WiMAX™, HSPA+, and LTE: A Comparative Analysis

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Author's Note

Performance of wireless systems is highly dependent on the operating environment, deployment choices and the end-to-end network implementation. Performance projections presented in this paper are based on simulations performed with specific multipath models, usage assumptions, and equipment parameters. In practice, actual performance may differ due to local propagation conditions, multipath, customer and applications mix, and hardware choices. The performance numbers presented should not be relied on as a substitute for equipment field trials and sound RF analysis. They are best used only as a guide to the relative performance of the different technology and deployment alternatives reviewed in this paper as opposed to absolute performance projections.

About the Author

Doug Gray is a Telecommunications Consultant and is currently under contract to the WiMAX Forum®. Gray has had extensive experience in broadband wireless access systems in engineering and management positions at Hewlett-Packard, Lucent Technologies and Ensemble Communications.

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WiMAX™, HSPA+, and LTE: A Comparative Analysis

1. Introduction

An earlier WiMAX Forum® white paper provided a very detailed description and performance analysis for WiMAX™ [Ref 1] and a follow-on white paper [Ref 2] provided a comparative analysis of WiMAX with 3G enhancements, EV-DO through Rev B and HSPA through 3GPP Rel-6. For WiMAX™ performance projections, both of those papers assumed a baseline configuration based on the WiMAX Air Interface Release 1.0 profiles. As was described in the earlier white papers, the WiMAX Release 1.0 system profile represented a subset of the features and functionality supported in the IEEE 802.16e-2005 Air Interface Standard. In this paper we consider some of the additional 802.16e-2005 supported features or enhancements for the air interface that have been approved or are being considered by the WiMAX Forum for inclusion in the next step in the backwards compatible WiMAX migration path, *WiMAX Air Interface Release 1.5*.

In section 2.0 some of the key PHY and MAC layer features for *WiMAX Air Interface Release 1.5* are described. Peak and average channel throughput and VoIP capacity are shown and compared with *WiMAX Air Interface Release 1.0* to provide the reader a view of the performance advantages achieved with these added features.

Section 3.0 describes the next steps in the 3GPP migration path known as HSPA+ and described by 3GPP Rel-7 and 3GPP Rel-8. Projected HSPA+ peak rate performance is then compared to WiMAX.

A description of 3G Long Term Evolution (LTE), also known as E-UTRA, is provided in Section 4.0. The performance requirements for LTE are defined in 3GPP Rel-8. Section 4.0 also provides a comparison of LTE Rel-8 projected performance with WiMAX. For these performance comparisons the emphasis is on peak channel data rate and average channel spectral efficiency, the two metrics most often referred to in describing or comparing these access technologies. LTE projections most often quoted in the press assume an FDD configuration with paired 20 MHz channels. Since LTE is also based on OFDMA and employs similar modulation schemes the projected performance with regard to these metrics, as expected, is similar under the same deployment conditions. The key difference between these two radio access solutions is with regard to timing and commercial availability. OFDM-based WiMAX networks for fixed services have been commercially deployed since 2006 and OFDMA-based WiMAX systems were first commercially deployed in 2008. Planned features for WiMAX with Air Interface Release 1.5 provide a straightforward upgrade path for field proven WiMAX systems. LTE on the other hand is currently in the development and trial phase. Some early adopters of LTE have announced that deployments will begin as early as 2010.

Section 5.0 provides a forward looking view regarding the next steps for both 3GPP and WiMAX with a brief description of LTE-Advanced and the IEEE 802.16m amendment to the 802.16 air interface standard. The 802.16m amendment will be the basis for WiMAX 2. Both LTE-Advanced, based on 3GPP Rel-10 and WiMAX 2 based on IEEE 802.16m are projected to meet IMT-Advanced requirements.

A timeline comparison for LTE and WiMAX is presented in Section 6.0. OFDMA-based WiMAX is field-proven, whereas LTE has yet to be commercially deployed. This clearly gives WiMAX a time-to-market advantage over LTE for either Greenfield or existing mobile operators. For existing mobile operators the challenges and costs of upgrading to ***WiMAX now or LTE later*** are similar. With the ability to reuse a considerable portion of the existing network infrastructure present day mobile operators can cost-effectively gain a considerable competitive advantage by deploying a WiMAX overlay to an existing mobile network today rather than waiting for LTE.

Unless otherwise noted, references to LTE in this paper will be with respect to LTE as defined by 3GPP Rel-8.

2. Planned Air Interface Enhancements for WiMAX

The first commercial OFDM-based WiMAX deployments based on the IEEE 802.16-2004 air interface standard occurred in 2006. Providing services for fixed, nomadic, or portable services, WiMAX quickly gained market acceptance as an alternative to broadband fixed wireline services. Since then the 802.16e-2005 amendment to the IEEE 802.16 air interface standard with the addition of OFDMA and other key features added mobility to the supported WiMAX usage models. Certified WiMAX products based on the 802.16e-2005 amendment have been commercially available since 2008. As of mid 2009 more than 130 products have received WiMAX certification and over 60% of these are Mobile WiMAX certified. There are now more than 500 WiMAX deployments currently underway serving a range of usage models from fixed to mobile services in more than 140 countries[1].

To further improve on the performance and features of WiMAX, the WiMAX Forum has completed and approved a portfolio of air interface enhancements [Ref 3]. Among the additional supported features are many air interface related enhancements that directly

[1] Information on product certifications and deployments is updated regularly and available on the WiMAX Forum website.

impact peak channel data rate and average channel and sector throughput. These are the metrics most often referenced in the discussion and comparison of different wireless access technologies and will be used in this paper to compare WiMAX with HSPA+ and LTE. A number of new frequency profiles and frequency division duplex (FDD) are also included with these enhancements. The new profiles address new spectrum allocations being made available by local regulators and FDD further expands the applicability of WiMAX into markets that have regulatory constraints on the use of TDD. FDD also gives operators added deployment flexibility where there are no such regulatory constraints and spectrum licenses are configured in paired channels.

2.1 WiMAX Air Interface Release 1.5

The air interface enhancements approved for WiMAX, designated as WiMAX Air Interface Release 1.5 (aka Air Interface R1.5), are scheduled for certification testing readiness in 2010. A more detailed description can be found in reference 3.

A summary of key PHY and MAC features or enhancements planned for Air Interface R1.5 are summarized in the following table:

Table 1: Key Features & Enhancements for WiMAX Air Interface R1.5

PHY/MAC Feature	Description
Duplex	• Support for Frequency Division Duplex (FDD) and Half Duplex FDD for increased deployment flexibility when spectrum licenses comprise paired channels.
20 MHz Channel BW	• 20 MHz added as an optional channel BW in the 1710-2170 MHz band.
AMC Permutation	• Adjacent Multi-carrier (AMC) provides more efficient sub-carrier utilization compared to PUSC in low mobility situations translating to higher peak data rate and higher average channel throughput.

PHY/MAC Feature	Description
MIMO Enhancements	• Downlink open and closed loop MIMO with AMC permutation. • UL collaborative spatial multiplexing (SM) for two MSs in AMC mode. • UL open loop STC/SM MIMO in AMC and PUSC mode • Cyclic delay diversity
MAC Efficiency Enhancements	• DL and UL Persistent Allocation of Information Elements (IE's) for reduced MAP overhead with both persistent and non-persistent traffic.
Handover Enhancements	• Improved efficiency with seamless handover
Load Balancing	• Load Balancing using preamble index and/or DL frequency override • Load Balancing using ranging abort timer • Load Balancing using BS initiated handover
Location Based Services (LBS)	• GPS-based LBS method • Assisted GPS (A-GPS) method • Non-GPS-based method
Enhanced Multicast & Broadcast Services (MBS)	• Optimization/Clarification to MBS procedures such as group DSx and inter-MBS zone continuity messages
WiMAX-WiFi-Bluetooth Coexistence	• Co-located coexistence Mode 1 • Co-located coexistence Mode 2 • Combine UL band AMC with operation with co-located coexistence

WiMAX Air Interface R1.5 also introduces several new TDD and FDD frequency profiles to address changing global spectrum allocations. Among the added profiles provided, coverage in the 698 to 862 MHz band is especially interesting in that it holds the promise of helping to bridge the digital divide in both developed and developing markets [Ref 4, 5]. Wireless access solutions in these lower frequency bands can provide a significant range and coverage advantage compared to allocations in the higher bands [Ref 6, 7]. As these lower bands become more widely available worldwide, the business case will be greatly enhanced for rural area deployments. Additionally, portions of these lower frequency bands are designated for public safety services, another important application well-suited to WiMAX. Profiles in the 1710 to 2170 MHz range, including the AWS (Advanced Wireless Services) band have also been added with Air Interface R1.5. This is one of the bands considered suitable for support of 20 MHz channel BW.

2.1.1 Peak Channel Rate Performance

The peak channel rate or peak user rate performance is a metric most often quoted in the comparison of varied access technologies. This is despite the fact that this data rate is only attainable in a limited portion of the cell coverage area where propagation conditions are sufficient to support the highest efficiency modulation scheme with minimal channel coding rate. Nevertheless, it is still an important metric for comparative purposes since it does reflect the best attainable channel performance and user experience. It is also directly proportional to the average channel throughput which, for deployment considerations, is a much more important performance metric.

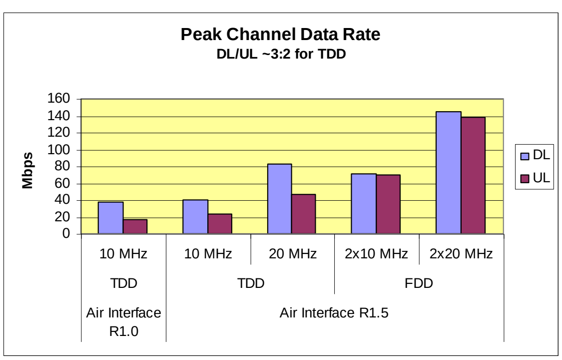
Table 2 summarizes the parameter assumptions used for the peak channel rate performance for both Air Interface R1.0 and R1.5. Although (2x2) MIMO is also supported in the UL, (1x2) SIMO is assumed in this and following examples to represent a baseline mobile station (MS) configuration. In the UL, 16QAM is a mandatory feature with both Air Interface R1.0 and R1.5 whereas 64QAM is optional. In Table 2, 64QAM with 5/6 coding rate is assumed for both Air Interface R1.0 and R1.5. The modulation and coding rate difference alone provides a net increase of 66% in the UL data rate. The use of AMC vs. PUSC provides the additional improvement in UL peak data rate.

The results for the peak channel data rate are shown graphically in Figure 1. The projections for TDD assume a DL to UL ratio of 29:18[2] (approximately 3:2).

[2] In TDD mode Mobile WiMAX can adapt to a DL to UL ratio ranging from 1:1 to 3:1.

Table 2: Parameters Assumed for WiMAX Peak Channel Rate Performance

	WiMAX		
	Air Interface R1.0	Air Interface R1.5	
Duplex	TDD	TDD	FDD
Channel BW	10 MHz	10 MHz	2 x 10 MHz & 2 x 20 MHz
Downlink	(2x2) SU-MIMO	(2x2) SU-MIMO	
Uplink	(1x2) SIMO	(1x2) SIMO	
Permutation	PUSC	AMC	
DL OH Symbols	3	3	3
DL Data Symbols	26	26	45
DL Modulation	64QAM	64QAM	
DL FEC Coding	5/6	5/6	
UL OH Symbols	3	3	
UL Data Symbols	15	15	45
UL Modulation	64QAM	64QAM	
UL FEC Coding	5/6	5/6	



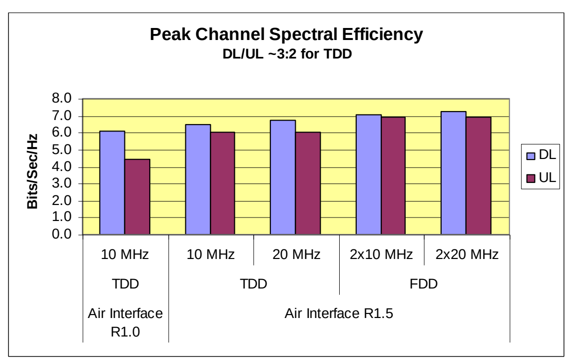


Figure 1: WiMAX Peak Data Rate Projections

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2.1.2 Average Channel Throughput Performance

Average channel or sector throughput performance provides a measure of the channel or sector capacity in a simulated multi-cellular deployment with multiple active users. Throughput performance is especially important in capacity-constrained deployments, typically encountered in high density urban environments. This parameter has a direct impact on the required base station to base station spacing necessary to satisfactorily meet peak busy hour capacity demands.

Evaluation Methodology

The evaluation methodology used for estimating throughput performance is similar to the methodology proposed by the NGMN Alliance [Ref 8] and the IEEE [Ref 9]. It is also consistent with the methodology being used for LTE Rel-8 simulations. The current methodology differs from the 1xEV-DV methodology [Ref 10] used in the past by 3GPP/3GPP2 and in earlier WiMAX Forum papers [Ref 1, 2]. The reader is cautioned therefore not to try to directly compare the results presented here with earlier results reported for WiMAX. The following table summarizes the key parameters used for the most recent simulations[3].

Table 3: Parameters Assumptions for Evaluation Methodology

Parameters	Values	
Number of Base Stations in Cluster	19	
Sectors per Base Station	3	
Operating Frequency	2500 MHz	
Frequency Reuse	1	
Duplex	TDD	FDD
Channel Bandwidth	10 & 20 MHz	2 x 10 & 2 x20 MHz
BS-to-BS Distance	0.5 kilometers	
Antenna Pattern	70° (-3 dB) with 20 dB front-to-back ratio	
Base Station Antenna Height	12 meters	
Mobile Terminal Height	1.5 meters	
BS Antenna Gain	15 dBi	

[3] Simulation results were provided by Intel Corporation

Parameters	Values
MS Antenna Gain	-1 dBi
BS Maximum PA Power	43 dBm
Mobile Terminal Maximum PA Power	23 dBm
# of BS Tx/Rx Antenna	Tx: 2; Rx: 2 [(2x2) MIMO)] & Tx: 4, Rx: 2 [(4x2) MIMO] for Release 1.5
# of MS Tx/Rx Antenna	Tx: 1; Rx: 2 [(1x2) SIMO]
BS Noise Figure	4 dB
MS Noise Figure	7 dB
Path Loss Model	I + 37.6 x Log(d) [d in km, I = 130.62 for 2500 MHz]
Log-Normal Shadowing Std Dev	8 dB
BS Shadowing Correlation	0.5
Penetration Loss	20 dB
Traffic	Full Buffer Data Traffic
Number of Users	30 per BS (10 per Sector)
Mobility	SCM with 3 km per Hour

Sector/Channel Throughput and Spectral Efficiency

Figure 2 provides a summary of the simulation results for TDD channel throughput and spectral efficiency for WiMAX with Air Interface R1.0 and R1.5. The DL to UL ratio is assumed to be approximately 3:2. The planned Air Interface R1.5 enhancements provide greater than 20% increase in DL average channel throughput.

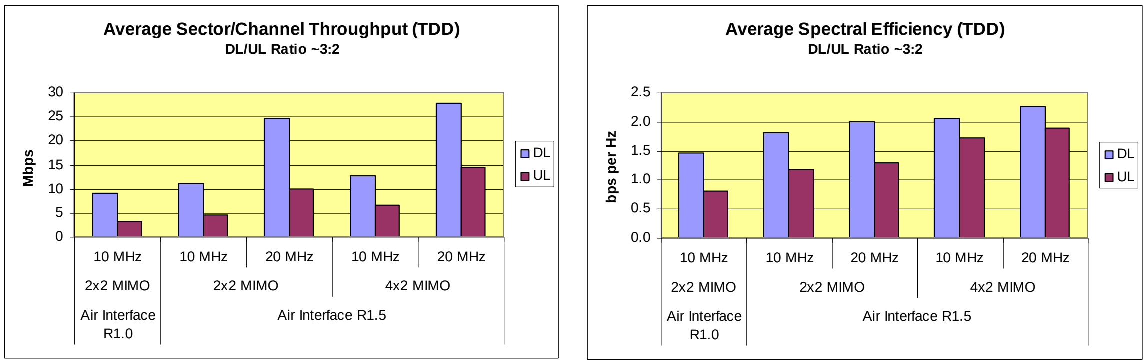

Figure 2: Average Channel/Sector Throughput (TDD)

The average channel or sector throughput and average spectral efficiency for FDD profiles with WiMAX is shown in Figure 3.

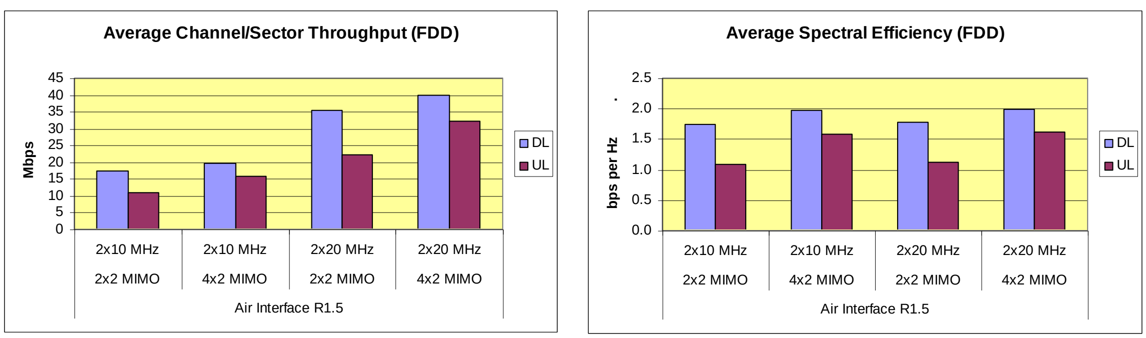

Figure 3: Average Channel/Sector Throughput (FDD)

VoIP Capacity

WiMAX Air Interface R1.0 has a VoIP capacity of 30 simultaneous VoIP sessions per MHz per sector assuming an AMR 12.2 kps speech CODEC[4]. For the same duplex method and channel BW with persistent scheduling and the other planned enhancements, the VoIP capacity is increased by more than 40% with Air Interface R1.5. With TDD and (2x2) MIMO the net VoIP capacity for a 10 MHz channel BW is approximately 215 simultaneous sessions for Air Interface R1.5. This compares to 150 VoIP sessions for Air Interface R1.0.

[4] The VoIP efficiency would be approximately 50% higher with EVRC 7.95 kbps

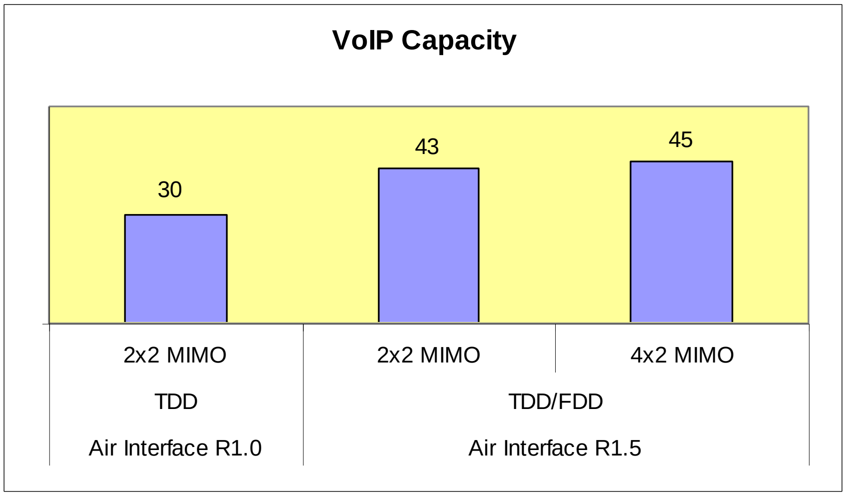

Figure 4: Simultaneous VoIP Calls per MHz

3. 3GPP Evolution: HSPA+

HSPA+ also referred to as HSPA Evolved is a further 3GPP enhancement to HSPA Rel-6. HSPA Rel-6 has been available as a WCDMA upgrade to 3G operators since 2007. HSPA Rel-6 supports a peak theoretical DL data rate of 14 Mbps and a peak theoretical UL data rate of 5.8 Mbps assuming no channel coding for error correction. HSPA+ provides an increase in both the DL and UL modulation efficiency as well as support for (2x2) MIMO at the base station. HSPA 3GPP Rel-7 supports 64QAM in the DL and 16QAM in the UL. Rel-7 also provides support for (2x2) MIMO in the DL. This DL feature however, is not supported simultaneously with 64QAM.

HSPA Rel-8 provides simultaneous support for 64QAM and (2x2) MIMO in the DL and adds the capability for dual carrier support [Ref 11, 12]. This feature, referred to as Dual Cell or Dual Carrier HSDPA (DC-HSDPA) enables the aggregation of two adjacent 5 MHz channels to provide the equivalent DL peak rate capability of a 10 MHz channel. DC-HSDPA is not supported with (2x2) MIMO but provides operators that have access to adjacent paired 5 MHz channels to get the equivalent peak performance without having to upgrade to a more advanced antenna system at the base station. This, in most cases, will represent a more cost-effective migration path for the operator since it does not necessitate a truck-roll to implement the base station antenna upgrade.

Theoretical peak DL rates reported for HSPA+ without error correction are 28 Mbps for Rel-7 and 42 Mbps for Rel-8. Theoretical peak UL rate without error correction is 11

Mbps. Other performance enhancements in HSPA Rel-7 and Rel-8 include increased VoIP capacity, reduced latency, and reduced UE battery consumption [Ref. 13].

Further enhancements being considered for HSPA in 3GPP Rel-9 include multi-carrier support for the aggregation of more DL channels, possibly up to four, without the requirement that the channels be contiguous. Another performance enhancement being considered for Rel-9 is dual carrier support in the UL to theoretically double UL peak rate performance over what is available with 3GPP Rel-8.

Since HSPA+ enhancements are backwards compatible with 3GPP Rel-5 and 3GPP Rel-6 it represents a relatively straightforward migration path for WCDMA operators to further increase key performance attributes in the access network. To take full advantage of the increased base station capacity another necessary network upgrade that must be taken into account is the need for additional capacity in the backhaul network. The cost for the required hardware upgrades to user devices must also be considered.

The following table provides a summary of key air interface enhancements for 3GPP Rel-7 and Rel-8 compared to HSPA defined by 3GPP Rel-6. Enhancements being considered for HSPA in 3GPP Rel-9 are not included in this table since this release is still in the study phase.

Table 4: Key Performance Enhancements for HSPA+

	HSPA	HSPA+ (HSPA Evolved)	
Parameter	**3GPP Rel-6**	**3GPP Rel-7**	**3GPP Rel-8**
Channel BW	5 MHz	5 MHz	5 MHz or 2 Contiguous 5 MHz Channels with DC-HSDPA
Duplex	FDD	FDD	
DL Modulation and BS Antenna	Up to 16QAM with (1x2) SIMO	Up to 64QAM with (1x2) SIMO or Up to 16QAM with (2x2) MIMO	Up to 64QAM with (2x2) MIMO or DC-HSDPA with (1x2) SIMO
UL Modulation	Up to QPSK	Up to 16QAM	
MS Antenna	(1x2) SIMO	(1x2) SIMO	

3.1 Comparing WiMAX and HSPA+

In an earlier white paper published by the WiMAX Forum [Ref. 2] a detailed analysis compared a baseline WiMAX Air Interface R1.0 configuration with 3GPP releases through HSPA Rel-6. This analysis showed that WiMAX had a higher DL and UL peak data rate and an average sector throughput that is 2 to 3 times higher than HSPA Rel-6. The throughput analysis in this case was based on simulations following the recommended 1xEV-DV methodology [Ref. 14].

Table 5 provides a summary of the peak rate comparisons for HSPA+ and WiMAX Air Interface R1.5. The peak rate projections for HSPA+ are stated with 3/4 and 5/6 coding rate for 16QAM and 64QAM respectively. This represents a more realistic deployment scenario and enables a direct comparison with WiMAX. For reference the values for HSPA+ with no error correction coding are listed in italics. To provide a direct comparison a WiMAX Air Interface R1.5 FDD solution is shown with paired 5 MHz channels. Also included for completeness is a WiMAX TDD solution with the same amount of occupied spectrum.

Table 5: WiMAX HSPA+ Performance Comparison

<table>
<tr><th rowspan="2">Parameter</th><th colspan="3">HSPA</th><th colspan="2" rowspan="2">WiMAX
Air Interface R1.5</th></tr>
<tr><th colspan="2">Rel-7</th><th>Rel-8</th></tr>
<tr><td>Duplexing</td><td colspan="3">FDD</td><td>FDD</td><td>TDD</td></tr>
<tr><td>Channel BW</td><td colspan="3">2 x 5 MHz</td><td>2 x 5 MHz</td><td>10 MHz</td></tr>
<tr><td>BS Antenna</td><td>(1x2)SIMO</td><td colspan="2">(2x2)MIMO</td><td colspan="2">(2x2)MIMO</td></tr>
<tr><td>MS Antenna</td><td colspan="3">(1x2)SIMO</td><td colspan="2">(1x2)SIMO</td></tr>
<tr><td>DL Mod-Coding</td><td>64QAM-5/6</td><td>16QAM-3/4</td><td>64QAM-5/6</td><td colspan="2">64QAM-5/6</td></tr>
<tr><td>DL Peak User Rate</td><td>17.5 Mbps
(21 Mbps w/o coding)</td><td>21 Mbps
(28 Mbps w/o coding)</td><td>35 Mbps
(42 Mbps w/o coding)</td><td>35.3 Mbps</td><td>39.9 Mbps[5]</td></tr>
<tr><td>UL Mod-Coding</td><td colspan="3">16QAM-3/4</td><td>64QAM-5/6</td><td>64QAM-5/6</td></tr>
</table>

[5] Assumes a DL to UL ratio of ~3:2

	HSPA		WiMAX Air Interface R1.5	
Parameter	**Rel-7**	**Rel-8**		
UL Peak User Rate	8.3 Mbps *(11 Mbps w/o coding)*		17.3 Mbps	11.5 Mbps[6]

As expected, the peak DL user rate for HSPA+ and WiMAX is similar since they are both based on the same modulation and coding and assume a comparable spectrum assignment of 10 MHz. The UL difference is attributable to the different modulation efficiencies for 16QAM (for HSPA+) vs. 64QAM and the difference in coding rate. The peak DL and UL data rate for WiMAX with TDD is shown for an assumed DL to UL ratio of approximately 3:2. Note that the table refers to peak *user* rate not *channel* rate; *with UL collaborative MIMO*, the peak *channel* rate for WiMAX in the UL is *34.6 Mbps and 23.0 Mbps respectively* for FDD with paired 5 MHz channels and TDD with a 10 MHz channel.

For a more complete comparative analysis between HSPA+ and WiMAX other performance factors must also be taken into account. WiMAX has many other attributes that sets it apart from HSPA+. Namely:

- Both WiMAX Air Interface R1.0 and R1.5 have higher average spectral efficiency than HSPA Rel-8 since the benefit of (2x2) MIMO with CDMA provides only a modest increase of about 20% in spectral efficiency whereas with OFDMA the increase is in the order of 60% [Ref 2]. (4x2) MIMO is also supported with WiMAX Air Interface R1.5 to provide a further increase in average spectral efficiency as shown in Figures 2 and 3.
- WiMAX Air Interface R1.0 supports channel BWs up to 10 MHz and R1.5 up to 20 MHz whereas HSPA+ is constrained to 5 MHz channel plans to comply with existing 3G WCDMA spectrum assignments. 3GPP Rel-8 does support the aggregation of 2 contiguous 5 MHz channels and 3GPP Rel-9 is considering further channel aggregation without the need for the channels to be contiguous but HSPA is still tied to a 2x5 MHz channel plan.
- WiMAX is based on an all-IP network architecture. Although HSPA+ is evolving towards an IP network it is still tied to a circuit-switched legacy network optimized for voice.

[6] Assumes a DL to UL ratio of ~3:2

- HSPA+ is still based on CDMA with its inherent limitations [Ref 2] whereas WiMAX is OFDMA-based with its advantages for:
    - High tolerance to multipath and self-interference
    - Scalable channel BW
    - Orthogonal uplink multiple access for reduced interference between multiple users
    - Frequency selective scheduling
    - Fractional frequency reuse

Although HSPA+ enables WCDMA 3G operators to gain a performance improvement over HSPA Rel-6 and provides a DL peak performance comparable to WiMAX and LTE, WiMAX offers today's operators the opportunity to overlay an existing network with a next generation access network based on OFDMA.

4. LTE

Long Term Evolution (LTE) also referred to as Enhanced-UTRA (E-UTRA) was initiated in 2004 with the purpose of defining the next phase in the 3GPP migration path. The LTE specification requirements were initially defined in 3GPP Rel-8 with further enhancements provided in 3GPP Rel-9. With LTE, 3GPP transitions from CDMA in the DL to OFDMA. In the UL LTE employs Single-Carrier FDMA (SC-FDMA).

Some of the key performance goals initially established by 3GPP for LTE are:

- Peak DL Data Rate: 100 Mbps for 20 MHz channel BW and (2x2) MIMO BS, Peak DL efficiency of 5 bps/Hz.
- Peak UL Data Rate: 50 Mbps for a 20 MHz channel BW and (1x2) SIMO MS, Peak UL efficiency of 2.5 bps/Hz.
- Average DL Throughput: 3 to 4 times HSDPA (3GPP Rel-6) at pedestrian speed
- Average UL Throughput: 2 to 3 times HSUPA (3GPP Rel-6) at pedestrian speed
- Channel BW: Scalable channel BW to 20 MHz (in contrast with fixed 5 MHz channels for UTRA)

- RAN Latency: 10 ms

The average throughput target requirements for LTE translates to, approximately 1.59 to 2.12 bps/Hz/Sector in the DL for the (2x2) and (4x2) antenna configuration, respectively, and approximately 0.66 to 0.99 bps/Hz/Sector in the UL for the (1x2) and (1x4) antenna configuration, respectively. The LTE requirements also call for a transition to an all-IP core network. This 3GPP initiative is referred to as Evolved Packet Core (EPC).

4.1 WiMAX and LTE

The performance projections for LTE most often cited in the public domain assume frequency division duplexing (FDD) with paired 20 MHz channels [Ref 15]. This is despite the fact that current worldwide spectrum allocations sufficient to support paired 20 MHz channels are very limited. To provide a direct comparison of LTE and WiMAX in FDD with paired 20 MHz channels is assumed for both cases. Peak data rates for LTE are usually reported without forward` error correction coding. The LTE peak rates in this table are presented with similar coding as WiMAX to represent a more realistic deployment scenario and to provide a one to one comparison with WiMAX. For reference purposes, the peak theoretical rates without forward error correction coding are also shown for both LTE and WiMAX in italics.

With support for UL collaborative spatial multiplexing, WiMAX achieves *138.2 Mbps for the UL channel data rate*. The *UL peak user data rate* for WiMAX would be *69.1 Mbps.*

Table 6: Peak Rate Comparisons for LTE and WiMAX

	LTE	WiMAX Air Interface R1.5
Duplex	FDD	FDD
Channel BW	2x20 MHz	2x20 MHz
BS Antenna	(2x2) MIMO	(2x2) MIMO
DL Modulation	64QAM	64QAM
DL Coding	5/6	5/6

	LTE		WiMAX Air Interface R1.5	
DL Peak Channel Rate	144.0 Mbps *(172.8 Mbps w/o coding)*		144.4 Mbps *(173.3 Mbps w/o coding)*	
MS Antenna	(1x2) SIMO		(1x2) SIMO	
UL Modulation	16QAM	64QAM	16QAM	64QAM
UL Coding	3/4	5/6	3/4	5/6
UL Peak Channel Rate	43.2 Mbps *(57.6 Mbps w/o coding)*	72.0 Mbps *(86.4 Mbps w/o coding)*	82.9 Mbps *(110.6 Mbps w/o coding)*	138.2 Mbps *(165.8 Mbps w/o coding)*

A summary of the average spectral efficiency comparisons between LTE and WiMAX are provided in Figure 5. Again the LTE values assume FDD with paired 20 MHz channels. To provide a more complete summary, Figure 5 includes several WiMAX deployment options. The WiMAX Air Interface R1.0 TDD profile assumes a 10 MHz channel BW, PUSC permutation for mixed mobility, and a DL to UL ratio of approximately 3:2. This configuration is included to provide a view of what has been commercially available since 2008. The FDD simulation results for WiMAX Air Interface R1.5 are based on paired 20 MHz channels to provide a one-to-one performance comparison to LTE, whereas the TDD Air Interface R1.5 simulation assumes a single 20 MHz channel with a 3:2 DL to UL ratio. Both WiMAX Air Interface R1.5 and LTE meet the average channel spectral efficiency requirements spelled out for LTE in 3GPP Rel-8.

As anticipated, since the underlying technologies for WiMAX and LTE are very similar the key performance parameters, namely peak and average throughput performance are comparable when considered for the same base station and mobile station antenna configurations.

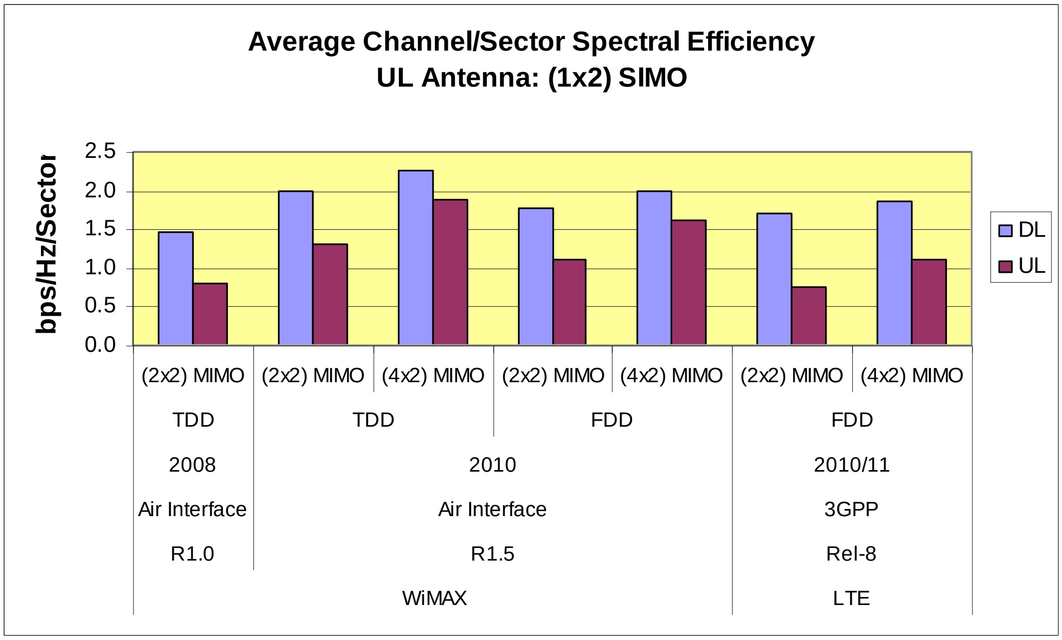

Figure 5: LTE-WiMAX Spectral Efficiency Comparison

Although the technologies adopted for both WiMAX and LTE have a lot in common there are some differences that are worth noting.

- The reported results for the LTE throughput simulations assume 2000 MHz whereas the WiMAX simulations were done assuming 2500 MHz to reflect performance in the IMT-Extension band, 2500-2690 MHz. This frequency difference will result in a higher path loss for WiMAX as compared to LTE[7]. Although simulations were not done to accurately quantify the difference between 2000 and 2500 MHz, it is reasonable to expect that this would give LTE a slight advantage in the average spectral efficiency numbers compared to WiMAX.
- LTE uses SC-FDMA, also referred to as DFT-spread OFDM, in the UL, whereas WiMAX uses OFDMA: With SC-FDMA both Fast Fourier Transform and Inverse Fast Fourier Transform are performed in both the receiver and the transmitter. With OFDMA, Fast Fourier Transform is applied on the receiver side and Inverse Fourier Transform on the transmitter side. The single carrier nature of SC-FDMA has the

[7] In the path loss model the parameter I = 128.15 dB for 2000 MHz and 130.62 dB for 2500 MHz. This reduces the SNR by almost 2.5 dB for the 2500 MHz simulation compared to 2000 MHz.

potential for a lower peak to average power ratio but otherwise provides UL benefits similar to OFDMA.

- LTE frame size is 1 millisecond vs. 5 milliseconds for WiMAX: The smaller frame size may translate to lower latency but at the expense of higher overhead. WiMAX will introduce the concept of sub-frames in WiMAX 2 for latency-sensitive applications.

5. IMT-Advanced and IEEE 802.16m

5.1 IMT-Advanced

IMT-Advanced is the ITU description for systems beyond IMT-2000. ITU Working Group 9 has projected requirements for future systems based on projected demand for mobile services, increased user expectations, and anticipated services and applications that may evolve over the next several years [Ref 16]. Based on these studies IMT-Advanced calls for a shared channel DL peak rate of 1000 Mbps in a low mobility scenario and 100 Mbps in a high mobility situation [Ref. 17, 18]. Low mobility is defined as pedestrian speed (10 km/hr) and high mobility as 350 km/hr. To be considered a candidate access technology, IMT-Advanced spells out minimum performance requirements for the following parameters:

- Peak and average channel spectral efficiency
- Cell edge user spectral efficiency
- VoIP Capacity
- Control and User Plane Latency
- Handover
- Channel bandwidth
- Mobility

Additional IMT-Advanced requirements address features required for anticipated applications, services, and the expected needs of users and operators; including QoS, roaming, interworking with other wireless networks, etc.

An example of IMT minimum requirements for sector (or channel) spectral efficiency, and concurrent VoIP sessions under various test environments, assuming (4x2) MIMO in the DL and (2x4) MIMO in the UL, is shown in Table 7.

Table 7: IMT-Advanced Minimum Requirements for Sector Spectral Efficiency

Test Environment	Speed	Downlink bps/Hz/Sector	Uplink bps/Hz/Sector	VoIP Calls/MHz/Sector
Indoor	Up to 10 km/hr	3.0	2.25	50
Micro-cellular	Up to 30 km/hr	2.6	1.8	40
Base Coverage Urban	Up to 120 km/hr	2.2	1.4	40
High Speed	Up to 350 km/hr	1.1	0.7	30

5.2 IEEE 802.16m

The IEEE 802.16m project was approved in December 2006 [Ref 19]. The goal of this project is to develop an amendment to the IEEE 802.16 WirelessMAN-OFDMA specification to enable air interface performance in licensed bands that meets or exceeds the requirements of IMT-Advanced. A final specification is scheduled for completion in the early part of 2010 and ratification expected mid 2010.

Key target performance requirements and features for the 802.16m amendment to the IEEE 802.16 Air Interface Standard are summarized in Table 8. Whereas many of the IMT-Advanced minimum performance targets assume (4x2) MIMO in the DL and (2x4) MIMO in the UL, many of the 802.16m numbers are referenced to a baseline configuration of (2x2) MIMO in the DL and (1x2) SIMO in the UL.

Table 8: Summary of Objectives for IEEE 802.16m

Parameter	Targeted Performance
• Frequency Bands	Licensed bands less than 6000 MHz (Typical: 450 MHz to 3800 MHz)
• Duplex	TDD, FDD, and H-FDD
• Scalable Channel Bandwidth	5, 7, 8.75, 10, 20, and 40 MHz
• Multi-carrier support for contiguous or non-contiguous channels:	Up to 100 MHz operating BW with channel aggregation
• Increased DL peak channel and user data rate:	>1000 Mbps with low mobility >100 Mbps with high mobility
• Peak DL Spectral Efficiency	8.0 bps/Hz with (2x2) MIMO 15.0 bps/Hz with (4x4) MIMO
• Peak UL Spectral Efficiency	2.8 bps/Hz with (1x2) SIMO 6.75 bps/Hz with (2x4) MIMO
• 2x Increase in Average DL Spectral Efficiency with (2x2) MIMO	>2.6 bps/Hz >0.26 bps/Hz per User
• 2x Increase in cell edge DL user throughput:	>0.09 bps/Hz/User
• 2x Increase in Average UL Spectral Efficiency with (1x2) SIMO	>1.3 bps/Hz >0.13 bps/Hz/User
• 2x Increase in cell-edge UL user throughput:	>0.05 bps/Hz/user
• VoIP Capacity: with (2x2) MIMO in DL and (1x2) SIMO in UL	>30 Concurrent sessions per MHz per sector for AMR 12.2 kbps speech codec
• Latency	User Plane: < 10 ms UL or DL Control Plane: Idle to Active <100 ms
• Frame Structure	Super Frame: 20 ms Frame: 5 ms Sub-Frame: 0.625 ms
• Mobility Support	Up to 500 km/hr

Parameter	Targeted Performance
• Advanced Antenna Systems	DL: (2x2), (2x4), (4x2), (4x4), (8x8) UL: (1x2), (1x4), (2x4), (4x4)
• Backwards Compatibility	Backwards compatible with WiMAX Air Interface R1.0 and R1.5

The proposed frame structure in 802.16m enables tradeoffs between lower latency with the *sub-frame* structure for latency-sensitive applications and lower overhead with *Super Frames* for large file transfers.

Other IEEE 802.16m features or performance enhancements to earlier releases include:

- Single-User and Multi-User MIMO (SU-MIMO and MU-MIMO)
- Multi-Hop Relay Support
- Support for Femto-Cells and Self-Organization (SON)
- Enhanced Multi-Cast and Broadcast Services
- Coexistence and interworking with other Radio Access Technologies
- Multi-Technology Mobile Support
- Enhanced power savings for reduced MS power consumption

5.3 WiMAX 2

With the anticipated completion of the IEEE 802.16m specification in 2010, the WiMAX Forum has already begun the development of the WiMAX 2 system profile. By moving forward in concert with the IEEE efforts the WiMAX Forum will be in a position to move very quickly to the certification phase for WiMAX 2 products soon after the ratification of IEEE 802.16m.

WiMAX 2 will provide further enhancements to DL and UL peak user and peak channel data rates. Average channel/sector throughput will also be increased to provide performance that meets or exceeds the IMT-Advanced requirements as outlined for the varied usage models in Table 7.

5.3.1 WiMAX Migration Path for DL Peak Channel Data Rates

Figure 6 provides a view of the WiMAX migration path for DL peak channel data rate from Air Interface R1.0 through WiMAX 2 with base station antenna configurations of

(2x2) and (4x4) MIMO. All of the DL peak values shown in the chart assume 64QAM with a 5/6 code rate and the TDD options assume a DL to UL ratio of 3:2.

With regard to timing, TDD and FDD profiles for WiMAX based on Air Interface R1.5 are anticipated in 2010 and the first certifiable WiMAX 2 products are expected to be available in 2011.

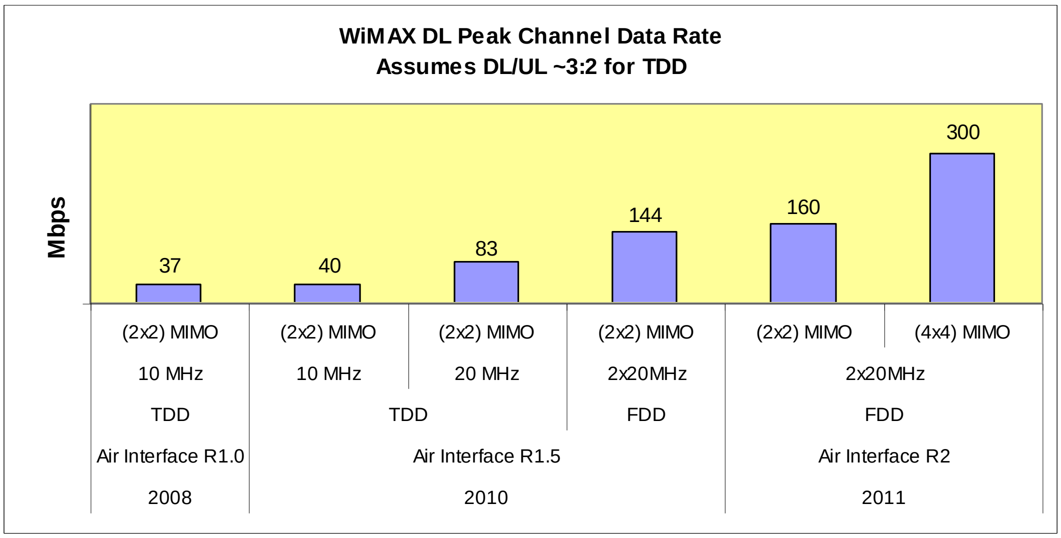

Figure 6: Peak DL Data Rate Migration Path for WiMAX

A TDD option for WiMAX 2 is not shown in the chart but it is possible to extrapolate the expected performance for TDD based on the planned FDD enhancements. With (4x4) MIMO and a 20 MHz channel BW with a 3:2 DL to UL ratio the peak DL data rate for a TDD implementation can be expected to exceed 170 Mbps. Based on these projections for WiMAX 2 with either TDD or FDD, meeting the IMT-Advanced peak DL peak data rate target requirement of 1000 Mbps with (4x4) MIMO would require the aggregation of multiple 20 MHz (or 40 MHz) channels.

5.3.2 Backwards Compatibility

The requirement for backwards compatibility for WiMAX 2 and other future WiMAX releases will help ensure a graceful migration path for operators that have deployed or will be deploying WiMAX systems. Backwards compatibility ensures the following:

- A WiMAX 2 Mobile Station will interoperate with a WiMAX[8] Base Station
- A WiMAX 2 Base Station and a WiMAX Base Station can coexist on the same carrier
- A WiMAX 2 Base Station will support both WiMAX and WiMAX 2 Mobile Stations
- A WiMAX 2 Base Station will support handoff of a WiMAX Mobile Station to or from a WiMAX Base Station or a WiMAX 2 Base Station
- A WiMAX 2 Base Station will efficiently interoperate with a WiMAX Mobile Station

5.4 LTE-Advanced

LTE-Advanced is 3GPP's answer to the IMT-Advanced requirements. Early efforts in developing the LTE-Advanced specification have begun and the standard will be completed as part of 3GPP Rel-10 scheduled for the end of 2010. Since this effort is still in its early phases of development, details have not been fully defined. In any case since it will be based on similar technology in the access network (OFDMA) and the target performance is driven by the same IMT-Advanced requirements, it can be expected that LTE-Advanced and WiMAX 2 will, in the end, have comparable performance with respect to the key air interface metrics.

The major distinction between these two technologies is not going to be with regard to performance but will be with regard to time-to-market (TTM). Depending on exactly when commercial LTE deployments begin; whether it is 2010 or 2011, WiMAX has a 2-3 year TTM advantage in the deployment of a next generation, OFDMA-based, all-IP network.

6. WiMAX has Time-to-Market Advantage

WiMAX products based on the IEEE 802.16e-2005 Air Interface Standard are already field-proven with deployments having begun in 2008. With more than 500 deployments covering over 430 million people worldwide, WiMAX is well-positioned for a high global take rate. Independent studies have predicted significant growth in the number of WiMAX subscribers over the next several years. One recent report[9] forecasts 140 million WiMAX subscribers in 2013. This growth in volume will be a key catalyst in driving down the cost of WiMAX subscriber stations.

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[8] WiMAX in this context includes systems based on both Air Interface R1.0 and Air Interface R1.5

[9] Infonetics Research Q2-09 report: WiMAX Equipment, Devices, and Subscriber market share forecast and Research Report

The close cooperation between the WiMAX Forum Technical Working Group and the IEEE 802.16m standards team, has enabled early work on a WiMAX 2 specification to begin. Given this early start, the WiMAX 2 specification is expected to be completed soon after the 802.16m amendment is ratified in 2010. This will pave the way for the WiMAX 2 certification process to begin in 2011. The LTE-Advanced specification is not scheduled for completion until the end of 2010.

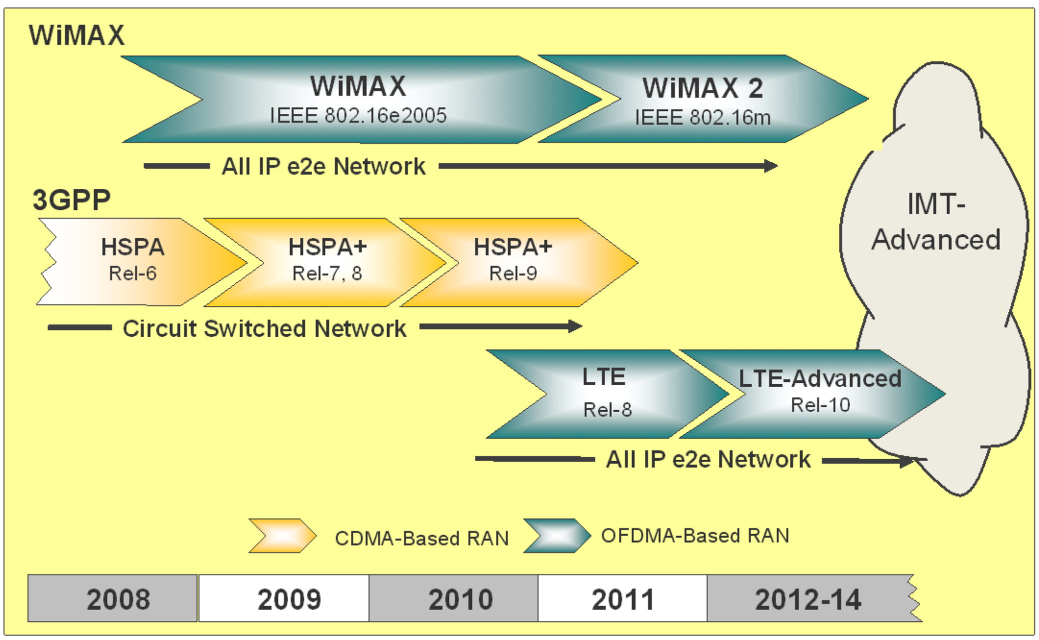

Figure 7: Timeline for Mobile WiMAX and 3GPP

6.1 Migration Path Options for Today's Mobile Operators

Many of today's mobile operators are already faced with capacity constraints in high density urban areas. WiMAX offers these operators another migration path option to not only add capacity to the access network to meet current demands but also the opportunity to offer new value-added services and applications not supported by the current network. Although HSPA+ gives WCDMA operators a relatively straightforward upgrade path for additional capacity in the access network, it does not offer the attributes that WiMAX or LTE can provide. Operators wanting to move to a truly next generation network can consider WiMAX today or wait for LTE in a year or two. In most cases operators will elect to phase in these advanced technologies by initially overlaying existing networks in the geographic areas that are capacity constrained. This preserves the existing network for traditional voice services and enables the offering of new, data-rich services on the overlay network. Whether it's WiMAX or LTE, the upgrade path from a cost and complexity point of view will be similar.

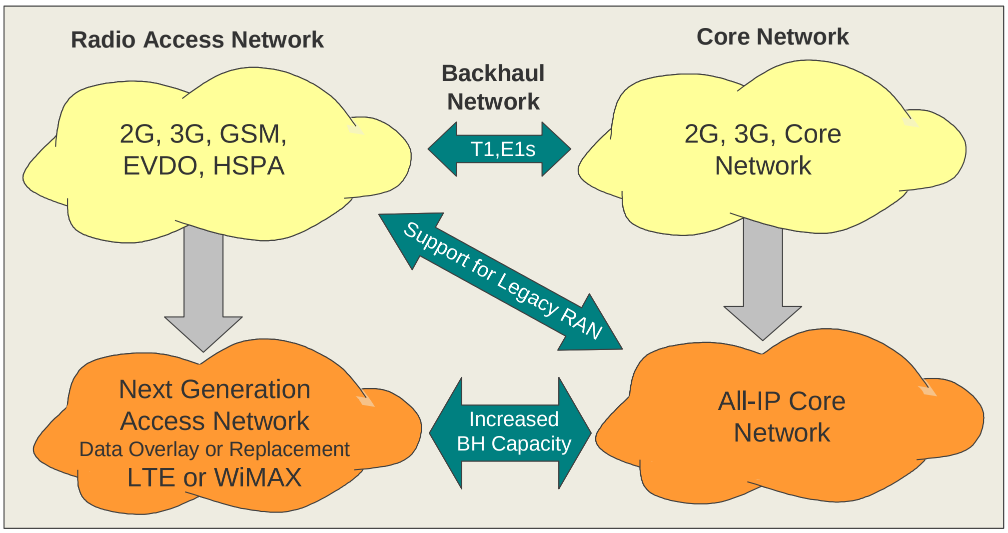

Figure 8: Migration Paths for Today's Mobile Operators

Either upgrade path requires the following considerations:

- Availability of suitable spectrum to support the wider channel bandwidths supported by WiMAX or LTE: Bands that deserve serious consideration for the support of 20 MHz channel BW include the 1710-2170 MHz band, the IMT-Extension band (2500-2690 MHz), and the so-called "Digital Dividend" (698-862 MHz[10]).
- Equipment upgrade in the radio access network: Both WiMAX and LTE require hardware upgrades and advanced antenna systems to gain the full performance benefits.
- Increased capacity in the backhaul network: For some operators this will represent a transition from leased T1 or E1 lines to point-to-point wireless for others it will be increasing the capacity of an existing microwave point-to-point link.

[10] Spectrum designated by "Digital Dividend" has regional differences: 698-806 MHz in the Americas and 790-862 MHz in Europe while Asia is a blend of the two.

- Transition from a circuit-switched to an all-IP end-to-end network:
- Requirement for multi-mode and multi-band subscriber devices to enable seamless internetwork transitions and global roaming: [LTE-2G/3G interworking and WiMAX-2G/3G interworking]. Some multi-mode WiMAX subscriber devices are already commercially available, a sampling of which are shown in Figure 9, and others will be introduced in the coming months.

Figure 9: A Sampling of WiMAX Multimode Devices

7. Summary and Conclusion

The WiMAX technology is field proven with more than 500 deployments worldwide providing services for fixed, nomadic, portable, and mobile broadband applications. The WiMAX Forum is moving aggressively to define a system specification for WiMAX 2 based on the 802.16m amendment to the IEEE 802.16 Air Interface Standard. This backwards compatible migration path will give operators the capability of meeting IMT-Advanced performance requirements for next generation broadband mobile networks in the 2011/2012 timeframe.

LTE and LTE-Advanced are 3GPP's response to the IMT-Advanced requirements. LTE which may be available as early as 2010 will have performance comparable to WiMAX with some modest air interface enhancements already approved by the WiMAX Forum with expected availability in 2010. The LTE-Advanced specification, defined by 3GPP Rel-10, is not expected to be finalized until the end of 2010. From a time-line perspective WiMAX 2 has a clear time-to-market advantage over LTE-Advanced.

HSPA+ is another interim step in the 3GPP migration path to get more capacity out of existing WCDMA networks. Proposed enhancements defined by 3GPP Rel-7 and Rel-8 provide peak performance comparable to WiMAX with Air Interface R1.5 and LTE. For today's WCDMA operators, HSPA+ is a relatively straightforward upgrade that does not require the acquisition of new spectrum licenses. Operators fortunate to have two contiguous WCDMA licenses can also take advantage of DC-HSPA. Although peak data rates are comparable, average channel or sector throughput performance for HSPA+ with advanced antenna systems is not expected to be comparable to either WiMAX or LTE.

Both the 3GPP and WiMAX migration paths are targeting to meet the same end result; the performance goals established by IMT-Advanced. OFDMA with an all-IP core network architecture have been accepted as the basic foundation for achieving these goals. Time-to-market is the key differentiator with WiMAX holding a significant advantage.

Acronyms

3GPP	Third Generation Partnership Project
AMC	Adjacent Multi-Carrier
AMR	Adaptive Multi-Rate
AWS	Advanced Wireless Services

BS	Base Station
BW	Bandwidth
CDMA	Code Division Multiple Access
CINR	Carrier to Interference + Noise ratio
CODEC	Coder-Decoder
DC-HSDPA	Dual Cell (or Carrier)-High Speed Downlink Packet Access
DFT-spread OFDM	Discrete Fourier Transform Spread Orthogonal Frequency Division Multiplex
DL	Downlink
EPC	Evolved Packet Core
E-UTRA	Enhanced Universal Terrestrial Radio Access
EV-DO	Evolution-Data Optimized
EV-DV	Evolution-Data Voice
EVRC	Enhanced Variable Rate CODEC
FDD	Frequency Division Duplex
FEC	Forward Error Correction
GPS	Global Position System
HD-FDD	Half-Duplex Frequency Division Duplex
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Uplink Packet Access
IE	Information Element
IMT	International Mobile Telecommunication
IP	Internet Protocol
ITU	International Telecommunication Union
LBS	Location Based Services
LTE	Long Term Evolution

MAC	Media Access Control
MAP	Media Access Protocol
MBS	Multicast Broadcast Services
MIMO	Multiple Input Multiple Output
MS	Mobile Station
MU-MIMO	Multi-User MIMO
NGMN	Next Generation Mobile Network
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
PUSC	Partially Used Sub-Channel
RAN	Radio Access Network
SC FDMA	Single Carrier Frequency Division Multiple Access
SIMO	Single Input Multiple Output
SON	Self Organizing Network
SM	Spatial Multiplexing
STC	Space Time Coding
SU-MIMO	Single User MIMO
TDD	Time Division Duplex
TTM	Time to Market
UE	User Equipment
UL	Uplink
UMB	Ultra Mobile Broadband
UTRA	Universal Terrestrial Radio Access
VoIP	Voice over Internet Protocol
WCDMA	Wideband Code Division Multiple Access
WiFi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access

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