ISSN No. 0976-5697
Volume 2, No. 2, Mar-Apr 2011
International Journal of Advanced Research in Computer Science
RESEARCH PAPER
Available Online at www.ijarcs.info

A Technical Comparison of Mobile WiMAX and Third Generation Mobile Technologies

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Abstract-- Mobile WiMAX, as a fourth generation technology, meets all the requirements for Personal Broadband access. It supports high data rates, high sector throughput, multiple handoff mechanisms, power-saving mechanisms for mobile devices, advanced QoS and low latency for improved support of real-time applications, advanced authorization, authentication and accounting (AAA) functionality.
Unlike the CDMA-based 3G systems, which have evolved from voice-centric systems, WiMAX is designed to meet the requirements necessary for the delivery of broadband data services as well as voice. UMTS, CDMA2000 and TD-SCDMA are all optimized for voice applications (with the obvious exception of EV-DO). These technologies have evolved over 7-10 years and data / broadband has been added to the standard incrementally.

Keywords: WiMax, 3G, CDMA, SCDMA, 3GPP, QoS,AAA

I. INTRODUCTION

Service operators face some tough decisions as they witness a rising demand for "anywhere, anytime" broadband access. Service-operators sense that there is a real business opportunity to provide a substantial increase to the all-important average revenue per user (ARPU). However, when considering the implementation aspect, service providers find the technological landscape dotted with options, trends, and hype. Many technologies, backed by strong vendors and consortiums are vying for the service providers' attention. In addition, many vendors, having invested considerable amount of resources and money in the different technologies, are loudly promoting their respective technologies.

This paper examines the different technological options facing a service provider considering deploying a personal, mobile, broadband access network. The paper provides a high level comparison of commonalities and differences of these various technologies. It focuses on high capacity technologies comparing WiMAX 4G technology and the different 3G options, 1xEVDO, HSDPA / HSUPA, WCDMA, CDMA2000 3G FDD based networks, and where possible, the "over the horizon" 3GPP-LTE.

II. OFDMA BASED SUBSCRIBER ACCESS

Orthogonal frequency division multiple access (OFDMA) gives 802.16e more flexibility when managing different user devices with a variety of antenna types and form factors. It reduces interference for user devices with Omni-directional antennas and improves NLOS capabilities that are essential when supporting mobile subscribers.

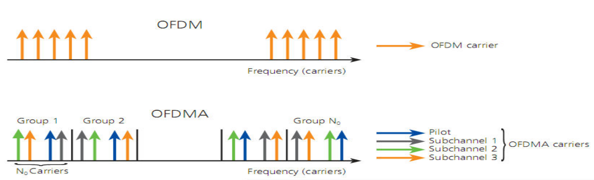

Figure 1: Single Carrier and OFDMA received Signals

III. SCALABLE CHANNEL BANDWIDTH

Mobile WiMAX employs scalable OFDMA (SOFDMA) to enable channel bandwidth scalable from 1.25 to 20 MHz.

Table I.: Data rate per cell for various coding techniques (in Mbps) Source: Intel [2]

Modulation	QPSK	QPSK	16 QAM	16 QAM	64 QAM	64 QAM
Code rate	1/2	3/4	1/2	3/4	2/3	3/4
1.75 MHz	1.04	2.18	2.91	4.36	5.94	6.55
3.5 MHz	2.08	4.37	5.82	8.73	11.88	13.09
5MHz	4.16	6.28	8.32	12.48	16.63	18.70
7 MHz	4.15	8.73	11.64	17.45	23.75	26.18
10 MHz	8.31	12.47	16.63	24.94	33.25	37.40
20 MHz	16.62	24.94	33.25	49.87	66.49	74.81

Table II : SOFDMA scalability parameter Source: dBrn Associates, Inc. [3]

System Bandwidth (MHz)	1.25	2.5	5	10	20
Sampling Frequency (MHz)	1.429	2.85	5.714	11.429	22.857
Sample Time (nano-secs)	700	350	175	88	44
FFT Size (sub-channels)	128	256	512	1024	2048
Sub-carrier Frequency Spacing	11.1607 KHz				

IV. ASYMMETRIC TRAFFIC SUPPORT

Time division duplex (TDD) enables efficient support of asymmetric traffic for easy support of IP-based traffic and channel reciprocity for easy support of advanced antenna systems.

Hybrid-automatic repeat request (H-ARQ) provides added robustness with rapidly changing radio path conditions in high mobility situations.

WiMAX can also support frequency division duplex (FDD), which dominates in 3G networks. FDD keeps the uplink and the downlink channels separate in frequency, whereas, TDD is a less complex, more efficient mechanism that uses a single frequency channel, with uplink and downlink traffic separated by a guard time.

V. SUB-CHANNELIZATION

Sub-channelization with multiple sub-carrier permutation options concentrates the transmit power into fewer OFDM carriers. This increases the system gain, which can either be used to extend the reach, overcome the building penetration losses, or reduce the power consumption of the CPE. Sub channeling enables a more flexible use of resources that support nomadic and mobile operation.

VI. POWER MANAGEMENT

Power Conservation Management ensures power-efficient operation of battery operated mobile handheld and portable devices in Sleep and Idle modes.

VII. OPTIMIZED HANDOFF

Network-optimized hard handoff (HHO) is supported to minimize overhead and achieve a handoff delay of less than 50 milliseconds.

VIII. MULTICAST AND BROADCAST SERVICE

Multicast and broadcast service (MBS) provides high data rate and coverage using a flexible radio resource allocation, low mobile device power consumption, and low channel switching time.

IX. ADVANCED ANTENNA SYSTEM

Advanced (or smart) antenna system (AAS) enables a wide range of advanced technologies such as multiple-input-multiple-output (MIMO), beam-forming, space-time coding and spatial multiplexing.

For IP-based services, the use of a TDD channel duplexing for the uplink and downlink, combined with OFDMA modulation facilities, makes it substantially less complex and more cost-effective to implement MIMO and beam forming in mobile WiMAX networks than in CDMA-based networks. MIMO and beam forming significantly improve throughput in TDD-based WiMAX networks.

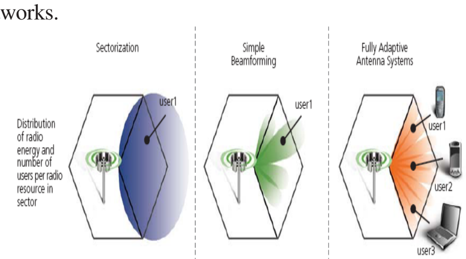

Figure 2 . Beam Forming

X. ADAPTIVE MODULATION AND CODING

In essence, adaptive modulation selects the highest data rate consistent with the required error rate, therefore trading off capacity for quality of service. The key feature of adaptive modulation is that it increases the range that a higher modulation scheme can be used over, since the system can flex to the actual fading conditions, as opposed to having a fixed scheme that is budgeted for the worst case conditions.

XI. BUILT-IN ADVANCED ERROR CORRECTION TECHNIQUES

Error correction techniques have been incorporated into WiMAX to reduce the system signal to noise ratio requirements. Strong Reed Solomon forward error correction (FEC), convolutional encoding, and interleaving algorithms are used to detect and correct errors to improve throughput. These robust error correction techniques help recover frames that may have been lost due to frequency selective fading or burst errors. This significantly improves the bit error rate (BER) performance for a given threshold level.

XII. FRACTIONAL FREQUENCY REUSE

Fractional frequency reuse controls co-channel interference to support universal frequency reuse with minimal degradation in spectral efficiency.

XIII. SHORT FRAME DURATION

A five millisecond frame size provides optimal tradeoff between overhead and latency.

XIV. PRIVACY AND SECURITY

Maintaining communications security has been an on-going concern with both fixed and mobile wireless networks. WiMAX supports both 56-bit digital encryption standard (DES) and 128-bit advanced encryption standard (AES). WiMAX also requires user terminal and base station authentication as well as data authentication with secure key exchange. The baseline authentication architecture for WiMAX employs X.509-based public key infrastructure (PKI) certificate authentication.

A. 3G *Technologies*

[a] Competing Technologies

The 3G partnership project (3GPP) and 3G partnership project 2 (3GPP2) have been defining standards for enhancements to today's 3G systems. The objective is to add network capacity and features enabling operators to offer new data-oriented services over their existing networks. The extensions are discussed below:

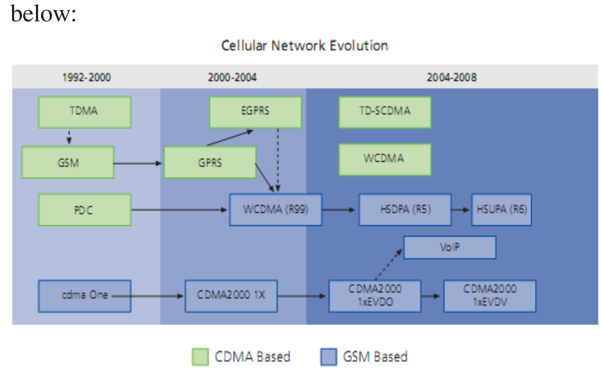

Figure 3. Cellular Network Evolution Source: Intel [2]

[i] Cdma Family

CDMA 2000 represents a family of technologies that includes CDMA2000 1X and CDMA2000 1xEV. CDMA2000 1X can double the voice capacity of cdma One networks and delivers peak packet data speeds of 307 Kbps in mobile environments. CDMA2000 1xEV includes:

CDMA2000 1xEV-DO is a high-speed data only system for 1.25 MHz FDD channels and delivers peak data speeds of 2.4Mbps supporting applications such as MP3 transfers and video conferencing.

CDMA2000 1xEV-DV provides integrated voice and simultaneous high-speed packet data multimedia services at speeds of UP TO 3.09 MBPS.

WIDEBAND CODE DIVISION MULTIPLE ACCESS (WCDMA) uses direct sequence spread spectrum (DSSS) to spread the signal over a 5 MHz spectrum. It is based on 3GPP Release 99 and provides data rates of 384 Kbps for wide area coverage and up to 2 Mbps for hot-spot areas. In addition to the use of orthogonal spreading codes, it uses quadrature phase shift keying (QPSK) for its modulation. [5]

Table III: Theoretical throughputs of CDMA systems Source: Intel [4]

Family	Technology	Theoretical Throughput	
		Forward link (Kbps)	Return link (Kbps)
	1 x 1.25MHz	614	614
	1 x EV-DO Rev 0 (1.25MHz)	2458	153
CDMA	1 x EV-DO Rev A (1.25MHz)	3072	1800
	1 x EV-DO Rev B (1.25MHz)	14745	5400
	GPRS (200KHz)	163	163
	EDGE (200KHz)	474	474
WCDMA	WCDMA Rel 99 (5MHz)	2688	2304
	HSDPA Rel 5 (5MHz)	14400	2300
	HSUPA Rel 5 (5MHz)	14400	5000

B. Hsdpa

3GPP Release 5 extends the WCDMA specification with high speed downlink packet access (HSDPA). HSDPA includes advanced features such as adaptive modulation and coding (AMC), hybrid automatic repeat request (HARQ), and de-centralized scheduling architecture.

The 3GPP has also defined WCDMA enhancements for the uplink path. This enhancement is known as high speed uplink packet access (HSUPA); the combination of HSDPA and HSUPA is simply known as HSPA (high speed packet Access).

C. Road Map For 3g Enhancements

1xEVDO Rev 0 had initial success in Korea and Japan beginning in 2003 with additional major deployments following in 2004 and 2005. The initial launch for EV-DO Rev A with CDMA2000 UL enhancements took place in Korea and Japan in 2005.

A further enhancement to the CDMA2000 standard is 1xEVDO-Rev B (also known as DO Multi-Carrier). This enhancement will increase the DL peak over the air data rate for a 1.25 MHz carrier to 4.9 Mbps and, by aggregating 3 carriers (known as 3xEVDO) in a nominal 5 MHz channel bandwidth, will provide a peak DL rate of 14.7 Mbps and a peak UL data rate of 5.4 Mbps. Commercial deployments for 1xEVDO-Rev B are not anticipated until 2008.

HSUPA/HSPA availability is not expected until 2007-2008. The 3GPP envisions additional long term WCDMA enhancements leading to UMTS terrestrial radio access node long term evolution (known as 3GPP-LTE or UTRAN LTE) also referred to as 3.99G or evolved UMTS. 3GPP2 is on a similar path with LTE for CDMA2000. Since approved standards for LTE are not expected until 2007, it is unlikely that products will be available until 2009 or later. [7]

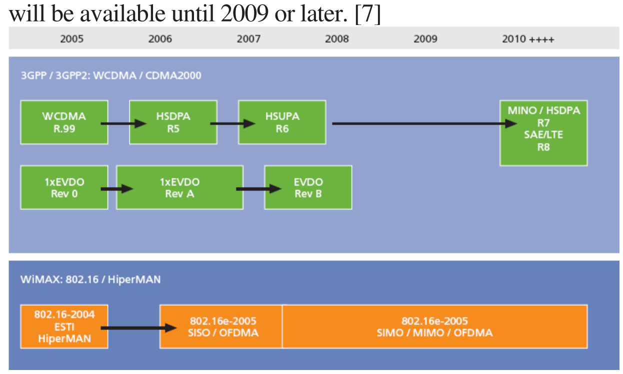

Figure 4. Mobile WiMAX will be available before 3G – LTE
Source: Alvarion [5]

I. Technological Comparison

3G enhancements have evolved from the 3G experiences and as a result, inherit both the advantages and limitations of legacy 3G systems. WiMAX on the other hand was initially developed for fixed broadband wireless access and is optimized for broadband data services.

The following sections review the similarities and differences of these technologies:

II. Common Features

Several features, designed to enhance data throughput, are common to EVDO, HSPDA / HSPA and mobile WiMAX including:

[a] Adaptive modulation and coding (AMC)
[b] Hybrid ARQ (HARQ)
[c] Fast Scheduling
[d] Bandwidth efficient handoff

D. Adaptive Modulation And Coding (Amc)

1xEVDO-Rev B introduces 64QAM to further increase the peak downlink data rate. 1xEVDO-Rev A and HSUPA introduce adaptive coding and modulation in the uplink to enhance uplink data rate with a finite number of specific packet sizes.

Mobile WiMAX supports AMC in both downlink and uplink with variable packet size. The uplink supports 16QAM modulation or 64QAM due to OFDMA orthogonal uplink sub-channels.

Table IV. : AMC Capability Source: WiMAX Forum [1], Notes:* Optional

Technology	DL Modulation	DL Code Rate	UL Modulation	UL Code Rate
	QAM64	Turbo, CC, Repetition:	QAM16	Turbo, CC, Repetition:
Mobile WiMAX	QAM16	1/12, 1/8, 1/4, 1/2, /3, 3/4, 5/6	QPSK	/12, 1/8, 1/4, 1/2, 2/3, 3/4, 5/6*
	QPSK		QAM64*	
HSDPA	QAM16		BPSK	BPSK
BPSK	QPSK	Turbo, CC:	BPSK	Turbo, CC:
HSPA (DPA+UPA)		/4, 1/2, 3/4, 4/4	QPSK	2/3, 3/4, 4/4

E. Hybrid Arq

All systems support HARQ as an important means to improve the robustness of data transmission over the wireless channel.

Chase combining (CC) or incremental redundancy (IR) can be implemented at the receiver to jointly process the packets in error and new retransmission to improve the packet reception. HARQ CC is supported by mobile WiMAX and HSPA; HARQ IR is supported by 1xEVDO. Multi-channel HARQ operation is supported by all systems.

F. Fast Scheduling

Mobile WiMAX, HSPA and 1xEVDO all apply fast scheduling in the downlink. HSPA uplink supports (1) Autonomous scheduling - all uplink transmissions can randomly occur in parallel with controlled rates; (2) Dedicated scheduling. However, due to non-orthogonal uplink, the quality of an individual link cannot be easily controlled even with dedicated scheduling.

Mobile WiMAX applies fast scheduling in both downlink and uplink. Furthermore, WiMAX performs scheduling on a per-frame basis and broadcasts the downlink/uplink scheduling in the MAP messages at the beginning of each frame. This is especially well suited for bursty data traffic and rapidly changing channel conditions.

G. Bandwidth Efficient Handoff

1xEVDO depends on the DSC signal for feedback on link conditions to accomplish "Virtual" Soft Handoff. HSPA does not support soft handoff but rather uses a more bandwidth efficient "Network Initiated Hard Handoff", which can be optimized for reduced delay. Mobile WiMAX supports "Network Optimized Hard Handoff" for bandwidth-efficient handoff with reduced delay, achieving a handoff delay of less than 50 ms. Mobile WiMAX also supports fast base station switch (FBSS) and marco diversity handover (MDHO) as options to further reduce the handoff delay.

The following table provides a summary of the attributes that have been discussed in more detail in the previous sections:

Table V: WiMAX, EVDO and HSPA Features - summary of comparative eatures
Source: Intel [6]

Attribute	1xEVDO Rev A	HSPA	Mobile WiMAX
Base Standard	CDMA2000/IS-95	WCDMA	IEEE 802.16e
Duplex Method	FDD	FDD	TDD (FDD optional)
Downlink	TDM	CDM-TDM	OFDMA
Uplink Multiple Access	CDMA	CDMA	OFDMA
Channel BW	1.25 MHz	5.0 MHz	Scalable: 4.375, 5,7, 8.75, 10 MHz
Frame Size DL	1.67 milliseconds	2 milliseconds	5 milliseconds TDD
UL	6.67 milliseconds	6.67 milliseconds	5 milliseconds TDD
Modulation DL	QPSK/8PSK/ 16QAM	QPSK/16QAM	QPSK/16QAM/ 64QAM
Modulation UL	BPSK,QPSK/8PSK	BPSK/QPSK	QPSK/16QAM
Coding	CC, Turbo	CC, Turbo	CC, Turbo
DL Peak Over the Air Data Rate	Rev A: 3.1 Mbps Rev B: 4.9 Mbps	14 Mbps	46(1:1)~54 (3:1) Mbps
UL Peak Over the Air Data Rate	Rev 0: 0.15 Mbps Rev A,B: 1.8 Mbps	5.8 Mbps	(DL/UL combined (32,14), (46, 8))
H-ARQ	Fast 4-Channel Synchronous IR	Fast 6-Channel Asynchronous CC	Multi-Channel Asynchronous CC
Scheduling	Fast Scheduling in the DL	Fast Scheduling in the DL	Fast Scheduling in DL and UL
Handoff	Virtual Soft Handoff	Network Initiated Hard Handoff	Network Optimized Hard Handoff
Tx Diversity and MIMO	Simple Open Loop Diversity	Simple Open & Closed Loop Diversity	STBC, SM
Beam forming	No	Yes (Dedicated Pilots)	Yes

H. Latency

Latency is defined as the round-trip-time (RTT) between the network gateway and the terminal and includes retransmission and queuing delays (does not include ISP+Internet+application/Codec and channel allocation delays).

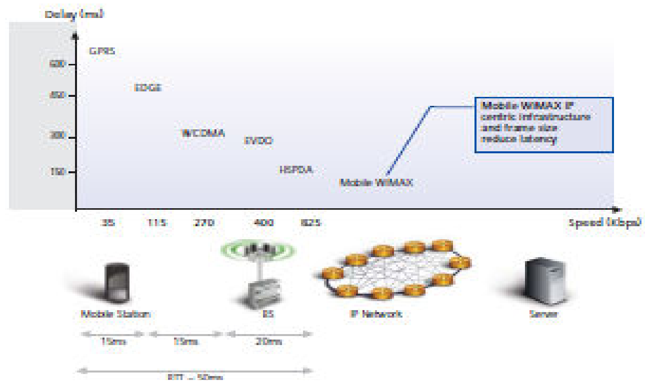

Figure 5. Comparing Latency WiMax vs. The Competition (ms)
Source: Intel [4]

RTT = Round-trip-time between base station and terminal
Best-case RTT = ~50 ms (no retransmissions or queuing delay)
Worst-case RTT = ~150 ms (100ms of ARQ + queuing delay)

I. Assumptions:

[a] Processing time at 802.16e terminal = 15 ms (same as HSDPA estimates)
[b] Processing time at 802.16e BS = 20 ms (same as HSDPA RNC+NodeB estimates)
[c] Transmission time for 802.16e = 13 ms (5 ms downlink frame, 5ms uplink frame and 3ms offset) Best case = No retransmissions or queuing delay
[d] Worst case = Assumes 100 ms of ARQ and queuing delay (50 ms queuing and 1 retransmission)

WiMAX delivers superior network performance and is more suited to handle real time applications.

J. Quality Of Service

Mobile WiMAX has been structured at inception itself to meet the tough requirements for the delivery of broadband services (end user experience similar to cable/DSL). With its ability to provide symmetric downlink / uplink capacity, fine resource granularity and flexible resource allocation, mobile WiMAX supports a wide range of data services and applications with varied QoS requirements as summarized in the table below:

Table VI：Mobile WiMAX applications and QoS Source: WiMAX Forum [8]

QoS Category	Applications	QoS Specifications
UGS Unsolicited Grant Service	VoIP	• Maximum Sustained Rate • Maximum Latency • Tolerance • Jitter Tolerance
rtPS Real-Time Polling Service	Streaming Audio or Video	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency • Tolerance • Traffic Priority
ErtPS Extended Real-Time Polling Service	Voice with Activity Detection (VoIP)	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency • Jitter Tolerance • Traffic Priority
nrtPS Non-Real-Time Polling Service	File Transfer Protocol (FTP)	• Minimum Reserved Rate • Maximum Sustained Rate • Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing, etc.	• Maximum Sustained Rate • Traffic Priority

K. Spectral Efficiency

As already seen in previous diagrams, mobile WiMAX has a higher spectral efficiency over competing technologies. The comparison is done between 5 MHz FDD and 10 MHz TDD (WiMAX and EVDO-B, HSDPA, HSUPA)

The Bottom Line – Bit per Second

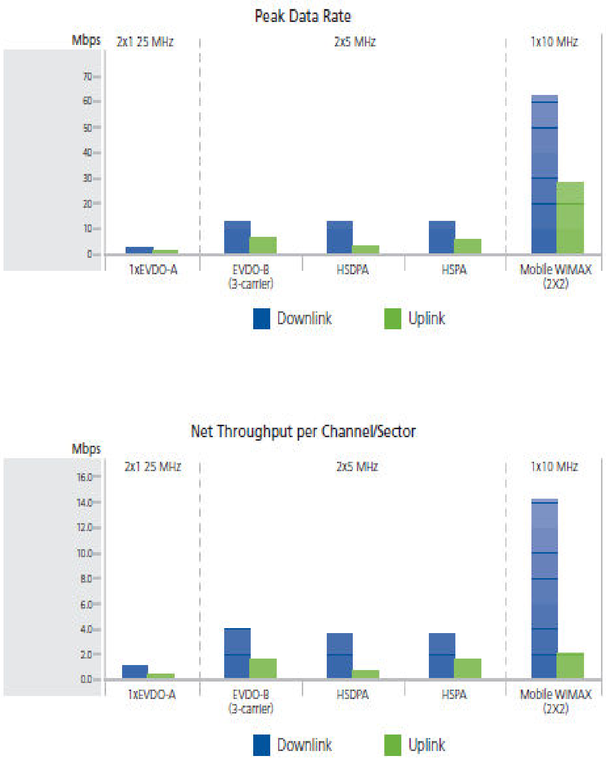

Figure 6. Comparing bitrates and throughputs (Mbps)

As can be seen, mobile WiMAX will outperform EVDO and HSPA substantially.

L. Wimax vs. 3g - Spectral Efficiency

Mobile WiMAX, as a 4G technology, deployments have higher spectral efficiency and will outperform EVDO and HSPA.

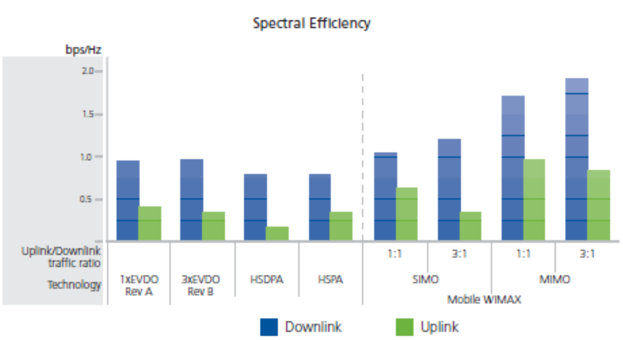

Figure 7. Mobile WiMAX vs. 3G Spectral Efficiency Comparison Source: WiMAX Forum [10].

M. Wimax vs. 3g - throughput comparison

Mobile WiMAX provides much better throughput than EVDO and HSxPA. Mobile WiMAX (with MIMO) provides ~3 times more throughput than HSPA or EVDO Rev B in the same occupied spectrum. Mobile WiMAX (with SIMO) has ~100% DL throughput advantage over EV-DO Rev B and a ~130% advantage over HSPA.

3G-LTE is the only 3G technology which may put a real match to WiMAX. However, it will not be *commercially available until at least 2010/2011. Furthermore, 3G-LTE does not provide an EVOLUTIONARY* path from existing 3G networks, but does require an effort closer to "fork-lift" revolution in the sense that it is a completely new network and requires entirely new devices.

Net Throughput per Channel / Sector

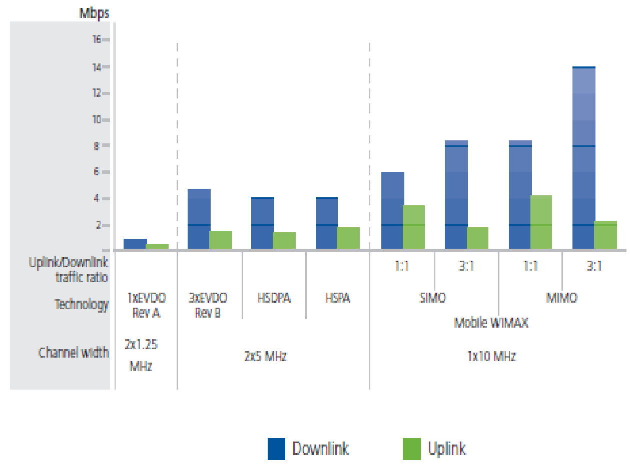

Figure 8. Mobile WiMAX vs. 3G Net Throughput Comparisons Source: WiMAX Forum [9].

N. Wimax vs. 3g: Base-Station Deployment

The throughput and spectral efficiency advantages of mobile WiMAX result in fewer base stations to achieve the same performance. Since deploying Radio Access Networks (base-stations) is a significant percentage of the capital investment and operational expenses of the deployment, this has a substantial impact on the business case of deploying a mobile Personal Broadband network, and far-reaching ramifications on the service provider's business and pricing model.

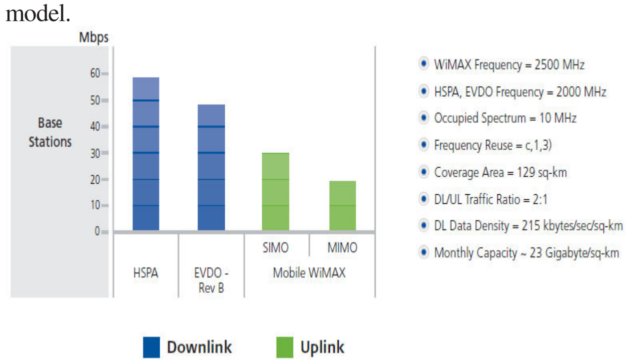

Figure 8. Mobile WiMAX vs. 3G Number of Required Sites Source: WiMAX Forum [16].

XV. CONCLUSION

Demand for bandwidth intensive services is on the rise. Service providers must make difficult decisions as to which technology to choose in order to enable them to offer advanced services and demand for high bandwidth throughput as subscribers want their broadband connection "anytime, anywhere".

Several technologies are considered by the service providers based on availability, technical merit, and features.

This document has attempted to compare among the different alternatives based on the criteria that is important to service providers, in a methodical fashion.

The paper discussed the various key inherent advantages mobile WiMAX posses as a technology designed for high bandwidth applications that is not chained to supporting legacy systems, while exercising lessons learned from deployments of these legacy systems.

The bottom line indicates that mobile WiMAX is a superior 4G technology designed to provide for 4G services, beyond current 3G technologies' horizon. It is also the only technology available today. While 3GPP-LTE may provide competition to mobile WiMAX it will only be available in 4-5 years time. Therefore a shrewd operator seeking an advanced, standards-based, technological platform that intelligently supports future enhancements will choose to deploy mobile WiMAX.

XVI. LIST OF ACRONYMS

3G	3rd Generations (cellular technologies)
3GPP	3rd Generation Partnership Program
3GPP2	Third Generation Partnership Project Two
AAS	Advanced Antenna System
ARPU	Average Revenue per User
E-UTRA	Enhanced UMTS Terrestrial Radio Access
EV-DO	Evolution Data Optimized
FDD	Frequency Division Duplex
HSDPA	High Speed Download Packet Access
HSPA	High Speed Packet Access
HSUPA	High Speed Upload Packet Access
LTE	Long Term Evolution
MBS	Multicast and Broadcast Services
NLOS	Non-Line-of-Sight
OFDMA	Orthogonal Frequency Division Multiple Access
SOFDMA	Scalable OFDMA
SP	Service Provider
TDD	Time Division Duplex
TDD	Time Division Duplex
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Node
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

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