WIMAX 2.0 for Operators

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BP Tiwari
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www.beyond4g.org

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DISCLAMER

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1. Executive Summary

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 operators to support humongous projected growing data demands and stay competitive in mobile data networks. The time to market and early competitiveness of WiMAX release 1.0 was successful in getting initial attraction from operators but there triumph will largely depend in continuous innovation and new suite of standards which will enable affordable and reasonable data services for their consumers.

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 Std 802.16 standards to meet the requirements of next generation mobile networks targeted by the cellular layer of IMT-Advanced.

WiMAX 2.0 or 16m standards work will be completed by the end of this year and the first 16m release will be available for industry by July, 2010[1]. Based on the inputs from supplier and past standardization experience it appears that operators will have WiMAX 2.0 systems for deployment as early as 2012. Work on the standard has been progressing very quickly, the experiences with 802.16e and even some of the learning's from LTE has enabled quick completion of standards.

Following are the key vital features of WiMAX 2.0 which is incorporated in standards and presented in this whitepaper.

- New spectrum in FDD and TDD band
- Support of IMT-A frequency bands
- At least two fold increase in average data throughput from the current Release
- 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
- Support for Location services
- Support for enhanced multicast and broadcast services
- Multicarrier aggregation upto 100 MHz
- Co-existence of 16e and 16m base stations and backward compatibility
- 2-3 fold improvement in VoIP calls per MHz (Optimized for voice)
- Coexistence of multi-technologies like Bluetooth, Wi-Fi and WiMAX
- Inter Radio Access technology handovers(3GPP)
- Improved scheduling and new QoS class

[1] IEEE : http://www.ieee802.org/16/tgm/core.html#10_0010

It is more apt for operators who have already deployed their networks with release 1.0 to migrate to WiMAX2.0 as the release 1.0 devices are backward compatible with 16m systems and the performance of 16m systems is adequate to support the requirements of IMT-A and other competing technologies like LTE and LTE-A.

While this paper will cover all the aspects of 16m performance and features for operators , aspects of coexistence of release 1.0 and release 2.0 systems is presented for WiMAX operators.

2. Introduction

WiMAX systems based on release 1 have shown significant advantage over their 3G competitors when it comes to deliver all IP based data services over wireless. Mobile Data is one of the fastest growing segments in wireless, and mobile data traffic will grow at a compound annual growth rate (CAGR) of 108 percent between 2009 and 2014[2]. The future and changing landscape of telecommunication industry provides great opportunities with significant growth in the overall telecommunications market both in volume and value. This growth will take place both in legacy voice and data services.

The future Wireless access technologies needs to take into account a number of common emerging trends consistent across many future potential development scenarios. A key trend is the increasing consumption of digital information by customers in several ways, which, in some cases require the network capacity to increase by a double-digit factor or even higher. Cisco global estimate shows that mobile data traffic has increased 160 percent from calendar year-end 2008 to calendar year-end 2009. And individually, some mobile carriers have published some dramatic traffic increases.

According to in-stat research, mobile broadband in now the second largest access technology behind DSL, making it 18% subscriber worldwide. Operators like Teliasonera reported increase in data traffic by 200% in Nordic and Baltic regions while the number of subscriber rose to 60% only. United Kingdom-based operator O2 reported that its mobile data traffic in Europe doubled every three months in 2009. Telecom Italia announced that its mobile traffic grew 216 percent from mid-2008 to mid-2009 and AT&T has reported that its mobile traffic increased 5000 percent in the past 3 years. In last quarter alone wireless data revenue grew 26% for AT&T. Five operators, NTT DoCoMo followed by Verizon Wireless, China Mobile, AT&T and KDDI exceed data revenues over US$ 10B clearly suggesting the emergence of data services as the biggest revenue generating services over the next decade.

The current version of mobile WiMAX based on IEEE 802.16e-2005 is considered as the first widely-deployed mobile data technology with OFDMA and MIMO. To consistently support the growing need of mobile data and provide an evolutionary path for wimax operators, IEEE 802.16 working group has started working on the new standard which will called 16m or WiMAX 2.0 and it has the following driving factors;

- To support global user and technology trends for next generation mobile networks
- 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.
- To play an important role in 4G mobile networks by supporting IMT-A requirement by updating its IEEE Std 802.16 standards to meet the requirements of next generation mobile networks targeted by the cellular layer of IMT-Advanced.

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[2] CISCO VNI, http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

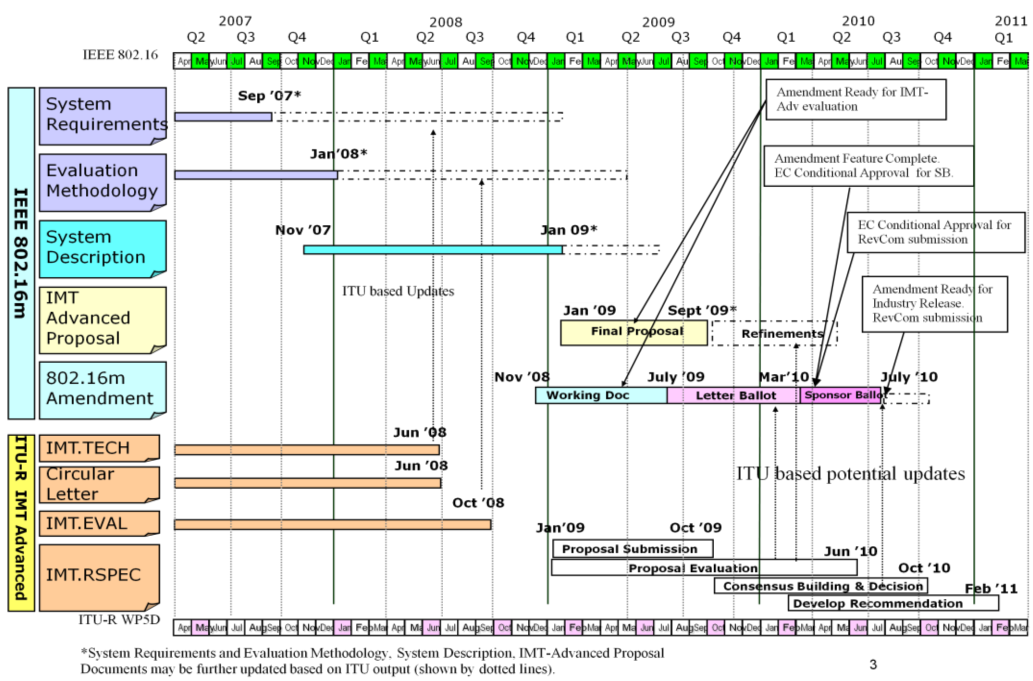
In the current paper we will cover aspects of WiMAX 2.0 for operators. With over 70 Mobile WiMAX deployments in 2.3, 2.5 and 3.5 GHz, WiMAX migration to support even superior quality of service , improved latency , high spectral efficiency, security and low cost of ownership is essential. WiMAX Release 2.0 enhances wimax performance as compared to its predecessors. This release will support operators with improved data rates, higher coverage and allow new services to be offered in their current Radio networks.

3. WiMAX 2.0 Availability

16m standards work item will be completed by the end of this year and first 16m release will be available for industry by July, 2010[3]. IEEE is expected to provide final approval for this new standard sometime this summer. IMT-A recommendation will complete in Q1 2011. Based on the inputs from suppliers and from the past standardization experience of 16e, it appears that operators will have WiMAX 2.0 systems for deployment as early as 2012. Industry chipset supplier like intel , Sequans has indicated availability of devices by 2012.[4]

Work on the standards front has been progressing very quickly, the experiences of 802.16e and even some of the learning's from LTE has enabled quick completion of standards. The know-how of certification by WiMAX Forum and established working groups will enable faster 16m deployments by proactively defining end to end protocols and procedures parallel to IEEE.

Figure 1 : Standardization timeline of WiMAX 2



[3] IEEE : http://www.ieee802.org/16/tgm/core.html#10_0010
[4] WiMAX.com : http://www.wimax.com/commentary/blog/blog-2010/march-2010/wimax-2-networks-ready-in-2012%2C-says-intel-0309

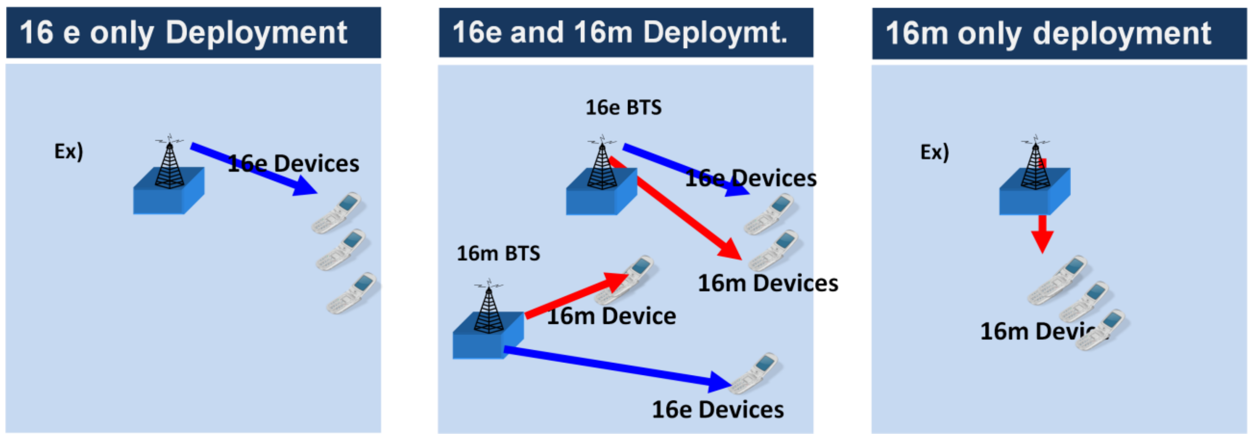
4. Key feature of WiMAX 2.0

4.1 Backward compatibility and coexistence

IEEE 802.16m base station will support interoperability with legacy Wireless MAN-OFDMA i.e. 16e systems. An IEEE 802.16m MS will operate with a legacy BS i.e. 16e base station at performance similar to 16e MS.

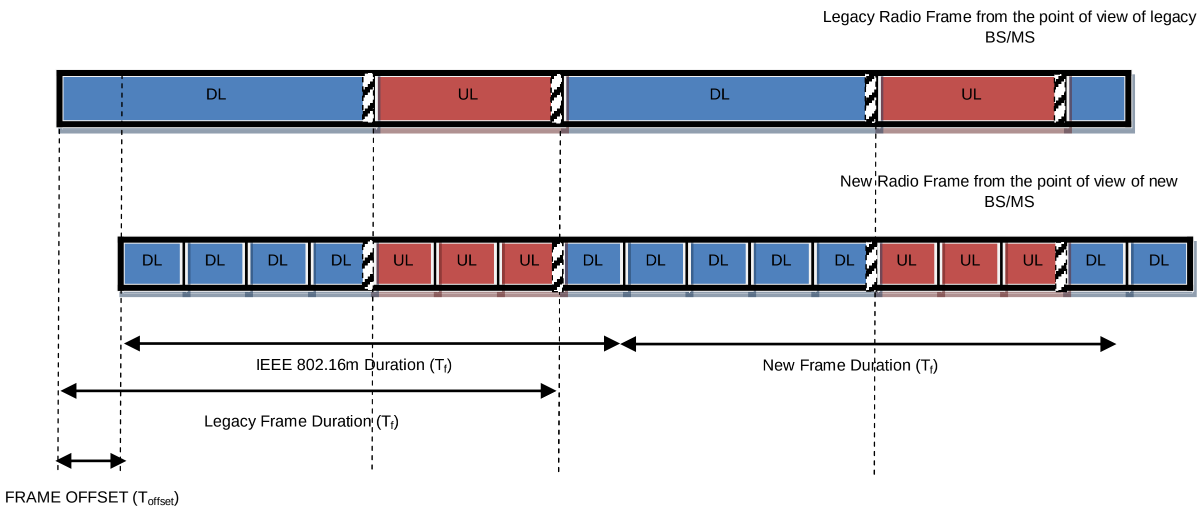
A 16m capable Base Station will support interworking with 16e and 16m device. Operators who are deploying 16e systems presently will have the option of smooth migration to 16m selectively or completely. 16m frame structure has the capability to coexist with legacy frame of 16e systems.

Figure 2 : WiMAX 2.0 deployment possibilities



The coexistence legacy and IEEE 802.16m frames is presented in figure 3. The Frame offset shown in Figure 3 is for illustration. It is an offset between the start of the legacy frame and the start of the IEEE 802.16m frame defined in a unit of sub frames. By choosing appropriate numbers uplink and downlink TDD symbols between 16m and 16e base stations required coexistence can be achieved. From operator perspective this is one the utmost importance feature as the migration of 16m is envisaged in steps.

Figure 3 : 16m and 16e frame coexistence



4.2 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[5]. 16m identified the following FDD and TDD frequency bands for deployment of systems. *(Please note the certification of these bands will depend largely on requirement and operators priority.)*

Figure 4 : WiMAX 2.0 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***

[5] BP Tiwari, www.beyond4g,org : http://www.beyond4g.org/wp-content/uploads/2010/03/WiMAX-1.5-for-operators-v2.pdf

4.3 Multi Antenna Architecture

4.3.1. MIMO schemes in 16m

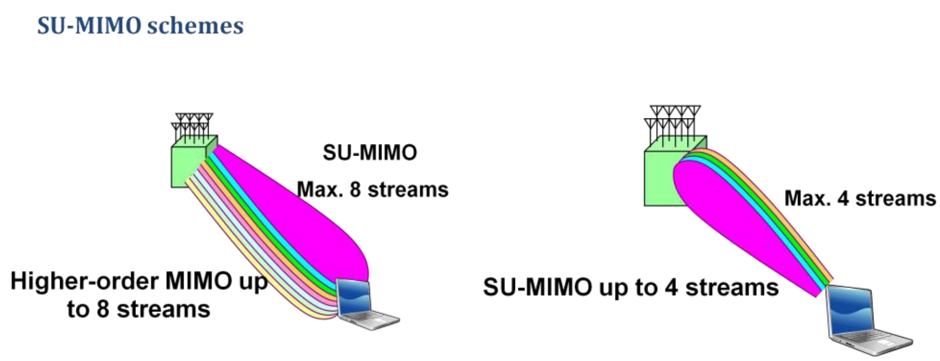
WiMAX 2.0 supports several advanced multi-antenna techniques including single and multi-user MIMO (spatial multiplexing and beamforming) as well as a number of transmit diversity schemes. In single-user MIMO (SU-MIMO) scheme only one user can be scheduled over one resource unit, while in multi-user MIMO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

4.3.2. SU-MIMO[6]

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.

Figure 5 : SU-MIMO



4.3.3. MU-MIMO[7]

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.

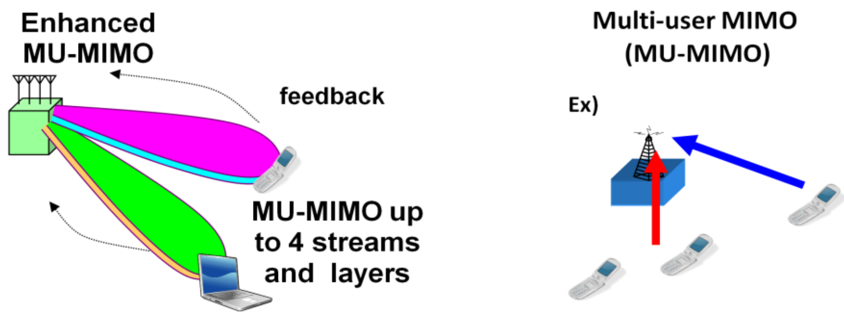
For open-loop MU-MIMO, CQI and preferred stream index feedback may be transmitted to assist the base station's scheduling, transmission mode switching, and rate adaptation. The CQI is frequency dependent.

[6] IEEE 802.16m Task Group : http://www.ieee802.org/16/tgm/docs/80216m-07_002r10.pdf

[7] IEEE working group : http://www.ieee802.org/16/tgm/index.html

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 6 : MU-MIMO

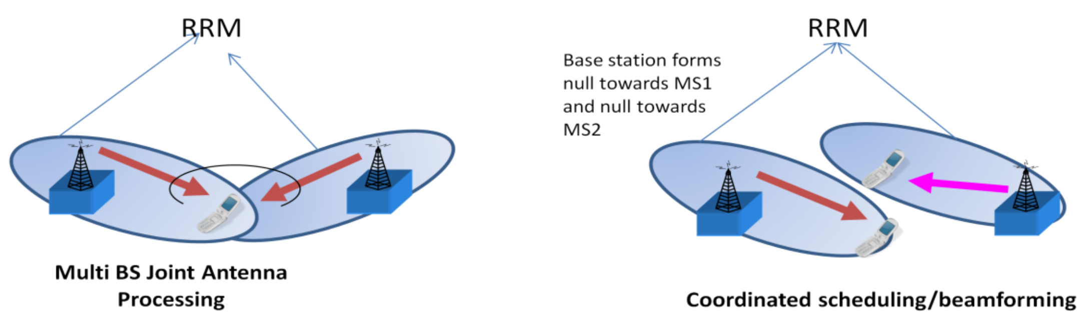


4.3.4. Multi BS MIMO

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 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 7 : Multi BS MIMO



4.3.5. Downlink MIMO Modes [8]

Table 1: supported MIMO modes in downlink

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**

4.3.6. Uplink MIMO Modes

Table 2: supported MIMO modes in uplink

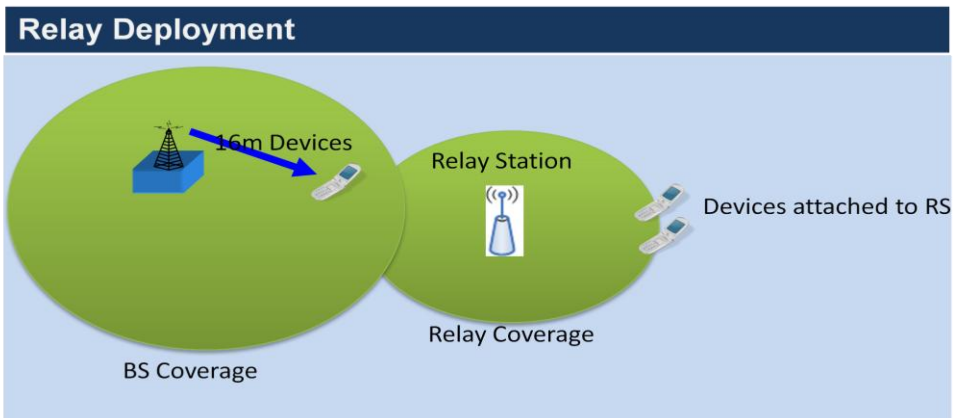
Mode index	Description	MIMO encoding format (MEF)	Maximum number of transmit antenna	Maximum number of streams per MS
Mode 0	Open-loop SU-MIMO	SFBC	2,4	**2**
Mode 1	Open-loop SU-MIMO (spatial multiplexing)	Vertical encoding	2,4	**4**
Mode 2	Closed-loop SU-MIMO (spatial multiplexing)	Vertical encoding	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**

[8] Candidate IMT-A based on IEEE technology : http://www.itu.int/md/R07-IMT.ADV-C-0004/en

4.4 Relay

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.

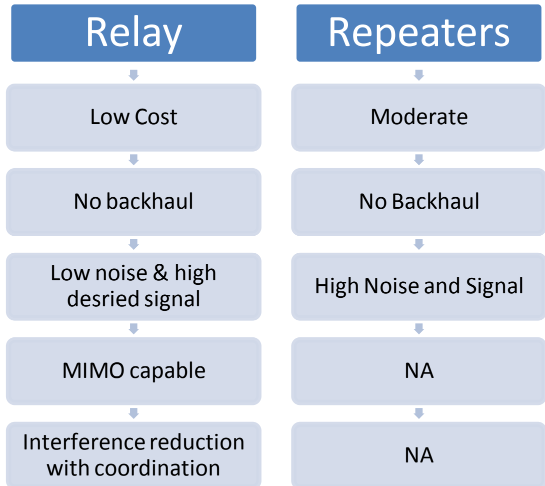
Figure 7 : Relay in 16m



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.

Figure 8 : Relay vs repeaters



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 9 : Relay usage scenarios

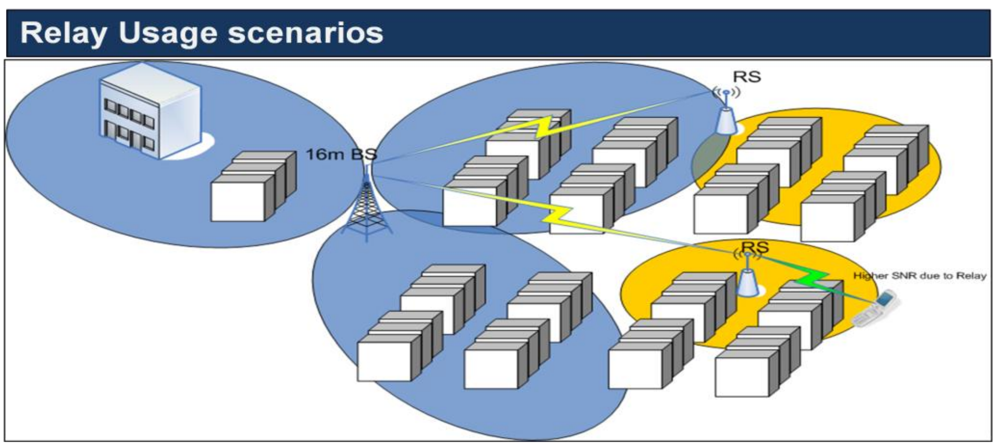


Figure 10 shows the relay-related connections in IEEE 802.16m. 16m BS (ABS) is a BS capable of acting as a 16m BS as well as a 16e BS. Multihop relay BS (MRBS) is a 16e BS with 16j RS support functionality. 16m MS (AMS) a MS capable of acting as a 16m MS as well as a 16e MS. Yardstick MS (YMS) is a 16e MS. Advanced RS (ARS) is a 16m RS and RS is a 16j RS. Interconnections between the entities shown in solid lines are supported by using various protocols such as 16e, 16j, and 16m. There is no protocol specified to interconnections shown in dashed lines. [9]

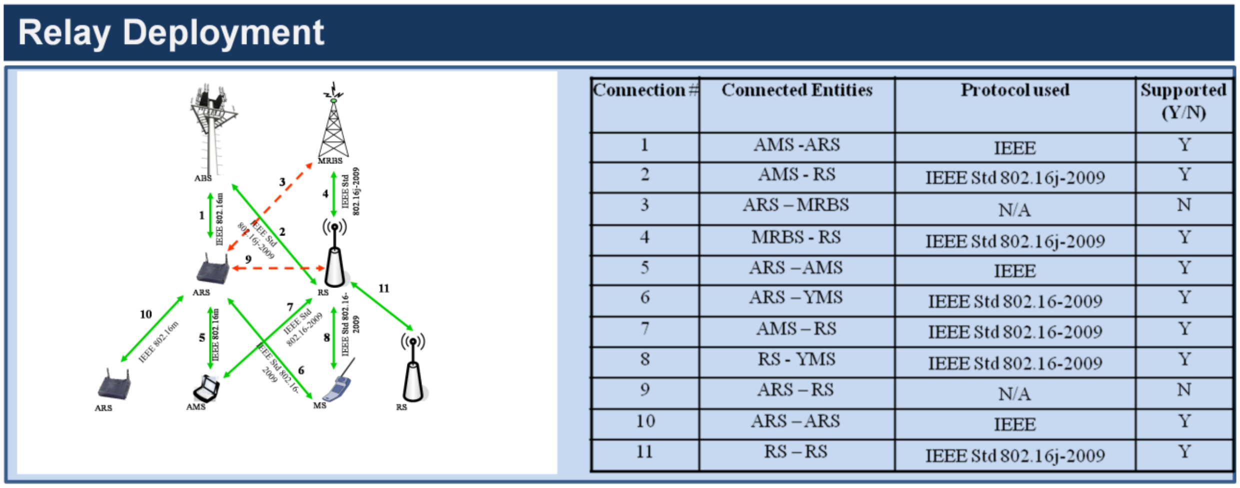
Uni-directional zones (e.g. DL Transmit Zone) can exploit scheduling benefits and bi-directional zones (e.g. Network Coding Transmit Zone) can exploit throughput benefits by using network coding.

Relaying is performed using a decode and forward paradigm, and ARS operates in time-division transmit and receive (TTR) mode. ARSs may operate in transparent or non-transparent mode. Cooperative relaying is a technique whereby either the ABS and one or more ARSs, or multiple ARSs cooperatively transmit or receive data

[9] IEEE 802.16m SDD : http://www.ieee802.org/16/tgm/core.html#09_0034

to/from one subordinate station or multiple subordinate stations. Cooperative relaying may also enable multiple transmitting/receiving stations to partner in sharing their antennas to create a virtual antenna array.

Figure 10 : Relay Interconnection protocols

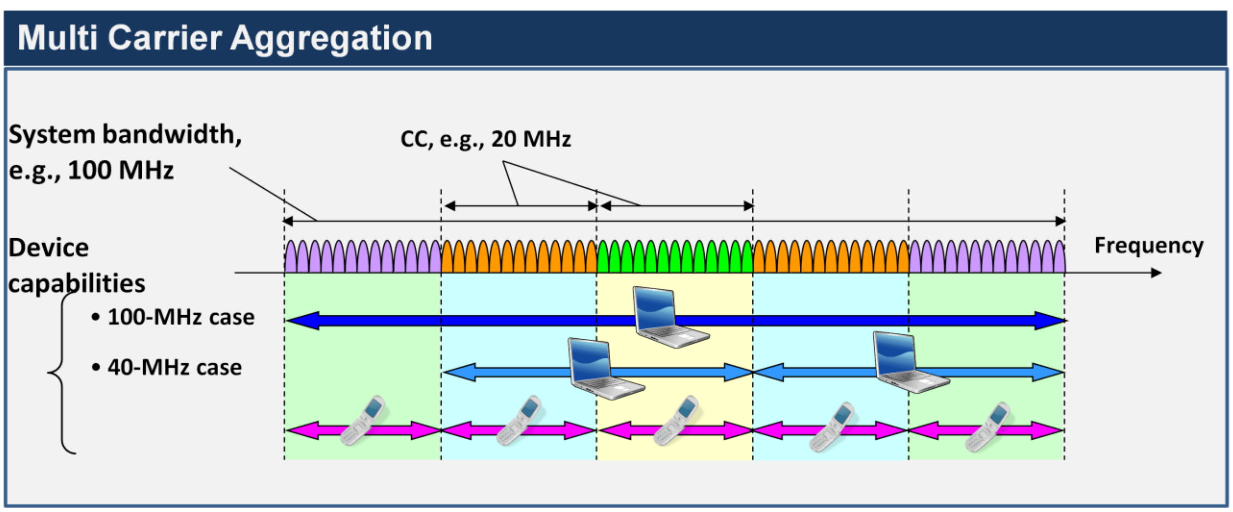


Connection #	Connected Entities	Protocol used	Supported (Y/N)
1	AMS -ARS	IEEE	Y
2	AMS - RS	IEEE Std 802.16j-2009	Y
3	ARS – MRBS	N/A	N
4	MRBS - RS	IEEE Std 802.16j-2009	Y
5	ARS – AMS	IEEE	Y
6	ARS – YMS	IEEE Std 802.16-2009	Y
7	AMS – RS	IEEE Std 802.16-2009	Y
8	RS - YMS	IEEE Std 802.16-2009	Y
9	ARS – RS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

4.5 Multi carrier aggregation

Flexible spectrum use is achieved through use of scalable OFDMA multiple access scheme in the DL and UL, tone dropping techniques in OFDMA, as well as use of one or multiple component RF carriers. Multiple component carriers can be aggregated to achieve up to 100 MHz of transmission bandwidth. The aggregated component carriers can be either contiguous or non-contiguous in the frequency domain. Channel bandwidth of 5,10,20 and 40(optional) is supported in 16m with multi carrier aggregation up to 100 Mhz.

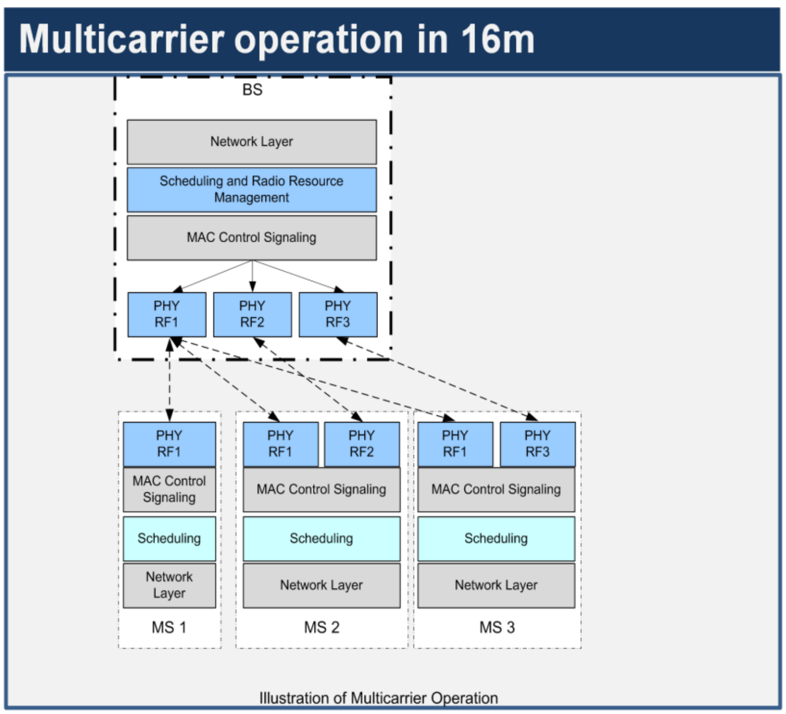
Figure 11 : Multi Carrier Aggregation



Multi-carrier functions: control and operation of a number of contiguous or non-contiguous RF carriers where the RF carriers can be assigned to unicast and/or multicast and broadcast services. The overlapped guard sub-carriers of contiguous carriers are aligned in order to be used for data transmission. A single MAC instantiation is used to control physical layer spanning over multiple frequency channels. A generalization of the protocol structure to multi-carrier support using a single MAC instantiation is shown in Figure 12. The load balancing functions and RF carrier mapping and control are performed via radio resource control and management functional group.
The carriers utilized in a multi-carrier system, from perspective of a 16m MS can be divided into two categories:

- A primary RF carrier is the carrier for 16m MS to complete network entry and is used by the 16m BS and the 16m MS to exchange traffic and full PHY/MAC control information.
- A secondary RF carrier is an additional carrier which the 16m BS may use for only traffic for 16m MSs capable of multi-carrier support.

Figure 12 : Multi Carrier Operation



Two multi-carrier operation modes are identified as follows;

- Multi-carrier aggregation: The 16m MS maintains the physical layer connection and monitors the control signaling on the primary carrier while processing data on the secondary carrier.
- Multi-carrier switching: The 16m MS switches the physical layer connection from the primary carrier to the secondary carrier that is one of partially configured carriers.

4.6 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.

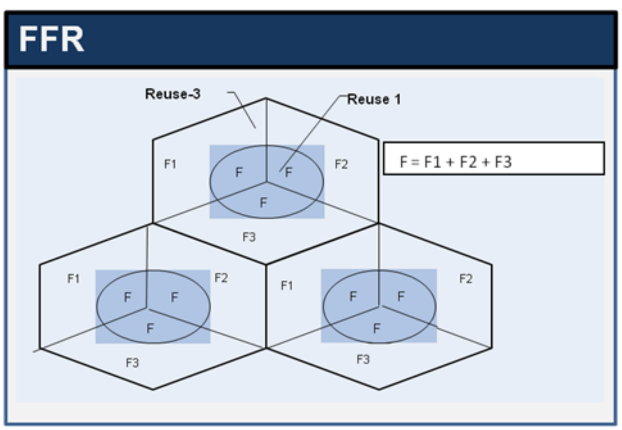
Group Resource Allocation (GRA): GRA is used to reduce resource allocation signaling (MAP) overhead for multiple connections with a pre-determined and well-known packet size. Instead of allocating resources to single user, the ABS may create one or more groups, each group containing more than one user.

4.7 Advanced Interference Management

4.7.1. Interference Mitigation using Fractional Frequency Reuse (FFR)

Fractional Frequency Reuse (FFR) is a technology that adopts different frequency reuse coefficient in different reuse groups. If the terminal is suitable to work in the condition where the reuse coefficient is 3, the reuse factor with coefficient 3 is provided for such terminal. If the terminal is suitable to work in the condition where the reuse coefficient is 1, the reuse factor with coefficient 1 is provided for such terminal. More flexible approach is to control all the sub-carrier groups with different transmission power to coordinate different cells radius. FFR can be realized in static mode and dynamic mode. In static mode, the frequency coefficient used by the terminal, which is associated with the terminal location, is relatively regular. When the terminal measures the interference in the adjacent downlink cell (sector) and reports the result to the base site, the base station shall allocate appropriate frequency coefficient to such terminal in response to the interference.

Figure 13 : Fractional frequency reuse



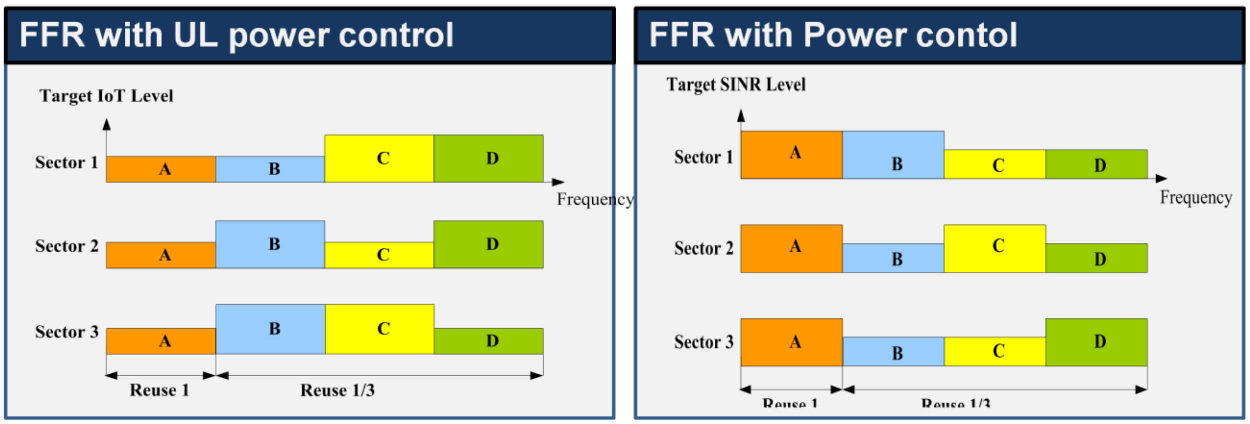
With basic RRM (Radio Resource Management) techniques, the cell spectral efficiency of reuse-1 with FFR lies between the spectral efficiencies of reuse-1 and reuse-3 depending on the manner in which the available frequency resources are assigned to the reuse-1 and reuse-3 FFR partitions. However, the decrease in the cell spectral efficiency in the case of basic FFR techniques is offset by the increase of the cell-edge spectral efficiency. With advanced FFR techniques, FFR gains are expected for both cell (average) and cell-edge spectral efficiency at the cost of increased RRM overheads.

Resource allocation in an FFR system takes several factors into consideration such as reuse factor in partition, power at partition, available multi-antenna technologies, as well as interference-based measurements taken at 16m MS.

In order to support FFR, the 16m BSs is capable of reporting interference statistics and exchanging its FFR configuration parameters which may include frequency partitions, power levels of each partition, associated metric of each partition with each other or with some control element in the backhaul network. Some of the coordination may be achieved by signaling over air-interface and the configuration format for FFR coordination is being studied.

Figure 14 show examples of integration of FFR with UL power control. Another example for SINR based UL power control is given figure 14 where different target SINR level may be designated for different frequency partitions.[10]

Figure 14 : FFR with power control

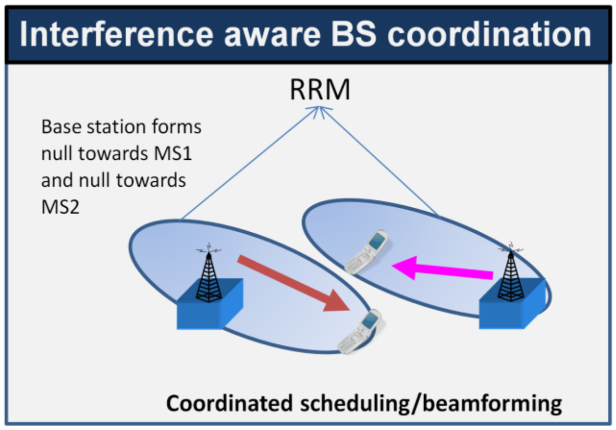


[10] IEEE 802.16m SDD : http://www.ieee802.org/16/tgm/core.html#09_0034

4.7.2. Interference aware base station coordination

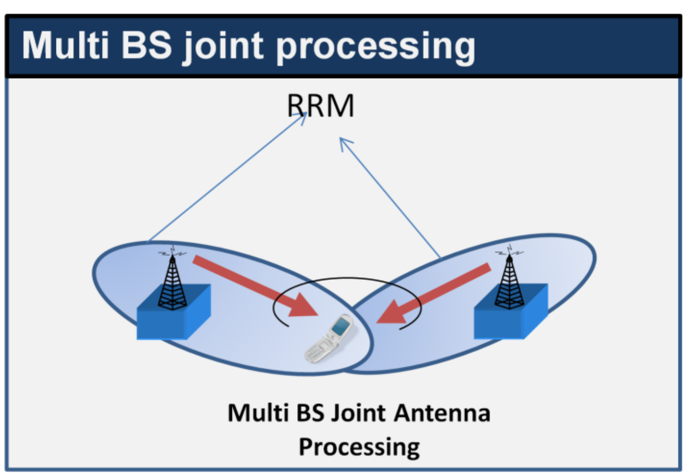
Single Cell Antenna Processing with Multi-ABS Coordination: The details of Multi base station antenna processing are presented in MIMO section. 16m supports interference mitigation techniques based on the MIMO schemes with extended inter-16 m BS coordination mechanisms and interference measurement support. The coordination between 16m BSs should be through efficient signaling over the backhaul network with slow frequency. The coordination information from adjacent 16m BS can help the scheduler on the serving 16m BS to mitigate interference through scheduling.

Figure 15 : Interference aware BS coordination



Multi-BS Joint Antenna Processing: 16m will support techniques to use joint MIMO transmission or reception across multiple 16m BSs for interference mitigation and for possible macro diversity gain, and the Collaborative MIMO (Co-MIMO) and the Closed-Loop Macro Diversity (CL-MD) techniques are examples of the possible options. For downlink Co-MIMO, multiple 16m BSs perform joint MIMO transmission to multiple 16m MSs located in different cells. Each 16m BS performs multi-user precoding towards multiple 16m MSs, and each 16m MS is benefited from Co-MIMO by receiving multiple streams from multiple 16m BSs. For downlink CL-MD, each group of antennas of one 16m BS performs narrow-band or wide-band single-user precoding with up to two streams independently, and multiple 16m BSs transmit the same or different streams to one 16m MS. Sounding based Co-MIMO and CL-MD are supported for TDD, and codebook based ones are supported for both TDD and FDD.

Figure 16 : Multi BS joint processing



4.7.3. Interference mitigation using power control mechanism and Scheduling

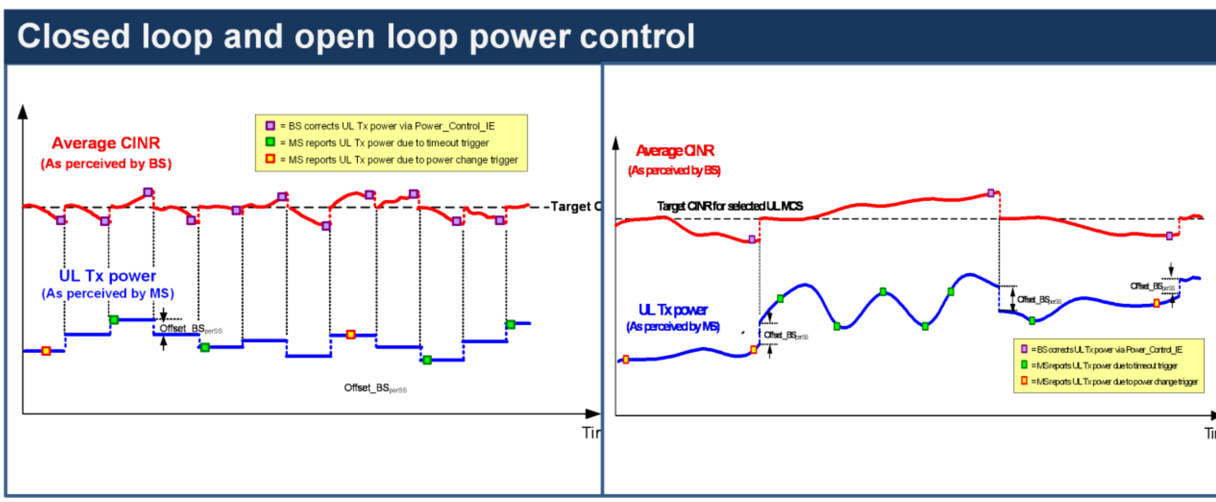
The 16m BS may use various techniques to mitigate the interference experienced by the MSs or to reduce the interference to other cells. The techniques may include sub-channels scheduling, dynamic transmit power control, dynamic antenna patterns adjustment, and dynamic modulation and coding scheme. As an example, the 16m BS may allocate different modulation and coding schemes (MCS) to mobiles through UL scheduling which indirectly controls mobile transmit power and the corresponding UL interference to other cells. The 16m BS can exchange information related to UL power control schemes with other neighbor ABSs. The MS may use interference information and its downlink measurements to control the uplink interference it causes to adjacent cells.

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

The 16m BS is capable of controlling the transmit power per sub-frame and per user. With DL power control, each user-specific information or control information would be received by the MSs with the controlled power level.

UL power control is supported to compensate the path loss, shadowing, fast fading and implementation loss. UL power control is also used to control inter-cell and intra-cell interference level. UL power control considers optimization of overall system performance and the reduction of battery consumption. UL power control consists of two different modes: Open-Loop Power Control (OLPC) and Closed-Loop Power Control (CLPC). The ABS transmits necessary information through control channel or message to 16m MSs to support UL power control. The parameters of power control algorithm are optimized on system-wide basis by the 16m BS, and broadcast periodic ally or trigged by events.

Figure 17 : Closed loop and open loop power control

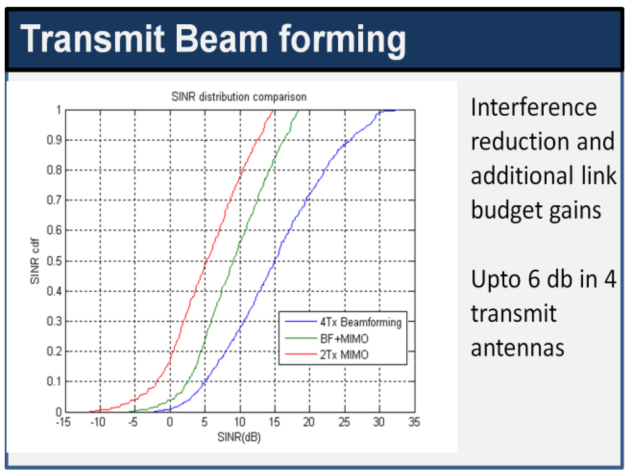


4.7.4. Transmit Beam forming

The adaptive antenna technology with beamforming is beneficial for coverage extension, signal quality improvement, interference mitigation and therefore throughput enhancement. The principle of BF is to coherently combine the signals transmitted / received by an antenna array constituted of M radiating elements to / from each terminal. This solution is actually very beneficial in radio environment where BSs are above the rooftop level, creating a lot of inter-cell interferences, and is robust in different environments.

The coherent combining of the various received information flows results in a beam formed towards the main direction of arrival of the energy transmitted /received from each individual user: this leads to improved sensitivity in the uplink as well as increased signal strength in the downlink, both allowing for range extension. In addition, the beamformer can provide general side lobe suppression outside the main beam.

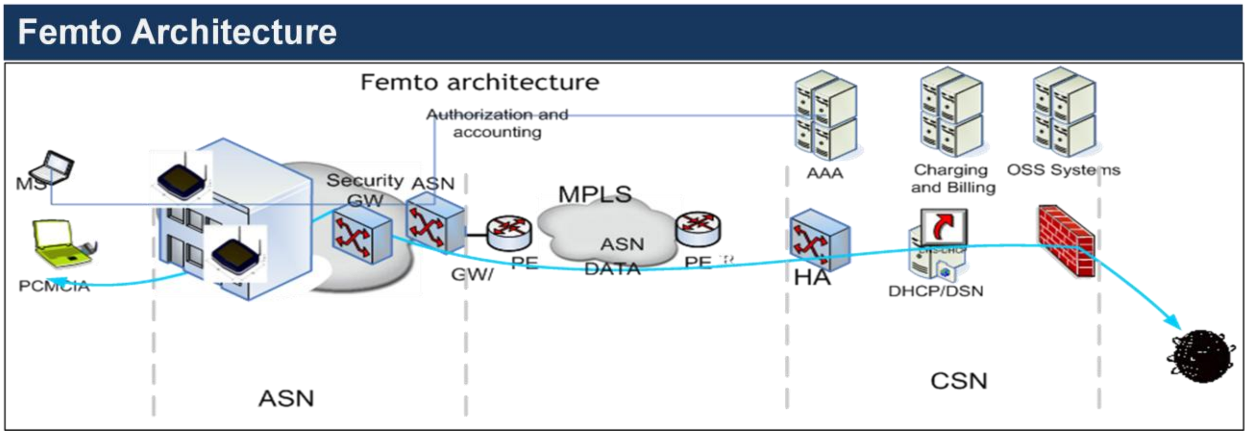
Figure 18 : Transmit beamforming for interference mitigation



4.8 Femtocells and self organizing networks

Femtocells in WiMAX 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 19 : 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.

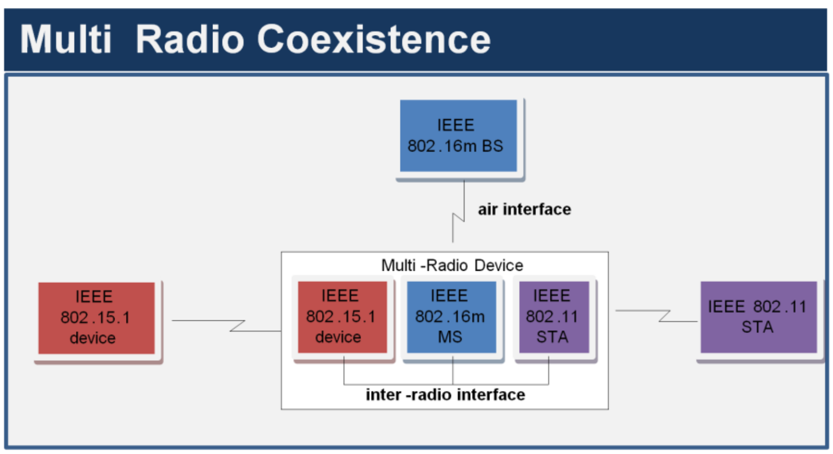
Self organization can be divided into the following two;

- 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 Mulit Radio Coexistence

IEEE 802.16m provides protocols for the multi-radio coexistence functional blocks of MSs and BSs or Relay stations to communicate with each other via air interface. Figure 20 shows an example of multi-radio device with co-located IEEE 802.16m MS, IEEE 802.11 station, and IEEE 802.15.1 device. The multi-radio coexistence functional block of the 802.16m obtains the information about other co-located radio's activities, such as time characteristics, via inter-radio interface. IEEE 802.16m provides protocols for the multi-radio coexistence functional blocks of 802.16m MS and BS or RS to communicate with each other via air interface 802.16m. MS generates management messages to report the information about its co-located radio activities obtained from inter-radio interface, and 802.16m BS or RS generates management messages to respond with the corresponding actions to support multi-radio coexistence operation.

Figure 20 : Multi Radio coexistence



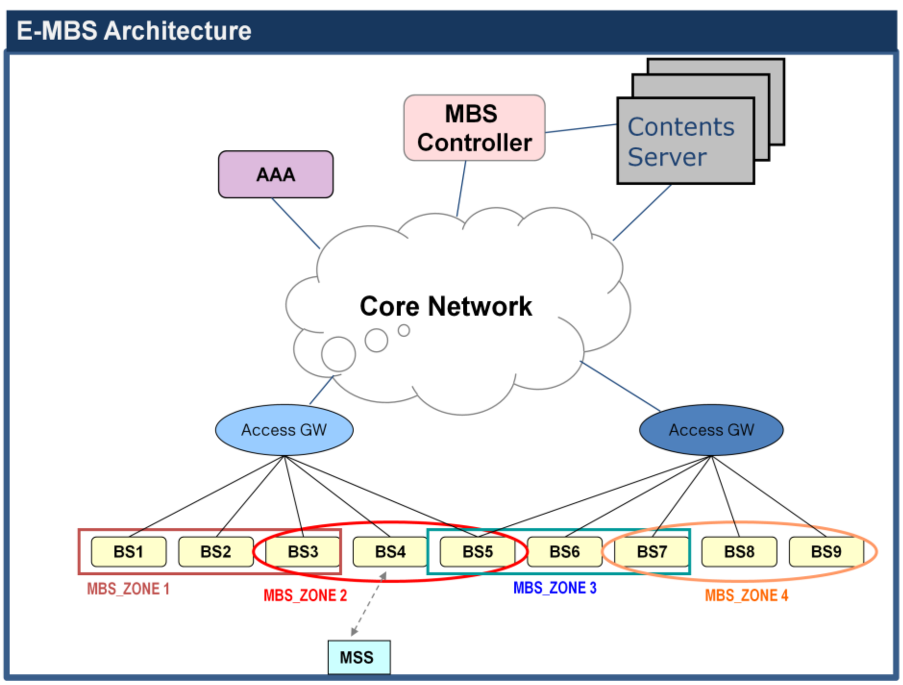
4.10 Support for Enhanced Multicast and broadcast services (E-MBS)

There are basically two methods(unicast or multicast) to support video over wireless. In unicast method, a unicast service flow is used based on user request and associated QoS (nrtPS in case of video) . The signaling procedure occurs in service flow creation, deletion and change over base station and mobile station is carried over each single service flow. Mobile stations are awake during reception of service. In unicast the required air resource increases in proportion to the number of users receiving service.

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 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 16m MS can continue to receive the E-MBS within the E-MBS zone in Connected State or Idle State.

Figure 21 : E-MBS Architecture



An 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 subframe and to allow 16m MSs combining but without any acknowledgement from 16m MSs.

4.11 Support for 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.

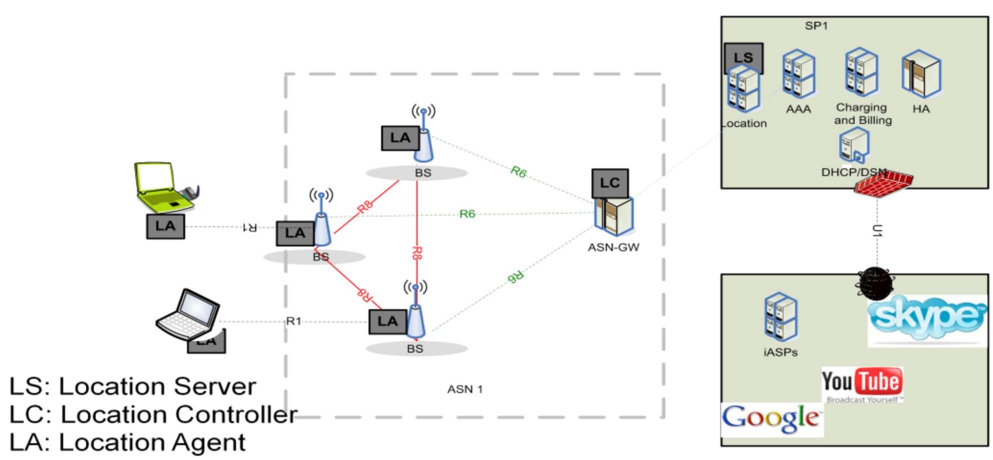
The service can be provided to;

- 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, 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 16 m BS . In addition, LBS are supported for 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, 16m MS should perform network re-entry to report location information when it is needed.

The 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 16m MS and its serving/attached or/and neighboring 16m BSs/ARSs. Location determination methods contain GPS based methods, assisted GPS and not GPS based.

Figure 22 : LBS Architecture

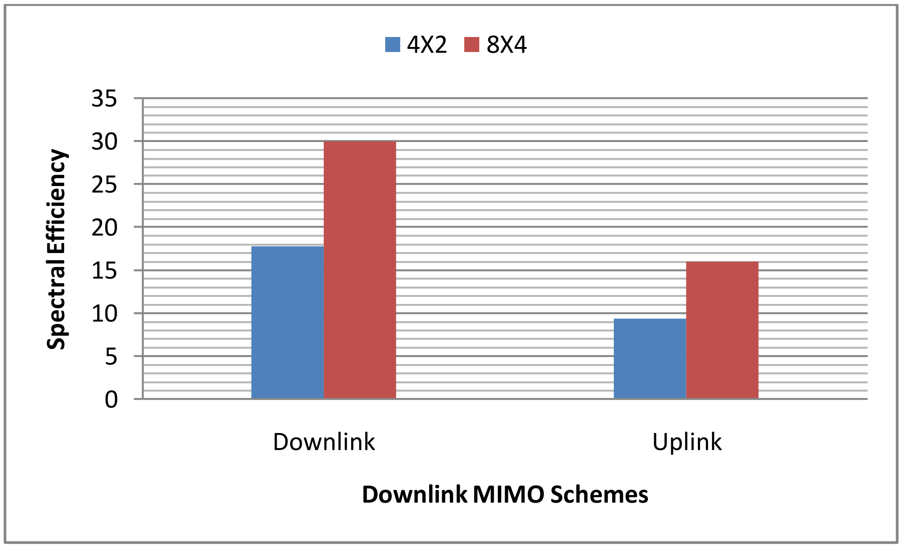


5. WiMAX 2.0 Performance

5.1 Peak Spectral Efficiency

Peak spectral efficiency for 16m systems is presented below in figure 23. With 8 layers spatial multiplexing peak spectral efficiency of 30 b/s/Hz can be supported. In uplink, with 4 layer spatial multiplexing peak spectral efficiencies of 16 b/s/Hz can be supported. Supported spectral efficiency in downlink and uplink meets the requirement of IMT-A.

Figure 23 : Peak spectral efficiency



5.2 Average Spectral Efficiency in 16m

The average spectral efficiency for 16m systems is presented below. MU-MIMO performs better with higher antenna configuration. The performance of 16m MU-MIMO with 4X2 configuration is roughly 2 times higher as compared to Release 1.0 systems. It also meets the requirement of IMT-A systems.

Figure 24 : Average spectral efficiency

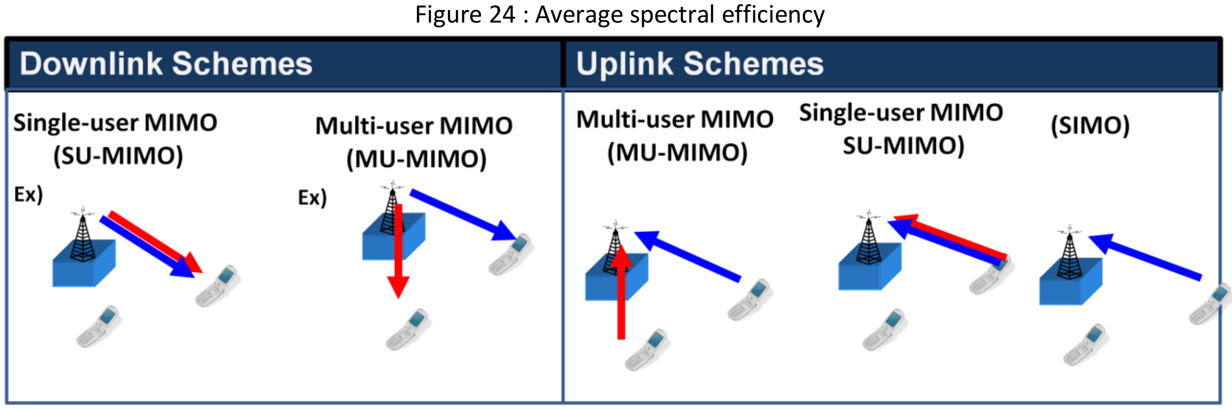


Figure 25 : Average downlink spectral efficiency

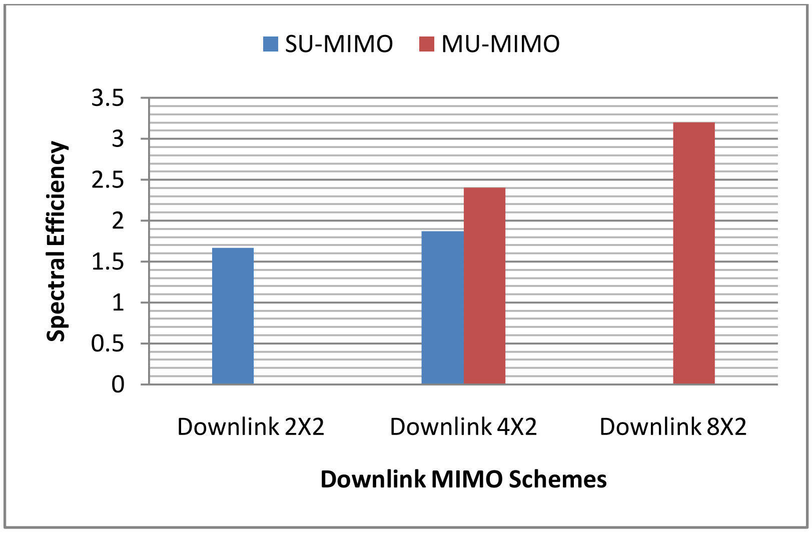
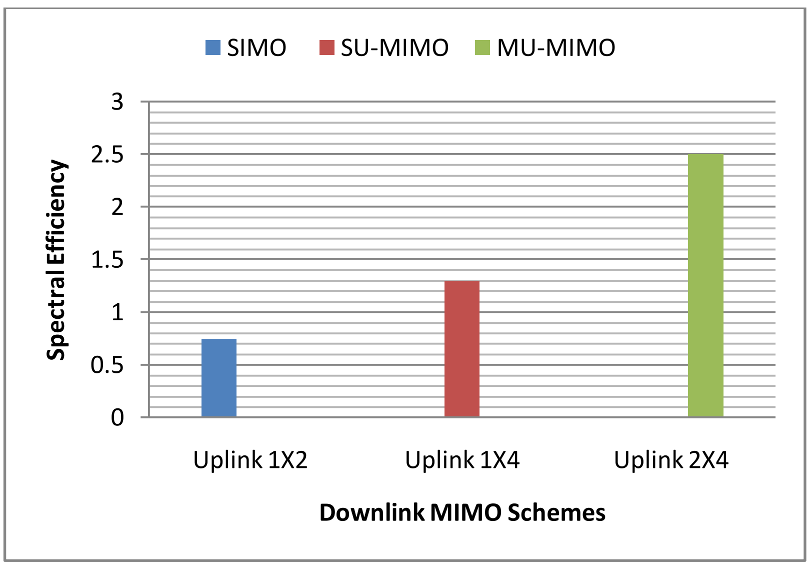


Figure 26 : Average uplink spectral efficiency



5.3 VoIP

Voice over IP capacity per sector per MHz is presented below. It meets the requirement of IMT advanced systems and performs at least 2 times better compared to release 1.0.

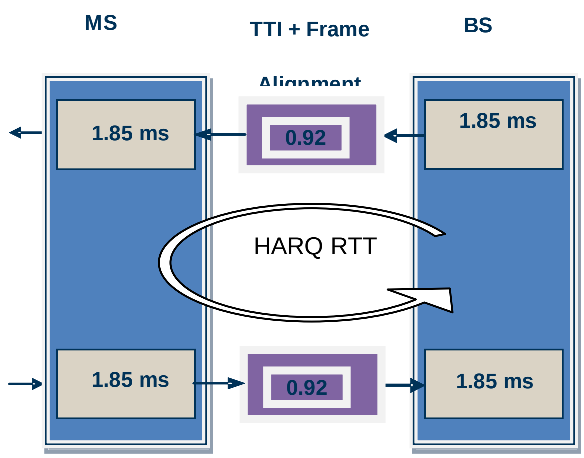
Table 3 : VoIP(per MHz/Sector)

Test environment	*DL*	*UL*	*Minimum {DL, UL}*
Indoor (InH)	*140*	*165*	*140*
Microcellular (UMi)	*82*	*104*	*82*
Base coverage urban (UMa)	*74*	*95*	*74*
High speed (RMa)	*89*	*103*	*89*

5.4 Latency

One way access latency for FDD system is 5.13 ms considering 10% HARQ retransmission and for 6.13 for 30% retransmission.

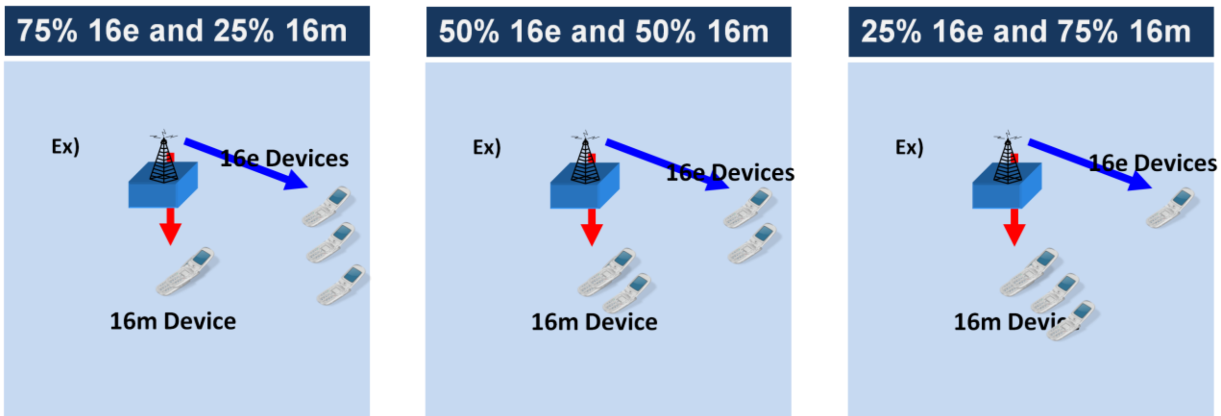
Figure 27: One Way Access latency



5.5 Coexistence performance of 16e and 16m systems

Since 16m is compatible with 16e and assuming legacy and 16m are to be deployed on the same carrier, it is expected that the performance will be weighted based on the resource partitioning of the carrier for 16e and 16m.

Figure 28: Coexistence performance of 16e and 16m systems



Assumption: 20 MHz total bandwidth in TDD mode, 4x 2 systems in the downlink, and 1x4 systems in the uplink; throughput numbers are given in ranges to account for different propagation and mobility scenarios for understanding only.

- Scenario 1: 75% .16e devices and 25% .16m devices:
  - Downlink average sector throughput: 21 Mbps – 25 Mbps
  - Uplink average sector throughput: 5.5 Mbps – 7 Mbps

- Scenario 2: 50% .16e devices and 50% .16m devices
  - Downlink average sector throughput: 24 Mbps – 28 Mbps
  - Uplink average sector throughput: 9 Mbps – 10.5 Mbps

- Scenario 2: 25% .16e devices and 75% .16m devices
  - Downlink average sector throughput: 27 Mbps – 32 Mbps
  - Uplink average sector throughput: 12 Mbps – 14 Mbps

6. Significance of WiMAX 2.0 for operators

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. 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 Std 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 16e and 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

Table 4 : Summary of all releases and IMT-A

Parameter	**Release-1**	**Release 1.5**	**Release 2**	IMT Advanced
Peak spectral efficiency (b /s/ Hz/ sector) (Mixed Mobility)	6.2(2X2) 1.3(1X2)	6.5(2X2) 1.3(1X2, Without 64 QAM)	DL: 8.0/15.0 (2x2/4x4) UL: 2.8/6.75 (1x2/2x4)	DL: 15.0 UL: 6.75

Average spectral efficiency (b /s/ Hz/ sector)	1.3 (2x2) 0.7(1X2)	1.6 (2x2) 0.9(1X2)	DL (4x2) = 2.41 UL (2x4) = 2.5	DL (4x2) = 2.2 UL (2x4) = 1.4
Cell Edge Spectral (b /s/ Hz/ sector)	DL (2x2) = 0.09 UL (1x2) = 0.05	DL (2x2) = 0.09 UL (1x2) = 0.05	DL (2x2) = 0.09 UL (1x2) = 0.05	DL (4x2) = 0.06 UL (2x4) = 0.03
Latency	C-plane: 100 ms (idle to active) U-plane: 40-50 ms	C-plane: 100 ms (idle to active) U-plane: 40-50 ms	C-plane: less than 100 ms (idle to active) U-plane: less than 10 ms	C-plane: 100 ms (idle to active) U-plane: 10 ms
Mobility	Support up to 120 Kmph	Support up to 350 Kmph	Support up to 350 Kmph	0.55 at 120 km/h 0.25 at 350 km/h
Handover Interruption time	< 60 ms	<60ms	Intra frequency: 27.5 Inter frequency: 40 (in a band) 60 (between bands)	Intra frequency: 27.5 Inter frequency: 40 (in a band) 60 (between band)
Voip Capacity	12,5 (MHz) TDD	31.6 FDD	60 (DL 2x2 and UL 1x2)	40 (4x2 and 2x4) (Base coverage urban)