284 23-3124 Uen Rev B | June 2009

white paper

LTE – an introduction

Long Term Evolution (LTE) offers a superior user experience and simplified technology for next-generation mobile broadband.

Contents

1 Executive summary

Mobile broadband is becoming a reality, as the internet generation grows accustomed to having broadband access wherever they go and not just at home or in the office. Of the estimated 3.4 billion people who will have broadband by 2014, about 80 percent will be mobile broadband subscribers – and the majority will be served by High Speed Packet Access (HSPA) and Long Term Evolution (LTE) networks.

People can already browse the internet or send e-mails using HSPA-enabled notebooks, replace their fixed DSL modems with HSPA modems or USB dongles and send and receive video or music using 3G phones. With LTE, the user experience will be even better. It will enhance more demanding applications such as interactive TV, mobile video blogging, advanced games and professional services.

LTE offers several important benefits for users and operators, including the following:

- Performance and capacity – One of the requirements of LTE is to provide downlink peak rates of at least 100Mbps. The technology allows for speeds more than 300Mbps and Ericsson has already demonstrated LTE peak rates of about 160Mbps. Radio access network (RAN) round-trip times will be less than 10ms, meaning LTE, more than any other technology, already meets key 4G requirements.
- Simplicity – LTE supports flexible carrier bandwidths, from 1.4MHz up to 20MHz. LTE also supports frequency division duplexing (FDD) and time division duplexing (TDD). Fifteen paired and eight unpaired spectrum bands have already been identified by the 3GPP for LTE and there are more bands to come. This means an operator can introduce LTE in new bands where it is easiest to deploy 10MHz or 20MHz carriers and eventually deploy LTE in all bands. LTE radio network products will have a number of features to help simplify the building and management of next-generation networks. For example, features such as self-configuration and self-optimization will simplify and reduce the cost of network roll-out and management. LTE will be deployed in parallel with simplified, IP-based core and transport networks that are easier to build, maintain and introduce services on.
- Wide range of terminals – In addition to mobile phones, many computer and consumer electronic devices, such as notebooks, ultra-portables, gaming devices and cameras, will incorporate embedded LTE modules. Because LTE supports handover and roaming to existing mobile networks, all these devices can have ubiquitous mobile broadband coverage from day one.

Operators can introduce LTE flexibly to match their existing network, spectrum and business objectives for mobile broadband and multimedia services.

2 Satisfying consumer requirements

Broadband subscriptions are expected to reach 3.4 billion by 2014 and about 80 percent of these consumers will use mobile broadband (see Figure 1). There is strong evidence supporting predictions of increased mobile broadband usage.

Consumers understand and appreciate the benefits of mobile broadband. Most people already use mobile phones and many also connect their notebooks over wireless LANs. The step towards full mobile broadband is intuitive and simple, especially with LTE that offers ubiquitous coverage and roaming with existing 2G and 3G networks.

Experience with HSPA technology shows that when operators provide good coverage, service offerings and terminals, mobile broadband usage takes off.

Packet data traffic overtook voice traffic during May 2007, based on a world average WCDMA network load (see Figure 2). This was mainly because of the introduction of HSPA in the networks. HSPA data cards and USB dongles have also become popular. Several operators have reported a four-fold increase in data traffic in the three months after launching HSPA.

In many cases, mobile broadband can compete with fixed broadband on price, performance, security and convenience. Users can spend less time setting up the WLAN connection, worrying about security or losing coverage and more time actually using the service.

A number of broadband applications are significantly enhanced with mobility. Community sites, search engines, presence applications and content-sharing sites such as YouTube are a few examples. With mobility, these applications become significantly more valuable to users. User-generated content is particularly interesting, because it changes traffic patterns, making the ability to uplink more important than ever. The high peak rates and short latency of LTE also enable real-time applications such as gaming and video-conferencing.

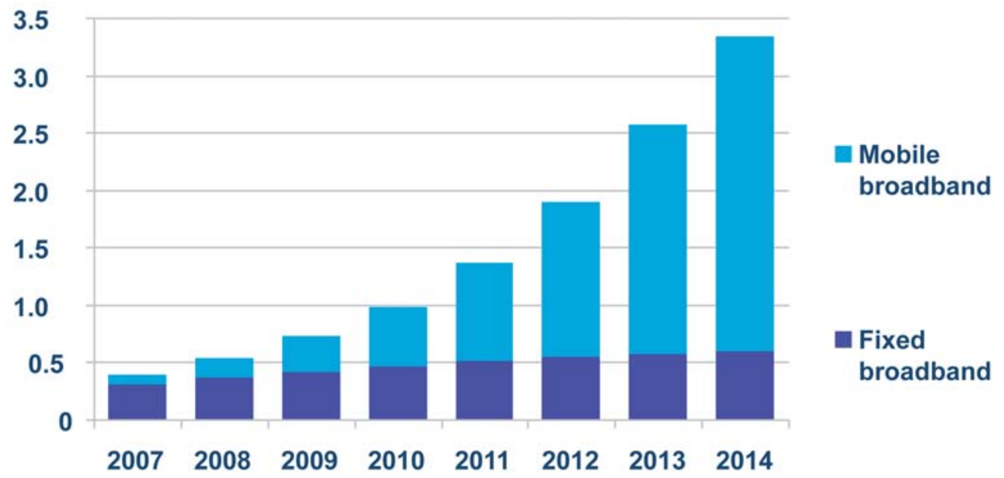


Figure 1: Broadband growth 2007–2014

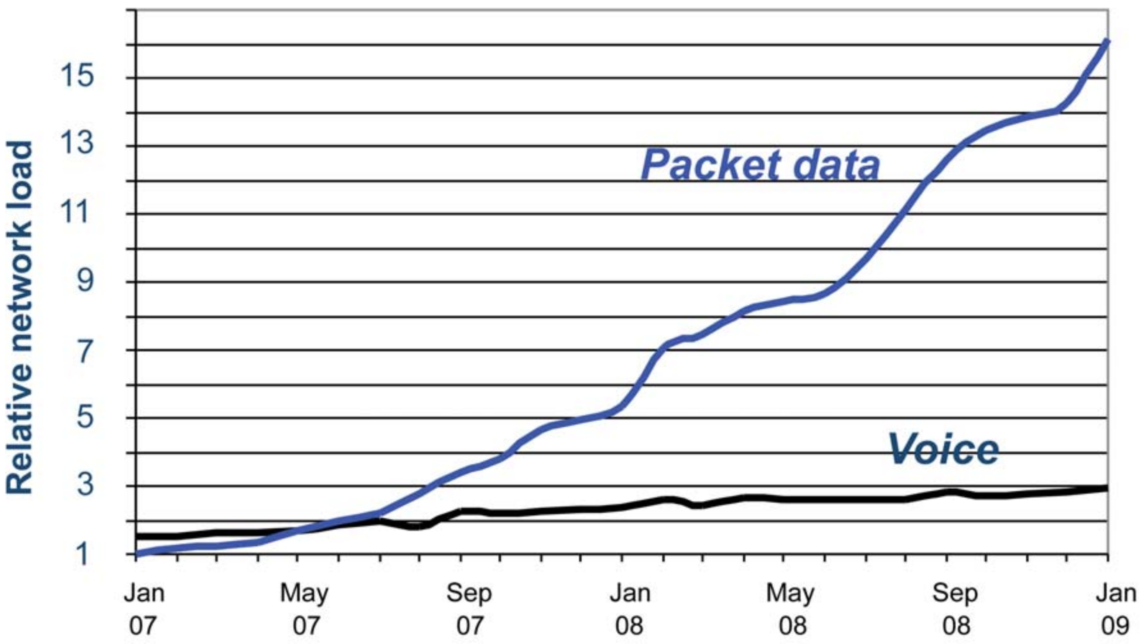


Figure 2: Strong growth of data traffic in WCDMA networks worldwide

3 Satisfying operator requirements

Operators are doing business in an increasingly competitive environment, competing not only with other operators, but also with new players and new business models. However, new business models also mean new opportunities and mobile operators have the advantage of being able to offer the competitive delivery of mobile broadband services using existing investments in 2G and 3G networks.

This is why operators are so active in formulating strategies and driving requirements for mobile broadband through standardization bodies. Some of the world's leading operators, vendors and research institutes have joined forces in the Next Generation Mobile Networks (NGMN) program. See www.ngmn.org for a list of members. The NGMN program works alongside existing standardization bodies and has established clear performance targets, fundamental recommendations and deployment scenarios for a future wide-area mobile broadband network. To be realized, the NGMN's vision of technology evolution beyond 3G requires:

- efficient re-use of existing assets, including spectrum;
- support for cost-efficient, end-to-end, low latency and cost-efficient "always-on" services at the time of introduction;
- adding unique value by supporting cost-efficient, end-to-end quality of service (QoS), mobility and roaming;
- no impact on the current HSPA roadmap;
- a new intellectual property rights (IPR) regime to support licensing that leads to much greater transparency and predictability of the total cost of IPR for operators, infrastructure providers and device manufactures.

Although not defined by the NGMN, LTE meets these requirements.

4 Standardization of LTE

LTE is the next major step in mobile radio communications and is introduced in 3GPP Release 8. LTE uses orthogonal frequency division multiplexing (OFDM) as its radio access technology, together with advanced antenna technologies.

The 3GPP is a collaboration agreement, established in December 1998, which brings together a number of telecommunications standards bodies, known as organizational partners. The current organizational partners are the Association of Radio Industries and Businesses (ARIB), China Communications Standards Association (CCSA), European Telecommunications Standards Institute (ETSI), Alliance for Telecommunication Industry Solutions (ATIS), Telecommunications Technology Association (TTA) and Telecommunication Technology Committee (TTC).

Researchers and development engineers from all over the world – representing operators, vendors and research institutes – are participating in the joint LTE radio access standardization effort.

In addition to LTE, the 3GPP is also defining an IP-based, flat network architecture. This architecture is defined as part of the System Architecture Evolution (SAE) effort. The LTE–SAE architecture and concepts have been designed for efficient support of mass market usage of any IP-based service. The architecture is based on an evolution of the existing GSM/WCDMA core network, with simplified operations and smooth, cost-efficient deployment.

Work has also been done via cooperation between the 3GPP and 3GPP2 (the CDMA standardization body) to optimize interworking between CDMA and LTE–SAE. This means that CDMA operators will be able to evolve their networks to LTE–SAE and enjoy the economies of scale and global chipset volumes that have been such outstanding advantages for GSM and WCDMA.

The starting point for LTE standardization was the 3GPP RAN (radio access network) Evolution Workshop, held in November 2004 in Toronto, Canada. A study item was started in December 2004 with the objective of developing a framework for the evolution of 3GPP radio access technology towards:

- reduced cost per bit;
- increased service provisioning – more services at lower cost with better user experience;
- flexible use of existing and new frequency bands;
- simplified architecture and open interfaces;
- reasonable terminal power consumption.

The study item was needed to certify that the LTE concept could fulfill a number of requirements specified in the 3GPP TR 25.913 Feasibility Study of Evolved UTRA and UTRAN [1] (see fact box on the 3GPP original requirements).

LTE performance has been evaluated in so-called checkpoints and the results were agreed on in a 3GPP meeting in South Korea in mid-2007. The results show that LTE meets and in some cases exceeds the targets for peak data rates, cell edge user throughput and spectrum efficiency, as well as VoIP and Multimedia Broadcast Multicast Service (MBMS) performance.

The specification work on LTE was completed in March 2009 as the SAE specifications were included. Implementation based on the March 2009 version will guarantee backwards compatibility.

Summary of the 3GPP original LTE requirements

* Increased peak data rates: 100Mbps downlink and 50Mbps uplink.
* Reduction of RAN latency to 10ms.
* Improved spectrum efficiency (two to four times compared with HSPA Release 6).
* Cost-effective migration from Release 6 Universal Terrestrial Radio Access (UTRA) radio interface and architecture.
* Improved broadcasting.
* IP-optimized (focus on services in the packet-switched domain).
* Scalable bandwidth of 20MHz, 15MHz, 10MHz, 5MHz, 3MHz and 1.4MHz.
* Support for both paired and unpaired spectrum.
* Support for inter-working with existing 3G systems and non-3GPP specified systems.

5 Technical merits

5.1 Architecture

In parallel with the LTE radio access, packet core networks are also evolving to the flat SAE architecture. This new architecture is designed to optimize network performance, improve cost efficiency and facilitate the uptake of mass-market IP-based services.

There are two nodes in the SAE architecture user plane; the LTE base station (eNodeB) and the SAE Gateway, as shown in Figure 3. This flat architecture reduces the number of involved nodes in the connections.The LTE base stations are connected to the core network over the so-called S1 interface.

Existing 3GPP (GSM and WCDMA/HSPA) and 3GPP2 (CDMA) systems are integrated to the evolved system through standardized interfaces, providing optimized mobility with LTE. For 3GPP systems, this means a signaling interface between the Serving GPRS Support Node (SGSN) and the evolved core network and for 3GPP2, a signaling interface between CDMA RAN and evolved core network. Such integration supports both dual and single radio handover, allowing for flexible migration to LTE.

Control signaling, for example for mobility, is handled by the Mobility Management Entity (MME) node, separate from the gateway, facilitating optimized network deployments and enabling fully flexible capacity scaling.

The Home Subscriber Server (HSS) connects to the packet core through an interface based on Diameter and not SS7, as used in previous GSM and WCDMA networks. Network signaling for policy control and charging is already based on Diameter. This means all interfaces in the architecture are IP interfaces.

LTE–SAE has adopted a class-based QoS concept. This provides a simple, yet effective solution for operators to offer differentiation between packet services.

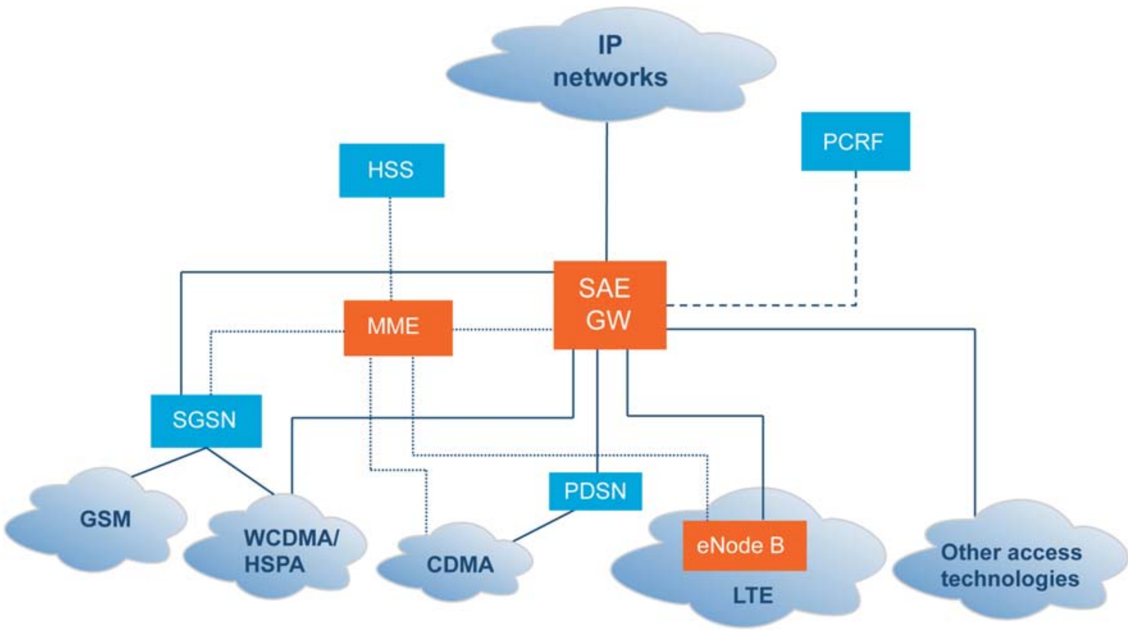


Figure 3: Flat architecture of LTE and SAE

5.2 Orthogonal frequency division multiplexing (OFDM) radio technology

LTE uses OFDM for the downlink, that is, from the base station to the terminal. OFDM meets the LTE requirement for spectrum flexibility and enables cost-efficient solutions for wide carriers with high peak rates. It is a well-established technology, for example in standards such as Institute of Electrical and Electronics Engineers (IEEE) 802.11a/b/g, 802.16, HiperLAN-2, Digital Video Broadcast (DVB) and Digital Audio Broadcast (DAB).

OFDM uses a large number of narrowband sub-carriers or tones for multi-carrier transmission. The basic LTE downlink physical resource can be explained as a time-frequency grid, as illustrated in Figure 4. In the frequency domain, the spacing between the sub-carriers, Δf, is 15kHz. In addition, the OFDM symbol duration time is $1/\Delta f$ + cyclic prefix. The cyclic prefix is used to maintain orthogonally between the sub-carriers, even for a time-dispersive radio channel.

One resource element carries QPSK, 16QAM or 64QAM modulated bits. For example with 64QAM, each resource element carries six bits.

The OFDM symbols are grouped into resource blocks. The resource blocks have a total size of 180kHz in the frequency domain and 0.5ms in the time domain.

Each user is allocated a number of so-called resource blocks in the time–frequency grid. The more resource blocks a user receives and the higher the modulation used in the resource elements, the higher the bit-rate.

Which resource blocks and how many the user receives at a given point depend on advanced scheduling mechanisms in the frequency and time dimensions. Scheduling of resources can be taken every ms, that means two resource blocks, 180kHz wide and in total one ms in length, called a scheduling block. The scheduling mechanisms in LTE are similar to those used in HSPA and enable optimal performance for different services in different radio environments.

In the uplink, LTE uses a pre-coded version of OFDM called Single Carrier Frequency Division Multiple Access (SC-FDMA). This is to compensate for a drawback with normal OFDM, which has a high Peak to Average Power Ratio (PAPR). High PAPR requires expensive and inefficient power amplifiers with high requirements on linearity, which increases the cost of the terminal and drains the battery faster.

SC-FDMA solves this problem by grouping together the resource blocks in a way that reduces the need for linearity and power consumption in the power amplifier. A low PAPR also improves coverage and the cell-edge performance.

A comprehensive introduction to LTE can be found in 3G Evolution: HSPA and LTE for mobile broadband [2].

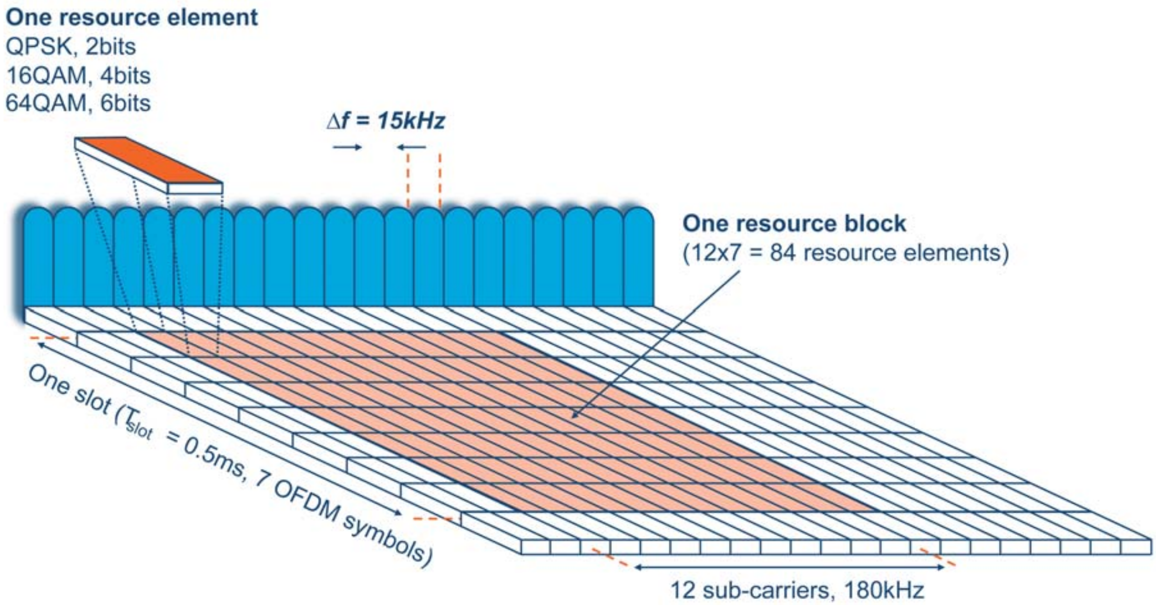


Figure 4: The LTE downlink physical resource based on OFDM

5.3 Advanced antennas

Advanced antenna solutions introduced in HSPA Evolution are also used by LTE. Solutions incorporating multiple antennas meet next-generation mobile broadband network requirements for high peak data rates, extended coverage and high capacity. Advanced multi-antenna solutions are vital to achieving these targets.

There is not one single antenna solution that addresses every scenario. Consequently, a family of antenna solutions is available for specific deployment scenarios. For example, high peak data rates can be achieved with multi-layer antenna solutions such as 2x2 or 4x4 multiple input, multiple output (MIMO), and extended coverage can be achieved with beam-forming.

5.4 Frequency bands for frequency division duplexing (FDD) and time division duplexing (TDD)

LTE can be used in both paired (FDD) and unpaired (TDD) spectrum. Leading suppliers' first product releases will support both duplex schemes. In general, FDD is more efficient and represents higher device and infrastructure volumes, but TDD is a good complement, for example, in spectrum center gaps. For more details, see the fact box on FDD and TDD. Because LTE hardware is the same for FDD and TDD, except for the radio unit, TDD operators will for the first time be able to enjoy the economies of scale that come with broadly supported FDD products.

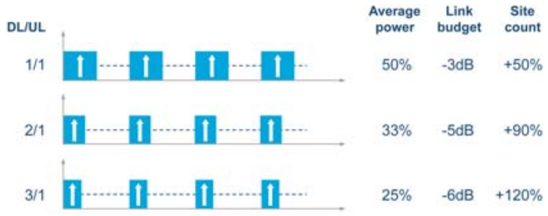
Fifteen different FDD frequency bands and eight different TDD frequency bands have been defined in the 3GPP for LTE use, as shown in Table 1. See also references [3] and [4]. It is likely that more bands will be added.

The first LTE network infrastructure and terminal products will support multiple frequency bands from day one, meaning LTE will be able to quickly reach high economies of scale and global coverage.

LTE is defined to support flexible carrier bandwidths from 1.4MHz up to 20MHz, in many spectrum bands and for both FDD and TDD deployments. This means an operator can introduce LTE in both new and existing bands. The first may be bands where it is generally easiest to deploy 10MHz or 20MHz carriers, for example, 2.6GHz (Band 7), Advanced Wireless Service (AWS) (Band 4), or 700MHz bands, but eventually LTE will be deployed in all cellular bands. Unlike other earlier cellular systems, LTE will be quickly deployed on multiple bands.

FDD and TDD

All current cellular systems use FDD and more than 90 percent of the world's available mobile frequencies are in paired bands. With FDD, downlink and uplink traffic is transmitted simultaneously in separate frequency bands. With TDD, the transmission in uplink and downlink is discontinuous within the same frequency band. For example, if the time split between downlink and uplink is 1/1, the uplink is used half the time. The average power for each link is then also half of the peak power. As peak power is limited by regulatory requirements, the result is that for the same peak power, TDD will offer less coverage than FDD.



Operators often want to allocate more than half of their resources to downlink peak rates. If the DL/UL ratio is 3/1, 120 percent more sites are needed for TDD, compared with FDD to cover the same area.

FDD bands

Band	Frequencies UL/DL (MHz)
1	1920 – 1980/2110 – 2170
2	1850 – 1910/1930 – 1990
3	1710 – 1785/1805 – 1880
4	1710 – 1755/2110 – 2155
5	824 – 849/869 – 894
6	830 – 840/875 – 885
7	2500 – 2570/2620 – 2690
8	880 – 915/925 – 960
9	1750 – 1785/1845 – 1880
10	1710 – 1770/2110 – 2170
11	1428 - 1453/1476 - 1501
12	698 – 716 /728 - 746
13	777 – 787 /746 - 756
14	788 – 798 /758 - 768
17	704 – 716/734 – 746

TDD bands

Band	Frequencies UL/DL (MHz)
33,34	1900 – 1920 2010 – 2025
35,36	1850 – 1910 1930 – 1990
37	1910 – 1930
38	2570 – 2620
39	1880 – 1920
40	2300 – 2400

Table 1: FDD (left) and TDD (right) frequency bands defined in the 3GPP (May 2009)

6 Terminals, modules and fixed wireless terminals

By the time LTE is available, mobile broadband devices will be mass market products. Industry analyst Informa recently forecast that by 2013 there will be about 900 million WCDMA devices sold annually and more than 75 percent of them will be HSPA-enabled.

Today, most people think “mobile phones” when mobile connections are discussed. But in the coming years, devices such as notebooks, ultra-portables, gaming devices and video cameras will operate over existing mobile broadband technologies such as HSPA and CDMA2000, as well as LTE through standardized mobile broadband modules. Many companies in the consumer electronics business will be able to deploy mobile broadband technology cost-effectively to further enhance the user value of their offerings.

Mobile Broadband Routers (MBRs) offer another opportunity to use mobile broadband efficiently. MBRs can be compared to fixed DSL modems with Ethernet, WLAN or POTS connections for devices at home or in the office. The main difference is that the broadband service is not carried over copper cables, but through the radio network. MBRs enable operators to provide broadband service cost-efficiently to all users who already have desktop computers with Ethernet connections or notebooks with WLAN connectivity.

Figure 6: Examples of devices that could use LTE

7 Cost efficiency

There is strong and widespread support from the mobile industry for LTE and many vendors, operators and research institutes are participating in its standardization.

One of the key success factors for any technology is economy of scale. The volume advantage is beneficial for both handsets and infrastructure equipment. It drives down the manufacturing costs and enables operators to provide cost-efficient services to their customers. This is also one of the main reasons greenfield operators will benefit from LTE.

Deployment of LTE will vary from country to country, according to regulatory requirements. The first devices will be multimode-based, meaning that wide-area coverage, mobility and service continuity can be provided from day one. Existing mobile networks can be used as fall-back in areas where LTE is not yet deployed.

It is important that the deployment of LTE infrastructure is as simple and cost-efficient as possible. For example, it should be possible to upgrade existing radio base stations to LTE using plug-in units, so they become both dual mode and dual band.

Standalone base stations for LTE will also be simpler to deploy than today's products. Network roll-out, operation and management can be simplified with plug-and-play and self-optimizing features, reducing both capex and opex for the operator.

8 Conclusion

LTE is well positioned to meet the requirements of next-generation mobile networks, both for existing 3GPP/3GPP2 operators and greenfielders. It will enable operators to offer high-performance, mass market mobile broadband services, through a combination of high bit-rates and system throughput, in both the uplink and downlink and with low latency.

LTE infrastructure is designed to be simple to deploy and operate, through flexible technology that can be deployed in a wide variety of frequency bands. LTE offers scalable bandwidths, from 1.4MHz up to 20MHz, together with support for both FDD paired and TDD unpaired spectrum. The LTE–SAE architecture reduces the number of nodes, supports flexible network configurations and provides a high level of service availability. LTE–SAE will also inter-operate with GSM, WCDMA/HSPA, TD-SCDMA and CDMA.

LTE will be available not only in next-generation mobile phones, but also notebooks, ultra-portables, cameras, camcorders, MBRs and other devices that benefit from mobile broadband.

9 Glossary

ARIB	Association of Radio Industries and Businesses
ATIS	Alliance for Telecommunication Industry Solutions
AWS	Advanced Wireless Services
DAB	Digital Audio Broadcast
DVB	Digital Video Broadcast
ETSI	European Telecommunications Standards Institute
FDD	frequency division duplex/duplexing
Hiper-LAN	high performance radio LAN
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
IEEE	Institute of Electrical and Electronics Engineers
IPR	intellectual property rights
LTE	Long Term Evolution
MBMS	Multimedia Broadcast Multicast Service
MBR	Mobile Broadband Router
MIMO	multiple input, multiple output
MME	Mobility Management Entity
NGMN	next generation mobile networks
OFDM	orthogonal frequency division multiplexing
PAPR	peak-to-average power ratio
PCRF	Policy and Charging Rules Function
PDSN	Pack Data Serving Node
POTS	plain old telephone service
QoS	quality of service
RAN	radio access network
SAE	System Architecture Evolution
SC-FDMA	Single Carrier Frequency Division Multiple Access
SGSN	Serving GPRS Support Node
TDD	time division duplex/duplexing
TTA	Telecommunications Technology Association
TTC	Telecommunication Technology Committee
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network

10 References

[1] 3GPP. TR 25.913. *Feasibility Study of Evolved UTRA and UTRA.*

[2] Dahlman, Parkvall, Skold and Beming. Academic Press, Oxford, UK, Second edition 2008. *3G Evolution: HSPA and LTE for Mobile Broadband*

[3] 3GPP. TS 25.104. *Base Station (BS) radio transmission and reception (FDD*)

[4] 3GPP. TS 25.105. *Base Station (BS) radio transmission and reception (TDD)*