WiMAX-LTE Technology Migration

WHITE PAPER

SITUATIONAL OVERVIEW

Wireless technologies come in waves. Generations of technologies address the insatiable and evolving demand for wireless services. Within every generation a number of competing standards vie for prominence. The stakes are high – ranging in the hundreds of billions of dollars.

Developing a wireless standard is a process of negotiation between ecosystem participants. Despite the lengthy process and large effort required to develop a standard, a larger effort is required to develop robust, stable, efficient and cost effective equipment. Commercial deployments follow equipment availability, technology trials and product trials. But herein lays the greatest challenge for wireless ecosystem participants: How to predict the potential market share of each wireless standard?

Market share of a wireless standard is critical: standards are created to enable mass markets, and by inference, a standard that fails to garner mass adoption is perhaps worse than a proprietary one as a proprietary 'standard' is an optimized and efficient solution for a particular usage scenario.

Market share has critical implications for the entire supply chain from silicon and component vendors to equipment vendors, wireless operators, and finally, even to wireless subscribers. The technology bets placed by each part of the supply chain have very large impact on profitability and even the survivability of players in the wireless infrastructure business. Hence, component and silicon vendors have to justify expenditures that can range on the order of tens of millions of dollars to develop, for example, a single baseband modem, while equipment vendor expenditures would range in the hundreds of millions of dollars, if not more, to develop equipment for an access network. Network operator investment can start in the hundreds of millions and end up in the billions of dollars for large national operators.

With services needing to be priced at the order of tens of dollars (or a few dollars in emerging markets), market share, is terms of subscriber count, is the only remedy to recoup invested capital. The failure of a wireless standard from gaining momentum in terms of market share has significant impact throughput the supply chain. Hence, different parties in the ecosystem develop strategies to mitigate their exposure. A common strategy is to invest in multiple wireless standards which is akin to purchasing call options on wireless standards. This strategy, 'investment duplication', is particularly common among large equipment vendors who develop equipment for multiple standards.

However, for wireless network operators, the 'investment duplication' strategy is generally not available, or in any case, is extremely costly. Yet the perils of a failed binary technology decision are all too evident: low revenues, profitability and valuation.

TECHNOLOGY OPTIONS

In the wireless space, fourth generation systems like LTE and WiMAX are beckoning. Today, the battle between WiMAX and LTE has mostly been settled on the major front – that of mobile services - in favor of LTE, even though LTE is yet to see mass deployments. As part of the 3GPP standard roadmap adopted by major wireless operators, LTE had a distinct advantage over WiMAX, which was enhanced by where network operators were in terms of investment and business cycle with 3G systems. As subscriber rates on 3G systems have only picked up in recent years and 3G enhancements such as HSPA and HSPA+ are being implemented, the pressure to roll out a 4G mobile wireless access technology has not been pressing. Combined with the financial crisis of 2008, the adoption of WiMAX by major network operators was not forthcoming.

Nevertheless, several WiMAX ‘pockets of resistance’ remain: fixed applications in emerging markets, rural markets in developed countries, niche applications in vertical markets such as electric smart grids, and in worldwide geographies in frequency bands above those used currently for mobile systems (e.g. 2.5 – 2.7 GHz and 3.x GHz bands) as shown in Table 1. In these applications, WiMAX has almost universally been used for fixed and portable access (indoor/outdoor modems, USB dongles) rather than mobile access (personal handsets).

TABLE 1 UTILIZATION OF SPECTRUM.

	Fixed Applications	Mobile Applications
FDD	**3.5 GHz**	**700 MHz 800/900 MHz 1700 MHz 1800/1900 MHz 2.1 GHz**
TDD	**2.3 GHz 2.5 GHz 3.5 GHz**	**N/A**
Leading Technology	**WiMAX**	**Currently: GSM/3G Future: LTE**

The advent of LTE and its aggressive promotion as substitute to WiMAX can be unsettling for Greenfield wireless network operators on the verge of selecting a technology as well as for established WiMAX operators looking for long term profitability, which as explained, is inextricably linked to the health of WiMAX the ecosystem. This point has been amply demonstrated by Qualcomm winning spectrum licenses in India’s BWA auction with the resolve to roll out TD-LTE.

This is a critical juncture in time when there is no apparent winner and no sure standard for services outside of mobile broadband. For operators of fixed broadband wireless networks (FBW), technology strategy – selection or migration – becomes a critical part of the corporate strategy with great consequences and ramifications. Yet, the wireless industry has been at similar junctures in the past: the battle between GSM and CDMA in the mid 1990’s, the evolution path from 2G to 3G which included Edge as a possible interim standard, and most recently the cannibalization of Fixed WiMAX standard based on 802.16-2004 in favor of Mobile WiMAX based on 802.16e-2005. Much can be gained from these past conflicts to guide a path for technology selection and migration.

LTE and WiMAX Overview

WiMAX and LTE share common characteristics, namely, a physical layer based on Orthogonal Frequency Division Multiplexing (OFDM), a flat IP architecture, and use of smart antenna techniques (MIMO) to achieve high data rates. However, the implementation of these techniques is different in both technologies. A very brief introduction of both WiMAX and LTE technologies is presented and the reader is referred to other Telesystem Innovations whitepapers for more details [1-4].

LTE Technology Overview

LTE implements OFDMA in the downlink while the uplink features Single Carrier – OFDM (SC-OFDM) which was selected to eliminate the peak-to-average power ratio (PAPR) problem on handsets and to lower cost. The frame size in LTE is 10 msec which is divided into ten sub-frames of 1 msec. Scheduling period is 1 msec which minimizes latency. LTE has two frame types: Type 1 (FDD) and Type II (TDD). Most of the LTE systems in trials today are FDD systems. TD-LTE has been lagging in its development due to smaller commercial following[1]. LTE also features seven MIMO modes that include transmit diversity and spatial multiplexing for two or four antennas [5]. Transmit diversity is based on Space Frequency Block Codes, while both closed and open loop spatial multiplexing options are available. Adaptive modulation and coding is supported with QPSK, 16QAM and 64QAM, the latter in the downlink path only (uplink implementation optional).

LTE differentiates from 3G standards by shifting key layer 2 and 3 functions from the core network to the base station. The LTE MAC performs scheduling and Hybrid ARQ functions. The Radio Link Control (RLC) Layer performs concatenation and segmentation. The Packet Data Convergence Protocol (PDCP) Layer performs header compression and encryption. The Radio Resource Control (RRC) Layer is a control plane function that services lower layers. The LTE network architecture, commonly called the Enhanced Packet System (EPS) is shown in Figure 1.

WiMAX Technology Overview

The physical layer features OFDMA in both the downlink and uplink paths with TDD access mode being standard in WiMAX 1.0 system profile. FDD was later added in WiMAX 1.5, but the ecosystem does not fully support this feature yet. Multiple antenna techniques are supported with Space Time Block Codes (Alamouti scheme) and spatial multiplexing with adaptive switching between the two modes. The WiMAX frame is 5 msec long which is divided into downlink and uplink sub-frames whose ratio is determined by traffic capacity requirements. Adaptive modulation schemes are supported similar to LTE albeit that WiMAX has fewer coding rate options which results in coarser selection of modulation and coding schemes.

The WiMAX MAC layer is rather sophisticated and combines the equivalent functionality of the LTE MAC, RLC, PDCP, and RRC. The WiMAX network architecture is shown in Figure 2.

[1] China Mobile has made public its interest and intent to deploy TD-LTE.

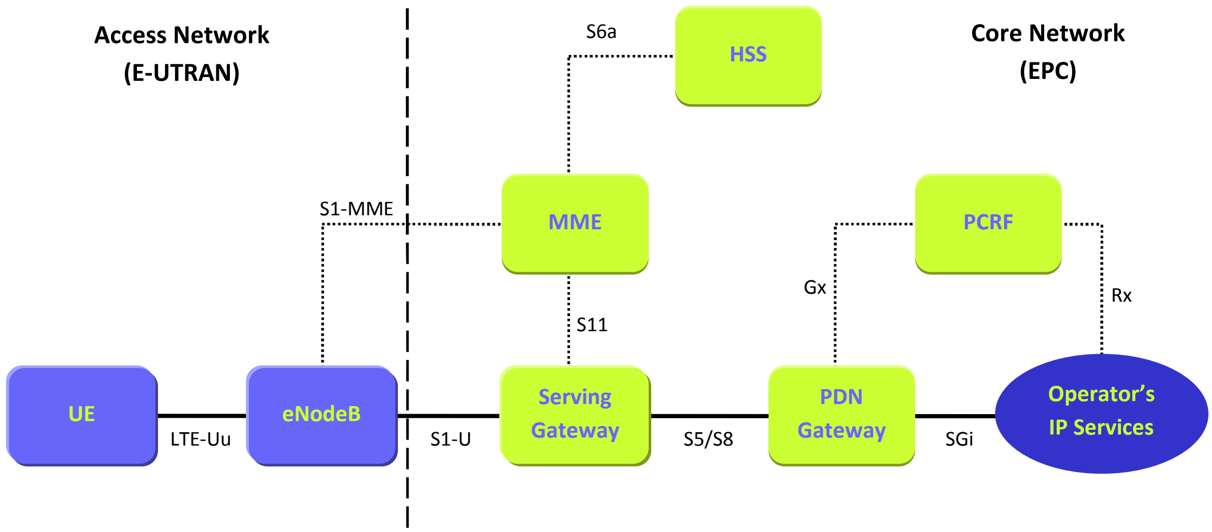

FIGURE 1 THE EPS NETWORK ELEMENTS.

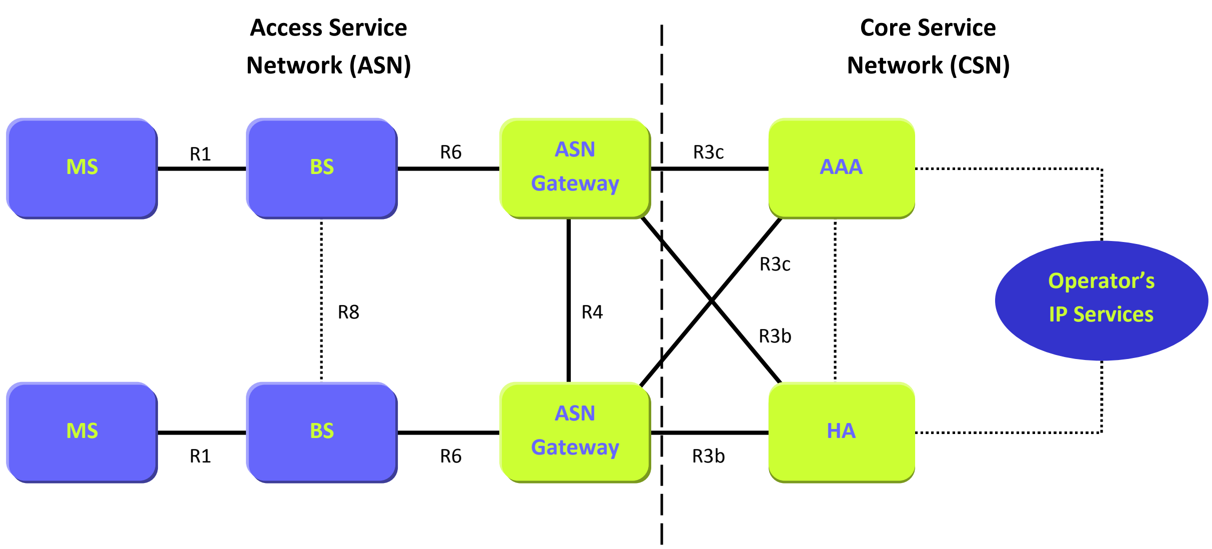

FIGURE 2 WIMAX NETWORK REFERENCE MODEL.

Comparative Analysis

Table 2 provides a comparative overview of key features in LTE and WiMAX. It shows that both technologies are well equipped with the latest innovations to provide high data and robust link in mobile fading channels. Both are based on flat IP network architecture and support different Quality of Service scheduling methods to ensure end-to-end reliability. Furthermore, both technologies are well equipped to support different types of frequency reuse schemes, particularly fractional frequency reuse which allows a higher reuse factor by assigning a subset of sub-carriers for exclusive use at the edges of the cell.

TABLE 2 COMPARATIE OERIEW BETWEEN LTE AND WIMAX.

Feature	WiMAX	LTE	Comment
Downlink Access PHY	OFDMA	OFDMA	
Uplink Access PHY	OFDMA	SC-FDMA	SC-FDMA chosen to eliminate Peak-to-Average Power Ratio for handhelds and to reduce cost.
Duplex Mode	TDD	FDD	Specified mainstream mode. WiMAX 1.5 specified FDD mode. LTE Frame Type II is for TDD operation.
Frame Length (msec)	5	1	LTE specifies 10 msec frame length, but scheduling is on 1 msec sub-frame basis. Hence, LTE is expected to provide lower latency than WiMAX.
Encryption	AES128	AES128	SNOW 3G option available for LTE systems.
Modulation	QPSK 16QAM 64QAM (DL)	QPSK 16QAM 64QAM (DL)	Both WiMAX and LTE support adaptive modulation and coding (AMC). LTE provides higher number of coding rate options than WiMAX which result in higher granularity AMC selection (1-2 dB vs. 3-4 dB).
Channel Coding	CTC	CTC	
Channel Bandwidth (MHz)	5 10	5 10	Stated mainstream channels. 5 MHz FDD channel in LTE uses total 10 MHz of spectrum. Other channel bandwidths are also available for both technologies.
Sub-carrier Spacing (kHz)	10.9	15	'Normal' LTE parameterization.
Cyclic Prefix Length (μsec)	11.4	4.7	Based on 1/32 CP for backhaul solution (SW Release 2).
OFDMA Symbol Time (μsec)	102.9	71.4	Both technologies with long enough symbol length to obviate the need for frequency equalizers.
Symbols/Frame	47	14	Stated value for 'Normal' LTE parameterization in one sub-frame of 1 msec. LTE frame of 10 msec would typically have 140 symbols.
FFT Size	512 1024	512 1024	512 for 5 MHz channel; 1024 for 10 MHz channel.
Data Sub-carriers	360 720	300 600	
QoS Support	Yes	Yes	Both standards support multiple QoS types across the air interface.
SM MIMO Support	Yes	Yes	Spatial Multiplexing for 2 or 4 antennas supported by both systems.
Transmit Diversity	STBC	SFBC	Space Time/Frequency Block Codes.
Receive Diversity	MRC	MRC	Standard on most equipment.
Hybrid ARQ	Chase Combining	Incremental Redundancy	Incremental Redundancy provides higher gain but is more complex to implement.
Transport Protocol	IP	IP	

Number of Subscribers	>100	>100	Subject to channel capacity and equipment capability.
Latency (ms)	30-45	20-30	Latency is a statistical measure that depends on a large number of factors such as the subscriber loading of the base station, the link quality, and QoS grade. LTE features lower latency because of smaller scheduling interval (1 msec) as opposed to WiMAX which is based on 5 msec frame. The values stated here are typical of what has been experienced.
Authentication	Device only	User & Device	WiMAX typically uses X.509 certificates which are well suited for fixed devices.
Mobility Support	Yes	Yes	Mobility support includes handover, power control (idle, sleep modes), and paging.

Table 3 shows the downlink throughput for WiMAX and LTE which are equivalent. The results are for single antenna and can be scaled in case of spatial multiplexing by 2 or 4 for 2x2 or 4x4 antennas, respectively (spatial multiplexing theoretical capacity increase is linear with Min(N_{Tx}, N_{Rx}), the number of transmit and receive antennas). Because LTE is FDD and WiMAX is TDD, a fair comparison would be between 5 MHz LTE and 10 MHz WiMAX. LTE throughput factors overhead for PDCCH, PBCH, reference and synchronization signals while that for WiMAX factors in layer 2 overhead associated with preamble and downlink MAP (6 overhead symbols). The WiMAX downlink sub-frame was for a total of 26 symbols, equivalent to a 55:45 traffic ratio.

TABLE 3 DOWNLINK THROUGHPUT FOR WIMAX AND LTE.

Modulation Scheme	WiMAX Downlink (TDD)			LTE Downlink (FDD)		
	Coding Rate	5 MHz	10 MHz	Coding Rate	5 MHz	10 MHz
QPSK	1/2	1.44	2.88	0.514	3.11	6.20
QPSK	3/4	2.16	4.32	0.663	4.01	7.99
16QAM	1/2	2.88	5.76	0.479	5.74	11.45
16QAM	3/4	4.32	8.64	0.643	7.74	15.26
64QAM	2/3	5.76	11.52	0.650	11.45	22.92
64QAM	3/4	6.48	12.96	0.754	13.54	27.38
64QAM	5/6	7.2	14.4	0.853	15.26	30.58

In terms of system gain, both WiMAX and LTE provide equivalent values as similar access technique (OFDM), modulation grades, coding (CTC), multiple antenna systems (space time/frequency coding; spatial multiplexing), and other features like Hybrid ARQ are used. This results in equivalent cell radius and subsequently cell count for a given market.

In summary, the two technologies would provide equivalent performance. Indeed, the battle between the two standards has not been focused on performance (as the battle between GSM and CDMA was centered mainly on capacity), but rather on the ubiquity of adoption, and henceforth, on the health of the ecosystem, sustainability and profitability.

SPECTRUM CONSIDERATIONS

Equipment vendors have focused their efforts on developing equipment in the frequency bands of the major mobile network operators who are one of the main forces behind LTE. A common 'profile' of the standard is necessary to drive high volumes and low prices in addition to supporting key services such as roaming. As mobile services became ubiquitous around the world, different spectral bands were opened globally for these services. The result is a relatively high number of bands where mobile wireless networks are operating in (or planned for operation) including: 700 MHz (USA), 800 MHz (North America, and 'digital dividend' band in some European countries), 900 and 1800 MHz (Europe, rest of world), 1700 MHz (North America AWS band), 1900 MHz (North America PCS band), and 2.1 GHz (Europe UMTS band). These bands, all configured for paired allocation (FDD), have been the main candidates for LTE deployments in addition to the 2.5-2.7 GHz band.

In contrast to LTE, WiMAX has been focused on deployments in higher frequencies, namely 2.3 GHz (Korea, India), 2.5-2.7 GHz (USA), and 3.4-3.6 GHz (Europe, rest of the world). Depending on geography, these bands feature unpaired (TDD) or paired allocations. The WiMAX Forum, the industry coalition behind WiMAX, certified equipment for compliance with the IEEE standard and for interoperability in these bands.

Meanwhile the frequency bands for TD-LTE which is being promoted as a substitute to WiMAX have focused on 2.3 GHz and 2.5 GHz, driven by interest of China Mobile and Indian broadband deployments and by US operator Clearwire, respectively. This leaves WiMAX relatively little challenged in the 3.x GHz bands for the time being.

The fragmentation of spectrum presents a challenge for equipment vendors as wireless devices (and base stations) need to support a continually higher number of frequency bands. It is particularly in the RF chain that includes RFICs, filters, mixers and power and low-noise amplifiers that this challenge becomes manifest. Even as component vendors strive to develop multi-band RFICs, supporting wide-band or dual-band power amplifiers is very challenging.

Multiple antenna systems add another complication by allowing different options such as 2x2, 2x4, and 4x4 systems[2] on the base station and another, but smaller set of options on the subscriber device (which are typically 1x2, but some have proposed higher order configurations).

Aside from complications resulting from the availability of different frequency bands on equipment design choices, spectrum fragmentation tends to slow down the certification process and can lead to a slower adoption of a standard. In the case of WiMAX, the focus was placed on the 'flagship' 2.5 GHz profile followed by 3.5 GHz and 2.3 GHz system profiles.

[2] This nomenclature indicates the number of transmit and receive antennas on the same equipment. While typical GSM and 3G systems are 1x2 – one transmit and two receive antenna systems – LTE is envisioned to be rolled out in a 2x2 configuration at the very least just as WiMAX has rolled out with 2x2 support being a standard feature.

Finally, and very importantly, spectrum has a great impact on the operator business case. Services must take into consideration the suitability and amount of available spectrum. For instance, higher propagation losses at higher frequencies lead to a greater cell count, as shown in Table 4, which increases investment requirements and delays achieving positive return on investment. Consequently, this has an effect on the size of the market and the resulting interest by the ecosystem and the types of companies that engage in it. Furthermore, the difference in operating frequency has an impact of migration strategies that include overlay of one technology over another as an interim roll out stage. Even though LTE and WiMAX have similar system gains, small spectrum allocation may force the operator to deploy in a different band, in which case, additional sites are required.

TABLE 4 CELL SIZE AND COUNT FOR DIFFERENT OPERATING FREQUENCIES.

Frequency (MHz)	900	1800	2500	3500
Cell Radius (m)	4900	3245	2670	2186
Path Loss at 4900 m (dB)	150	158	162	165
Site Count for 100 km^2 market	2	4	6	9
Relative Site Count	1.0	2.0	3.0	4.5
Assumes a maximum allowable path loss of 150 dB. Cell radius was calculated assuming 30 m base station height and 2 m subscriber station height and 90% area confidence interval. Hexagonal cells are assumed for cell count calculations.				

To summarize, in planning to roll out a wireless technology, be it initial deployment or network migration, it is imperative to develop a well grounded perspective on the challenges that the spectrum landscape presents and how it impacts the business case of equipment vendors as well as the certification process. Every equipment vendor support certain system profiles, but not all the profiles – at least not simultaneously – and especially not in the early stage of a technology lifecycle. Availability of equipment, or the lack thereof, can have a detrimental effect on the business case. This in turn impacts technology selection and migration plans.

INFRASTRUCTURE EQUIPMENT CONSIDERATIONS

Both WiMAX and LTE feature a similar network architecture, the main elements of which can be categorized as following:

- Consumer devices
- Base stations
- Gateways
- Core Network Elements (e.g. AAA/HSS)
- Backhaul systems
- Routers, switches, VoIP softswitches, and session border controllers
- Management systems

Migration from one technology to another requires a strategy for each of the above items.

Consumer Devices: WiMAX' lead has a distinct advantage in providing a number of choices for consumer devices that include outdoor and indoor modems and USB dongles in addition to a few models of handsets and laptops with integrated WiMAX baseband chipset. TD-LTE is yet to see commercial units. At this stage, a migration from WiMAX to TD-LTE would require swapping consumer devices.

Base Stations: Base station architecture includes the logical modules shown in Figure 3. These module can all be combined into a single mechanical unit (as is the case in zero-foot print, all-outdoor base stations), or split indoor-outdoor architecture in which the radio is typically placed remote from the indoor baseband unit and close to the antenna.

Migration of the base station between technologies is a possible but intricate proposition that many vendors claim, but few support in totality. To consider the ability to migrate a WiMAX base station to LTE, each module needs to be considered separately, as well as the combined solution.

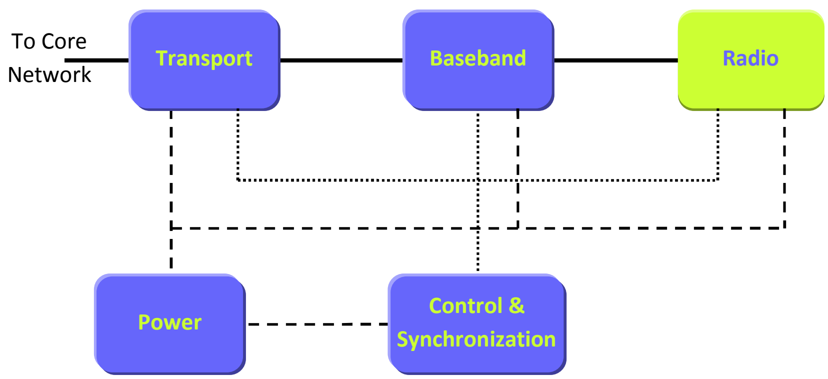

FIGURE 3 BASE STATION LOGICAL ARCHITECTURE.

Since both WiMAX and LTE are based on the same physical layer technology, a radio could support both WiMAX and LTE. The radio design, with required linearization techniques, crest factor reduction and/or amplifier power backoff to accommodate technical characteristics of OFDMA, as for example the peak-to-average power ratio, is similar. As the radio unit accounts for about 40% of the base station cost, the ability to migrate a radio between technologies saves the operator a large part of the base station expense.

The baseband module could in theory be upgraded through a firmware upgrade if the unit uses programmable devices such as FPGAs, DSPs, and NPUs (baseband module based on technology specific system on chip – SoC – is not firmware upgradeable to another technology). However, this may not necessarily be a straight forward process. The same applies to firmware of the transport module which includes higher layer protocol stack to interface with the core network. Finally, the synchronization module is critical and many base station designs fail to upgrade between technologies as internal clocking and synchronization requirements between WiMAX and LTE are different.

Although WiMAX and LTE base stations feature similar throughput rates and support similar number of subscribers which implies similar provisioning of resources such as memory and processing power, the ability to migrate a software-defined base station from WiMAX to LTE is not a certain and straightforward proposition.

Gateways: The WiMAX ASN Gateway is a major network element that acts as the conduit for any user traffic and control plane signaling between the base and subscriber stations and core network elements. The LTE Serving and Packet Data Network Gateways have similar functions. Both technologies have implemented open interfaces to facilitate inter-vendor interoperability. Moreover, different vendors support different architectures as, for example, separating the data and control planes, or keeping them on one hardware unit. Selecting the proper architecture, product and vendor is an important aspect in migration of the gateways from WiMAX to LTE. Fortunately, as the traffic load of WiMAX and LTE base stations is expected to be similar, both technologies would require similar provisioning of resources at the gateway.

Core Network Elements: These elements are typically provided by third party vendors who support the required primitives for a technology and conduct interoperability tests with core network element vendors and RAN equipment vendors (base stations and consumer devices).

Backhaul Systems: These systems would be the same for WiMAX and LTE since base stations for both technologies are expected to support the same number of users and subscriber throughput. A design for WiMAX should require the same backhaul capabilities as that for LTE provided that all air-interface parameter are the equivalent (e.g. channel bandwidth, number of antennas).

Management Systems: OSS/BSS systems are another critical part of the network. Network and element management are captured under OSS with responsibility for provisioning, configuration, fault, performance management. Billing and customer care solutions are captured under BSS. Although WiMAX and LTE are similar, these systems need to integrate with other network elements such as the access or packet data network gateways and the AAA/HSS servers. Interoperability testing is required to ensure that the installed system supporting the WiMAX network can support the LTE network in an error-free manner. The strategy for OSS/BSS migration needs to take a holistic account of what options the WiMAX network uses. For example, WiMAX device provisioning can be through TR069 which has been implemented in fixed networks and leverages extension of the DSL network, or through OMA/DM which is widely deployed in mobility systems. Migration to LTE can therefore be more involved a complete strategy for upgrading the management systems is required.

Finally, switches, IP routers and other network elements such as VoIP softswitches and session border controllers need to be tested for interoperability, even though they interface with the wireless network at higher layers of the network protocol stack.

As a rule of thumb, the further an element is removed from the air interface, the higher likelihood that no hardware change is required so that functional interoperability is what is required for migration purposes.

Operational Considerations

Wireless subscribers do expect uninterrupted service. It is not feasible to have a prolonged service interruption during the migration process. This requirement adds to the complexity of this process. Therefore, switching between two networks must either occur almost instantly without a long delay in service unavailability, or the switch must occur over a prolonged period of time where two wireless technologies operate simultaneously until one is turned off after all subscribers have been migrated to the new service. Given the risks associated with the first approach and the complexity of the wireless network in addition to logistical constraints, it is a highly unlikely course to take for wireless operators.

Migration from WiMAX to LTE, as that between any two technologies, involves repeating processes already performed for the incumbent network such as RAN planning, design and optimization. Managing these processes requires careful planning to ensure successful execution of the migration strategy. The following factors need to be to consider including:

1- Acquisition of additional spectrum: Wireless network operators with small spectrum allocation would find a challenge in running two wireless networks simultaneously in the same spectrum. Although both WiMAX and LTE feature fractional frequency reuse (FFR) which reduces the spectrum requirements, FFR may not be supported by the equipment vendors. Additional spectrum may be required.

2- Frequency planning: The migration plan must include detailed frequency plans and transition timelines.

3- Capacity planning: Frequency planning is done with consideration to capacity requirements in order to maintain the quality of service subscribers expect.

4- Subscriber devices: swapping subscriber devices is an important issue along with provisioning and configuring the new devices.

The operational process of migration between WiMAX and LTE requires careful thought and planning: it is a most critical aspect of network migration. Wireless network operators need to work the details of the migration process with their equipment vendors to ensure uninterrupted service.

Financial and Commercial Considerations

Migration from WiMAX to LTE is a critical strategic decision that needs to be taken to fulfill the business vision of the network operator. Making the decision to migrate can be arduous as it involves significant effort and expense. Defining the corporate business vision helps in clarifying the criteria against which the migration decision is evaluated against and helps to streamline the decision making process.

Financial and commercial considerations are key elements to justify the migration decision. Migration needs to be considered in the context of improving competitiveness by providing greater service, better performance and lower cost. This enhances the operator bottom line by increasing revenues and reducing costs. The scale and ubiquity of a technology adoption and its evolutionary roadmap are important factors to this end.

A financial model is an important tool to identify and monetize the different parts of the migration plan to estimate their value to the network operator. The plan would reflect the required capital acquisitions and operational expenses such as additional equipment, spectrum, human resources, interoperability testing, equipment/network acceptance testing, planning, design and optimization among other expenses.

The financial model allows the network operator to explore and compare different migration strategies including the timing of investments. A proper understanding of the technology and commercial landscape is essential to build an appropriate model and account for proper inputs.

CONCLUSIONS

Migration of wireless networks from one technology to another is a challenging task that should be undertaken with full considerations of the overall vision and market strategy for the network operator. WiMAX and LTE technologies offer similar technical performance and the battle between them transcend technical aspects into the realm of ecosystem viability, cost and variety of consumer devices, service competitiveness, and ultimately, profitability for the network operator which drives valuation. Technology migration is a complex process that must be planned carefully. Different elements of the wireless network must be considered and a plan to migrate each element must be defined that includes specific steps and timelines. The support of the vendor community is essential and careful consideration of vendor promises must be weighed. A financial model that captures all the elements of the migration plan serves as a tool to validate the need for migration as well as to evaluate and benchmark different migration options to establish the best strategy for a particular operator.

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[2] Telesystem Innovations Inc. 'LTE in a Nutshell: System Requirements,'

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Abbreviations and Acronyms

3GPP	3rd Generation Partnership Project
AAA	Authentication Authorization Accounting
AES	Advanced Encryption Standard
ARQ	Automatic Repeat Request
AuC	Authentication Center
AWS	Advanced Wireless Services
BSS	Business Support System
CDMA	Code Division Multiple Access
CTC	Convolutional Turbo Codes
DSP	Digital Signal Processor
EPC	Evolved Packet Core
EPS	Evolved Packet System
FBW	fixed broadband wireless
FDD	Frequency Domain Duplex
FFR	Fractional Frequency Reuse
FPGA	Field Programmable Gate Array
GSM	Global System For Mobiles
HARQ	Hybrid Automatic Repeat Request
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control Layer
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
NPU	Network Processor Unit
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OMA/DM	Open Mobile Alliance - Device Management
OSS	Operational Support System
PAPR	peak-to-average power ratio
PCRF	Policy Control Enforcement Function
PCS	Personal Communication System
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
P-GW	Packet Data Network Gateway
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RFIC	Radio Frequency Integrated Circuit
RLC	Radio Link Control
RRC	Radio Resource Control
RRM	Radio Resource Management
SAE	System Architecture Evolution

SBR	Signaling Radio Bearers
SFBC	Space Frequency Block Coding
S-GW	Serving Gateway
SoC	System on Chip
STC	Space Time Coding
TDD	Time Domain Duplex
TR069	Technical Report 069
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
WiMAX	Worldwide Interoperability for Microwave Access

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TSI 100623-006