http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 7 (4): 570-579, 2008
ISSN 1812-5638

Mobile Broadband: Comparison of Mobile WiMAX and Cellular 3G/3G+ Technologies

Muhammad Khalil Shahid, Tang Shoulian and Ao Shan
School of Economics and Management,
Beijing University of Posts and Telecommunications, Beijing, China

Abstract: This study not only provides the overview of all kind of broadband technologies, both wire-line and wireless, but also compares the two prominent broadband mobile technologies- 3G Mobile Cellular and Mobile WiMAX. It compares technical as well as spectrum aspects. In order to make this research comprehensive, WIMAX is compared with existing 3G/3G+ Cellular technologies like High Speed Packet Access (HSPA) as well as with future technologies like Long Term Evolution/Ultra Mobile Broadband (LTE/UMB) by making some assumptions to get some practical results. This study concludes that, in the wake of bandwidth hunger new applications and services, Mobile WiMAX has a great potential to become main stream technology and it has become both threat and opportunity for Mobile Cellular operators.

Key words: Broadband technologies, mobile broadband, WiMAX, 3G/3G+ cellular, LTE/UMB

INTRODUCTION

Broadband is a high speed and always on connectivity for providing high bandwidth applications and services such as Online Gamming, Video on Demand (VoD), voice over Internet Protocol (Goode, 2002), file sharing, user generated contents and managed/hosting services to business customers. These bandwidth hunger applications and services are compelling network operators to deploy high speed technologies in Access and Core networks. Broadband is evolving and what we thought in the near past as broadband now has become narrowband mainly due to rapid technological innovations, convergence (Shahid *et al*., 2007; Blackman, 1998; Sherif, 1998) and increased customer's demands for high bandwidth services. The demand and penetration rate of broadband is more in developed regions due to saturation in narrowband markets, intense competition, e-culture and more GDP per Capita. Worldwide regional percentage share for broadband penetration is shown in Fig. 1. More than 50% subscribers are from North America and Western Europe regions, thus showing the widened digital divide (Conradie and Jacobs, 2003; Friedman and Deek, 2003) in the world. There are many alternatives available for broadband access due to technological advancements and innovations but wireless and mobile technologies are gaining remarkable consideration in operator's strategies and policy maker's policies due to customer's demands of having access every where, every time (also known as personal broadband) and low cost and rapid deployment features of these technologies.

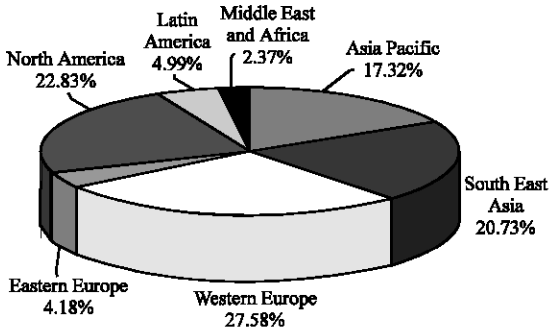

Fig. 1: Broadband share by Regions in June 2006 (Source: OECD)

Wireless subscribers have already surpassed wire-line subscribers for narrowband voice and wireless technologies are playing significant role in bridging digital divide. The traditional telecom and cable operators all around the world are trying to enter mobile broadband market with new wireless mobile technologies like WiMAX to offer bundled services (Quadruple Play including wireless). The wireless broadband is rapidly penetrating and is substituting other wire-line technologies. The two prominent mobile broadband technologies are existing 3G/3G+ Cellular Mobile and forthcoming WiMAX technologies. The main questions to answer are: which technology is better, both technologically and economically and which technology will be the future mobile broadband technology? This study compares these technologies not only technologically but also considers some economic

Corresponding Author: Muhammad Khalil Shahid, School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing, China

factors. This research is different from other researches in this area in the respect that it not only compares the two mobile broadband technologies, both technically and economically, by making assumptions to get some practical outcomes but also compares Mobile WIMAX with both existing and future 3G Cellular technologies.

TECHNOLOGIES IN BROADBAND

Two kinds of networks needed to offer any kind of service, whether narrowband or broadband, are:

- Core/Backbone Network
- Access Network

The core network, also known as Backbone network, is a high speed, high capacity network to support all traffic which is routed to/from customers connected to the Access Network. The Core Network of each operator is further connected to core network and/or access networks (mostly wireless operators are connected to core network via leased lines) of other operators and this core/Backbone network is also connected with International Backbone Network to provide Internet. The various technologies used in each kind of networks are mentioned below.

Technologies in core/backbone network: The increasingly high bandwidth applications and services, such as VoIP, IPTV, Video on Demand, file sharing, user-generated content, online gaming, social networking, are exerting great pressures on the core network and operators are facing serious problems in coping with this issue. Current assessments of traffic in the carrier backbone estimate that bandwidth requirements are doubling every 12-18 months and this rate of growth is expected to remain constant for the foreseeable future (Zik, 2007). Even the one Tbps high capacity network of NTT in Japan became insufficient to support high traffic from customers and needed upgrade. This is very important part of the whole network as all the traffic from access and metro networks ultimately passes through this. The operators have already deployed Fiber in their core networks. The most of the operators are using Dense Wavelength Division Multiplexing (DWDM) (Han, 2006) and Course Wavelength Multiplexing (CWDM) (Kawata *et al*., 2004) technologies in their Ultra long haul, long haul and metro networks. DWDM technology increases the capacity of existing fiber strand multiple times by allowing many wavelengths to travel in the same fiber. The operators mainly have used ring topologies for their core and metro networks. The 10G interfaces on DWDM networks have extensively been deployed and now 40G are under deployment. Synchronous Digital Hierarchy (SDH/SONET) Systems have been mostly interfaced with these high capacity DWDM networks. Internet Protocol (IP) over WDM technology (Veitch, 2002) is also increasingly getting place in operators' networks. Though 40G Ethernet interfaces are under deployment, the need for 100G Ethernet is already been realized by operators. The adaptive dispersion compensation technology used for 40 Gbps can be employed for 100 Gbps bit rates (Zik, 2007). The carriers are also using Internet Multimedia Subsystem (IMS) (Tang, 2005) which is IP based and is access agnostic. IMS makes roaming possible in different kind of wire-line and wireless broadband access networks.

Technologies in access network: We can broadly divide broadband access technologies in two camps:

- Wire line access technologies
- Wireless access technologies

Wire-line access technologies: The various kind of broadband wire-line access technologies available in the market include Digital Subscriber Line (DSL), Cable Modem, Fiber to the Home/Curb/Neighborhood (FTTx), Broadband over power line (BPL)/Power Line Carrier (PLC).

DSL: This technology makes use of the existing copper infrastructure and upgrades the performance of the copper line to carry high bandwidth services and applications. This technology expands the useable frequency band of the copper line. The higher frequencies are used to transmit the data and the lower frequencies are used to transmit voice or fax transmissions. It includes many variants and upgrades including Asynchronous DSL (ADSL and ADSL2+), Very high speed DSL (VDSL and VDSL2) and Rate-adaptive DSL (RDSL). Worldwide, DSL remains by far the most popular broadband access technology with market share of around 65% in 2007. The growth rate of DSL is decreasing in many countries due to strong growth in fiber and wireless access technologies which are gradually replacing this technology. The basic problem with DSL is distance limitation due to signal attenuation. Attenuation describes the weakening of signal strength as it travels over the copper line. The maximum bandwidth of DSL is limited by the distance of the user from the local exchange, quality of the copper wire and the amount of noise/crosstalk on the line. To minimize the impact of noise/crosstalk, different advanced techniques used are Rapid Rate Adaptation (RRA),

Repetitive Impulse Noise Protection (REIN), micro-cut and far end crosstalk FEXT cancellation, which will not only enhance the stability of the line but also increase the available bandwidth. Another issue is need for heavy investment for upgrading DSL to meet the demands of bandwidth hunger services and applications.

FTTx: The various options for FTTx deployments include both point to point and point to multipoint configurations. The Passive Optical Network (PON) solutions are examples of point to multipoint including Ethernet Passive Optical Network (EPON), Gigabits Passive Optical Network (GPON), Wavelength Division Multiplexing-Passive Optical Network (WDM-PON) (Chanclou *et al*., 2006). EPON and GPON technologies are most innovative options which provide more bandwidths per subscriber. EPON based on IEEE standard P802.3ah is popular in the Japan and is penetrating in other Asian countries, including China and Korea. EPON can deliver data streams of up to 1 Gbps and operates at a distance of up to 20 km between the OLT (Optical Line Terminator) and Optical Network Terminal (ONT). GPON-based on ITU-T standards G.984.1, G.984.2, G.984.3, G.983.4 and G.983.5-has some technical advantages over EPON due to which GPON needs less Central Office nodes. Point to Point Ethernet is mainly used for business services and can provide highest bandwidth per subscriber. WDM-PON is a future standard for FTTH. The new high bandwidth applications such as High Definition TV (HDTV), online gaming, video on demand and many others are making the business case for fiber deployment attractive. Verizon in the US and NTT in Japan are adopting the future-looking strategy of deploying Fiber to the home (FTTH) while AT and T has adopted the Fiber to the Node (FTTN) strategy along with VDSL2 to offer its IPTV U-Verse services. The two options of FTTH and FTTN are shown in the Fig. 2 (Sevalia, 2008). Verizon in the US has already offered Internet service that runs at

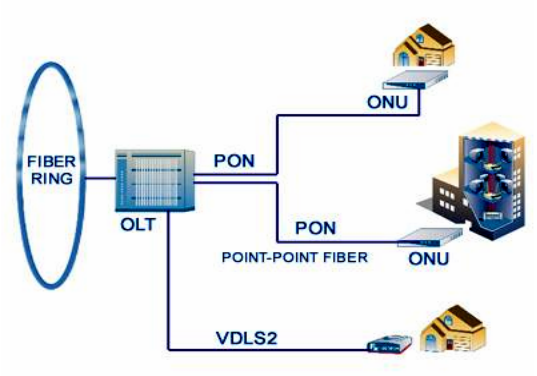

Fig. 2: Fiber to the home/Node access solutions

50 Mbps (Mega bits per second) and it is testing service at 100 Mbps. Although this technology is innovating rapidly yet deployment cost for fiber is still very high. According to one report, at the end of 2005 the cost of deploying per FTTP (Fiber-to-the-Premises) connection was US$1, 021; by the end of 2006 that had fallen to US$850 (McClelland, 2007). Another issue is Customer Premises Equipment (CPE) cost which is much higher than cost of CPE for DSL technologies.

Cable modem: Traditionally coaxial cable has been used for providing TV programs and other entertainments like movies, sports and other similar entertainments. It can be upgraded to provide triple play and other high bandwidth services. The full coaxial systems are gradually being replaced with hybrid systems consisting of fiber optic and coaxial lines. These cable networks are also referred to as Hybrid Fiber Coaxial (HFC). The main advantage of this technology is lesser investment in new infrastructure as it needs only up gradation of existing infrastructure like DSL technology. The major drawback of this technology is shared access which results in drastic decrease in connection speed when more subscribers are online.

BPL: BPL is an access solution to transmit data over electricity wiring. Technically, BPL allows customers to simply plug a special modem into any outlet in their home to access high speed Internet. Although BPL technology has a unique characteristic of higher electricity penetration than telephony all around the world yet it does not appear to represent a major disruptive technology, especially from a price-performance perspective (Tongia, 2004).

Wireless access technologies: Broadband Wireless Access (BWA) is now becoming substitute for wire-line broadband access. Wireless Access can be further subdivided into Wireless Fixed Access and Wireless Mobile Access. The various wireless access technologies include

- Satellite Access
- Local Multipoint Distribution System (LMDS)
- Multi-channel Multipoint Distribution System/ Service (MMDS)
- Worldwide Interoperability for Microwave Access (WiMAX)/Wi-Fi
- 3G/3G+ Cellular Mobile access

Satellite Technology is based on space satellite and ground receivers (similar to small dishes used for catching Video services) with common name of Very Small

Aperture Terminal (VSAT). It has unique characteristics of covering the entire globe. Users send and receive information to the Internet via a satellite dish to a receiver on a satellite in space. The satellite retransmits the signal to and from the network operation center that is connected to the Internet. Its main disadvantages are lower speed and highly installation and monthly charges than other wired and wireless technologies.

Local Multimedia Distribution System/Services (LMDS) and Multi-channel Multipoint Distribution System/Service (MMDS) have suffered either an early failure or slow adoption due to the lack of standardization, poor interoperability and Line of Sight (LOS) requirements. New entrants like Teligent, Nextlink and Winstar entered the market with networks based on LMDS in the late 1990s, but they went bankrupt due to their focus on saturated urban areas instead of remote areas and due to high license fees. The other big carriers, such as MCI and Sprint, invested in an alternative MMDS but too could not gain significant market share. 3G Cellular Mobile technology also took disappointing start due to lack of applications, customer devices and extremely high license fees but now getting momentum due to technological innovations in applications and services area. Wireless Fidelity (Wi-Fi), an unlicensed technology, has become a widely adopted technology without the need of backward compatibility with the existing cellular infrastructure. Wi-Fi networks are designed for indoor use with a broadcast range of several hundred feet or use a group of access points to cover a large outdoor environment such as a neighborhood, shopping mall or campground. These include both public and private networks. Wi-Fi has a shorter range as it is a LAN (Local Area Network) technology while WiMAX, bigger version of Wi-Fi, is a MAN (Metropolitan Area Network) technology. Among these WiMAX is taking the attention of market players.

THIRD GENERATION (3G) CELLULAR MOBILE TECHNOLOGIES AND BEYOND

International Mobile Telecommunications 2000 (IMT2000) is a generic name for all 3G technologies by International Telecommunications Union (ITU). Earlier two technologies in IMT2000 are Wideband Code Division Multiple Access (WCDMA), also known as Universal Mobile Telecommunications System (UMTS) in Europe and Code Division Multiple Access 2000 (cdma2000). WCDMA is a technology with backward compatibility with GSM (Global System for Mobile Communications) technology (based on TDMA Technology), while cdma2000 is an advanced technology of cdma One (IS-95 CDMA) (Kalavakunta and Kripalani, 2005). Another standard used is TD-SCDMA (Time Division-Synchronous CDMA) in China (Hsiao-Hwa *et al*., 2002). WCDMA uses Direct Sequence Spread Spectrum (DSSS) to spread the signal over a 5 MHZ spectrum. It is based on Third Generation Partnership Project (3GPP) Release 99 and provides data rates of 384 Kbps for wide area coverage and up to 2 Mbps for hot-spot areas. The improvements in WCDMA for data capabilities came in the form of High Speed Packet Access (HSPA) technologies which improved the data speeds to 14.4 Mbps for down links and 5.76 Mbps for uplinks (Bachl *et al*., 2007). CDMA 2000 evolutions for data handling capabilities have came in the form of cdma2000 1x, 1x-EV-DV (Evolutionary Data and Voice), 1x EV-DO (Evolutionary Data Only) and cdma2000 3x. The cdma2000 3x is an ITU-approved standard. It is part of what the ITU has termed IMT-2000 CDMA MC. It can provide the speed of around 2-4 Mbps. The ITU approved the inclusion of Orthogonal Frequency Division Multiple Access (OFDMA) technology in the IMT-2000 set of standards in late 2007. The IMT-2000 family of standards will now support four different access technologies, including OFDMA (includes WiMAX), FDMA (Frequency Division Multiple Access), TDMA and CDMA.

Japan was the first country to introduce 3G networks in the country. The deployment of 3G technologies in the Europe delayed due to high license fees (the operators were left with fewer resources to invest in equipment and installations), lack of high data applications and unavailability of devices. Now it is gradually taking boost in developed countries and now extra spectrum is being auctioned in some European countries to fulfill the increasing demands. Apart from this, technological advancements are also underway in the form of 3.5G, Long Term Evolution (LTE) or Super 3G and Ultra Mobile Broadband (UMB) in order to coup with the demands of increasing data rate applications and services such as interactive video.

Long Term Evolution (LTE) and Ultra Mobile Broadband (UMB): Although HSPA and cdma2000 3x technologies have reasonably increased the data rates yet these are unable to fulfill the requirements for dramatic explosions of bandwidth hunger applications and services. The existing 3G cellular networks are developed for both voice and data communications. This situation was demanding some revolutionary standard which must ensure not only the expansion of wireless networks' capacity but also the fulfillment of requirements for the future high data rate applications. The 3GPP group introduced LTE and

3GPP2 group introduced UMB solution for this reason (Bachl *et al*., 2007). In May 2007, a group of leading telecom technology manufacturers and network operators comprised of Alcatel-Lucent, Ericsson, France Telecom/Orange, Nokia, Nokia Siemens Networks, Nortel, T-Mobile and Vodafone, launched a joint initiative aimed at driving high performance mobile broadband networks based on 3GPP Release 8 Long Term Evolution/System Architecture Evolution (LTE/SAE) specifications (Nokia Siemens Networks, 2007). The LTE/SAE Trial Initiative targets mobile broadband peak data rates exceeding 100 Mbps. The deployments for LTE are expected in 2010 and its commercial availability is expected in 2011. Verizon in the US and NTT DoCoMo in Japan has shown his commitments to deploy LTE solution. The prominent features of LTE include:

- High data rates of up to 100 Mbps for downlinks and 50 Mbps for uplinks
- Data-centric networks instead of voice-centric networks
- Use of advanced OFDMA technology instead of CDMA
- Horizontally oriented structure instead of vertically oriented
- Flexibility for operators to deploy in different sized bands according to availability of spectrum
- Higher spectral efficiencies by using advanced antenna systems like MIMO (Multi Input Multi Output)

WiMAX

WiMAX has emerged as a promising technology for broadband access as it is the only wireless technology which emerged with true wireless broadband experience. The IEEE 802 committee set up a working group in 1999 to develop a new standard for BWA applications, IEEE 802.16. Later, another industrial association, the Worldwide Interoperability for Microwave Access (WiMAX) Forum (WiMAX Forum) was formed in 2001 to promote the 802.16. IEEE 802.16 networks are also often referred to as WiMAX networks. Two commonly used standards are IEEE 802.16d and IEEE 802.16e. IEEE 802.16d standard uses Orthogonal Frequency Division Multiplexing (OFDM) and supports fixed and nomadic access in Line of Sight (LOS) and Non Line of Sight (NLOS) environments. IEEE 802.16e, which was officially approved in December 2005, further enhanced the ability of WMAN with mobility support. It provides support for handoffs and roaming. It uses Scalable Orthogonal Frequency Division Multiplexing Access (SOFDMA)-a multi-carrier modulation technique. S-OFDMA allows for an increase in range of channel bandwidths from 1.25 MHZ up to 20 MHZ (Fitchard, 2006; Lu *et al*., 2006). OFDM and OFDMA are two different variants of the same technology and both distribute the data over a large number of carriers that are spaced apart at precise frequencies. The numerous sub-carriers are then collected at the receiver and recombined to form one high-speed transmission. The main difference between both transmission methods is that OFDM allows only one user on the channel at any given time whereas OFDMA allows multiple-access on the same channel. The comparison of devices, speed, hands-offs and mobility for fixed and mobile WiMAX is shown in Table 1.

IEEE 802.16e standard provides service providers the ability to offer a wide range of new and revolutionary high-speed mobile applications and services. By using an IEEE 802.16e/WiMAX-based backbone network to connect Wi-Fi hotspots to the Internet, costly wired infrastructure can be avoided and again, mobile hotspot services can be provided (Niyato and Hossain, 2007). Through avoiding the high costs and delays associated with laying fiber or upgrading cable networks, companies can enter the market quickly and deliver broadband services at relatively low costs. The development of Mobile WiMAX has been on the basis of IP which allows seamless compatibility with existing Internet applications. Through maintaining a unified all-IP-based network rather than multiple legacy networks for various services, capital expenditure (CAPEX) and operating expenditure (OPEX) can be greatly reduced. Accordingly, carriers can offer better mobile Internet access services to end users at a lower cost than with other technologies. Telecom View, the American market research company, forecasted that reach 131 million and that the total number of terminals the total number of Mobile WiMAX subscribers will

Table 1: Comparison of fixed and mobile WiMAX (Source: WiMAX Forum)

Definition	Devices	Locations/speed	Handoffs	802.16d	802.16e
Fixed access	Outdoor and indoor CPEs	Single/stationary	No	Yes	Yes
Nomadic access	Indoor CPEs, PCMCIA cards	Multiple/stationary	No	Yes	Yes
Portability	Laptop PCMCIA or mini cards	Multiple/walking speed	Hard Handoff	No	Yes
Simple mobility	Laptop PCMCIA or mini cards, PDAs or smartphones	Multiple/lower vehicular speed	Hard Handoff	No	Yes
Full mobility	Laptop PCMCIA or mini cards, PDAs or smartphones	Multiple/high vehicular speed	Soft Handoff	No	Yes

sold will reach 110 million by the end of 2011. In the same year, the CAPEX of operators is projected to exceed US$26 billion.

After the inclusion of OFDM-based technologies in the IMT2000 standard by the ITU Mobile WiMAX will become more competitive with 3G Cellular for using the 3G extension bands and potentially, with existing 3G bands (Hoskins, 2007) and it will make it easier for regulators to assign spectrum for WiMAX. WiMAX is getting attention in both developed and developing countries for broadband access due to low cost, rapid deployment and other advanced technical features. The fixed WiMAX applications are already being deployed to complement and compete with DSL and cable networks in rural and other underserved areas, particularly in the new EU member States (Hoskins, 2007). The second and third-tier cellular players that have not invested in 3G technologies are now looking to leapfrog directly to WiMAX and first-tier cellular players, like Sprint, is investing for the long-term economic and time-to-market advantages of mobile WiMAX over other advanced technologies like LTE/UMB (Gozalvez, 2006). The majority of the operators in developing countries especially in Asia are considering deploying WiMAX as part of their broadband access strategies. Service providers, especially competitive service providers, are using WiMAX as a perfect chance to get into the broadband and wireless business.

Metropolitan WiMAX network topologies: There are various kind of topologies but two typically used are:

- WiMAX Multipoint (MtP) Access plus Point-to-Point (PtP) (or Daisy-Chained) Backhaul
- WiMAX Multipoint (MtP) Access plus Mesh Point-to-Point (PtP) Backhaul

The key difference in Daisy-Chained and simple PtP topology is that daisy-chaining reduces overall path availability performance and increased delay and delay variability as shown in Fig. 3 and 4 (Boch, 2007). The daisy chain, however, allows the effective reach of the metro fiber Point of Presence (PoP) to be considerably extended. In the second topology, an Ethernet mesh is used as shown in Fig. 5 (Boch, 2007). The main advantage of this topology is superior path availability due to the inherent angle diversity and location diversity within the meshed backhaul layer. The meshed solution is often resulted in reduced average path lengths than single layer PtP topology.

Key features of WiMAX: The key features of WiMAX technology include (WiMAX Forum):

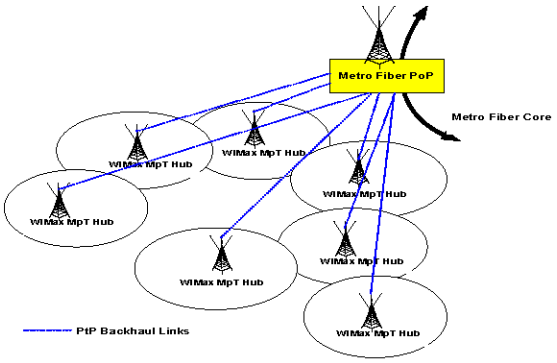

Fig. 3: Point to point Backhaul topology

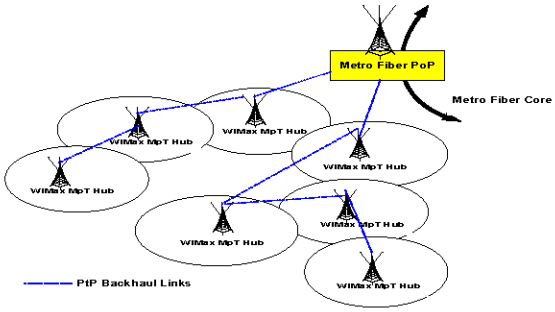

Fig. 4: Daisy-Chained Backhaul topology

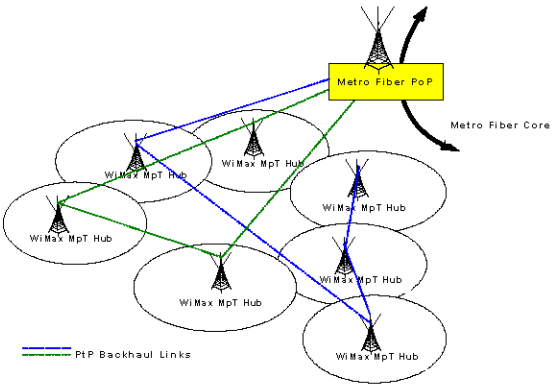

Fig. 5: Mesh Backhaul topology

- Advanced performance (high per-user throughput and low latency)
- Wide variety of devices (Laptop add-in cards and modules, game consoles)
- IP-based, optimized for packet-based data applications
- Support for IMS (Internet Multimedia Subsystems)
- Next generation multiplexing technique

- Support for Advanced antenna techniques/systems like MIMO (Multi Input Multi Output) and beam forming
- Multiple handoff mechanisms (supports a variety of handoff mechanisms)
- Worldwide availability (operates in three spectrum bands: 2.3-2.4, 2.496-2.69 and 3.4-3.6 GHz)
- Dynamic bandwidth allocation (enabling flexible management of spectrum resources and a more efficient use of spectrum)
- Easy integration within the wider wireless ecosystem (encompassing technologies like 2G, 3G and Wi-Fi)
- Tolerance to Multi-path and Self-Interference
- Global roaming (allows subscribers to access different networks using the same device and a single, familiar interface)
- Equipment based on open standards, an attractive Intellectual Property Rights (IPR) structure and high base station capacity

COMPARISON OF WiMAX WITH 3G/3G+ CELLULAR MOBILE

In order to compare these two technologies, we first make following assumptions in order to get some useful results

- There is an increasing demand for high bandwidth mobile applications and services
- The technologies will deliver the functionalities and speed as claimed
- The technologies will appear in the market according to time line provided

We can compare these from different aspects and phases.

Comparison with existing 3G technologies: As mobile WiMAX is going to be appear in the market in mid 2008, it is good to first compare it with existing 3G Cellular mobile technologies. WiMAX has an obvious advantage of speed over its competing 3G Technologies like HSPA and cdma2000 3x. WiMAX is ideal for data applications as it is based on IP based Packet- switching technology as compared with circuit-switched 3G which were invented for mix of voice and data applications (Hussain *et al*., 2007). On the other hand, 3G is ideally suited for voice services as quality of service deteriorate in WiMAX under heavy traffic and cost of service goes up exponentially. 3G has also advantage in the field of mobility due to its inherited mobile capabilities while in mobile WiMAX mobility has been added as an additional feature. The detailed comparison of these technologies is given in Table 2.

Spectrum comparison: The availability and efficient utilization of spectrum is most important aspect of wireless systems due to scarcity of this expensive resource. The advantage to 3G technologies is availability of spectrum which can be a great problem for mobile WiMAX. Regulatory restrictions can also pose problem for WiMAX. According to one study, 77% of regulators still limit 3.5 GHz usage to fixed-only applications (Fellah, 2007) but now things are changing. Some countries like China and India are promoting 3G technologies. In China, for example, the 2.3 and 2.5 GHz bands are reserved for 3G and cable transmission respectively, while the 3.5 GHz spectrum went to fixed WiMAX and no spectrum has been assigned for mobile WiMAX (Morris, 2007). The same situation is in India, where the most concern is about penetration of voice services instead of data services due to country lower teledensity (number of lines per hundred inhabitants of the country).

Table 2: Comparison of 3/3.5G cellular and mobile WiMAX (Source: Intel Technical White Paper, 2004)

Comparative advantages	3/3.5G cellular	Mobile WiMAX	Remarks
Flexible bandwidth allocations		✓	Advantage of using multiple (both time and frequency) Duplexing modes in WiMAX
Performance in multi-path environment		✓	OFDMA performs better in suppressing ISI (Inter Symbol Interference) in WiMAX
Lower attenuation (Wider coverage)	✓		3/3.5G Cellular operates in lower frequency bands usually less than 2 GHz
Standardized		✓	IEEE 802.16e standard for mobile WiMAX
Voice capabilities	✓		Features such as multiple voice coding schemes, user selectable Enhanced Variable Rate CODEC (EVRC) are integrated in 3/3.5G
Data capabilities		✓	OFDMA Superior technology used in WiMAX for data
Mobility capabilities	✓		Better seamless hands-off and seamless roaming in 3/3.5G Cellular
Frequency reuse	✓		CDMA frequency reuse ratio is 1 while OFDMA is 1 to 3
Resistance to frequency selective fading		✓	Errors in sub-carriers can be corrected in OFDMA in WiMAX
Lower Bit Error Rate (BER)		✓	OFDMA symbols are longer in duration than CDMA symbols
Higher throughput		✓	Better use of AMC (Adaptive Modulation and Coding) techniques (Ergen *et al*., 2003)
Higher number of users supported		✓	Fewer number of codes available in CDMA technology
Lower equipment cost		✓	No need for RACK Receivers and direct implementation of algorithms in frequency domain in WiMAX
Use of advanced radio techniques		✓	Better Use of MIMO and smart antenna technologies for WiMAX

Table 3: Comparison of LTE and mobile WiMAX

Advantages	LTE	Mobile WiMAX
Time to market		✓
Stickiness of operators	✓	
Re use of existing infrastructure	✓	
Standardized technology		✓
Free from legacy burdens (Proprietary interfaces)		✓
Presence of interfaces in user devices		✓
Inherited mobility support	✓	
Speed		✓

WiMAX has an edge over 3G for its low cost spectrum. The average spectrum cost/Hz in Europe for 3G is almost 1000 times more than average WiMAX cost/Hz in the Europe (Fellah, 2007). This high cost is mainly due to auction of 3G licenses in Europe due to over excitement shown by operators after the success of 2G/2.5G Cellular mobile services and some exaggerated industry predictions about the need and success of data/multimedia services. Though WiMAX network needs more equipment (base stations) due to its operation in higher frequency bands (there is a requirement of twice the equipment for each doubling of frequency) yet it is still economical to use WiMAX Equipment. There is also another reason for low cost spectrum for WiMAX is restrictions on mobility. There are total 721 and 106 license holders for BWA/WiMAX and 3G, respectively and this huge difference is mainly due to low cost spectrum which provided the chance for many small operators to compete in the market (Fellah, 2007). The other main difference is nature of licenses issued for two technologies: 3G licenses are on national basis while WiMAX are mainly regional basis. The carriers owned the same amount of spectrum for both technologies in average (Fellah, 2007).

Comparison with LTE: The main advantage to LTE is commercial lead of 3G in Europe and in many other countries. About 100 operators in 73 countries have launched HSPA. So it is natural choice for operators to opt for LTE instead of new standard. However, there is a concern about reuse of existing 3G infrastructures for LTE due to its completely different air interface. The main advantage to WiMAX is its time-to- market which is almost three years ahead of LTE. Mobile WiMAX is a standard based technology (IEEE 802.16e) while LTE is still not standardized. WiMAX is without the costly proprietary interfaces and royalties found in 3G Cellular networks (CDMA-based) and is free from legacy burdens. Standardized technology also may provide easier upgrade paths to future technologies. Another advantage to WiMAX is already presence of interfaces for this technology in many user devices. Some of these aspects are shown in Table 3.

DISCUSSION

The comparison of the two technologies shows pros and cons of both technologies. The success of WiMAX in the market will not only depend on the technology to deliver up to the expectations but also will be affected from the behavior of regulators and policy makers towards this technology and availability of spectrum. According to one report, the majority of wireless mobile broadband market will be served by both 3G+ Cellular and WiMAX technologies in 2012 and LTE, UMB will also available by that time. More than 200 operators are deploying WiMAX world around including existing cellular operators, new entrants and fixed line DSL and cable operators. WiMAX is ideally suited for providing access to rural and remote areas in both developed and developing countries and is getting popularity in developing countries where operators still have not invested in legacy 3G infrastructure. The hurdles in WiMAX deployment includes: unavailability of spectrum, regulatory biasing, lower PC penetration and lower GDP per Capita in these developing countries. GDP per capita in emerging economies of China and India is still below USD1000 per annum while in the US, Japan and Western Europe, the GDP per capita ranges from USD24,000 to USD36,000 per annum (Wieland, 2006). This low GDP per Capita can affect the ability of customers to pay for high cost Customer Premises Equipment (CPE) for WiMAX. This problem can be resolved by renting out the CPE by service providers instead of selling it in the beginning. Fixed WiMAX networks have already been deployed in many European countries to provide broadband access to remote areas and also used as complement for DSL. In some countries it is emerging as competitor against DSL and Cable technologies and in developing countries even as a substitute. For improving mobility capabilities Mobile WiMAX can take the advantage by using the work of proposed IEEE 802.21 hand- off group which will work on the common standard to specify a common handoff framework applicable to all 802 standards.

CONCLUSIONS

The rapid increase in high bandwidth applications and services are increasing pressures on cellular mobile networks. So, sooner or later traditional cellular mobile operators will have to shift the data traffic from their network to ease the burden (congestion) on their networks. The better choice for this may be some data-centric standardized network and obviously, the option available in hand to these operators is only the Mobile WiMAX. The viable business case for Mobile WiMAX has already been proved (Lannoo *et al*., 2007). On the

other hand, still HSPA like advanced 3G technologies have reasonably been improved the data rates and still the major portion (about 80%) of the revenue for operators is coming from voice services (Morris, 2007). So, some operators like Verizon and NTT DoCoMo are adhered with LTE to wait for this technology to come in the market. However, if our assumption of rapid increase in data services and applications becomes reality, the chances of which are high by looking at the trends in recent past, then the operators who opted for Mobile WiMAX, like Sprint Nextel, SOFTBANK Group and Telefonica, will get definite competitive edge over their competitors for providing personal broadband-everywhere, every time. The new entrants will also have strengthened their positions in the market by using Mobile WiMAX before the appearance of LTE/UMB in the market. Another advantage to mobile WiMAX is the fact that by the time LTE will come in the market, there is a possibility that some upgraded version of Mobile WiMAX will also come in the market, hence giving it an edge over its competing technologies for speed and other functionalities. In short, Mobile WiMAX has a great potential to become main stream technology and it has become both threat and opportunity for Mobile Cellular operators.

REFERENCES

Bachl, R., P. Gunreben, S. Das and S. Tatesh, 2007. The long term evolution towards a new 3GPP air interface standard. Bell Labs Technol. J., 11 (4): 25-51.

Blackman, C., 1998. Convergence between telecommunications and other media: How should regulation adapt? Telecommun. Policy, 22 (3): 163-170.

Boch, E., 2007. Wireless Metro WiMAX Backhaul: Licensed vs. Unlicensed. Converge Network Digest, August 30. http://www.convergedigest.com/bp/bp1.asp?ID=391&ctgy=Mesh.

Chanclou, P., S. Gosselin, J.F. Palacios, V.L. Álvarez and E. Zouganeli, 2006. Overview of the optical broadband access evolution: A joint article by operators in the IST network of excellence e-photon/one. IEEE Commun. Mag., 44 (8): 29-35.

Conradie, P. and S.J. Jacobs, 2003. Bridging the digital divide. Eng. Manage. J., 13 (1): 30-33.

Ergen, M., S. Coleri and P. Varaiya, 2003. QoS aware adaptive resource allocation techniques for fair scheduling in OFDMA based BWA systems. IEEE Trans. Broadcasting, 49 (4): 362-370.

Fellah, A., 2007. Spectrum Analysis-The Critical Factor in BWA/WiMAX versus 3G: An updated and expanded appraisal. Research report by Maravedis Inc. http://www.wimaxforum.org/news/reports/3GvsWiMAXSpectrumBrochureFeb20071.pdf.

Fitchard, K., 2006. OFDMA Prepares to move on. WiMAX Forum and Westech Communications white paper. http://www.intel.com/netcomms/technologies/wimax/Telephony _WiMAX_2006.pdf.

Friedman, R.S. and F.P. Deek, 2003. Innovation and education in the digital age: Reconciling the roles of pedagogy, technology and the business of learning. IEEE Trans. Eng. Manage., 50 (4): 403-412.

Goode, B., 2002. Voice over Internet protocol (VoIP). Proceedings of the IEEE, 90 (9): 1495-1517.

Gozalvez, J., 2006. Mobile WiMAX rollouts announced. IEEE Veh. Technol. Mag., 1 (3): 53-59.

Han, S., 2006. Designing hybrid SONET and DWDM networks. IEEE Commun. Mag., 44 (11): 106-113.

Hoskins, R., 2007. Mobile WiMAX to Compete in 3.5 GHz against 3G, HSPA, HSPA+ and LTE. Broadband Wireless Exchange Mag., June 21. http://www.bbwexchange.com/pubs/2007/06/21/page1409-619306.asp.

Hsiao-Hwa Chen, Chang-Xin Fan and W.W. Lu, 2002. China's perspectives on 3G mobile communications and beyond: TD-SCDMA technology. IEEE Wireless Commun., 9 (2): 48-59.

Hussain, I., S. Hussain, I. Khokhar and I. Raja, 2007. OFDMA as the technology for the next generation mobile wireless internet. Proceedings of the 3rd International Conference on Wireless and Mobile Communications (ICWMC'07).

Kalavakunta, R. and A. Kripalani, 2005. Evolution of mobile broadband access technologies and services considerations and solutions for smooth migration from 2G to 3G networks. IEEE International Conference on Personal Wireless Communications, Jan. 23-25, pp: 144-149.

Kawata, H., T. Ogawa, N. Yoshimoto and T. Sugie, 2004. Multichannel video and IP signal multiplexing system using CWDM technology. J. Lightwave Technol., 22 (6): 1454-1462.

Lannoo, B., S. Verbrugge, J. Van Ooteghem, B. Quinart, D. Colle, M. Pickavet, P. Demeester and M. Casteleyn, 2007. Business scenarios for a WiMAX deployment in Belgium. IEEE Mobile WiMAX Symposium, 25-29 March, pp: 132-137.

Lu, Y., L. Zhang, C. Yin and G. Yue, 2006. Adaptive radio resource allocation for multiple traffic OFDMA broadband wireless access system. J. China Universities of Posts Telecommun., 13 (4): 1-6.

McClelland, S., 2007. The FTTH cost challenge. Telecommunications® online, May 31. http://www.telecommagazine.com/search/article.asp?HH_ID=AR_3222&SearchWord.

Morris, I., 2007. WiMAX under attack. Telecommunications® online, May 31. http://www.telecommagazine.com/search/article.asp?HH_ID=AR_3222&SearchWord.

Nokia Siemens Networks, 2007. Nokia Siemens Networks Tests LTE at 173 Mbps. Converge Network Digest, December 19. http://www.convergedigest.com/searchdisplay.asp? ID=23361&SearchWord=3G.

Niyato, D. and E. Hossain, 2007. Integration of WiMAX and Wi-Fi: Optimal pricing for bandwidth sharing. IEEE Commun. Mag., 45 (5): 140-146.

Sevalia, P., 2008. It's All about Access-A Comparison of Fiber vs Copper in 2008. Converge Network Digest, January 07. http://www.convergedigest.com/bp/bp1.asp ?ID=503&ctgy=Loop.

Shahid, M.K., S.L. Tang and R. Jie, 2007. Convergence in communications industry: Regulatory challenges, issues and trends. IEEE WiCOM07 Conference, September 23-25, Shanghai, China.

Sherif, M.H., 1998. Convergence: A new perspective for standards. IEEE Commun. Mag., 36 (1): 110-111.

Tang, B.Y.C., 2005. Evolving to wireless and wire-line convergence-An overview of IMS. 14th Annual International Conference, WOCC2005, 22-23 April: 27.

Tongia, R., 2004. Can broadband over Power Line Carrier (PLC) compete? A techno-economic analysis. Telecommun. Policy, 28 (7-8): 559-578.

Veitch, P., 2002. Resilience for IP-over-DWDM backbone networks. Elect. Commun. Eng. J., 14 (1): 39-48.

Wieland, K., 2006. The WiMAX Opportunity: Do Emerging Markets Offer WiMAX the Best Environment to Flex its Muscles as a Standardized Fixed Wireless Access Technology? Telecommunications®, April, 1. http://www.telecommagazine.com/International/article.asp?HH_ID=AR_1922.

Zik, J., 2007. Network Evolution to 100 Gbps. Converge Network Digest, December 11. http://www.convergedigest.com/bp/bp1.asp?ID=498&ctgy=Loop.