White paper for the GSMA

The momentum behind LTE worldwide

January 2011

Ref: 18091-446

analysys mason

Contents

Analysys Mason Limited
Bush House, North West Wing
Aldwych
London WC2B 4PJ
UK
Tel: +44 (0)20 7395 9000
Fax: +44 (0)20 7395 9001
enquiries@analysysmason.com
www.analysysmason.com
Registered in England No. 5177472

1 Executive summary

With wireless data traffic forecast to continue its growing trend in the next three to five years, 3G/W-CDMA networks are expected to reach their limits in terms of capacity and throughput. As such, operators will have to deploy data-optimised radio networks in order to cope with the increased demand. This paper examines the importance of the timely release of the required frequency bands for these data-optimised networks.

Our main findings are as follows:

- **The global take-up of many different wireless data services, particularly on smartphones, is driving overall wireless network traffic**. Data traffic is expected to increase much faster than voice traffic with data accounting for just over 90% of total wireless network traffic worldwide by 2015. Mobile operators will need to increase network capacity to handle this growth in demand. HSPA/HSPA+ has so far been able to meet this demand. Many operators will however need to augment their networks with improved access technology and leverage additional spectrum, to meet this rapidly growing demand in the future. HSPA+ networks; and in particular LTE networks, will likely serve as the most efficient next generation mobile network technology options to achieve this goal.

- **Commercial deployments of LTE services have begun**. As of January 2011, there were eighteen LTE networks operational across the major developed markets of North America, Western Europe and Central Eastern Europe/Commonwealth of Independent States. The networks are utilising a range of spectrum bands between 700MHz and 2.6GHz. Although all these networks have launched using the FDD variant of LTE, we expect that LTE TDD services are likely to commence in 2011. We expect that by 2015, LTE services will account for about 250 million mobile connections globally. Western Europe and Developed Asia will lead this growth with the developed region accounting for over 65% of the connections.

- **Spectrum availability is essential to the success of LTE as a new service platform**. The ability to take advantage of new spectrum allocations and the opportunity to potentially re-farm existing GSM spectrum are two important developments that will shape LTE deployment strategies. Any constraints in spectrum availability will limit the network capacity benefits of LTE. This will directly affect the timing at which mobile operators can launch LTE network services capable of handling the expected growth of mobile data traffic.

- **MNOs could start to benefit from lower cost LTE deployments from as early as 2012**. The momentum behind LTE is likely to drive down cost of network access equipment and if operators increasingly embrace network infrastructure sharing, the potential capex savings on LTE network deployment could be substantial.

- **With the right approach and strategy, operators are likely to benefit from a sound LTE business case**. Utilising the right mix of paired and unpaired spectrum bands for LTE along with the efficient use of 3G solutions such as HSPA+ in existing bands are essential ingredients in enabling timely and successful deployment of these data-optimised radio networks. This will ensure that operators can offer truly global next generation mobile platforms that can facilitate interoperability with both with legacy 3GPP and non-3GPP standards as well as aid these operators' in achieving their goal of meeting rapidly growing mobile data demand.

2 Introduction and objectives

3G network service availability today is significantly lower than that of 2G networks. Reasons for this include restrictive licence conditions on operators in developed countries as well as limited mobile broadband (MBB) service coverage in emerging countries. However, increasing government activities focusing on providing universal access to broadband services is expected to change this. As wireless services are expected to be a key component of universal provision; either becoming the primary broadband technology or supporting fixed infrastructure, spectrum usage rights are now increasingly technology and service neutral with national regulatory authorities (NRAs) becoming more flexible in allowing spectrum users to determine the technology they deploy and (in some cases) services they provide.

With the prevalence of smartphones forecast to spread globally and the consequent increase in the number of MBB data connections (referring to all connections using 3G, HSPA, LTE or similar to connect a PC as shown in Figure 2.1), network operators around the world are increasingly looking to provide efficient networks with high-speed downlink capacity. In order to achieve this goal, the majority of mobile network operators (MNOs) are now migrating their current-generation mobile networks to the latest evolution of HSPA+ as well as next-generation mobile network technologies such as WiMAX and LTE.

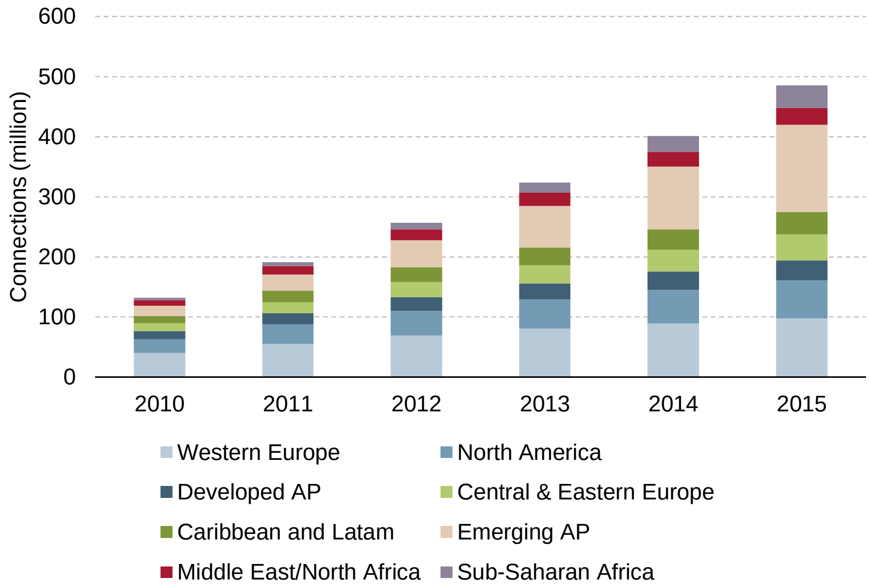

Figure 2.1: Mobile broadband connections, by region, 2010 –2015 [Source: Analysys Mason, 2010]

The success of wireless solutions relies on the availability of spectrum, as well as the timing of the auctions of the required spectrum bands. LTE will require new or additional spectrum to be made available in the high-frequency bands that offer high capacity (e.g. 2.3GHz and 2.6GHz) as well as in the lower frequency bands which provide greater coverage (e.g. 700MHz, 800MHz and those released within the digital dividend[1]). Any constraints in spectrum availability will limit the network performance benefits of LTE.

In addition, the choices that operators make with regards to spectrum will determine the range, capacity and building penetration of their next-generation mobile network, which, in turn, will affect cell count, and therefore operating expenditure (opex) and capital expenditure (capex). Therefore, the ability to take advantage of new spectrum allocations and opportunities to potentially ‘re-farm’ (i.e. re-allocate) existing GSM spectrum are two important factors that will shape deployment strategies of next-generation mobile network access technologies such as WiMAX, HSPA/HSPA+ and LTE.

This white paper analyses the momentum behind LTE markets worldwide to derive a consolidated view of the commercial and technological aspects of FDD and TDD spectrum worldwide. The objective of this white paper is to:

- enable governments to understand how to release appropriate spectrum for MBB and help shape their spectrum policies depending on different market situations and operator requirements
- enable financial analysts to gain an understanding of the value network MNOs place on various spectrum bands they have or might acquire and how this relates to the type of services and coverage operators can attain

As FDD and TDD bands will not represent the same value to each operator, this paper also examines how operators should look to combine FDD and TDD spectrum holdings into a cohesive Mobile Broadband strategy and approach.

Structure of this white paper

The remainder of this white paper is structured as follows:

- Section 3 highlights the market overview of next generation mobile networks (NGMN)
- Section 4 examines the technology ecosystems, exploring operator and vendor activities as well as maturity and proliferation of the technologies in terms of infrastructure and devices
- Section 5 provides an overview of the performance capabilities (both theoretical and real world) different NGMN technologies
- Section 6 addresses key questions regarding the LTE business case
- Section 7 explores how LTE could support services operators will likely offer.

In addition, the annex contains relevant reference material

- Annex A contains a technical overview of LTE and WiMAX
- Annex B contains a glossary of terms used throughout this white paper

---

1 The ‘digital dividend’ refers to spectrum bands(between 200MHz - 1GHz) that will be freed up in the switchover from analogue to digital terrestrial TV.

3 Market overview

3.1 Mobile broadband data traffic growth

Historically, voice telephony has accounted for the majority of wireless network traffic. However, the take-up of many different data services, particularly on smartphones, is driving up data's share of overall wireless network traffic. Our forecasts[2] shows that voice traffic will increase between 2010 and 2015, but data traffic is expected to increase much faster and will dominate the service mix in developed and emerging markets by 2015, with data accounting for 94% and 85% of total wireless network traffic in developed and emerging markets respectively (see Figure 3.1).

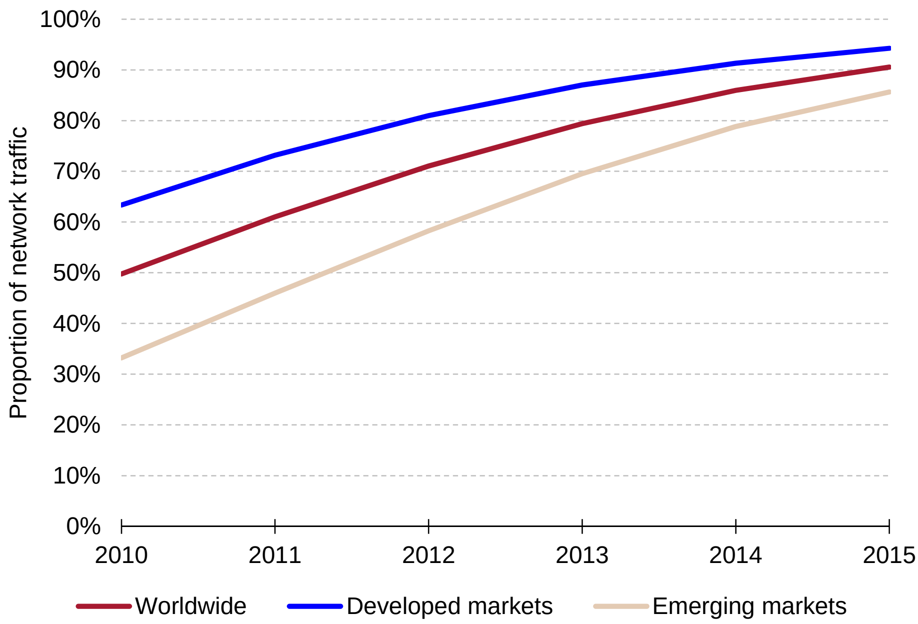

Figure 3.1: *Data services as a proportion of wireless network traffic, worldwide, 2010–2015 [Source: Analysys Mason, 2010]*

Major market factors driving this increase include:

- **improved cellular devices** – in particular 'plug-and-play' wireless USB dongles, an increased number of laptops with embedded modems, and a greater proportion of smartphone handsets
- **technology evolution** – technology enhancements lead to the deployment of high capacity networks with improved throughputs (e.g. HSPA networks), which allow support for a wider range of applications and leads to increased usage

[2] Analysys Mason Research forecast report, *Wireless Network Traffic 2010 – 2015 forecast and analysis* (http://www.analysysmason.com/Research/Content/Reports/RDTN0_Wireless_traffic_forecast/).

- **affordable pricing and bundling**. The increase in MBB penetration by the introduction of unlimited usage tariffs as well as the widespread introduction of voice bundles with generous allowances of any-time, any-network minutes

- **new services** – for example, the new wave of mobile services including video, social networks and machine-to-machine (M2M) services

- **increasing indoor usage** – due to fixed–mobile substitution of voice telephony as well as improved indoor coverage through the introduction of femtocells

- **increasing mobile connections** – led by mobile penetration growth in emerging markets and the adoption of secondary devices such as USB modems in developed markets.

MNOs need to increase network capacity to handle this growth in demand. In the short term, enhancing W-CDMA networks should be sufficient. In the long term, however, the leading operators in these markets will need to roll out Evolved high-speed packet access (HSPA+) and 4G technologies. WiMAX will be an option for a few operators. LTE, together with evolved 3G networks, will however likely serve as the main technology option required to meet the demands of growing mobile traffic in the future.

3.2 LTE market developments

LTE is the latest development in the GSM family of mobile technology standards. It is the response from the UMTS standards body, 3GPP, to the rising demand for data among mobile subscribers. It is all-IP in both the core and access sub-networks and as such:

- offers significant performance improvements compared with legacy networks
- has the full support of the mobile industry
- can offer significant opex and capex savings
- offers a more flexible use of spectrum compared with legacy networks

As the natural evolutionary successor to the leading global GSM and HSPA (and HSPA+) wireless technologies, LTE serves as a possible migration path for other major systems including CDMA, TD-SCDMA and even WiMAX. Consequently, a number of major operators have confirmed their long-term strategy to move to LTE, building confidence that equipment vendors will be able to create and benefit from economies of scale and support a variety of devices and services.

LTE product development, field trials and deployments are already underway in Western Europe, Central and Eastern Europe (CEE), North America, the Asia Pacific, Latin America and the Middle East. These trials are being conducted by MNOs in collaboration with the major tier-1 equipment and chipset manufacturers such as Ericsson, Motorola, Alcatel Lucent, Huawei, Nokia Siemens Network and Qualcomm. The first few LTE networks have been launched using the LTE FDD variant of the technology.

Region	***Country***	***Operator***	***Spectrum band***	***Launch date***
North America	USA	Verizon	700MHz	December 2010
Western Europe	Finland	Elisa	1800MHz	December 2010
Western Europe	Denmark	TeliaSonera	2.6GHz	December 2010
Asia Pacific	Japan	NTT DOCOMO	1500MHz	December 2010
Asia Pacific	Hong Kong	CSL	1800MHz / 2.6GHz	November 2010
Western Europe	Sweden	Net4Mobility	2.6GHz	November 2010
Western Europe	Germany	Vodafone	800MHz	November 2010
Western Europe	Austria	Telekom Austria	2.6GHz	October 2010
Western Europe	Austria	T-Mobile	2.6GHz	October 2010
North America	USA	MetroPCS	1.7 / 2.1GHz	September 2010
CEE	Poland	CenterNet / Aero2	1800MHz	September 2010
CIS	Uzbekistan	Ucell	2.6GHz	August 2010
CIS	Uzbekistan	MTS	2.5 / 2.7GHz	July 2010
Western Europe	Finland	TeliaSonera	1800MHz / 2.6GHz	June 2010
Western Europe	Norway	TeliaSonera	2.6GHz	December 2009
Western Europe	Sweden	TeliaSonera	2.6GHz	December 2009

Figure 3.2: Operational LTE networks as at January 2011 [Source: Analysys Mason]

TeliaSonera became the first MNO in the world to introduce commercial LTE services in Oslo, Norway and Stockholm, Sweden. The operator positioned LTE as a premium data service with its launch dongle operating on LTE only (i.e. it cannot be used on 2G or 3G networks). However, the MNO also started offering dual-mode HSPA/LTE Samsung dongles as of June 2010.

December 2010 saw the launch of a number of LTE networks around the major wireless markets of North America, Western Europe and Asia Pacific. The Elisa (in Finland) and TeliaSonera (in Denmark) networks became operational utilising 1800MHz and 2.6GHz bands respectively. Verizon (in the USA) and NTT DOCOMO (in Japan) also launched their networks but utilising the 700MHz and 1500 MHz bands – signalling the start of deployments in lower frequency bands[3]. At the time of writing this paper, Globacom in Nigeria also announced that it had launched its LTE network in Lagos; which would make it the first African operator to do so.

There have been two cases of operators sharing network infrastructure. Polish network operators CenterNet and Mobyland (part of Aero2) were the first network operators in the world to implement a shared network architecture in September 2010 utilising the 1800MHz band. The most recent of these shared LTE network launch was in Sweden with Tele2 Sweden and Telenor Sweden launching their commercial LTE mobile broadband services in November 2010 via their equal joint network venture Net4Mobility. The joint venture shares 2.6GHz and 900MHz spectrum with the initial service launch utilising the 2.6GHz band.

[3] along with Vodafone's 800MHz LTE network in Germany in November 2010

Given the current global dominance of GSM-based operators, we expect the GSM based family of technologies (i.e. HSPA and LTE) to be the dominant means of supporting mobile broadband[4] in the future.

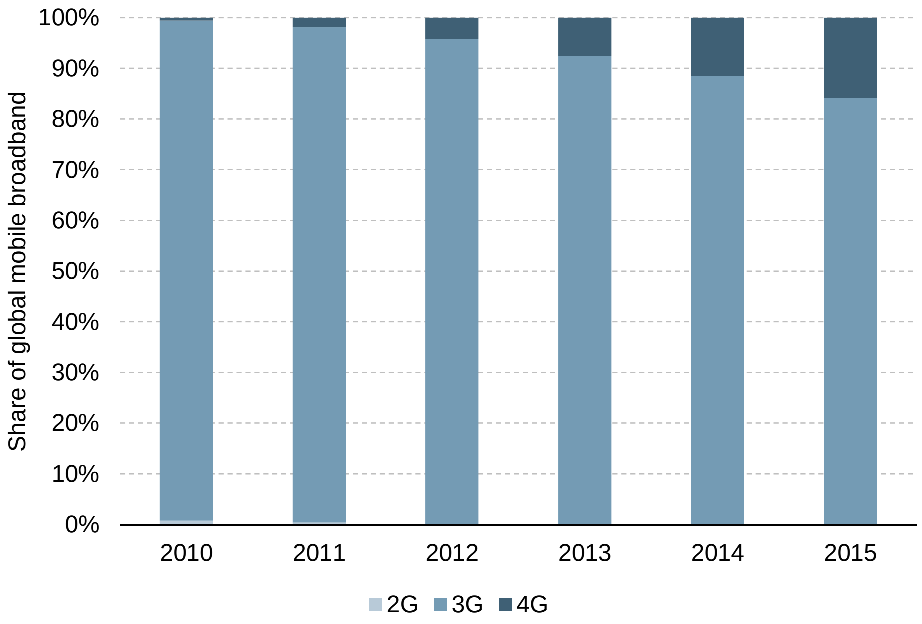

Figure 3.3: MBB market share by technology, worldwide, 2010–2015 [Source: Analysys Mason, 2010]

In particular, by 2015, we expect that about 250 million subscribers worldwide will have access to mobile data through LTE networks. We note, however, that despite the increasing availability of 4G technologies (LTE and WiMAX), 3G (HSPA and HSPA+) will likely account for most of the mobile broadband market by 2015, as shown in Figure 3.3 above.

LTE in the developed market

In developed markets, we expect to see widespread deployment of LTE by 2014, with significant take-up by early-adopter MNOs by the end of 2012. Figure 3.4 illustrates the year-end LTE deployment forecasts for the period 2010–2015.

4 Specifically in this context, 'mobile broadband' refers to all connections using 3G, HSPA, LTE or similar to connect a PC or laptop via a USB modem, dongle, embedded modem or peripheral device (such as a home hub). We explicitly exclude handset access

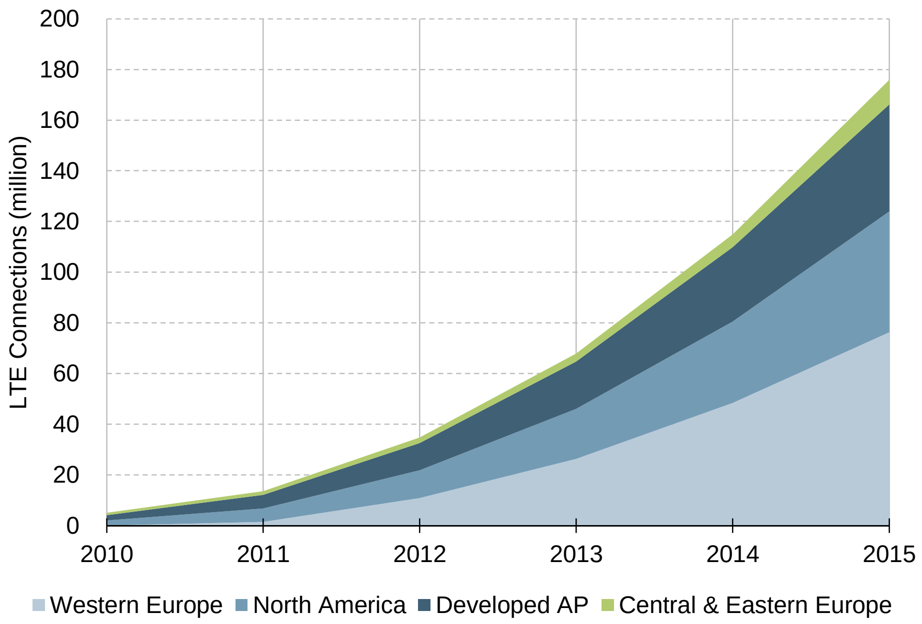

Figure 3.4: LTE connection forecast in developed markets; 2010 – 2015 [Source: Analysys Mason]

- **In Europe,** mobilkom austria launched the first commercial HSPA+ system in March 2009 and there are now over 35 operational HSPA+ networks in the region. In Western Europe, we expect that many operators will launch LTE networks in 2011 with the CEE operators launching their networks from late 2011 onwards, once spectrum is made available. LTE is likely to be deployed first in urban 'hot spots' (primarily in the 2.6GHz band) with fuller urban coverage to follow. For instance, EMT's (Estonia) LTE network is already operational with limited coverage in the city centre surroundings of Tallinn.

- **In North America,** operators are rapidly deploying HSPA+ networks, however, LTE networks are also emerging. In the United States, MetroPCS was the first to launch in September 2010 followed by Verizon 3 months later. AT&T have expressed their intent to launch LTE in the 700MHz band in early 2011. Sprint Nextel expects to stay focused on WiMAX, although its wholesale partner Clearwire commenced LTE trials in August 2010. In Canada, Rogers Communications has indicated that it will continue exploiting its HSPA assets in the short term, while Telus and Bell intend to move to LTE in 2011 utilising the 2.1GHz band.

- **In Asia–Pacific (developed countries)**, MNOs have embraced HSPA with over 25 HSPA networks already in operation. Although some countries had developed their own standards in the past, the majority of MNOs are now choosing to deploy LTE. NTT DOCOMO in Japan launched LTE services in December 2010 utilising the 1.5GHz band with plans to cover up to 50% of the population by 2014. In Australia, Telstra commenced LTE trials in June 2010 in the 1800MHz spectrum band and has indicated the possibility of launching services in both the 700MHz and 2.6GHz bands.

LTE in the emerging market

Based on our forecasts as of 3Q 2010, major deployments of LTE in emerging markets are expected to commence by 2013 at the earliest.

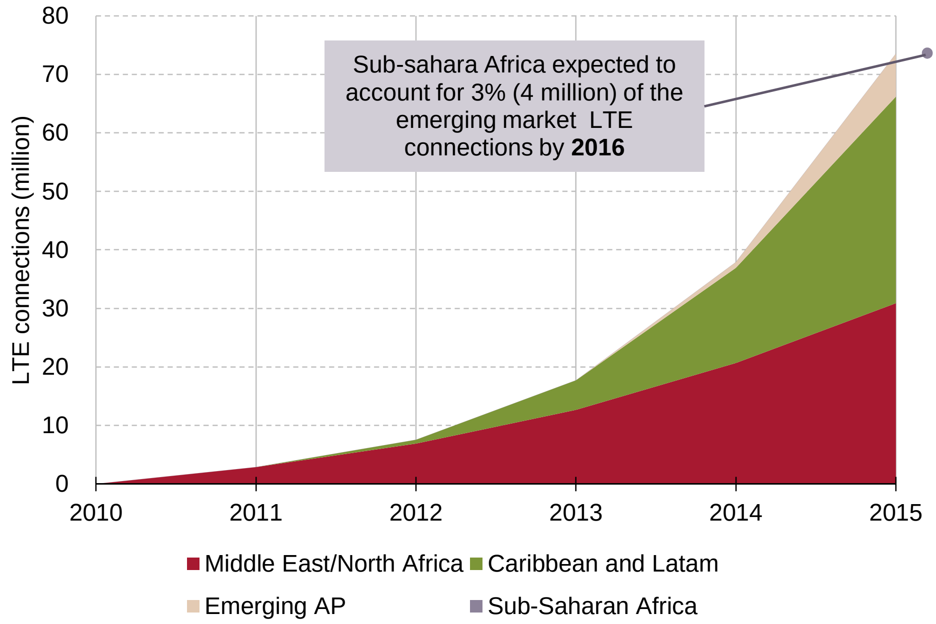

Figure 3.5: LTE connection forecast in emerging markets; 2010 – 2015 [Source: Analysys Mason]

- **In the Middle Eastern and North Africa**, mobile broadband services offered via HSPA networks have become widespread with over 25 operational networks and 8 HSPA+ services as at September 2010. Some major MNOs have concluded LTE trials. STC and Zain in Saudi Arabia are deploying LTE and both expect their 2.6GHz LTE networks to be operational by the end of 2010. Zain also expects to launch LTE in Jordan and Bahrain in 2011 and recently completed video streaming, high-resolution videoconferencing and voice over LTE trials in Bahrain. Etisalat in the UAE has commenced the roll-out of its LTE network and expects to launch services by the end of 2010.

- **In the Caribbean and Latin American**, major LTE deployments are expected to begin in 2012. Telefónica (Argentina) and Entel PCS (Chile) have already commenced LTE trials and the national regulatory authorities (NRAs) in the region are working towards releasing spectrum. In August 2010, Anatel (the Brazilian NRA) announced its decision to re-farm wireless spectrum in the technology-neutral 2.6GHz band for 4G services in time to launch services before the 2014 FIFA World Cup. Subtel (the Chilean NRA) also confirmed that it expects licences for the 2.6GHz band to be awarded by June 2011. Although Caribbean MNOs are now also trialling LTE, so far most have deployed WiMAX solutions (e.g. Claro in the Dominican Republic and Digicel in Jamaica).

- **The Asia–Pacific (emerging countries)**, mobile broadband is expected to increase from 17 million connections as at end of 2010 to 145 million connections in 2015 (as illustrated in Figure 2.1), accounting for the largest global share of mobile broadband growth by 2015. However, not all of these connections will be LTE connections, as delays in releasing the required spectrum are expected to initially limit LTE deployment in the region. Spectrum auction activities that have taken place recently in this region suggest that NRAs and MNOs are only just starting to release spectrum suitable for LTE:

  – The Chinese government delayed auctioning of 3G licenses, with three licences eventually being issued in January 2009 (one to China Mobile for local standard TD-SCDMA and the other two to China Unicom and China Telecom for W-CDMA and CDMA EV-DO respectively). Mobile broadband adoption has since been relatively low. China, despite having over 750 million wireless subscribers, currently has just over 25 million 3G subscribers between the three MNOs.

  – The Indian NRA, TRAI, finally allocated '3G' [sic] 2.3GHz bands in September 2010, after much delay. MNOs are yet to decide whether to launch LTE or even WiMAX. Broadband penetration has also been low in India, at just over 9 million subscribers as at the end of June 2010, out of a total population of over 1 billion.

  – The Thai NRA, NTC, scheduled the first round of 3G auctions in August 2010, and this was expected to be followed by an auction of the 2.3GHz and 2.6GHz spectrum bands the following month. The auctions have been further delayed and state-owned integrated telecommunications service provider TOT remains the only operator currently licensed to provide 3G network services utilising the 1.9GHz band.

  – In other markets, MCMC (the Malaysian NRA) confirmed 2.6GHz spectrum allocation to nine operators, which include incumbent MNOs and WiMAX players, in late September 2010. Although ITRB (the Indonesian NRA) has so far mostly commented on WiMAX developments, Indonesia's leading operator Telkomsel commenced LTE trials in late September 2010 and other MNOs are calling for release of spectrum suitable for 4G services. The two other major emerging countries in the region, Pakistan and Bangladesh, have yet to auction spectrum suitable for LTE.

- **In Sub-Saharan Africa**, there were about 20 HSPA networks and 2 HSPA+ networks as at September 2010. Due to issues concerning mobile broadband service affordability, it is expected that LTE networks in the region will not be deployed in high volumes until after 2015. MNO and NRA activities however suggest plans are being made for eventual LTE adoption. In South Africa, Vodacom launched the region's first LTE trial utilising the 2.1GHz spectrum band in June 2010, and the South Africa NRA, ICASA, recently issued auction notifications for the 2.6GHz and 3.5GHz bands. At the time of writing this paper, there were unconfirmed reports that Globacom in Nigeria had launched its LTE network which would make it the first operator to do so in Africa.

Impact of regulatory decisions on the mobile broadband market

MNOs need to plan their networks so that they can react to a range of potential future traffic scenarios. Therefore, they need access to sufficient spectrum so that they can meet higher traffic forecasts and prevent any network degradations. Although LTE can be deployed using 10MHz of bandwidth, 2×20MHz of contiguous spectrum would be ideal in providing maximum capacity and highest spectral efficiency. Any constraints in spectrum availability will limit these LTE benefits and is also likely to affect 4G service launch dates in the markets discussed above.

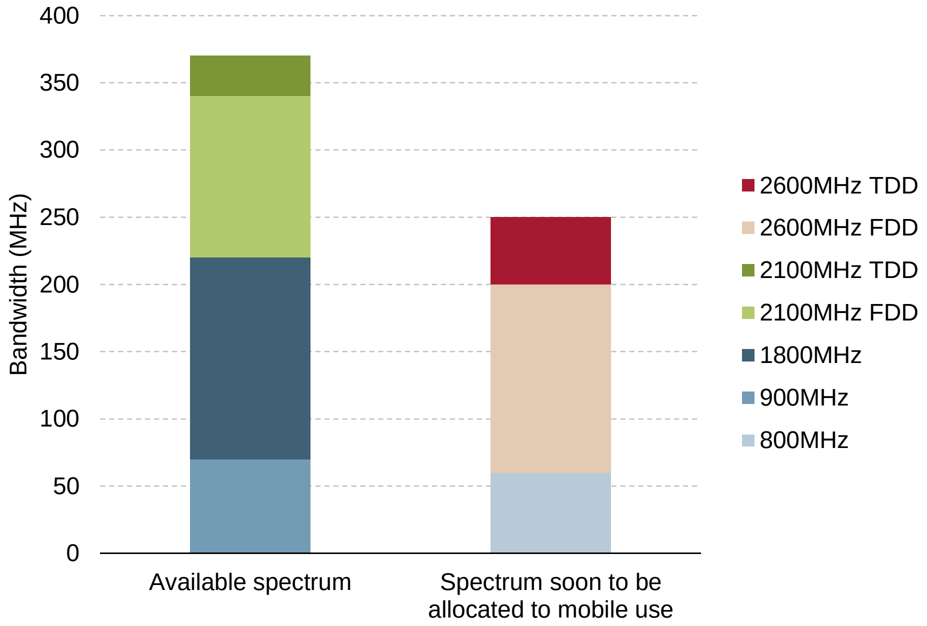

Figure 3.6: Available spectrum and spectrum to be awarded in the next five years for mobile use in Europe [Source: Analysys Mason, 2010]

A large amount of spectrum is planned to be made available in Europe during the next five years, in addition to the amount that is already available as shown in Figure 3.6 above. This signifies spectrum scarcity is unlikely in the short to medium term in Europe. Although the situation is similar in some non-EU markets, other markets, such as those in the Asia–Pacific, are already experiencing the effects of the unavailability of required spectrum bands on high-capacity wireless network deployments. As more data-centric networks are deployed, NRAs around the world will need to start increasing the amount of spectrum available on a timely basis, where possible.

3.3 WiMAX market overview

WiMAX networks are IP-based networks that utilise inexpensive spectrum[5]. WiMAX has gained a strong foothold in emerging markets with poor fixed-line infrastructure. There are currently over

[5] Spectrum used for mobile has been expensive, which has led WiMAX operators to utilise other relatively cheaper unpaired bands.

530 operational WiMAX networks[6] in over 140 countries worldwide, around 66% of which operate in emerging markets. As at mid-2010, there were around 10 million global WiMAX subscribers. WiMAX has been deployed in various spectrum bands, but the majority has been in the 3.5GHz band (see Figure 3.7).

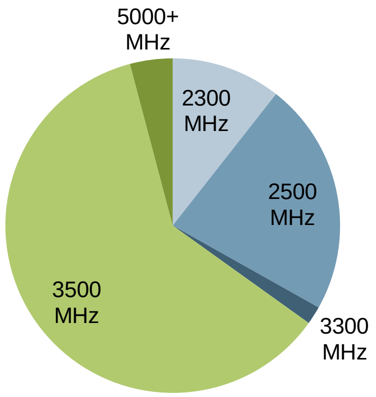

Figure 3.7: Global WiMAX deployments by frequency; June 2010 [Source: WiMAX Forum]

WiMAX in developed markets

There over 280 operational WiMAX networks in developed markets so far. Yota (Russia), Clearwire (USA) and Imagine Communications (Ireland) have been the most successful:

- **Yota** launched its WiMAX service in September 2008 in the 2.5–2.7GHz band. End-user devices include dongles and laptops embedded with mobile WiMAX. With over 600 000 subscribers (as at September 2010), Yota is by far the largest mobile WiMAX operator in Europe.

- **Clearwire** commenced deployment of its 2.5GHz WiMAX network in September 2008 in the highly developed US broadband market, which had a household fixed broadband penetration of over 70%. By June 2010, it had accumulated just under 1.7 million WiMAX subscribers.

- **Imagine Communications** experienced very fast adoption of its 3.5GHz WiMAX service in Ireland, which has one of the highest wireless broadband penetration rates in the world at 12% of the population. The service provider attributes its fast growth to the poor coverage and premium price of DSL services, allowing it to compete with HSPA as an alternative for fixed-line DSL.

Developed markets with low broadband penetration could be potential markets for future WiMAX growth. These markets often have pockets of sophisticated broadband deployment; such as large

6 Analysys Mason's WiMAX tracker (http://www.analysysmason.com/Research/Content/Trackers/RDTN0_WiMAX_tracker/).

urban deployments of fibre-to-the-building (FTTB), or are affluent markets with a sophisticated mobile infrastructure where 3G MNOs have been slow in meeting latent broadband demands.

WiMAX in emerging markets

The majority of WiMAX deployments have been in emerging markets with the lack of good fixed or mobile infrastructure and the availability of low cost unpaired spectrum. WiMAX operators have the taken the opportunity to establish a strong position in the broadband market in these regions.

- **Packet One (P1) Networks** in Malaysia launched its 2.3GHz WiMAX network in August 2008. P1 initially targeted the metropolitan areas of Kuala Lumpur and the Klang Valley but its WiMAX network now covers about 35% of the population with active subscriber numbers just under 200 000 as at June 2010.

- **Wateen Telecom** in Pakistan saw the opportunity to target the underdeveloped broadband market and deployed a WiMAX network in December 2007. As at March 2010, Wateen had captured 25% broadband market share – second only to incumbent PTCL’s 51% share.

India; which recently awarded TDD spectrum bands, could be a key growth market for WiMAX in 2011. MNOs will have to consider the pros and cons of early network deployment utilising WiMAX against the likely economies of scale cost benefits of LTE in the medium to long term.

The lack of broadband wireless spectrum (most notably in the 2.6GHz band) has been the main factor which has led to WiMAX being unable to capitalise upon its early mover marketing advantage (at circa 3 years) over alternative mobile broadband technologies.

In markets where mobile broadband is used solely as a substitute for poor residential DSL services and where there has not been a need for national coverage, WiMAX operators have taken the opportunity to offer competitively priced services. However, as fixed line broadband networks evolve and become widespread in metropolitan areas, particularly in the emerging markets, we expect to see WiMAX predominantly being deployed as a substitute for DSL in rural areas, rather than as a direct alternative for mobile broadband technologies based on HSPA or LTE.

4 Overview of the technology ecosystems

4.1 The LTE ecosystem

With over 85% of the world's mobile subscribers utilising 3GPP standards (GSM and HSPA), LTE has strong industry support from MNOs, terminal, chipset and equipment vendors, application and platform developers, and content and services providers. We expect that the LTE ecosystem will be able to build on the success and volumes that have been established by previous 3GPP standards in the same way that HSPA has benefited from GSM.

Equipment vendors and mobile operators will take advantage of this already established base of GSM and HSPA subscribers. Existing 3G equipment and terminal vendors[7] have committed to providing LTE equipment creating a multi-vendor market with interoperable products and potentially cost-effective upgrades from existing equipment. This will increase the choice of products and reduce costs through competition. Vendors are seeking to ensure MNOs can re-use existing assets wherever possible, thereby enabling MNOs to minimise capital expenditure on network equipment.

Vendor support for LTE is building confidence throughout the industry that the ecosystem will be able to create economies of scale and support a variety of terminals and services. Consequently, a number of major MNOs have confirmed their long-term strategy to move to LTE and over 130 firm network deployment commitments have been made worldwide.

4.2 The WiMAX ecosystem

The WiMAX ecosystem is already well established, with devices and network equipment available in the market supporting a wide range of services from backhaul provision to various outdoor applications that require high-speed nomadic coverage. A number of WiMAX service providers and vendors are however starting to buy into the potential benefits of economies of scale offered by LTE. Yota in Russia announced in May 2010 its intention to commence roll-out of an LTE network, citing the global shift towards LTE by operators and vendors as its reason for the switch to LTE and adding that its delay in deploying LTE was due to the immaturity of the technology.

Clearwire has also announced plans to conduct LTE trials from late 2010 and throughout early 2011. The operator had remained technology agnostic in the past deploying WiMAX initially to meet the immediate subscriber demand for ubiquitous and affordable mobile broadband services. The LTE trials, Clearwire states, ensures it "leverage(s) a number of possible opportunities [to] future-proof [its] network"[8]. The operator also restated its commitment to WiMAX stating that it is

---

7 These include the large wireless/integrated vendors like Alcatel Lucent, Ericsson, Huawei, Motorola, Nokia Siemens Networks, QUALCOMM, Samsung, and ZTE to name a few.

8 Clearwire August 2010 press release on LTE trials

"conducting [LTE] technical trials to determine how it could potentially add LTE technology to coexist with WiMAX".

Future growth in WiMAX connections is likely to be driven by the increase in consumer products coming to market, including tri-band smartphones capable of global roaming. This could help bolster confidence in the WiMAX ecosystem. However, of all the major tier-1 vendors, Motorola and Huawei (both of which are also investing in the FDD and TDD variants of LTE) are notably still investing in WiMAX. Ericsson and Alcatel-Lucent are now solely developing (and in the case of Ericsson deploying) commercial LTE network equipment, and Cisco has recently withdrawn from the WiMAX market. Alvarion, which maintains about 20% of the remaining mobile WiMAX market share, recently announced that it will commence support for LTE TDD systems, with trials expected to commence in 2011.

4.3 The role of national regulatory authorities

Spectrum availability plays an important role in the migration to next-generation mobile technologies, and a number of NRAs around the world have started to auction spectrum suitable for 4G services.

In the developed markets, several EU countries have already awarded 2.6GHz licences. These include Denmark, Finland, Germany, the Netherlands, Norway and Sweden, with Germany also awarding licences at 800MHz. The UK expects to proceed with planned auctions of 800MHz and 2.6GHz spectrum in 2011. In Japan, the focus has been on re-farmed 800MHz / 900MHz spectrum and new bands such as 2.3GHz and 2.6GHz. NTT DOCOMO is one of three operators in Japan to be awarded spectrum in the 1.5GHz band for LTE services.

In the emerging markets, two auctions of spectrum for 3G and 4G mobile services have recently been concluded in Mexico, for licences in the 1.9GHz (PCS) and 1.7GHz (AWS) spectrum bands. The PCS and AWS bands used for the release of spectrum for 3G and 4G services in Mexico aligns with the band plans used for mobile broadband services in the USA and Canada, as well as in a number of other Latin American countries. India's auction of broadband wireless access (BWA) using the 2.3GHz band has also recently been concluded.

4.4 The role of consumer terminals

Terminal availability, especially the introduction of high-capacity wireless handsets and dongles, has been one of the major drivers of mobile data usage and will be an important factor in the success of LTE.

MNOs are however likely to retain their GSM and UMTS networks in the medium to long term (i.e. the next five to ten years). The need to support legacy handsets is one important reason [9]. A

[9] Others include **coverage** (GSM networks have higher coverage than UMTS/HSPA networks. It is plausible that MBB networks (e.g. LTE) may not be demanded in some rural areas) **and the effects of spectrum on roaming** (delays in releasing required bands for 4G services is likely to slow down LTE adoption in some countries. Therefore, some MNOs may have to keep their GSM/UMTS networks operational in order to support roaming traffic on their networks)

large percentage of consumers own GSM, UMTS and HSPA devices (handsets and dongles), and will continue to do so for many years. Therefore, mobile operators will need to maintain these legacy networks in order to serve these consumers.

The growth in demand for higher-spec, higher-resolution handsets with video capabilities and larger storage capacity is however likely to positively influence the availability of consumer LTE terminals. These terminals, some of which will be multi-mode with GSM and 3G access, are likely to be introduced in phases from 2011 with vendors expecting it to take one to two years thereafter for widespread availability (see Figure 4.1).

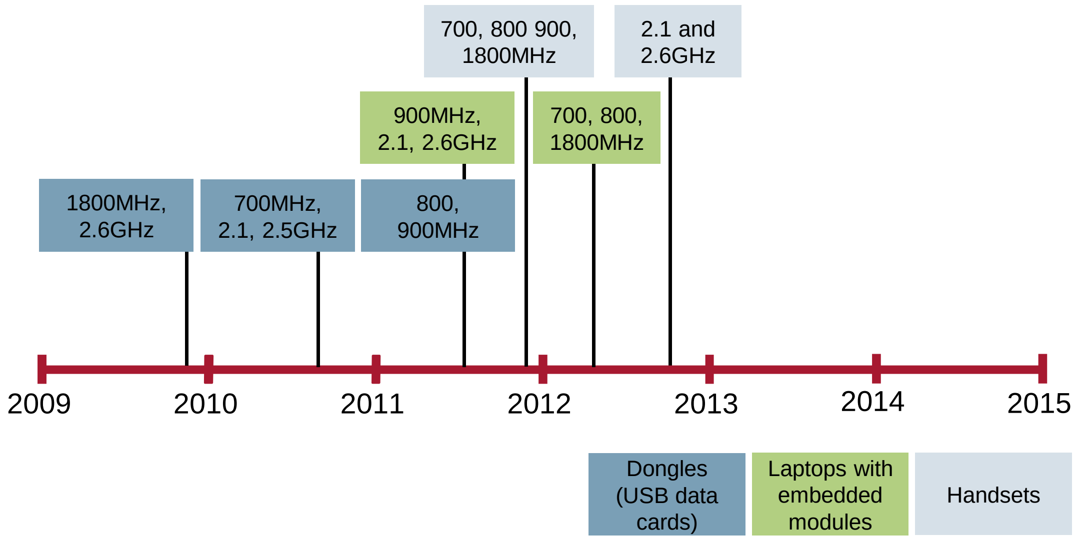

Figure 4.1: Expected LTE terminal availability [Source: Analysys Mason, 2010]

5 Comparison of technologies

5.1 LTE and mobile WiMAX technical comparison

LTE Rel-8 and 802.16e WiMAX

Although mobile WiMAX and LTE share common technical features, there are certain key differences:

- LTE has been designed for a diverse range of carriers from 700MHz to 2500MHz. This allows for better radio propagation characteristics in the lower bands and also gives MNOs the opportunity to obtain more spectrum as they become available.
- LTE using SC-FDMA for uplink radio interface ensures that terminal power consumption is reduced which is important for mobile terminal battery life considerations
- The smaller frame size of LTE allows for lower latency in LTE networks which helps better support voice calls over IP.

Figure 5.1 illustrates the theoretical and typical real-world downlink rates that each technology can achieve and shows that **average[10] (rather than peak) downlink data rates also vary**. This is because, even at similar bandwidth, downlink rates vary depending on antenna configuration, modulation schemes used, number of simultaneous users on the network as well as location of users (with those close to the base station getting better rates than those at the cell edge).

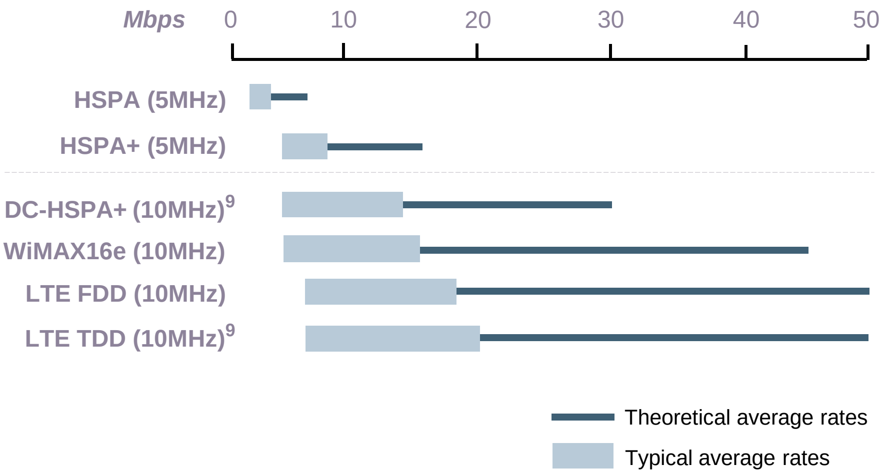

Figure 5.1: Range of achievable downlink data rates [Source: Analysys Mason 2010]

[10] Note that Figure 5.1 also illustrates the expected downlink rates of the TDD variant of LTE. These are likely to be slightly higher than LTE FDD systems as TDD systems (LTE and WiMAX) can allocate more time slots to the downlink. The DL/UL ratio assumed here is 70:30. This is discussed further in the paragraph below. Also, average downlink rates for DC-HSPA+ networks are based on a May 2009 drive test result carried out by Signals Research Group on behalf of the GSMA.

TDD systems benefit from the efficiency with which they allocate bandwidth (in the form of time slots) to the uplink and downlink. So for example, 10% of time slots can be for the brief requests via the uplink, and 90% for the substantial amounts of data that follow on the downlink mirroring typical user internet browsing characteristics. With FDD systems, the downlink path can sometimes be constrained while the uplink path is underutilised. TDD advantages were once WiMAX-specific but can now be offered through LTE, allowing MNOs to offer either LTE-FDD, LTE-TDD or a mixture of both, depending on local spectrum availability.

LTE-Advanced and 802.16m WiMAX

The aim of LTE-Advanced and 802.16m WiMAX (R2.0) is to meet or exceed the IMT-Advanced requirements. A key feature of IMT-Advanced is interworking with other radio access systems, allowing for worldwide roaming and enhanced peak data rates. It is expected that WiMAX R2.0 and LTE-Advanced will be deployed in late 2012. A comprehensive comparison of these technologies is not currently possible as the standards have not yet been finalised.

5.2 Cost of deployment

Access network costs typically represent one-third of an European MNO’s total expenditure. Although majority of this is expenditure will be down to cost items such as site acquisition and power, Analysys Mason benchmarks show that BTS costs still account for about 15% of this expenditure in both developing and emerging markets (see Figure 5.2).

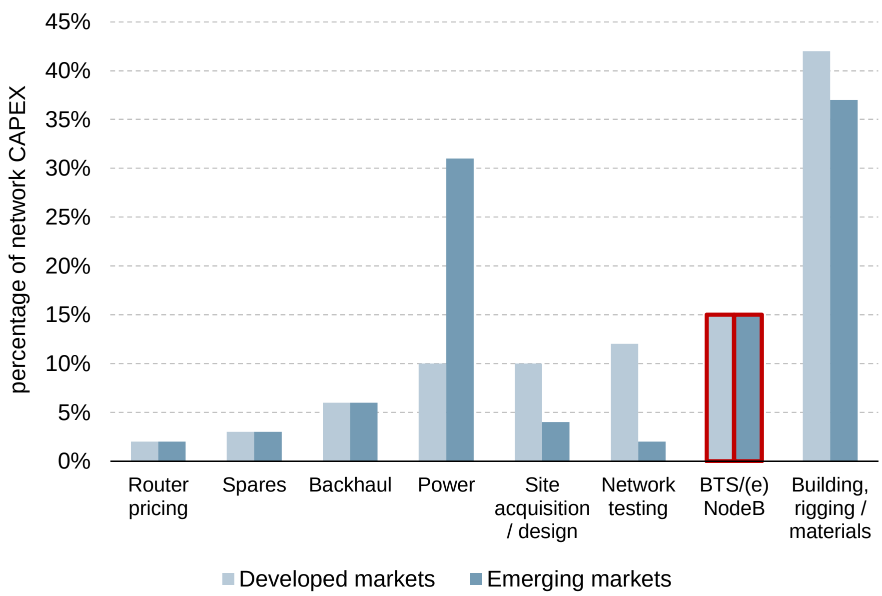

Figure 5.2: Network capex in developed and emerging markets [Source: Analysys Mason, 2010]

Although our cost benchmarks show current cost of LTE base station being higher than that of mobile WiMAX, we expect to see LTE BTS cost likely follow historical cost trends of 3G equipment and be driven down; an approximation of which is illustrated in Figure 5.3 below:

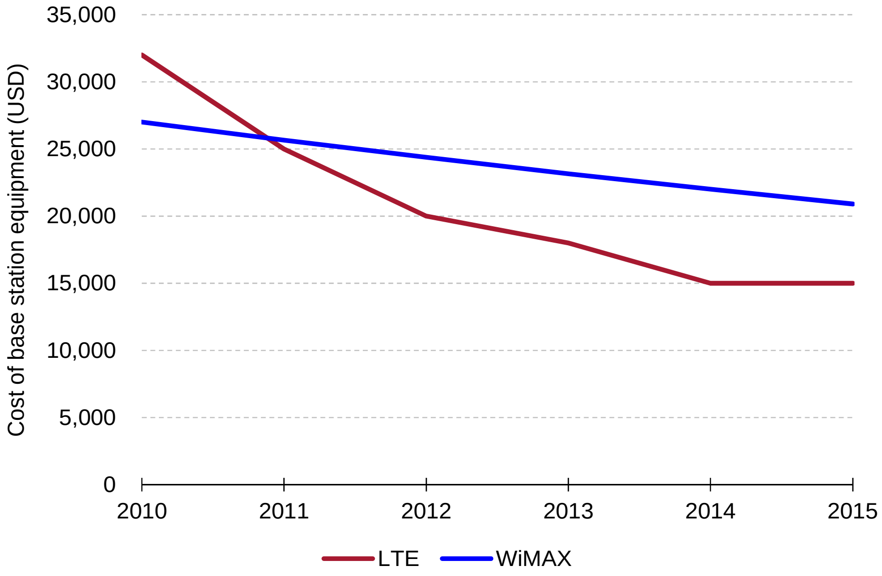

Figure 5.3: LTE base station cost evolution [Source: Analysys Mason, 2010]

We also expect that MNOs will increasingly share site infrastructure further offering cost saving opportunities. Figure 5.4 illustrates the potential substantial savings for operators participating in a joint venture new-build of an LTE network of 2500 sites deployed over a five year period.

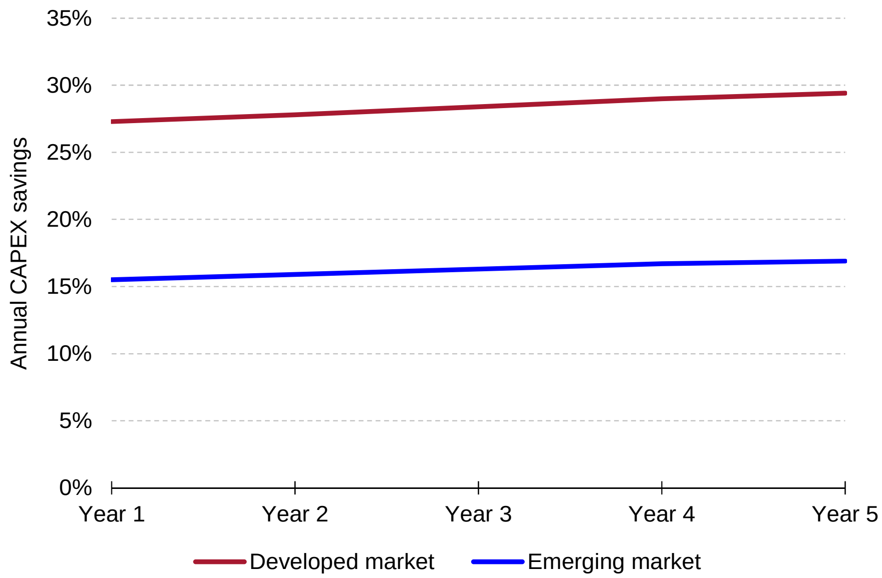

Figure 5.4: Accumulated capex savings in a joint venture LTE network deployment initiative [Source: Analysys Mason, 2010]

We therefore expect that the larger economies of scale that will be generated over the next few years means MNOs could start to benefit from lower cost LTE deployments from as early as the beginning of 2012.

6 Business case for LTE

Operators are finding it challenging to drive revenue growth, profitably, in the increasingly competitive telecom markets. Traditional revenue growth is slowing sharply with global mobile voice revenue registering a 2% decline in 2009 – a notable shift from the 6% growth in 2008.

Reduced cost of service delivery

Voice services have become commoditised in most markets and most new additions are low-ARPU subscribers. Low-cost, flat-rate data tariffs have made data services much more affordable, and in particular traffic-intensive services such as video streaming are contributing further to the increase in network traffic. The adoption of data services has been welcomed enthusiastically by MNOs as it increases, or at least helps to maintain, ARPU, but revenue per gigabyte is falling.

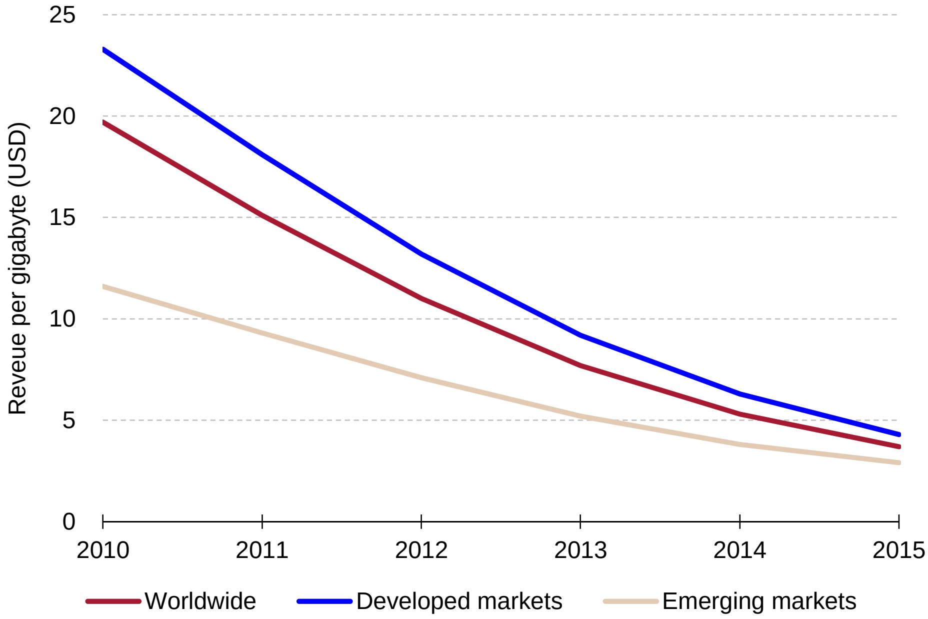

Figure 6.1: Revenue per gigabyte of mobile broadband traffic, 2010–2015 [Source: Analysys Mason 2010]

The combination of a substantial rise in mobile broadband traffic per connection and a marginal increase in revenue (assuming the current flat-rate data pricing model continues) will result in a significant decline in revenue per gigabyte in both developed and emerging markets. This is putting pressure on MNO profit margins, and as a result is dampening investor interest in the industry sector. However, the introduction of successive network enhancements, such as more spectrally-efficient technologies such as HSPA+ and LTE, will require fewer nodes to deliver the same network capacity, and LTE employs a flat-RAN architecture, which also reduces the number of network nodes. This combination helps to reduce carriage costs, thereby improving the economics of providing mobile broadband, and hence limits the impact of declining revenue per gigabyte on MNO profit.

Reduced capacity concerns

Our forecasts have shown that volume of data traffic will increase significantly by 2015, at which time each UMTS (HSPA) cell will be carrying higher traffic volumes during the peak hour periods. This growth will put pressure on cell capacity and require substantial increases in mobile spectrum or amount of mobile infrastructure if provided over legacy UMTS technologies.

We believe that HSPA+ with MIMO, at the least, will be required to meet peak hour demands in the short term, although not in dense urban areas which will still experience even more capacity demands. By 2015, operators will need to upgrade many urban and dense urban sites to HSPA+ with 64 QAM, 2×2 MIMO, or LTE, in order to maintain a cell loading that allows sites to cope with peaks in demand without compromising quality of service. Furthermore, users will increasingly use mobile devices to access voice and data services from their homes and workplaces. By 2015, almost 90% of worldwide wireless traffic is expected to originate indoors.

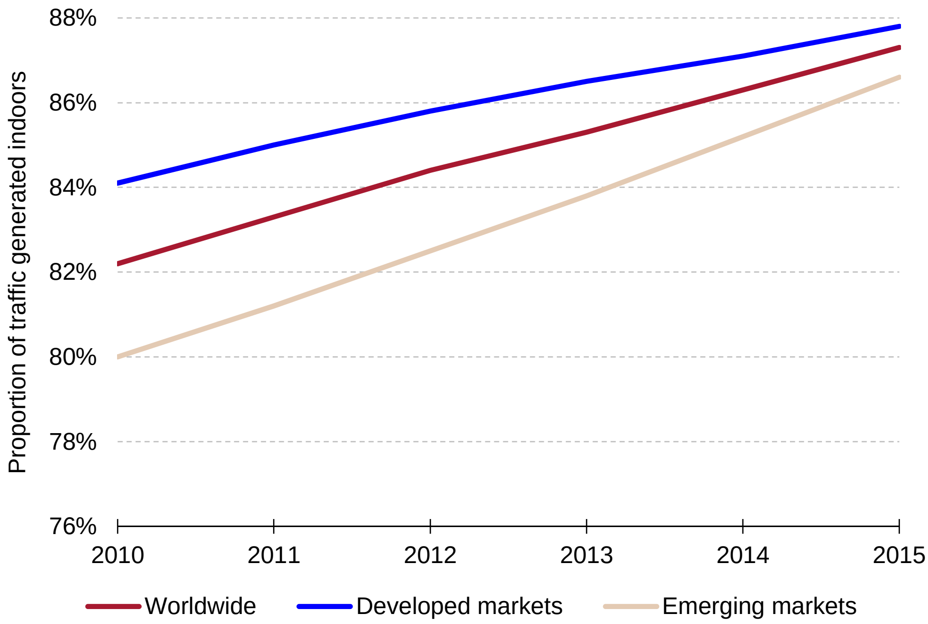

Figure 6.2: Proportion of wireless network traffic generated indoors, [Source: Analysys Mason 2010]

Increasing fixed–mobile substitution and the use of smartphones in the developed markets together with poor ADSL services and increasing numbers of basic handsets in the emerging markets, is driving the growth of indoor usage. MNOs will need to provide good quality indoor coverage with deep in-building penetration. LTE can effectively penetrate indoors but MNOs will require access to low frequency bands in order to maintain provision of indoor wireless network coverage.

Choice between paired and unpaired spectrum

The indoor coverage benefits of low frequency bands will however mean that they will be in great demand. Although spectrum bands are being made available across the world, these have been in several bands, each with different amounts of bandwidth and varied propagation characteristics.

Adding further to the debate on choice of spectrum is the unexpectedly rapid maturing of the TDD version of LTE, which is now expected to be in commercial operation by as early as 2011. This momentum behind LTE TDD is partly driven by the likelihood that the recently licensed BWA (TDD) spectrum in India would mean imminent LTE TDD service launch in the region. China Mobile's first major public offering of LTE TDD services (utilising a bandwidth of 20MHz in the 2.3GHz spectrum band) at the 2010 World Expo in Shanghai has also been a major factor.

LTE TDD's backward compatibility with TD-SCDMA systems as well as FDD modes of LTE will ensure global interoperability of LTE handsets and terminals in the future. We therefore expect that LTE FDD networks will likely utilise re-farmed 900MHz and 1800MHz bands where coverage is required. For areas where high-capacity, data-centric mobile broadband services are required, the 2.6GHz band (for LTE FDD networks) together with the 2.3GHz band (for LTE TDD networks), appear to be emerging as key candidate frequency bands.

Recent auctions of the 2.6GHz band supports this view as MNOs are now buying up both TDD and FDD spectrum suitable for LTE services, but as illustrated in Figure 6.3 below, prices vary:

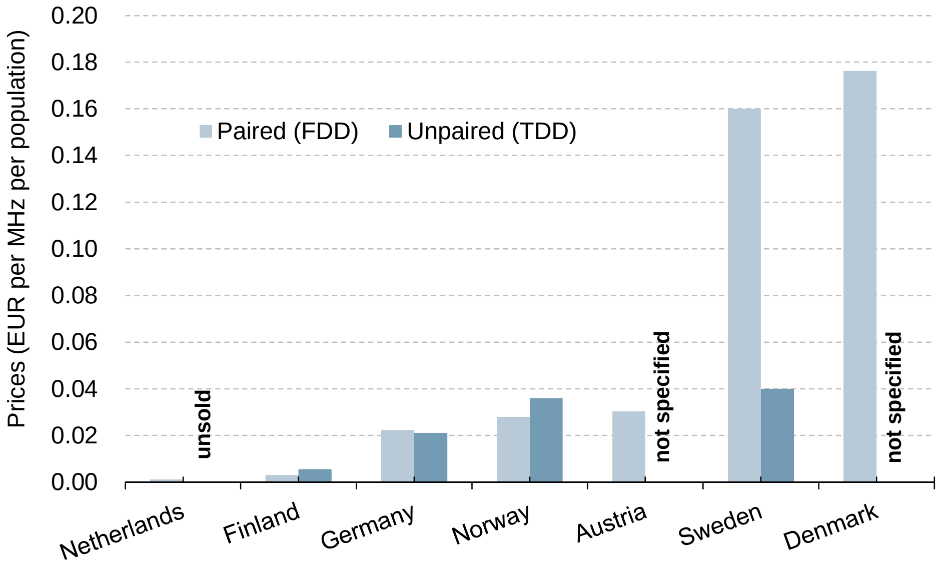

Figure 6.3: Prices raised in 2.6GHz auctions in Europe [Source: Analysys Mason 2010]

There are several reasons for the varied prices in the recent 2.6GHz auctions carried out in Europe.

- The Dutch auction raised low revenue due to the spectrum caps on existing MNOs to allow for the introduction of new entrants. This cap also resulted in lack of interest in the TDD bands.

- The Finnish auction raised a low amount with only one MNO acquiring the TDD bands, which sold for nearly twice as much as the two comparable FDD packages. The lack of bidders, as well as the operating restrictions, contributed to limited competition.

- By contrast, the Danish licences attracted higher prices from the four incumbent MNOs; three of which also gained unpaired bands. With no spectrum caps, neutrality on usage and a lower population, this auction highlights the discrepancies in prices.

- As part of Germany's 'super auction', the paired and unpaired 2.6GHz licences raised less revenue than the scarce 800MHz bands on offer. Revenues from the 1800MHz bands were also lower, although this could be as a result of the apparent lack of LTE equipment in this band. Deutsche Telecom indicated that it will use the 800MHz spectrum to roll out LTE to rural areas, and the 1800MHz and 2.6GHz bands to provide coverage in dense urban areas.

- FDD bands tend to sell for much less but in Sweden, FDD bands sold for five times more.

- Elsewhere, India's anticipated 3G auction generated higher revenue (EUR0.34 per MHz per head of population) than the European auctions in Figure 6.3 – specifically twice that of the Danish auction and nearly 40% more than the equivalent 2.1GHz band in Germany. It is also worth noting that scarcity of spectrum likely pushed up prices in India.

Analysys Mason is of the view that MNOs need to hold a mix of spectrum for LTE deployment: sub-1GHz spectrum bands to provide both wide coverage and indoor penetration for rural and urban connections respectively, and higher-frequency bands for capacity, particularly in urban areas. More importantly however, LTE, with its capability to be deployed as LTE-FDD and/or LTE-TDD networks supporting multi-mode 2G, 3G and LTE FDD/TDD terminals, presents operators with the opportunity to adopt deployment policies based on the right variant of an LTE network best suited to spectrum they already possess, but also based on local spectrum availability as governed by future spectrum bands they (and their competitors) intend to acquire.

Other considerations

LTE will most likely be deployed on a site-by-site basis contributing to other costs linked to the:

- integration of LTE to existing operator access infrastructure
- flexibility of transition and running of two or more networks at the same time
- possible loss of revenue when decommissioning legacy networks

It is therefore likely that MNOs will have to consider a number of strategic choices. Deploying LTE only where there is significant additional demand for capacity, and thus a demonstrable return on investment and pursuing an aggressive in-building penetration strategy are two options that may be key to assuring revenue streams and offsetting the risk of macro network deployment. In the end however, operators' strategies will be defined by a combination of their individual business objectives, capability (capacity) of legacy infrastructure, local spectrum availability, the availability of devices and the demand for data services.

7 Service delivery considerations for LTE

Profitability is a major challenge for all operators, and mobile voice services still remain the main driver of operator revenue. According to Analysys Mason's global market share report[11], mobile voice services accounted for more than 35% of telecoms service revenue in 2009.

Maintaining legacy revenue streams

Although LTE is a fully IP packet-switched technology that is very efficient at delivering data, it was not designed to support circuit-switched voice (CSV) and SMS, which continue to be the biggest revenue streams for MNOs.

MNOs have two options for supporting CSV and SMS after the introduction of LTE:

- continue to support voice on a GSM or UMTS platform, reserving LTE for data
- migrate voice to the LTE platform in an approach known as 'voice over LTE' (VoLTE)

The efficient and cost-effective delivery of VoLTE will require operators to implement IP Multimedia Subsystem (IMS, a mechanism for controlling multimedia sessions in the packet-switched domain). MNOs are however not expected to have migrated completely to IMS until 2012. As such, further interim solutions could be required of which we expect the main solutions to include:

- **circuit-switched fall-back (CSFB)** – this is the official 3GPP-specified standard for delivering voice services to LTE devices until full-scale IMS deployments are complete. CSFB routes voice calls and SMS messages via the existing CS core and 2G and 3G access networks.

- **voice over LTE generic access (VoLGA)** – this utilises existing generic access network (GAN) technology standard to convert CS voice via an access gateway into a VoIP tunnel that can then be transmitted over LTE, but using GSM/UMTS signalling, rather than SIP. This is the same method that is used to deliver VoIP over Wi-Fi to public WLAN hotspots and domestic WLANs.

Analysys Mason's analysis of industry activities suggests that CSFB will be the preferred option in the short term. As no new investment in hardware is needed (CSFB requires only a software modification to the MSC), it allows operators to deliver voice and SMS with LTE-enabled handsets before eventual migrating to IMS without having to deploy an interim VoLTE solution.

---

11 Analysys Mason Research report, *Worldwide telecoms market share report 2009* (http://www.analysysmason.com/Research/Content/Reports/RDIG0_Worldwide_telecoms_market_shares/)

Developing newer revenue streams

Consumers currently have access to a range of high value wireless data services (e.g. video streaming, online gaming) at a price potentially far below what they would otherwise be willing to pay. The competitive pricing of data services will continue to drive demand for data around the world. Also, better throughputs offered by HSPA+ and LTE networks are likely to be consumed by higher-bandwidth applications, thereby further driving data usage. The combination of these two trends is likely to prevent improvements in MNO data margins.

However, the introduction of LTE will likely offer MNOs an ideal opportunity to launch new pricing schemes in association with content producers. For example, premium video streaming services carrying standard-definition catch-up or broadcast TV could be priced at an increment to a standard data bundle, and interactive real-time applications such as VoIP could be priced differently to online gaming and IPTV services.

Several MNOs are starting to abandon flat-rate data pricing. Verizon Wireless has already stated that it will adopt tiered pricing when it launches LTE, in a deliberate move away from the unlimited data plans it offers on its 3G network. This could represent the last opportunity for MNOs to participate in the value created through wireless delivery of entertainment and information services to consumers.

Content and device characteristics, rather than the network, will define consumer service experiences in the future. This brings with it major challenges, and opportunities, for MNOs seeking to develop and deliver services across multiple terminals. Compared with previous network technologies, LTE offers capex and opex savings, and considerable performance improvements, including higher data rates and reduced latency, which will support new services such as gaming, TV and video. As such, LTE will not only be necessary, but it will also represent a valuable opportunity for MNOs that want to differentiate their mobile data offerings.

Annex A: Technical overview of LTE and WiMAX

Background and definitions

IEEE 802.16e (commonly known as mobile WiMAX Release 1.0) was standardised in 2005 by the IEEE 802.16 working group as an amendment to the 802.16d standard to support mobility services. Mobile WiMAX uses Time Division Duplexing (TDD) as well as Orthogonal Frequency Division Multiple Access (OFDMA) on the radio interface. It also uses an all-IP flat core network which aims to reduce latency. An updated version (Release 1.5) was certified in 2009 for operation in more spectrum bands and incorporates Frequency Division Duplexing (FDD) operating mode allowing for deployment flexibility which enables it to be deployed in more countries.

LTE (also referred to as E-UTRA) was defined by 3GPP Rel-8 in 2008 with further enhancements by Rel-9 in 2009. LTE utilises OFDMA in the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink as opposed to previous 3GPP technology which use Code Division Multiple Access (CDMA) for the downlink and uplink. LTE is also based on an all-IP network architecture and can operate in both FDD and TDD modes.

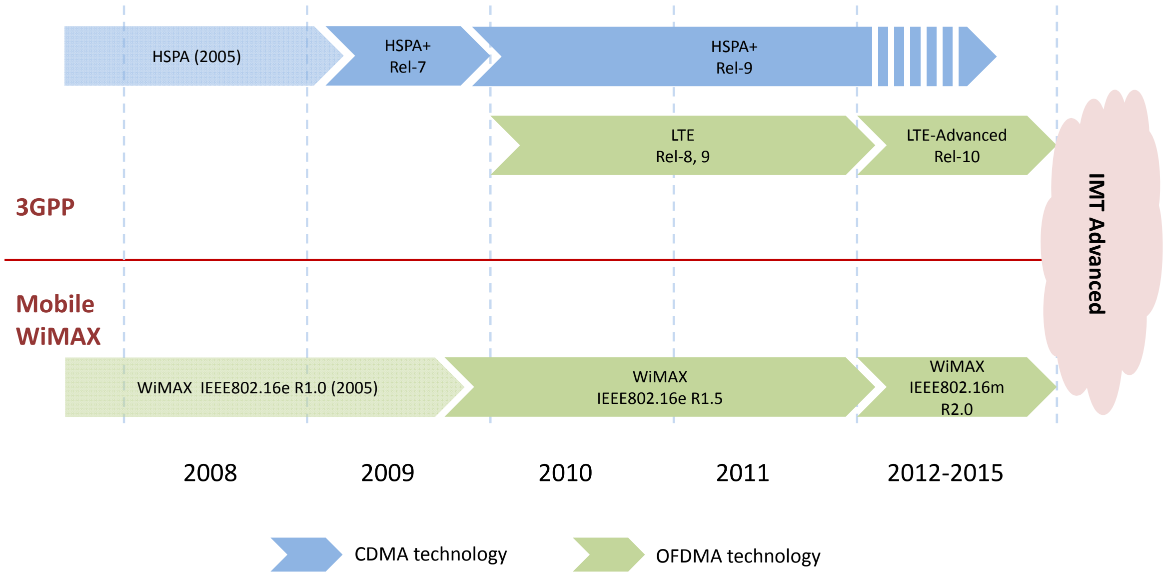

Figure A.1: Mobile WiMAX and 3GPP LTE deployment timescales [Source: Analysys Mason]

Figure A.1 shows the timescales of mobile WiMAX and LTE deployment, and illustrates that although mobile WiMAX R1.0/1.5 has a market deployment lead on LTE Rel-8, LTE-Advanced and IEEE802.16m will be deployed about the same time around 2012.

The IEEE 802.16 working group approved development of a further upgrade to IEEE 802.16m (Release 2.0) in December 2006 with the objective to meet or exceed the requirements of IMT-

Advanced. 3GPP partners also made a formal submission of LTE Release 10 (Rel-10) to the ITU in September 2009, also as a proposed candidate for IMT-Advanced.

LTE Rel-8 vs 802.16e WiMAX

Although mobile WiMAX and LTE share common technical features, there are also some differences. The table below summarises key technical features of LTE Rel-8 and WiMAX (R1.0 & R1.5).

	LTE (3GPP R8)	*WiMAX 802.16e (R1.0)*
Duplexing	FDD & TDD	TDD, FDD and TDD (R1.5)
Range of frequency bands (MHz)	**700MHz up to 2.6GHz**	2.3GHz up to 3.5GHz
Channel bandwidth (MHz)	1.25, 3, 5, 10, 15, **20**	1.25, 3.5, 5, 7, 8.75, 10
Downlink air interface	OFDMA	OFDMA
Uplink air interface	**SC-FDMA**	OFDMA
Sector throughput (10MHz)	**15.7** Mbps (2x2) [12]	14.2 Mbps (2x2)[13]
Frame size (millisecond)	**1ms**	5ms
Mobility	Up to **350** km/hr	Up to 120 km/hr
Adaptive modulation schemes	QPSK, 16-QAM, 64-QAM	**BPSK**, QPSK, 16-QAM, 64-QAM

Figure A.2: WiMAX and LTE comparison with key differences highlighted [Source: Analysys Mason 2010]

12 Motorola LTE sector throughput performance (http://business.motorola.com/experiencelte/lte-depth.html)

13 At 3:1 downlink/uplink ration. Source: “Mobile WiMAX: A Performance and Comparative Summary. Doug Gray, September 2006, WiMAX Forum & Comparing Mobile WiMAX, 3G and Beyond – A technical comparison of mobile WiMAX and 3G mobile technologies, Alvarion”

Annex B: Glossary of terms

2G	Second Generation mobile access technology
3G	Third Generation mobile access technology
3GPP	3rd Generation Partnership Project
4G	Fourth Generation mobile access technology
ADSL	Asymmetric Digital Subscriber Line
ARPU	Average Revenue Per User
AP	Asia-Pacific
AWS	Advanced Wireless Spectrum (Canadian 1700MHz band)
BPSK	Binary Phase Shift Keying
BTS	Base Transceiver Station
BWA	Broadband Wireless Access
Capex	Capital expenditure
CDMA	Code Division Multiple Access
CEE	Central and Eastern Europe
CIS	Commonwealth of Independent States
CSFB	Circuit-switched fall-back
CSV	Circuit-switched voice
DC-HSPA+	Dual carrier High-speed Packet Access Evolved
DL	Downlink
DSL	Digital Subscriber Line
EU	European Union
E-UTRA	Evolved – UMTS Terrestrial Radio Access
EV-DO	Evolution Data Optimized
FDD	Frequency Division Duplex
FTTB	Fibre-to-the-building
GAN	Generic Access Network
GHz	Gigahertz
GSM	Global System for Mobile Communications
HSPA	High-speed Packet Access
HSPA+	High-speed Packet Access Evolved
IEEE	Institute of Electrical and Electronics Engineers
ICASA	Independent Communications Authority of South Africa
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IP	Internet Protocol
IPTV	IP television
ITRB	Indonesian Telecommunication Regulatory Body
LHS	Left hand side
LTE	Long Term Evolution
M2M	Machine-to-Machine

MBB	Mobile broadband
Mbps	Million bits per second
MCMC	Malaysian Communications and Multimedia Commission
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MNO	Mobile network operator
ms	millisecond
MSC	Mobile Switching Centre
NGMN	Next Generation Mobile Network
NRA	National regulatory authority
NTC	National Telecommunications Commission (NRA in Thailand)
OFDMA	Orthogonal Frequency Division Multiple Access
Opex	Operating expenditure
PCS	Personal Communication System (Unites States)
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature phase shift keying
RHS	Right hand side
SC-FDMA	Single Carrier Frequency Division Multiple Access
SMS	Short Message Service
Subtel	Sub-Secretaria de Telecomunicaciones (NRA in Chile)
TDD	Time Division Duplex
TD-SCDMA	Time Division – Synchronous Code Division Multiple Access
TRAI	Telecom Regulatory Authority of India
UK	United Kingdom
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VoIP	Voice over Internet Protocol
VoLGA	Voice over LTE generic access
VoLTE	Voice over LTE
W-CDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless Local Area Network