A White Paper from the UMTS Forum

Mobile Broadband Evolution: the roadmap from HSPA to LTE

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Executive Summary

With subscriptions now approaching one hundred million worldwide, HSPA (High Speed Packet Access) networks are delivering on the initial 3G mobile broadband promise. The drivers for this dramatic growth in HSPA uptake, however, are not purely technological. Consumer expectations have evolved over recent years. Users have become accustomed to a new wave of services, from social networks to instant messaging. A competitive mobile environment, meanwhile, has given birth to flat-rate data tariffs that mirror fixed broadband, where uptake was stimulated by flat, affordable pricing.

In many parts of the world mobile broadband services are now available at prices and speeds comparable to fixed broadband, and mobile broadband-enabled laptops are creating sharp increases in mobile traffic.

Fixed Internet traffic is not about to migrate in volume to the spectrum-constrained mobile environment. Nonetheless, mobile data traffic may overtake mobile voice traffic as early as 2011, and much sooner in some countries. This will have a significant impact on the design, rollout and operation of future mobile networks.

Networks with greater capacity but lower costs per bit need to be deployed to handle the future demand for mobile broadband. The roadmap developed by 3GPP enables operators to do this, irrespective of their legacy network infrastructure. 3G HSPA is the first step, followed by flat network architecture options such as 3G HSPA Evolution (HSPA+) and 3G Long Term Evolution (LTE) that promise even higher throughput.

The enhanced user experience delivered by HSPA includes faster connections, video capability and low latency. As such, HSPA technology will succeed GSM as the workhorse of cellular. It is set to be the dominant mobile data technology for the rest of the decade.

HSPA is also backward compatible with WCDMA systems, allowing operators to maximise returns from their WCDMA investments. This compatibility is an important characteristic of 3GPP standards, allowing phased upgrades and a choice of evolution paths for operators.

Progress beyond HSPA continues with HSPA Evolution, or HSPA+, which leverages operator investments in HSPA, enabling lower transport costs per bit. It is also the stepping stone to an entirely new radio platform.

3G/WCDMA will remain highly competitive for several more years as a result of enhancements such as HSPA and HSPA+. However the paradigm shift from voice to data demands an entirely new approach to network design, implying flat, all-IP architectures without a circuit switched domain.

3GPP Long Term Evolution (LTE) is a wireless broadband Internet system based upon TCP/IP, the core protocol of the Internet. Co-existing with WCDMA and HSPA networks, it provides substantial performance improvements at a vastly reduced cost per bit, enabling operators to embrace new business models.

LTE is backward compatible with non-3GPP as well as 3GPP technologies. Furthermore, its ability to interwork with legacy and new networks – plus seamless integration of Internet applications – will drive convergence between fixed and mobile systems, facilitating new types of services.

LTE introduces a new radio interface plus an evolution of the 3G/UTRAN access network, designed to deliver higher data rates and fast connection times. A key attraction of LTE for mobile operators is its inherent spectral flexibility through its variable carrier bandwidth. It can be deployed in many different frequency bands with minimal changes to the radio interface.

Another hallmark of LTE is the appearance of an Evolved Packet Core (EPC) network architecture, simplifying connectivity with 3GPP and 3GPP2 technologies as well as WiFi and fixed line broadband networks.

First technical deployments of LTE are expected in the second half of 2009, for commercial service openings between 2010 and 2012. The industry ecosystem that already surrounds LTE displays very strong operator and vendor commitment to LTE.

The phased release approach of 3GPP allows operators to introduce LTE in a flexible fashion, balancing their legacy network investments, spectrum holdings and business strategies for mobile broadband. The combination of multiband terminals with backwardly compatible infrastructure is central to this flexibility, allowing operators to build out service capability in line with device and spectrum availability. The deployment of LTE co-existing with WCDMA/HSPA promises to mirror the success of the deployment of WCDMA/HSPA co-existing with GSM/EDGE.

Industry support for LTE is not limited to the 3GPP community. LTE's backward compatibility with 3GPP2 networks also raises the possibility of migration from CDMA2000 to LTE – as already signalled by several major operators in North America and Asia.

Some regions of the world do not yet have licensed spectrum for deployment of radio technologies such as WCDMA/HSPA or LTE. The natural evolution path for GSM operators in those regions is to migrate to WCDMA/HSPA, once 3G licences become available, and subsequently to migrate to LTE when warranted by user demand and business strategies.

Looking beyond LTE, new access networks with wider spectrum bandwidths will eventually be needed to support anticipated dramatic increases of mobile traffic. Currently under study within the ITU, IMT-Advanced will support peak data rates of up to 100 Mbit/s for high mobility and up to 1 Gbit/s for low mobility scenarios. 3GPP will address these requirements in an upgrade for LTE networks referred to as "LTE-Advanced".

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Table of Contents

Figures

1 Mobile Broadband Takes Off

Mobile broadband has finally arrived; in a big way. The volume of high speed mobile data traffic has increased explosively since the deployment of HSPA networks. By mid-2007 mobile broadband traffic exceeded voice traffic in some HSPA coverage areas. Just nine months later, 75% of total traffic over these networks globally was high speed mobile broadband (Figure 1).

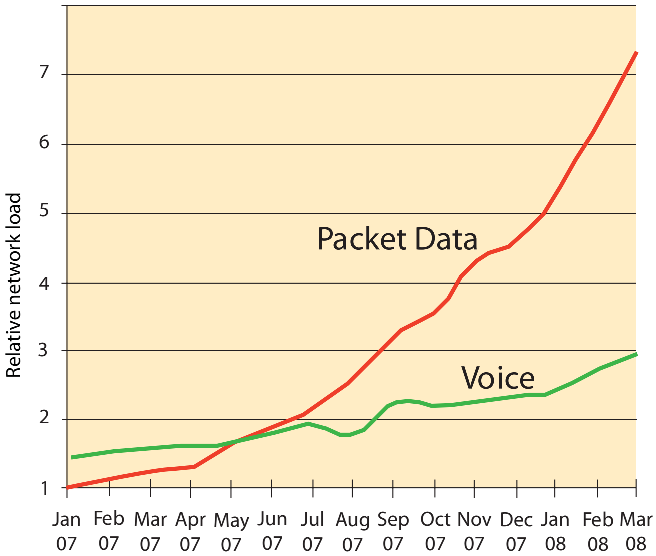


Figure 1: Growth in data traffic
Source: Ericsson

Mobile Internet access, an important component of mobile broadband, has now come of age. According to Nielsen Mobile, mobile Internet in the USA has now reached a critical mass with 40 million active users, offering a large and diverse enough base of users to support large-scale mobile marketing efforts. Some individual mobile websites now attract a reach as large as major cable networks or leading newspapers and magazines. Consumer devices, networks, data packages, content and consumer interest have come together to turn the mobile Internet into a mass medium.

HSPA networks are now delivering on the initial 3G mobile broadband promise. And the traffic volumes are already impressive. It is time to deploy a new vocabulary. Measuring IP traffic volumes in gigabytes and terabytes is no longer sufficient. Mobile data traffic globally in 2007 was some 17 petabytes per month, according to Cisco, and will rise to 65 petabytes per month during 2008.

1.1 Drivers for growth

The enhanced speeds and performance delivered by HSPA networks are not the sole cause of this dramatic growth in mobile broadband traffic. Technology by itself rarely triggers a market transition. For mobile broadband, two other factors have coincided with technology availability to create an inflection point for growth.

An innovative approach to tariffing is the second factor fuelling the current boom in mobile data. Early mobile broadband service offerings were perceived to be expensive and opaque and take-up was low. But the widespread deployment of HSPA networks within the intensely competitive mobile environment has given birth to a range of flat-rate data tariffs which have dramatically boosted mobile broadband adoption. This mirrors the experience in the fixed data services world where broadband uptake only truly took off after the introduction of flat-rate tariffs. Fixed-fee, unlimited data use is now the preferred subscription model for mobile data users.

Consumer expectations are not only the third but are also the most important factor. Unless consumers are eager to adopt mobile broadband services, the new networks and pricing regimes will have little impact. Consumer expectations and requirements for mobile broadband have evolved dramatically over recent years as users become accustomed to high speed access with fixed broadband.

The availability of broadband has had a significant impact on Internet usage in the fixed environment. Broadband users visit the Internet five times as often and consume five times as many web pages as dial-up users. Broadband users globally made 2.5 billion visits to YouTube in July 2007 compared with 19 million from dial-up users and spent over 50% more time per visit.

Today, a desktop computer without Internet access has limited value. Tomorrow, a laptop or portable notebook without mobile broadband access will seem just as incomplete.

The rapid penetration of fixed broadband in developed markets has spawned unexpected new services with a profound impact on consumer expectations – and a profound impact on network operators as the growth in traffic becomes increasingly unpredictable. Operators are accustomed to having control over new types of services coming onto their networks but, now that services are driven by web companies, it does not work that way anymore.

No-one predicted the enormous popularity of virtual worlds, geospatial services or instant messaging. Few anticipated the deployment, use and impact of social networking applications. Multiple new forms of communication have materialised as people discover and explore the benefits of social networking sites and the power of instant online communication. These developing communication 'personas' are currently trapped to fixed or tethered solutions and consumers are demanding mobility solutions that enable 'anytime anywhere' access to their communication personas.

Those demands are surfacing at just the right time. Consumers can now experience mobile broadband at data rates and prices comparable with fixed broadband. The confluence of supply and demand is driving mobile broadband into a new growth phase. Many of the broadband users expected to get online over the next few years will use wireless networks as their primary broadband access method. Mobile broadband subscribers are predicted to outnumber fixed broadband subscribers in the very near future (Figure 2).

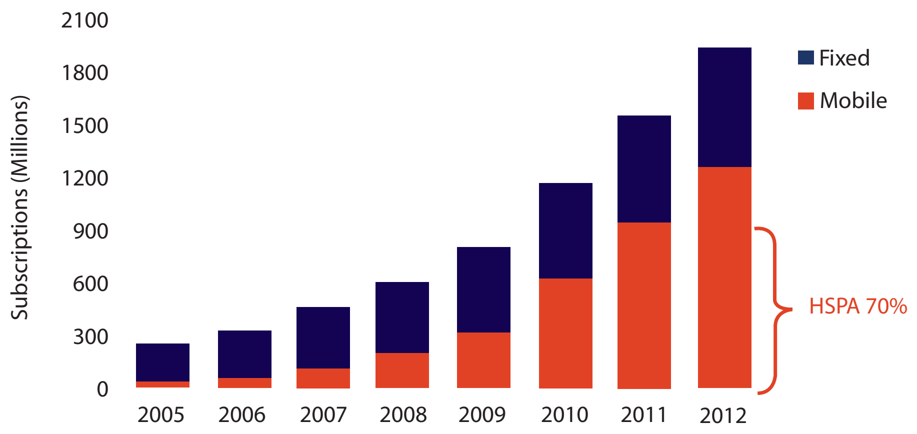


Figure 2: Broadband subscription forecast
Source: Ericsson

But subscriber numbers alone can be misleading. Fixed broadband and Internet traffic is not about to migrate in volume to the spectrum-constrained mobile environment. A single fibre optic link has greater inherent capacity than the entire available radio frequency spectrum. Mobile data will never be more than a relatively small proportion of global communications traffic.

Traffic patterns, business models and revenue sources are evolving very differently in the fixed and mobile environments. Mobile data traffic of some 65 petabytes per month may sound impressive but it is much less than 1% of global IP traffic. That proportion, however, is set to rise substantially.

Internet traffic in the USA is estimated to be between 900 and 1550 petabytes per month, up from 750 to 1250 petabytes at the end of 2008. Much of that traffic is video. If only a small proportion gets to be carried over mobile networks the impact will be considerable.

1.2 Mobile broadband substitution

In many parts of the developed world mobile broadband services are now available at prices and speeds comparable with fixed broadband, and mobile broadband-enabled laptops are creating sharp increases in mobile traffic. A mobile broadband substitution effect is becoming evident, similar to the mobile voice call substitution effect that began in the late nineties. Mobile broadband is even being seen as a substitute for fixed broadband in many parts of the developing world which lack an adequate fixed infrastructure.

Mobile substitution effects should be approached with care. Although they are often characterised as a mobile subscription taking the place of a fixed subscription the reality is that such substitutions are relatively rare. In most cases subscribers have both a fixed and a mobile subscription. In the UK 7% of adults have no mobile subscriptions and about 10% have only a mobile subscription. The vast majority, over 80%, have both fixed and mobile subscriptions. The services are complementary and the majority of traffic is carried over the fixed network, although the proportion originating on mobile is increasing with time (Figure 3). The mobile voice substitution effect refers primarily to traffic rather than subscriptions.

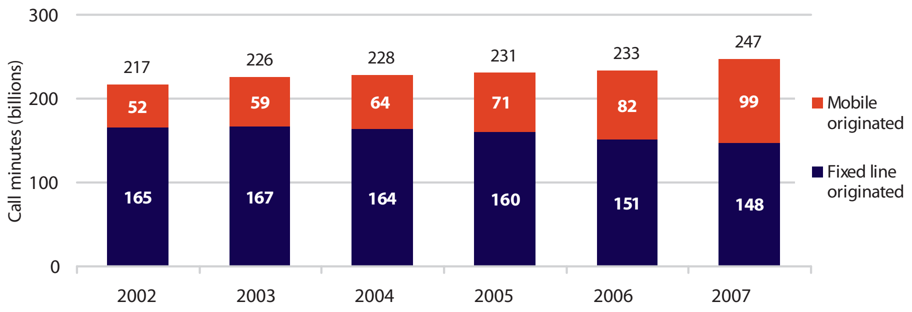


Figure 3: Fixed and mobile minutes in the UK
Source: Ofcom

Just as with voice, mobile broadband will be used instead of fixed broadband in certain circumstances, leading to a mobile broadband substitution effect. Again this refers to traffic rather than mobile broadband subscriptions replacing fixed broadband subscriptions. Indeed the distinction between fixed and mobile broadband subscriptions is becoming increasingly blurred under the impact of convergent services using picocells and femtocells.

Cisco's predictions for IP traffic (Figure 4) indicate that mobile broadband is currently less than 1% of total traffic. But broadband traffic is predicted to grow substantially over the next few years and mobile will take an increasing proportion of that traffic, although still remaining a small percentage of the total.

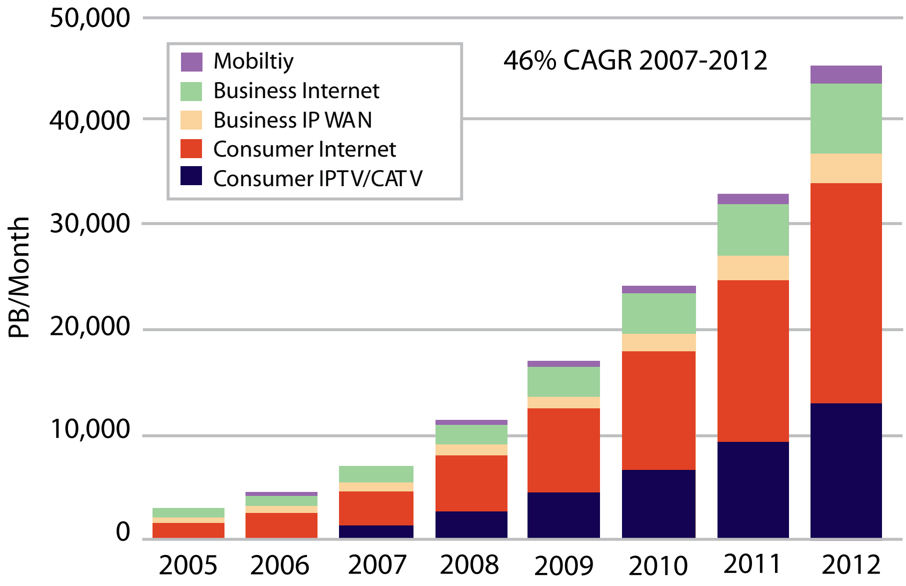


Figure 4: IP traffic forecasts
Source: Cisco Systems

Based on the mobile broadband substitution effect, Cisco is projecting very strong growth for mobile data. They predict mobile data traffic will double each year from now until 2012. Mobile data traffic in 2012 will be over twenty times what it is today.

Cisco's mobile data forecast is based on Informa's mobile broadband connections forecast, but differs in growth assumptions. Informa estimates that mobile data traffic amounts to 15 petabytes per month in 2007. Cisco's estimate is 17 petabytes per month. However, Cisco's estimate for 2012 is six times the highest forecast from Informa. But this is only high when viewed in the context of current mobile usage; it is relatively modest compared with laptop fixed-line usage. Cisco's forecast makes some aggressive assumptions regarding the potential for mobile broadband to start to act as a substitute for fixed broadband.

Informa also predicts a traffic boom driven by a dramatic increase in the use of advanced applications such as mobile browsing and video, with mobile video traffic growing more than 30-fold by 2012.

Mobile data traffic could overtake mobile voice traffic around 2011, and much sooner in come countries. This will be a significant milestone. Voice has always driven the design, rollout and operation of mobile networks. Future networks may have to take a different approach.

Growth will not stop in 2012 of course. Earlier UMTS Forum traffic forecasts – "Magic Mobile Future 2010-2020" – that predate the social networking phenomenon predicted traffic growth of more than 20-fold between 2012 and 2020, fuelled by increasing use of video.

1.3 The impact of video

In regions with high penetration of fixed broadband, bandwidth-hungry applications such as video, P2P and telepresence are all generating massive bandwidth demand. As a result, global IP traffic has more than doubled over the past two years and now exceeds 10,000 petabytes, or 10 exabytes per month. That is a lot of data. Watching 10 exabytes of video would take well over half a million years.

Consumer video is responsible for the majority of this traffic. Massive amounts of bandwidth are consumed by IP transport of video on demand, Internet video streams and downloads, and the exchange of video and other files through P2P. Video is increasingly being distributed over unicast connections, addressing individual consumers, rather than over broadcast connections, addressing a larger number of consumers simultaneously.

The Discovery Institute believes this is a manifestation of the 'Life after Television' scenario where video moves out of the broadcast mode and into the narrowcast, multicast and consumer-driven models of the Internet. Such behaviour is already apparent in the USA. According to comScore, Americans make about 10 billion searches each month to the five core search engines. But the number of videos viewed online now exceeds the total number of web search queries. During 2008 some 12 billion video streams are being consumed over the Internet each month by US Internet users. User generated content makes up almost 95% of this traffic.

Emerging video standards are set to increase IP traffic bandwidth requirements dramatically. Standard definition 2D TV, requiring a 2 Mbit/s channel, is increasingly being replaced by high-definition TV requiring 6 to 7 Mbit/s. Forty hours of high-definition video generate as much traffic as a million email messages. In time 2D HDTV will make way for 3D Super TV which will occupy Gbit/s bandwidths. The download bandwidth needed by a typical home in the developed world is projected to be in the range 20-100 Mbit/s by 2010 and will exceed a Gbit/s by 2020.

Devices are already available that allow users to set up a variety of 'always on' video connections between friends and family members. These can be displayed on wall-mounted high-definition displays, or carried as low-definition keychain-sized trinkets (with wireless access to the Internet). Such 'virtual windows' enable users to open permanent visual portals across the globe with sustained interactive connections between remote parties.

In the business sector, HD Telepresence systems now coming into use require symmetrical 15 Mbit/s connections. Just 75 hour-long telepresence calls would generate as much traffic as the entire Internet in 1990.

Even without futuristic virtual windows, global IP traffic of 10 exabytes per month will grow to just under 44 exabytes per month in 2012, according to Cisco's global IP traffic forecast. The annual run rate of traffic in late 2012 will be 522 exabytes per year – double today's available storage capacity on all the hard drives, tapes, CDs, DVDs and memory across the entire world. Annual global IP traffic will exceed half a zettabyte in four years. The fixed broadband world has its own vocabulary.

The vast bulk of this traffic will remain on fixed broadband networks. But the popularity of 'follow me' services in ultra-broadband networks indicates that some video traffic is liable to be time-shifted or place-shifted onto mobile. Fixed mobile convergence and quadruple play offerings will accelerate this trend.

New models and cultures are also rapidly coming into play. Consumers now produce as well as consume. They have production capabilities that encourage collaborative approaches. Creating user-generated content has become popular among younger generations, who share personal information and media, such as photos, videos and blogs through websites such as Facebook, MySpace, YouTube and QQ.

The success of such sites highlights the emerging social aspects of video. Entertainment is no longer the primary purpose of video. Video not only delivers information and provides entertainment but also now serves as a platform for social interaction and as a means of expression. **Video is becoming an integral part of communication services** – already 25% of Skype traffic contains a video component. One way or another, video is going to have an increasing impact in the mobile broadband environment.

1.4 The data challenge

Video consumes huge amounts of bandwidth. But consumer willingness to pay for a video service is not correlated with the bandwidth consumed by that service. In the data dominated world, unlike the voice dominated world, increased traffic does not result in proportionate increased revenue.

In the data dominated world, the value to end-users of applications is not proportional to data volumes. Revenues and traffic have become decoupled (Figure 5). Many operators are experiencing a 10-fold increase in data traffic but more like a 10% increase in data revenue.

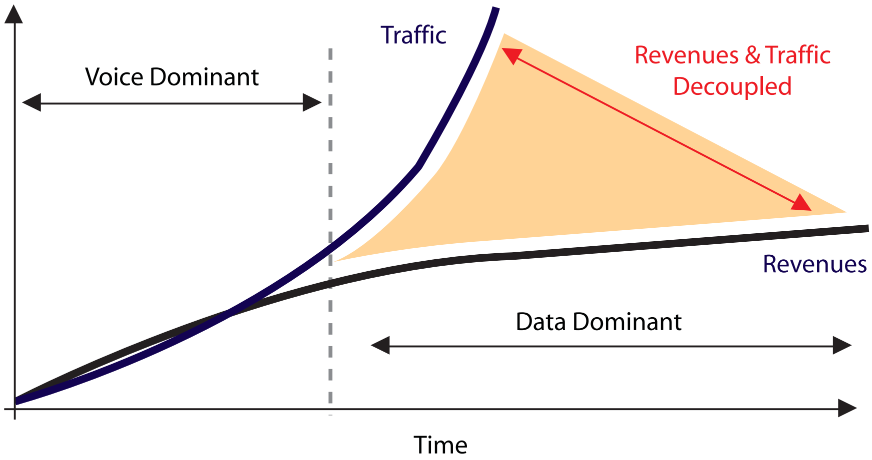


Figure 5: The traffic and revenue challenge
Source: Unstrung

The success of mobile voice networks on a large scale does not automatically guarantee a similar victory for data services. Data and voice do not scale in the same way. Data is non-deterministic and uses a connectionless medium (IP) over which packets belonging to a single session can traverse several paths. Mobile data faces challenges of scale that need to be handled within the Radio Access Network (RAN) and the backhaul networks.

These are complex challenges. Meeting them by distribution of resources across the network alters the processing hierarchy and may compromise latency objectives. But effective scaling of services based on packet transport is essential as many events can create massive localised surges in demand.

Massive increases in data traffic can stress the existing radio access network and backhaul infrastructure. One suggested solution is to optimise the network to support the dominant traffic type, moving from voice-driven to data-driven architectures (Figure 6).

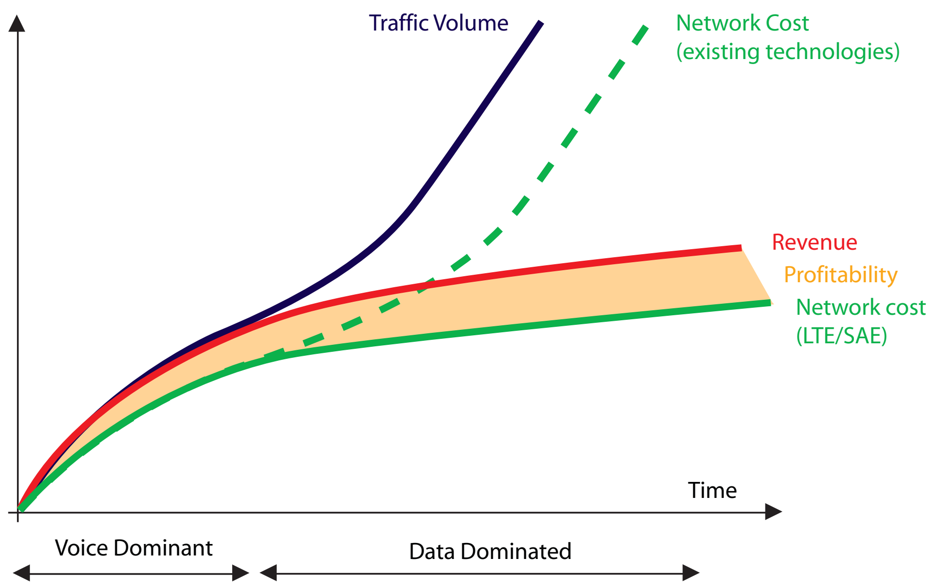


Figure 6: The cost per bit must be reduced for operators to remain profitable
Source: Nokia Siemens Networks

Networks with greater capacity but lower costs per bit need to be deployed to handle the future demand for mobile broadband. The roadmap developed by 3GPP enables operators to do just that – irrespective of their legacy network infrastructure. 3G HSPA is the first step, followed by flat network architecture options such as 3G HSPA Evolution (HSPA+) and 3G Long Term Evolution (LTE) that promise even higher throughput.

These network evolution options provide a toolkit that will allow operators to satisfy the demand for mobile broadband and more than compensate for the decline in voice and messaging revenues (Figure 7).

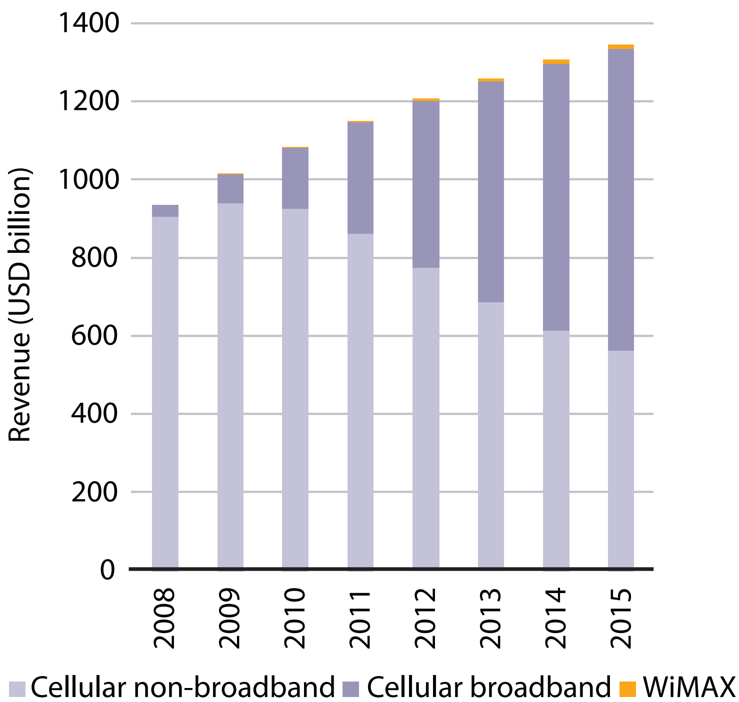


Figure 7: Wireless service revenue worldwide, 2008–2015
Source: Analysys Mason, 2008

2 The 3G+/HSPA Phenomenon

High Speed Packet Access (HSPA) is designed to enhance data service in WCDMA networks. HSPA networks deliver throughputs in the region of 1 Mbit/s, providing mobile subscribers with an experience similar to that of DSL or cable modems.

HSPA networks are being implemented in phases. The initial High Speed Downlink Packet Access (HSDPA) networks increased peak data rates on the downlink to 1.8 Mbit/s. Subsequent deployments are seeing these peak rates increase towards a theoretical maximum of 14.4 Mbit/s. On average, the peak throughputs of HSDPA networks are doubling every year.

2.1 High rates of adoption

The pace of introduction of HSDPA networks has been phenomenal. It took four years for the first 100 networks to deploy Release 99 3G. With HSDPA this milestone was reached in just over a year (Figure 8).

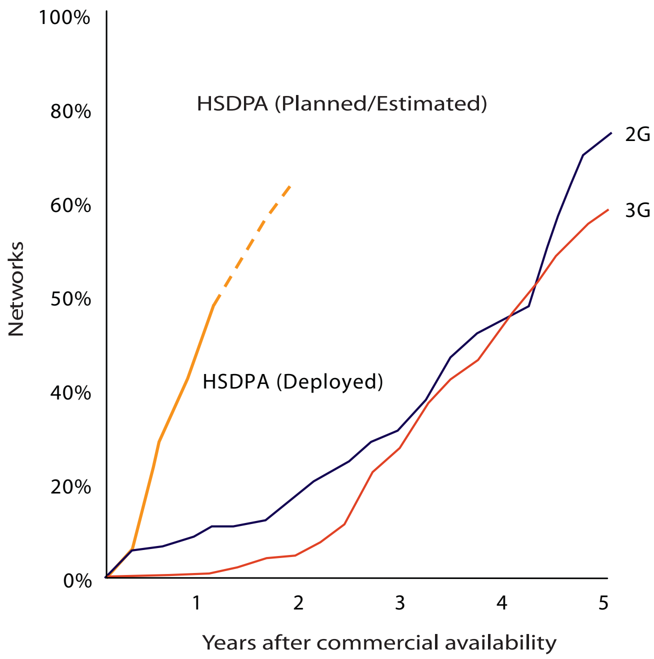


Figure 8: 3G+/HSDPA networks deployed three years quicker than 2G & 3G
Source: Booz and Company

End November 2008 saw around 230 commercial HSDPA operators in 100 countries. A further 30 networks are in the process of deployment. So far 55 operators have deployed High Speed Uplink Packet Access (HSUPA) to increase peak data rates on the uplink from 0.4 to 1.4 Mbit/s. Subsequent enhancements could increase these peak rates to 5.8 Mbit/s.

As with most network upgrades, HSDPA implementation mainly occurs in a hotspot-like fashion. Initial deployments in areas of high subscriber density are followed by extensions of coverage as the demand for mobile broadband expands.

Even though few HSDPA networks have national coverage yet, the number of worldwide subscribers using HSPA (the generic term for HSDPA and HSUPA) networks now exceeds 70 million. Uptake is accelerating with HSPA connections swelling by some four million every month (Figure 9).

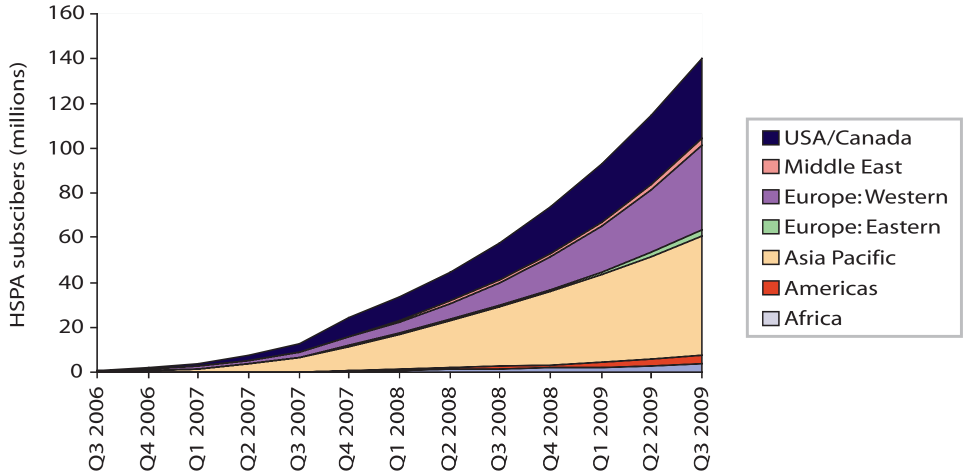


Figure 9: HSPA subscriber numbers
Source: Wireless Intelligence

This subscriber growth, coupled with flat rate mobile data tariffs comparable with fixed line broadband pricing, is driving an explosive increase of data traffic. HSPA networks help operators to manage such traffic growth through lower transport costs. The access cost per megabyte with basic WCDMA is Euro 0.06, according to modelling studies of a 10,000 base station network deployment made by Analysys Research for the UMTS Forum. With HSPA this halves to Euro 0.03 per megabyte.

Current mobile data usage on HSPA networks is primarily through laptops, using data cards, USB modems or embedded modules. As the penetration of HSDPA handsets increases, traffic growth could accelerate even further, driven by consumer video consumption.

The penetration of HSDPA handsets is predicted to increase very rapidly indeed. Just over three years after their introduction, the rate of HSDPA handset shipments will exceed that of all CDMA handsets worldwide (Figure 10).

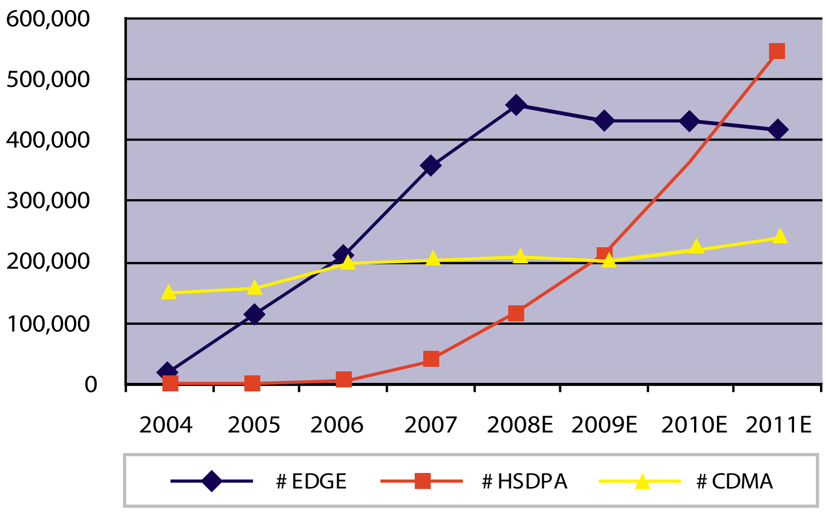


Figure 10: Handset shipments by technology
Source: Deutsche Bank

The enhanced user experience delivered by HSPA includes faster connections, video capability and low delays when web browsing or downloading emails with large attachments. Business users get DSL grade of access to the corporate intranet and Internet. HSPA in a laptop is like desktop performance gone mobile. Consumers get the ability to download content without painful delays and improved uplink speeds that address the growing interest in user-generated content.

HSPA technology will succeed GSM as the workhorse of cellular. It is set to be the dominant mobile data technology for the rest of the decade.

2.2 The HSPA upgrade

GSM networks have almost universally upgraded to Enhanced Data Rates for GSM Evolution (EDGE) which improves spectral efficiency through adaptive modulation and coding techniques. Upgrading 3G/WCDMA networks to 3G+/HSPA is an analogous improvement, again taking advantage of technology developments to make the most efficient use of shared resources.

HSPA is backward compatible with WCDMA systems. For most vendors' implementations, HSPA is essentially a software upgrade over the existing WCDMA networks. Operators do not have to scrap existing infrastructure but can upgrade cell sites in the network as and when demand dictates. Utilisation of existing networks is a material benefit for operators, enabling them to maximise the returns from sunk costs of WCDMA investments that exceed US$500 billion globally. The flexibility presented by such backward compatibility is an important characteristic of 3GPP standards, allowing phased upgrades and a choice of evolution paths for operators.

A primary motivation behind HSPA is to reduce the cost of transporting packet-based multimedia over existing WCDMA mobile cellular infrastructure. Reductions in the cost per bit are achieved through enhancements to the spectral efficiency and data carrying capacity in both the downlink and the uplink.

In WCDMA, data is carried over dedicated transport channels code multiplexed onto an RF carrier. WCDMA is essentially a static system in which a user occupies a channel at a constant data rate. Individual users can hog capacity, reducing overall cell throughput. The system is designed to deliver maximum performance with continuous data streams.

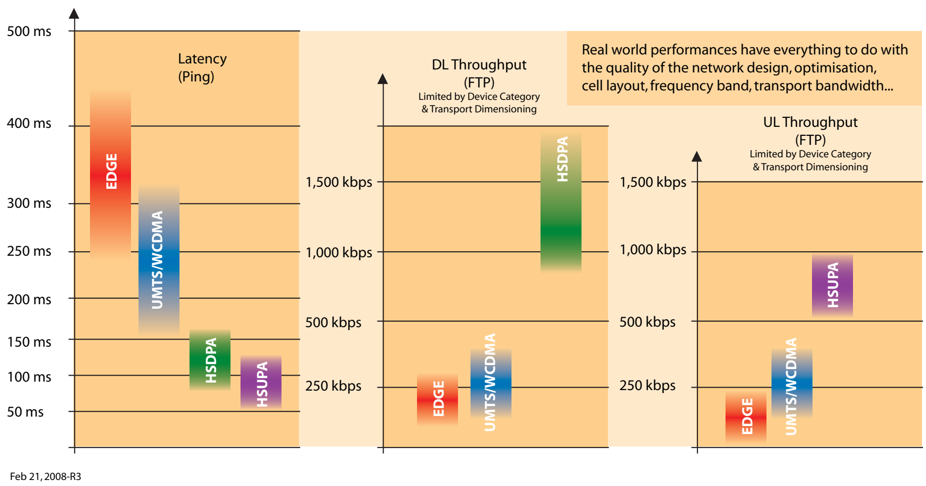
Most data traffic, however, comes in bursts. HSDPA is designed to handle bursty packet data at high bit rates. Deploying a new transport channel shared between several users, HSDPA dynamically changes the bandwidth allocated to individual users according to the local radio conditions. Several users can be time multiplexed to ensure an efficient use of resources.

In HSDPA the modulation scheme and coding is also adjusted dynamically according to the quality of the radio link. Adaptive modulation and coding techniques ensure the highest possible data rate is achieved not only for users close to the base station with good signal quality but also for distant users at the cell edge.

Reallocation of resources is also efficient. In HSPA decisions on the transmission of data packets are made in the base station, close to the air interface, rather than deeper in the network. This results in fast scheduling, allowing resources to be reallocated dynamically to enable differential user and service levels. It really is fast – resources can be redistributed every five hundredth of a second.

Moving decisions to the base station to improve response times also allows fast retransmission of data packets when interference causes link errors.

HSPA promises significantly improved data throughput capacity, reduced latency, and an increase in the number of users that can be supported at high data rates on a single radio carrier. These promises are already being observed in practice (Figure 11).



Data for initial HSPA implementations (2007) under typical load conditions; devices limited to 3.6 Mbit/s in DL and 1.5 Mbit/s in UL.

Figure 11: HSPA observed performances
Source: Tom Keathley and Alain Ohana (AT&T)//3G Americas: HSPA LTE Workshop, February 2008

2.3 HSPA Evolution

The evolutionary approach to standardisation adopted by 3GPP produces regular enhancements to standards driven by improvements in underlying technologies. Most importantly, consecutive releases of 3GPP standards are always backward compatible with previous releases. This allows handovers to be enabled between the different releases, providing continuity of service and allowing operators to take a phased approach to network deployments.

A typical upgrade strategy for an operator is to upgrade the network to the next release progressively so that for a significant period both standards are in operation. This approach allowed WCDMA to leverage the Opex and Capex investment in GSM while evolving into the IP world. Network upgrades could be matched to user demand enabling operators to take full advantage of their existing investments.

HSPA is also currently being deployed in stages, initially increasing throughput and capacity and reducing latency in urban areas while using EDGE for service continuity elsewhere in the network. HSPA coverage is subsequently extended across the network at a rate determined by the operator's business model, legacy investments and user demand.

The evolutionary process is continuing with HSPA Evolution, or HSPA+, which further enhances the end-user experience through higher peak rates, lower latency, greater capacity, increased battery times, improved support for VoIP and multicast services, and a true 'always-on' experience. HSPA+ enhances the capacity for non-real-time traffic as well as real-time services.

HSPA+ supports higher order modulation schemes that enable users to experience significantly higher data rates under favourable radio propagation conditions. It also introduces MIMO (Multiple Input, Multiple Output) capabilities to increase peak data rates and spectral efficiency.

MIMO is an antenna technology that uses advanced signal processing techniques to increase capacity in a radio link; it employs multiple transmit and receive channels and antennas with different data streams sent over each antenna. In HSPA+, MIMO transmits multiple data streams in parallel to a single terminal. The data streams travel across different communications paths and can be separated by the receiver through appropriate decoding. This can result in a significant gain in throughput.

With MIMO technologies and higher order modulation, HSPA+ will eventually be capable of delivering 42 Mbit/s peak bit rate in the downlink and 11 Mbit/s in the uplink over a 5 MHz channel.

Continuous Packet Connectivity (CPC) enhancements in HSPA+ improve reaction times after idle states in which no data is being transferred. They do this in an intelligent way through discontinuous transmission and discontinuous reception features that minimise power consumption and radio layer signalling. As wake-from-idle times can take about a second, avoiding numerous transitions from idle to active states is necessary to deliver a true always-on connection experience. CPC is the key to this, allowing users to stay longer in connected mode without compromising battery life. Minimising power consumption in these situations produces significant battery life improvements, extending talk time by up to 50%. HSPA+ could provide almost three times the VoIP capacity of current HSPA networks (Figure 12).

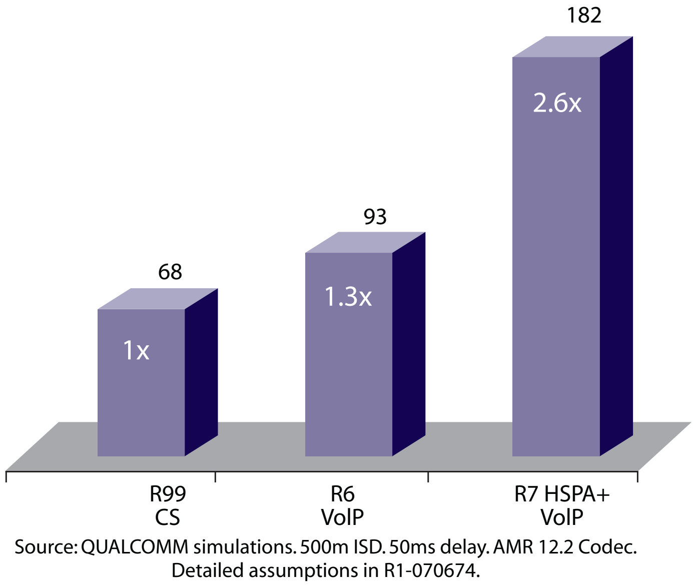


Figure 12: Voice capacity per sector (5 MHz)
Source: Qualcomm

HSPA+ introduces an optional all-IP flat architecture that reduces latency to around 10 ms compared with 60 ms for HSPA and provides backhaul based on IP/MPLS transport. The flat architecture essentially makes the base stations into IP routers that connect to the network via standard gigabit Ethernet connected to the Internet. It eliminates the need for a Radio Network Controller (RNC) for data traffic and decreases very significantly the load on the Serving GPRS Support Node (SGSN), resulting in a significant reduction of the cost per bit.

HSPA+ continues to evolve, and future combinations of multicarrier techniques and MIMO technologies could in principle achieve 84 Mbit/s peak on the downlink and 23 Mbit/s peak uplink. These rates could only be achieved by operators with access to multiple adjacent paired 5 MHz bands. They are the highest data rates that could be achieved in existing 3G networks based on 5 MHz WCDMA technology. Further improvements can only come with a new mobile network technology.

HSPA+ is a logical development of the 3G/WCDMA approach, leveraging operator investments in HSPA and enabling a lower cost per bit. It is also the stepping stone to an entirely new radio platform called 3GPP Long Term Evolution (LTE).

3 The LTE Roadmap

3G/WCDMA will remain highly competitive for several more years as a result of enhancements such as HSPA and HSPA+. But the volume of data traffic will grow significantly over the next decade. By 2015, according to Cisco's estimates, there could be 100 times more mobile data traffic than there is today. Even the most conservative forecasts are predicting a tenfold increase.

This shift from voice to data is significant in a number of ways. Data services demand significantly more network resources than traditional voice services, so increases in data capacity will have to be accompanied by a lower cost of data delivery. Operators will have to deploy spectrally efficient data technologies that dramatically reduce the cost per bit. These technologies will have to be significantly more efficient to make their deployment cost effective. The implementation of a new technology creates extra costs in adapting information systems, revising operational procedures, and ensuring interworking with legacy networks.

Even more fundamentally, the shift from voice to data demands an entirely new approach to network design. Future networks will no longer be designed for voice. Next generation networks designed for data will be all-IP, with flat architectures and without a circuit switched domain.

Voice networks are essentially dimensioned to accommodate peak busy hour traffic but this would be an unaffordable luxury in the data world. Next generation networks will have to be dynamic and self-optimising, adapting to changes in demand and user behaviour. Network complexity will have to be reduced, removing duplication and simplifying operational and management systems. Features such as plug-and-play and self-configuration will be required to simplify and reduce the cost of network rollout and management. Next generation networks will have open interfaces, be operationally efficient and highly automated with distributed control.

No single factor can deliver all these promises. Next generation networks will involve performance improvements and new approaches to the air interface, the radio access network and the core network, reducing network hierarchy and eliminating bottlenecks. And, of course, they will need to be backward compatible with previous generations.

3.1 The approach to LTE

LTE is a wireless broadband Internet system. It is an all-IP network based upon TCP/IP, the core protocol of the Internet, with higher level services such as voice, video and messaging, built on top.

LTE delivers in two dimensions. It is designed not only to provide substantial performance improvements but also to vastly reduce the cost per bit, enabling operators to embrace new business models.

LTE is backward compatible with non-3GPP as well as 3GPP technologies. Its ability to interwork with legacy and new networks, and its seamless integration of Internet applications will drive the convergence between fixed and mobile systems and facilitate new types of services. LTE heralds a new era with the transition from circuit switched approaches for voice traffic to a fully packet switched model.

This transition from existing networks that combine circuit and packet switching to all-IP requires considerable simplification of the system architecture. Such an

Evolved Packet Core (EPC) (previously called System Architecture Evolution (SAE)) focuses on a flat architecture that provides for seamless integration with IP-based communications networks.

Automation of network processes through the adoption of self-organising network (SON) principles is a key feature of LTE. SONs contain equipments that can sense their surroundings and have sufficient intelligence to configure themselves and synchronise with surrounding networks on an ongoing basis. Self-configuring techniques will ease the deployment of small cell networks by eliminating manual configuration of equipment at the time of deployment. Self-optimising techniques will enable operational cost reductions by dynamically optimising radio network performance during operation.

3.2 LTE technology

LTE contains a new radio interface and access network designed to deliver higher data rates (up to peak rates of 75 Mbit/s on the uplink and 300 Mbit/s on the downlink) and fast connection times. The technology solution chosen by 3GPP for the LTE air interface uses Orthogonal Frequency Division Multiplexing (OFDM) and MIMO technologies, together with high rate modulation.

LTE uses the same principles as HSPA for scheduling of shared channel data and fast link adaptation, enabling the network to optimise cell performance dynamically. In fact LTE is based entirely on shared and broadcast channels and contains no dedicated channels carrying data to specific users. This increases the efficiency of the air interface as the network no longer has to assign fixed levels of resource to each user but can allocate air interface resources according to real-time demand.

LTE will co-exist with the WCDMA and HSPA networks that will also continue to evolve within 3GPP.

3.2.1 OFDMA

An OFDM-based approach to a completely new air interface was a radical step for 3GPP. An evolutionary approach based on further enhancement to WCDMA could, in principle, have met the performance goals. In practice, however, the high levels of power consumption and the processing capability required would have made the resulting technology unsuitable for handheld mobile devices. OFDM-based technologies can achieve the targeted high data rates with simpler implementations involving relatively low cost and power-efficient hardware.

Data rates in WCDMA networks are constrained by the 5 MHz channel width. LTE overcomes these limitations by deploying in bandwidths up to 20 MHz. At bandwidths below 10 MHz, HSPA+ and LTE provide similar performance for the same number of antennas. Use of a wider RF band such as 20 MHz leads to group delay problems in WCDMA that limit the achievable data rate. LTE removes these limitations by deploying OFDM technology to split the 20 MHz channel into many narrow sub-channels. Each narrow sub-channel is driven to its maximum and the sub-channels subsequently combined to generate the total data throughput.

Assigning different sub-channels to different users results in Orthogonal Frequency Division Multiple Access (OFDMA) systems. OFDMA avoids problems caused by multipath reflections by sending message bits slowly enough so that any delayed copies (reflections) are late by only a small fraction of a bit time. Thousands of narrow sub-channels are deployed to send many low speed messages simultaneously that are then combined at the receiver to make up one high speed message. This avoids the distortion caused by multipath while maintaining a high bit rate.

The narrow sub-channels in OFDMA are allocated on a burst by burst basis using algorithms that take account of RF environmental factors such as channel quality, loading and interference. Resistance to interference is determined by the orthogonal nature of OFDM in which the null of a carrier phase response is mapped to be exactly on the peak of the adjacent carrier. Good phase noise performance is therefore vital to prevent leakage across carriers.

LTE uses OFDMA in the downlink but Single Carrier – Frequency Division Multiple Access (SC-FDMA) in the uplink. SC-FDMA is technically similar to OFDMA but is better suited for handheld devices because it is less demanding on battery power.

3.2.2 MIMO

LTE uses MIMO techniques to send data over separate signal paths that occupy the same RF bandwidth at the same time, leading to significant increases in achievable data rates and throughput. MIMO antenna systems are a magic ingredient in the quest for broadband wireless systems with higher capacity, performance and reliability. They provide a mechanism for bypassing the constraints imposed by Shannon's Law.

Shannon's Law states that there is a fundamental limit to the amount of information that can be transmitted over a communications link. The volume of error-free data that can be transmitted over a channel of any given bandwidth is limited by noise. Without noise, an infinite amount of information could be transmitted over a finite amount of spectrum. But, in reality, throughput is limited because power is needed from the transmitter to overcome any noise in the channel.

Cellular networks are inherently noisy environments prone to interference from other users and from neighbouring cell sites. Interference cancellation techniques have produced spectacular gains in spectral efficiency but they cannot nullify the effects of thermal noise. There is always a degree of thermal background noise in any system with a temperature above absolute zero.

Today's technologies are approaching the ceiling imposed by Shannon's Law at which any further capacity gains are essentially cancelled out by noise. All technologies are approaching the theoretical limit for spectral efficiency as they all use techniques such as efficient schedulers, higher order modulation, and adaptive modulation and coding to achieve roughly the same performance. Further gains in throughput and data rates will have to come from techniques enabling the use of higher bandwidths rather than from attempts to squeeze more bit rate into a channel.

Shannon's Law applies to a single radio link between a transmitter and a receiver. But MIMO techniques create multiple radio links; each individual link is limited by Shannon's Law but, collectively, they can exceed it.

3.3 Spectrum flexibility

MIMO is a good example of current technology trends. The focus is now on creating more usable frequencies instead of attempts to increase spectral efficiency. Receive diversity technologies such as MIMO can do this by sending the same information from two or more separate transmitters to an equal number of receivers, cutting down on the information loss of a single transmission. Beam forming technologies are another approach, reducing interference by steering radio links towards a specific user.

OFDMA is a third approach that relies on increasing flexibility in the use of spectrum. By splitting a channel into thousands of very narrow sub-channels, each on a different frequency, each carrying a part of the signal, OFDMA provides a mechanism for transmitting over bigger chunks of spectrum, avoiding the limits imposed by the small channel widths in CDMA technologies.

Increasing flexibility in the use of spectrum has been by far the biggest factor driving the increase in capacity in cellular systems that we have seen over the last 45 years. During this time the number of radio frequency conversations which can be conducted concurrently in a given physical area has doubled every 30 months – an observation known as Cooper's Law – which has resulted in a one-million-fold overall increase in capacity.

Topology based architectures featuring small cells serving few users (picocells and femtocells) are a natural extension of this trend and are particularly suited to multimedia data services which are predominantly used in indoor environments. Picocells and femtocells are yet another mechanism for defeating the absolute limits imposed by Shannon's Law.

Flexibility in the use of spectrum is a major feature of LTE technology which is not only resistant to interference between cells but also spreads transmission efficiently over the available spectrum. The net result is an order of magnitude increase in the number of users per cell compared with WCDMA.

LTE is designed to be capable of deployment in many different frequency bands with minimal changes to the radio interface. It can also be deployed in 1.4, 1.6, 3, 3.2, 5, 10, 15 and 20 MHz bandwidths. Operators are therefore able to refarm existing GSM or CDMA spectrum for LTE deployments and can continue to expand in those bands as more spectrum becomes available. Operators can also make the most of the capacity offered by newly available spectrum bands at 2.3, 2.5 and 3.4 GHz by deploying LTE over 10 MHz or 20 MHz carriers and can benefit from the superior coverage and in-building penetration of the UHF bands by deploying LTE in spectrum made available through the digital dividend.

Flexible spectrum usage is supported even further through FDD/TDD harmonisation in LTE where there is a clear convergence between paired spectrum and unpaired spectrum solutions. The specifications for handover procedures and parameters such as frame and slot structures facilitate coexistence with other operators on adjacent channels and with overlapping or adjacent spectrum at country borders.

The technology convergence represented by FDD/TDD harmonisation reduces the complexity of standardisation, ensuring better support for global roaming and delivering future economies of scale.

3.4 EPC technology

Evolved Packet Core is a simplified network architecture designed for seamless integration with IP-based communications networks. It is solely packet based. The main option is to handle circuit and multimedia calls through the converged IMS Core. An alternative – under study in 3GPP for LTE Release 9 – will be to handle circuit switched calls through the legacy MSC and a mediation function. EPC delivers an all-IP network that allows for connectivity and handover to other access technologies, including all 3GPP and 3GPP2 technologies as well as WiFi and fixed line broadband such as DSL and GPON.

The E-UTRAN network is considerably simpler than previous 3GPP networks (Figure 13). All IP packet processing issues are managed at the core (EPC) site, allowing faster response times for scheduling and re-transmission and so improving latency and throughput. The RNC has been completely removed and most of the RNC functionalities moved to the eNodeB which is connected directly to the evolved packet core.

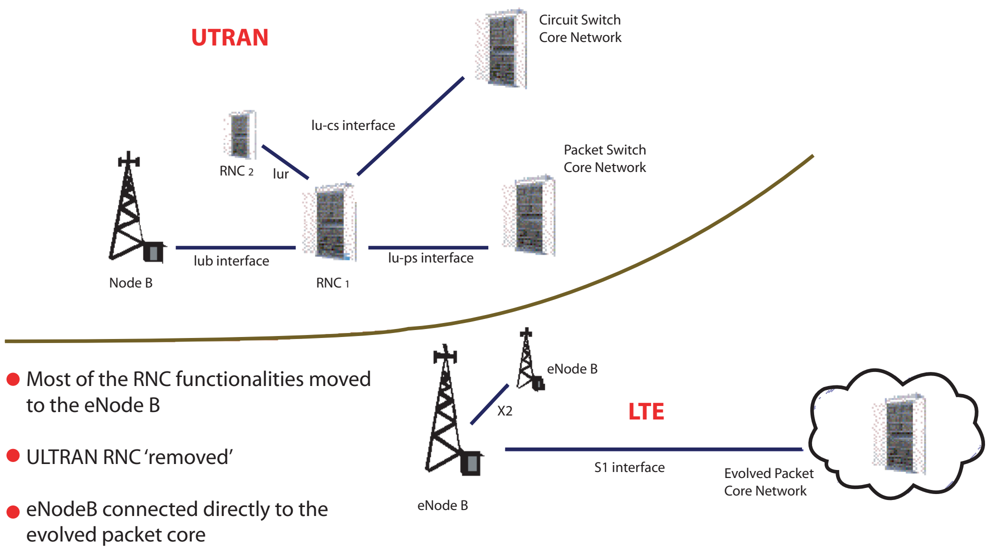


Figure 13: LTE simplified architecture
Source: 3GPP

The evolved packet core has specific functions built in that allow direct connection and extension to other wireless networks. Operators can manage critical functions such as mobility, handover, billing, authentication and security within the mobile network whilst extending the network to other IP-based access technologies.

IP protocols were developed in wired networks where the data link endpoints and associated capacity (bandwidth) are usually static. Traffic flow problems in fixed networks arise when links are overloaded or broken. Overloads can be managed by controlling traffic volumes; limiting the number of users connected to a hub and the bandwidth they are offered.

It is more difficult with wireless. In a wireless link, particularly a fast adaptive link such as LTE, capacity is a function of time-dependent environmental factors such as RF path loss and distance from the base station. Capacity also varies with cell loading, a parameter outside an operator's control as the number of users in a cell can also vary with time.

Wireless systems require dynamic IP routing, flow control and end-to-end Quality of Service (QoS) provisioning mechanisms that can adapt to varying bandwidth. This is a non-trivial issue as the variations can not only be fast (RF fading happens in less than a second) but can also be variable (the level of RF loss can vary 20-30dB in a few seconds), causing data rates to vary from 100 kbit/s to 10 Mbit/s in less than a second. Other variations are also unpredictable as they depend on the behaviour of users in the cell.

LTE uses retransmission technology in the eNodeB to manage the rapidly varying data rates. This requires buffering and flow control mechanisms into the eNodeB from the core network to prevent data overflow or loss when there are sudden signal fades that trigger a high degree of retransmission.

Flatter networks such as EPC increase performance as packets no longer need to be processed by multiple nodes in the network. The trade-off is a less hierarchical structure which makes central management more complex.

3.4.1 The role of IMS

A major motivation for LTE/EPC is to support Next Generation Network (NGN) philosophies and Fixed Mobile Convergence (FMC) business models. Moving mobile networks to all-IP enables effective convergence scenarios involving mixed technology deployments. Combined with the IP Multimedia Subsystem (IMS), this greatly simplifies management and maintenance requirements.

Changing access technologies today – from WLAN access to an HSPA data card for example – can require full connection, registration and authentication on each access network followed by manual intervention to switch from one to the other. Even when the mobile device supports both access technologies, the data flow cannot be handed over seamlessly without the user being aware of the change.

The solution is to connect 3GPP and non-3GPP mobile networks to the core network through IMS. IMS allows seamless handover between multiple access technologies and provides the necessary mobility and routing management. The core network sees the mobile network as another IP network and does not need to manage mobility, authentication or security control as the user changes access technology.

IMS uses the Session Initiation Protocol (SIP) to allow fast connection between mobile devices and the core network. Initial setup of data sessions in traditional wireless networks can take between one and 15 seconds compared with milliseconds in a fixed network.

The marriage of LTE with IMS will provide operators with a cost effective network that allows integration with the core network for customer care, billing and network management. It will provide mobile users with an always connected high speed experience – truly untethering the desktop.

3.5 Current status

LTE and EPC form the basis of 3GPP Release 8 which was functionally frozen in December 2008. However, for some time now the standard has been complete enough for hardware designers to produce chipsets, test equipment and base stations.

LTE test equipment has been shipping from several vendors since early 2008 and LTE chipsets were on show at the Mobile World Congress in February 2008. Downlink data rates exceeding 100 Mbit/s have already been demonstrated with baseline LTE devices and prototype systems using 4x4 MIMO antennas have achieved rates above 300 Mbit/s in laboratory conditions. Early latency results are also encouraging with measured roundtrip delays less than 10 milliseconds. The first deployments of LTE are expected in the second half of 2009 for a commercial service opening in 2010.

The degree of industrial support for LTE is evidenced by the attendance at 3GPP specification groups and the volume of contributions within those groups which have both reached unprecedented levels. The intellectual input to the development of LTE is truly enormous.

This is significant because, to be successful globally, a technology not only has to deliver competitive performance but also has to become the kernel of a vibrant and widespread ecosystem worldwide. Such an ecosystem engenders economies of scale in which substantial production volumes drive down manufacturing costs which in turn boosts sales income. This positive feedback allows unrivalled investment in research and development that ensures continuing competitive advantage.

The development of a global LTE ecosystem is evidenced by the LTE SAE Trial Initiative (LSTI), a global group of 21 LTE equipment vendors and eight operators who are planning phased interoperability tests to ensure the availability of a wide range of LTE devices that will function consistently on all LTE networks worldwide.

The healthy industry ecosystem that already surrounds LTE displays very strong operator and vendor commitment to LTE, not only from key members of the 3GPP community but also from prominent players currently deploying 3GPP2-based technologies. There is gathering momentum behind an evolutionary roadmap that positions LTE/EPC (previously called LTE/SAE) as a converged standard for all mobile operators, including operators with TDD spectrum allocations as well as those with FDD systems based on either 3GPP or 3GPP2 standards.

LTE supports both paired and unpaired spectrum allocations so LTE terminals can be built to handle both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) operation. A common set of features for LTE FDD and TDD equipment is currently being defined to enable early cross-vendor interoperability tests between devices and infrastructure. Such tests will avoid situations that plagued some previous standard releases where commercial availability of devices lagged behind the deployment of infrastructure by several months.

The advantages of the LTE approach have been recognised by a recent decision of the Next Generation Mobile Networks (NGMN) Alliance. NGMN is an initiative by a group of major mobile operators to establish performance targets, recommendations and deployment scenarios for a future wide area mobile broadband network. The NGMN Alliance concluded in June 2008, based on the results of technology evaluations, that LTE/EPC is the first technology which broadly meets NGMN recommendations.

3.6 LTE benefits

LTE can be seen as the next step in the evolution of the GSM/UMTS cellular family. It is a major step. LTE is designed to deliver a range of services focused on data and a user experience comparable with that of a PC user in a fixed broadband environment.

Technical benefits for operators include flexible spectrum usage and fewer types of functional elements (nodes). Economic benefits include increased spectrum efficiency and backhaul, based on IP/MPLS (Internet Protocol/ Multi Protocol Label Switching), that is optimised compared with current HSPA networks.

The all-IP nature of LTE means converged services will become a reality. LTE will coexist with other next generation access technologies, and end-users will be able to roam from fixed to mobile networks with no disruption in service.

But the bottom line advantage of LTE is that it can deliver the massive capacity required by the shift to data and video at a much reduced cost. For a typical deployment of 10,000 base stations, Analysys Mason estimate in their recent report to the UMTS Forum – "Global Mobile Broadband: Market potential for 3G LTE" – the downlink capacity of an LTE network to be 4000 terabytes per month for a 2x10 MHz deployment, an order of magnitude greater than the capabilities of HSPA networks (Figure 14).

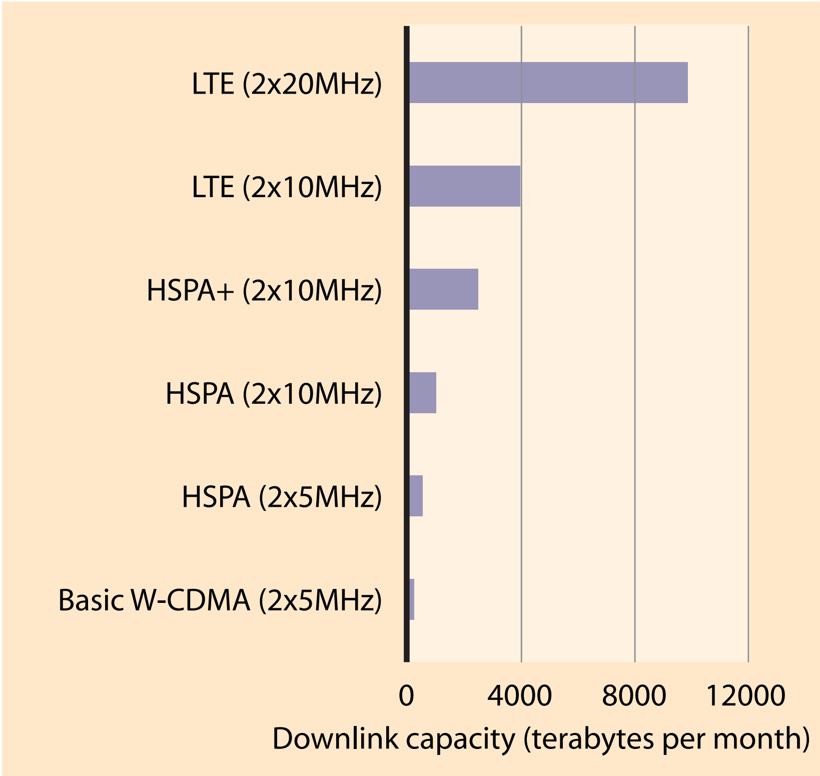


Figure 14: Estimated network capacities for WCDMA, HSPA, HSPA+ and LTE for a typical deployment of 10,000 base stations
Source: Analysys Mason, 2008

This massive increase in capacity comes at a lower cost per bit. The cost per megabyte could drop by a factor of 3, from Euro 0.03 for HSPA (2x5 MHz) to Euro 0.01 for LTE (2x5 MHz), according to the Analysys Mason study.

High Definition (HD) video streaming will be possible with LTE. Increased uplink data rates will encourage video blogging through the improved ability to upload video content to social networking sites. Collaborative Web 2.0 applications will boost mobile Internet adoption, driven by mobile social networking services already being developed by Google and Yahoo!

Pictures taken on LTE devices will be automatically synchronised with and backed up on home computer systems where they will be available to view through IPTV set top boxes. Users will be able to embrace 'follow me content' services where video traffic is time-shifted or place-shifted between mobile and fixed networks. LTE's ability to interconnect to other technologies delivers a simplified and fully integrated service level and experience.

The low cost of data delivery combined with the low latency inherent in LTE will make real-time online gaming, popular on the home PC today, a reality anywhere. The LTE infrastructure could even compete with mobile TV broadcast systems using the proposed Multicast Broadcast Single Frequency Network (MBSFN) functionality.

4 Deployment Scenarios

LTE does not support circuit switched services. Moving all services and traffic to the packet domain with a common all-IP network in LTE provides a solid foundation for Fixed Mobile Convergence (FMC), enabling new business models built upon triple-play and quadruple-play services.

4.1 Voice over IP

LTE can utilise Voice over IP (VoIP) together with an IMS (IP Multimedia Subsystem) network to deliver delay sensitive, real-time voice services. VoIP can provide a richer user experience than circuit switched voice through its integration with other packet services. Possibilities include HD voice (wideband voice), packet-based video telephony, video sharing, low-latency gaming, place shifting of media and social networking.

LTE users will be able to add and remove IP services in real-time and enrich communications with personalisation capabilities. They will be able to share music, video clips and pictures instantaneously during voice calls. They will be able to utilise presence information to choose between different communication mechanisms such as instant messaging, push-to-talk or voice calls.

Current WCDMA networks use highly efficient circuit switched voice rather than VoIP for primary voice services. WCDMA networks have the significant advantage, compared with other radio technologies, of being able to support simultaneous circuit switched and packet switched users on the same radio channel.

Interesting options for voice services become available with HSPA networks. Voice services are symmetric and require balanced uplink and downlink capacity. Broadband capability on both the uplink and the downlink is available in HSPA networks once both HSUPA and HSDPA have been deployed. Increasing voice capacity over HSPA channels to support more users can be done either through a hybrid approach called CS (Circuit switched) Voice over HSPA or through VoIP.

CS Voice over HSPA can be implemented even if packet voice cannot be supported in the core network. Circuit switched voice traffic is packetised, carried over HSPA channels and then simply fed back into the existing circuit switched infrastructure immediately beyond the radio access network. This takes advantage of the high data throughput capability of HSPA channels to increase voice capacity. The CS over HSPA approach requires only minor changes to the radio network and allows legacy WCDMA devices to continue using dedicated traffic channels for voice communications while later devices can use the HSPA channels.

CS Voice over HSPA can more than double voice capacity compared with current Release 99 voice implementations. It is expected to be widely deployed as an intermediate step on the migration path to VoIP over HSPA or LTE. As HSPA can support circuit switched and packet switched services on the same channel, voice traffic can be migrated easily from the CS to the PS domain over time (Figure 15).

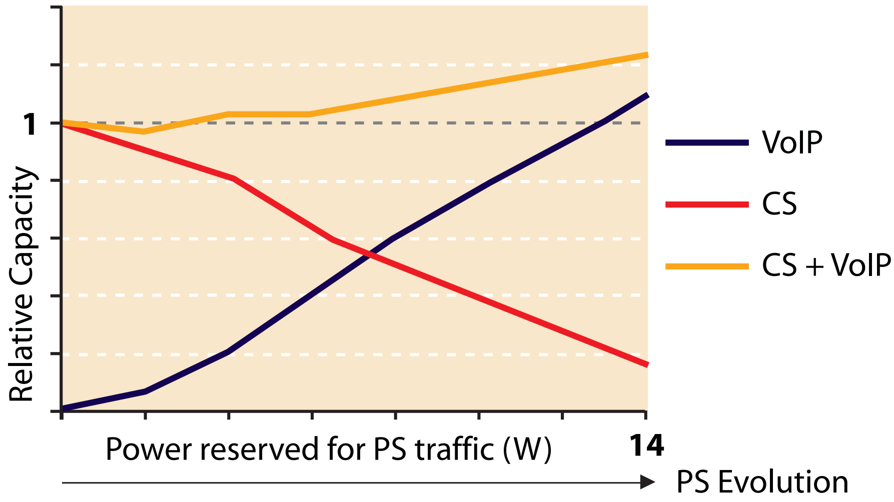


Figure 15: Ability for HSPA to support circuit and packet voice users
Source: 3G Americas

VoIP over HSPA will not be used immediately for primary voice services as it requires considerable new infrastructure in the core network. But, once an IP core network has been deployed to support LTE, the same core can also be used to support VoIP over HSPA. Deploying LTE in parts of the network could enable upgrades to VoIP over HSPA in the rest of the network.

Because of its highly efficient uplink, LTE is extremely efficient for VoIP traffic. 3GPP estimates a capacity of almost 500 users in 10 MHz of spectrum.

4.2 Operator migration paths

Most deployment scenarios involve multiple technologies in different combinations across different geographies in a single network. The actual radio technology deployed is just one of the variables – the precise details of deployment scenarios are determined by many other factors such as spectrum availability and backhaul capacity.

Significant backhaul bandwidth will be required to support technologies such as LTE. Some operators may therefore initially deploy LTE in hotspots or dense urban areas and then gradually expand the coverage as backhaul capacity becomes available.

The availability of suitable multiband terminals is another essential component determining the timing and coverage of technology upgrades and deployments. Mobile broadband enabled devices with multi-access capability are required to ensure that users can move seamlessly between the best available services.

The ability to leverage the existing base of handsets is an important factor for many operators as they migrate to HSPA+ and LTE to obtain the benefits of a flat architecture for the delivery of true mobile broadband (Figure 16).

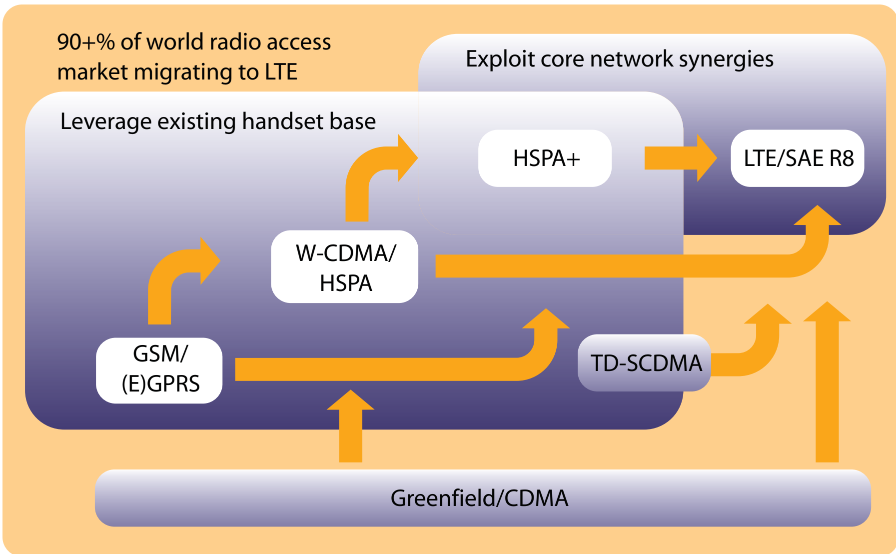


Figure 16: Operator migration paths to LTE
Source: Nokia Siemens Networks

Upgrading user equipment takes time and it can be many years before all users have been migrated from one technology to the next. During these years, most networks and devices will be multimode, typically spanning more than one technology generation.

Different regions of the world are at different stages on the road to LTE. Mature markets in the developed world are already seeing widespread deployments of HSPA whereas many emerging markets are still rolling out GSM/EDGE networks. Added to that divergence is the fact that LTE has profoundly impacted the balance between current technology roadmaps and has disrupted the overall dynamics of the market. The days of parallel technology universes seem to be numbered. The plans of some major CDMA operators to realign their migration paths towards LTE could result in some LTE deployments occurring as early as 2010 (Figure 17)

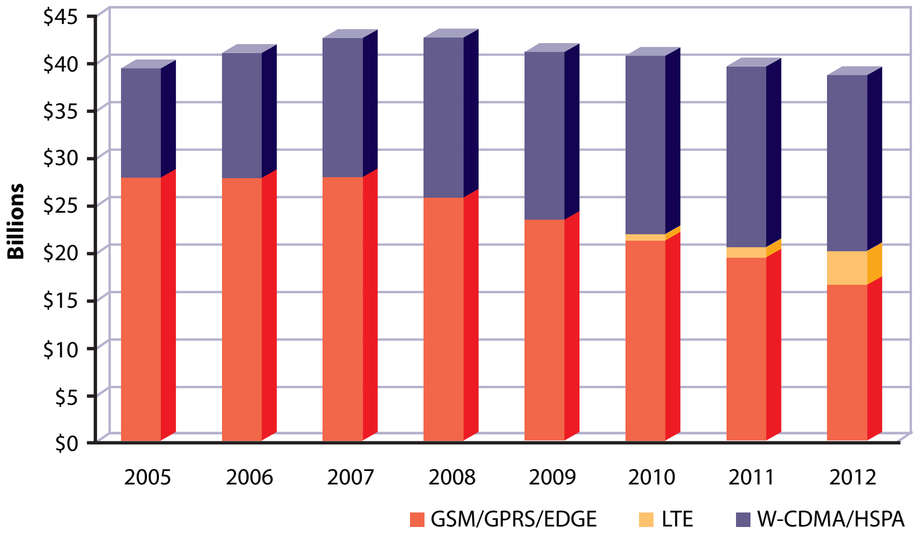


Figure 17: Global capex forecast for GSM, WCDMA and LTE
Source: Heavy Reading

However it will probably be another five years before the number of LTE subscribers starts to make significant inroads into the huge base of subscribers enjoying mobile broadband services over HSPA/HSPA+ (Figure 18).

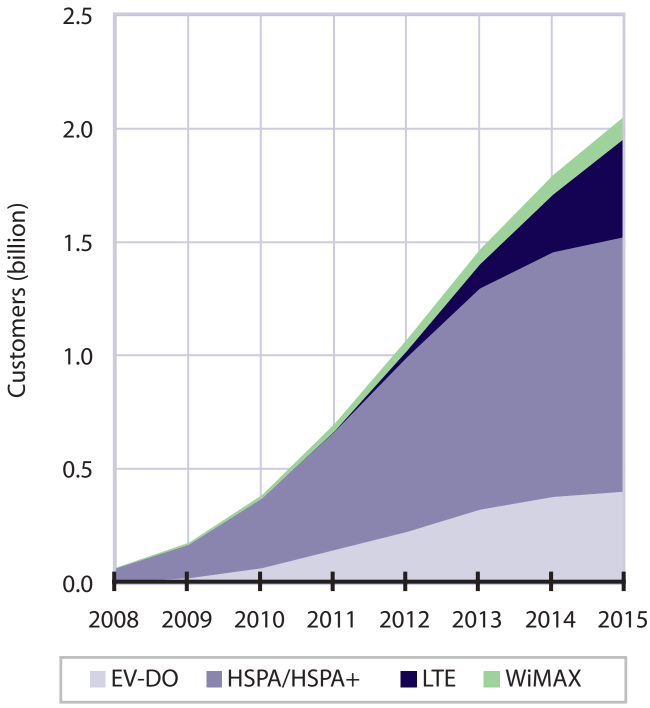


Figure 18: Wireless broadband customer forecasts worldwide, by technology
Source: Analysys Mason

4.2.1 Migration paths for 3GPP WCDMA operators

The phased release evolutionary approach of 3GPP allows operators to introduce LTE in a flexible fashion, balancing their legacy network investments, spectrum holdings and business strategies for mobile broadband. The combination of multiband terminals with backwardly compatible infrastructure is central to this flexibility. The deployment of LTE coexisting with WCDMA/HSPA promises to mirror the success of the deployment of WCDMA/HSPA coexisting with GSM/EDGE.

The ability to roll out LTE in phases whilst ensuring an acceptable user experience across the entire network is provided by HSPA and HSPA+ in conjunction with a common IMS network. This flexibility allows for migration strategies to be optimised across all geographies taking account of the demographics of different coverage zones. Many combinations are possible, allowing operators to build out service capability in line with device and spectrum availability.

AT&T Mobility, Telstra and Vodafone have already announced their commitment to LTE using HSPA/HSPA+ as bridge standards. AT&T Mobility plans to deploy LTE in 700 MHz spectrum where it has a contiguous band of 20 MHz for LTE transition across 82% of the population in the top 100 markets in the USA.

Other major GSM/WCDMA operators that have announced their commitment to LTE include France Telecom/Orange, Telecom Italia, TeliaSonera and T-Mobile.

Many operators across the world have already reserved spectrum for LTE, not only in the higher frequency bands such as 2.6 GHz, but also in UHF bands released by the transition from analogue to digital television. The OFDMA approach adopted for LTE delivers outstanding flexibility in the use of spectrum across a wide range of channel widths up to 20 MHz. Although LTE will frequently be deployed in new or refarmed spectrum, its support for both FDD and TDD opens up new horizons for operators with existing TDD spectrum holdings.

4.2.2 Migration paths for GSM operators

Some regions of the world do not yet have licensed spectrum for deployment of radio technologies such as WCDMA/HSPA or LTE. The natural evolution path for GSM operators in those regions is to migrate to WCDMA/HSPA once 3G licences become available, and subsequently to migrate to LTE when warranted by user demand and business strategies.

In some countries, regulatory constraints may mitigate against the issuing of 3G licences or the deployment of WCDMA/HSPA technologies. In these circumstances, GSM operators could migrate directly from GSM/EDGE to LTE via the deployment of Evolved EDGE.

Evolved EDGE offers a 50% increase in spectral efficiency and capacity and a 100% increase in peak data rates compared with current EDGE systems. Standards have already been defined and Evolved EDGE could be available for deployment around 2009 to 2010.

Evolved EDGE (EDGE+) will provide service continuity with LTE such that users will not have a hugely different experience when moving between environments. Together with devices supporting dual-mode GSM-EDGE/LTE operation, this will provide GSM operators without 3G licences with the option of a migration path to LTE.

4.2.3 Migration paths for 3GPP2 operators

LTE is backward compatible with non-3GPP as well as 3GPP networks. In particular, it is backward compatible with 3GPP2-based networks such as EV-DO. This raises the possibility of migration from CDMA2000 to LTE.

A number of major CDMA operators have already announced they will be switching networking technologies and migrating to LTE. These include Verizon Wireless in the USA, KDDI in Japan, KTF and SKT in South Korea and the newly formed China Telecom in China.

5 Mobile Devices

The unprecedented success of HSPA has put mobile broadband on the fast track to becoming an essentially free, limitless and ubiquitous commodity. The HSPA devices market has developed at a far greater pace than other technologies. Three years after service launch, the number of HSDPA devices available worldwide is over twice the number of GSM/EDGE devices and over six times the number of WCDMA devices at the same point in their service development.

Users already have a choice of over 1000 HSDPA devices (source: GSA December 2008). However it will take some time before existing handsets are replaced in volume; most mobile data traffic is currently generated from laptops.

In addition to mobile phones and laptops, a wide variety of computer and consumer electronic devices is expected to incorporate HSPA and LTE embedded modules in the future. The personal computer is already evolving from a static office device to a personal device with a built-in mobile broadband connection. The latest generation of consumer devices – including cameras, music players and portable games consoles – already includes WiFi connectivity and will be seeking wide area connectivity in the future. As LTE networks are launched, such devices could have ubiquitous mobile broadband coverage from day one, as LTE supports handover and roaming to existing mobile networks.

Ultra-portable laptops and handsets with large screen capabilities are blurring the distinction between handsets and laptops, and LTE networks are likely to serve a much greater diversity of devices than is available today.

Some users may choose to have multiple devices (notebooks, ultra-portables, gaming devices, personal digital assistants (PDAs), music players, cameras and mobile phones) each optimised for a unique purpose.

Others will prefer a single device, one that 'does it all.' Smartphones already represent the convergence of the PDA, a fully capable mobile computer and a phone. Future devices could include numerous embedded features such as multi-megapixel video cameras and recorders, music players, email, messaging, document handling and gaming, and will become true personal broadband communicators.

All these devices will exist within a new services ecosystem in which device manufacturers could play an increasingly direct role. Devices such as the Blackberry and the iPhone have demonstrated the latent market demand for services that merge rich multimedia and ubiquitous communications capabilities. New business models that marry the power of the networks to that of devices are already evolving in response to these developments.

6 Beyond 3G: LTE-Advanced

LTE is well positioned to satisfy market demands over the next decade as long as, like its predecessors, it continues to evolve in line with the growth in mobile traffic, the increase in user expectations and the evolving nature of services and applications resulting from the convergence of communications, broadcasting and the Internet.

LTE specifications have already been submitted by 3GPP to the ITU:

- They are now incorporated in the latest update of the IMT-2000 family, as approved by the ITU
- They will therefore formally become part of the 3G family (though some observers might refer to LTE as '3.9G')

But looking ahead it is clear that new networks and more spectrum will eventually be needed to deliver the anticipated volume of traffic. Study groups within the ITU, in particular ITU-R WP5D, have researched these requirements in detail within the framework of the 'IMT-Advanced' project.

The ITU has started the IMT-Advanced process and an ITU Circular letter has now been received inviting proposals for inclusion within the IMT Advanced family. The specifications for IMT-Advanced systems are all-encompassing. They require support for both low and high mobility applications at a wide range of data rates to meet user and service demands in multiple environments. New Radio Interface Technologies (RITs) will be required to meet these requirements.

IMT-Advanced will need to support peak data rates of up to 100 Mbit/s for high mobility and up to 1 Gbit/s for low mobility scenarios. It will need to deliver worldwide roaming capability, the ability to interwork with other radio access systems, and compatibility of services with fixed networks.

IMT-Advanced will be fully IP-based and will require 100 MHz radio channels, often in new spectrum, to deliver the high data rates demanded. Almost 400 MHz of new spectrum has already been identified at WRC'07, including 200 MHz in the 3.4 – 3.6 GHz on a global basis, whereas the 3.4 – 3.8 GHz range will be available for mobile technologies in the European Union, sufficient to move ahead full speed with the development of IMT-Advanced. Nevertheless more spectrum will clearly be needed beyond year 2015 due to the mobile broadband traffic growth and technology evolutions, as predicted in several studies before WRC'07. The future spectrum beyond 2015 under consideration should therefore be the range 3.8 – 4.2 GHz, upper part of the C band, to be allocated after appropriate sharing studies and recommendations.

RITs for IMT-Advanced are currently being developed for submission to the ITU's comprehensive evaluation process. Candidate RITs are due by October 2009 and the subsequent evaluation reports should be completed by June 2010. The final recommendations for the IMT-Advanced radio interface specifications are scheduled for completion by February 2011 and official validation at the WRC-2011.

3GPP will address these requirements in a software upgrade for LTE networks called 'LTE-Advanced'. In addition to supporting the enhanced peak data rates required, LTE-Advanced will also target faster switching between power states and improved performance at the edges of cells.

7 Conclusions

Operators are now experiencing massive increases in non-SMS mobile data traffic following the introduction of HSPA capabilities in 3G networks. But mobile broadband traffic volumes are low compared with fixed line traffic – mobile broadband currently accounts for less than 1% of IP traffic globally.

In the fixed world, broadband traffic is predicted to grow massively over the next few years, driven primarily by consumer video. Mobile will take an increasing proportion of that traffic, although still remaining a relatively small percentage of the total, and is predicted to increase by at least one, and possibly two, orders of magnitude by 2015.

The bad news is that this enormous traffic growth will not be accompanied by a concomitant increase in revenues. New networks with a lower cost per bit will eventually be required to satisfy the predicted demand for mobile broadband traffic.

The good news is that HSPA+ and LTE technologies, probably deployed in new or refarmed spectrum, will deliver spectral efficiencies capable of providing the required performance. The emergence of LTE as the next technology of choice for both 3GPP and non-3GPP networks could result in unprecedented global economies of scale, further improving the cost per bit characteristics of these networks.

The demand for mobile broadband has been demonstrated. The business case for mobile broadband demands new networks capable of delivering a low cost per bit. Both HSPA+ and LTE meet those requirements and are on target to become the next workhorses for mobile broadband over the next decade.

8 Appendices

8.1 Acronyms

3GPP	Third Generation Partnership Project
ARPU	Average Revenue per User
CDMA	Code Division Multiple Access
CN	Core Network
CPC	Continuous Packet Connectivity
DSL	Digital Subscriber Line
EDGE	Enhanced Data Rates for Global Evolution
eNodeB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EV-DO	Evolution, Data Optimised
FDD	Frequency Division Duplex
FMC	Fixed Mobile Convergence
FTTH	Fibre to the Home
GERAN	GSM EDGE Radio Access Network
GPON	Gigabit Passive Optical Network
GPRS	General Packet Radio Service
GSM	Global System for Mobile communication
HD	High Definition
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
HSPA+	HSPA Evolution
HSUPA	High Speed Uplink Packet Access
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IP	Internet Protocol
ITU	International Telecommunication Union
LSTI	LTE SAE Trial Initiative
LTE	Long Term Evolution
MBSFN	Multicast Broadcast Single Frequency Network
MIMO	Multiple Input, Multiple Output
MPLS	Multi-Protocol Label Switching
NGMN	Next Generation Mobile Networks
NGN	Next Generation Network
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
P2P	Peer-to-Peer
PDA	Personal Digital Assistant
QoS	Quality of Service
RAN	Radio Access Network
RIT	Radio Interface Technology
RNC	Radio Network Controller
SAE	System Architecture Evolution
SC-FDMA	Single Carrier – Frequency Division Multiple Access
SD	Standard Definition
SGSN	Serving GPRS Support Node
SIP	Session Initiation Protocol
SON	Self-Organising Network
TCP/IP	Transmission Control Protocol/Internet Protocol
TDD	Time Division Duplex
UMTS	Universal Mobile Telecommunications System
UTRAN	Universal Terrestrial Radio Access Network
VoIP	Voice over IP
WCDMA	Wideband CDMA
WiFi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WRC'07	World Radiocommunication Conference 2007

8.2 Further Reading

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