Tx streams are shown in Figure 44 and Figure 45, respectively. Each BS chooses one of the three pilot pattern sets (Pilot #0, Pilot #1 and Pilot #2) shown in Figure 44 and Figure 45. The index of the pilot pattern set p_k used by a particular BS with Cell_ID = k is determined according to equation (1)

$$p_k = \mathrm{mod}(k,3) \qquad (1)$$

The pilot pattern in Figure 46 is used for 3 and 4 data streams DL dedicated and common pilots. Rank-1 precoding may use two stream pilots.

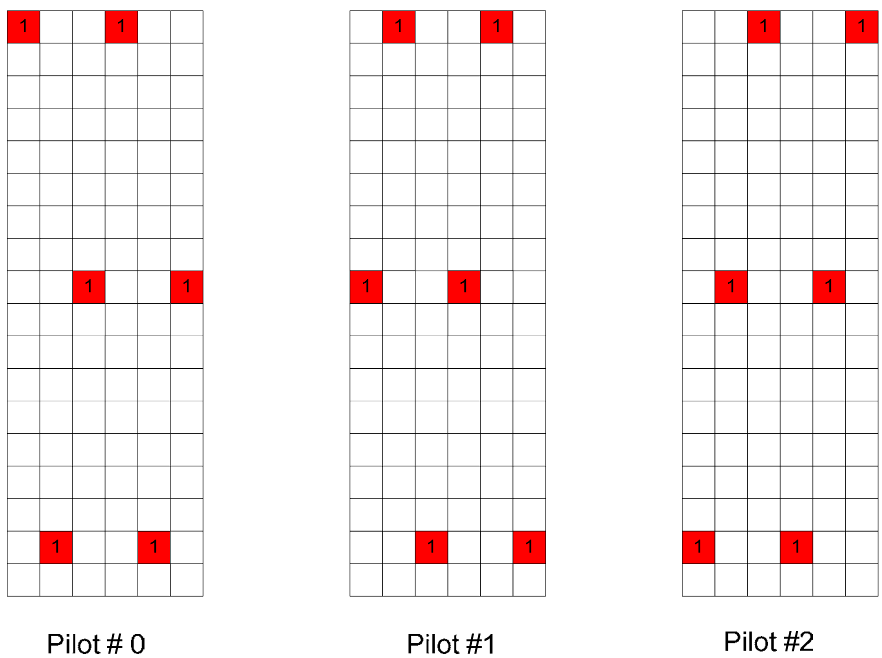

Figure 44: Interlaced pilot patterns for one pilot stream

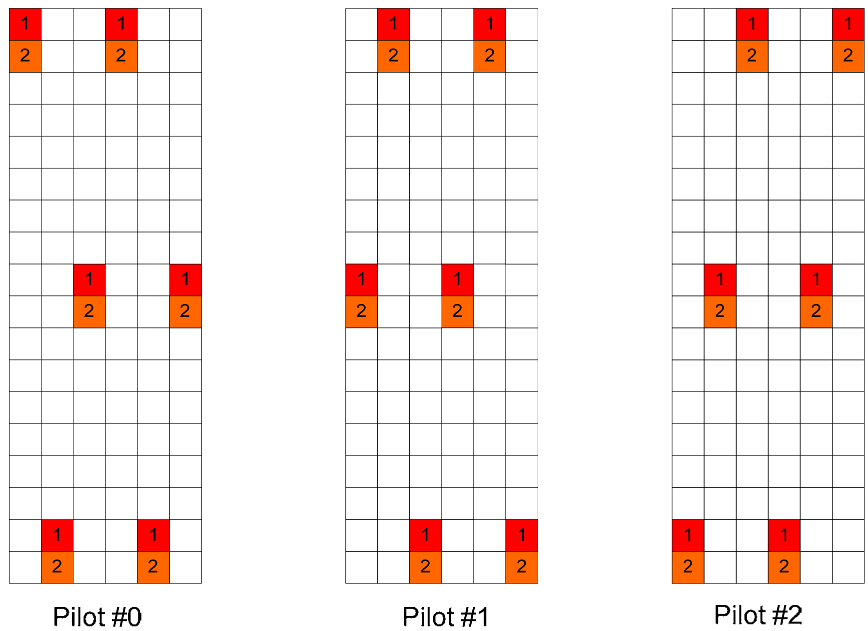

Figure 45: Interlaced pilot patterns for two pilot streams

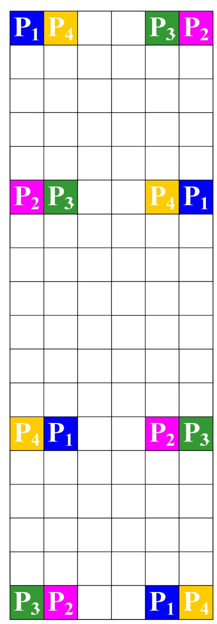

Figure 46: Pilot Pattern for four stream pilots, P_k denotes pilot for stream k.

The pilot pattern of the type-3 subframe is obtained by deleting the third OFDMA symbol of the type-1 subframe. The pilot pattern of the type-2 subframe is obtained by adding the third OFDMA symbol of the type-1 subframe to the end of the type-1 subframe.

The pilot patterns for eight Tx streams are shown in Figure 47 with the subcarrier index increasing from top to bottom and the OFDMA symbol index increasing from left to right. Subfigure (a) in Figure 47 shows the pilot pattern for eight Tx streams in subframe with six OFDMA symbols; Subfigure (b) in

Figure 47 shows the pilot pattern for eight Tx streams in subframe with five OFDMA symbols; Subfigure (c) in Figure 47 shows the pilot pattern for eight Tx streams in subframe with seven OFDMA symbols.

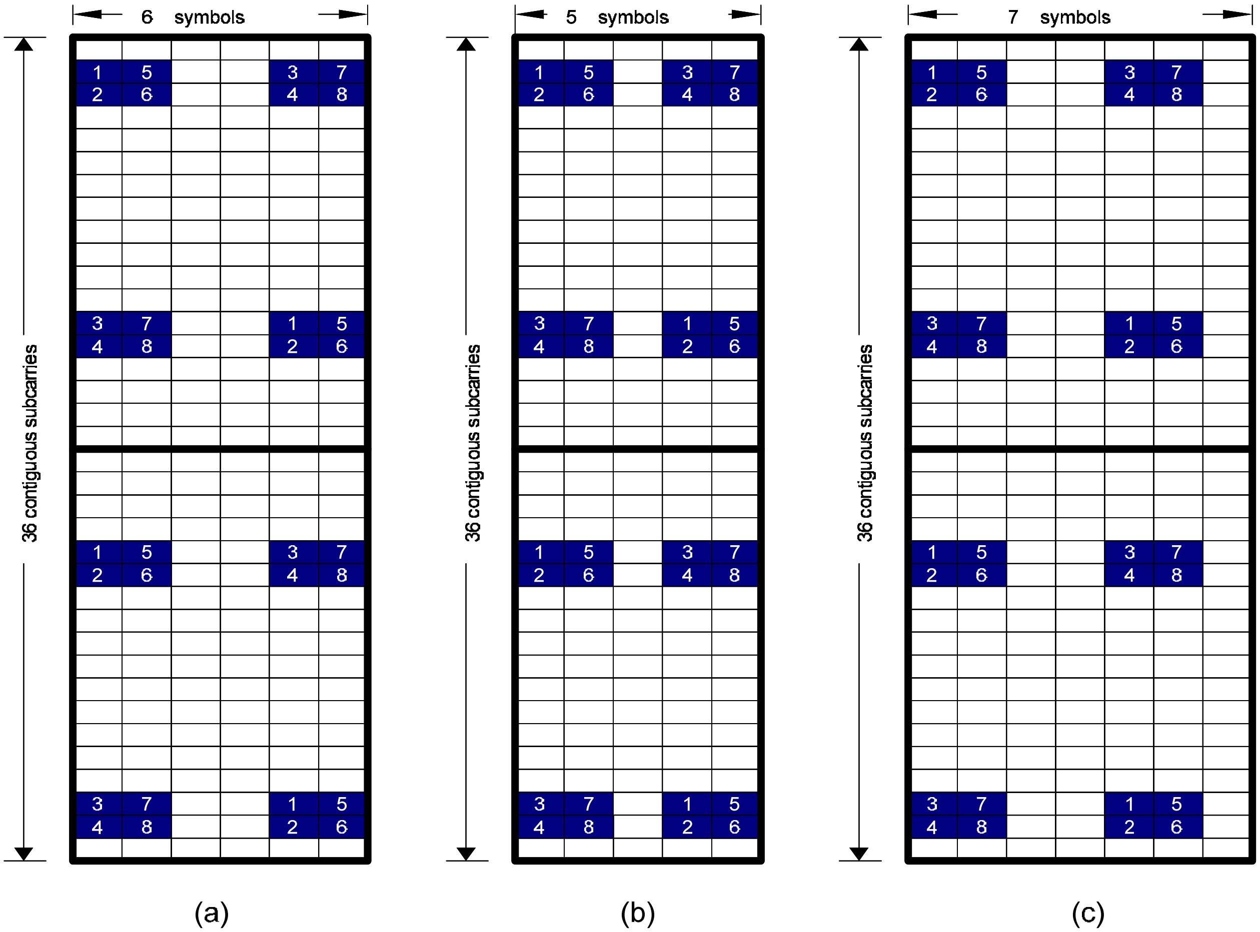

Figure 47: Pilot pattern for eight Tx streams

11.5.3.2 E-MBS Zone Specific Pilot for MBSFN

E-MBS zone specific pilots are transmitted for multi-cell multicast broadcast single frequency network (MBSFN) transmissions. An E-MBS zone is a group of ABSs involved in an SFN transmission. The E-MBS zone specific pilots that are common inside one E-MBS zone but different between neighboring E-MBS zones are configured. Synchronous transmissions of the same contents with common pilot from multiple ABS in one MBS zone would result in correct MBSFN channel estimation.

The E-MBS zone specific pilots depend on the maximum number of Tx streams within the E-MBS zone. Pilot structures/patterns should be supported up to two Tx streams. The definitions of the E-MBS zone specific pilots are being studied.

11.5.3.3 MIMO Midamble

MIMO midamble is used for PMI selection in closed loop MIMO. For open-loop MIMO, midamble can be used to calculate CQI. The midamble signal occupies one OFDMA symbol in a downlink sub-frame.

11.6 Uplink Physical Structure

Each UL subframe is divided into four or fewer 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). The example in Figure 48 illustrates the uplink physical structure with two frequency partitions. In the example shown, frequency partition 2 includes both localized and distributed resource allocations and *Sc* stands for subcarrier.

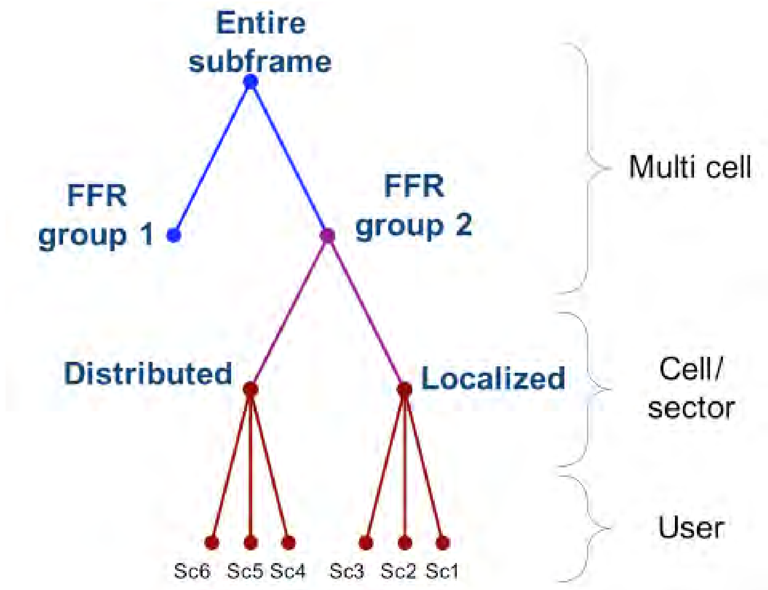

Figure 48: Example of uplink physical structure

11.6.1 Physical and Logical Resource Unit

A physical resource unit (PRU) is the basic physical unit for resource allocation that comprises P_{sc} consecutive subcarriers by N_{sym} consecutive OFDMA symbols. P_{sc} is 18 subcarriers and N_{sym} is 6, 7 and 5 OFDMA symbols for type-1, type-2, and type-3 subframes respectively. A logical resource unit (LRU) is the basic logical unit for distributed and localized resource allocations and its size is $P_{sc} \cdot N_{sym}$ subcarriers for data transmission. 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 (DRU) can be used to achieve frequency diversity gain. The DRU contains a group of subcarriers which are spread across distributed resource allocations within a frequency partition. The size of the DRU equals the size of the PRU, i.e., P_{sc} subcarriers by N_{sym} OFDMA symbols. The minimum unit for forming the DRU is a tile. The uplink tile size is $6 \cdot N_{sym}$. An 18x2 tile size for UL transmit power optimized distributed groups and other tile sizes are being studied. Details of the UL transmit power optimized distributed allocation are being studied.

11.6.1.2 Contiguous Resource unit

The localized resource unit, also known as contiguous resource unit (CRU) can be used to achieve frequency-selective scheduling gain. The CRU contains a group of subcarriers which are contiguous across the localized resource allocations. The size of the CRU equals the size of the PRU, i.e., P_{sc} subcarriers by N_{sym} 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 AMS 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, type-2 or type-3.

11.6.2.2 Uplink Subcarrier to Resource Unit Mapping

The PRUs are first subdivided into subbands and minibands, where a subband comprises N_1 adjacent PRUs and a miniband comprises N_2 adjacent PRUs, where N_1 =4 and N_2 =1. Subbands are suitable for frequency selective allocations as they provide a contiguous allocation of PRUs in frequency. Minibands are suitable for frequency diverse allocation and are permuted in frequency.

The main features of resource mapping include:

1. Support of CRUs and DRUs in an FDM manner.
2. DRUs comprising multiple tiles which are spread across the distributed resource allocations to obtain frequency diversity gain.

FFR may be applied in the uplink.

Based on the main design concepts above, the uplink resource unit mapping process is illustrated in Figure 49 and defined as follows:

1. An outer permutation is applied to the PRUs in the units of N_1 and N_2 PRUs. Direct mapping of outer permutation can be supported only for CRUs.
2. The reordered PRUs are distributed into frequency partitions.
3. A frequency partition is divided into localized and/or distributed resource allocations. Sector specific permutation can be supported; direct mapping of the resources can be supported for localized resource. The sizes of the distributed/localized groups are flexibly configured per sector. Adjacent sectors do not need to have same configuration of localized and diversity resources.
4. The subcarriers in the localized and distributed resource allocations are further mapped into LRUs by direct mapping for CRUs and by tile-permutation for DRUs.

11.6.2.3 Subchannelization for Uplink Distributed Resource Allocation

An inner permutation defined for the uplink distributed resource allocations, which spreads the tiles of the DRU across all the distributed resource allocations within a frequency partition. Each of the DRUs of an uplink frequency partition is divided into 3 tiles of 6 adjacent subcarriers over N_{sym} symbols. The tiles within a frequency partition are collectively tile-permuted to obtain frequency diversity gain across the allocated resources.

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 is defined for the power optimized allocation that spreads the hopping units across frequency. The granularity of the inner permutation is equal to the tile size for forming a DRU according to Section 11.6.1.1.

11.6.2.4 Subchannelization for Uplink Localized Resource

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

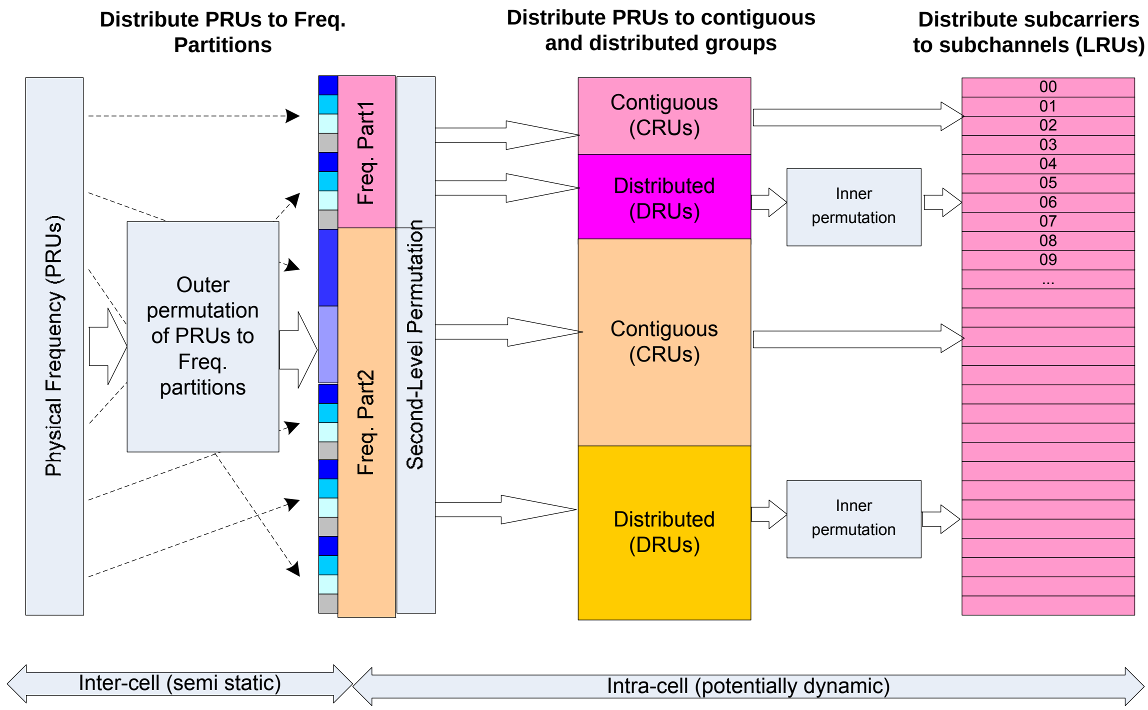

Figure 49: Illustration of the uplink resource unit mapping

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.

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

The uplink pilot patterns are specified within a CRU comprising $P_{sc} \cdot N_{sym}$ subcarriers for contiguous resource allocations and within a tile comprising $6 \cdot N_{sym}$ subcarriers for distributed resource allocations.

The base downlink 18x6 pilot patterns defined in Section 11.5.3 are used for the uplink 18x6 pilot patterns, which include pilots for up to four Tx streams. Interlaced pilot patterns are not used for the uplink.

The pilot structure for distributed resource allocations with a 6-by-6 tile is shown in Figure 50, with the subcarrier index increasing from top to bottom and the OFDMA symbol index increasing from left to right, where the number of Tx streams is one or two. Rank-1 precoding may use two stream pilots.

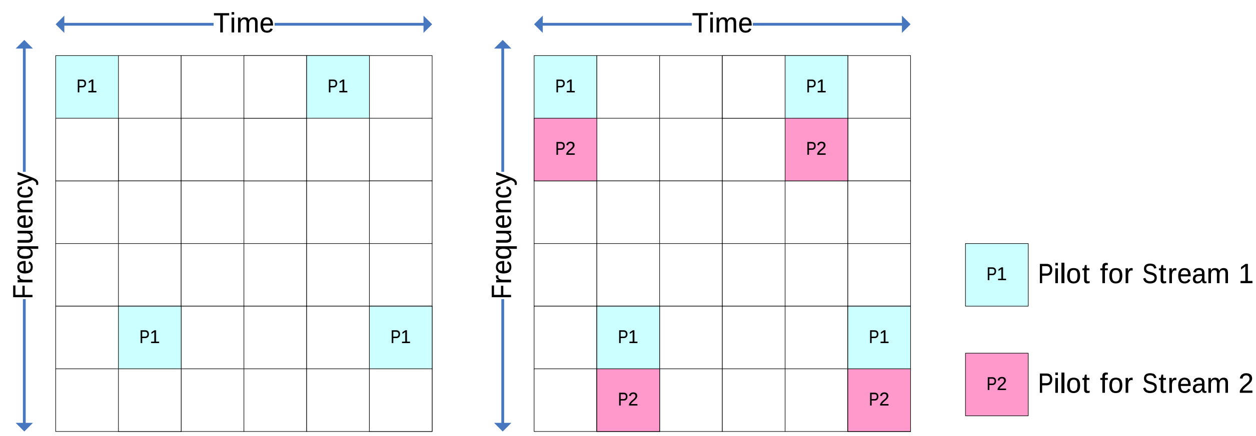

Figure 50: Uplink pilot patterns for one and two streams

11.6.4 WirelssMAN-OFDMA System Support

The IEEE 802.16m uplink physical structure supports both frequency division multiplexing (FDM) and time division multiplexing (TDM) with the WirelessMAN OFDMA reference system.

When the WirelessMAN OFDMA reference system operates in the PUSC mode, a symbol structure according to IEEE 802.16m PUSC should be used in order to provide FDM-based legacy support.

11.6.4.1 Distributed Resource Unit for IEEE 802.16m PUSC

Unlike the DRU structure defined in Section 11.6.1.1, a DRU in IEEE 802.16m PUSC contains six tiles whose size is $4 \cdot N_{sym}$, where N_{sym} depends on the subframe type. Figure 51 shows a tile structure when a subframe has 6 symbols.

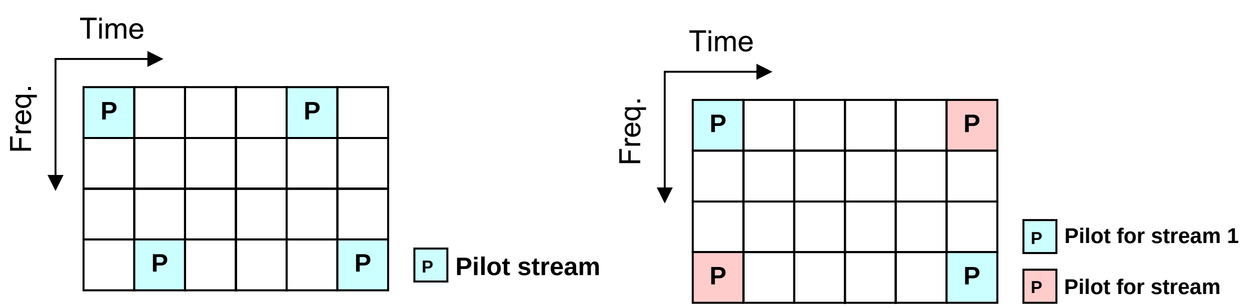

Figure 51: Tile structure in IEEE 802.16m PUSC

11.6.4.2 Subchannelization for IEEE 802.16m PUSC

The subchannelization for IEEE 802.16m PUSC is identical to the WirelessMAN OFDMA reference system uplink PUSC [4]. For a given system bandwidth, the total usable subcarriers are allocated to form tiles (four contiguous subcarriers) and every tile is permuted according to permutation defined in uplink PUSC [2]. Once subchannelization is done, every subchannel is assigned to either the WirelessMAN OFDMA reference system or the IEEE 802.16m system. Figure 52 shows the uplink frame which is divided in frequency domain into two logical regions – one is for the WirelessMAN OFDMA reference system PUSC subchannels and the other is for IEEE 802.16m PUSC DRUs.

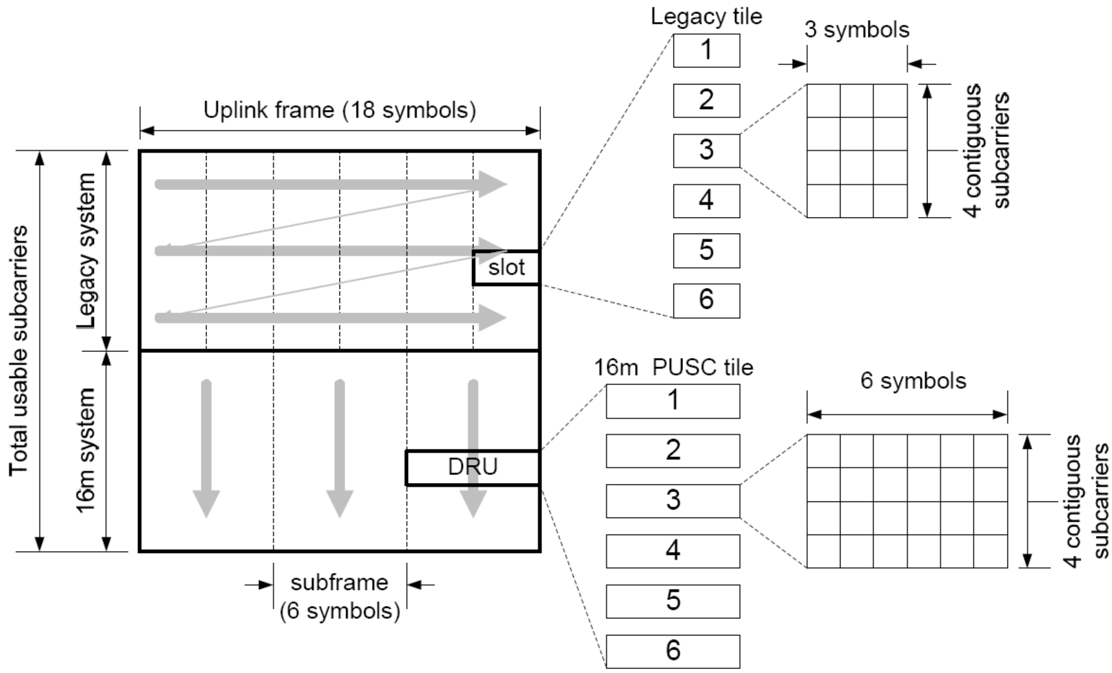

Figure 52: Subchannelization of IEEE 802.16m PUSC and DRU Structure

11.7 Downlink 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 AMS can access the system without decoding legacy FCH and legacy MAP messages.

11.7.1 Downlink 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 System Configuration Information

This includes a minimal set of time critical system configuration information and parameters needed for the mobile station (AMS) to complete cell selection and system access in a power efficient manner

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 AMSs after system acquisition. Examples of this class include information required for handover such as handover trigger, and neighbor ABS information.

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 Downlink Control Information

11.7.2.1 Advanced Preamble (A-PREAMBLE)

The Advanced Preamble (A-PREAMBLE) is a DL physical channel which provides a reference signal for timing, frequency, and frame synchronization, RSSI estimation, channel estimation, and ABS identification.

11.7.2.1.1 Advanced Preamble Design Considerations

Table 5 defines considerations taken into account in the design of the A-PREAMBLE.

Convergence time	Time interval for the probability of error in A-PREAMBLE 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	Selection of an ABS among the co-channel ABS's whose received powers averaged over the convergence time are within 3 dB of the ABS 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 A-PREAMBLE
Cell ID set	The cell ID set is the set of unique A-PREAMBLE symbols for differentiating between macrocell/femtocell/sector/relay transmitters
Multi-bandwidth support	Design of A-PREAMBLE for different bandwidths as specified in Table 4
Multi-carrier support	Design of A-PREAMBLE to support functionality described in Sections 8.1.3 and 17

Table 5: Definitions related to the A-Preamble

11.7.2.1.1.1 Overhead

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

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

11.7.2.1.1.2 Synchronization

The A-Preamble provides time and frequency synchronization including frame and superframe alignment.

11.7.2.1.1.3 Coverage

The coverage of the IEEE 802.16m A-PREAMBLE is not worse than the minimum of the required coverage for broadcasting channel, control channel and unicast data channel under channel conditions defined in the IEEE 802.16m evaluation methodology for the supported cell sizes.

11.7.2.1.1.4 Cell IDs

The cell ID is obtained from the A-PREAMBLE. To support femtocell BS and ARS deployments, the number of unique cell IDs that can be conveyed by the SA-PREAMBLE is equal to 768.

11.7.2.1.1.5 MIMO Support and Channel Estimation

The IEEE 802.16m A-PREAMBLE supports multi-antenna transmissions. Channel estimation is supported from the A-PREAMBLE in order to enable control/data channel decoding.

11.7.2.1.1.6 Multi-carrier Multi-bandwidth Support

IEEE 802.16m A-PREAMBLE supports multi-bandwidth and multi-carrier operations.

11.7.2.1.1.7 Measurement Support

IEEE 802.16m A-PREAMBLE supports noise power estimation.

11.7.2.1.1.8 Sequence Requirements

The A-Preamble PAPR and peak power is no larger than that of other downlink signals.

11.7.2.1.2 Advanced Preamble Architecture

11.7.2.1.2.1 Overview

11.7.2.1.2.1.1 Hierarchy

IEEE 802.16m supports hierarchical synchronization with two levels. These are called the Primary Advanced Preamble (PA-PREAMBLE) and Secondary Advanced Preamble (SA-PREAMBLE). The PA-PREAMBLE is used for initial acquisition, superframe synchronization and sending additional information. The SA-PREAMBLE is used for fine synchronization, and cell/sector identification (ID).

11.7.2.1.2.1.2 Multiplexing

PA-PREAMBLE and SA-PREAMBLE are TDM

11.7.2.1.2.1.3 Number of Symbols in A-PREAMBLE

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

In mixed deployments, the presence of the IEEE Std 802.16-2009 preamble is implicit.

11.7.2.1.2.1.4 Location of Synchronization Symbols

In mixed deployments, the IEEE Std 802.16-2009 preamble is located in the first symbol of the IEEE Std 802.16-2009 frame. The location of the A-PREAMBLE symbol(s) is fixed within the superframe.

One PA-Preamble symbol and three SA-Preamble symbols exist within the superframe. The location of the A-Preamble symbol is specified as the first symbol of frame. PA-Preamble is located at the first symbol of second frame in a superframe while SA-Preamble is located at the first symbol of remaining three frames as depicted in Figure 53.

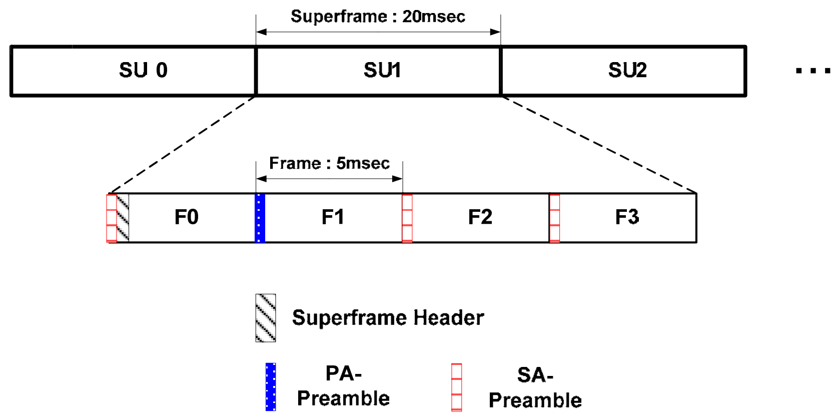

Figure 53: Structure of the A-Preamble

The length of sequence for PA-Preamble is 216 regardless of the FFT size. PA-Preamble carries the information related to system bandwidth, and carrier configuration, where the subcarrier index 256 is reserved for DC subcarrier.

SA-Preamble sequences are partitioned and each partition is dedicated to specific base station type like Macro BS, Femto BS and etc. The partition information is broadcasted in the Secondary Superframe Header (S-SFH)

For the support of femtocell deployment, a femtocell BS should self-configure the segment or subcarrier set for SA-Preamble transmission based on the segment information of the overlay macrocell BS for minimized interference to macrocell if the femtocell BS is synchronized to macrocell BSs. The segment information of the overlay macrocell BS may be obtained by communications with macrocell BS through backbone network or active scanning of SA-Preamble transmitted by macrocell BS.

11.7.2.1.2.1.5 Properties of PA-PREAMBLE & SA-PREAMBLE

The PA-PREAMBLE has these properties:

- Common to a group of sectors/cells
- Supports limited signaling (e.g., system bandwidth, carrier information, etc.)
- Fixed number of subcarriers (but the occupied bandwidth is less than 5MHz)

The SA-PREAMBLE has these properties:

- 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 IEEE Std 802.16-2009 and IEEE 802.16m equipment) deployments. In mixed deployments the IEEE Std 802.16-2009 preamble will be always present. As discussed in the design considerations, the IEEE 802.16m A-PREAMBLE is designed so as not to degrade the performance of legacy acquisition. The IEEE 802.16m A-PREAMBLE enables AMSs to synchronize in frequency and time without requiring the IEEE Std 802.16-2009 preamble.

The IEEE 802.16m PA-PREAMBLE supports a timing synchronization by autocorrelation with a repeated waveform. The structure of PA-PREAMBLE is not identical to that of legacy preamble in the time domain.

The structure of the A-Preamble for legacy support is illustrated in 54.

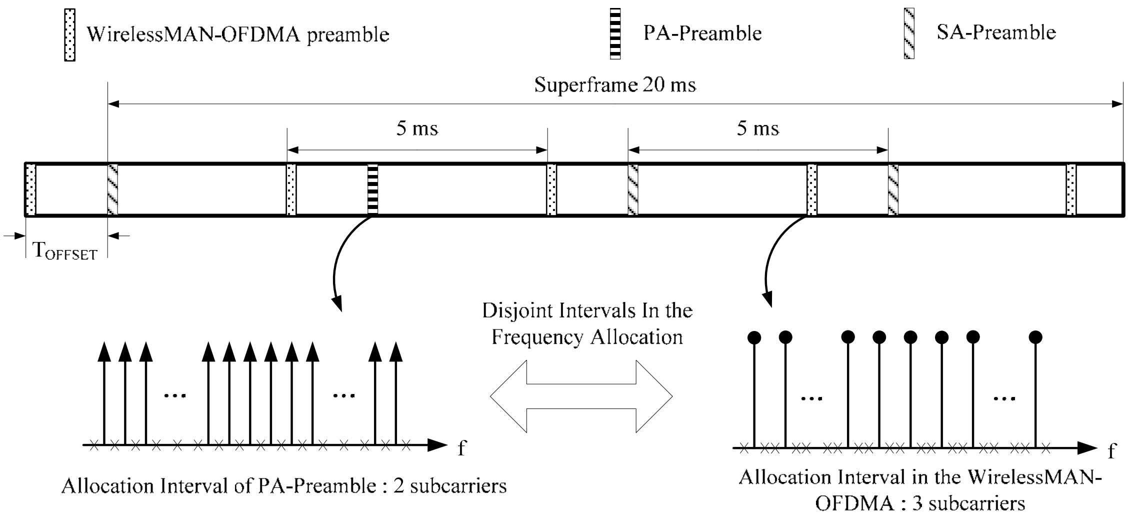

Figure 54: A-Preamble transmission structure with legacy support

11.7.2.1.2.3 Cell ID Support

Sectors are distinguished by the Advanced Preamble. Each segment uses an SA-Preamble composed of a carrier-set out of the three available carrier-sets in the following manner:

- Segment 0 uses SA-Preamble carrier-set 0.
- Segment 1 uses SA-Preamble carrier-set 1.
- Segment 2 uses SA-Preamble carrier-set 2.

11.7.2.1.2.4 Multicarrier and Multi-bandwidth Support

For the 512-FFT size, the 144-bit SA-Preamble sequence is divided into 8 main blocks, namely, A, B, C, D, E, F, G, and H. The length of each block is 18 bits. Each segment ID has different sequence blocks. For the 512-FFT size, A, B, C, D, E, F, G, and H are modulated and mapped sequentially in ascending order onto the SA-Preamble subcarrier-set corresponding to segment ID. For higher FFT sizes, the basic blocks (A, B, C, D, E, F, G, H) are repeated in the same order. For instance in the 1024-FFT size, E, F, G, H, A, B, C, D, E, F, G, H, A, B, C, D are modulated and mapped sequentially in ascending order onto the SA-Preamble subcarrier-set corresponding to segment ID.

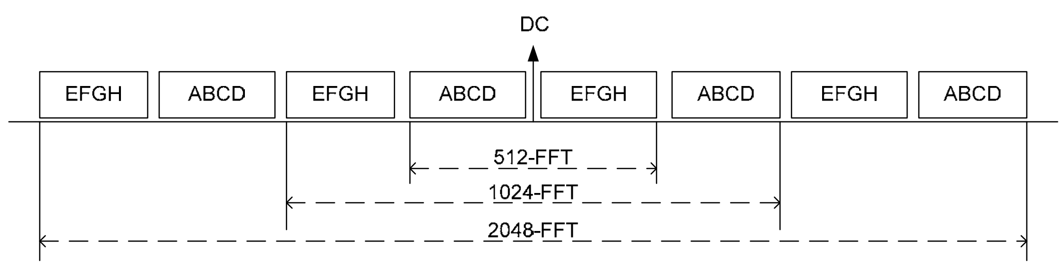

Figure 55: The allocation of sequence block for each FFT size

A circular shift is applied over three consecutive sub-carriers after applying subcarrier mapping. Each subblock has common offset. The circular shift pattern for each subblock is:

[2,1,0……., 2,1,0, ….., 2,1,0, 2,1,0, DC, 1,0,2, 1,0,2, ……, 1,0,2, …….1,0,2] where the shift is right circular.

For the 512-FFT size, the blocks (A, B, C, D, E, F, G, H) experience the following right circular shift (0, 2, 1, 0, 1, 0, 2, 1), respectively. Figure 56 depicts the symbol structure of SA-Preamble in the frequency domain for the 512-FFT.

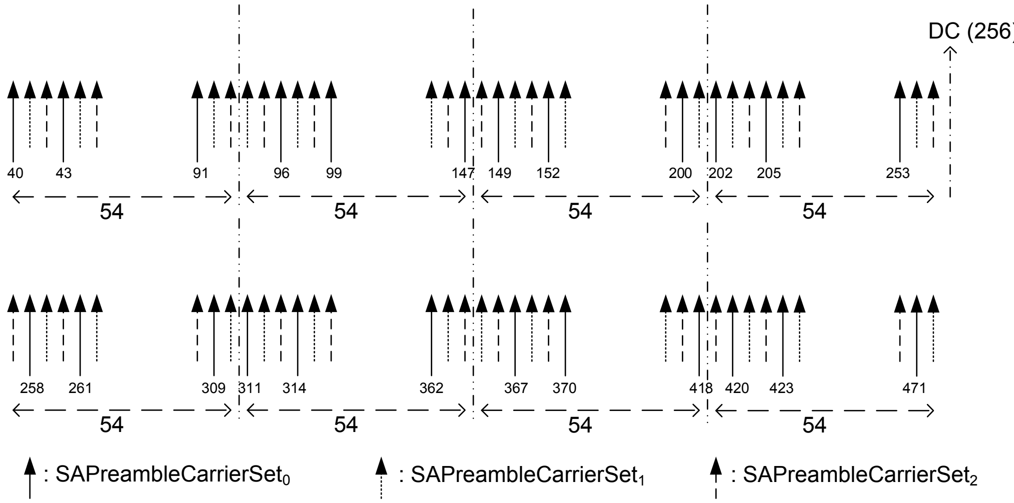

Figure 56: SA-Preamble symbol structure for 512-FFT

11.7.2.1.2.5 MIMO Support and Channel Estimation

For multiple antenna systems, the SA-Preamble blocks are interleaved on the number of antennas (1, 2, 4 or 8). Where employed, MIMO support is achieved by transmitting A-PREAMBLE subcarriers from known antennas. Multiple antenna transmission is supported using:

(a) Cyclic delay diversity (with antenna specific delay values) for the PA-Preamble and

(b) Interleaving within a symbol (multiple antennas can transmit within a single symbol but on distinct subcarriers) for the SA-Preamble.

11.7.2.1.3 Advanced Preamble Sequence Design Properties

The A-PREAMBLE enables timing synchronization by autocorrelation. The power can be boosted.

The PA-PREAMBLE is mapped with every other subcarrier on the frequency domain. Frequency reuse of 1 is applied to PA-PREAMBLE.

Frequency reuse of 3 is applied to SA-PREAMBLE.

11.7.2.2 Superframe Header (SFH)

The Superframe Header (SFH) carries essential system parameters and system configuration information. The SFH is divided into two parts: Primary Superframe Header (P-SFH) and Secondary Superframe Header (S-SFH).

11.7.2.2.1 Primary Superframe Header (P-SFH) and Secondary Superframe Header (S-SFH)

The Primary Superframe Header (P-SFH) and the Secondary Superframe Header (S-SFH) carry essential system parameters and system configuration information. The P-SFH is transmitted every superframe. The P-SFH IE is of fixed size and contains essential system information. It is mapped to the P-SFH.

When present, the S-SFH may be transmitted over one or more superframes. The S-SFH is of variable size. The size of S-SFH is indicated by the P-SFH. Essential system parameters and system configuration information carried in the S-SFH is categorized into multiple subpacket IEs. The S-SFH IEs are transmitted with different timing and periodicity and are mapped to the S-SFH.

The S-SFH Sub-Packet 1 (SP1) Information Element (IE) includes information needed for network re-entry. S-SFH SP2 contains information for initial network entry and network discovery. S-SFH SP3 contains remaining information for maintaining communication with the ABS.

11.7.2.2.2 Location of the SFH

The SFH includes P-SFH and the S-SFH, and is located in the first subframe within a superframe. The P-SFH and S-SFH are contained within a 5 MHz bandwidth.

11.7.2.2.3 Multiplexing of the P-SFH and S-SFH with Other Control Channels and Data Channels

The P-SFH/S-SFH is TDM with the A-PREAMBLE.

If SFH occupies narrower BW than system BW, the P-SFH and S-SFH in SFH are FDM with data within the same subframe.

The P-SFH is FDM with the S-SFH within the first subframe.

11.7.2.2.4 Transmission Format

The P-SFH and S-SFH are transmitted using predetermined modulation and coding schemes. The modulation for the P-SFH and the S-SFH is QPSK.

The coding rates for the P-SFH and S-SFH are FFS.

Multiple antenna schemes for transmission of the P-SFH/S-SFH are supported. The AMS is not required to know the antenna configuration prior to decoding the P-SFH.

Two-stream SFBC with two Tx antennas is used for P-SFH and S-SFH transmission. For more than 2-Tx antenna configurations, the P-SFH and S-SFH are transmitted using 2-stream SFBC with precoding, which is decoded by the AMS without any information on the precoding and antenna configuration.

The physical processing of the P-SFH IE is shown in Figure 57.

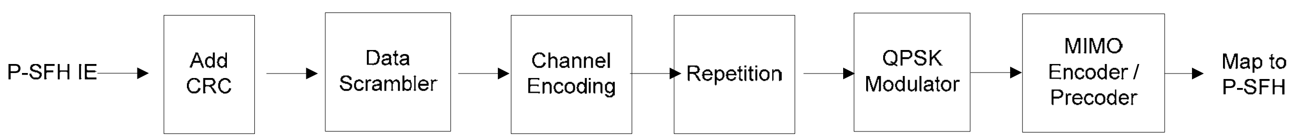

Figure 57: Physical Processing of the P-SFH

The physical processing of the S-SFH IE is shown in

Figure 58.

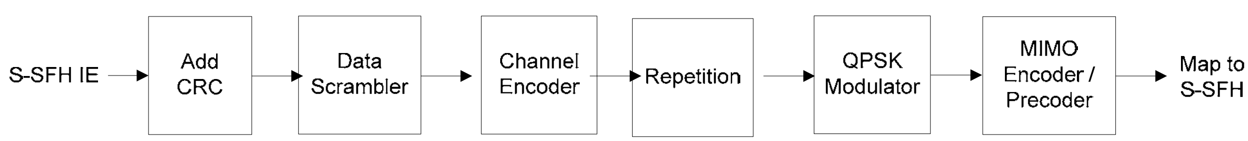

Figure 58: Physical Processing of the S-SFH

Rate 1/4 tail-biting convolutional codes are used for the P-SFH and S-SFH.

11.7.2.2.5 Resource Allocation

The P-SFH and S-SFH are transmitted in a predefined frequency partition.

The PHY structure for transmission of P-SFH and S-SFH is described in Section 11.5.1. The P-SFH and S-SFH use distributed LRUs.

11.7.2.3 Advanced MAPs (A-MAP)

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.

User-specific control information is further divided into assignment information, HARQ feedback information, and power control information, and they are transmitted in the assignment A-MAP, HARQ feedback A-MAP, and power control A-MAP, respectively. All the A-MAPs share a region of physical resources called A-MAP region.

In the DL subframes where the A-MAP regions can be allocated, each frequency partition may contain an A-MAP region. The A-MAP region occupies the first few distributed LRUs in a frequency partition. The structure of an A-MAP region is illustrated as an example in the following figure. The resources occupied by each A-MAP physical channel may vary depending on the system configuration and scheduler operation. The A-MAP region consists of a number of distributed LRUs.

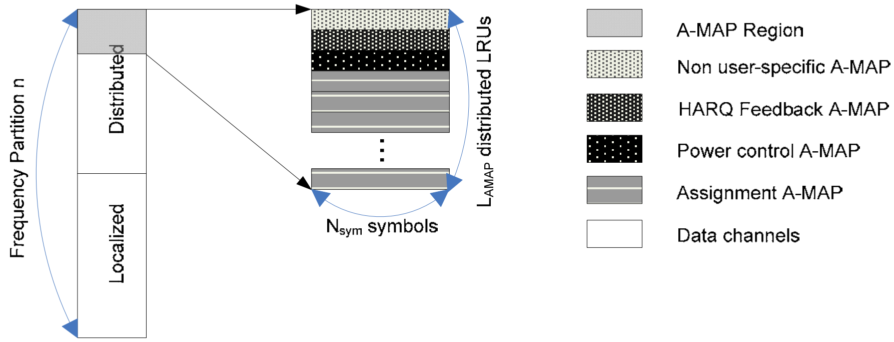

Figure 59: The structure of an A-MAP region

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 SFH may be included in this category.

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. HARQ ACK/NACK information for uplink data transmission is carried by DL ACK channel which is separated from control blocks for other user specific control information.

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

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. The group message contains bitmaps to signal resource assignment, MCS, resource size etc. VoIP is an example of the subclass of services that use group messages.

The user-specific A-MAP consists of the Assignment A-MAP, the HARQ Feedback A-MAP and the Power Control A-MAP.

Assignment A-MAP

The Assignment A-MAP contains resource assignment information which is categorized into multiple types of resource assignment IEs (assignment A-MAP IE). Each assignment A-MAP IE is coded separately and carries information for one or a group of users.

The minimum logical resource unit in the assignment A-MAP is called an MLRU. The assignment A-MAP IE is transmitted with one MLRU or multiple concatenated MLRUs in the A-MAP region. The number of logically contiguous MLRUs is determined based on the assignment IE size and channel coding rate, where channel coding rate is selected based on AMS' link condition. Assignment A-MAPs are grouped together based on MCS level and A-MAP IE sizes. Assignment A-MAPs in the same group are transmitted with the same MCS level and contain the same A-MAP IE size. Each assignment A-MAP group contains several logically contiguous MLRUs. The number of assignment A-MAPs in each assignment A-MAP group is signaled through non-user specific A-MAP.

HARQ Feedback A-MAP

The HARQ feedback AMAP carries HARQ ACK/NACK information for uplink data transmission.

Power Control A-MAP

The Power Control A-MAP carries fast power control command to AMS.

11.7.2.3.2 Multiplexing Scheme for Data and Unicast Service Control

Within a subframe, control and data channels are multiplexed using FDM. Both control and data channels are transmitted on LRU that span all OFDM symbols in a subframe.

11.7.2.3.3 Location of Control Blocks

The first IEEE 802.16m DL subframe of each frame contains one A-MAP region. Multiple A-MAP regions in a subframe are FFS. An A-MAP region can include both non-user specific and user specific control information.

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

An example illustrating the location of an A-MAP region in TDD with 4:4 subframe DL: UL split is provided in Figure 60.

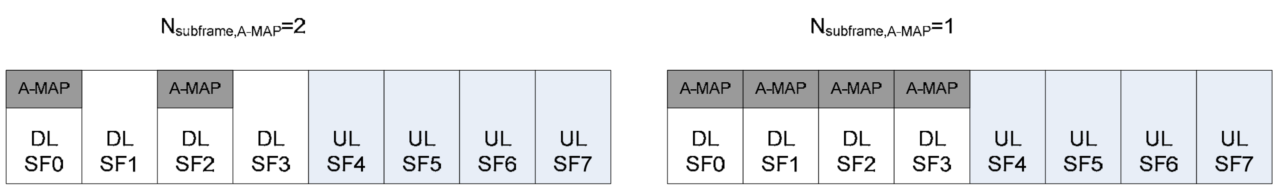

Figure 60: Example on the Location of A-MAP regions in a TDD system with a 4:4 subframe DL:UL split

In the FDD mode, the first IEEE 802.16m DL subframe of each frame contains one A-MAP region. In the TDD mode, the first IEEE 802.16m DL subframe after each UL to DL transition contains one A-MAP region.

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, power control, etc.

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 elements intended for a single user or a group of users, multiple information elements are coded separately. The modulation and coding scheme (fixed/variable) of each information element is FFS.

Non-user-specific control information in a A-MAP region is transmitted at a fixed MCS for a given system configuration.

The coding chain for the non-user-specific A-MAP-IE is shown in Figure 61.

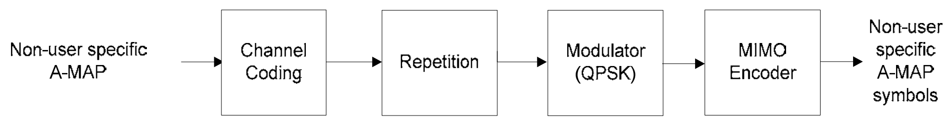

Figure 61: Physical processing of the Non-user specific A-MAP

The Assignment A-MAP (A-A-MAP) includes one or multiple A-A-MAP-IEs and each A-A-MAP-IE is encoded separately. Figure 62 illustrates the procedure for constructing A-A-MAP symbols. Following rate matching and repetition, the encoded bit sequences are modulated using QPSK. For a given system configuration, assignment A-MAP IEs can be encoded with two different effective code rates. The set of code rates is (1/2, 1/4) or (1/2, 1/8).

Rate 1/4 tailbiting convolutional codes are used for the Assignment A-MAP.

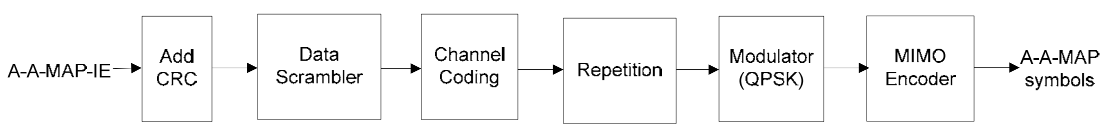

Figure 62: Physical processing of the Assignment A-MAP

The HARQ feedback A-MAP (HF-A-MAP) contains HARQ-feedback-IEs for ACK/NACK feedback information to uplink data transmission. Each HF-A-MAP IE carries 1 bit information. Depending on the channel conditions, the modulation can be QPSK or BPSK. If QPSK is used, 2 HF-A-MAP IEs are mapped to a point in the signal constellation. If BPSK is used, each HF-A-MAP IE is mapped to a point in the signal constellation. The coding chain for the HF-A-MAP IE is shown in Figure 63.

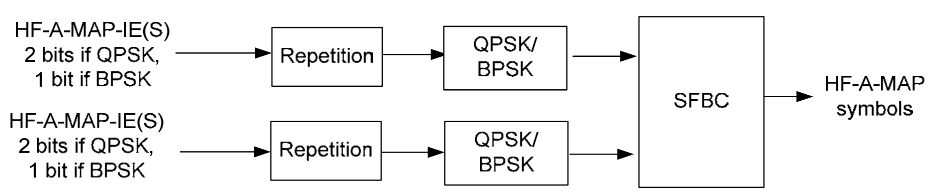

Figure 63: Physical processing of the HF A-MAP

Power Control A-MAP (PC-A-MAP) contains PC-A-MAP-IEs for closed-loop power control of the uplink transmission. The ABS transmits the PC-A-MAP-IE to every AMS which operates in closed-loop power control mode. The coding chain for the HF-A-MAP IE is shown in Figure 64.

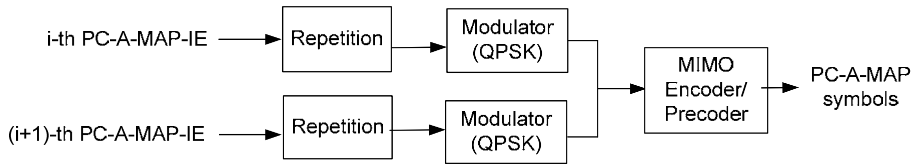

Figure 64: Physical processing of the Power Control A-MAP

11.7.2.4 E-MBS MAPs

E-MBS MAPs are classified into cell specific and non-cell specific control channels. SFH provides the location information for both cell-specific and non-cell specific E-MBS MAPs.

The cell specific control channel carries all cell specific information while the non cell specific control channel carries all information on multiple BS transmission.

One cell specific E-MBS MAP and one or more non cell specific E-MBS MAPs may exist in a cell. Multiple cell specific information are jointly encoded into one cell specific E-MBS MAP. Each E-MBS MAP may support one or more E-MBS services within an MBS zone.

11.7.2.4.1 Multicast Service Control Information/Content

The cell specific E-MBS MAP provides all essential parameters for retrieving single-BS E-MBS, and it also contains some control parameters which are cell specific for multi-BS E-MBS.

11.7.2.4.2 Multiplexing Scheme for Data and Multicast Service Control

Within a subframe where multicast data and E-MBS MAPs are carried, E-MBS MAPs and data channels are multiplexed using FDM. Within a MBS scheduling interval, each E-MBS control channel is transmitted at the beginning of the corresponding E-MBS zone interval in order to decode the burst information.

11.7.2.4.3 Location of Control Blocks Within a Frame/Subframe

11.7.2.4.4 Transmission Format

A multicast service control information element is defined as the basic element of the multicast service control. A multicast service control information element is non-user specific and is addressed to all users in the cell.

11.7.2.4.5 Resource Allocation

11.7.2.5 Transmission of Additional Broadcast information on Traffic Channel

Examples of additional broadcast information include system descriptors, neighbor ABS information and paging information.

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

The essential configuration information about different RATs may be transmitted by an ABS. Such messages may be structured as broadcast or unicast messages.

The configuration of different RATs may be defined in a variable length MAC management message. This message should include information such as:

- RAT Logical Index
- RAT Type: 16m, 16e only, 3GPP/3GPP2, DVB-H, etc.

- If other RAT : List of configuration Parameters

The configuration parameters should include all information needed for efficient scanning and if needed handing over/switching to such RATs with minimal signaling with the target RAT.

11.7.3 Mapping Information to DL Control Channels

Information	Channel	Location
Synchronization information	Advanced Preamble (A-PREAMBLE): Primary Advanced Preamble (PA-PREAMBLE) and Secondary Advanced Preamble (SA-PREAMBLE)	PA-Preamble is located at the first symbol of second frame in a superframe. SA-Preamble is located at the first symbol of remaining three frames.
System configuration information	Primary Superframe Header (P-SFH) and Secondary Superframe Header (S-SFH)	Inside SFH
Extended system parameters and system configuration information	Additional Broadcast Information on Traffic Channel	Outside SFH
Control and signaling for DL notifications	Additional Broadcast Information on Traffic Channel	Outside SFH
Control and signaling for traffic	Advanced MAP	Outside SFH

Table 6: Mapping information to DL control channels

11.8 Downlink MIMO Transmission Scheme

11.8.1 Downlink MIMO Architecture and Data Processing

The architecture of downlink MIMO on the transmitter side is shown in Figure 65.

The MIMO Encoder block maps L (≥1) layers onto Mt (≥L) streams, which are fed to the Precoder block. A layer is defined as a coding and modulation path fed to the MIMO encoder as an input. A stream is defined as an output of the MIMO encoder which is passed to the precoder.

For SU-MIMO, only one user is scheduled in one Resource Unit (RU), and only one FEC block exists at the input of the MIMO encoder (vertical MIMO encoding or SFBC encoding at transmit side).

For MU-MIMO, multiple users can be scheduled in one RU, and multiple FEC blocks exist at the input of the MIMO encoder (horizontal MIMO encoding at transmit side).

The Precoder block maps stream(s) to antennas by generating the antenna-specific data symbols according to the selected MIMO mode.

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

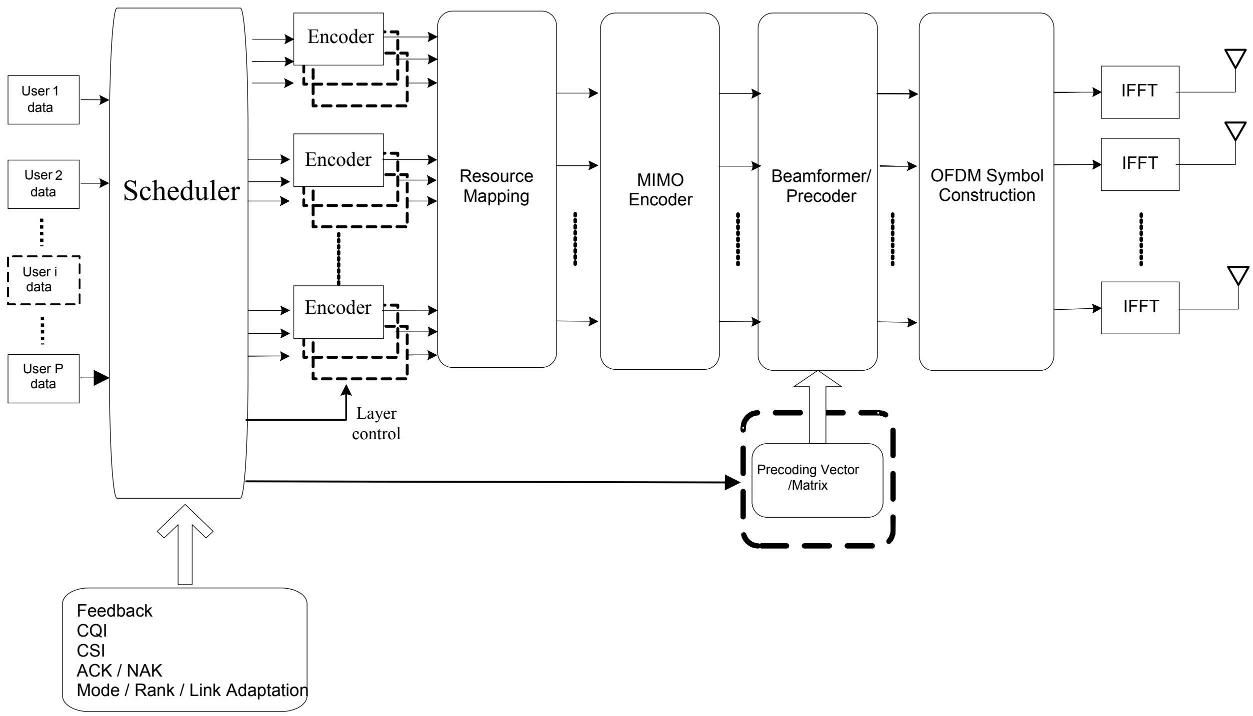

Figure 65: DL MIMO Architecture

The Scheduler block schedules users to resource units 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 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 allocated to the same Resource Unit.
- *Rank*: For the spatial multiplexing modes in SU-MIMO, the number of streams to be used for the user allocated to the Resource Unit.
- *MCS level per layer*: The modulation and coding rate to be used on each layer.
- *Boosting*: The power boosting values to be used on the data and pilot subcarriers.
- *Band selection*: The location of the localized resource allocation in the frequency band.

11.8.1.1 Antenna Configuration

The ABS employs a minimum of two transmit antennas. Configurations of 2, 4 and 8 transmit antennas are supported. The AMS employs a minimum of two receive antennas.

11.8.1.2 Layer to Stream Mapping

Layer to stream mapping is performed by the MIMO encoder. 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 as specified in equation (2).

$$\mathbf{s} = \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_M \end{bmatrix}, \quad (2)$$

where, s_i is the *i*-th input symbol within a batch.

Layer to stream mapping of the input symbols is done in the spatial dimension first. The output of the MIMO encoder is an $M_t \times N_F$ MIMO STC matrix as given by equation (3), which serves as the input to the precoder.

$$x = S(s), \quad (3)$$

where, M_t is the number of streams, N_F is the number of subcarriers occupied by one MIMO block, x is the output of the MIMO encoder, s is the input layer vector, $S(s)$ is an STC matrix, and

$$\mathbf{x} = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,N_F} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,N_F} \\ \vdots & \vdots & \ddots & \vdots \\ x_{M_t,1} & x_{M_t,2} & \cdots & x_{M_t,N_F} \end{bmatrix} \quad (4)$$

For SU-MIMO transmissions, the STC rate is defined as in equation (5)

$$R = \frac{M}{N_F} \quad (5)$$

For MU-MIMO transmissions, the STC rate per layer (R) is equal to 1.

There are three MIMO encoder formats (MEF):

- Space-frequency block coding (SFBC)
- Vertical encoding (VE)
- Horizontal encoding (HE)

For SU-MIMO, MIMO encoding allows for spatial multiplexing and transmit diversity transmission schemes. Spatial multiplexing MIMO employs vertical encoding within a single layer (codeword). Transmit diversity employs either vertical encoding with a single stream, or space-frequency block coding. For MU-MIMO, horizontal encoding of multiple layers (codewords) is employed at the base-station, while only one stream is transmitted to each mobile station.

For open-loop transmit diversity with SFBC encoding, the input to the MIMO encoder is represented by 2 × 1 vector.

$$\mathbf{s} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} \quad (6)$$

The MIMO encoder generates the SFBC matrix.

$$\mathbf{x} = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \quad (7)$$

where $\mathbf{x}$ is 2x2 matrix. The SFBC matrix, $\mathbf{x}$, occupies two consecutive subcarriers.

For horizontal encoding and vertical encoding, the input and the output of the MIMO encoder is represented by an $M \times 1$ vector.

$$\mathbf{x} = \mathbf{s} = \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_M \end{bmatrix} \quad (8)$$

where, s_i is the i-th input symbol within a batch.

For vertical encoding, $s_1 \ldots s_m$ belong to the same layer (codeword).
For horizontal encoding, $s_1 \ldots s_m$ belong to different layers (codewords).

The number of streams depends on the MIMO encoder as follows:

- For open-loop and closed-loop spatial multiplexing SU-MIMO, the number of streams is $M_t \leq \min(N_T, N_R)$, where M_t is no more than 8. N_T and N_R are the numbers of transmit and receive antennas, respectively.
- For open-loop transmit diversity, M_t depends on the space-time coding scheme 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 8 Tx antennas.

11.8.1.3 Stream to Antenna Mapping

Stream to antenna mapping is performed by the precoder. The output of the MIMO encoder is multiplied by an Nt×Mt precoder, W. The output of the precoder is denoted by an Nt×NF matrix, z, as in equation (9).

$$\mathbf{z} = \mathbf{W}\mathbf{x} = \begin{bmatrix} z_{1,1} & z_{1,2} & \cdots & z_{1,N_F} \\ z_{2,1} & z_{2,2} & \cdots & z_{2,N_F} \\ \vdots & \vdots & \ddots & \vdots \\ z_{N_t,1} & z_{N_t,2} & \cdots & z_{N_t,N_F} \end{bmatrix}, \quad (9)$$

where, N_t is the number of transmit antennas, N_F is the number of subcarriers occupied by one MIMO block and $z_{j,k}$ is the output symbol to be transmitted via the j-th physical antenna on the k-th subcarrier.

Non-adaptive precoding and adaptive precoding are supported:

- Non-adaptive precoding is used with OL SU MIMO and OL MU MIMO modes.
- Adaptive precoding is used with CL SU MIMO and CL MU MIMO modes.

For non-adaptive precoding on a given subcarrier k, the matrix W_k is selected from a predefined unitary codebook. W_k changes every $u \cdot P_{SC}$ subcarriers and every v subframes, in order to provide additional spatial diversity. The values of u and v depend on the MIMO scheme and type of resource unit.

For adaptive precoding, the form and derivation of the assembled precoding matrix, $W_f=[w_{1,f} \ldots w_{K,f}]$, is vendor-specific. The precoding vector on the f-th subcarrier for the j-th stream, $w_{j,f}$, is derived at the BS from the feedback of the AMS. Beamforming is enabled with this precoding mechanism. If the columns of the assembled precoding matrix are orthogonal to each other, it is defined as unitary precoding. Otherwise, it is defined as non-unitary precoding. Non-unitary precoding is only allowed with CL MU-MIMO.

In the downlink closed-loop SU-MIMO and MU-MIMO, all demodulation pilots are precoded in the same way as the data, regardless of the number of transmit antennas, allocation type and MIMO transmission mode. The precoding matrix is signaled to the AMS via precoding of the demodulation pilots.

11.8.2 Transmission for Data Channels

11.8.2.1 Downlink MIMO Modes

There are five MIMO transmission modes for unicast DL MIMO transmission as listed in Table 7.

Mode index	**Description**	**MIMO encoding format (MEF)**	**MIMO precoding**
Mode 0	OL SU-MIMO	SFBC	non-adaptive
Mode 1	OL SU-MIMO (SM)	Vertical encoding	non-adaptive
Mode 2	CL SU-MIMO (SM)	Vertical encoding	adaptive
Mode 3	OL MU-MIMO (SM)	Horizontal encoding	non-adaptive
Mode 4	CL MU-MIMO (SM)	Horizontal encoding	adaptive

Table 7: Downlink MIMO modes

The allowed values of the parameters for each DL MIMO mode are shown in Table 8.

	Number of transmit antennas	**STC rate per layer**	**Number of streams**	**Number of subcarriers**	**Number of layers**
	N_t	R	M_t	N_F	L
MIMO mode 0	2	1	2	2	1
	4	1	2	2	1
	8	1	2	2	1
MIMO mode 1 and MIMO mode 2	2	1	1	1	1
	2	2	2	1	1
	4	1	1	1	1
	4	2	2	1	1
	4	3	3	1	1
	4	4	4	1	1
	8	1	1	1	1
	8	2	2	1	1
	8	3	3	1	1
	8	4	4	1	1
	8	5	5	1	1
	8	6	6	1	1
	8	7	7	1	1
	8	8	8	1	1
MIMO mode 3 and MIMO mode 4	2	1	2	1	2
	4	1	2	1	2
	4	1	3	1	3
	4	1	4	1	4
	8	1	2	1	2
	8	1	3	1	3
	8	1	4	1	4

Table 8: Downlink MIMO Parameters

M_t refers to the number of streams transmitted to one MS with MIMO modes 0, 1, and 2. M_t refers to the total number of streams transmitted to multiple MS on the same RU with MIMO modes 3 and 4.

All MIMO modes and MIMO schemes are supported in either distributed or localized resource mapping. Table 9 shows permutations supported for each MIMO mode. The definitions of DRU, mini-band based CRU, and subband based CRU, are in subclause 11.5.

	DRU	Mini-band based CRU (diversity allocation)	Mini-band and Subband based CRU (localized allocation)
MIMO mode 0	Yes	Yes	No
MIMO mode 1	Yes, with M_t=2	Yes	Yes
MIMO mode 2	No	Yes, with M_t=1	Yes
MIMO mode 3	No	No	Yes
MIMO mode 4	No	Yes	Yes

Table 9: Supported permutation for each Downlink MIMO mode

Mini-band based CRU diversity allocation represents resource allocation composed of non-contiguous minibands.

11.8.2.2 Open-Loop Region

An M_t-stream open-loop region is defined to allow for base stations coordination of their open-loop MIMO transmissions. Only a limited set of OL MIMO modes are allowed for transmission in the open-loop region. There is no limitation to the use of any OL MIMO mode outside the OL region.

The allowed MIMO modes in the open-loop region are:

- In 1-stream open-loop region: MIMO mode 1 (M_t = 1 stream)
- In 2-stream open-loop region: MIMO mode 0 and MIMO mode 1 (M_t = 2 streams)
- In 2-stream open-loop region: MIMO mode 3 (M_t = 2 streams)

A resource in the open-loop region is associated with a specific set of parameters:

- Number of streams M_t
- Resource unit (e.g. subframe, frequency partition, LRU)
- MIMO mode

All base stations that are coordinated over the same open loop region should use the same number of streams, in order to guarantee low interference fluctuation and thus improve the CQI prediction at the AMS. All pilots are precoded by non-adaptive precoding with M_t streams in the open-loop region. CQI measurements should be taken by the AMS on the precoded demodulation pilots rather than on the downlink reference signals.

11.8.2.3 Single-user MIMO (SU-MIMO)

Single-user MIMO (SU-MIMO) schemes are used to improve the link performance, by providing robust transmissions with spatial diversity, or large spatial multiplexing gain and peak data rate to a single AMS, or beamforming gain.

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

For open-loop SU-MIMO, both spatial multiplexing and transmit diversity schemes are supported. In the case of open-loop SU-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. CQI and rank feedback may or may not be frequency dependent.

For closed-loop SU-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. CQI, PMI, and rank feedback may or may not be frequency dependent.

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

11.8.2.4 Multi-user MIMO (MU-MIMO)

Multi-user MIMO (MU-MIMO) schemes are used to enable resource allocation to communicate data to two or more AMSs. MU-MIMO enhances the 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. Both unitary and non-unitary MU-MIMO linear precoding techniques are supported.

For open-loop MU-MIMO, CQI and preferred stream index feedback may be transmitted to assist the base station's scheduling, transmission mode switching, and rate adaptation. The CQI is frequency dependent.

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

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

11.8.2.4.1 Feedback and Control Signaling Support for SU-MIMO and MU-MIMO

For MIMO operation with downlink closed-loop precoding in FDD and TDD systems, unitary codebook based feedback is supported. In TDD systems, uplink sounding based downlink precoding is also supported.

The base codebook is optimized for both correlated and uncorrelated channels. A codebook is a unitary codebook if each of its matrices consists of columns of a unitary matrix.

In FDD systems and TDD systems, a mobile station may feedback some of the following information for supporting SU-MIMO and MU-MIMO transmissions:

- STC rate (Wideband or sub-band) for SU-MIMO
- Sub-band selection
- CQI (Wideband or sub-band, per layer)
- PMI (Wideband or sub-band for serving cell and/or neighboring cell)
- Long-term CSI, including an estimate of the transmitter spatial correlation matrix

For CQI feedback, the mobile station measures the downlink reference signal or the demodulation pilots in the allocated resource unit, 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. For MU-MIMO, the CQI is calculated at the mobile station assuming that the interfering users are scheduled by the serving base station using rank-1 precoders orthogonal to each other and orthogonal to the rank-1 precoder represented by the reported PMI.

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

- λ The standard mode: the PMI feedback from an AMS represents an entry of the base codebook. It is sufficient for the base station to determine a new precoder.
- λ The transformation mode: The PMI feedback from an AMS represents an entry of the transformed base codebook according to long term channel information.
- λ The differential mode: the PMI feedback from an AMS represents an entry of the differential codebook or an entry of the base codebook at PMI reset times. The feedback from a MS provides a differential knowledge of the short-term channel information. This feedback represents information that is used along with other feedback information known at the BS for determining a new precoder.

An AMS supports the standard and transformation modes and may support the differential mode.

A unique base codebook is employed for SU and MU MIMO feedback. The MU MIMO codebook can be configured as the full set or as a subset of the base codebook to support both unitary and non-unitary precoding. The codebook subsets (including the full set of the base codebook) to be used for feedback are explicitly or implicitly indicated by the BS. The transformation and differential feedback modes are applied to the base codebook or to a subset of the base codebook.

An enhanced UL sounding channel is used to feedback CSI-related information by the AMS 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 AMS antennas to enable the ABS 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 WirelessMAN OFDMA reference 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 unquantized CSI-related information can be specific to a particular specified portion of the band (narrowband feedback) or specific to the entire bandwidth (wideband feedback).

11.8.2.5 Rank and Mode Adaptation

To support the numerous radio environments for IEEE 802.16m systems, both MIMO mode and rank adaptation are supported. ABSs and AMSs may adaptively switch between DL MIMO techniques depending on parameters such as antenna configurations, system load, channel information, AMS speed and average CINR. 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.

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, AMS may request adaptation. The decision of rank and mode adaptation is made by the ABS. Semi-static adaptation occurs slowly with low feedback overhead.

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.

11.8.3 Transmission for Control Channel

11.8.3.1 Transmission for Broadcast Control Channel

A SU open-loop technique that provides diversity gain is used for the Broadcast Control Channel. The 2-stream SFBC with two transmit antennas is used for P-SFH and S-SFH transmission. For more than 2-Tx antenna configuration, P-SFH and S-SFH are transmitted by 2-stream SFBC with precoding, which is decoded by the AMS without any information on the precoding and antenna configuration.

11.8.3.2 Transmission for Unicast Control Channel

The 2-stream SFBC is used for the Downlink Unicast Control Channel.

11.8.4 Advanced Features

11.8.4.1 Multi-BS 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 are supported. 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-BS 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 11.8.1 are used for E-MBS. Support for SCW and MCW is FFS. No closed loop MIMO scheme is supported in E-MBS.

11.9 Uplink Control Structure

11.9.1 Uplink 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.

11.9.1.1 Channel Quality Feedback

Channel quality feedback provides information about channel conditions as seen by the AMS. This information is used by the ABS 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 wideband and/or narrowband spatial characteristics of the channel that are required for MIMO operation. The MIMO mode, precoder matrix index, rank adaptation information, 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 in MIMO transmission 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. Reference signals for measuring and adjusting the uplink timing offset are used for these purposes.

11.9.1.5 Bandwidth Request

Bandwidth requests are used to provide information about the needed uplink bandwidth to the ABS. Bandwidth requests are transmitted through indicators or messages. A bandwidth request indicator notifies the ABS of a UL grant request by the AMS sending the indicator. Bandwidth request messages can include information about the status of queued traffic at the AMS such as buffer size and quality of service, including QoS identifiers.

11.9.1.6 E-MBS Feedback

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

E-MBS may employ a common uplink channel which is used by AMSs to transmit feedback. E-MBS feedback transmission through a dedicated channel is FFS. If a predefined feedback condition is met, a NACK is transmitted through a common E-MBS feedback channel. The feedback condition may be configured by either the ABS or the network.

During E-MBS service initiation, a common feedback channel per E-MBS service may be allocated. The allocation of the common E-MBS feedback channel may be configured by the ABS.

11.9.2 Uplink Control Channels

The UL subframe size for transmission of control information is 6 symbols. Other UL subframe sizes for transmission of control information are FFS.

11.9.2.1 Uplink Fast Feedback Channel

The UL fast feedback channel carries channel quality feedback and MIMO feedback and BW REQ indicators.

There are two types of UL fast feedback control channels: primary fast feedback channel (PFBCH) and secondary fast feedback channels (SFBCH). The UL PFBCH carries 4 to 6 bits of information, providing wideband channel quality feedback and MIMO feedback. It is used to support robust feedback reports. The UL SFBCH carries narrowband CQI and MIMO feedback information. The number of information bits carried in the SFBCH ranges from 7 to 24. A set of predefined numbers of bits in this range is supported. The SFBCH can be used to support CQI reporting at higher code rate and thus more CQI information bits. The SFBCH can be allocated in a non-periodic manner based on traffic, channel conditions etc. The number of bits carried in the fast feedback channel can be adaptive.

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 AMS 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

The process of composing the PFBCH and SFBCH are illustrated in Figure 66 and Figure 67

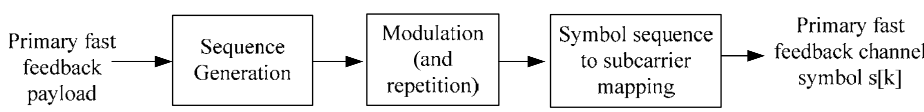

Figure 66: Mapping of information in the PFBCH.

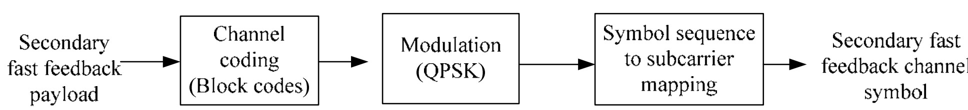

Figure 67: Mapping of information in the SFBCH.

A UL feedback mini-tile (FMT) is defined as 2 contiguous subcarriers by 6 OFDM symbols. The primary and secondary fast feedback channels comprise 3 distributed FMTs. 2 pilots in each FMT can be used for coherent detection in the SFBCH.

Figure 68 and Figure 69 illustrate the symbol mapping of the PFBCH and SFBCH respectively.

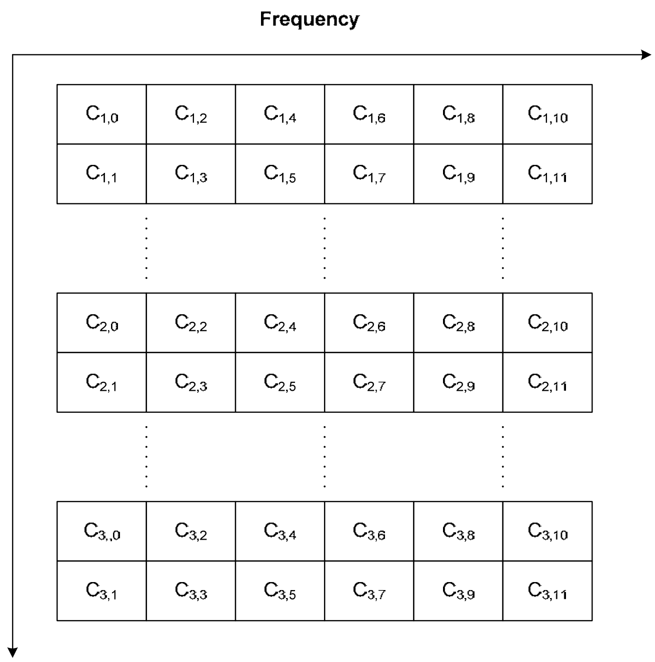

Figure 68: PFBCH comprising three distributed 2x6 UL FMTs

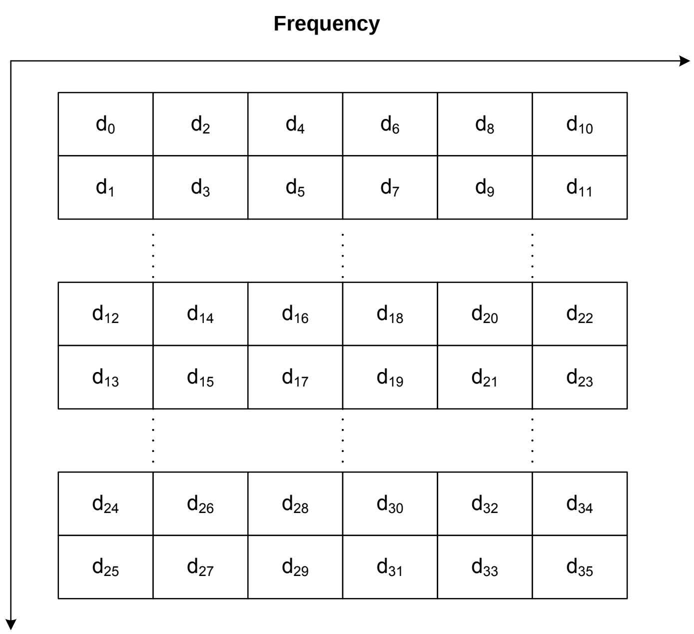

Figure 69: SFBCH comprising of three distributed 2x6 UL FMTs.

11.9.2.2 Uplink 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.

TDM/FDM or TDM/CDM is used to multiplex multiple HARQ feedback channels.

11.9.2.2.2 PHY Structure

The UL HARQ feedback channel comprises three distributed UL feedback mini-tiles (FMT), where the UL FMT is defined as 2 contiguous subcarriers by 6 OFDM symbols.

A total resource of 3 distributed 2x6 UL FMTs supports 6 UL HARQ feedback channels. The 2x6 UL FMTs are further divided into UL HARQ mini-tiles (HMT). A UL HARQ mini-tile has a structure of 2 subcarriers by 2 OFDM symbols as illustrated in Figure 70.

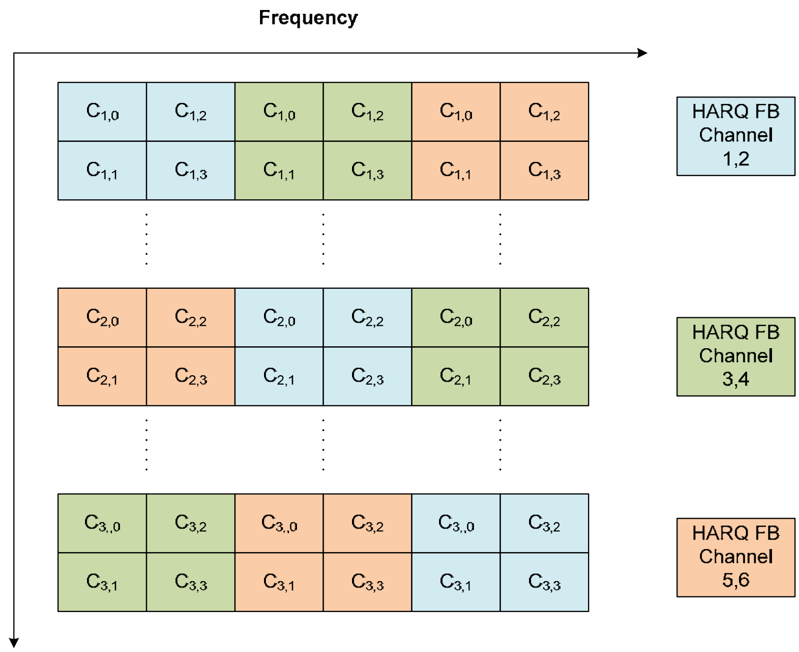

Figure 70: 2x2 HMT Structure

11.9.2.3 Uplink Sounding Channel

The UL sounding channel is used by an AMS to send a sounding signal for MIMO feedback, channel quality feedback and acquiring UL channel information at the ABS. The sounding channel occupies specific UL sub-bands or whole UL OFDMA symbol(s).

11.9.2.3.1 Multiplexing with Other Control Information and Data

The ABS can configure an AMS to transmit an UL sounding signal on specific UL sub-bands or across the whole UL band. The sounding signal is transmitted over predefined subcarriers within the intended sub-bands. The periodicity of the sounding signal for each AMS is configurable.

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

11.9.2.3.2 Multiplexing Sounding Feedback for Multiple Users

The ABS can configure multiple AMSs to transmit UL sounding signals on the corresponding UL sounding channels. The UL sounding channels from multiple users or multiple antennas per user can be CDM, FDM, or TDM.

Strategies for combating inter-cell-interference may be utilized to improve the sounding performance.

11.9.2.3.2.1 Opportunistic UL Sounding

Opportunistic UL sounding may be needed for sounding channel quality. The usage of opportunistic UL sounding and the details of the scheme used are FFS.

11.9.2.3.3 Uplink Sounding Channel Power Control

Power control for the UL sounding channel is supported to manage the sounding quality. Each AMS's transmit power for UL sounding channel may be controlled separately according to its sounding channel target CINR value. The details of power control scheme are FFS.

11.9.2.3.4 PHY Structure

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

11.9.2.4 Ranging Channel

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 Ranging Channel for Non-Synchronized Mobile Stations

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

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

11.9.2.4.1.2 PHY Structure

The physical ranging channel for non-synchronized mobile stations consists of three parts: 1) ranging cyclic prefix (RCP), 2) ranging preamble (RP) and 3) guard time (GT). The length of RCP is not shorter than the sum of the maximum channel delay spread and round trip delay (RTD) of supported cell size. The length of GT is not also shorter than the RTD of supported cell size. The length of the ranging preamble is equal to or longer than RCP length of ranging channel. The details on the length of each part and its configurations are FFS. To support large cell sizes, the ranging channel for non-synchronized AMSs can span multiple concatenated subframes.

The physical resource of ranging channel for non-synchronized mobile stations is consecutive Nr_{sc} ranging subcarriers ($BW_{RCH\text{-}NS}$ Hz corresponding to continuous Nr_{ru} CRUs) and Nr_{sym} OFDMA symbols ($T_{RCH\text{-}NS}$ sec). As a default configuration, Nr_{sc} and Nr_{sym} are equal to [TBD] ranging subcarriers and N_{sym} OFDMA symbols, respectively, where N_{sym} depends on the subframe type as described in Section 11.6.

Figure 71 shows the default ranging channel structure spanning one subframe. The ranging preamble is repeated as a single opportunity. Only one instance of the ranging preamble with an RCP can be used by different non-synchronized AMS for increasing ranging opportunities. When the preamble is repeated as a single opportunity, the second RCP can be omitted for coverage extension. The guard subcarriers are reserved at the edge of non-synchronized ranging channel(s) physical resource. CDM allows multiple AMSs to share the same ranging channel. The details of the ranging structure within the localized resource are FFS. In the TDD mode, the GT can be omitted for extending the length of RCP.

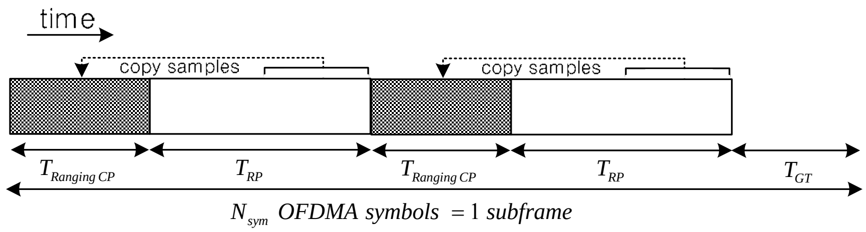

Figure 71: Default ranging structure for non-synchronized AMSs

Support for multi-antenna transmission is FFS. In the LZone with PUSC non-contiguous resource for ranging channel may be considered

11.9.2.4.2 Ranging Channel for Synchronized Mobile Stations

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

11.9.2.4.2.1 Multiplexing with Other Control channels and Data Channels

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

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

11.9.2.4.2.2 PHY Structure

The ranging sequence design and mapping to subcarriers are TBD. Support for multi-antenna transmission is FFS.

11.9.2.5 Bandwidth Request Channel

Contention based random access is used to transmit bandwidth request information on this control channel. Prioritized bandwidth requests are supported on the bandwidth request channel. The mechanism for such prioritization is TBD.

The random access based bandwidth request procedure for MZone or LZone with AMC is described in Figure 72. In these cases, a 5-step regular procedure (step 1 to 5) or an optional 3-step 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, AMS sends a bandwidth request indicator and a message for quick access that may indicate information such as AMS addressing and/or request size (FFS) and/or uplink transmit power report (FFS), and/or QoS identifiers (FFS), and the ABS may allocate uplink grant based on certain policy. The 5-step regular procedure is used independently or as a fallback mode for the 3-step bandwidth request quick access procedure. The AMS may piggyback additional BW REQ information along with user data during uplink transmission (step 5). Following Step 1 and Step 3, ABS may acknowledge the reception of bandwidth request. If AMS does not receive any acknowledgement or UL grant, it waits until the expiration of a pre-defined period and restarts the bandwidth request. The pre-defined period may be differentiated by factors such as QoS parameters (e.g. scheduling type, priority, etc). In case BW is granted immediately, there is no need for ABS to send an explicit acknowledgment.

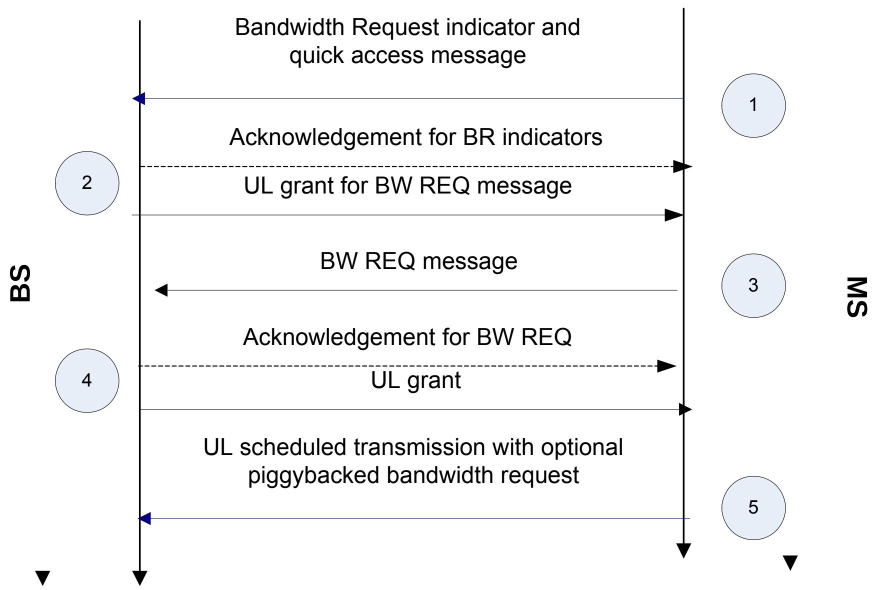

Figure 72: Bandwidth request procedure in the MZone or the LZone with AMC

The bandwidth request procedure for LZone with PUSC is described in Figure 73. In LZone with PUSC, only a 5-step regular procedure is supported. In step 1, AMS sends a bandwidth request indicator only. The rest of LZone with PUSC bandwidth request procedure shall be the same as the 5-step procedure in Figure 72.

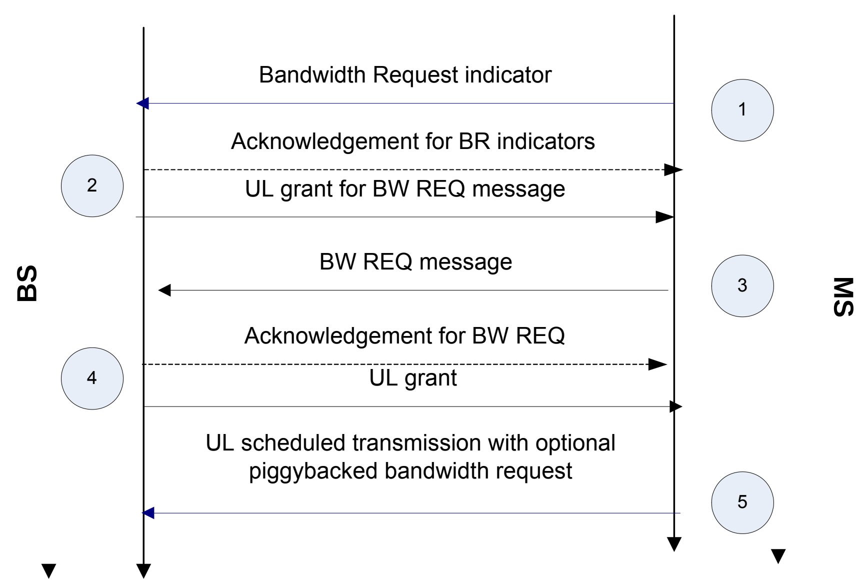

Figure 73: Bandwidth request procedure in the LZone with PUSC

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 bandwidth request (BW REQ) channel contains resources for the AMS to send a BW REQ access sequence and an optional quick access message at the step-1 of the bandwidth request procedure shown in Figure 72. In the LZone with PUSC, a BW REQ tile is defined as 4 contiguous subcarriers by 6 OFDM symbols. The number of BW REQ tiles per BW REQ channel is 3. Each BW REQ tile carries BW REQ access sequence only.

In the MZone, a BW REQ tile is defined as 6 contiguous subcarriers by 6 OFDM symbols. Each BW REQ channel consists of 3 distributed BW-REQ tiles. Each BW REQ tile carries a BW REQ access sequence and a BW REQ message. The AMS may transmit the access sequence only and leave the resources for the quick access message unused.

CDM allows multiple bandwidth request indicators to be transmitted on the same BW REQ channel. In addition, multiple BW REQ channels may be allocated per subframe using FDM.

11.9.3 Uplink 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 Uplink Control Information to Uplink Control Channels

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

Table 10: UL Control Channel Mapping

11.10 Power Control

The power control scheme is supported for DL and UL based on the frame structure, DL/UL control structures, and fractional frequency reuse (FFR).

11.10.1 Downlink Power Control

The ABS should be capable of controlling the transmit power per subframe and per user. With downlink power control, each user-specific information or control information would be received by the AMS with the controlled power level. DL Advanced MAP (A-MAP) should be power controlled based on AMS 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 this is done jointly for the users sharing the pilots.

Power Control in DL supports SU-MIMO and MU-MIMO applications.

11.10.2 Uplink Power Control

Uplink power control is supported to compensate the path loss, 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 is aiming at enhancing the overall system performance and reducing of battery consumption. Uplink power control consists of two different modes: open-loop power control (OLPC) and closed-loop power control (CLPC). ABS can transmit necessary information through control channel or message to AMSs to support uplink power control. The parameters of power control algorithm are optimized on system-wide basis by the ABS, and broadcasted periodically or trigged by events.

AMS can transmit necessary information through control channel or message to the ABS to support uplink power control. ABS can exchange necessary information with neighbor ABSs 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 is 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 ABS. The AMS can determine the transmit power based on the transmission parameters sent by the ABS, uplink channel transmission quality (e.g. indicated as ACK or NACK), 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 ABS link target SINR and/or target Interference to other cells/sectors. In order to achieve target SINR, the serving ABS 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 for each frequency partition are determined and broadcasted by ABS, 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 commands from ABS. Base station measures uplink channel state information and interference information using uplink data and/or control channel transmissions and sends power control commands to AMSs while minimizing signaling overhead.

According to the power control command from ABS, AMS 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 AMS measurements and ABS corrections for efficient operations. Closed loop power control is active during data and control channel transmissions. Both CLPC and OLPC could be active during data transmission. AMS could be in either CLPC or OLPC mode. The AMS could request to change the power control mode from open-loop to closed-loop and vice versa. The ABS could also send the unsolicited power control mode change command to the AMS.

11.11 Link Adaptation

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

11.11.1 Downlink Link Adaptation

11.11.1.1 Adaptive Modulation and Channel Coding Scheme

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

11.11.2 Uplink Link Adaptation

11.11.2.1 Adaptive Modulation and Channel Coding Scheme

IEEE 802.16m supports the adaptive modulation and channel coding (AMC) scheme for UL transmission. The serving ABS can adapt the modulation and coding scheme (MCS) level based on the UL channel quality estimation and the maximum transmission power by AMS. The definition of UL channel quality 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

IEEE 802.16m system should support the transmission format used in WirelessMAN OFDMA reference 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 Uplink MIMO Transmission Scheme

11.12.1 Uplink MIMO Architecture and Data Processing

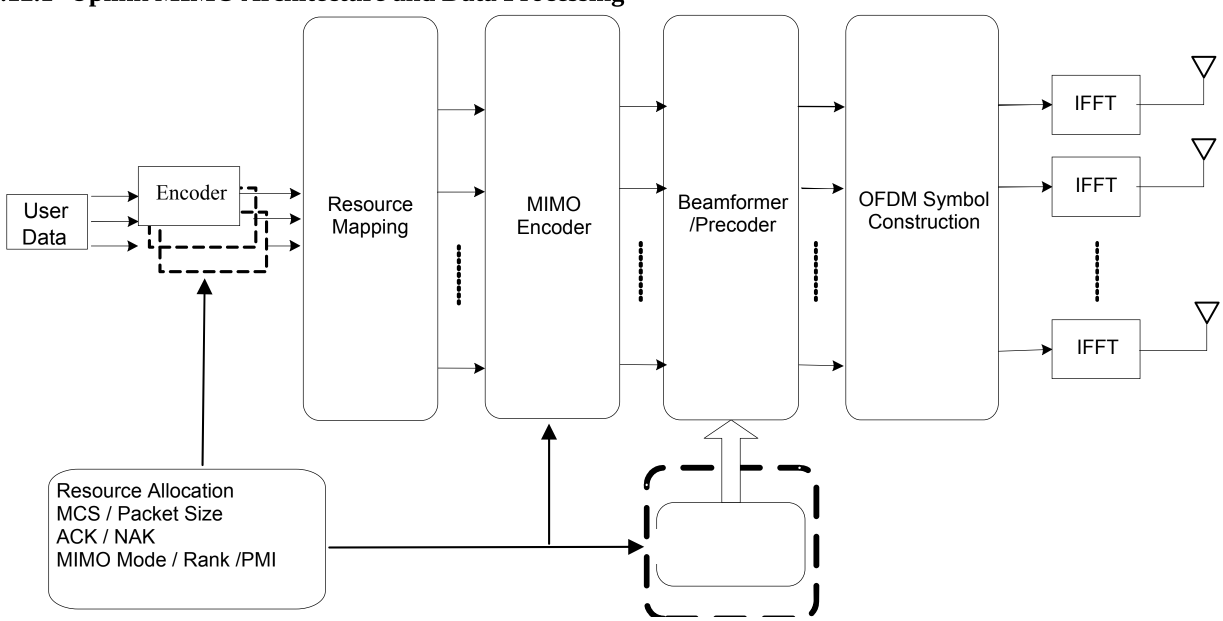

Figure 74: UL MIMO Architecture

The architecture of uplink MIMO on the transmitter side is illustrated in Figure 74.

The MIMO Encoder block maps a single layer (L=1) layers onto Mt (Mt ≥L) streams, which are fed to the Precoder block. A layer is defined as a coding and modulation path fed to the MIMO encoder as an input. A stream is defined as an output of the MIMO encoder which is passed to the precoder.

For SU-MIMO and Collaborative spatial multiplexing, only one FEC block exists in the allocated RU (vertical MIMO encoding at transmit side).

The Precoder block maps stream(s) to antennas by generating the antenna-specific data symbols according to the selected MIMO mode.

The MIMO encoder and precoder blocks are omitted when the MS has one transmit antenna.

Decisions with regards to each resource allocation include:

- *Allocation type*: Whether the allocation 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*: 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 to be used on each layer.
- *Boosting*: The power boosting values to be used on the data and pilot subcarriers.
- *Band selection*: The location of the localized resource allocation in the frequency band.

11.12.1.1 Antenna Configuration

The antenna configurations are denoted by (N_T, N_R) where N_T denotes the number of AMS transmit antennas and N_R denotes the number of ABS receive antennas. Antenna configurations of N_T = 1, 2, or 4 and $N_R \geq 2$ are supported.

11.12.1.2 Layer to Stream Mapping

There are two MIMO encoder formats (MEF) on the uplink:

- Space-frequency block coding (SFBC)
- Vertical encoding (VE)

Uplink SU-MIMO transmit processing is the same as on the downlink as described in Section 11.8.1.2. Uplink MU-MIMO is performed by transmit processing with vertical encoding at each AMS.

The number of streams depends on the MIMO encoder as follows:

- For open-loop and closed-loop spatial multiplexing SU-MIMO, the number of streams is $M_t \leq \min(N_T, N_R)$, where M_t is no more than 4. N_T and N_R are the number of transmit antennas at the AMS and the number of receive antennas at the ABS.
- For open-loop transmit diversity, M_t depends on the space-time coding scheme employed by the MIMO encoder.
- MU-MIMO can have up to 4 streams. The number of streams allocated to one user is not limited to 1. SFBC encoding is not allowed at the MS with uplink MU-MIMO transmissions.

11.12.1.3 Stream to Antenna Mapping

There is no precoding if there is only one transmit antenna at the MS.

Non-adaptive precoding and adaptive precoding are supported on the uplink:

- Non-adaptive precoding is used with OL SU MIMO and OL MU MIMO modes.
- Adaptive precoding is used with CL SU MIMO and CL MU MIMO modes.

For non-adaptive precoding on a given subcarrier k, the matrix Wk is selected from a predefined unitary codebook. Wk changes every $u \cdot PSC$ subcarriers and every v subframes, in order to provide additional spatial diversity. The values of u and v depend on the MIMO scheme and type of resource unit.

For adaptive precoding, the precoder W is derived at the BS or at the MS, as instructed by the BS. With 2Tx or 4Tx at the MS in FDD and TDD systems, unitary codebook based adaptive precoding is supported. In this mode, a MS transmits a sounding signal on the uplink to assist the precoder selection at the BS. The BS then signals the uplink precoding matrix index to be used by the MS in the a downlink control message. With 2Tx or 4Tx at the MS in TDD systems, adaptive precoding based on the measurements of downlink reference signals is supported. The MS chooses the precoder based on the downlink measurements. The form and derivation of the precoding matrix does not need to be known at the BS.

In uplink SU-MIMO and MU-MIMO, all demodulation pilots are precoded in the same way as the data regardless of the number of transmit antennas, allocation type and MIMO transmission mode.

11.12.2 Transmission for Data Channels

11.12.2.1 Uplink MIMO Modes

There are five MIMO transmission modes for unicast UL MIMO transmission as listed in Table 11

Mode index	Description	MIMO encoding format (MEF)	MIMO precoding
Mode 0	OL SU-MIMO	SFBC	non-adaptive
Mode 1	OL SU-MIMO (SM)	Vertical encoding	non-adaptive
Mode 2	CL SU-MIMO (SM)	Vertical encoding	adaptive
Mode 3	OL Collaborative spatial multiplexing (MU-MIMO)	Vertical encoding	non-adaptive
Mode 4	CL Collaborative spatial multiplexing (MU-MIMO)	Vertical encoding	adaptive

Table 11: Uplink MIMO modes

The allowed values of the parameters for each UL MIMO mode are listed in Table 12.

	Number of transmit antennas	STC rate per layer	Number of streams	Number of subcarriers	Number of layers
	N_t	R	M_t	N_F	L
MIMO mode 0	2	1	2	2	1
	4	1	2	2	1
MIMO mode 1 and MIMO mode 2	2	1	1	1	1
	2	2	2	1	1
	4	1	1	1	1
	4	2	2	1	1
	4	3	3	1	1
	4	4	4	1	1
MIMO mode 3 and MIMO mode 4	2	1	1	1	1
	4	1	1	1	1
	4	2	2	1	1
	4	3	3	1	1

Table 12: Uplink MIMO Parameters

M_t refers to the number of streams transmitted by one MS.

All MIMO modes and MIMO schemes are supported in either Distributed or Localized resource mapping. The following table shows the permutations supported for each MIMO mode. The definition of tile based DRU, mini-band based CRU, and subband based CRU are in 15.3.8.

	Tile based DRU	Mini-band based CRU (diversity allocation)	Mini-band based CRU Sub-band based CRU (localized allocation)
MIMO mode 0	Yes	Yes	No
MIMO mode 1	Yes, with $M_t \leq 2$	Yes	Yes
MIMO mode 2	Yes, with $M_t \leq 2$	Yes	Yes
MIMO mode 3	Yes, with $M_t=1$	Yes	Yes
MIMO mode 4	Yes, with $M_t=1$	Yes	Yes

Table 13: Supported permutation for each Uplink MIMO mode

11.12.2.2 Single-user MIMO (SU-MIMO)

SU-MIMO schemes are used to improve the link performance in the uplink, by providing robust transmission with spatial diversity, or large spatial multiplexing gain and peak data rate to a single AMS, or beamforming gain.

Both open-loop SU-MIMO and closed-loop SU-MIMO are supported for the antenna configurations specified in Section 11.12.1.1. Both spatial multiplexing and transmit diversity schemes are supported with open-loop SU-MIMO. Transmit precoding and beamforming are supported with closed-loop SU-MIMO.

11.12.2.3 Multi-user MIMO (MU-MIMO)

Uplink MU-MIMO is supported to enable spatially multiplexing of multiple AMSs on the same radio resources (e.g. the same time and the same frequency allocation) for uplink transmission.

11.12.2.3.1 Open-loop MU-MIMO

AMSs with a single transmit antenna are supported in open-loop MU-MIMO transmissions.

AMSs with multiple transmit antennas are also supported in open-loop MU-MIMO transmissions. Uplink open-loop SU-MIMO spatial multiplexing modes of all rates, and transmit diversity mode with rank 1, are supported in open loop MU-MIMO for AMSs with more than one transmit antenna. In this case, non-adaptive precoding is performed at the AMS. SFBC is not supported with OL MU MIMO transmissions.

The ABS is responsible for scheduling users and the number of transmitted streams such that it can appropriately decode the received signals according to the number of transmitted streams and the number of receive antennas. The total number of transmitted streams does not exceed the number of receive antennas at the ABS.

11.12.2.3.2 Closed-loop MU-MIMO

Unitary codebook based precoding is supported for both TDD and FDD. In this case, the AMS follows indication of PMI from the ABS 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.

11.12.2.3.3 Feedback and Control Signaling Support for SU-MIMO and MU-MIMO

Channel state information may be obtained in TDD and FDD by the following methods:

- Downlink reference signals. These reference signals support measurements at the AMS of the channel from the physical antennas of the ABS.
- A downlink control channel may carry information computed based on uplink reference signals. Such information can include but is not limited to MIMO mode and PMI.

The ABS may transmit some or all of the following uplink MIMO transmission parameters: 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.

A unique codebook supports both CL SU MIMO and CL MU MIMO codebook-based transmissions.

In FDD systems and TDD systems, a mobile station may transmit a sounding signal to assist the operation of uplink CL SU-MIMO and CL MU-MIMO.

11.13 Channel Coding and HARQ

11.13.1 Channel Coding

11.13.1.1 Block Diagram

Figure 75 shows the channel coding and modulation procedures. The following sections provide more details on the coding and modulation procedures in the IEEE 802.16m transmit chain.

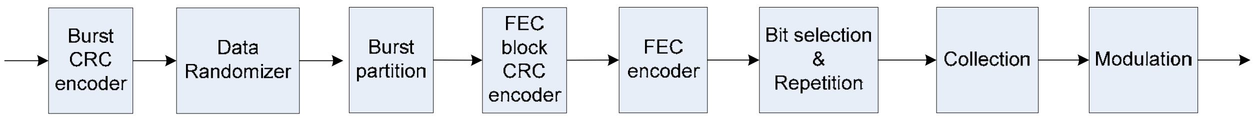

Figure 75: Chanel coding procedure

11.13.1.2 Partition into FEC Blocks

A burst CRC is appended to a burst before the burst is further processed by burst partition. The 16-bit burst CRC is calculated based on all the bits in the burst. When the burst size including burst CRC exceeds the maximum FEC block size, the burst is partitioned into K_{FB} FEC blocks, each of which is encoded separately. If a burst is partitioned into more than one FEC blocks, an FEC block CRC is appended to each FEC block before the FEC encoding. The FEC block CRC of an FEC block is calculated based on all the bits in that FEC block. Each partitioned FEC block including 16-bit FEC block CRC has same length. The maximum FEC block size is 4800 bits. 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).

11.13.1.3 FEC Encoding

IEEE 802.16m uses the CTC (convolutional turbo code) of code rate 1/3 defined in the IEEE Std 802.16-2009 standard for data bursts. The structure of the IEEE Std 802.16-2009 CTC interleaver is maintained. The use of other coding schemes like CC and LDPC are FFS.

The FEC encoder block depicted in Figure 57 includes the sub-block interleavers. The structure of the IEEE Std 802.16-2009 sub-block interleaver is maintained.

11.13.1.4 Bit Selection and Repetition

Bit selection and repetition are used in IEEE 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 total subcarriers in the allocated LRU are segmented to each FEC block. Mother Code Bits, the total number of information and parity bits generated by FEC encoder, are considered as a maximum size of circular buffer. In case that the size of the circular buffer N_{buffer} is smaller than the number of Mother Code Bits, the first N_{buffer} bits of Mother Code Bits are considered as selected bits. Repetition is performed when the number of transmitted bits is larger than the number of selected bits. 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 WirelessMAN OFDMA reference 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 11.13.2.2 and depends on the MIMO stream. QAM Symbols are mapped to the input of the MIMO encoder.

11.13.1.6 Modulation and Coding Set

Only the burst size NDB listed in Table 14 are supported in the physical layer. The sizes include the addition of CRC (per burst and per FEC block) when application. Other sizes require padding to the next burst size. The code rate and modulation depend on the burst size and the resource allocation.

idx	N_{DB} *(byte)*	K_{FB}	*idx*	N_{DB} *(byte)*	K_{FB}	*idx*	N_{DB} *(byte)*	K_{FB}
1	6	1	23	90	1	45	1200	2
2	8	1	24	100	1	46	1416	3
3	9	1	25	114	1	47	1584	3
4	10	1	26	128	1	48	1800	3
5	11	1	27	145	1	49	1888	4
6	12	1	28	164	1	50	2112	4
7	13	1	29	181	1	51	2400	4
8	15	1	30	205	1	52	2640	5
9	17	1	31	233	1	53	3000	5
10	19	1	32	262	1	54	3600	6
11	22	1	33	291	1	55	4200	7
12	25	1	34	328	1	56	4800	8
13	27	1	35	368	1	57	5400	9
14	31	1	36	416	1	58	6000	10
15	36	1	37	472	1	59	6600	11
16	40	1	38	528	1	60	7200	12
17	44	1	39	600	1	61	7800	13
18	50	1	40	656	2	62	8400	14
19	57	1	41	736	2	63	9600	16
20	64	1	42	832	2	64	10800	18
21	71	1	43	944	2	65	12000	20
22	80	1	44	1056	2	66	14400	24

Table 14: Burst sizes

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. Chase Combining is supported and treated as a special case of IR. The 2-bit SPID is used to indicate the starting position.

11.13.2.2 Constellation Re-arrangement

Constellation re-arrangement (CoRe) is supported in IEEE 802.16m. The CoRe can be expressed by a bit-level interleaver within a tone. Two CoRe versions are supported.

11.13.2.3 Adaptive HARQ

The resource allocation and transmission formats in each retransmission in the downlink can be adaptive according to control signaling. The resource allocation in each retransmission in the uplink can be fixed or adaptive according to control signaling.

11.13.2.4 Exploitation of Frequency Diversity

In HARQ re-transmissions, the bits or symbols can be transmitted in a different order to exploit the frequency diversity of the channel.

11.13.2.5 MIMO HARQ

For HARQ 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 HARQ IR. In this case, the predefined set of mapping patterns should be known to both transmitter and receiver.

11.13.2.6 Aggressive HARQ Transmission

In DL HARQ, the ABS may transmit coded bits exceeding current available soft buffer capacity.

11.13.2.7 ARQ Feedback

IEEE 802.16m supports a basic ACK/NACK channel to transmit 1-bit feedback.

12 Support for Location Based Services

The IEEE 802.16m system supports MAC and PHY features needed for accurate and fast estimation and reporting of AMS location. Such location capabilities defined in IEEE 802.16m when combined with appropriate network level support allows enhanced location based services as well as emergency location services, such as E911calls.

In addition to native location capabilities the system also supports additional timing and frequency parameters needed to assist GPS or similar satellite based location solutions.

12.1 Location Based Services Overview

Location determination can be made by either:

- AMS managed location, in which the mobile measures, calculates and uses the location information with minimal interaction with the network
- Network managed location, in which the location is determined by the network and the network reports the location to requesting entities. The location process may be triggered by the network or the application on the AMS.

IEEE 802.16m supports basic MAC and PHY features to support both use cases, with or without use of GPS or equivalent satellite based location solution.

The service can be provided to:

- The end user providing the AMS with value added services
- External emergency or lawful interception services.
- The network operator using the location information for network operation and optimization

IEEE 802.16m system entities will support LBS applications by providing them with:

- Relevant measurements, periodic or event driven
- Resources (time and frequency slots) to perform the relevant measurements
- Communication channels (unicast and broadcast), as allocated to higher layer applications of any type.

It should be emphasized that the actual implementation of the LBS application or method of location determination is out of the scope of IEEE 802.16m.

In order to enhance location based service, AMS should send report location-related information which includes the location information or the measurement for determining location in response to the request of ABS . In addition, LBS is supported for AMS in connected state as well as idle state. For the connected state, AMS can report location information when it is needed. For the idle state, AMS should perform network re-entry to report location information when it is needed.

The AMS positioning is performed by using measurement methods, such as TDOA, TOA, AOA, and etc., whose relevant location-related parameters may include cell-ID, RSSI, CINR, RD, RTD, angle, and Spatial Channel Information. These parameters are exchanged between the AMS and its serving/attached or/and neighboring ABSs/ARSs. The measurements of these parameters are extracted by processing DL and/or UL signals at the AMS and ABSs, respectively. Positioning algorithms that depend on such measurements have certain performance tradeoffs in terms of positioning accuracy, latency, and signaling overhead. Two or more measurements can be utilized to provide higher accuracy estimate of the AMS position.

12.1.1 LBS Network Reference Model

LBS architecture is a functional model consistent with the WiMAX network reference model (NRM) [15]. LBS architecture is shown in. The architecture has support for

- Both periodic and event based location information services
- Both user initiated and network initiated location procedure with the same functional decomposition
- Basic cell/sector based location information services
- Enhanced sub-sector location based on mobile based or network based calculation
- GPS capability detection and utilization when supported by the AMS

The end to end LBS system architecture is out of the scope of IEEE 802.16m. However the standard supports underlying MAC and PHY features to allow location related measurement and signaling both in the control plane and in the user plane.

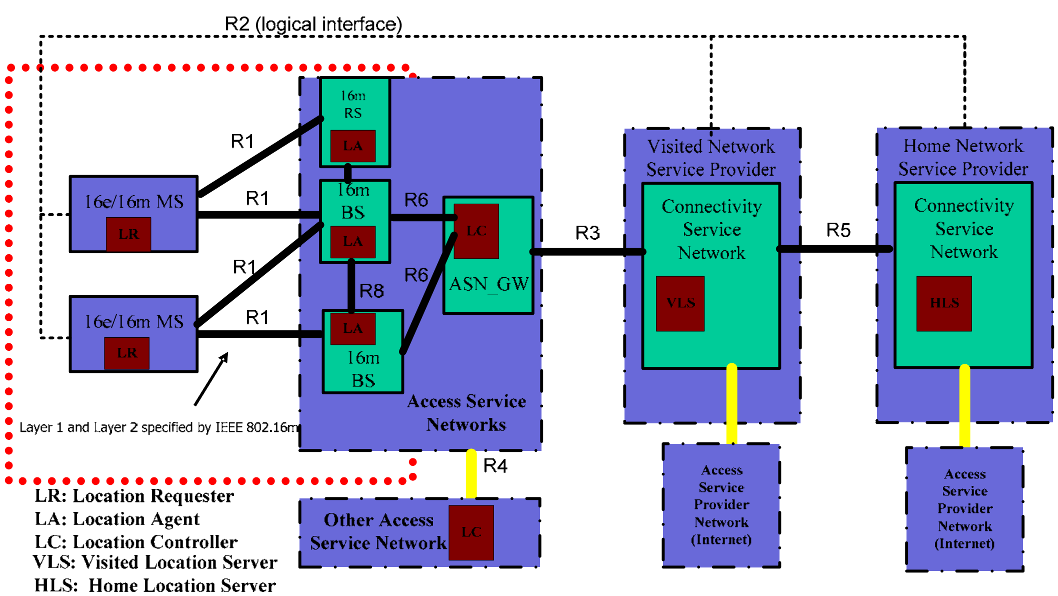

Figure 76: LBS Network Reference Model

12.1.2 LBS Applications

A user is subscribed to a set of LBS applications. Applications differ by the type of service they provide, the location determination technique they use, and where the LBS system elements reside. An LBS application is defined by the following:

1. List of subscribed AMSs.
2. Type of 802.16m PHY measurements Also by the measurement update rate and triggering event.
3. communication channels it needs (unicast downlink and/or uplink, multicast or broadcast)
4. QoS requirement (priority, data rate, latency) for each requested uplink and downlink channel.

12.2 Location Determination Methods for LBS

12.2.1 GPS-Based Method

An AMS, which is equipped with GPS capability can utilize IEEE 802.16m MAC and PHY features to estimate its location when GPS is not available, e.g. indoors.

12.2.1.1 Assisted GPS (A-GPS) Method

Assisted GPS (A-GPS), consisting of the integrated GPS receiver and network components, assists a GPS device to speed up GPS receiver "cold startup" procedure. In order to achieve this goal, the ABS provides the IEEE 802.16m AMS with the GPS Almanac and Ephemeris information downloaded from the GPS satellites. By having accurate, surveyed coordinates for the cell site towers, the ABS can also provide better knowledge of ionospheric conditions and other errors affecting the GPS signal than the device alone, enabling more precise calculation of position.

12.2.2 Non-GPS-Based Method

Non-GPS-Based methods rely on the role of the serving and neighboring ABSs/ARSs. LBS related measurements may be supported in the DL and UL as follows.

a) Location Measurements in Downlink

In DL, the AMS receives signals which are existing signals (e.g. preamble sequence) or new signals designed specifically for the LBS measurements, if it is needed to meet the requirement from the serving/attached ABS and multiple neighboring ABSs/ARSs. The ABSs/ARSs are able to coordinate transmission of their sequences using different time slots or different OFDM sub-carriers.

b) Location Measurements in Uplink

Various approaches can be utilized at the serving/attached ABS/ARS to locate the AMS such as TOA and AOA. These measurements are supported via existing UL transmissions (e.g. ranging sequence) or new signals designed specifically for the LBS measurements.

The ARSs support a set of PHY and MAC features to assist serving ABS in LBS and may be used in cooperation with serving ABS and other ARS to make LBS measurements. In addition to TDOA measurements the ARSs support Round Trip Delay(RTD)/Time of arrival (TOA) measurements using DL and UL frame resources, which may be designated for to LBS purposes. Optionally ARSs may perform AOA measurements.

12.2.3 Hybrid Methods

Hybrid method combines at least two kinds of measurement methods to perform location estimation.
Furthermore, GPS can combine with non-GPS-based schemes, such as TDOA and AOA, to provide accurate location estimation in different environments.

For the combination methods, measurement-based scheme, such as TDOA and TOA, can be consolidated to estimate AMS's position. The measurement can be executed by the different trigger modes, such as pre-request, periodic, and event-trigger, to meet the requirements of different LBS applications.

12.2.3.1 AMS Assisted Positioning

Hybrid method may be implemented by combination of measurement-based methods or AMS assisted positioning method.

For AMS assisted positioning method, the GPS position (if capable) and ranging signal measurements reported from assisting AMSs, and ranging signal measurements at ABSs (such as TDOA and AOA) are utilized to determine the location of a positioned AMS. AMS assisted positioning is optional for AMS. An AMS capable of participating as an assisting MS should signal the capability to ABS. A GPS capable AMS assisting ABS to locate the non-GPS AMS's is disabled by default.

12.3 Reporting Methods for LBS

For E911 services, the AMS location can be reported to ABS through UL inband signaling. Other reporting methods are FFS.

12.3.1 Reporting Types

According to the measurement methods of LBS, some location information or some LBS measurement parameters such as CINR/RSSI/RD/RTD/Angle are transmitted to the ABS to measure the location.

12.3.2 Reporting Mode

An AMS supported LBS reports location information if any of following location information reporting condition is met.
-Timer based location information reporting
-Threshold based location information reporting

An LBS-capable AMS should support the following reporting modes: per-request, periodic, and event-triggered reporting modes. The event-triggered reporting mode is a variation of the periodic reporting mode with reporting criteria, such as a moving distance threshold and updated timer expiration. For example, the AMS will report the location when the distance between the current location and the last reported location beyond the "moving distance threshold".

12.4 LBS Operation

IEEE 802.16m utilizes protocols carried in user plane for transferring location information (e.g. GPS assistance, position information, WiMAX measurements) between an AMS and the location server. IEEE 802.16m may utilize a service flow, with needed QoS, for transferring location information.

12.4.1 Connected State

The system should be able to locate the mobile when in connected state.

For connected state, LBS can be initiated by the ABS or the AMS. LBS message contains some LBS information, which may include identifier of the AMS, and indicator of LBS measurement method. Other associated parameters for LBS measurement are FFS. Indicator of LBS measurement is used to instruct the ABS and/or the AMS to perform LBS measurement and report location information.

12.4.2 Idle State

The system should be able to locate the mobile when in idle state. The ABS may use paging or other network initiated multicast signaling to initiate a location process on the AMS.

The AMS in idle mode can receive a paging message which may include identifier of the AMS and indicator for LBS measurement method; other associated parameters for LBS measurement are FFS. AMS should perform network re-entry and LBS measurement with attached ABS and neighbor ABSs. When AMS gets LBS measurement parameters, AMS may report them as location information to attached ABS.

13 Support for Enhanced Multicast Broadcast Service

13.1 General Concepts

Enhanced multicast and broadcast services (E-MBS) are point-to-multipoint communication systems where data packets are transmitted simultaneously from a single source to multiple destinations. The term broadcast refers to the ability to deliver contents to all users. Multicast, on the other hand, refers to contents that are directed to a specific group of users that have the associated subscription for receiving such services.

Both Static and Dynamic Multicast are supported.

The E-MBS content is transmitted over an area identified as a zone. An E-MBS zone is a collection of one or more ABSs transmitting the same content. The contents are identified by the same identifiers (IDs). Each ABS capable of E-MBS service can belong to one or more E-MBS zones. Each E-MBS Zone is identified by a unique E-MBS_Zone ID.

An AMS can continue to receive the E-MBS within the E-MBS zone in Connected State or Idle State. The definitions of E-MBS service area and E-MBS region are being studied.

An ABS may provide E-MBS services belonging to different E-MBS zones (i.e. the ABS locates in the overlapping E-MBS zone area).

E-MBS data bursts may be transmitted in terms of several sub-packets, and these sub-packets may be transmitted in different subframe and to allow AMSs combining but without any acknowledgement from AMSs.

AMSs in an E-MBS zone are allocated a common Multicast STID (MSTID).

13.1.1 Relationship to Basic MBS in Reference System

The basic concepts and procedures in E-MBS are consistent with MBS definitions in the IEEE Std 802.16-2009, however, the concepts have been adapted to the new MAC and PHY structure.

E-MBS refers to a data service offered on multicast connection using specific MBS features in MAC and PHY to improve performance and operation in power saving modes. An ABS may allocate simple multicast connections without using E-MBS features.

13.2 E-MBS Transmission Modes

Two types of access to E-MBS may be supported: single-ABS access and multi-ABS access. The single-ABS access is implemented over multicast and broadcast transport connections within one ABS, whereas multi-ABS access is implemented by transmitting data from service flow(s) over multiple ABSs. The E-MBS content PDUs are transmitted by all ABSs in the same E-MBS zone. That transmission is supported either in the non-macro diversity mode or macro diversity mode. An E-MBS zone may be formed by only one ABS. The AMS may support both single-ABS and multi-ABS access. E-MBS service may be delivered via either a dedicated carrier or a mixed unicast-broadcast carrier.

13.2.1 Non-Macro Diversity Support

Non-macro diversity support is provided by frame level coordination in which the transmission of data across ABSs in an E-MBS Zone is not synchronized at the symbol level. However, such transmissions are coordinated to be in the same frame. This MBS transmission mode is supported when macro-diversity is not feasible.

13.2.2 Macro Diversity Support

The macro diversity operating mode for E-MBS is as a wide-area multi-cell multicast broadcast single frequency network (MBSFN). A single-frequency network (SFN) operation can be realized for broadcast traffic transmitted using OFDMA from multiple cells with timing errors within the cyclic prefix length. An MBS zone with SFN is illustrated in Figure 77.

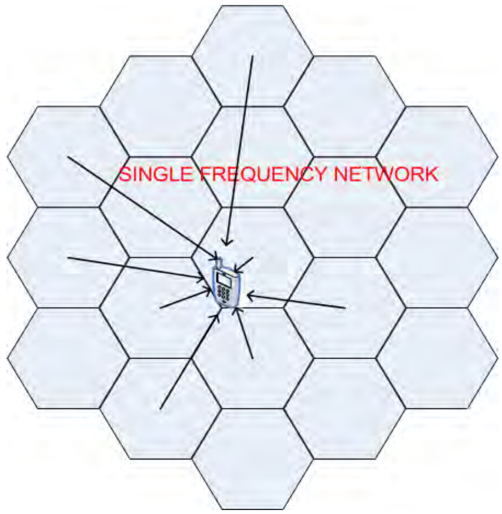

Figure 77: A single frequency network where multiple ABSs transmit the same content.

The transmission of data across ABSs in a multi-ABS E-MBS Zone is synchronized at the symbol level allowing macro-diversity combining of signals and higher cell edge performance. It requires the multiple ABS participating in the same Multi-ABS-MBS service to be synchronized in the transmissions of common multicast/broadcast data. Each ABS transmits the same PDUs, using the same transmission mechanism (symbol, subchannel, modulation, and etc.) at the same time.

13.3 E-MBS Operation

13.3.1 E-MBS Operation in Connected State

Details on E-MBS Operation in Connected State are being studied.

13.3.2 E-MBS Operation in Idle State

An idle AMS is notified for the commencement of a certain E-MBS service the AMS has subscribed to including emergency broadcast. Not all E-MBS services require notification.
Details on E-MBS Operation in Idle State are being studied.

13.3.3 E-MBS Operation with Retransmission

The use of HARQ (retransmissions) with E-MBS operation is FFS. An ABS may use a network-coding based retransmission scheme that does not require a feedback channel. Other schemes requiring feedback channels are being studied.

13.3.4 E-MBS Operation with Link Adaptation

The use of link adaptation in E-MBS operation is being studied.

13.4 E-MBS Protocol Features and Functions

13.4.1 E-MBS PHY Support

13.4.1.1 Multiplexing of Unicast Data and E-MBS Data

IEEE 802.16m supports E-MBS data multiplexing on a mixed carrier, using both TDM and FDM multiplexing schemes for unicast and E-MBS traffic. When the E-MBS data is time division multiplexed with unicast data, the E-MBS and unicast data are carried in different subframes. When the E-MBS data is frequency division multiplexed with unicast data, the PRU resources in units of N2 PRUs are partitioned into two sets; one meant for unicast data and the other for E-MBS data. Following time or frequency division multiplexing of the unicast of E-MBS data, the subchannelization of unicast and E-MBS data is done independently.

13.4.1.2 Enhanced Schemes

13.4.1.3 Frame and Control Channel Structure

In unicast/multicast mixed carrier, E-MBS uses the same frame structure used for unicast carrier. The E-MBS data is multiplexed with Unicast traffic. The S-SFH indicates E-MBS region which may span over multiple subframes for each E-MBS zone. If a superframe contains E-MBS subframes, E-MBS subframes are allocated with fixed pattern within superframe. The pattern may vary between superframes. Figure 78 illustrates the frame structure when E-MBS subframes are present in superframes.

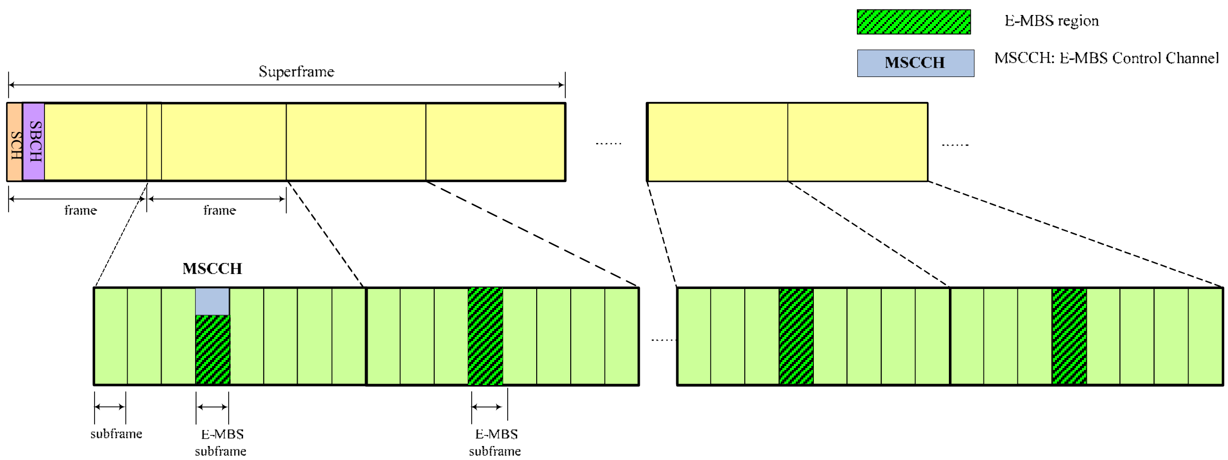

Figure 78: Illustration for E-MBS support in Mixed Broadcast/Unicast Carrier

For unicast/multicast mixed carrier, the control channel design to support E-MBS is as follows

- S-SFH
  - Provides pointers to help AMS find the location of the E-MBS MAP.

- E-MBS MAP (E-MBS Service Control Channel)
  - Indicates physical layer parameters of E-MBS data channels for each service using joint coding.
  - E-MBS MAP is transmitted at the beginning of E_MBS resource during one E-MBS scheduling interval.
  - The E-MBS MAP can point to burst locations up to N superframes ahead within the E-MBS scheduling interval.

13.4.2 E-MBS MAC Support

13.4.2.1 E-MBS Zone Configuration

Each E-MBS zone is assigned a unique zone ID. All the ABSs in an E-MBS zone broadcast the same E-MBS zone ID. If an ABS belongs to several E-MBS zones, it broadcasts the entire set of zone IDs with which it is associated. Multiple E-MBS zones or multiple E-MBS services of one E-MBS zone may be configured on one or more carriers in the multi-carrier deployments.

13.4.2.2 E-MBS Scheduling Interval

The E-MBS scheduling interval can span several superframes. The length of the E-MBS scheduling interval may be constrained by the required channel switching times. For each E-MBS Zone there is an E-MBS Scheduling Interval (MSI), which refers to a number of successive frames for which the access network may schedule traffic for the streams associated with the E-MBS Zone prior to the start of the interval. The length of this interval depends on the particular use case of E-MBS. E-MBS MAP addresses the mapping of E-MBS data associated with an E-MBS Zone for the entire MSI. The E-MBS MAP message is structured such that it may be used to efficiently define multiple transmission instances for a given stream within an MSI.

13.4.2.3 Mapping of E-MBS Data for Power Saving

An AMS decodes only the E-MBS data bursts associated with user selected content. The AMS wakes up in each E-MBS scheduling interval in order to check whether there is data to be decoded. To facilitate power saving mechanism, the ABS includes an indication of the next E-MBS data transmission (e.g. in the S-SFH or through the E-MBS MAP). This results in the maximum power saving in E-MBS service. After decoding the E-MBS data bursts, the AMS returns to sleep mode (see Figure 79).

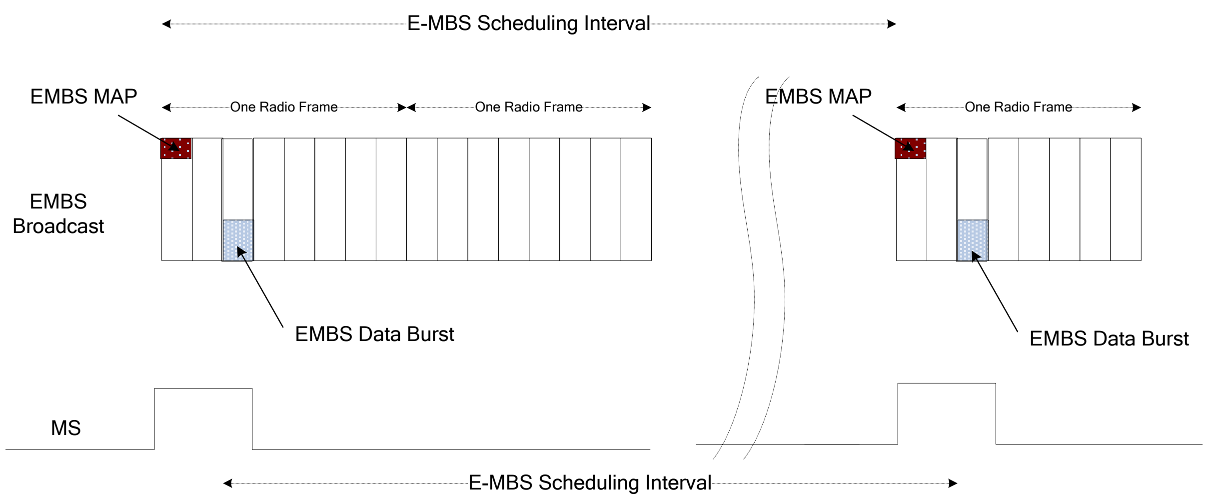

Figure 79: Illustration of E-MBS power saving

13.4.2.4 E-MBS Mobility Management

When an AMS moves across the E-MBS zone boundaries, it can continue to receive E-MBS data from the ABS in Connected State or Idle State. In Connected State, the AMS performs handover procedure for E-MBS.

During E-MBS zone transition in Idle State, the AMS may transit to Connected State to perform handover or it may initiate E-MBS location update process for the purpose of E-MBS zone transition unless the AMS already has the MSTID mappings in the target E-MBS zone.

13.4.3 E-MBS CS Layer Support

13.4.3.1 Header Compression

13.4.3.2 Forward Error Correction

The Convergence Sublayer provides forward error correction (FEC), which complements the FEC provided by the PHY layer. The FEC provided by the convergence sublayer takes advantage of extended time diversity and deeper interleaving in order to achieve adequate IP packet error rates.

13.5 E-MBS Transmission on Dedicated Broadcast Carriers

The E-MBS traffic could be transmitted in a dedicated carrier, or a unicast/E-MBS mixed carrier.

13.5.1 Deployment Mode for E-MBS Transmission on Dedicated Broadcast Carrier

IEEE 802.16m system may designate the carriers for E-MBS only.

13.5.2 E-MBS Dedicated Carrier

E-MBS data can be transmitted in broadcast only carrier. In this case a fully configured unicast or unicast/E-MBS mixed carrier could be used to provide signaling support needed for service initiation, and additions and terminations as well as other service and security related exchanges between the AMS and the ABS or the E-MBS servers in the network. The Broadcast Only carrier, may be transmitted at higher power and be optimized for improve performance.

The multi-carrier AMS which is capable of processing multiple radio carriers at the same time may perform normal data communication at one carrier while receiving E-MBS data over another carrier. It may also receive multiple E-MBS streams from multiple carriers simultaneously.

Transmission of indications to all AMSs or those in the same paging Group on the E-MBS Dedicated Carrier is being studied.

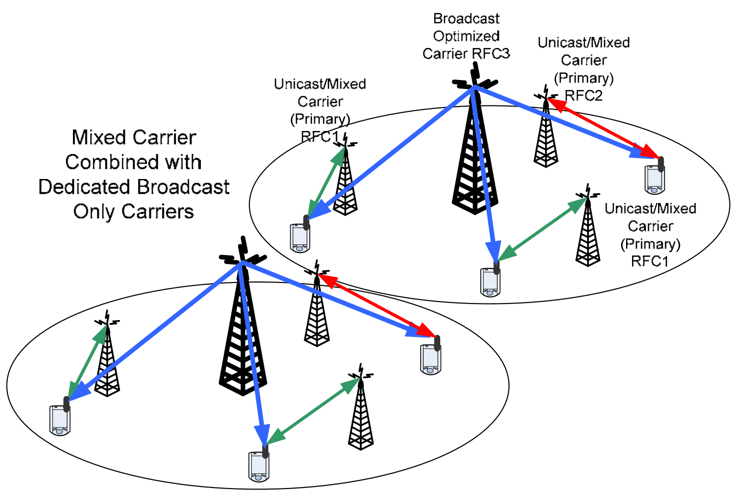

Figure 80: E-MBS deployment with broadcast only and mixed carrier

13.5.2.1 Channel Coding

IEEE 802.16m supports FEC with large block size in E-MBS. The use of LDPC is being studied.

13.6 Reusing E-MBS Transmission in IEEE Std 802.16-2009 Zones or Carriers

The E-MBS content which is transmitted to IEEE Std 802.16-2009 MSs can be accessed by IEEE 802.16m AMSs operating on the same or a different carrier.

The EMBS control signaling in the ABS indicates the availability of the service as well as contents. If the MBS content is also being transmitted to IEEE Std 802.16-2009 MSs in an E-MBS zone, the ABS may direct the AMS to the IEEE Std 802.16-2009 zone in the same carrier or other carriers if supported by the AMS.

The information provided by the ABS should be sufficient for the AMS to synchronize with the E-MBS data transmissions in a timely manner. E-MBS connection setup and updates for AMSs may be performed using E-MBS control signaling in IEEE 802.16m. AMSs in the IEEE Std 802.16-2009 zone use the connection setup mechanisms in the reference system.

14 Support for Multi-Hop Relay

14.1 Relay Model

The relay models describe the modes of relay operation supported in IEEE 802.16m. Relaying is performed using a decode and forward paradigm. The ABS and ARSs deployed within a sector operate using either time division duplexing (TDD) or frequency division duplexing (FDD) of DL and UL transmissions. An ARS operates in time-division transmit and receive (TTR) relaying mode mode.

ARSs may operate in transparent or non-transparent mode. Transparent relay is limited to the scenario where the superordinate station is a non-transparent ARS or an ABS. The ABS can support the co-existence of the transparent and the non-transparent ARSs.

Cooperative relaying is a technique whereby either the ABS and one or more ARSs, or multiple ARSs cooperatively transmit or receive data to/from one subordinate station or multiple subordinate stations. Cooperative relaying may also enable multiple transmitting/receiving stations to partner in sharing their antennas to create a virtual antenna array.

ARS may transmit data to the super-ordinate and sub-ordinate station(s) using the same LRU (e.g., MIMO, network coding, etc)

14.1.1 Zone Configuration for Supporting Transparent Relay

In the transparent ARS frame, the DL Receive Zone is located at the beginning of DL subframes, which is followed by the DL Access Zone, and UL zone configuration is the same as non-transparent ARS case. The DL subframes in the superordinate station of a transparent ARS, e.g., ABS or non-transparent ARS, starts with the DL Transmit Zone.

14.2 Scheduling Model

An ARS operates in distributed or centralized scheduling. When an ABS is configured to operate in centralized scheduling, the ABS schedules all radio resources in its cell. In distributed scheduling, each station (ABS or ARS) schedules the radio resources on its subordinate link within the radio resources assigned by the ABS. The ABS may exercise additional control over the scheduling of its ARSs.

14.3 Security Model

The ARS operates in centralized or distributed security mode.

14.4 Data and Control Functions

14.4.1 Relay Station State Diagram

The Figure 81 illustrates the Relay Station state transition diagram for an ARS. The diagram consists of three states, Initialization State, Access State, and Operational State.

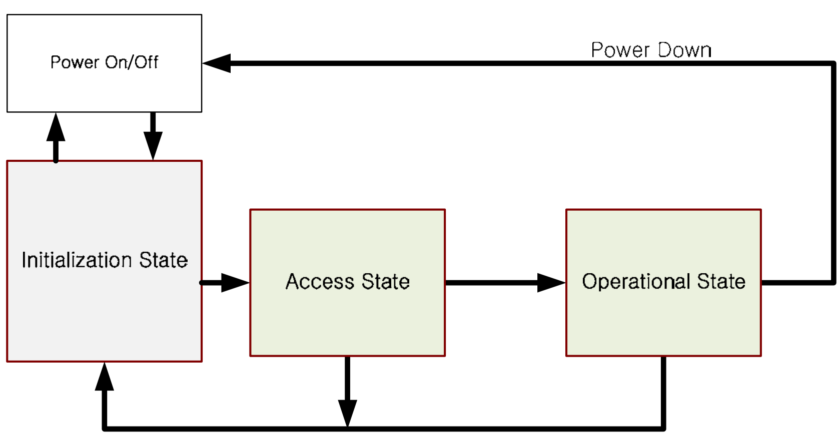

Figure 81: State Transition Diagram of IEEE 802.16m Relay Station

14.4.1.1 Initialization State

In the initialization state, the ARS performs cell selection by scanning and synchronizing to an ABS or ARS A-PREAMBLE, and acquiring the system configuration information through SFH before entering Access State. During this state, if the ARS cannot properly perform the SFH information decoding and cell selection, it should return to perform scanning and DL synchronization. If the ARS successfully decodes SFH information and selects one target ABS or ARS, it transits to the Access State.

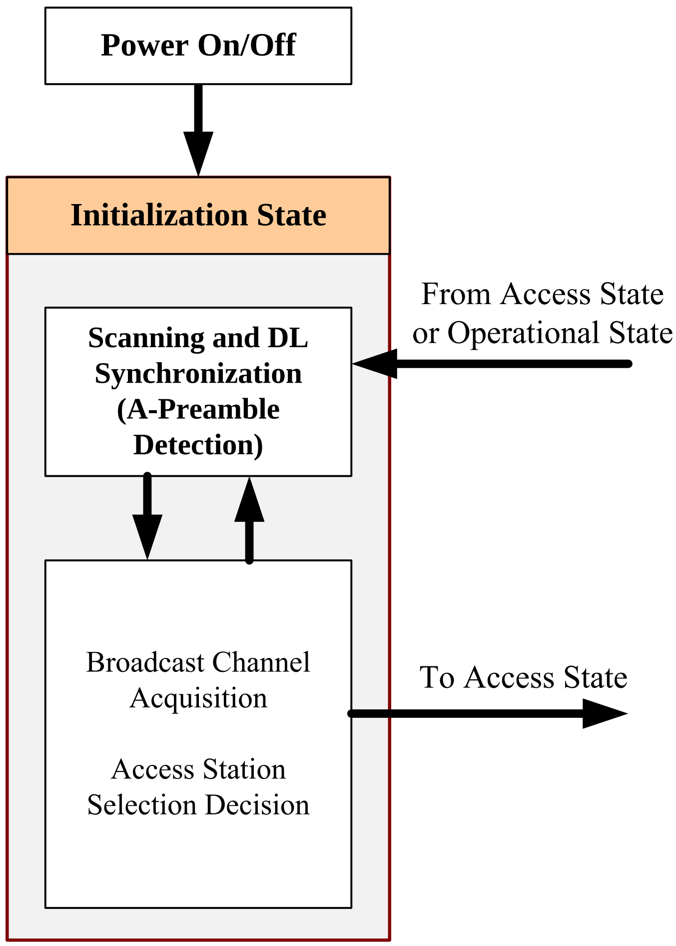

Figure 82: Procedures in the Initialization State of IEEE 802.16m Relay

14.4.1.2 Access State

The ARS performs network entry with the target ABS while in the Access state. Network entry is a multi step process consisting of ranging, pre-authentication capability negotiation, authentication and authorization, capability exchange, registration, neighbor station measurement & access station selection (optional), and ARS operation parameters configuration. The ARS receives its Station ID and transitions to the Operational state. Upon failure to complete any one of the steps of network entry the ARS transitions to the Initialization state.

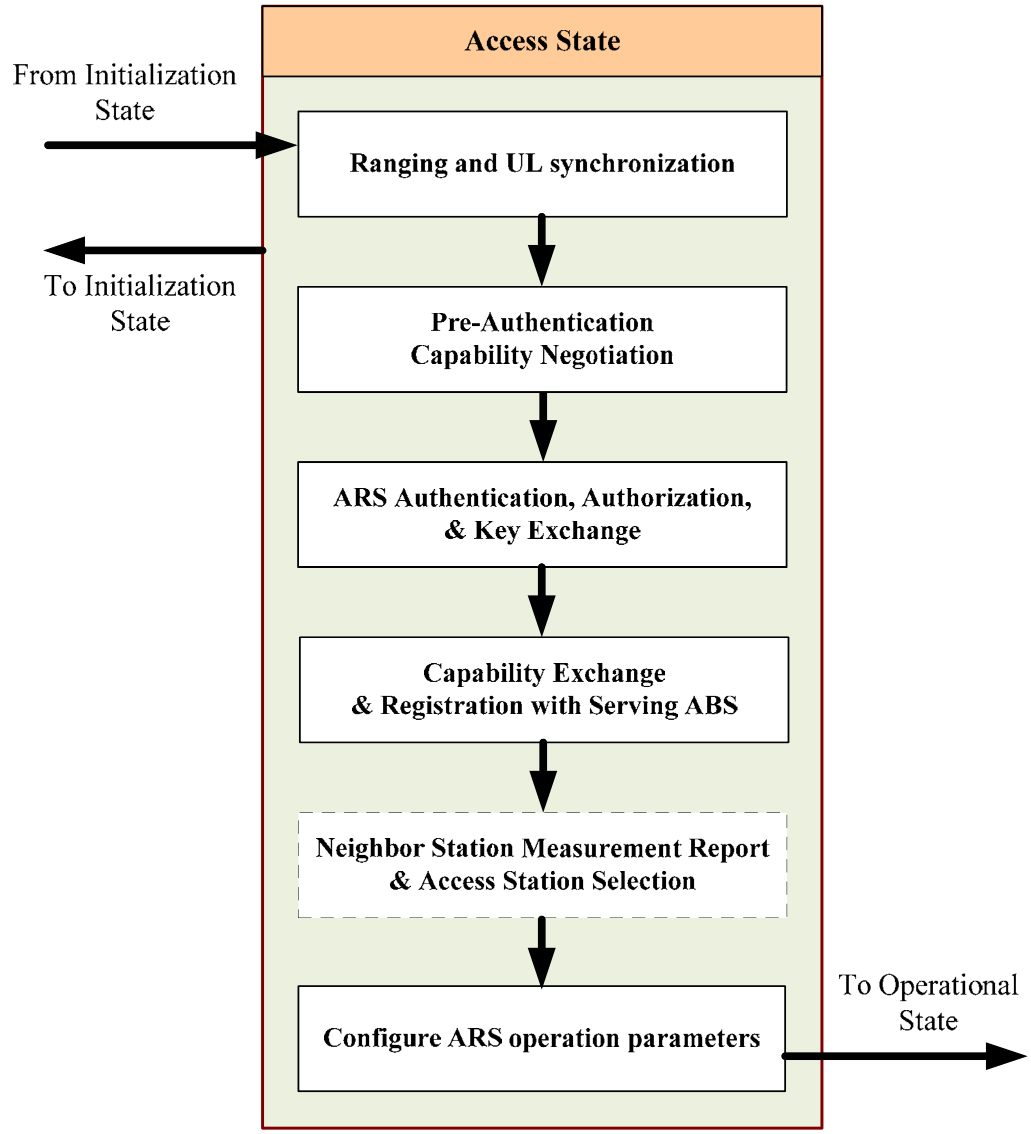

Figure 83: Procedures in the Access State of IEEE 802.16m Relay

14.4.1.3 Operational State

During Operational State, the ARS performs tasks that are required to relay the DL/UL traffic transaction between the ABS/ARS and AMS/ARS.

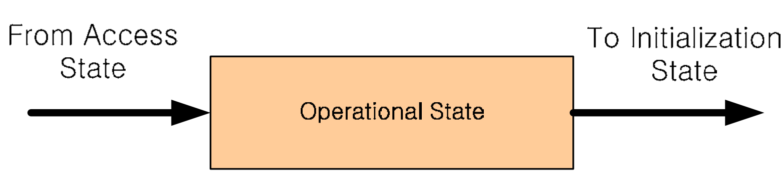

Figure 84: Procedures in the Operational State of IEEE 802.16m Relay

14.4.2 Addressing

Each ARS is uniquely identified by a STID. When tunnel mode is used, each tunnel established between an ABS and an ARS is assigned with a unique FID. The tunnel connection is uniquely identified by the combination of ARS STID and the associated FID.

The individual MPDUs from/to AMSs can be packed together in the payload of a relay MAC PDU or concatenated to a relay MAC PDU transmitted over the relay link. The STIDs for each individual MAC PDU is carried in the relay MAC PDU. The Access ARS uses the STID information carried in DL relay MAC PDU to generate A-MAP over the access link. The ABS uses the STID information carried in UL relay MAC PDU to identify which AMS the MPDU belongs to.

14.4.3 MAC PDU Construction

One or more tunnels may be established between the ABS and the access ARS after the network entry is performed. Each tunnel between an ARS and ABS is identified by a unique Flow ID. Connections of an AMS may be mapped to one or multiple tunnels.

The mode for constructing and forwarding MPDUs through a tunnel is called tunnel mode. In the tunnel mode, the MAC PDUs that traverse a tunnel are encapsulated in a relay MAC PDU with the relay MAC header carrying a tunnel identifier. Multiple MAC PDUs from connections that traverse the same tunnel can be concatenated into a relay MAC PDU for transmission.

14.4.4 Topology Discovery

An ABS determines that an AMS/an ARS sending initial ranging is directly accessing the ABS, or through an ARS. The ABS discovers topology information of all the ARS and AMS connected through it during the initial ranging.

14.4.5 ARQ mechanism

When distributed scheduling is used, The ARS may perform ARQ operation with adjacent stations (superordination and subordinate station) or the ARS may perform ARQ operation with ABS and AMS. ABS or MS shall clear the buffer when it receive ACK from MS or ABS respectively

When centralized scheduling is used, the ARS is not involved in the ARQ operation between the ABS and the AMS.

14.4.6 HARQ mechanism

When distributed scheduling is used, the ARS performs HARQ operation with adjacent stations (superordination and subordinate station)

When centralized scheduling is used, the ARS performs HARQ operation with adjacent stations, but the ARS informs HARQ burst failure information to ABS for retransmission scheduling.

14.4.7 ARS Network entry and Initialization

The ARS follows network entry and initialization procedure of AMS. Additionally, ARS may perform interference measurement of neighbor stations, path creation, and tunnel connection establishment with ABS. ARS operation parameters are obtained from access station by configuration signaling.

14.4.8 AMS Network Entry support in ARS

The network entry procedure may be distributed between the ARS and the ABS. The ARS should handle the initial link adaptation with AMS. The remaining AMS network entry procedures such as capability negotiation, connection establishment, authentication, registration are processed between AMS and ABS.

14.4.9 AMS Mobility Support

14.4.9.1 AMS Handover Support

The ABS controls the handover of AMS including scanning and network topology advertisement. The ARS only relays the MAC control signaling (e.g., HO command message and HO indication message) between the subordinate AMS and the ABS.

In the case that the same AMS's context is used between an ABS and the ABS's subordinate ARSs, the transfer of the AMS's context can be omitted when the AMS moves around under the ABS. An ARS supports its AMS's handover to other access station, when the current connection with its access station is lost or for load balancing.

14.4.9.2 AMS Idle Mode Support

The ABS is responsible for generating MAC control signaling (e.g., DREG-CMD, MOB_PAG-ADV of WirelessMAN-OFDMA Reference system) which may be relayed by an ARS to the subordinate AMS. An ARS can have the same or a subset of paging groups which are assigned to its superordinate ABS.

14.4.10 Relay Path Management

The ABS controls the path management centrally including path establishment, removal and update by explicit signaling. Path establishment can be implemented during the network entry of an ARS, and the path establishment procedure can be combined with the procedure for establishing a tunnel connection of the ARS if tunneling is allowed. The explicit path information and a uniquely assigned path ID can be included in the signaling.

When a connection for an AMS is established, the connection to path binding information can be updated along the path.

14.4.11 Interference Mitigation Support for Relay

Interference mitigation techniques described in Section 20 may also be used between the ABS and ARSs within a sector under the control of the ABS.

14.4.12 Relay Support of Multi-Carrier Operation

ARSs may support multi-carrier functionality. All operational principles for multi-carrier operation apply to a system involving ARSs unless explicitly stated otherwise. When multicarrier is enabled in an ARS, only the fully configured carriers are relayed. For a multicarrier capable AMS, all the carriers over which a service is provided to the AMS, are transmitted by the same station (ABS or ARS).

15 Support for Femtocell BS

15.1 Overview of Femtocell BS

A Femtocell BS is a BS with low transmit power, typically installed by a subscriber in home or SOHO to provide the access to closed or open group of users as configured by the subscriber and/or the access provider. A Femtocell BS is connected to the service provider's network via broadband (such as DSL, or cable). The femtocell BSs may communicate with the overlapped macrocell BS for exchanging control messages over the air-interface (e.g. via Relay Link).

Femtocell BSs typically operate in licensed spectrum and may use the same or different frequency as macro-cells. Their coverage may overlap with macro BS.

Femtocell BS is intended to serve public users, like public hot spot, or to serve CSG (Closed Subscriber Group) that is a set of subscribers authorized by the Femtocell BS owner or the service provider. CSG can be modified by the service level agreement between the subscriber and the access provider.

15.2 Femtocell BS State Diagram

Figure 85 illustrates the Femtocell BS state diagram. The state diagram contains an initialization and operational state.

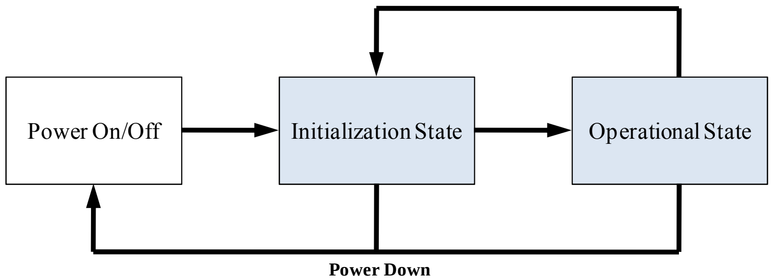

Figure 85: State transition diagram of Femtocell BSs

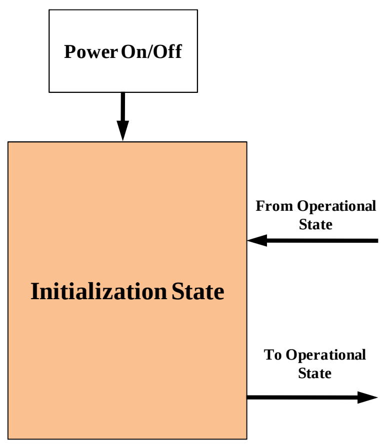

Figure 86: Femtocell BS initialization state

In the initialization state, procedures like configuration of radio interface parameters and time synchronization may be performed (Figure 86).

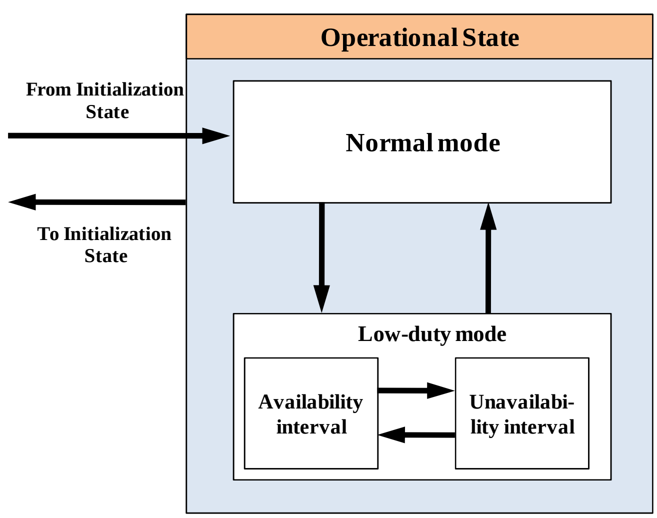

Figure 87: Femtocell BS operational state

After successfully attaching to the network, a femtocell BS enters the operational state. In the operational state, two operational modes may be supported: normal mode and low-duty mode. In the low duty mode, availability intervals alternate with unavailability intervals. See Section 15.10 for further Details.

15.3 Types of Base Stations

A Femtocell BS may belong to one of the following subscriber types.

• CSG-Closed Femtocell BS: A CSG-Closed Femtocell BS is accessible only to the MSs, which are in its CSG, except for emergency services. MSs which are not the members of the CSG, should not try to access CSG-Closed Femtocell BSs.
• CSG-Open Femtocell BS: A CSG-Open Femtocell BS is primarily accessible to the MS's that belong to its CSG, while other MS's, outside CSG, may also access such Femtocell BS, and will be served at lower priority. CSG-Open Femtocell BS will provide service to such MSs' as long as the QoS of MSs in its CSG is not compromised.
• OSG (Open Subscriber Group) Femtocell BS: An OSG Femtocell BS is accessible to any MSs.

CSG Femtocell BS refers to either CSG-Open Femtocell BS or CSG-Closed Femtocell BS.

15.4 PHY and MAC level identifier

15.4.1 PHY level cell identifier

CSG and/or OSG Femtocell BSs and macro BSs are differentiated using SA-PREAMBLE. It enables AMSs to quickly identify cells types, avoid too frequent handover attempts into and out of a Femtocell BS, and avoid performing unnecessary network entry/re-entry.

15.4.2 MAC level identifier

CSG and OSG Femtocell BSs are differentiated using MAC level identifiers to help an AMS determine its designated Femtocells vs. other Femtocells based on which it can apply necessary rules and procedures for network entry and handover in a timely fashion. A common CSGID is assigned to all the CSG Femtocell BSs which are part of the same CSG. An AMS uses this broadcasted CSGID for accessibility check for the CSG Femtocell BS.

15.4.3 CSG white list

MS maintains a CSG white List for authorized access to CSG-Closed and CSG-Open femtocell BS. The list contains the identifiers of CSG-Closed and CSG-Open femtocell BS for which MS is a CSG member.

15.5 Synchronization

A Femtocell BS should synchronize with the network to a common timing and frequency signal. Femtocell BSs may use different schemes to achieve synchronization with the network to handle various deployment scenarios. Femtocell BS may maintain synchronization with the overlay BSs over the air by utilizing low duty operation mode to synchronize with the overlay BS's A-PREAMBLE to automatically adjust its DL synchronization.

A Femtocell BS may also obtain Time and Frequency Synchronization from e.g., GPS, wired interfaces, IEEE1588, etc.

15.6 Network Entry

15.6.1 Femtocell BS Identification and Selection

At the physical layer, femtocell BS is identified as described in Section 15.4.1. At the MAC layer, femtocell BS is identified as described in Section 15.4.2.

The cell selection and reselection may prioritize towards the accessible CSG-closed Femtocell. MSs that are not members of CSG for a CSG-Closed Femtocell BSs shall not attempt network entry, handover, re-entry from idle mode, or location update to the BSs regardless of channel quality such BS's except in case of emergency call. MSs that are not members of CSG for a CSG-Open Femtocell BS's shall not attempt network entry, handover, re-entry from idle mode, or location update to the BSs unless it is critical to maintain their connection or in case of emergency call.

15.6.2 Femtocell BS Information Acquisition

Femtocell BSs have a capability to provide information (e.g. Femtocell NSP information) to MSs which do not have cached information of the Femtocell BS regardless of its subscriber group type (e.g. OSG, CSG). Femtocell BSs may broadcast such network access information of neighbor Femtocell BSs, or unicast, such system information of neighbor accessible femtocell BSs of the MS, in order for MSs to identify and select a proper Femtocell BS. MS can get system information either by scanning all available Femtocell BSs or may request such information from Femtocell BSs that are capable of delivering access information.

15.6.3 Femtocell BS Detection

A Femtocell BS may monitor DL and UL signal associated with an MS which is served by overlay macro BS. The monitoring is initiated by overlay macro BS or MS or by the Femtocell BS itself to detect the existence of the MS in its coverage. Then the Femtocell BS can inform the macro BS over the backhaul that the MS is in its coverage and subsequently handover to Femtocell BS can be accomplished.

15.6.4 Ranging Channel Configuration

Synchronized ranging channel designed for macro BS is used for initial ranging, handover ranging and periodic ranging of a femtocell. BW REQ is done in exactly the same manner as in a regular macro cell.

15.6.5 Ranging

For CSG-open femtocell, the AMSs transmit a selected ranging preambles on a selected ranging opportunity to perform contention-based ranging process based on priority. The AMS shall decide the algorithm (either random selection or random backoff) to select ranging opportunity based on their priority, eg. CSG members, which have higher priority, may use random selection, while non-CSG members, which have lower priority, may use random backoff algorithm.

15.7 Handover

The handover process of an MS between a Femtocell BS and a macro BS or between two Femtocell BSs will follow the same procedure as described in Section 10.3.2 with the exception of steps described in this section. When the Femtocell BS is going to be out of service either by instruction or by accident, it should instruct all its subordinate MSs to hand over to the neighbor macro BSs or Femtocell BSs. The MS should be able to prioritize the accessible Femtocell BSs over the macrocell BSs

15.7.1 HO from Macro BS to Femtocell BS

MS's that are not members of CSG for a CSG-Closed Femtocell BS's shall not attempt network entry or handover to the BS's regardless of channel quality such BS's except in case of emergency call.

MS's that are not members of CSG for a CSG-Open Femtocell BS's shall not attempt network entry or handover to the BS's unless it is critical to maintain their connection or in case of emergency call.

The network provides certain system information (e.g., carrier frequency of the Femtocell BS, that are located in the overlay macro BS serving area) to MSs for supporting handover between a macro BS and a Femtocell BS. An MS may cache this information for future handover to the specific Femtocell BS.

HO should be triggered based on certain criteria, such as signal strength, the proximity of MS to the Femtocell BS, and /or loading, etc. The macro BSs shall not broadcast the system information of the neighbor CSG-Closed Femtocell BSs in its neighbor list. At the time of handover preparation, the system information of a target accessible Femtocell BS may be unicast or multicast to the MS upon MS request/network trigger or obtained by the MS monitoring the Femtocell BS, or based on the cached information of the MS.

The macro BSs may unicast or broadcast certain information (e.g. Cell ID, carrier frequency etc.) of OSG/CSG Femtocell BSs to facilitate MSs scanning for Femtocell BSs. An MS may scan and report information of surrounding Femtocells BS(s) in order to receive the optimized neighbor list containing information of accessible neighbor CSG/OSG Femtocell BS(s) in the vicinity of MS. The MS may also request the accessible neighbor OSG/CSG Femtocell BSs information from the overlay macro BS when certain conditions are met.

15.7.2 HO from Femtocell BS to Macro BS or Other Femtocell BS

The set of macro BSs and/or Femtocell BSs that are the neighbor list of the serving Femtocell BS are provided by the network or cached in the MS. The serving Femtocell BS broadcasts or unicasts this list of neighbor accessible Femtocell BSs and/or macro BSs to the MS.

The handover process between Femtocell BS and macro BS or between Femtocell BS and Femtocell BS is the same as defined in Section 10.3.2 with the exceptions as defined in this subsection

When an MS successfully handovers between a Femtocell BS and a macro BS, the MS or the network may cache the information of the macro BS or the MS, respectively, to facilitate the next HO process between the macro BS and the Femtocell BS.

15.8 Load Management and Balancing

It is important to efficiently balance the load between the macro and femto BS and adapt them to network dynamics to optimize capacity and QoS. To achieve this, some traffic performance metric (load, utility, etc.) can be periodically collected from the macro and femto BS to decide on the amount of resources that can be used by the macro, micro and the femto BS. How the macro and femto BS decide to use these resources in a distributed manner is not within the scope of this document. The periodicity (semi-static nature) of such information collection could also be implementation dependent.

The femto network architecture allows for improved capacity, whereby resources allocated to macro BS can be reused by some of the femto BS. To aid in such improved reuse of resources, some geographic information on the macro resource allocation (eg. sector, zone or location of region where a macro resource is allocated to a macro MS) could be provided to the femto BS via backhaul network. This reuse of macro resources by femto BS will coexist with FFR operations.

15.9 Idle Mode

The OSG Femtocell BSs operate like macro BSs when paging an MS.

Femtocell BS shall support idle mode. The CSG-closed Femtocell BSs may broadcast the paging messages that are related to only the MSs of this CSG.

Dependent on topology design to support both Femtocell BS and macro BS, one or more PGs may be assigned to a Femtocell or a macro BS. The overlay macro BS and the Femtocell BS may share the same paging group ID.

15.10 Low-duty Operation Mode

Besides the normal operation mode, Femtocell BSs may support low-duty operation mode, in order to reduce interference to neighbor cells. The low-duty operation mode consists of available intervals and unavailable intervals. During an available interval, the Femtocell BS may become active on the air interface for synchronization and signaling purposes such as paging, transmitting system information, ranging or for data traffic transmission for the MSs. During an unavailable interval, it does not transmit on the air interface. Unavailable interval may be used for synchronization with the overlay macro BS or measuring the interference from neighbor cells.

The Femtocell BS may enter low-duty operation mode either if all MSs attached to the Femtocell BS are in idle or sleep mode, or if no MS is in the service range of the Femtocell BS at all.

In case a Femtocell BS supports both AMS and YMS, the network may signal the Femtocell BS to stop or start transmission of LZone/MZone when an YMS/AMS leaves or enters the overlay macro BS of its Femtocell BS respectively. The Femtocell BS switches between the low-duty operation mode and the normal operation mode when it receives requests from the overlay macro BS, the core network, or an MS for network entry, HO, or the exit of the sleep mode.

Macrocell/femtocell may broadcast/unicast femtocell FAs and patterns of low duty cycle over the air.

15.11 Interference Avoidance and Interference Mitigation

An MS may be requested by its serving macro BS or Femtocell BS to report the signal strength measurement of neighbor BSs, including macro and/or Femtocell BSs. The reported information can be used by the serving BS to coordinate with its neighbor BSs to mitigate the interference at the MSs. An MS experiencing large interference from a nearby CSG-Closed Femtocell BS which is not a member of the CSG may report the interference to the serving BS, and the reported information should include system information of the inaccessible CSG-closed Femtocell BS (e.g., BS_ID of the femtocell BS). The serving BS and/or the network may request the interfering Femtocell BS to mitigate the interference by reducing transmission power, and/or blocking some resource region. In order to enable the interference avoidance or mitigation schemes, the Femtocell BS shall be capable to scan the signals transmitted from neighbor BSs.

Alternatively, the interference between Femtocells and/or macro cells can be mitigated by static or semi-static radio resource reservation and resource sharing using FDM and/or TDM manner. The operation of resource reservation shall not contradict with the FFR operation defined in 20.1. A Femtocell BS may detect and reserve the resources autonomously, or in cooperation with the overlay macro BS. An MS connected to a macro BS or Femtocell BS may detect the least interfered resource from surrounding Femtocells and/or Macro BSs and report it to the serving BS, so that the serving BS may select appropriate resources for its traffic.

In order to reduce interference on the control signaling such as SFH and essential control signaling of Femtocells and/or macro BSs, different resources block arrangements may be used among Femtocells and/or macro cells for transmitting control signaling. The MS can derive the resource block arrangements for control signaling based on A-PREAMBLE.

A Femtocell BS may select the carrier frequency to avoid the mutual interference between macro/micro cells and Femtocells or among Femtocells based on the measurement result of surrounding reception power.

15.12 Femtocell-assisted LBS

If an MS is connected to a Femtocell BS, the network can figure out the location of the MS. If an MS is not connected to any Femtocell BSs, the MS may collect the information of neighbor Femtocell BSs by scanning and report to the serving macro BS. Based on the reported information from the MS, the network can determine the location of the MS.

15.13 MIMO Support

Femtocell BS may support multi-antenna techniques for improving throughput and mitigating interference performance.

15.14 Power Control

DL and UL power control shall be supported by the Femtocell BSs.

When applying transmit power control in DL and UL, the maximum transmit power for DL and UL are limited and it should take into account building penetration losses.

DL closed-loop power control shall be supported by Femtocell BS in order to reduce interference to the surrounding macro BS or neighbor Femtocell BSs.

15.15 Femtocell BS Reliability

Femtocell BS shall disable downlink air interface transmitter as soon as the connection with the service provider network is lost for a configurable pre-defined time. In such a case, Femtocell BS should support the mechanisms to ensure service continuity of the MSs prior to disabling air interface. For example, the BS initiated handover depicted in15.7. When a Femtocell BS needs disable air interface, it should send out an indication, which contains available out-of-service information such as out of service reasons and expected downtime and/or expected uptime, if it is able to do so, to prevent MS entry or reentry from other cells. Upon reception of the indication, the subordinated MSs should perform handover to neighboring cells.

15.16 Multicarrier Operation

Multi-carrier operation may be supported by Femtocell. All operational principles for multi-carrier operation apply to a system involving femtocell unless explicitly stated otherwise. Femtocell ABS may select carriers to assign activate them to for an AMS as secondary carriers and the selection of carriers is possibly made based on interference management schemes described in Section 15.11.

16 Support for Self-organization

Self Organizing Network (SON) functions are intended for BSs (e.g. Macro, Relay, Femtocell) to automate the configuration of BS parameters and to optimize network performance, coverage and capacity. The scope of SON is limited to the measurement and reporting of air interface performance metrics from MS/BS, and the subsequent adjustments of BS parameters.

16.1 Self Configuration

Self-configuration is the process of initializing and configuring BSs automatically with minimum human intervention.

16.1.1 Cell Initialization

During the cell initialization, BS MAC and PHY parameters (e.g. ranging code, RF parameters) may be downloaded from the core networks automatically, or determined by the BS itself.

16.1.2 Neighbor Discovery

Existing cellular networks still require much manual configuration of neighboring macro BS that will greatly burden the operators in the network deployment. Therefore, the initial neighbor list is obtained from core network automatically. Any change of the neighbor environment such as BSs are added or removed should automatically trigger the BS to generate an updated neighbor list. The information for updating the neighbor list (e.g. macro BS, Femtocell BS) is collected by BS/RS/MS measurement, core network, inter-BS network signaling, BS's own management. Examples of the parameters that are measured by a macro BS include BSID, Cell site in longitude, latitude, Sector Bearing (indicating the direction where the sector is pointing), and BS attributes (e.g. Channel Bandwidth, FFT Size, Cyclic Prefix, etc.). Other parameters, such as BSID, BS attributes (e.g. Channel Bandwidth, FFT Size, Cyclic Prefix, etc.) may be used to update the neighbor list in the macro BS.

The BS should direct an MS to perform the frequency measurements of serving BS and/or non-serving BS (e.g. inter-RAT neighbor cell measurement may be based on MS traffic conditions). The BS may use cached or feedback information on signal strength, BSID and some additional information, e. g. MS position, battery status and report history for a certain MS, in order to reduce the undesirable transmission from the MS (e.g. BS may select a subset of MSs to perform measurements and produce reports).

16.2 Self Optimization

Self-optimization is the process of analyzing the reported SON measurement from the BS/MS and fine-tuning the BS parameters in order to optimize the network performance which includes QoS, network efficiency, throughput, cell coverage and cell capacity

The reported SON measurements from BS/MS may include but not confined to

- Signal quality of serving BS and neighbor BSs
- Interference level from the neighbor BSs
- BSID of neighbor BS
- Status of mobility management (HO)

- Time and location information of MS at a measurement
- Load information of neighbor BS

16.2.1 Coverage and Capacity Optimization

The coverage and capacity optimization aims to detect and resolve the blind areas for reliable and maximized network coverage and capacity when an MS cannot receive any acceptable signals from any BSs. When an MS resumes the connection after experiencing service interruption in a blind area, the MS should perform the measurement (e.g. RSSI, SINR, I and INR) and report the event together with cached information (e.g. last serving BS ID, neighbor list, location information , timestamp and RTD etc.) to the serving BS. BS can direct the MS to not report its cached information, in order to limit the amount of data that is reported. The SON functions process the reported information and then determine the location of the blind areas in order for subsequent coverage extension and capacity optimization.

16.2.2 Interference Management and Optimization

Inter-cell interference should be maintained at the acceptable level. Newly deployed BS may select the carrier frequency, antenna setting, power allocation, and/or channel bandwidth based on the interference level and the available capacity of the backhaul link. This can be achieved by a set of measurements by scanning the surrounding neighbor cells with/without additional information collected from other MS and BS. The reassignment/modification due to interference management should take into consideration of the load status and other parameters (e.g. antenna and power setting optimization for Femtocell BS etc). When a new BS is deployed, the initialization for interference management should be automatically configured by a SON server.

16.2.3 Load Management and Balancing

Cell reselection and handover procedures of an MS may be performed at the direction of the BS to balance traffic load and minimize the number of handover trials and redirections. The load of the cells, modification of neighbor lists, and the selection of alternative carriers should be automatically managed through inter-BS communication and the SON server. A BS with unsuitable load status may adjust its cell reselection and handover parameters to control the imbalanced load with the neighbors BSs.

16.2.4 Self-optimizing FFR

Self-optimizing FFR is designed to automatically adjust FFR parameters, frequency partitions and power levels, among BS sectors in order to optimize system throughput and user experience.

17 Support for Multi-carrier Operation

17.1 Multi-carrier Operation Principles

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

- A primary carrier is the carrier used by the ABS and the AMS 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 AMS operation, such as network entry. Each AMS has only one carrier it considers to be its primary carrier in a cell.
- A secondary carrier is an additional carrier which the AMS may use for traffic, only per ABS'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 supports both single carrier AMS and multicarrier AMS.
- Partially configured carrier: A carrier with only downlink transmission in TDD or a downlink carrier

without paired UL carrier in FDD mode and configured with all control channels to support downlink transmission.

A primary carrier is fully configured while a secondary carrier may be fully or partially configured depending on deployment scenarios.

The following is common to all multi-carrier operation modes:

- The system defines N standalone fully configured RF carriers, each fully configured with all synchronization, broadcast, multicast and unicast control signaling channels. Each AMS 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, each configured with all control channels needed to support downlink transmissions 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 AMS mobility, state and context through the primary carrier.
- Some information about the secondary carriers including their presence and location is made available to the AMS through the primary carriers. The primary carrier may also provide AMS the information about the configuration of the secondary carrier.
- The resource allocation to an AMS 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 AMS 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 utilizing the primary RF carrier for data transfers, the ABS may dynamically schedule resources for an AMS across multiples secondary RF carriers. Multiple AMSs, 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 AMS will consider only one fully configured RF carrier to be its primary carrier in a cell. A secondary carrier for an AMS, if fully configured, may serve as primary carrier for other AMSs.

There are two multicarrier deployment scenarios.

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. AMS 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 downlink transmission only service like multicast and broadcast services. Such supplementary carriers may be used only in conjunction with a primary carrier and cannot operate standalone to offer IEEE 802.16m services for an AMS.

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

- Carrier aggregation
  - AMS always maintains its physical layer connection and monitor the control information on the primary carrier.
- Carrier switching
  - AMS can switch its physical layer connection from the primary to the secondary carrier per ABS's instruction. AMS connects with the secondary carrier for the specified time period and then returns

to the primary carrier. When the AMS is connected to the secondary carrier, the AMS does not need to maintain its physical layer connection to the primary carrier.

- This mode is used for primary carrier switching to partially configured carriers for downlink only transmission.

17.2 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 mixed mode operation, the legacy channel raster is maintained. 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 88.

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

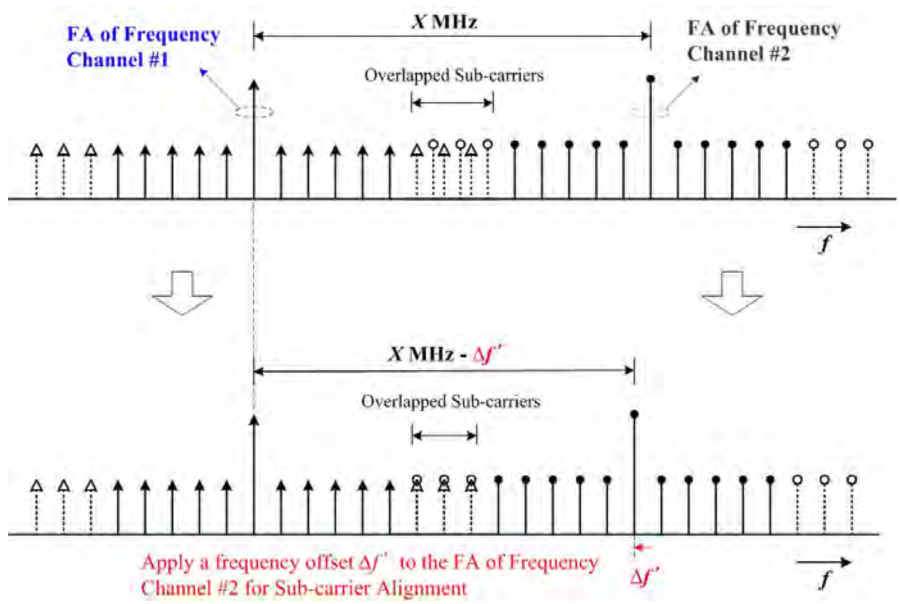

Figure 88: Illustration of Sub-carrier alignment by applying a fraction of sub-carrier spacing to the FA of adjacent frequency channel

17.3 PHY Aspects of OFDMA Multi-carrier Operation

Multi-carrier support in the physical layer is shown in Figure 89. A single MAC PDU or a concatenated MAC PDUs is received through the PHY SAP and they can form a FEC block called PHY PDU. The figure shows that the physical layer performs channel encoding, modulation and MIMO encoding for a PHY PDU and generates a single modulated symbol sequence. Any one of the multiple carriers (primary or secondary carriers) can deliver a modulated symbol sequence. Different modulated symbol sequences transmitted on the same or different carriers may have different MCS and MIMO schemes. Or, in case of allocation on DRU, a single modulated symbol sequence may be segmented into multiple segments where each segment can be transmitted on a different carrier. The same MCS level and MIMO scheme are used for all segments of a PHY PDU. The physical layer performs subcarrier mapping for a modulated symbol sequence or a segment of the sequence relevant to the given carrier.

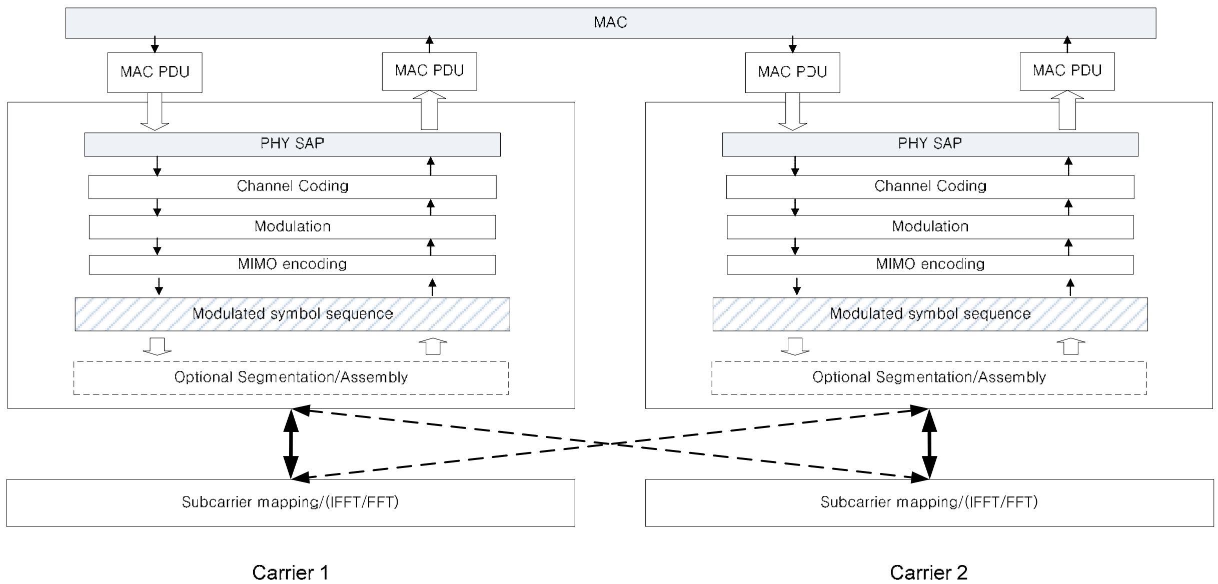

Figure 89: An example of the physical layer structure to support multi-carrier operation

The following describes the details of the PHY PDU transmission operation:

1. For a PHY PDU, the PHY delivers a single modulated symbol sequence. This modulated symbol sequence, is regarded as a single HARQ packet the same as in a single carrier system.
2. A modulated symbol sequence of a PHY PDU can be transmitted as follows:
   A. Transmitting the modulated symbol sequence on a single RF carrier. Note that in the same time, different PHY bursts may be transmitted to an AMS from different RF carriers.
   B. Transmitting the modulated symbol sequence on DRUs across several RF carriers, via PHY burst segmentation and mapping to different RF carriers, by using the same MCS and MIMO scheme.
3. In the multi-carrier system, an LRU is defined independently per carrier. The RF carrier specific physical layer performs subcarrier mapping based on the LRU per carrier. It must be noted that the radio resource utilization on each RF carrier may be different.

PHY segmentation, i.e. transmitting one PDU across multiple carriers is FFS.

17.3.1 Frame Structure

Multicarrier support in the frame structure is illustrated in Figure 90 and Figure 91.

17.3.1.1 Frame Structure to Support Multi-carrier Operation

The support for multiple RF carriers is provided 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 90 shows that the same frame structure would be applicable to both single carrier and multicarrier mode of operation. A number of narrowband carriers can be aggregated to support effectively wideband operation. Each carrier may have its own Advanced Preamble and superframe header. Further, some carriers may have less information in superframe header based on the carrier configuration. A multi-carrier AMS is an MS which can utilize radio resources across multiple RF carriers under the management of a common MAC. Depending on MS's capabilities, such utilization may include aggregation or switching of traffic across multiple RF carriers controlled by a single MAC instantiation.

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. When carriers are in non-contiguous spectrum, the number of uplink subframes is not necessarily the same for all the carriers in TDD.

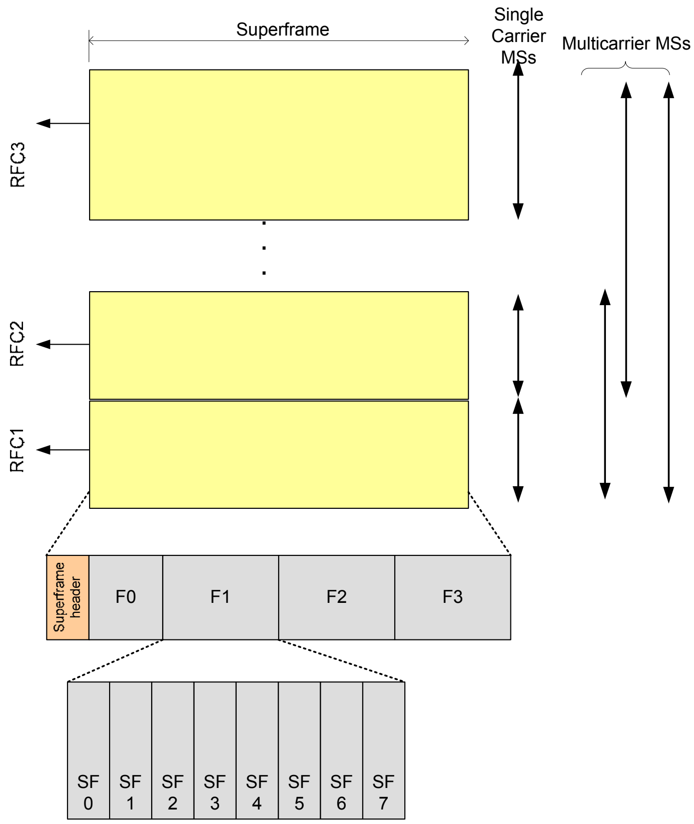

Figure 90: Example of multi-carrier support in the frame structure

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

Figure 91 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 AMSs. One or multiple of the 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, it is no necessary 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 are supported for multiplexing of legacy and AMSs in the legacy and IEEE 802.16m mixed carrier. The TDM in the figure is an example.

In case 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 being studied.

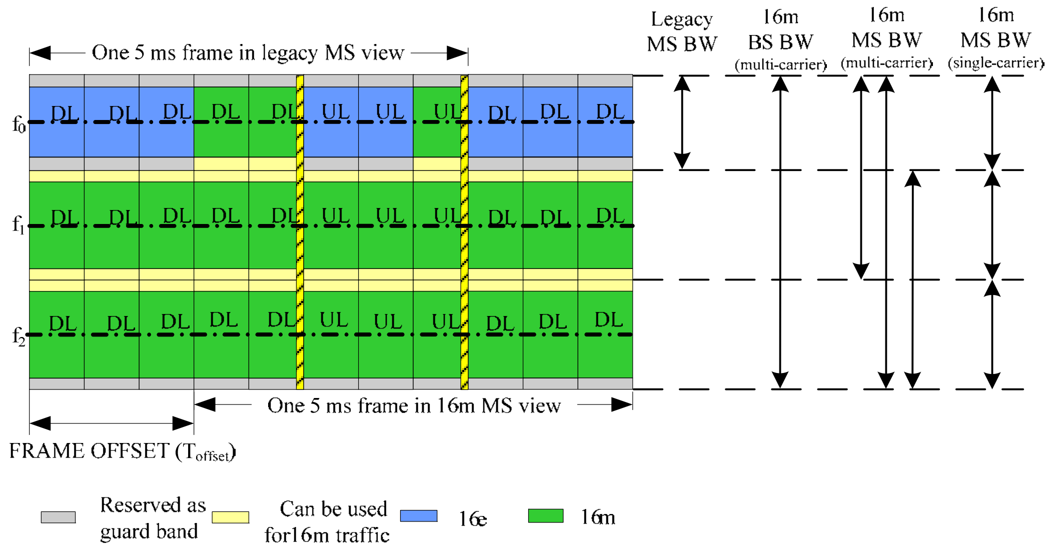

Figure 91: Illustration of frame structure supporting legacy frames with a wider channel

17.3.2 Channel Coding, Modulation and HARQ

For a PHY PDU, channel encoding, modulation and MIMO encoding are performed as in a single carrier operation to generate a single modulated symbol sequence. The modulated symbol sequence can be segmented and transmitted over DRUs in multiple carriers as shown in Figure 61.

The modulated symbol sequence is regarded as a single HARQ packet. HARQ feedback for PHY PDU sent across primary and secondary carriers can be carried in the primary carrier. HARQ feedback for PHY PDU sent only in the secondary carrier can be carried in the secondary carrier.

17.3.3 Data Transmission over Guard Resource

The guard sub-carriers between contiguous RF carriers in the new zone can be utilized for data transmission if the sub-carriers on contiguous RF carriers are well aligned. The serving ABS and the AMS need to negotiate their capability to support guard sub-carrier data transmission. The set of guard sub-carriers utilized for data transmission is defined as guard resource.

17.3.3.1 PHY Structure Support

Each carrier can exploit subcarriers at band edges as its additional data subcarriers. The guard resource forms integer multiples of PRUs. The resulting data subcarriers (including guard resource) form PRUs. The PRU structure used for guard resource is the same as the structure of the ordinary PRU in 11.5 and 11.6. For the carrier, CRUs may be constructed from the PRUs including PRUs from guard resource. Support of DRU is FFS.

The ABS provides information regarding the use of guard resource for data channels. Guard resource is not used for control channels transmission.

Figure 92 below illustrates example of exploiting guard subcarriers for data transmission.

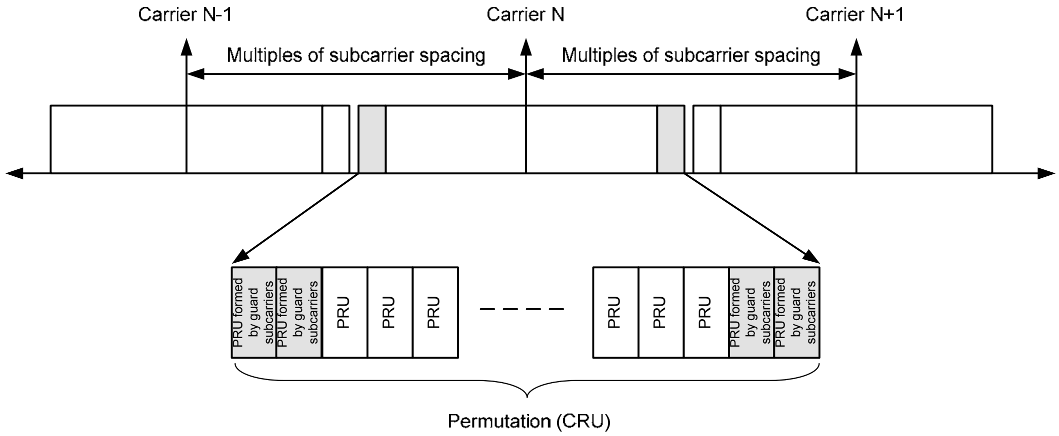

Figure 92: Example of data transmission using the guard subcarriers

17.3.4 Allocation Scheme for OFDMA Multi-carrier

A specific allocation element is used to indicate the allocation of OFDMA data regions which is defined as a set of LRUs. A modulated symbol sequence of a PHY PDU can be sent through a single carrier (primary or secondary). In this case, there is only one data region for the modulated symbol sequence in a carrier. Additionally, a modulated symbol sequence of a PHY PDU can be segmented for the allocation in DRU and multiple carriers can deliver the segments through each carrier. In this case, there are multiple data regions for the modulated symbol sequence across multiple carriers. The segmentation is only allowed for the allocation in DRU. Allocation information indicates a data region or multiple data regions with other parameters like MCS level. When multiple PHY PDUs are transmitted over multiple carriers in a subframe, the delivery order is being studied.

For each AMS the allocation information for both its Primary and secondary carriers is sent through the primary carrier, or the allocation information for each carrier is sent through the carrier itself.

17.3.5 Data Regions and Sub-carrier Mapping for OFDMA Multi-carrier Operation

When a modulated symbol sequence is transmitted through one carrier, the sequence is mapped using the same mapping rule of the single carrier mode. When a modulated symbol sequence is segmented, each segment can be mapped to OFDMA data regions over multiple carriers using the algorithms defined below, where logical carrier index is defined is being studied.

a) Segment the modulated symbol sequence into blocks sized to fit into a single LRU.

b) Map each segmented block onto one LRU from the lowest LRU index in the OFDMA data region of the carrier with the lowest logical carrier index.

c) Continue the mapping so that the LRU index increases. When the edge of the data region is reached, continue the mapping from the lowest LRU index in the OFDMA data region of the carrier with the next available logical carrier index.

d) Continue the mapping until the all modulated data symbols are mapped.

An example is shown in Figure 93. Within the LRU, subcarrier mapping follows the mapping rule for a single carrier case.

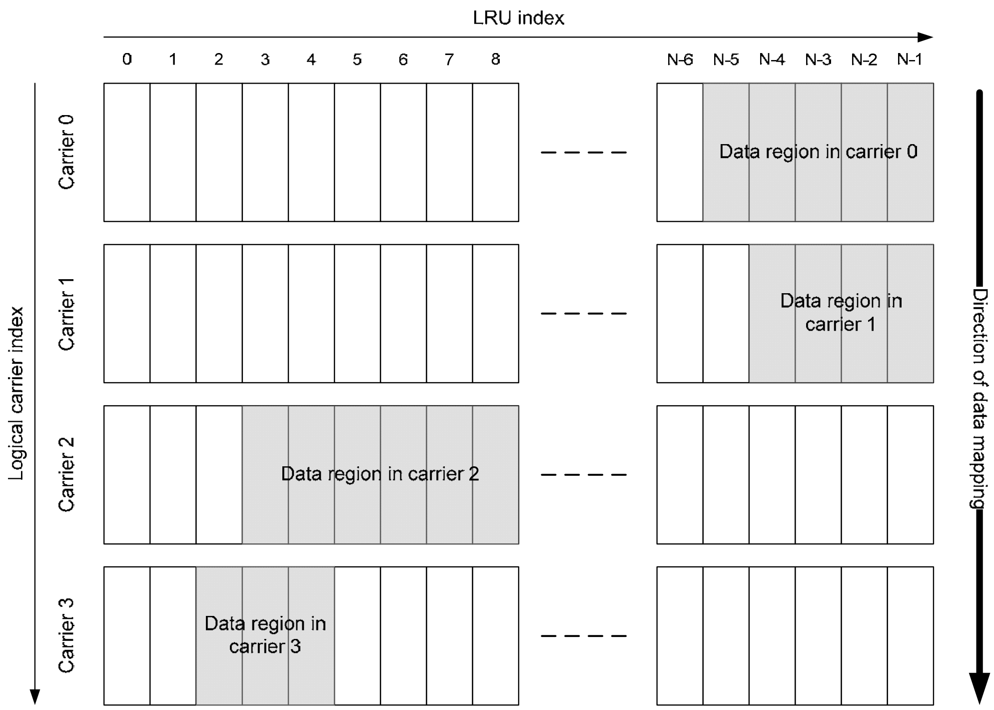

Figure 93: Example of modulated symbol sequence mapping in OFDMA multi-carrier operation

17.3.6 Downlink Control Structure

All DL controls channel needed for single carrier operation are needed for the fully configured carrier. For partially configured carrier, DL control channels necessary for UL transmission are not present.

Obtaining System Information of Secondary Carriers

- For the case where the AMS can simultaneously decode multiple carriers, the AMS can decode the Superframe Headers of its secondary carriers. ABS may instruct the AMS, through control signaling on the primary carrier, to decode Superframe Headers of specific set of secondary carriers.
- When the AMS cannot simultaneously decode multiple carriers, the ABS can convey the system information of secondary carriers to AMS, through control signaling on the primary carrier.

17.3.6.1 A-PREAMBLE

Primary and Secondary SCHs are present in a fully configured and partially configured carrier. In a fully configured and partially configured carrier, the location and transmission format of A-PREAMBLE is the same as that of the single carrier described in 11.7.2.1.

17.3.6.2 SFH

The SFH is present in a fully configured and partially configured carrier. In a fully configured and partially configured carrier, the location and transmission format of P-SFH/S-SFH is the same as that of single carrier described in Section 11.7.2.2.

17.3.6.3 A-MAP

A-MAP is present in a fully configured carrier. The location and transmission format of A-MAP on the fully configured carrier is the same as that defined in 11.7.2.3.

The presence and use of A-MAP on the partially configured carrier is being studied.

17.3.6.4 Additional Broadcast Information

All additional broadcast information related to multicarrier operation is carried with the fully configured carrier. Except uplink information, all additional broadcast information related to operation of partially configured carrier can be carried by the partially configured carrier.

17.3.7 Uplink Control Structure

All UL controls channel needed for single carrier operation are supported for the fully configured carrier. A partially configured carrier does not have any uplink capability, optimized for downlink only transmissions such as multicast and broadcast services.

17.3.7.1 Uplink Fast Feedback Channel

The ABS configures the set of carriers for which the AMS reports fast feedback information. The ABS may only allocate resource to the AMS on a subset of those configured carriers. Fast feedback information for link adaptation for SIMO and information for MIMO operation can be sent through the primary carrier. The fast feedback information related to the assigned secondary carriers can be carried in those carriers if supported by their configuration.

17.3.7.2 Uplink HARQ Feedback Channel

HARQ feedback for PHY PDU sent across primary and secondary carriers can be carried in the primary carrier. HARQ feedback for PHY PDU sent in secondary is carried in the secondary if supported by the secondary carrier configuration

17.3.7.3 Uplink Ranging Channel

UL initial ranging for non-synchronized AMS is conducted on a fully configured carrier. UL periodic ranging for synchronized AMS is conducted on the primary carrier but may also be performed in a secondary carrier if supported by the secondary carrier. The issue of periodic ranging on the secondary carrier, autonomously performed by the AMS or directed by the ABS, is being studied. The serving ABS transmits the ranging response on the same carrier that the UL ranging is received.

17.3.7.4 Uplink sounding channel

UL sounding is performed on the primary and secondary carrier.

17.3.7.5 Bandwidth Request Channel

The BW request channel is transmitted only on the primary carrier.

17.3.8 Uplink Power Control

Depending on the correlation between RF carriers, separate controls of UL power for different RF carriers are necessary. Thus, one or multiple power control commands for multiple carriers are supported. Although multiple power control commands are allowed, the power control commands or messages can be sent to AMS through the primary carrier.

17.4 MAC Aspect of OFDMA Multi-carrier Operation

The MAC layer in OFDMA multi-carrier mode operates in the same way as single carrier MAC.

17.4.1 Addressing

There is no difference between a single carrier and OFDMA multi-carrier operation from an addressing perspective as described in sub-clause 10.1.

17.4.2 Security

All the security procedures between AMS and ABS are performed using only the AMS's primary carrier. The security context created and maintained by the procedures is managed per ABS through the primary carrier.

17.4.3 Initial Entry

The AMS attempts initial ranging and network entry only with a fully configured carrier. An AMS needs to know which carrier(s) of the ABS are fully configured carriers.

The ABS may use a preamble sequence selected from a predefined set of sequences reserved for partially configured carriers. By detecting a preamble sequence designated for partially configured carrier the AMS skips that carrier and proceed with scanning and selection of alternative carrier.

Once the AMS detects the A-PREAMBLE on a fully configured carrier, the AMS may proceed with decoding the SFH or the extended system parameters and system configuration information where the ABS indicates its configuration and its support for multicarrier feature. The AMS can decide on proceeding with network entry with the current carrier or going to alternative carriers based on this information.

Once a candidate primary carrier is determined the initial network entry procedures are the same as in single carrier mode. The carrier on which the AMS successfully performs initial network entry becomes the primary carrier of the AMS. After successful ranging, the AMS follows the capability negotiation procedure in which it provides ABS with its OFDMA multi-carrier capabilities, such as carrier aggregation or carrier switching. The ABS may provide configuration parameters of other carriers to the AMS. The ABS may assign secondary carriers to the AMS, through negotiation with the AMS.

The AMS may skip UL ranging (for time/frequency synchronization and power adjustment purpose) with secondary carrier. In this case, AMS uses the same timing, frequency and power adjustment information for the secondary carrier as in the primary carrier. The AMS may perform fine timing/frequency/power adjustment on the secondary carrier through measuring the A-Preamble and/or pilot on the secondary carrier. The AMS may perform UL ranging with secondary carrier. In this case, power adjustment results in the primary carrier may be used as initial transmission power for UL ranging over the secondary carrier and the ranging resource for synchronized AMS is used. Initial ranging on the secondary carrier is directed by the ABS. For this, the ABS may assign the dedicated ranging code through the primary carrier to enhance the ranging in the secondary carrier.

17.4.4 MPDU Processing

The construction and transmission of MAC PDU in OFDMA multi-carrier operation mode is the same as that in single carrier operation mode.

17.4.5 Bandwidth Request and Allocation

All bandwidth requests are transmitted on the AMS's primary carrier using the assigned UL control channels following the same procedures as single carrier mode. Bandwidth request using piggyback scheme is also allowed in the secondary carriers. The ABS may allocate UL resources which belong to a specific carrier or a combination of multiple carriers.

17.4.6 QoS and Connection Management

QoS and Connection management in multicarrier mode are based on single carrier mode. The Station ID and all the Flow IDs assigned to an AMS are unique identifiers for a common MAC and used over all the carriers. The followings are also applicable:

1. The connection setup signaling is performed only through the AMS's primary carrier. The connection is defined for a common MAC entity.
2. AMS's QoS context is managed per service flow for each AMS, and is applicable across primary carrier and secondary carriers and collectively applied to all carriers.
3. Flow ID is maintained per AMS for both primary carrier and secondary carriers.
4. The required QoS for a service flow may be one of the parameters considered in order to determine the number of secondary carriers assigned to the AMS.

17.4.7 Carrier Management

The following steps summarize the high level sequence of procedures involved in the MC operation:

1. ABS periodically broadcasts its MC mode and MC configuration
   - The carriers listed in the MC configuration message are called *Available Carriers*. Not all available carriers can be assigned to an AMS but all available carriers are introduced to AMS's along with their respective Physical Carrier Index.
   - The ABS may also send the detailed MC configuration to the AMS broadcast messaging.

2. AMS Performs initialization and network entry. The process is the same as SC mode.
3. AMS and ABS perform MC Capability negotiation. Example Capabilities may include:

   - Carrier Switching Only
   - Capability to concurrently receive and aggregate MC's and Max No. of Carriers
   - Capability to concurrently aggregate and transmit on MC's, Max No. of Carriers. Note the AMS's MC capability may be different for TX and RX.
   - Capability to support Aggregation across Non-contiguous Spectrum, Max RF distance between carriers. This is in addition to AMS's support for multiple band classes.

Based on AMS RF capabilities, loading of available carriers or other factors, the ABS may provide more detailed configuration information on subset of available carrier designated as Assigned Secondary Carriers to AMS. The ABS may assign a logical carrier index to each assigned secondary carrier for the AMS. Primary carrier is always assign with logical carrier index 0.The ABS may update and release the assigned secondary carriers based on loading and other factors.
The AMS does not perform any PHY/MAC processing on Assigned Secondary Carriers until directed by the ABS.

4. The ABS allocates a subset of assigned secondary carriers to be ready for the potential use for MC data transmission based on QoS requirement, loading and other factors. This subset is called the *Active Secondary Carriers*.
   - AMS performs PHY/MAC processing on those active carriers. The ABS may update and release the active secondary carriers based on QoS requirement, loading and other factors.
   - The ABS makes MC traffic allocation which may be:
   - Aggregation across all fully configured active carriers.
   - Aggregation involving at least one partially configured active carrier
   - Switching from one fully configured active carrier to another fully configured carrier which will result in primary carrier change
   - Switching to a partially configured active secondary carrier.

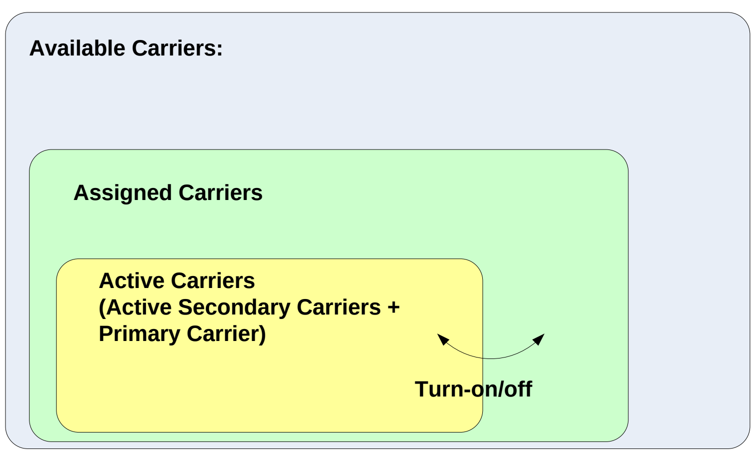

Figure 94: Illustration of the Relation between Available, Assigned and Active Carriers

	Definition and Properties
Available Carriers	Multiple carriers which are available in an ABS - Not all Available carriers may be supported by the AMS - No Processing on these Carriers - Referred to with Physical Carrier Indexes, which are unique within an ABS.
Assigned Carriers	Subset of Available Carriers which may be potentially used by the AMS - Determined according to the capability of the AMS, SLA's , loading of available carriers of the ABS or other factors. - No processing on these carriers until directed by the ABS. - Referred to with Physical Carrier Indexes, which are unique within an ABS. - Additional logical carrier indexes are allocated. Logical Carrier Indexes are unique only within the AMS.
Active Carriers	Subset of Available Carriers which are ready to be used for MC assignments. - Determined based on QoS requirement and other factors - PHY/MAC processing are required for the active carriers. - Referred to with Logical Carrier Indexes

Table 15 Definitions of Available, Assigned and Active Carriers

17.4.7.1 Primary Carrier Change

The ABS may instruct the AMS, through control signaling on the current primary carrier, to change its primary carrier to one of the available fully configured carriers within the same ABS for load balancing purpose, carriers' varying channel quality or other reasons. AMS switches to the target fully configured carrier at action time specified by the ABS. The carrier change may also be requested by the AMS through control signaling on the current primary carrier. Given that a common MAC entity manages both serving and target primary carriers, the network re-entry procedures at the target primary carrier is not required. The ABS may direct an AMS to change the primary carrier without scanning.

The ABS may instruct AMS to perform scanning on other carriers which are not serving the AMS. The AMS reports the scanning results back to the serving ABS, which may be used by the ABS to determine the carrier for the AMS to switch to. In this case, if the target carrier is not currently serving the AMS, the AMS may perform synchronization with the target carrier if required.

17.4.7.2 Carrier Switching Between a Primary Carrier and a Secondary Carrier

Primary to secondary carrier switching in multi-carrier mode is supported when secondary carrier is partially configured. The carrier switching between a primary carrier and a secondary carrier can be periodic or event-triggered with timing parameters defined by multi-carrier switching message on the primary carrier. When an AMS switches to a secondary carrier, its primary carrier may provide basic information such as timing and frequency adjustment to help with AMS's with fast synchronization with the secondary carrier.

17.4.8 Handover Support

An AMS in multi-carrier operation follows the handover operation in single carrier mode of IEEE 802.16m. MAC management messages in relation with handover between an AMS and an ABS are transmitted over the AMS's primary carrier. Similar to the procedure defined in 10.3.2.2.3, if directed by serving ABS via HO Command control signaling, the AMS performs network re-entry with the target ABS on the assigned fully configured carrier at action time while continuously communicating with serving ABS. However, the AMS stops communication with serving ABS on primary/secondary carriers after network re-entry at target ABS is completed. In addition, AMS cannot exchange data with target ABS prior to completion of network re-entry. Multiplexing of network re-entry signaling with target ABS and communications with serving ABS is done via multiple radio carriers. Figure 63 shows a general handover call flow for AMS with multi-carrier capability.

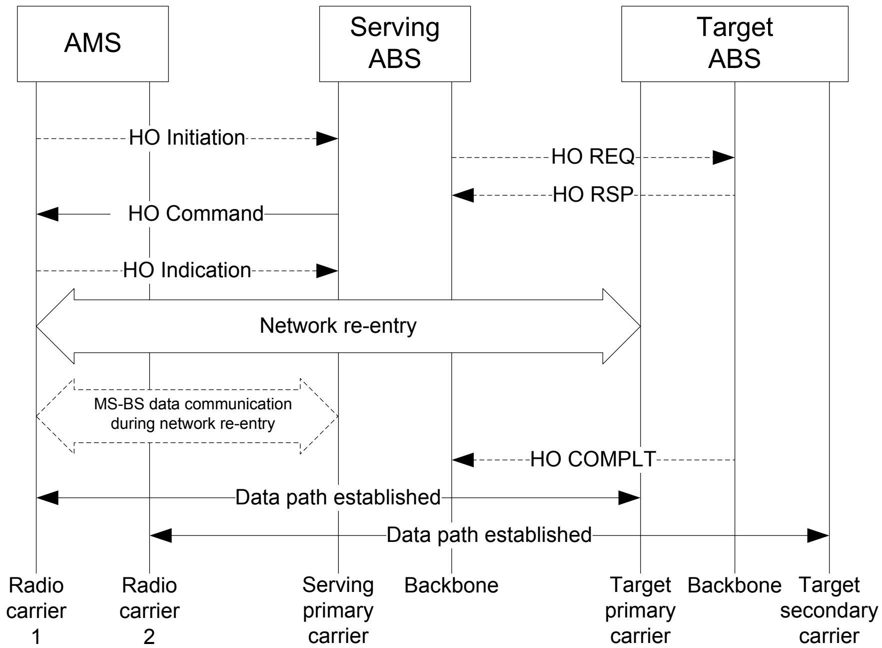

Figure 95: A general call flow for an AMS with multi-carrier capability

In case AMS is capable to process multiple carriers at the same time, the target primary carrier can be different than the one chosen in serving cell. Figure 96 shows an example HO call flow of the case in which AMS is capable to process multiple carriers at the same time and the target primary carrier is different from the serving primary carrier.

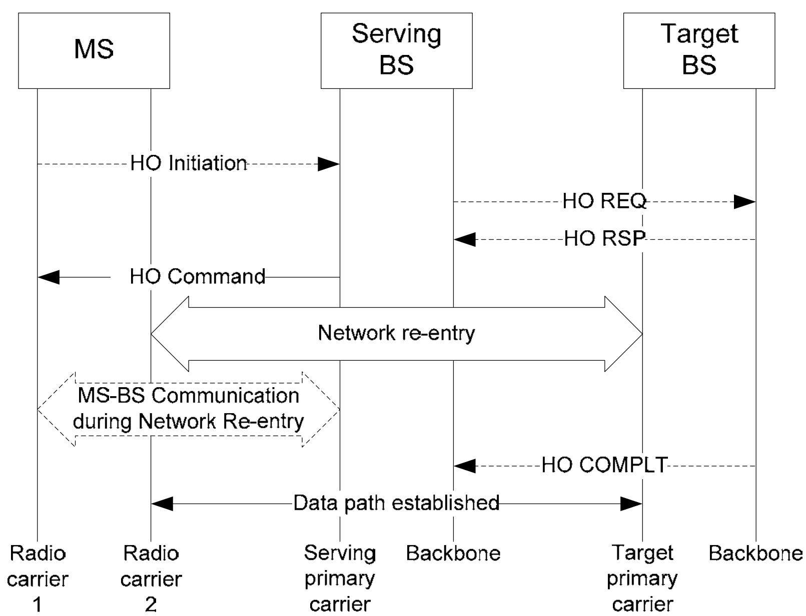

Figure 96: An example call flow for multi-carrier HO in which the target primary carrier is different from the serving primary carrier

To facilitate AMS's scanning of neighbor ABS's fully configured carriers, the serving ABS may broadcast/multicast/unicast the neighbor ABS's multi-carrier configuration information to the AMS.

When an AMS receives handover notification from an ABS or when an AMS sends HO notification to an ABS, the

AMS may get the information on OFDMA multi-carrier capabilities of one or more possible target ABSs in the handover transaction.

After handover to a certain target ABS is determined, the AMS conducts network re-entry through its target primary carrier. After the completion of network re-entry procedure, the AMS and the ABS may communicate over AMS's primary and/or secondary carriers.

Regardless of multi-carrier support, an AMS capable of concurrently processing multiple radio carriers, may perform scanning with neighbor ABSs and HO signaling with the target ABS using one or more of its available radio carriers, while maintaining normal operation on the primary carrier and secondary carriers of the serving ABS. The AMS may negotiate with its serving ABS in advance to prevent allocation over those carriers used for scanning with neighboring ABSs and HO signaling with the target ABS.

17.4.9 Power Management

The AMS is only assigned to one or more secondary carrier during the active/normal mode. Therefore, the power saving procedures in OFDMA multi-carrier mode of operation are the same as single carrier mode and all messaging including idle mode procedures and state transitions are handled by the primary carrier.

In active/normal mode AMS can be explicitly directed through the primary carrier to disable reception on some secondary carriers to satisfy the power saving. When reception is disabled, no allocation can be made on those secondary carriers. When the primary carrier indicates that there is no allocation in secondary carriers, the AMS can disable reception on that carrier.

17.4.9.1 Sleep Mode

When an AMS enters sleep mode, the negotiated policy of sleep mode is applied to a common MAC regardless of OFDMA multi-carrier mode and all carries powers down according to the negotiated sleep mode policy. During the listening window of sleep mode, the traffic indication is transmitted through the primary carrier. Data transmission follows the normal operation (no sleep) defined for multiple carriers.

- One set of unified sleep mode parameters (i.e., sleep window and listening window configuration) are configured for an AMS regardless of single carrier or multi-carrier operation.
- During listening window, AMS monitors the traffic indication on the primary carrier. If traffic indication is negative, AMS goes back to sleep. If traffic indication is positive, AMS continues to monitor the primary carrier control channel to know if it has traffic scheduled for transmission on the primary carrier and/or secondary carrier. Note that the serving ABS may request AMS to switch its primary carrier during the listening window for load balancing or power saving.

17.4.9.2 Idle Mode

During paging listening interval, AMS monitors paging notification on a fully configured carrier. The procedure for paging is the same as defined for single carrier. The selection of the paging carrier in the multicarrier deployment is the same for single carrier and multicarrier capable AMSs. When paged, the AMS can perform network re-entry procedure with the paged carrier.

Messages and procedures to enter the idle mode between AMS and ABS are processed through the primary carrier. The network re-entry procedure from idle mode is similar to those of initial network entry. One set of unified idle mode parameters (i.e., paging listening interval and paging unavailable interval configuration) is configured for an AMS regardless of single carrier or multi-carrier operation.

17.4.10 E-MBS Support

IEEE 802.16m system may designate the partially configured carriers for E-MBS only. The multi-carrier AMS which is capable to process multiple radio carriers at the same time may perform normal data communication at one carrier while receiving the E-MBS content over another carrier.

18 Support for Interference Mitigation

This section introduces the interference mitigation schemes by using fractional frequency reuse (FFR), advanced antenna technology, power control and scheduling. Interference mitigation schemes such as conjugate-data-repetition (CDR) may be supported.

18.1 Interference Mitigation using Fractional Frequency Reuse (FFR)

IEEE 802.16m supports 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 Section 11.5.2.2 and in Section 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 97.

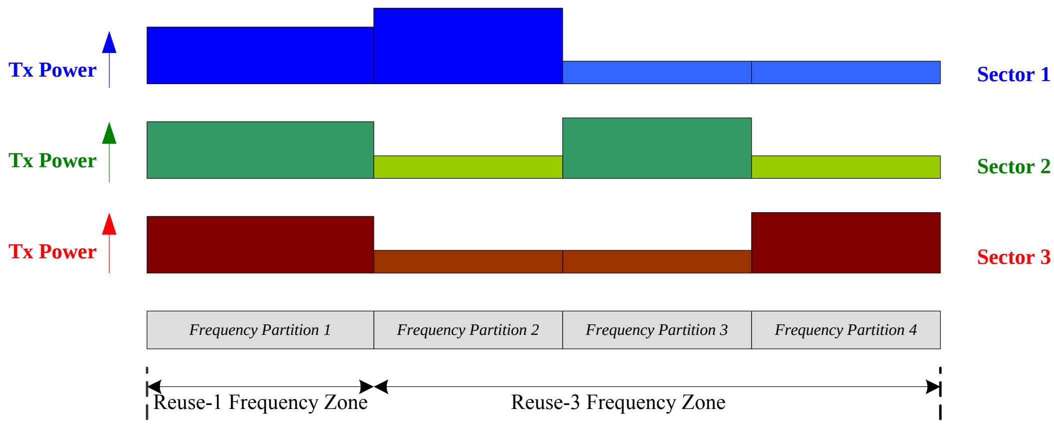

Figure 97: Basic concept of Fractional Frequency Reuse (FFR)

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 AMSs in the frequency partitions with lower frequency reuse factor, due to lower interference levels. This will be helpful for the AMSs located around cell boundary or for the AMSs suffering severe inter-cell interference. On the other hand, ABS may apply higher frequency reuse factor for some frequency partitions to serve the AMSs which do not experience significant inter-cell interference. This will be helpful for ABS to serve more AMSs 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 AMS.

18.1.1 Downlink FFR

18.1.1.1 Interference Measurement and Signaling Support

For DL FFR, the AMSs is capable of reporting the interference information to serving ABS. The serving ABS can instruct AMS to perform interference measurement over the designated radio resource region in solicited/unsolicited manner, or the AMS may perform the autonomous interference measurement without the instruction by ABS. Examples of interference measurement include SINR, SIR, interference power, RSSI, etc. The AMS can also recommend the preferred frequency partition to serving ABS 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 ABS can transmit necessary information through a signaling channel or message to facilitate the measurement by AMS. The information includes the frequency reuse parameters of each frequency partition, 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 being studied.

18.1.1.2 Inter-ABS Coordination

In order to support FFR, the ABSs is 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 being studied.

The Figure 98 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.

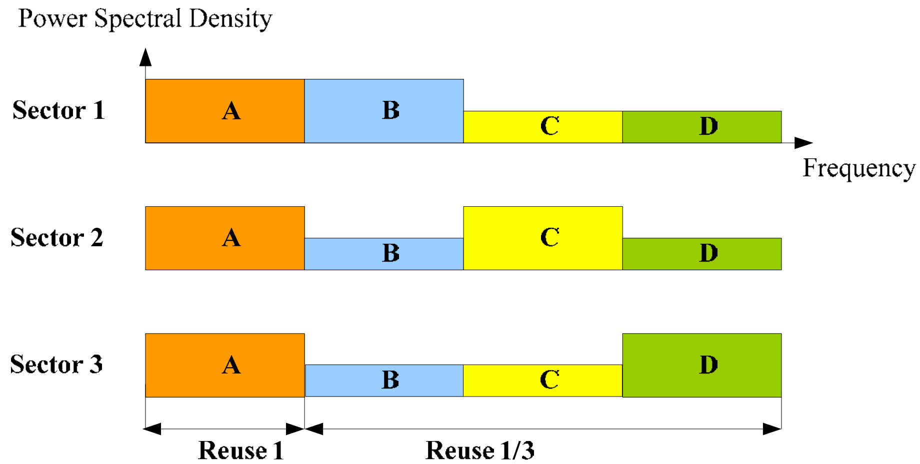

Figure 98: Example to integrate FFR and DL power control

18.1.2 Uplink FFR

18.1.2.1 Interference Measurement and Signaling Support

For UL FFR, the ABSs are capable to estimate the interference statistics over each frequency partitions. In order to support UL FFR, the ABS can transmit necessary information through a feedback channel or message to the AMS. The information can include the frequency reuse parameters of each frequency partitions and the corresponding uplink power control parameters and IoT target level.

18.1.2.2 Inter-ABS Coordination

In order to support UL FFR, for every FP, the ABSs is 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 being studied.

Figure 99 a and b shows examples of integration of FFR with UL power control (Section 11.10.2). In Figure 99a, system adaptively designates different IoT targets for UL power control over different PRUs in each frequency partition. An AMS 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, an AMS 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 ABS can adjust the frequency partitions and the corresponding target IoT level in coordination with other ABSs.

Another example for SINR based UL power control is given in Figure 99(b), where different target SINR level may be designated for different frequency partitions.

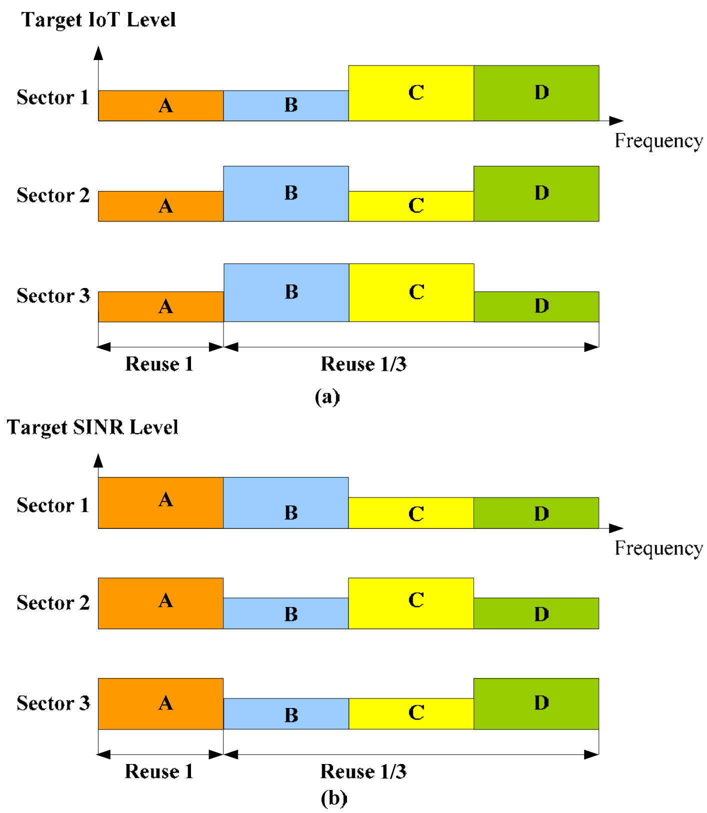

Figure 99: Example to integrate FFR and UL power control

18.2 Interference Mitigation using Advanced Antenna Technologies

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

18.2.1 Single Cell Antenna Processing with Multi-ABS Coordination

The details of single cell antenna processing are defined in Section 11.8. This subsection introduces the interference mitigation techniques based on the MIMO schemes defined in Section 11.8 with extended inter-ABS coordination mechanisms and interference measurement support. Note that the inter-ABS coordination mechanisms in this subsection do not require data forwarding between different cells, i.e. different ABS will not transmit the same data to an AMS. The coordination between ABS should be through efficient signaling over backhaul and on a slow frequency. The coordination information from adjacent ABS can help the scheduler on the serving ABS to mitigate interference through scheduling.

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 AMS can estimate which PMIs in neighboring cell will result in severe interference level and report the PMI restriction or recommendation to the serving ABS. The serving ABS can then forward this information to recommend its neighboring ABSs a subset of PMIs to use or not to use. Based on this information, the neighboring ABS can configure the codebook and broadcast or multicast it.

In addition, the PMI coordination can also be applied in UL. One example is that the neighboring ABSs can estimate the sounding signal transmitted by specific AMS and identify which PMIs may result in significant interference. By forwarding this information over the backhaul network, the serving ABS can instruct the AMS 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 an ABS can be exploited to null its interference to neighboring cells.

18.2.1.1 Inter-ABS Coordination

In order to support PMI coordination to mitigate inter-cell interference, the ABSs is capable of exchanging the interference measurement results such as the 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 ABS through estimating the sounding signals transmitted by specific AMSs. 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 ABSs.

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

18.2.1.2 Interference Measurement

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

For UL PMI coordination, the ABS is capable of measuring the channel from the interfering AMS using sounding signals. Neighboring ABS should calculate the PMIs with least interference and forward them to the serving ABS. The mechanism to identify the interfering AMS is FFS.

The priority of selection of PMIs forwarded from neighboring ABS 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 ABS. 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), ABSs 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 AMSs.

In order to support precoding with interference nulling to mitigate inter-cell interference, an ABS is capable of measuring the channel from an interfering AMS.

18.2.2 Multi-ABS Joint Antenna Processing

This subsection introduces the techniques to use joint MIMO transmission or reception across multiple ABSs 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 ABSs perform joint MIMO transmission to multiple AMSs located in different cells. Each ABS performs multi-user precoding towards multiple AMSs, and each AMS is benefited from Co-MIMO by receiving multiple streams from multiple ABSs. For downlink CL-MD, each group of antennas of one ABS performs narrow-band or wide-band single-user precoding with up to two streams independently, and multiple ABSs transmit the same or different streams to one AMS. Sounding based Co-MIMO and CL-MD are supported for TDD, and codebook based ones are supported for both TDD and FDD.

18.2.2.1 Closed-loop Multi-ABS MIMO

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

18.2.2.1.1 Inter-ABS 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, an ABS that is unable to decode data for a particular user may request a neighboring ABS 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-ABS MIMO techniques, channel state information can be derived either through different pilots or sounding channels per sector or cell.

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

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

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

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

18.2.2.1.2 Measurement Support

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

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

In order to support codebook based CL-MD, the AMS is capable of measuring the channel from the interfering ABS, and calculate the PMI for it. In order to support sounding based CL-MD, the ABS is capable of measuring the channel from an interfering AMS, and calculates the precoding matrix for it.

In order to support codebook based Co-MIMO, the AMS is capable of measuring the channel from all ABSs involved in coordination, and calculates the PMIs for them. In order to support sounding based Co-MIMO, the ABSiscapable of measuring the channel from all AMSs involved in coordination, and calculates the precoding matrixes for these users.

18.3 Interference Mitigation using Power Control and Scheduling

ABS may use various techniques to mitigate the interference experienced by AMS 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, ABS 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. ABS can exchange information related to UL power control schemes with other neighbor ABSs. AMS may use interference information and its downlink measurements to control the uplink interference it causes to adjacent cells.

Using interference information ABS may attempt intra-ABS techniques such as alternative traffic scheduling, adjustment of MCS to avoid interference and ABS may also use inter-ABS techniques such as the examples depicted in Sections 20.1and 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 11.10.2). Both the UL and DL power control techniques may be further cooperated with the FFR (Section 20.1) and the advanced antenna technologies (Section 20.2) for better performances.

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

18.4 Interference Mitigation Using Cell/sector-specific Interleaving

Cell/sector specific interleaving may be used to randomize the transmitted signal, in order to allow for interference suppression at the receiver.

19 RF Requirements

20 Inter-ABS Synchronization

20.1 Network Synchronization

For TDD and FDD realizations, it is recommended that all ABSs should be time synchronized to a common timing signal. In the event of the loss of the network timing signal, ABSs continues to operate and automatically resynchronizes to the network timing signal when it is recovered. The synchronizing reference is 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 ABSs provided that they meet the frequency accuracy requirements of [TBD]. This applies during normal operation and during loss of timing reference.

20.2 Downlink Frame Synchronization

At the ABS, the transmitted downlink radio frame is 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, is 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 100 shows the protocol architecture of IEEE 802.16e which will be used as reference system. The MAC layer is composed of two sublayers: Convergence Sublayer (CS) and MAC Common Part Sublayer (CPS).

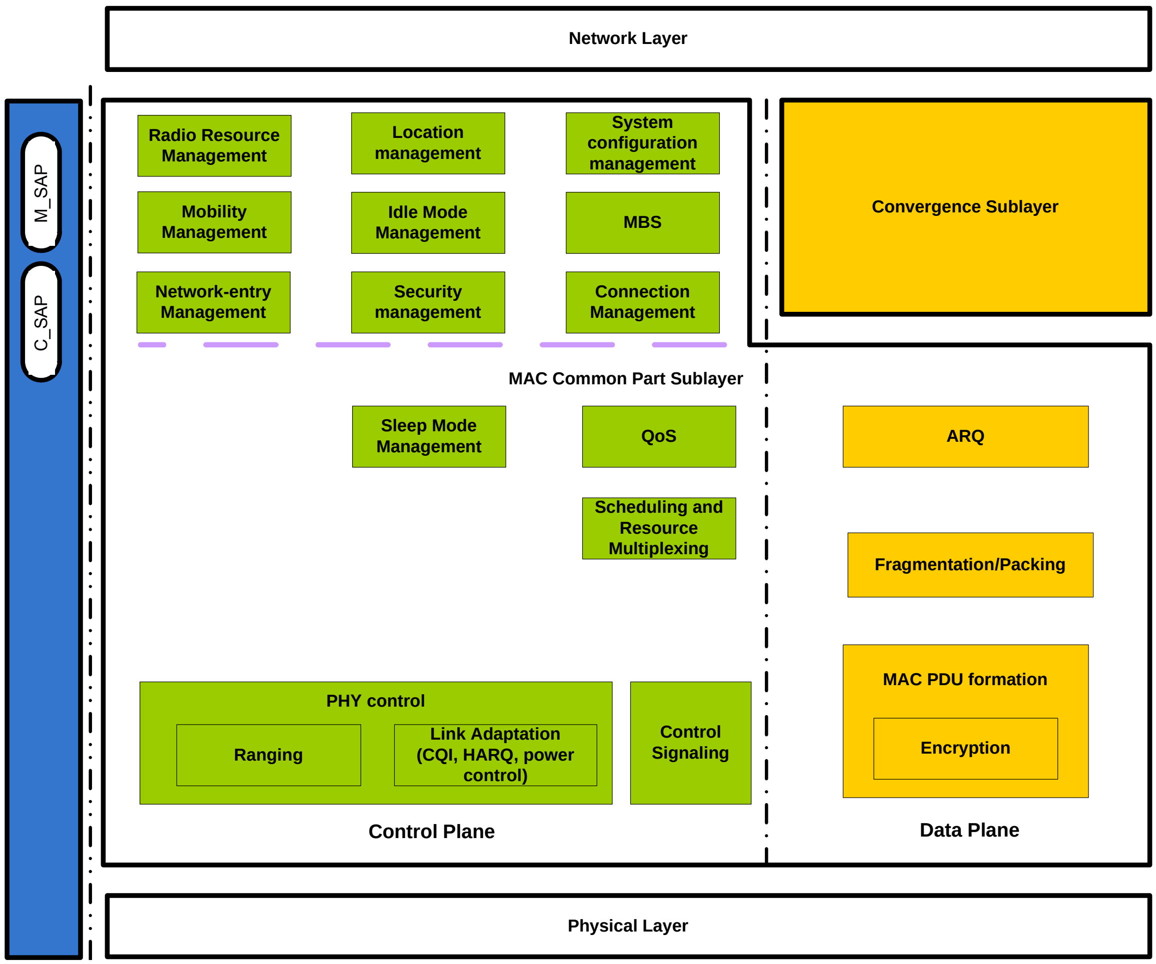

Figure 100: The IEEE 802.16e protocol architecture

For convenience, the 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 relate to radio resource functionalities 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 processes related to handover procedure. Mobility Management block manages candidate neighbor target ABSs based on some criteria, e.g. PHY signaling report, loading, etc. and also decides whether AMS performs 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 the initialization procedures, i.e., ranging (this does not mean physical ranging, it implies the ranging messages needed to in order to assist in the 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 AMS, 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 operates 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 a sequence number is assigned to each logical 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 ABS/AMS 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 AMS/ABS 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 a sub-header is then added 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.

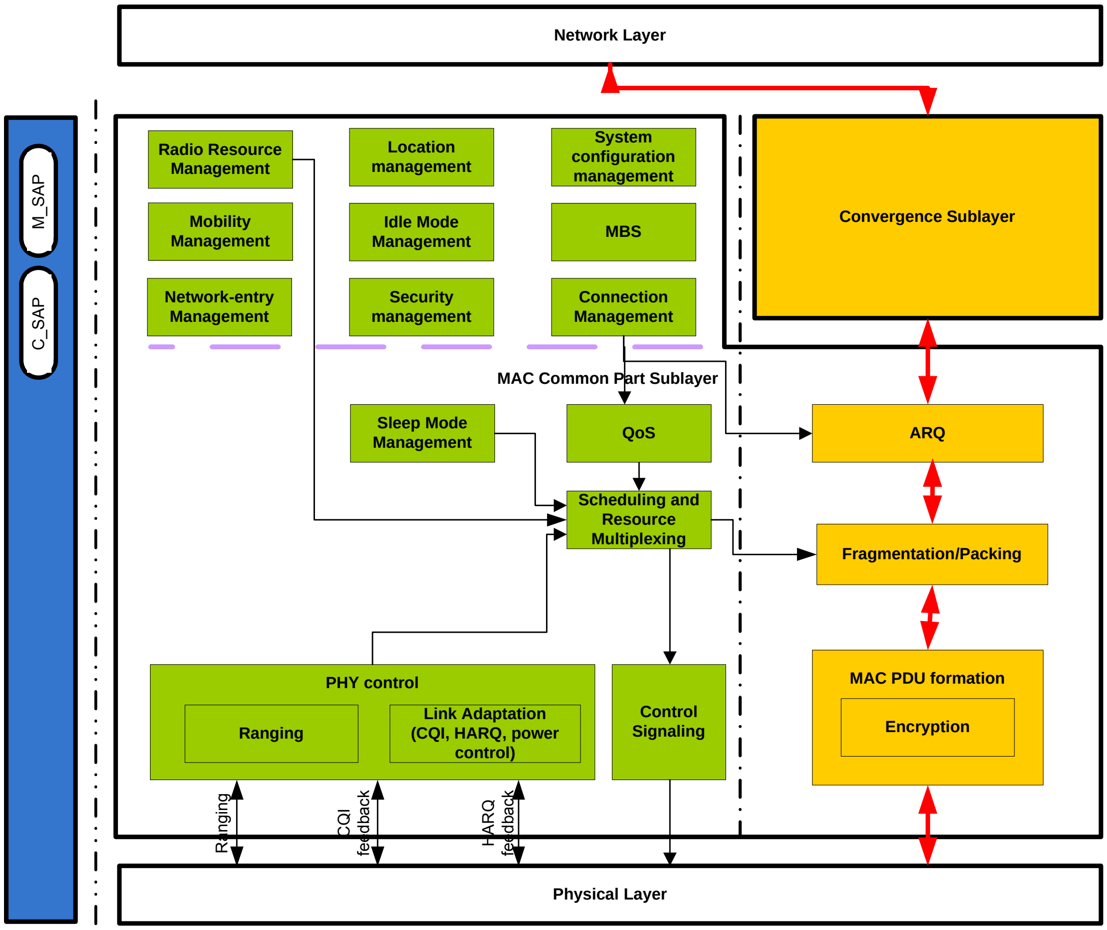

Figure 101: The IEEE 802.16e AMS/ABS data plane processing flow

A1.2 The IEEE 802.16e AMS/ABS Control Plane Processing Flow

Figure 102 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 messages 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 (AMS to ABS, ABS to AMS).

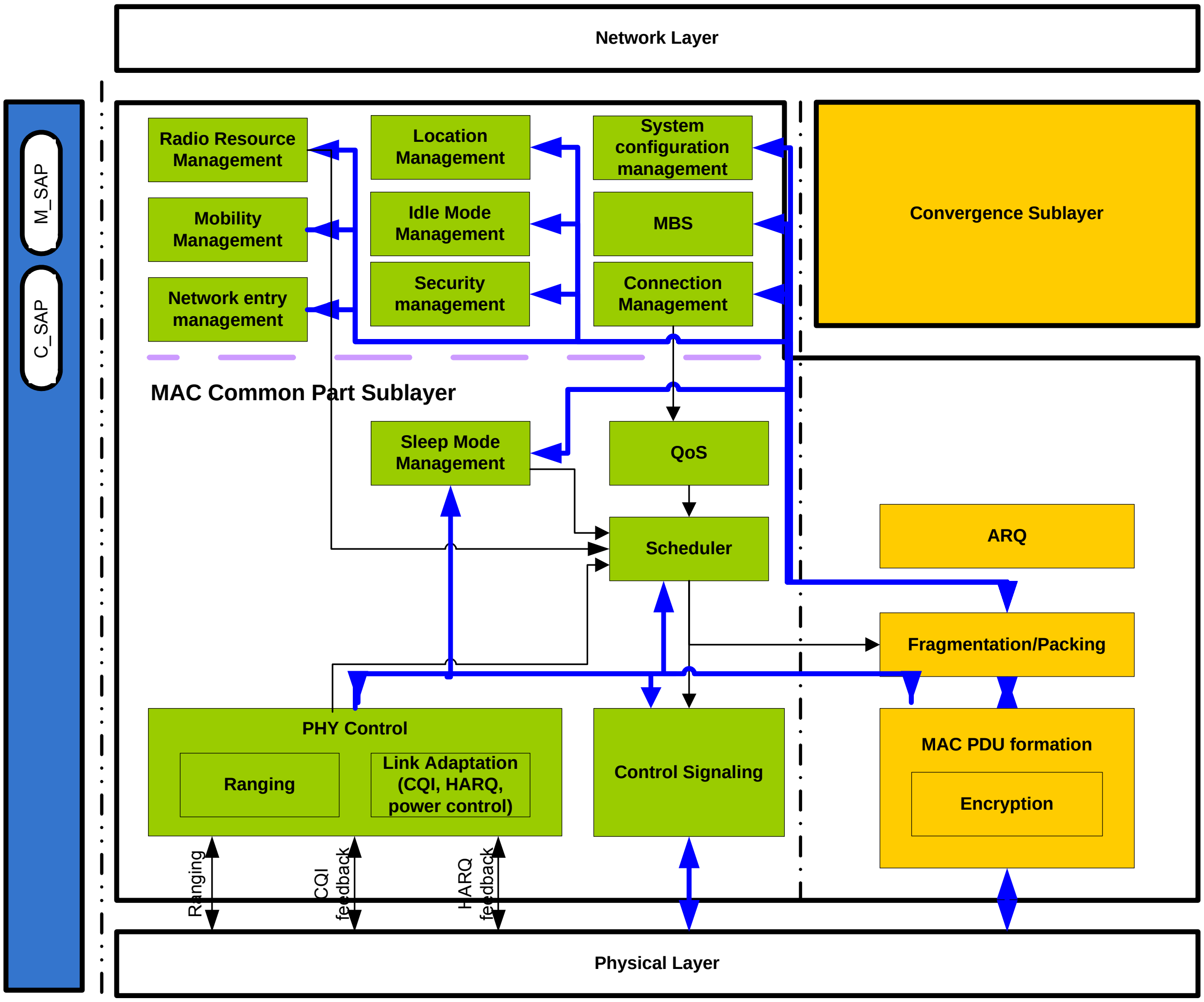

Figure 102: The IEEE 802.16e AMS/ABS control plane processing flow

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 16. The access latency with 30% frame error rate over the airlink is 4.67 AMS which is less than 10 AMS 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		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 + $T'_{ASN\_GW}+T_{R6}$

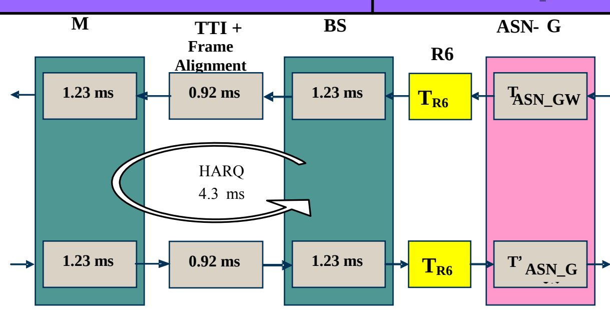

Table 16: Data plane access latency

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 17.

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 AMS, that further reduces the total delay budget. It is shown that the IDLE_STATE to ACTIVE_STATE transition time of less than 80 AMS 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 17: Control plane access latency