ITU Centres of Excellence for Europe

Next Generation Mobile and Wireless Networks

Module 4

4G mobile network: Mobile WiMAX 2.0 (IEEE 802.16m)

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4. Module 4: Mobile WiMAX 2.0 (IEEE 802.16m)

4.1. Introduction

Broadband wireless technologies have evolved in last ten years to keep pace with the growing demand for high bandwidth data requirements and applications. From proprietary BWA (broadband wireless access) technologies came fixed WiMAX in 2004 based on the IEEE 802.16d standard - providing a common platform for fixed and nomadic wireless broadband services.

Recognizing the importance of mobility the mobile WiMAX profile in 2005 based on the IEEE 802.16e standard was released - providing full mobility in addition to fixed and nomadic broadband services. Advanced antenna designs including MIMO (multiple-input/ multiple-output) along with other techniques including adaptive beamforming were subsequently added to increase performance, capacity and coverage of the networks.

The mobile WiMAX air interface utilizes orthogonal frequency division multiple access (OFDMA) as the preferred multiple-access method in the downlink (DL) and uplink (UL) for improved multipath performance and bandwidth scalability.

Even WiMAX provided high performance capabilities it still fell short of the International Telecom Union's (ITU) key requirements for consideration as an IMT advanced (4G) technology - specifically, providing downlink speeds of 100 Mbps in a wide area with high-mobility.

Since January 2007, the IEEE 802.16 Working Group has embarked on the development of a new amendment of the IEEE 802.16 standard (i.e., IEEE 802.16m) as an advanced air interface to meet the requirements of the IMT-Advanced.

At the ITU Telecom World 2009 conference in Geneva, Switzerland, the WiMAX Forum™ and member companies announced their support of the IEEE's submission to the ITU of the 802.16m standard as a candidate for consideration as an IMT advanced technology. The WiMAX Forum also announced that WiMAX Release 2, which is based on the standard, would be finalized in parallel with 802.16m, to ensure that the next generation of WiMAX networks and devices will remain backward compatible with WiMAX networks based on 802.16e.

IEEE 802.16m specification has been approved at the beginning of 2011. Initial availability of WiMAX 2.0 products based on 802.16m is expected at the beginning of 2012.

Depending on the available bandwidth and multi-antenna mode, the next-generation mobile WiMAX will be capable of over-the-air data-transfer rates in excess of 1 Gb/s and support a wide range of high-quality and highcapacity IP-based services and applications while maintaining full backward compatibility with the existing mobile WiMAX systems to preserve investments and continuing to support first-generation products. There are distinctive features and advantages such as flexibility and the extensibility of its physical and mediumaccess- layer protocols that make mobile WiMAX and its evolution more attractive and more suitable for the realization of ubiquitous mobile Internet access.

The next-generation mobile WiMAX will build on the success of the existing WiMAX technology and its time-to-market advantage over other mobile broadband wireless access technologies. In fact, all OFDM-based, mobile broadband access technologies that have been developed lately exploit, enhance, and expand fundamental concepts that were originally utilized in mobile WiMAX.

The IEEE 802.16m will be suitable for both green-field and it can also be deployed as an overlay to existing fixed or mobile access networks such as 2.5G/3G cellular systems or cable/digital subscriber line (DSL) networks by supporting different levels of interworking to ensure service continuity. The same network can used for a variety of usage models such as wireless backhaul to WiFi hot spots, fixed/nomadic access to customer premises equipment (CPE) and residential gateways (RGs), and mobile access to notebooks, smart phones, and next-generation WiMAX embedded ultra-mobile devices.

The WiMAX architecture also enables open access to Web-based applications and enhanced Internet services as well as operator managed "walled garden" services in the same network, allowing operators to explore creative service offerings and Internet friendly business models.

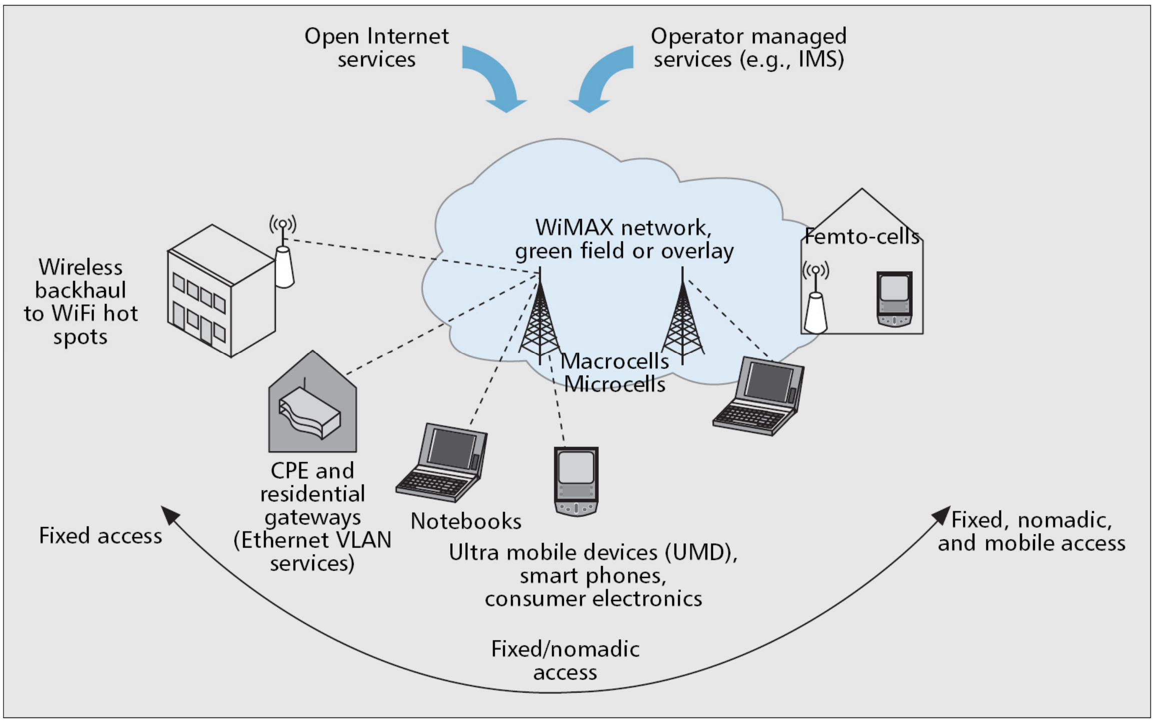


Figure 4.1 Mobile WiMAX enabling variety of usage models

The backward compatibility feature will allow smooth upgrades and an evolution path for the existing deployments. It will enable roaming and seamless connectivity across IMT-advanced and IMT-2000 systems through the use of appropriate interworking functions. In addition, the IEEE 802.16m system utilizes multihop relay architectures for improved coverage and performance.

4.2. IEEE 802.16m system requirements

Full backward compatibility and interoperability with the reference system is required for IEEE 802.16m systems, although the network operator can disable legacy support in green-field deployments. The reference system is defined as a system that is compliant with a subset of the IEEE 802.16e-2005 features. The backward compatibility feature ensures a smooth migration from legacy to new systems without any significant impact on the performance of the legacy systems, as long as they exist. Furthermore, the requirements for IEEE 802.16m were selected to ensure competitiveness with the emerging 4G radio-access technologies while improving and extending existing functionalities of the reference system.

The IMT-advanced requirements defined and approved by ITU-R/Working Party 5D and published as Report ITU-R M.2134 are referred to as target requirements in the IEEE 802.16m system requirement document and will be evaluated based on the methodology and guidelines specified by Report ITU-R M.2135. A careful examination of the IMT-advanced requirements reveals that they are a subset of, and less stringent than, the IEEE 802.16m system requirements; therefore, the IEEE 802.16m standard can qualify as an IMT-advanced technology. Table 1 summarizes the IEEE 802.16m baseline system requirements and the corresponding requirements specified by Report ITU-R M.2134.

Table 4.1 IEEE 802.16m and IMT-Advanced system requirements

Requirements	**IMT-Advanced [3]**	**IEEE 802.16m [6]**
Peak data rate (b/s/Hz)	DL: 15 (4 × 4) UL: 6.75 (2 × 4)	DL: 8.0/15.0 (2 × 2/4 × 4) UL: 2.8/6.75 (1 × 2/2 × 4)
Cell spectral efficiency (b/s/Hz/sector)	DL (4 × 2) = 2.2 UL (2 × 4) = 1.4 (base coverage urban)	DL (2 × 2) = 2.6 UL (1 × 2) = 1.3 (mixed mobility)
Cell-edge user spectral efficiency (b/s/Hz)	DL (4 × 2) = 0.06 UL (2 × 4) = 0.03 (base coverage urban)	DL (2 × 2) = 0.09 UL (1 × 2) = 0.05 (mixed mobility)
Latency	*C-plane: 100 ms (idle to active)* *U-plane: 10 ms*	*C-plane: 100 ms (idle to active)* *U-plane: 10 ms*
Mobility (b/s/Hz at km/h)	0.55 at 120 km/h 0.25 at 350 km/h (link-level)	Optimal performance up to 10 km/h Graceful degradation up to 120 km/h Connectivity up to 350 km/h Up to 500 km/h depending on operating frequency
Handover interruption time (ms)	Intrafrequency: 27.5 Interfrequency: 40 (in a frequency band) 60 (between frequency bands)	Intrafrequency: 27.5 Interfrequency: 40 (in a frequency band) 60 (between frequency bands)
VoIP capacity (Active users/sector/MHz)	40 (4 × 2 and 2 × 4) (Base coverage urban)	60 (DL 2 × 2 and UL 1 × 2)
Antenna configuration	Not specified	DL: 2 × 2 (baseline), 2 × 4, 4 × 2, 4 × 4, 8 × 8 UL: 1 × 2 (baseline), 1 × 4, 2 × 4, 4 × 4
Cell range and coverage	Not specified	Up to 100 km Optimal performance up to 5 km

Multicast and broadcast service (MBS)	Not specified	4 b/s/Hz for ISD 0.5 km 2 b/s/Hz for ISD 1.5 km
MBS channel reselection interruption time	Not specified	1.0 s (intrafrequency) 1.5 s (interfrequency)
Location-based services (LBS)	Not specified	Location determination latency < 30 s MS-based position determination accuracy < 50 m Network-based position determination accuracy < 100 m
Operating bandwidth	Up to 40 MHz (with band aggregation)	5 to 20 MHz (up to 100 MHz through band aggregation)
Duplex scheme	Not specified	TDD, FDD (support for H-FDD terminals)
Operating frequencies (MHz)	IMT bands 450–470 698–960 1710–2025 2110–2200 2300–2400 2500–2690 3400–3600	IMT bands 450–470 698–960 1710–2025 2110–2200 2300–2400 2500–2690 3400–3600

4.3. IEEE 802.16m network reference model

The baseline WiMAX network architecture is designed to meet the requirements while maximizing the use of open standards and IETF protocols in a simple all-IP architecture. Among the design requirements are supports for fixed and mobile access deployments as well as unbundling of access, connectivity, and application services to allow access infrastructure sharing and multiple access infrastructure aggregation.

The WiMAX network architecture can be logically represented by a network reference model (NRM) represented in Figure 4.2. It identifies key functional entities and reference points over which the network interoperability specifications are defined. The WiMAX NRM differentiates between network access providers (NAPs) and network service providers (NSPs). The NAP is a business entity that provides WiMAX radio access infrastructure, while the NSP is the business entity that provides IP connectivity and WiMAX services to WiMAX subscribers according to some negotiated service level agreements (SLAs) with one or more NAPs. The network architecture allows one NSP to have a relationship with multiple NAPs in one or different geographical locations. It also enables NAP sharing by multiple NSPs. In some cases the NSP may be the same business entity as the NAP.

The WiMAX NRM, consists of several logical network entities: MSs, an access service network (ASN), and a connectivity service network (CSN), and their interactions through reference points R1–R8. Each MS, ASN, and CSN represents a logical grouping of functions as described in the following:

- Mobile station (MS): generalized user equipment set providing wireless connectivity between a single or multiple hosts and the WiMAX network. In this context the term MS is used more generically to refer to both mobile and fixed device terminals.

- Access service network (ASN): represents a complete set of network functions required to provide radio access to the MS. These functions include layer 2 connectivity with the MS according to IEEE 802.16 standards and WiMAX system profile, transfer of auathentication, authorization, and accounting (AAA) messages to the home NSP (HNSP), preferred NSP discovery and selection, relay functionality for establishing layer 3 (L3) connectivity with MS (i.e., IP address allocation), as well as radio resource management. To enable mobility, the ASN may also support ASN and CSN anchored mobility, paging and location management, and ASN-CSN tunneling.

- Connectivity service network (CSN): a set of network functions that provide IP connectivity services to WiMAX subscriber(s). The CSN may further comprises network elements such as routers, AAA proxy/ servers, home agent, and user databases as well as interworking gateways or enhanced network servers to support multicast and broadcast services and location-based services. A CSN may be deployed as part of a green field WiMAX NSP or part of an incumbent WiMAX NSP. The following are some of the key functions of the CSN:

  – IP address management
  – AAA proxy or server
  – QoS policy and admission control based on user subscription profiles
  – ASN-CSN tunneling support
  – Subscriber billing and interoperator settlement
  – Inter-CSN tunneling for roaming
  – CSN-anchored inter-ASN mobility
  – Connectivity to Internet and managed WiMAX services such as IP multimedia services (IMS), location-based services, peer-to-peer services, and broadcast and multicast services
  – Over-the-air activation and provisioning of WiMAX devices

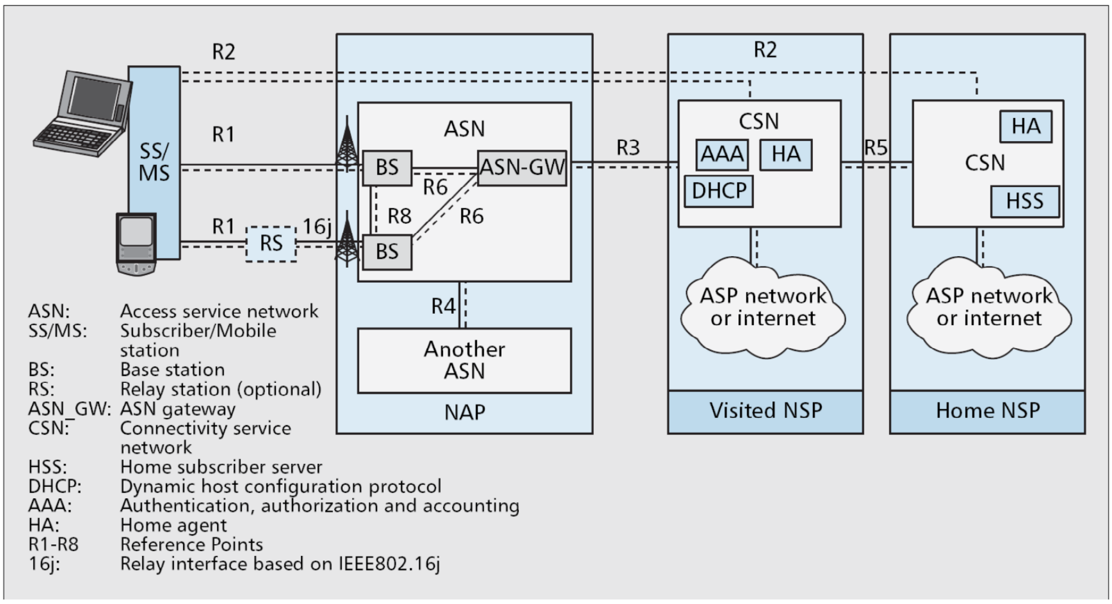


Figure 4.2 WiMAX Network Reference model

The network supports two tiers of mobility architecture. ASN anchored mobility occurs on every BS handover, irrespective of IP subnet/prefix or Mobile IP foreign agent changes. This handover is completely transparent to the core network (CSN) as the ASN functions manage data path changes within or between ASNs to maintain uplink (UL) and downlink (DL) bearer paths for the MS. The CSN anchored handover is triggered when the foreign agent or IP subnet/ prefix changes. This handover procedure is based on client or proxy Mobile IP for IPv4 or IPv6.

The ASN may be implemented as an integrated ASN where all functions are collocated in the same logical entity, or it may have a decomposed configuration in which the ASN functions are selectively mapped into two separate nodes, a BS and an ASN gateway (ASN-GW). A decomposed ASN may consist of one or more BSs and at least one instance of an ASN-GW. The BS and ASN-GW functions can be described as follows:

- Base station (BS): a logical network entity that primarily consists of the radio related functions of an ASN interfacing with an MS over-the-air link according to MAC and PHY specifications in IEEE 802.16 specifications subject to applicable interpretations and parameters defined in the WiMAX Forum system profile. In this definition each BS is associated with one sector with one frequency assignment but may incorporate additional implementation-specific functions such as a DL and UL scheduler.

- ASN gateway (ASN-GW): a logical entity that represents an aggregation of centralized functions related to QoS, security, and mobility management for all the data connections served by its association with BSs through R6t. The ASN-GW also hosts functions related to IP layer interactions with the CSN through R3 as well as interactions with other ASNs through R4 in support of mobility.

Typically multiple BSs may be logically associated with an ASN. Also, a BS may be logically connected to more than one ASN-GW to allow load balancing and redundancy options.

The WiMAX network specification defines a single decomposed ASN profile (ASN C) with an open R6 interface as well as an alternative ASN profile B that may be implemented as an integrated or a decomposed ASN in which R6 is proprietary or not exposed.

The normative definitions of intra-ASN reference points (R6 and R8) are only applicable to profile C. Note that in release 1.5 profile A has been removed to reduce the number of implementation options and create a better framework for network interoperability.

4.3.1. WIMAX network evolution

The mobile WiMAX roadmap currently shows three releases of the network specifications: 1.0, 1.5 and 2.0.

The initial release, 1.0, targeted basic mobile Internet services using an all-IP architecture supporting both integrated and decomposed ASN profiles. This release supports all basic features needed to enable early WiMAX deployments, including:

- ASN and CSN mobility (for mobility support)

- Paging and location management
- IPv4 and IPv6 connectivity
- Preprovisioned/static QoS
- Optional radio resource management (RRM)
- Network discovery/selection
- IP/Ethernet CS support
- Flexible credentials, pre- and postpaid accounting
- Roaming (RADIUS only)
- 3GPP I-WLAN compatible interworking

The WiMAX Network Release 1.5 development started in 2007 with a focus on enabling retail distributed devices, advanced managed IP services, and 3G interworking as well as commercial grade VoIP. The following are some of the key features of network release 1.5:

- Over-the-air (OTA) activation and provisioning
- Location-based services (LBS)
- Multicast broadcast service (MBS)
- IMS integration
- Dynamic QoS and policy and charging (PCC) compatible with 3GPP Release 7
- Telephony VoIP with emergency call services and lawful interception
- Full NAP sharing support
- Handover data integrity
- Multihost support
- Ethernet services, VLAN, DSL IWK
- Enhanced open Internet services

- Diameter-based AAA

Release 1.5 also defines the normative R8 between BSs and discontinues ASN profile A, leaving only one R6 definition in a single decomposed ASN configuration (profile C).

WiMAX network release 2.0is designed to enable e2e features to complement enhancements made in System Profile Release 2.0 based on IEEE 802.16m. Some features identified by the WiMAX Forum driven by new deployment requirements following release 1.5, are integrated as part of release 2.0. The following are examples of such features:

- Multimedia session continuity
- 3GPP/2 interworking (optimized handover)
- Network management, including self-organized/optimized networks (SONs)
- Seamless WiFi-WiMAX handover
- Roaming enhancements
- Support for multihop relay stations
- Support for femto-cells
- Device reported metrics

4.4. IEEE 802.16m protocol structure

The IEEE 802.16 standard describes medium-access-control (MAC) and physical layer (PHY) protocols for fixed and mobile broadband wireless-access systems. 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 required to support various radio resource configuration, coordination, signaling, and management. This set of functions is collectively referred to as the control-plane functions. A management plane also is defined for external management and system configuration. Therefore, all management entities fall into the management-plane category.

The IEEE 802.16 MAC layer is composed of two sublayers: the convergence sublayer (CS) and the MAC common-part sublayer (MAC CPS). For convenience, MAC CPS functions are classified into two groups based on their characteristics as shown in Figure 4.2.

The upper and lower classes are called the resource control and management functional group and the MAC functional group, respectively.

The control-plane functions and data-plane functions also are classified separately. As shown in Figure 4.2, the radio-resource control and management functional group comprises several functional blocks including:

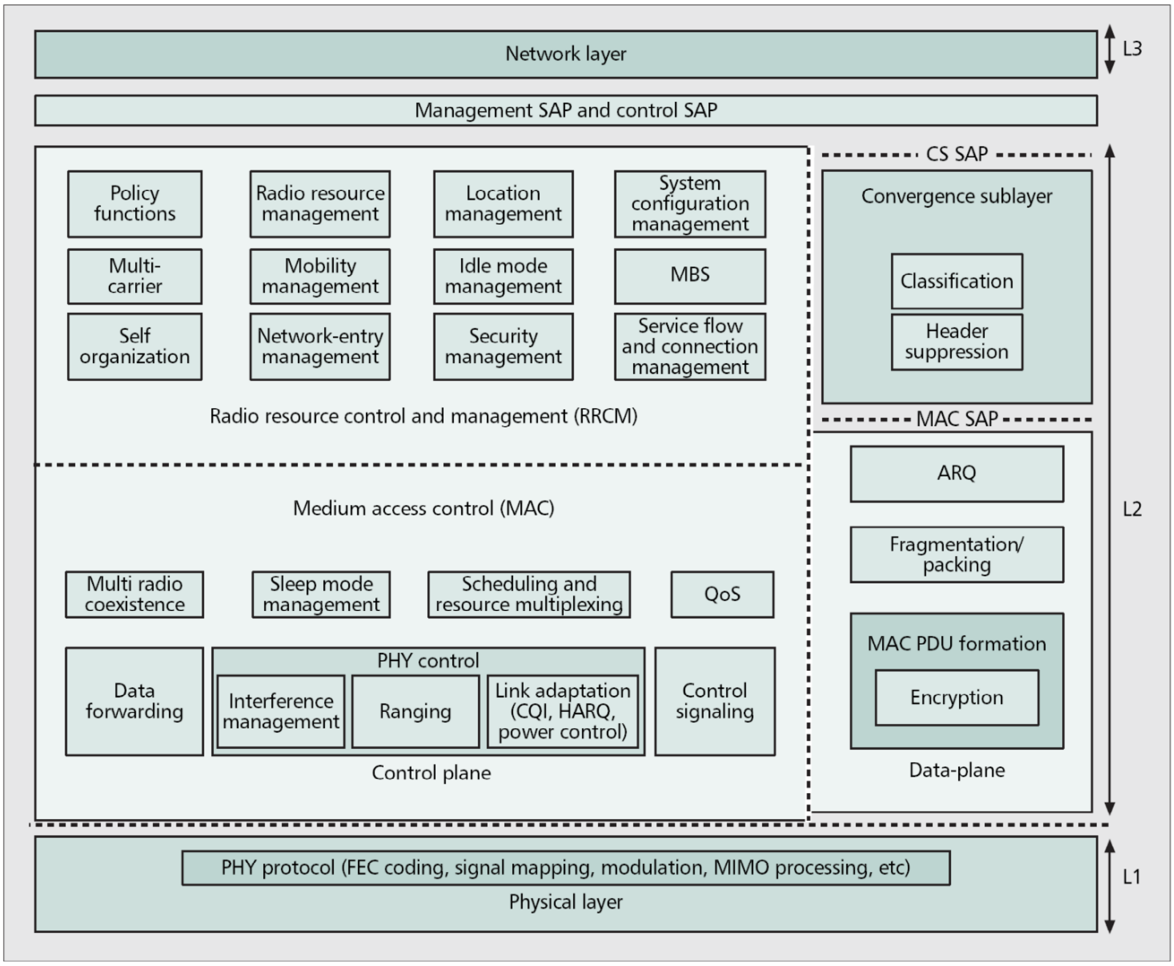


Figure 4.3 IEEE 802.16m protocol structure

- Radio-resource management: This block adjusts radio network parameters related to the traffic load and also includes the functions of load control (load balancing), admission control, and interference control.
- Mobility management: This block scans neighbor BSs and decides whether an MS should perform a handover operation.
- Network-entry management: This block controls initialization and access procedures and generates management messages during initialization and access procedures.
- Location management: This block supports location-based service (LBS), generates messages including the LBS information, and manages the location-update operation during idle mode.

- Idle-mode management: This block controls idle-mode operation and generates the paging- advertisement message, based on a paging message from the paging controller in the core network.

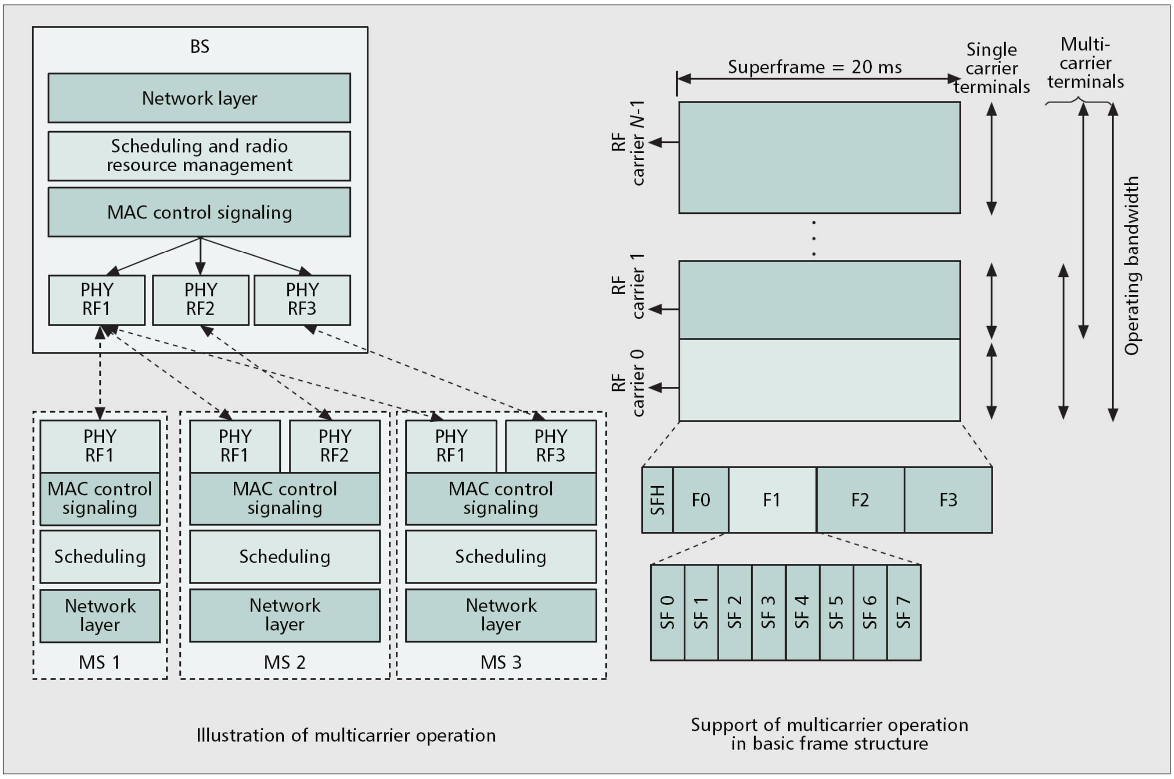


Figure 4.4 IEEE 802.16m multicarrier protocol stack and frame structure

- Security management: This block performs key management for secure communication. Using a managed key, traffic encryption/ decryption and authentication are performed.

- System configuration management: This block manages system-configuration parameters and generates broadcast-control messages, such as a DL/UL channel descriptor.

- Multicast and broadcast service (MBS): This block controls and generates management messages and data associated with the MBS.

- Connection management: This block allocates connection identifiers (CIDs) during initialization/handover service-flow creation procedures; interacts with the convergence sublayer to classify MAC service data units (MSDUs) from upper layers; and maps MSDUs into a particular transport connection.

The MAC functional group includes functional blocks that are related to physical layer and link controls such as:

- PHY control: This block performs PHY signaling such as ranging, channel quality measurement/feedback (CQI), and hybrid automatic repeat request (HARQ) acknowledgment (ACK) or negative acknowledgment (NACK) signaling.

- Control signaling: This block generates resource-allocation messages such as DL/UL medium-access protocol (MAP), as well as specific control signaling messages, and other signaling messages not in the form of general MAC messages (e.g., a DL frame control header).

- Sleep mode management: This block handles sleep mode operation and generates management messages related to sleep operation and can communicate with the scheduler block to operate properly according to the sleep period.

- Quality-of-service (QoS): This block performs rate control based on QoS input parameters from the connection management function for each connection.

- Scheduling and resource multiplexing: This block schedules and multiplexes packets based on the properties of the connections.

- Automatic repeat request (ARQ): This block performs the MAC ARQ function. For ARQ-enabled connections, the ARQ block splits MSDUs logically and sequences logical ARQ blocks.

- Fragmentation/packing: This block performs the fragmentation or packing of MSDUs based on input from the scheduler block.

- MAC PDU formation: This block constructs MAC protocol data units (PDUs) so that a BS/MS can transmit user traffic or management messages via PHY channels.

The IEEE 802.16m protocol structure is similar to that of IEEE 802.16 with additional functional blocks for new features including the following:

- Relay functions: Relay functionality and packet routing in relay networks

- Self-organization and self-optimization functions: a plug-and-play form of operation for an indoor BS (i.e., a femtocell)

- Multi-carrier functions: Control and operation of a number of adjacent or non-adjacent radio-frequency (RF) carriers where the RF carriers can be assigned to unicast and/or multicast and broadcast services. A single MAC instantiation is used to control several physical layers. If the MS supports multi-carrier operation, it can receive control and signaling, broadcast, and synchronization channels through a primary carrier, and traffic assignments can be made on the secondary carriers.
  A generalization of the protocol structure for multi-carrier support using a single MAC instantiation is shown in Figure 4.4. The load-balancing functions and the RF-carrier

mapping and control are performed by the radio-resource control and management functional class. From the perspective of an MS, the carriers utilized in a multi-carrier system can be divided into two categories:

– A primary RF carrier is the carrier that is used by the BS and the MS to exchange traffic and full PHY/MAC control information.

– A secondary RF carrier is an additional carrier that the BS may use for traffic allocations for mobile stations capable of multicarrier support.

Based on the primary and/or secondary usage, the carriers of a multi-carrier system can 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. The information and parameters related to multi-carrier operation and the other carriers also can be included in the control channels.

– Partially configured carrier: A carrier with only essential control-channel configuration to support traffic exchanges during multicarrier operation. If the user-terminal RF front end and/or its baseband is not capable of processing more than one RF carrier simultaneously, the user terminal may be allowed, in certain intervals, to monitor secondary RF carriers and to resume monitoring of the primary carrier prior to transmission of the synchronization, broadcast, and non-user-specific control channels.

• Multi-radio coexistence functions: Protocols for multi-radio coexistence, where the MS generates management messages to report the information about its co-located radio activities obtained from the inter-radio interface, and the BS responds with the corresponding messages to support multi-radio coexistence operation.

4.5. IEEE 802.16m Physical Layer characteristics

4.5.1. WiMAX 2.0 Frequency band support

The first release of WiMAX was TDD and most of the deployments were in 2.3, 2.5 and 3.5 GHz bands. Later in release 1.5 additional support for FDD and H-FDD were introduced with new spectrum in 1.7 and 2.1 GHz were added. IEEE 802.16m identified new frequency bands for FDD and TDD deployment of systems (Table 4.2).

4.5.2. IEEE 802.16m Operation modes and frame structure

IEEE 802.16m uses OFDMA as the multiple access scheme in the DL and UL. It further supports both time-division duplex (TDD) and frequency-division duplex (FDD) schemes including the half-duplex FDD (HFDD) operation of the mobile stations in the FDD networks.

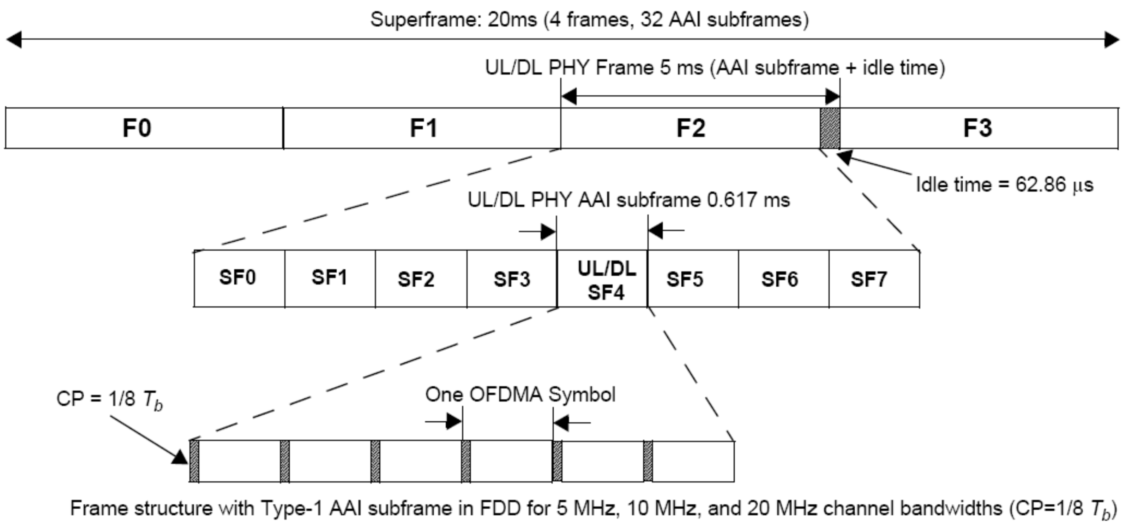
Table 4.2 IEEE 802.16m frequency bands

Band Class	UL AMS Transmit Frequency (MHz)	DL AMS Receive Frequency (MHz)	Duplex Mode
1	2300-2400	2300-2400	TDD
2	2305-2320, 2345-2360	2305-2320, 2345-2360	TDD
	2345-2360	2305-2320	FDD
3	2496-2690	2496-2690	TDD
	2496-2572	2614-2690	FDD
4	3300-3400	3300-3400	TDD
5L	3400-3600	3400-3600	TDD
	3400-3500	3500-3600	FDD
5H	3600-3800	3600-3800	TDD
6	1710-1770	2110-2170	FDD
	1920-1980	2110-2170	FDD
	1710-1755	2110-2155	FDD
	1710-1785	1805-1880	FDD
	1850-1910	1930-1990	FDD
	1710-1785, 1920-1980	1805-1880, 2110-2170	FDD
	1850-1910, 1710-1770	1930-1990, 2110-2170	FDD
7	698-862	698-862	TDD
	776-787	746-757	FDD
	788-793, 793-798	758-763, 763-768	FDD
	788-798	758-768	FDD
	698-862	698-862	TDD/FDD
	824-849	869-894	FDD
	880-915	925-960	FDD
	698-716, 776-793	728-746, 746-763	FDD
8	1785-1805, 1880-1920, 1910-193, 2010-2025, 1900-1920	1785-1805, 1880-1920, 1910-193, 2010-2025, 1900-1920	TDD
9	450-470	450-470	TDD
	450.0-457.5	462.5-470.0	FDD

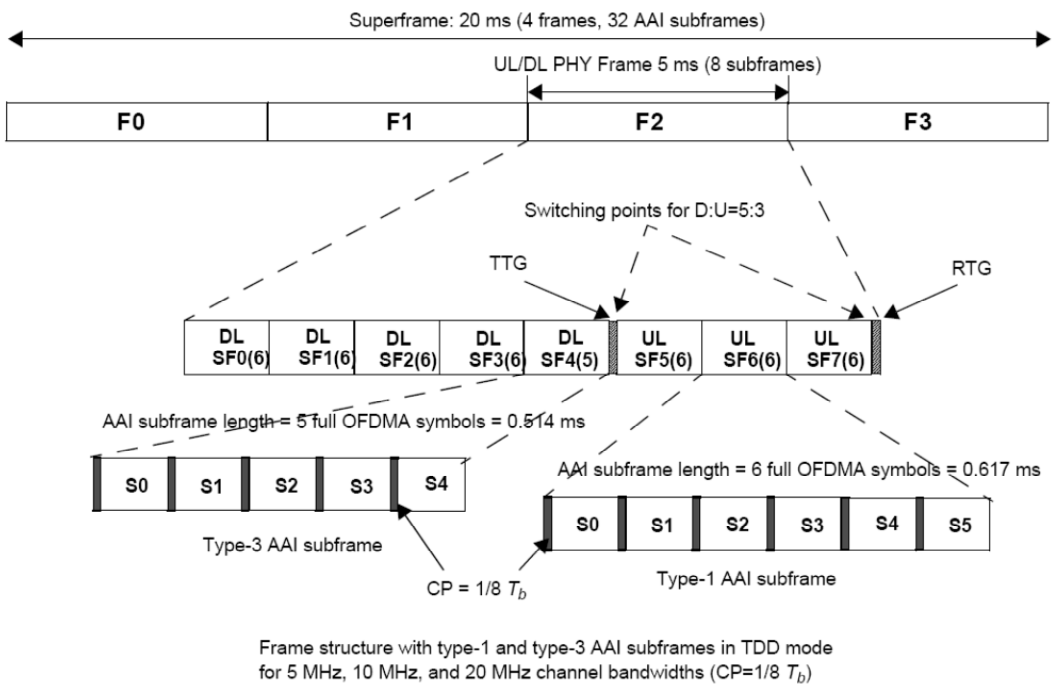
The frame structure attributes and baseband processing are common for both duplex schemes.

The super-frame is a new concept introduced in IEEE 802.16m, where a super-frame is a collection of consecutive, equally-sized radio frames, where the beginning is marked with a super-frame header. The super-frame header carries short-term and long-term system-configuration information (Figure 4.5).

To decrease the air-link access latency, the radio frames are further divided into a number of sub-frames where each sub-frame comprises an integer number of OFDMA symbols. The transmission time interval is defined as the transmission latency over the air-link and is equal to a multiple of sub-frame length (default one sub-frame).



a) FDD mode



b) TDD mode

Figure 4.5 IEEE 802.16m frame structure for 5/10/20 MHz channel bandwidth

There are three types of sub-frames depending on the size of the cyclic prefix:

- Type-1 subframe, which consists of six OFDMA symbols
- Type-2 subframe, which consists of seven OFDMA symbols
- Type-3 subframe, which consists of five OFDMA symbols

In all of the sub-frame types, some of the symbols can be idle symbols. In the basic frame structure, the super-frame length is 20 ms (comprising four radio frames), radio frame size is 5 ms (comprising eight sub-frames), and sub-frame length is 0.617 ms. The use of the sub-frame concept with the latter parameter set would reduce the one-way air-link access latency from 18.5 ms (corresponding to the reference system) to less than 5 ms.

The concept of time zones that is applied to both TDD and FDD systems was introduced in IEEE 802.16m. The new and legacy time zones are time-division multiplexed across the time domain for the DL. For UL transmissions, both time- and frequency-division multiplex approaches are supported for the multiplexing of legacy and new terminals. The non-backward compatible improvements and features are restricted to the new zones. All backward compatible features and functions are used in the legacy zones. In the absence of a legacy system, the legacy zones disappear, and the entire frame is allocated to the new zones.

The legacy and new radio frames are offset by a fixed number of sub-frames to accommodate new features such as the IEEE 802.16m preambles, super-frame header (system-configuration information), and control channels (Figure 4.6).

Multiple-RF carriers can be accommodated with the same frame structure that is used for single-carrier operation. All RF carriers are time aligned at the frame, subframe, and symbol level (Figure 4.4).

Alternative frame structures for 7 and 8.75 MHz bandwidth, as well as for CP = 1/16 and CP = 1/4 are used, which incorporate a different number of OFDMA symbols per sub-frame or a different number of sub-frames per frame.

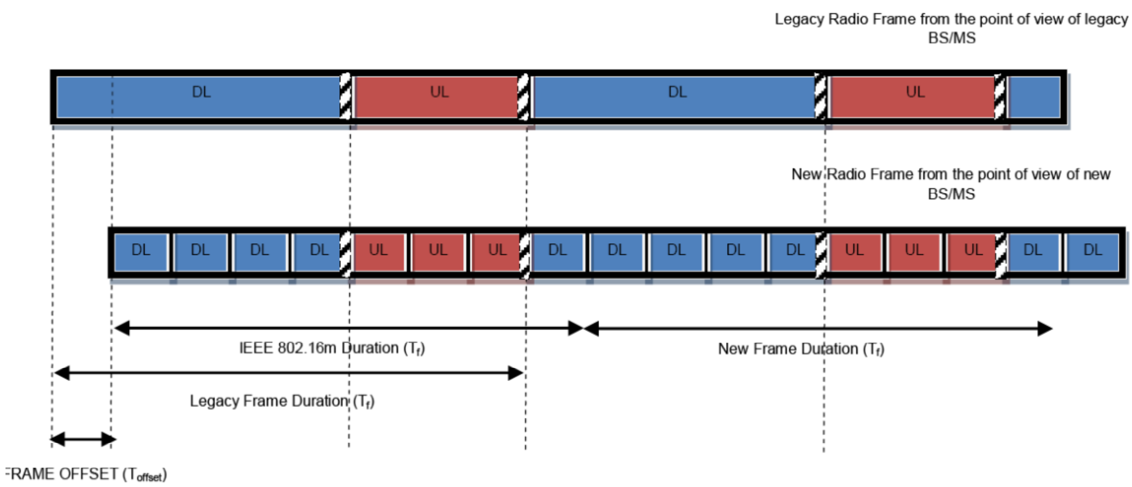


Figure 4.6 IEEE 802.16m and IEEE 802.16 e frames coexistence

4.5.3. Physical and logical resource blocks

A physical resource unit is the basic physical unit for resource allocation that comprises 18 contiguous subcarriers by six contiguous OFDMA symbols. A logical resource unit is the basic logical unit for distributed and localized resource allocations. A logical resource unit comprises 18× 6 subcarriers occupying a 196.88-kHz bandwidth in the frequency domain.

Distributed resource units are used to achieve frequency diversity gain. A distributed resource unit contains a group of subcarriers that are spread across a frequency partition. The size of the distributed resource units is equal to that of a physical resource unit. Localized resource units are used to achieve a frequency-selective scheduling gain. A localized resource unit comprises a group of subcarriers that are contiguous across frequency. The size of the localized resource units is equal to that of the physical resource units. To form distributed and localized resource units, the subcarriers over an OFDMA symbol are partitioned into guard and used subcarriers.

4.5.4. MODULATION AND CODING

IEEE 802.16m supports quadrature-phase shift keying (QPSK), 16-QAM, and 64-QAM modulation schemes in the DL and UL. The performance of adaptive modulation generally suffers from the power inefficiencies of multilevel- modulation formats. This is due to the variations in bit reliabilities caused by the bit-mapping onto the signal constellation.

Table 4.2 Modulation and coding schemes

MCS index	Modulation	Code rate
0000	QPSK	31/256
0001	QPSK	48/256
0010	QPSK	71/256
0011	QPSK	101/256
0100	QPSK	135/256
0101	QPSK	171/256
0110	16QAM	102/256
0111	16QAM	128/256
1000	16QAM	155/256
1001	16QAM	184/256
1010	64QAM	135/256
1011	64QAM	157/256
1100	64QAM	181/256
1101	64QAM	205/256
1110	64QAM	225/256
1111	64QAM	237/256

To overcome this issue, a constellation rearrangement scheme is utilized where a signal constellation of quadrature amplitude modulation (QAM) signals between retransmissions is rearranged; that is, the mapping of the bits onto the complex-valued symbols between successive HARQ retransmissions is changed, resulting in averaging the bit reliabilities over several retransmissions and lower packet-error rates. The mapping of bits to the constellation point depends on the constellation rearrangement type used for HARQ retransmissions and also can depend on the MIMO scheme. The complex-valued modulated symbols are mapped to the input of the MIMO encoder. Incremental-redundancy HARQ is used in determining the starting position of the bit selection for HARQ retransmissions.

Both convolutional code and convolutional turbo code with variable code rate and repetition coding are supported. The modulation and coding schemes used in a data transmission are selected from a set of 16 modulation coding schemes (MCSs). Note that rate matching is used to create more MCS granularity.

4.5.5. Multi-antenna techniques in IEEE 802.16m

WiMAX 2.0 (IEEE 802.16m) supports several advanced multi-antenna techniques including single and multi-user MIMO (spatial multiplexing and beam-forming) as well as a number of transmit diversity schemes. In single-user MIMO (SU-MIMO) scheme only one user can be scheduled over one resource unit, while in multi-user MIMO (MU-MIMO), multiple users can be scheduled in one resource unit.

4.5.5.1. 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 MS, or beamforming gain. Both open-loop SU-MIMO and closed-loop SU-MIMO is supported in 16m. For open-loop SU-MIMO, both spatial multiplexing and transmit diversity schemes are supported. 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.

SU-MIMO schemes

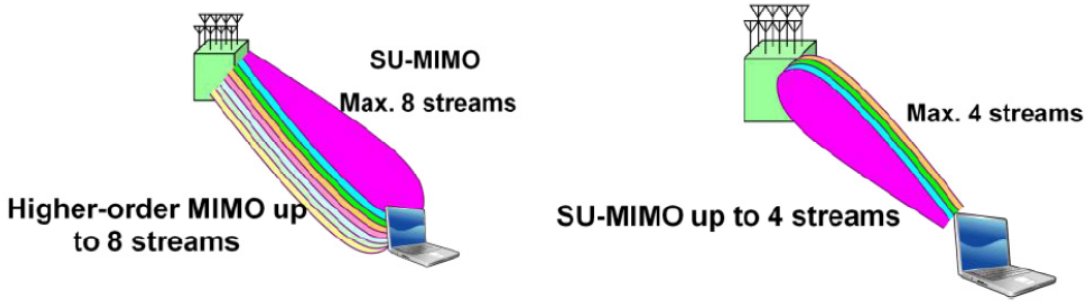


Figure 4.7 SU-MIMO

4.5.5.2. MU-MIMO

Multi-user MIMO (MU-MIMO) schemes are used to enable resource allocation to communicate data to two or more MSs . MU-MIMO enhances the system throughput. Multi-user transmission with one stream per user is supported in MU-MIMO mode. 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.

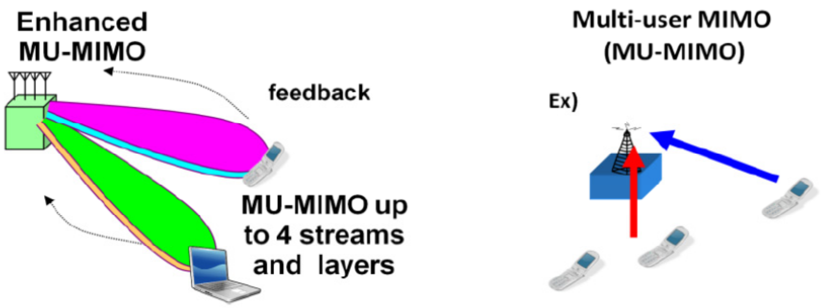


Figure 4.7 MU-MIMO

4.5.5.3. 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 can be considered. For closed-loop multi-BS MIMO, CSI feedback via codebook based feedback or sounding channel will be used. The feedback information may be shared by neighboring BSs via network interface. This places significant obligation in low latency backhauls. COMP - Coordinated multi-point (CoMP) is a new class of transmission schemes for interference reduction in the 802.16m technology. Enabling features such as network synchronization, cell- and user-specific pilots, feedback of multicell channel state information and synchronous data exchange between the base stations can be used for interference mitigation and for possible macro diversity gain. The collaborative MIMO (Co-MIMO) and the closed-loop macro diversity (CL-MD) techniques are examples of the possible options. For downlink Co-MIMO, multiple BSs perform joint MIMO transmission to multiple MSs located in different cells. Each BS performs multi-user precoding towards multiple MSs, and each MS is benefited from Co-MIMO by receiving multiple streams from multiple BSs. For downlink CL-MD, each group of antennas of one BS performs narrow-band or wide-band single-user precoding with up to two streams independently, and multiple BSs.

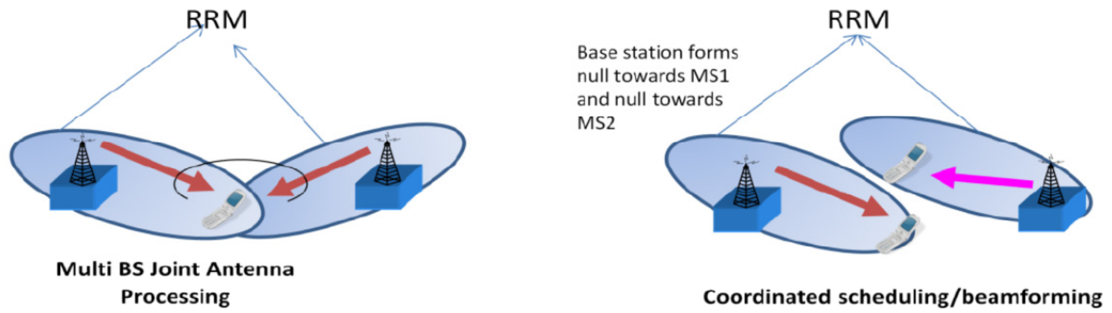


Figure 4.8 Multi BS-MIMO

In DL and UL different MIMO techniques are available in 802.16m. They are listed in Table 4.3 and 4.4 respectively.

Table 4.3 Supported MIMO techniques by IEEE 802.16m in DL

Mode index	Description	MIMO encoding format (MEF)	Possible number of antenna in BS	Maximum number of streams at BS
Mode 0	Open-loop SU-MIMO	SFBC	2,4,8	2
Mode 1	Open-loop SU-MIMO (spatial multiplexing)	Vertical encoding	2,4,8	8
Mode 2	Closed-loop SU-MIMO (spatial multiplexing)	Vertical encoding	2,4,8	8
Mode 3	Open-loop MU-MIMO (spatial multiplexing)	Horizontal encoding	2,4,8	4
Mode 4	Closed-loop MU-MIMO (spatial multiplexing)	Horizontal encoding	2,4,8	4
Mode 5	Open-loop SU-MIMO (TX diversity)	Conjugate Data Repetition	2,4,8	1

Table 4.4 Supported MIMO techniques by IEEE 802.16m in UL

Mode index	Description	MIMO encoding format (MEF)	Maximum number of transmit antenna	Maximum No. of streams per MS
Mode 0	Open-loop SU-MIMO	SFBC	2,4	2
Mode 1	Open-loop SU-MIMO (spatial multiplexing)	Vertical encoding	2,4	4
Mode 2	Closed-loop SU-MIMO (spatial multiplexing)	Vertical encoding	2,4	4
Mode 3	Open-loop Collaborative spatial Multiplexing (MU-MIMO)	Vertical encoding	2,4	3
Mode 4	Closed-loop Collaborative spatial Multiplexing (MU-MIMO)	Vertical encoding	2,4	3

4.6. IEEE 802.16M MAC layer

There are various MAC functionalities and features that are specified by the IEEE 802.16m standard, some of which are extensions of the existing features in mobile WiMAX. The following sections briefly describe selected MAC features.

4.6.1. MAC addressing

The IEEE 802.16m standard defines permanent and temporary addresses for a mobile station that identify the user and its connections during operation. The MS is identified by a unique 48-bit identifier. The MS is further assigned the following temporary identifiers:

- A station identifier during network entry (or network re-entry) that uniquely identifies the MS within the cell
- A flow identifier that uniquely identifies the management and transport connections with the MS.

4.6.2. Network entry

Network entry is the procedure through which an MS detects a cellular network and establishes a connection with that network. The network entry includes the following steps:

- Synchronization with the BS by acquiring the preambles
- Acquiring the required information such as BS and network service provider identifiers for initial network entry and cell selection
- Ranging

- Authentication and registration
- Service-flow set up

Neighbor search is based on the same DL signals as initial network search except that some information is provided through neighbor advertisement messages by the serving BS.

4.6.3. Connection management

Connections are identified by the combination of the station identifier and the flow identifier. Two types of connections (i.e., management and transport connections) are specified. Management connections are used to carry MAC management messages. Transport connections are used to carry user data including upper-layer signaling messages and data-plane signaling such as ARQ feedback. Fragmentation and augmentation of the MSDUs are supported on transport connections.

Management connection is bidirectional, and the predefined values of the flow identifier are reserved for unicast management connection(s). Management connections are established automatically after the station identifier is assigned to an MS during initial network entry. Transport connection, on the other hand, is unidirectional and is established with a unique flow identifier assigned during the service-flow establishment procedure. Each active service flow is uniquely mapped to a transport connection.

4.6.4. MAC management messages

To satisfy the latency requirements for network entry, handover, and state transition, IEEE 802.16m supports the fast and reliable transmission of MAC management messages. The transmission of MAC management messages using HARQ is under consideration, where retransmissions can be triggered by an unsuccessful outcome from the HARQ entity in the transmitter.

If the MAC management message is fragmented into multiple MSDUs, only unsuccessful fragments are retransmitted.

4.6.5. MAC header

IEEE 802.16m specifies an efficient MAC header for small payload applications comprising fewer fields with a shorter size, reducing the header size to two bytes. The new MAC header consists of the extended header indicator, flow identifier, and payload length fields.

4.6.6. ARQ and HARQ functions

An ARQ block is generated from one or multiple MSDUs or MSDU fragment(s). ARQ blocks can be variable in size and are sequentially numbered.

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. Then, the ARQ entity in the transmitter can initiate retransmission and resegmentation of the appropriate ARQ blocks.

IEEE 802.16m uses adaptive asynchronous and non-adaptive synchronous HARQ schemes in the DL and UL, respectively. The HARQ operation is relying on an *N*-process (multichannel) stop-and-wait protocol. In adaptive asynchronous HARQ, the resource allocation and transmission format for the HARQ retransmissions may be different from the initial transmission.

A non-adaptive synchronous HARQ scheme is used in the UL, where the parameters and the resource allocation for the retransmission are known a priori.

4.6.7. Mobility management and handover

IEEE 802.16m supports both network-controlled and MS-assisted handover (HO). The MS executes the HO as directed by the BS or cancels the procedure through the HO cancellation message.

The MS also can maintain communication with the serving BS while performing network re-entry at the target BS as directed by the serving BS. The HO procedure is divided into three stages: HO initialization, HO preparation, and HO execution. Upon completion of the HO execution, the MS is ready to perform network reentry with the target BS. In addition, the HO cancellation procedure is defined to allow an MS to cancel the HO procedure.

The HO preparation is completed when the serving BS informs the MS of its HO decision through the HO control command. The control signaling includes an action time for the MS to start network re-entry with the target BS and an indication whether the MS should maintain communication with the serving BS during network re-entry. If the communication cannot be maintained between the MS and the serving BS during network re-entry, the serving BS stops allocating resources to the MS for transmission in action time. If directed by the serving BS through the HO control command, the MS performs network re-entry with the target BS during action time while continuously communicating with the serving BS. The MS cannot exchange data with the target BS prior to completion of network re-entry.

4.6.8. Power management

Sleep mode is a state in which an MS performs pre-negotiated periods of absence from the serving BS. Using the sleep mode, the MS is provided with a series of alternative listening and sleep windows. The listening window is the time interval in which the MS is available for transmit/receive of control signaling and data.

The IEEE 802.16m has the capability of dynamically adjusting the duration of sleep and listening windows within a sleep cycle based on changing traffic patterns and HARQ operations. When the MS is in active mode, sleep parameters are negotiated between the MS and the BS. The BS instructs the MS to enter the sleep mode. MAC management messages can be used for the sleep mode request/response. The period of the sleep cycle is measured in units of frames or super-frames and is the sum of the sleep and listening windows. During the MS listening window, the BS can transmit the traffic indication message intended for one or multiple MSs.

Idle mode enables the MS to become periodically available for DL broadcast-traffic messaging such as paging a message without registering with the network. The network assigns MSs in the idle mode to a paging group during idle mode entry or location update. The MS monitors the paging message during the listening interval. The start of the paging-listening interval is calculated based on the paging cycle and the paging offset. The serving BS transmits the list of paging group identifiers at the predetermined location at the beginning of the paging available interval. The IEEE 802.16m paging mechanism uses a two-step procedure that includes a paging indication followed by a full paging message. The paging indications, if present, are transmitted at the predetermined location. The paging message contains the identification of the MSs to be notified of pending traffic or a location update.

4.6.9. Quality of Service

The QoS parameters are defined per service flow and thereby for each MAC connection established between the base station and mobile station. An MS can have multiple active service flows at each time instant. 16m MAC associates a unidirectional flow of packets which have a specific QoS requirement with a service flow. A service flow is mapped to one transport connection with one flow identifier. The BS and MS provide QoS according to the QoS parameter sets, which are negotiated between the BS and the MS during the service flow setup/change procedure. The QoS parameters can be used to schedule traffic and allocate radio resource. In addition, UL traffic may be policed based on the QoS parameters. The following are the typical QoS parameters that are used in conjunction with scheduling services in the 16m;

- Traffic priority
- Maximum sustained traffic rate
- Minimum reserved traffic rate
- Maximum latency

The following QoS classes are supported in 16m;

- **Unsolicited Grant Service (UGS)** is designed to support real-time service flows that transport fixed-size data packets on a periodic basis, such as T1/E1 and VoIP without silence suppression.
- **Real-time Polling Service (rtPS) is** designed to support real-time service flows that transport variable-size data packets on a periodic basis, such as Moving Pictures Experts Group (MPEG) video.
- **Extended rtPS (ertPS)** is a scheduling mechanism which builds on the efficiency of both UGS and rtPS. The ABS shall provide unicast grants in an unsolicited manner

like in UGS, thus saving the latency of a BR. However, whereas UGS allocations are fixed in size, ertPS allocations are dynamic.

- **Non-real-time polling service (nrtPS**) offers unicast polls on a regular basis, which assures that the service flow receives request opportunities even during network congestion. The ABS typically polls nrtPS connections on an interval on the order of one second or less.
- **Best effort (BE) service provides service for BE traffic.**

The proposed new 16m base station supports following additional information field parameters (relative to that of IEEE Std 802.16-2009 {1}):

- **Tolerated packet loss rate**: The value of this parameter specifies the maximum packet loss rate for the service flow.
- **Indication of Associated Flows**: A parameter that indicates the flow(s) that is associated with the current service flow if any.
- **Adaptive polling and granting: 16m supports adaptation of service flow QoS** parameters. One or more sets of QoS parameters are defined for one service flow. The 16m MS and 16m BS negotiate the supported QoS parameter sets during service flow setup procedure. When QoS requirement/traffic characteristics for traffic changes, the 16m BS may autonomously switch the service flow QoS parameters such as grant/polling interval or grant size based on predefined rules. In addition, the 16 MS may request the 16m BS to switch the Service Flow QoS parameter set with explicit signaling. The 16m BS then allocates resource according to the new service flow parameter set.

Scheduling Services: 16m also provides a specific scheduling service to support real-time non-periodical applications such as on-line gaming.

In addition to the above services, the system also supports:

Persistent Allocation (PA): PA is used to reduce resource allocation signaling (MAP) overhead for connections with periodic traffic pattern and with relatively fixed payload size.

Group Resource Allocation (GRA): GRA is used to reduce resource allocation signaling (MAP) overhead for multiple connections with a pre-determined and well-known packet size. Instead of allocating resources to single user, the ABS may create one or more groups, each group containing more than one user.

4.7. Relaying

Intelligent relays are an effective technology to achieve important deployment tools to provide cost effective methods of delivering high data rate and avoid coverage holes in deployments areas. In addition, upgrading the networks in order to support higher data rates is equivalent to an increase of signal-to-interference plus noise ratio (SINR) at the receivers' front-end. Also, through deployment the network providers have to avoid coverage area holes.

A traditional solution to increase the receiver's SINR is to deploy additional BSs or repeaters to serve the coverage area holes with required data rates. In most of the cases, the cost of the BS is relatively high and arranging backhauls quickly might be a challenge in serving coverage holes. By now industry has used RF repeaters; however repeater has the problem of amplifying the interference and has no intelligence of signal control and processing. In order to achieve a more cost effective solution, relay stations (RS) capable of decoding and forwarding the signals from source to destination through radio interface would help operators to achieve higher SINR in cost effective manner. Relay stations do not need a wire-line backhaul; the deployment cost of RSs is expected to be much lower than the cost of BSs. The system performance could be further improved by the intelligent resource scheduling and cooperative transmission in systems employing intelligent relays.

Deploying RS can improve IEEE 802.16m network in different dimensions. The following figures illustrate the different benefits that can be achieved by deploying RS within an IEEE802.16m network.

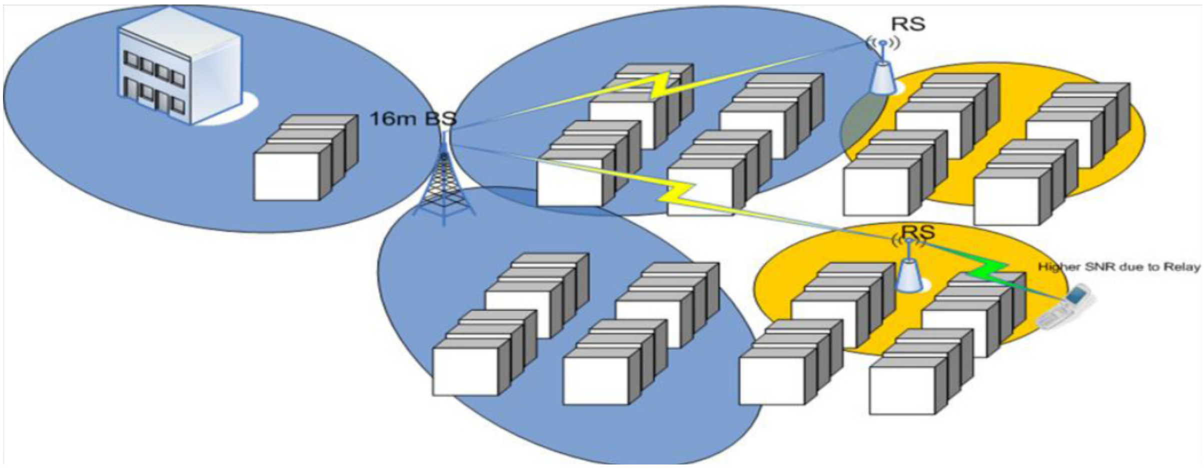


Figure 4.9 Relay usage in Mobile WiMAX 2.0

4.8. Femto-cells and self organizing networks

Femtocells in 802.16m are low powered access points typically used in home or SOHO to provide the access to closed or open group of users as configures by the subscribers. Femtocells are normally connected to service provider's network through broadband or other access technologies. For the femtocell BSs which can support Relay Link transmission, it may establish the air interface connection with the overlapped macrocell BS for exchange of control messages.

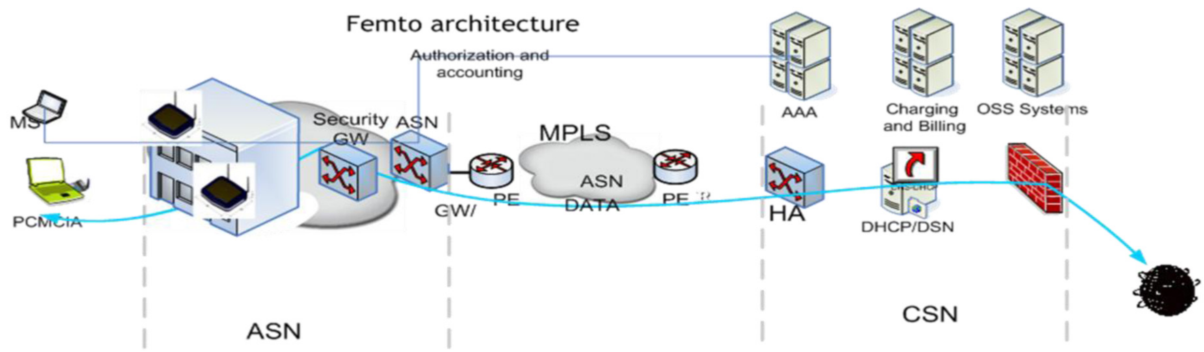


Figure 4.10 Femtocells and self organizing networks

Femtocell BS is intended to serve public users, like public WiFi hot spot, or to serve closed subscriber group (CSG) 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. Femtocells coupled with the features of self organizing systems, automatic neighbor establishment, coverage and capacity optimization, software up gradations and handover optimization will be supported in 16m to maximize the overall network performance. Please note that SON functions are intended for any BSs (e.g. Macro, Relay, Femtocell) to automate the configuration of BS and has remarkable ability to optimize network performance, coverage and capacity, but particularly are more important to femtocell , since femtocell is typically installed by a subscriber. The scope of SON in IEEE 802.16m is limited to the measurement and reporting of air interface performance metrics from MS/BS, and the subsequent adjustments of BS parameters.

Self organization can be divided into the following two;

- Initializing and configuring BSs automatically with minimum human intervention (Cell initialization, Neighbor discovery, and Neighbor Macro BS Discovery)

- Self-optimization 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.

4.9. Enhanced Multicast and broadcast services (E-MBS)

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. The E-MBS content is transmitted over an area identified as a zone. An E-MBS zone is a collection of one or more IEEE 802.16m BSs 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 802.16m MS can continue to receive the E-MBS within the E-MBS zone in Connected State or Idle State.

An 802.16m BS 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 sub-frame and to allow 802.16m MSs combining but without any acknowledgement from 802.16m MSs.

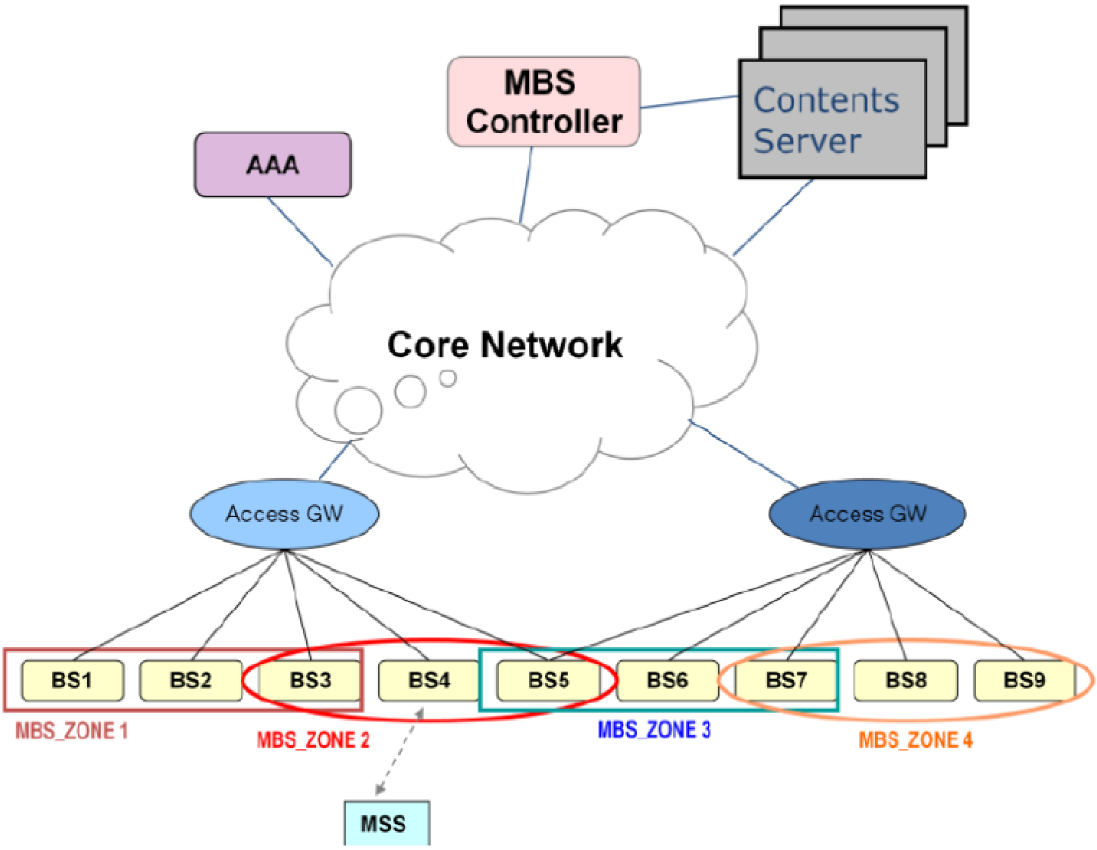


Figure 4.10 E-MBS delivery

4.10. Location based services

Location is seen as one the major new business model drivers in new WiMAX Networks. A major difference between mobile broadband networks and fixed networks is that the former can be subject to location changes. This provides a huge opportunity for location based services (LBS) which have very broad potential to integrate with high performance mobile services.

General LBS include the updating of maps, provision of information on the location of shops, service points, etc., depending on the location of the user. As LBS become more intuitive to use, require regular updates when on the move and have access to the sophistication of applications like Google Maps and Google Earth, they are expected to drive network traffic to considerable volumes.

Operators are strongly interested in LBS as a route to providing true personalized services, and, with true broadband connectivity, they will be able to take advantage of devices with embedded GPS to offer their own and third party services, e.g. using Google Maps or similar. Services such as these raise the possibility of new business models to be developed for charging users or specialist service providers for use of network capacity. 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

In order to enhance location based service, 802.16m MS should send report location-related information which includes the location information or the measurement for determining location in response to the request of 802.16m BS . In addition, LBS are supported for 802.16m MS 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, 802.16m MS should perform network re-entry to report location information when it is needed.

The 802.16m MS 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 802.16m MS and its serving/attached or/and neighboring 802.16m BSs/ARSs. Location determination methods contain GPS based methods, assisted GPS and not GPS based.

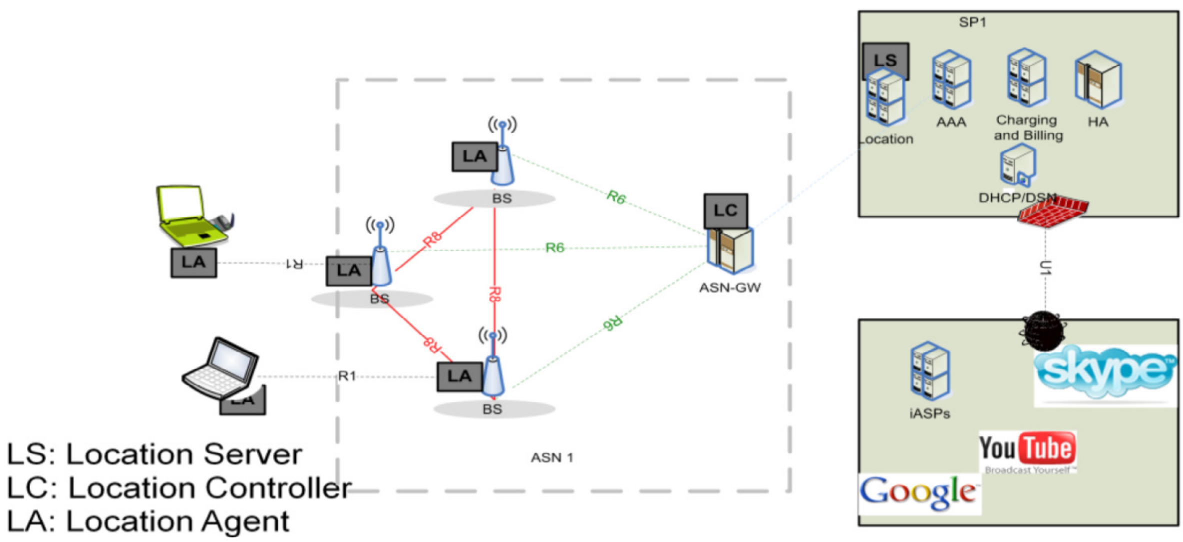


Figure 4.11 Architecture for LBS

4.11. VoIP over Mobile WiMAX

Mobile WiMAX provides a number of features to support VoIP. Prioritization of delay-sensitive VoIP traffic is achieved through the classification of flows into scheduling classes. Voice activity detection and Extended Real-Time Polling Service (ertPS) conserve air link resources during periods of silence. HARQ and channel aware scheduling are used reduce transmission latency over the air link. Protocol header compression is supported to transport the speech sample efficiently.

Silence suppression using ertPS

Service flows such as VoIP with silence suppression generate larger data packets when a voice flow is active, and smaller packets during periods of silence. rtPS is designed to support real-time service flows that generate variable size data packets on a periodic basis. rtPS requires more request overhead than UGS, but supports variable grant sizes. In conventional rtPS, a bandwidth request header is sent in a unicast request opportunity to allow the Subscriber Station (SS) to specify the size of the desired grant. The desired grant is then allocated in the next UL subframe.

Although the polling mechanism of rtPS facilitates variable sized grants, using rtPS to switch between VoIP packet sizes when the SS switches between the talk and silent states introduces access delay. rtPS also results in MAC overhead during a talk spurt since the size of the VoIP packet is too large to be accommodated in the polling opportunity, which only accommodates a bandwidth request header. The delay between the bandwidth request and subsequent bandwidth allocation with rtPS could violate the stringent delay constraints of a VoIP flow. rtPS also incurs a significant overhead from frequent unicast polling that is unnecessary during a talk spurt.

The ertPS scheduling algorithm improves upon the rtPS scheduling algorithm by dynamically decreasing the size of the allocation using a grant management subheader or increasing the size of the allocation using a bandwidth request header. The size of the required resource is signalled by the Mobile Station by changing the Most Significant Bit (MSB) in the transmitted data.

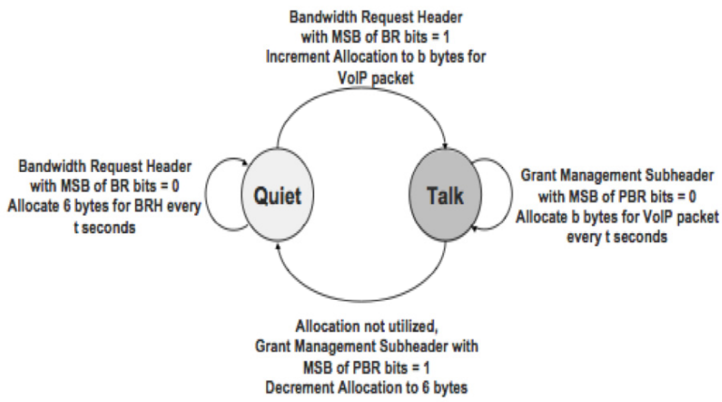


Figure 4.12 Request header and Grant Sub-header for VoIP packets

Hybrid ARQ

The one-way delay budget for VoIP on the DL or the UL is limited between 50 and 80 ms. This includes queuing and retransmission delay. Enabling HARQ retransmissions for error recovery significantly improves the ability of the system to meet the stringent delay budget requirements and outage criteria for VoIP.

Hybrid automatic repeat request (Hybrid ARQ or HARQ) is a combination of forward error-correcting coding and error detection using the ARQ error-control method. In standard ARQ, redundant bits are added to data to be transmitted using an error-detecting code such as cyclic redundancy check (CRC). In Hybrid ARQ, forward error correction (FEC) bits are added to the existing Error Detection (ED) bits to correct a subset of all errors while relying on ARQ to detect uncorrectable errors. As a result Hybrid ARQ performs better than ordinary ARQ in poor signal conditions, but in its simplest form this comes at the expense of significantly lower throughput in good signal conditions. There is typically a signal quality cross-over point below which simple Hybrid ARQ is better, and above which basic ARQ is better.

Channel Aware Scheduling

Unidirectional connections are established between the BS and the MS to control transmission ordering and scheduling on the mobile WiMAX air interface. Each connection is identified by a unique Connection Identification (CID) number. Every MS, when joining a network, sets up a basic connection, a primary management connection and a secondary management connection. Once all of the management connections are established, transport connections are set up. Traffic allocations on the DL and the UL are connection based, and a particular MS may be associated with more than one connection.

In every sector, the Base Station (BS) dynamically schedules resources in every Orthogonal Frequency Division Multiple Access (OFDMA) frame on the UL and the DL in response to traffic dynamics and time-varying channel conditions. Link adaptation is enabled through channel quality feedback, adaptive modulation and coding and HARQ. Resource allocation on the DL and UL in every OFDMA frame is communicated in Mobile Application Part (MAP) messages at the beginning of each frame. The DL-MAP is a MAC layer message, which is used to allocate radio resources to Mobile Stations (MS) for DL traffic. Similarly, the UL-MAP is a MAC layer message used to allocate radio resources to the MS for UL traffic. The BS uses information elements within the DL-MAP and UL-MAP to signal traffic allocations to the MS.

The BS scheduler also supports resource allocation in multiple subchannelization schemes to balance delay and throughput requirements with instantaneous channel conditions.

Dynamic Resource Allocation for VoIP

To support VoIP in an OFDMA system, VoIP packets need to be scheduled on the DL and the UL within a fixed delay bound every time a packet arrives at the BS and at the MS, respectively. The OFDMA resources in frequency and time as well as transmit power and transmission mode need to be specified in each allocation. Furthermore, the MS identification and HARQ transmission related information also need to be specified.

All this information is sent using a robust Modulation and Coding Scheme (MCS), thereby consuming additional resources. In WiMAX, control information associated with resource allocation is signalled through MAP elements. Compressed MAPs can be used with subMAPs to reduce MAP overhead. The compressed MAP header is coded with the most robust MCS and subMAPs can be coded with higher order MCSs. Although compressed MAPs and subMAPs conserve resources compared to conventional MAPs, MAP overhead associated with the larger number of allocations for VoIP can be considerably high.

Dynamic scheduling for every VoIP packet incurs a significant amount of MAP overhead. The motivation for persistent scheduling comes from the fact that the VoIP traffic is periodic and generates constant size packets. As the name suggests, persistent scheduling conserves resources by persistently allocating resources that are required periodically. We discuss two different ways of persistently allocating the resources, namely individual persistent scheduling and group scheduling.

Individual Persistent Scheduling: The basic idea behind individual persistent scheduling is that a user is assigned a set of resources for a period of time and the necessary information for the packet transmission are sent only once at the beginning of the assignment. For the rest of the period of allocation, the MS is assumed to know all of the information for data reception on the DL and data transmission on the UL. Note that the allocation period can be infinite. In other words, persistent scheduling is in effect until updated.

In the case of dynamic scheduling, a MAP element is required to specify resource allocation information every time a VoIP packet is scheduled. On the other hand, in the case of persistent scheduling, resource allocation information is sent once in a persistent MAP element and not repeated in the subsequent frames. The additional resource that becomes available due to MAP overhead reduction can be used to increase VoIP capacity.

Resource allocation/deallocation for talk spurts/silence periods

As discussed earlier, VoIP users switch between talk spurts and silence. On the average, users in a typical VoIP call will be in either mode for duration of the order of a second.

Every time a user goes into a talk spurt, resources need to be allocated with all of the information necessary to identify the allocation. The resource is allocated periodically with persistent scheduling as long as the user is in the active state. Similarly, every time the user goes into the silence mode, resources need to be deallocated. Since the frequency of allocation and deallocation of resource for conversational voice (50% voice activity factor) is typically once every 250 Mobile WiMAX frames (1.25 s), the overhead associated with a persistently scheduled allocation is small compared with the overhead in dynamic scheduling.

Link Adaptation/MCS Changes

In a mobile environment, the channel conditions are time varying. In order to be spectrally efficient, the MCS used for data transmission and reception needs to be adapted according to channel variations. Adjustment in MCS requires changes in the amount of allocated resources. As a result, every time the MCS needs to be adapted, the BS needs to deallocate or allocate a persistently scheduled resource. Depending on the frequency at which the MCS changes, signalling the changing persistent allocation could result in considerable overhead. Consequently, for fast link adaptation, individual persistent scheduling is not recommended, since the overhead involved in adapting to the channel variations will defeat the purpose of persistent scheduling.

Reliable MAP Reception

Since persistent scheduling allocates resources not only for the current frame, but also for future frames, the impact of losing MAP information associated with persistent scheduling is much higher than it is with dynamic scheduling. Hence, it is important to make the MAP transmission reliable. A MAP ACK channel can be used to ensure that the MS has received the persistent allocation. This ACK channel is very similar to the HARQ ACK channel. One issue with this approach is that the ACK channels increase overhead in the uplink. In order to reduce the ACK channel overhead in the uplink, shared NACK channels can be used to acknowledge subsequent MAP reception, that is, a MAP ACK channel is used for the initial persistent scheduling assignment, and a shared MAP NACK channel is used for the subsequent assignments. In the case of the shared MAP NACK channel, multiple users use the same NACK channel resource. If the BS receives a MAP NACK signal from one or more users, the incorrect reception of the MAP is detected. The BS can either retransmit the MAP information to all users sharing the NACK channel or intelligently retransmit the MAP information to only those users who signalled the loss of the MAP information.

4.12. IPTV over Mobile WiMAX

Unprecedented advances in broadband Internet access and scalable video coding technologies, such as H.264/MPEG4 advanced video coding (AVC), have made Internet Protocol television (IPTV) possible. Technological readiness and current market competition have forced many telecoms to migrate from simple data services to triple-play (data, voice, and video) or even quadruple- play services (triple-play services plus mobile) on a single infrastructure to ensure their survival and to earn new revenue. As a consequence, IPTV is touted by many companies as the next killer application that will maximize the true value of their current customer base and enable future business growth. We have witnessed many industrial activities designed to benefit from the trend of IPTV over legacy metropolitan area network infrastructures, including the field services or trials operated by PCCW, Swisscom, and SingTel, the middleware released by Microsoft, as well as the equipment and solutions launched by Alcatel-Lucent, Nortel, and so on.

With the prevalence of wireless communication, we have witnessed the recent advances in miniaturization of mobile devices, affordable wireless communication equipment, and improved small-scale energy supplies. With this premise, a new application scenario for IPTV over wireless networks has been envisioned that aims to promote the existing IPTV services with more convenience, flexibility, and cost-effectiveness by taking advantage of wireless metropolitan area network (WMAN) technologies such as IEEE 802.16d/e/m (referred to as WiMAX). WiMAX is considered as an effective but challenging leverage to extend IPTV services in the wireless and mobility dimension.

4.12.1. Overview of IPTV services and architecture

In general, IPTV services can be classified by their type of content and services.

•**On-demand content**: With pre-encoded and compressed content, a customer is allowed tobrowse an online movie catalogue, to watch trailers, and to select a movie of interest. Unlike the case of live video, a customer can request or stop the video content at anytime and is not bound by a particular TV schedule. The playout of the selected movie starts nearly instantaneously on the customer's TV or PC.

•**Live content**: In this case, a customer is required to access a particular channel for the content at a specific time, similar to accessing a conventional TV channel. A customer cannot request to watch the content from the beginning if he or she joins the channel late. Similar to a live satellite broadcast, live content over IPTV can be a showing of a live event or a show encoded in real-time from a remote location, such as a soccer game.

•**Managed services**: Video content can be offered by the phone companies who operate the IPTV business or obtained from syndicated content providers, in which the content is usually well-managed in terms of the coding and playout quality, as well as in the selection of video titles. Bandwidth for delivery and customer equipment are arranged carefully for serving the best playout performance and quality to the customers.

•**Unmanaged services**: The technology of IPTV itself enables playout of any live or ondemand video content from any third party over the Internet. Therefore, nothing stops a customer from accessing video content directly from any third party online such as YouTube (or Google Video), individuals, or an organization. With a wide range of choices for content selection, obviously the unmanaged services have an advantage at the expense of non-guaranteed playout quality and performance.

4.12.2. Generic IPTV architecture

Figure4.13 shows a generic architecture for running IPTV services. Common building blocks are classified in terms of *customer premise*, *video headend*, and *transport networks*.

Customer premises

Set-Top Box (STB) — Set-Top Box is a device on the customer side that interfaces with the user terminal (e.g., a television, a PC, or a laptop) with DSL or cable wiring or other access technology. STB is usually installed with middleware client software to obtain the program guide data, decode MPEG2, MPEG4 video data, and display on the screen.

Alternatively, a Web browser can obtain the program guide data from a central server. An STB can be integrated with a DSL or cable modem or even with an IEEE 802.11 switch for home Internet access networking.

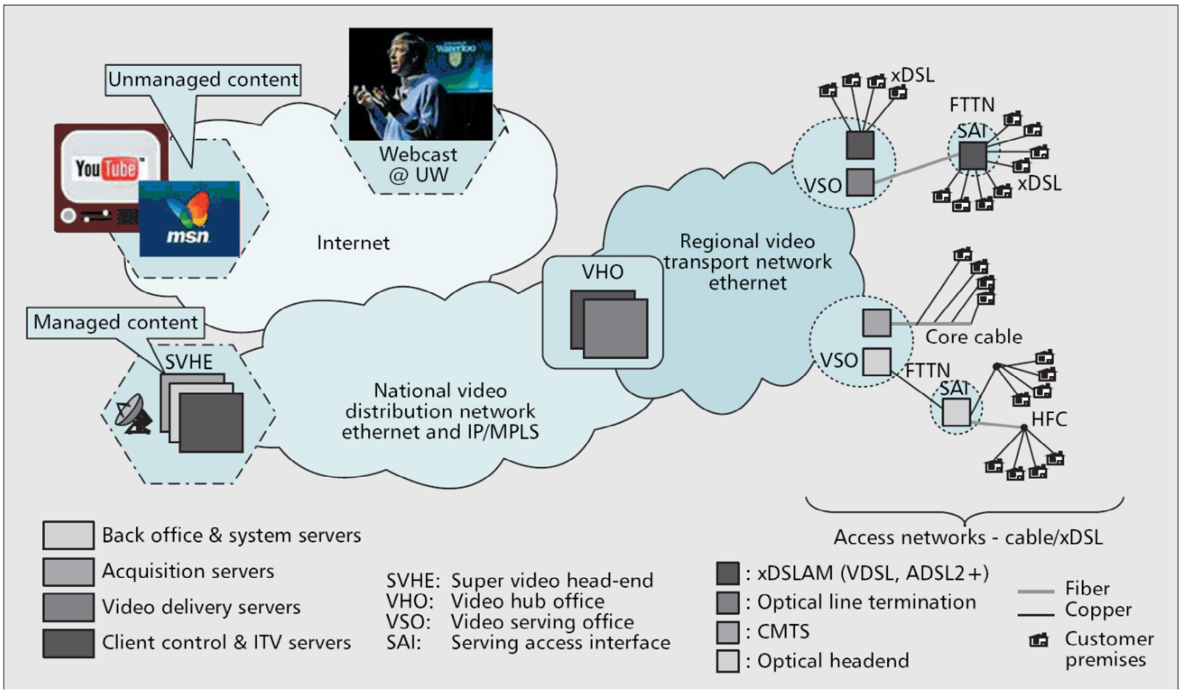


Figure 4.13 General IPTV architecture

Video headend

Video encoders and video on-demand servers are the major sources of video content for IPTV services. The video headend is composed of the following components:

- Video Encoder
- Live Video Broadcast Server
- Video On-Demand (VoD) Server
- Content Subscriber Management

Transport networks

There are two major parts of the transport network in general — *core* and *access* networks.

Core Networks — These connect the access networks to customer premises and can be simply a single national distribution network running Gigabit Ethernet or IP/MPLS plus various regional distribution networks running carrier grade Ethernet. Managed content is usually centralized and processed within the national distribution network before being delivered to different access networks. However, a wider range of choices for the unmanaged content by other content providers can be made, and the unmanaged content is fed into the national distribution network to the customers through the Internet.

Access Networks — These serve as a critical part of the transport network and are used to reach each individual customer at his or her home through the STB. The technologies available today are mainly xDSL and coaxial hybrid fiber cable (HFC) or fiber techniques such as fiber-to-the-node (FTTN), to extend the reach to customer communities before xDSL or cable wiring. Because the bandwidth of the access networks usually is very limited, to cater to all of the customers for simultaneous access of the TV channels, multicasting has been widely adopted to enable a scalable delivery of video data for IPTV. Instead of unicasting multiple flows of live content across the whole transport network, a goal of multicasting is to conserve bandwidth and minimize unnecessary packet duplication. A single transmission of each unique video data is shared among a group of customers who demand the same live content. Data is replicated only at appropriate branching locations, such as a regional edge router when it is necessary to fork another substream to reach another group of customers or an individual customer.

4.12.3. Future trends of IPTV

Future IPTV is expected to provide high quality video contents such as high definition television (HDTV), mobility such as mobileTV, and access to unmanaged content, where the following future trends and possible application scenarios are envisioned.

Portable media devices at customer premises

In addition to large flat panel TVs that are becoming more capable of full support for HDTV signals, many portable multimedia devices such as iPhone, iPod, BlackBerry, as well as powerful cell phones and PDA, are already on the shelf to support complete IP-based triple or quadruple services in a single device. Today, watching a live seminar presentation on a cell phone while on the train or retrieving a popular video clip from YouTube over the Internet is no longer science fiction, but a reality.

HDTV in video headend

Due to the growing demand from consumers for better video experiences and proactive differentiation among competitive media providers, future IPTV services should provide two different types of TV quality: standard definition TV (SDTV) and HDTV. The SDTV bandwidth ranges from 1 to 4 Mb/s, and the HDTV bandwidth ranges from 4 to 13 Mb/s. The typical number of TV channels available from a provider is between 250 and 300 SDTV channels, with an additional 10 to 20 HDTV channels. If a home has approximately four television sets, two to three SDTV and one to two HDTV, the sets simultaneously consume up to 20 Mb/s.

At this point, bandwidth management among different traffic classes to homes becomes a critical issue. In case a wireless access technology such as WiMAX is adopted, it will be of ultimate importance to adopt an efficient multicasting scheme at the BS by fully exploring the fading channel diversity of all the receiving subscriber stations (SS).

Advanced video coding technologies

H.264/MPEG4 was recently standardized by the International Telecommunications Union-Telecommunication (ITU-T), and is designed to packetize the video data into real-time transport protocol (RTP), such that a substantial improvement over MPEG-2 performance, especially for both HDTV and VoD contents, can be obtained. The latest video coding schemes enable the same content to be encoded once while supporting heterogeneous conditions of transport and end-user devices that make it possible for the same content to be subscribed by home and mobile users at the same time with different types of device/communication media.

Evolution of access networks

Currently, some mobile service providers already are offering on-demand unicast streaming of mobileTV via 2.5G general packet radio service (GPRS) and 3G. New compression technologies allow on-demand streaming of TV channels but with limited capacity, supported by existing cellular networks. On the other hand, triple or quadruple play services (broadband, voice, TV, and mobile) over a single IP-infrastructure are in high demand by many service providers, where IPTV over wireless networks is obviously a must. Enabling wireless capability for delivering IPTV through the latest wireless technologies such as WiMAX, cellular IP, IP over CDMA, and so on is expected.

4.12.4. Key success factors and IPTV over WiMAX

It is important to envision what will occur in future IPTV services in order to choose the correct technologies for corresponding extensions, but it is even more critical to identify the key success factors for launching a successful IPTV service.

THE KEY SUCCESS FACTORS

Economy of Scale — Economy of scale characterizes a production process or service operation, in which an increase in the number of producing units may cause a decrease in the average fixed cost of each unit. By optimizing the economy of scale for operating IPTV services, one can minimize the risks and secure the early advent of ultimate success. This translates to the need of an access network technology that can support more subscribers and mobile TV for future requirements.

Scheduled Live Content and Quality Assurance — Quality of service and quality of experience for end users have been identified as critical requirements of IPTV services. In the long run, watching IPTV content will be just like surfing different Web sites over the Internet. Watching unmanaged live or on-demand content offered by different service and media providers in the world would provide the true value of IPTV services to customers. However, an IPTV channel is still critical to ensure comparable TV quality and experiences similar to those of the conventional cable, satellite, or digital TV services. Offering managed and scheduled SDTV programs with a quality guarantee is required to secure a head start and the success of IPTV service.

WHY IPTV OVER WIMAX?

WiMAX should always be included to facilitate the previously mentioned success factors for the IPTV services due to the following factors:

Maximize the Number of Subscribers — Obviously, the success of the launch of IPTV services is determined by the time and volume of profitable operations. Getting the maximum number of subscribers as soon as possible for a newly launched IPTV service program is a clear goal for any service provider. It has been reported from time to time that xDSL and cable broadband access is not available in some areas due to geographical distance and user-density. Meanwhile, the deployment of xDSL and cable wiring overhead is not as easy and scalable as that of WMAN technologies.

As an alternative to the conventional wired access network technologies, WiMAX offers the ease of deployment similar to other wireless technologies, but with larger service coverage and more bandwidth. The cost for infrastructure deployment and for service provision can be dramatically reduced. Delivering IPTV services over WiMAX to complement the current IPTV deployment can capture the maximum number of subscribers under the same infrastructure and provide even better accessibility to the same pool of video content for mobile users in the future.

Converged Wireless Broadband Access Network — Telecoms are actively seeking ways to offer triple or quadruple play services. WiMAX is considered a very good candidate to provide new services such as wireless broadband access and mobile voice over Internet Protocol (VoIP) telephony. Launching IPTV over WiMAX can further achieve economy of scale in terms of more services and better service availability under a common infrastructure.

Supporting the Future Trends — We have enumerated the emerging trends of IPTV for the aspects of mobility, accessing unmanaged content, and supporting high-quality video, such as HDTV. WiMAX offers benefits for such promotion with its reservation-based bandwidth allocation, cost-effective and infrastructure-free deployment, and stringent QoS support for the four types of service: unsolicited granted service (UGS), real-time polling service (rtPS), non real-time polling service (nrtPS), and best effort (BE) traffic.

Enabling rtPS in the wireless broadband access can support perfectly the bandwidth requirements of managed content of the IPTV service providers, especially for paid HDTV and SDTV. With more and more portals available in the Internet core that offer a great deal of rich and free on-demand video content, it is a very attractive approach to allow not only home IPTV users, but also mobile users to access this unmanaged content without affecting the quality and performance of other paid live content. The incorporation of rtPS and BE services can be manipulated to support these demands, such that the best flexibility and economy can be achieved without losing much quality in content delivery. The extendibility for supporting the future trends of IPTV services over common WiMAX access infrastructure creates long-term and growing economies of scale to the state-ofthe- art IPTV operation.

4.13. WiMAX 2.0 business opportunities

With over 70 mobile WiMAX deployments worldwide in 2.3 , 2.5 and 3.5 GHz and continuously growing , the role of WiMAX 2.0 is pivotal for these operators to support humongous projected growing data demand and remain competitive in mobile data networks. WiMAX release 1.0 was successful in getting attraction from operators but there triumph remains in the hand of continuous innovation and new suite of standards which will support delivery affordable and reasonable data services. IEEE 802.16m will play important role to provide evolutionary path to Mobile WiMAX Release 1.0 operators to remain competitive in ever challenging mobile data networks and provide a platform for delivery of new services. It will also play an important role in shaping 4G mobile networks by supporting IMT-A requirement by updating its IEEE 802.16 standards to meet the requirements of next generation mobile networks targeted by the cellular layer of IMT-Advanced. Following are the summary of key features of WiMAX 2.0 ;

- Radio specification for FDD and TDD
- Support of IMT-A identified frequency bands
- At least 2 times the average data throughput of current Release in similar spectrum
- Advanced interference management methods to support true reuse 1 deployments as compared to current reuse 3 deployments
- Round trip access latency is reduced to less than 10-20 ms levels which will allow more demanding services like online gaming etc.
- Support for self organizing networks
- Support for femtocells
- Support of Relays stations
- Multicarrier aggregation upto 100 MHz
- Co-exsistence of 802.16e and 802.16m base stations and backword compatibility
- Over 70 VoIP call per MHz
- Coexistence of multi-technologies like Bluetooth, Wi-Fi and WiMAX
- Inter Radio Access technology handovers(3GPP)
- Improved scheduling and new QoS class
- Support for enhanced multicast and broadcast services
- Support for Location based services
- Improved link budget with higher antenna configuration

Acronyms

A-MIMO	Adaptive multiple input multiple output
AA	Anchor authenticator
AAA	Authentication, authorization, and accounting
AAS	Adaptive antenna system (also advanced antenna system)
AASN	Anchor ASN
ACK	Acknowledge
ADPF	anchor data path function
AES	Advanced encryption standard
AF	Application function
AG	Absolute grant
aGW	E-UTRAN access gateway
AK	Authorization key
AKA	Authentiction and key agreement
AM	Authorization module
AMC	Adaptive modulation and coding
AMS	Adaptive MIMO switching
API	Application program interface
AR	Access router
ARIB	Association of radio industries and businesses
ARQ	Automatic repeat request
AS	Authentication server or access stratum
ASN	Access service network
ASP	Application service provider
BE	Best effort
BGCF	Breakout gateway control function
BRAS	Broadband remote access server
BS	Base station
BSID	Base station identifier
BU	Binding update
CAC	Connection admission control
CC	Chase combining (also convolutional code)
CCI	Co-channel interference
CCoA	Collocated care of address
CDF	Cumulative distribution function
CID	Connection identifier
CINR	Carrier to interference + noise ratio
CMAC	Cipher-based message authentication code
CMIP	Client mobile IP
CoA	Care of address
COA	Change of authority
COS	Class of service
CP	Control plane or cyclic prefix
CQI	Channel quality indicator
CS	Convergence sublayer
CSN	Connectivity service network

CSTD	Cyclic shift transmit diversity
CTC	Convolutional turbo code
CWTS	China wireless telecommunication standard group
DHCP	Dynamic host configuration protocol
diffserv	Differentiated services
DL	Down link
DNS	Domain name service
DoS	Denial of service
DP	Decision point or data path
DPCCH	Downlink physical control channel
DRC	Data rate control
DSC	Data source control
DSL	Digital subscriber line
DSLAM	Digital subscriber link access multiplexer
DVB	Digital video broadcast
E-UTRA	Evolved universal terrestrial radio access
E-UTRAN	Evolved universal terrestrial radio access network
E2E	End-to-end
EAP	Extensible authentication protocol
EESM	Exponential effective SIR mapping
ERT-VR	Extended real-time variable rate
ertPS	Extended real-time polling service
ETSI	European Telecommunications Standards Institute
FA	Foreign agent
FBSS	Fast base station switching
FCAPS	Fault configuration accounting performance and security
FCH	Frame control header
FDD	Frequency division duplex
FFT	Fast Fourier transform
FQDN	Fully qualified domain name
FRD	Fast router discovery
FTP	File transfer protocol
FUSC	Fully used subcarrier
FWA	Fixed wireless access
GPRS	General packet radio services
GSM	Global system for mobile communication
GW	Gateway
HA	Home agent
HARQ	Hybrid automatic repeat request
HHO	Hard hand-off
HLA	Hot-line application
HLD	Hot-line device
HMAC	Keyed-hashing for message authentication code
HO	Hand-off or hand over
HO ID	Hand-off identifier
HRPD	High-rate packet data
I-WLAN	Interworking with wireless LANs
IANA	Internet assigned numbers authority

IE	Information elements
IEEE	Institute of Electrical and Electronics Engineers
IEFT	Internet Engineering Task Force
IFFT	Inverse fast Fourier transform
IID	Interface identifier
IK	Integrity key
IKEv2	Internet key exchange protocol version 2
IMS	IP multimedia subsystem
IMSI	International mobile subscriber identity
IP	Internet protocol
IPsec	IP security
IPv4	Internet protocol version 4
IPv6	Internet protocol version 6
IR	Incremental redundancy
ISF	Initial service flow
ISI	Intersymbol interference
ISM	Industrial, scientific, and medical bands
IWF	Internetworking function
IWG	Interworking gateway
IWU	Internetworking Unit
L1	Layer 1 (physical layer)
L2	Layer 2 (data link layer)
L3	Layer 3 (network layer)
LBS	Location-based services
LDPC	Low-density parity check
LE	License-exempt deployments
LMDS	Local multipoint distribution system
LOS	Line of sight
LPF	Local policy function
LR	Location register MSID, BSID
LSB	Least-significant byte
LTE	Long-term evolution
MAC	Medium access control
MAI	Multiple access interference
MAN	Metropolitan area network
MAP	Media access protocol
MDHO	Macrodiversity hand over
MIMO	Multiple input multiple output
MIP	Mobile IP
MIP6	Mobile IP version 6
MLD	Maximum likelihood symbol detection
MM	Mobility management
MMSE	Minimum mean-squared error
MN HOA	Allow-MN-HA assignment
MPLS	Multi protocol label switching
MS	Mobile station
MSID	Mobile station identifier
MSK	Master session key

MSO	Multiservices operator
NA	Neighbor advertisements
NACK	Not acknowledge
NAI	Network access identifier
NAP	Network access provider
NAPT	Network address port translation
NAS	Network access server or Nonaccess stratum
NAT	Network address translation
NLOS	Non–line-of-sight
NMS	Network management system
NRM	Network reference model
NRT-VR	Non–real-time variable rate
nrtPS	Non–real-time polling service
NS	Neighbor solicitation
NSP	Network service provider
NUD	Neighbor unreachability detection
OAM	Operations and maintenance
OFDM	Orthogonal frequency division multiplex
OFDMA	Orthogonal frequency division multiple access
OTA	Over-the-air
OUI	Organization unique identifier
P-CSCF	Proxy-call session control function
PA	Paging agent
PBX	Private branch exchange
PC	Paging controller
PDCP	Packet data convergence protocol
PDFID	Packet data flow ID
PDG	Packet data gateway
PDU	Packet data unit
PEAP	Protected EAP
PER	Packet error rate
PF	Policy function
PF	Proportional fair (scheduler)
PG	Paging group
PG ID	Paging group identifier
PHS	Packet header suppression (PHS)
PKM	Public key management
PoA	Point of attachment
PS	Physical slot
PSK	phase shift keying
PSTN	Public switched telephone network
PtP	Peer to peer
PUSC	Partially used subcarrier
QAM	Quadrature amplitude modulation
QoS	Quality of service
QPSK	Quadrature phase shift keying
RA	Router advertisement or reverse activity
RAB	Reverse-link activity bit

RADIUS	Remote access dial in user service
RG	Relative grant
RLC	Radio link control
RNC	Radio network controller
RO	Route optimization
RP	Reference point
RPC	Reverse power control
RR	Resource-reservation or round Robin
RRA	Radio resource agent
RRC	Radio resource controller
RRI	Reverse rate indicator
RRM	Radio resource management
RS	Router solicitation
RS	Reed-Solomon coding
RSVP	Resource reservation protocol
RT-VR	Real-time variable rate
RTG	Receive/transmit transition gap
rtPS	Real-time polling service
RUIM	Removable user identity module
S-CSCF	Serving-call session control function
S-OFDMA	Scalable orthogonal frequency division multiple access
SA	Security association
SAE	System architecture evolution
SCI	Spare capacity indicator
SDFID	Service data flow ID
SDMA	Space (or spatial) division (or diversity) multiple access
SDU	Service data unit
SFA	Service flow authorization
SFID	Service flow ID
SFM	Service flow management
SFN	Single frequency network
SGSN	Serving GPRS support node
SHO	Soft hand-off
SI	Subscriber identity
SII	System information identity or service identity information
SIM	Subscriber identity module
SIMO	Single input multiple output (antenna)
SINR	Signal to interference + noise ratio
SISO	Single input single output (antenna)
SLA	Service-level agreement
SM	Spatial multiplexing
SMS	Short message service
SMTP	Simple mail transport protocol
SNIR	Signal to noise + interference ratio
SNMP	Simple network management protocol
SNR	Signal to noise ratio
SS	Subscriber station
SSL	Secure sockets layer

STBC	Space–time block code
STC	Space–time coding
SUBC	Subscriber credentials
TBS	Target BS
TCH	Traffic channel
TCP	Transmission control protocol
TD-CDMA	Time division code division multiple access
TD-SCDMA	Time division synchronous code division multiple access
TDD	Time division duplex
TDM	Time division multiplex
TE	Terminal equipment
TEK	Traffic encryption key
TFRI	Transport format-related information
TIA	Telecommunications Industry Association
TLS	Transport layer security
TTA	Telecommunications Technology Association
TTC	Telecommunication Technology Committee
TTG	Transmit/receive transition gap
TU	Typical urban (as in channel model)
U-NII	Unlicensed national information infrastructure
UDP	User datagram protocol
UDR	Usage data record
UE	User equipment
UGS	Unsolicited grant service
UICC	Universal integrated circuit card
UID	User identity
UL	Uplink
UP	User plane
USIM	Universal subscriber identity module
V-AAA	Visited AAA proxy
V-MIMO	Virtual multiple input multiple output (antenna)
VLAN	Virtual LAN
VoIP	Voice over Internet protocol
VPN	Virtual private network
VSM	Vertical spatial multiplexing
WAG	WLAN access gateway
WATSP	WiMAX ASN transport signaling protocols
WEP	Wired equivalent privacy
Wi-Fi	Wireless fidelity
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network
WPA	Wi-Fi protected access
WWAN	Wireless wide area network

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