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Long Term Evolution (LTE): an introduction

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White Paper

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

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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. Out of the estimated 1.8 billion people who will have broadband by 2012, some two-thirds will be mobile broadband consumers – and the majority of these will be served by HSPA (High Speed Packet Access) and LTE (Long Term Evolution) 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 further enhance more demanding applications like interactive TV, mobile video blogging, advanced games or professional services.

LTE offers several important benefits for consumers and operators:

- ***Performance and capacity*** – One of the requirements on LTE is to provide downlink peak rates of at least 100Mbit/s. The technology allows for speeds over 200Mbit/s and Ericsson has already demonstrated LTE peak rates of about 150Mbit/s. Furthermore, RAN (Radio Access Network) round-trip times shall be less than 10ms. In effect, this means that LTE – more than any other technology – already meets key 4G requirements.

- ***Simplicity*** – First, LTE supports flexible carrier bandwidths, from below 5MHz up to 20MHz. LTE also supports both FDD (Frequency Division Duplex) and TDD (Time Division Duplex). Ten paired and four unpaired spectrum bands have so far been identified by 3GPP for LTE. And there are more band to come. This means that an operator may introduce LTE in ‘new’ bands where it is easiest to deploy 10MHz or 20MHz carriers, and eventually deploy LTE in all bands.
  Second, LTE radio network products will have a number of features that simplify the building and management of next-generation networks. For example, features like plug-and-play, self-configuration and self-optimization will simplify and reduce the cost of network roll-out and management.
  Third, 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 LTE embedded modules. Since LTE supports hand-over and roaming to existing mobile networks, all these devices can have ubiquitous mobile broadband coverage from day one.

In summary, 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 1.8 billion by 2012. Around two-thirds of these consumers will use mobile broadband. Mobile data traffic is expected to overtake voice traffic in 2010, which will place high requirements on mobile networks today and in the future.

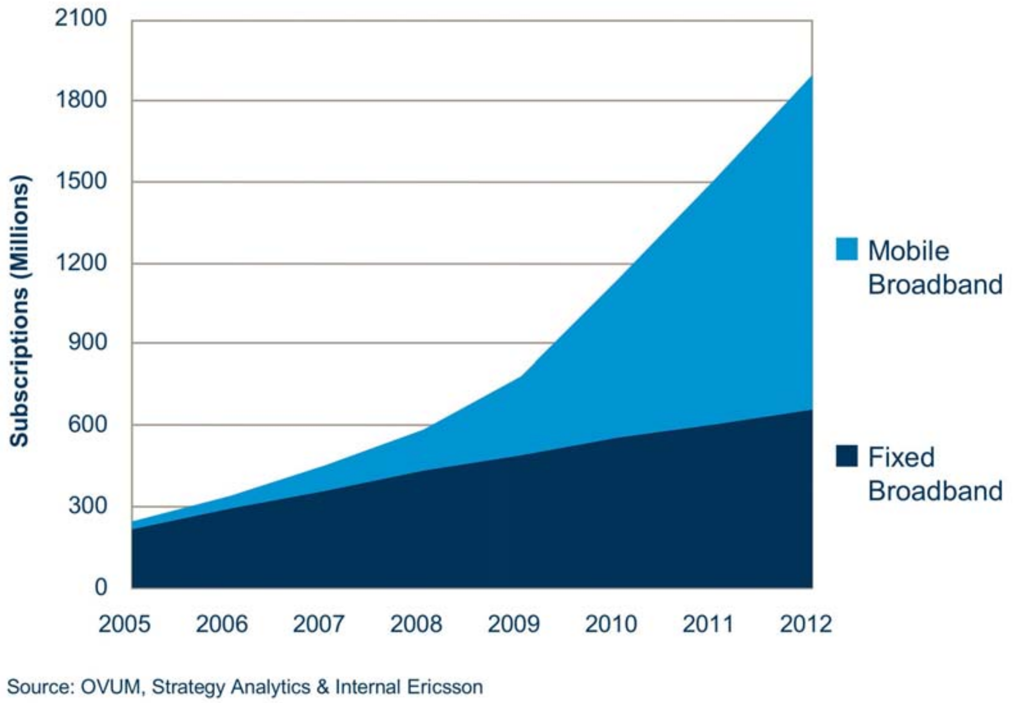


Figure 1 Broadband growth 2005–2012

There is strong supporting evidence for the take-off of mobile broadband.

First, 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.

Second, experience from HSPA shows that when operators provide good coverage, service offerings and terminals, mobile broadband rapidly takes off.

Packet data traffic started to exceed voice traffic during May 2007 as an average world in WCDMA networks (see Figure 2). This is mainly due to the introduction of HSPA in the networks. Recently HSPA data cards and USB dongles have become very popular. Several operators have seen a four fold increase in data traffic in just 3 months after they launched HSPA.

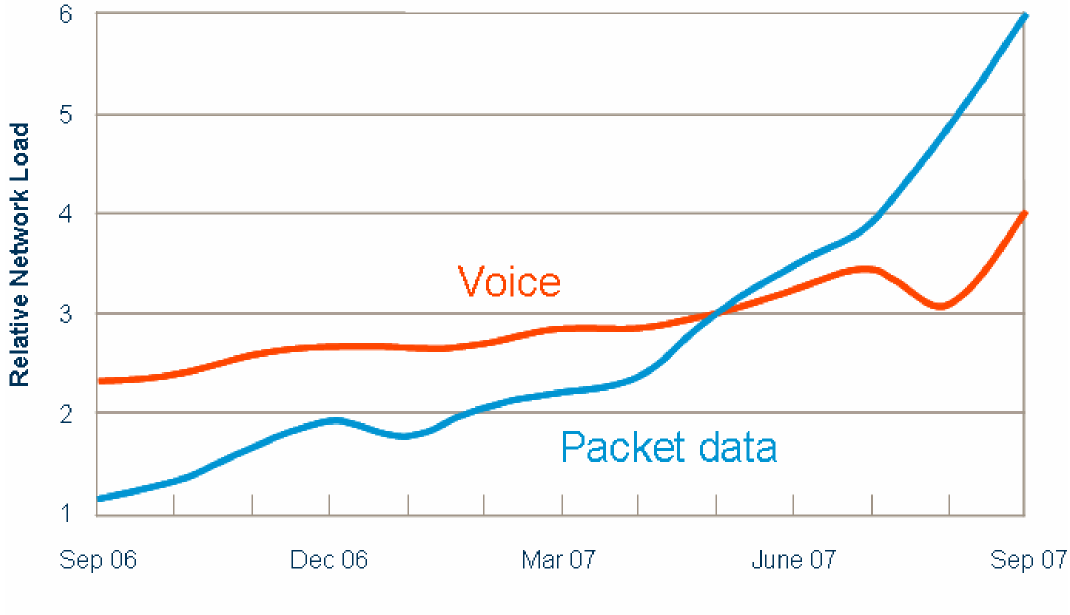


Figure 2 Growth of voice and data traffic in WCDMA networks world wide

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

Third, a number of broadband applications are significantly enhanced with mobility. Community sites, search engines, presence applications and content-sharing sites like YouTube are just a few examples. With mobility, these applications become significantly more valuable to people. User-generated content is particularly interesting, because it changes traffic patterns to make the uplink much more important. The high peak rates and short latency of LTE enable real-time applications like gaming and IPTV.

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 competitive delivery of mobile broadband services built on existing investments in 2G and 3G networks.

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

1. Efficient reuse of existing assets, including spectrum
2. Competitiveness in terms of an overall customer proposition (support for cost-efficient end-to-end low latency and cost-efficient "Always-on") at the time of introduction and ahead of rival technologies whilst adding unique value by supporting cost-efficient end-to-end Quality of Service, mobility, and roaming.
3. No impact to the current HSPA roadmap.
4. A new IPR regime to support the licensing in a manner, which leads to much greater transparency and predictability of the total cost of IPR for operators, infrastructure providers, and device manufacturers.

Although not defined by NGMN, LTE meets NGMN's requirements.

4 Standardization of LTE

LTE is the next major step in mobile radio communications, and will be introduced in 3rd Generation Partnership Project (3GPP) Release 8. LTE uses Orthogonal Frequency Division Multiplexing (OFDM) as its radio access technology, together with advanced antenna technologies.

3GPP is a collaboration agreement, established in December 1998 that brings together a number of telecommunications standards bodies, known as 'Organizational Partners'. The current Organizational Partners are ARIB, CCSA, ETSI, ATIS, TTA and TTC. Researchers and development engineers from all over the world – representing more than 60 operators, vendors and research institutes – are participating in the joint LTE radio access standardization effort.

In addition to LTE, 3GPP is also defining 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.

Moreover, work was recently initiated between 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 strong benefits for GSM and WCDMA.

The starting point for LTE standardization was the 3GPP RAN Evolution Workshop, held in November 2004 in Toronto, Canada. A study item was started in December 2004 with the objective to develop a framework for the evolution of the 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 3GPP *TR 25.913 Feasibility Study of Evolved UTRA and UTRAN* [1] (see the fact box on 3GPP original requirements).

LTE performance has been evaluated in so-called checkpoints and the results were agreed on in 3GPP plenary sessions during May and June 2007 in South Korea. 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 goal is to complete standardization of LTE before the end of 2007. After the first release, adaptations will be made with change requests and functionality will grow in the next releases of the standard.

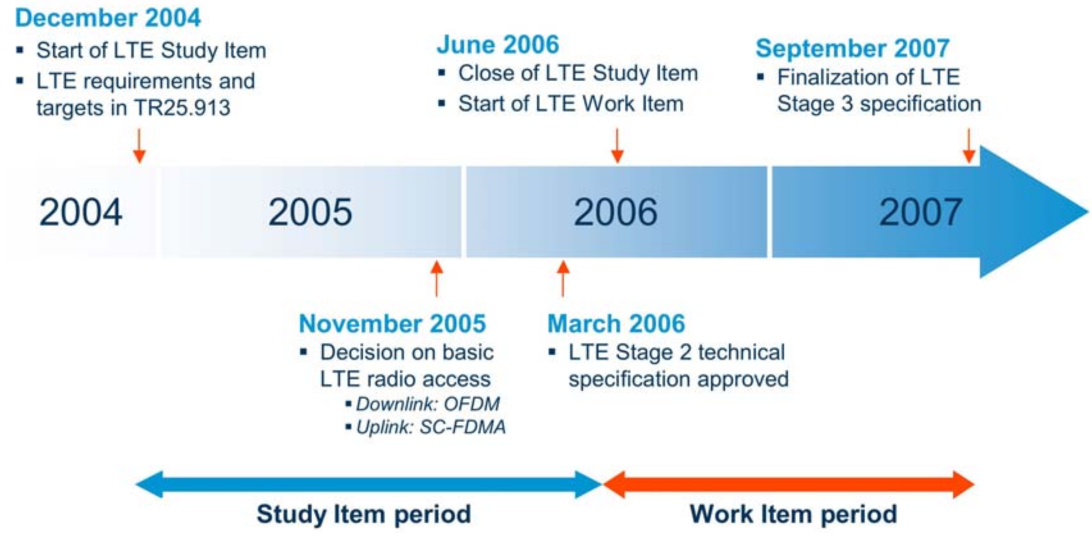


Figure 3 Standardization timeline for 3GPP Long Term Evolution

Fact box: Summary of the 3GPP original LTE requirements

* Increased peak data rates: 100Mbit/s downlink and 50Mbit/s uplink
* Reduction of Radio Access Network (RAN) latency to 10ms
* Improved spectrum efficiency (2 to 4 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 and <5MHz
* Support for both paired and unpaired spectrum
* Support for interworking 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 only two nodes in the SAE architecture user plane: the LTE base station (eNodeB) and the SAE Gateway, as shown in Figure 4. The LTE base stations are connected to the Core Network using the Core Network–RAN interface, S1. This flat architecture reduces the number of involved nodes in the connections.

Existing 3GPP (GSM and WCDMA/HSPA) and 3GPP2 (CDMA2000 1xRTT, EV-DO) 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 SGSN and the evolved core network and for 3GPP2 a signaling interface between CDMA RAN and evolved core network. Such integration will support 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. This facilitates optimized network deployments and enables 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 that all interfaces in the architecture are IP interfaces.

Existing GSM and WCDMA/HSPA systems are integrated to the evolved system through standardized interfaces between the SGSN and the evolved core network. It is expected that the effort to integrate CDMA access also will lead to seamless mobility between CDMA and LTE. Such integration will support both dual and single radio handover, allowing for flexible migration from CDMA to LTE.

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

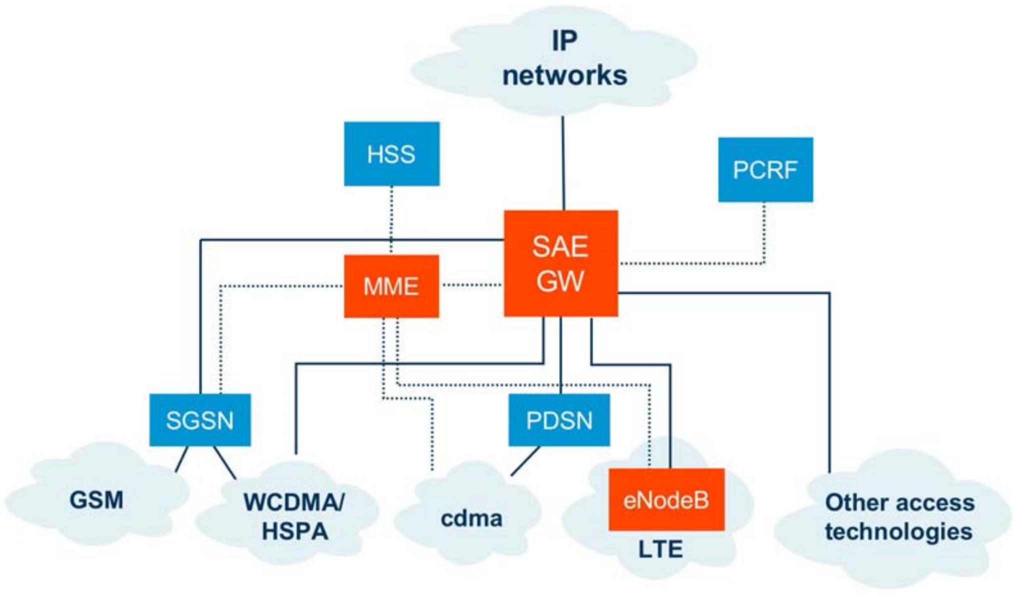


Figure 4 Flat architecture of Long Term Evolution and System Architecture Evolution

5.2 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 very wide carriers with high peak rates. It is a well-established technology, for example in standards such as IEEE 802.11a/b/g, 802.16, HIPERLAN-2, DVB and DAB.

OFDM uses a large number of narrow sub-carriers for multi-carrier transmission. The basic LTE downlink physical resource can be seen as a time-frequency grid, as illustrated in Figure 5. In the frequency domain, the spacing between the sub-carriers, Δf, is 15kHz. In addition, the OFDM symbol duration time is 1/Δf + 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. 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 1ms Transmission Time Interval (TTI) consists of two slots (Tslot).

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

Which resource blocks and how many the user gets at a given point in time depend on advanced scheduling mechanisms in the frequency and time dimensions. The scheduling mechanisms in LTE are similar to those used in HSPA, and enable optimal performance for different services in different radio environments.

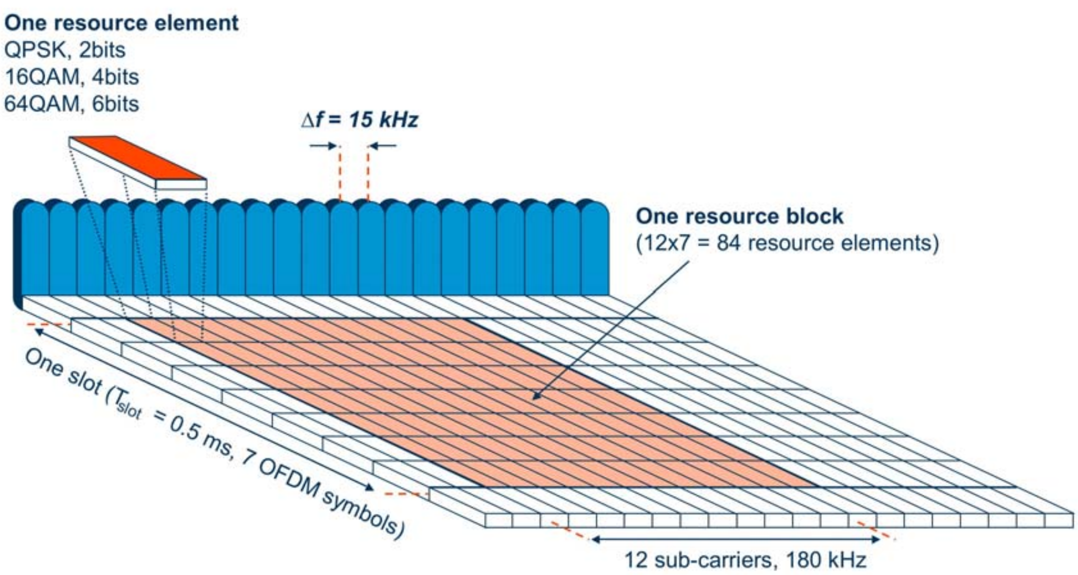


Figure 5 The LTE downlink physical resource based on OFDM

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 very 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 such a way that reduces the need for linearity, and so 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].

5.3 Advanced antennas

Advanced antenna solutions that are introduced in evolved High Speed Packet Access (eHSPA) 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.

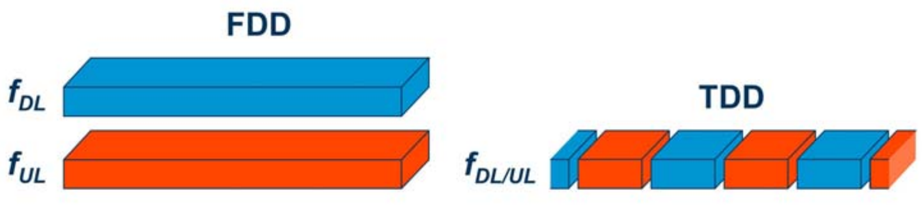
Advanced multi-antenna solutions are key components to achieve these targets. There is not one antenna solution that addresses every scenario. Consequently, a family of antenna solutions is available for specific deployment scenarios. For instance, high peak data rates can be achieved with multi-layer antenna solution such as 2x2 or 4x4 Multiple Input Multiple Output (MIMO) whereas extended coverage can be achieved with beam-forming.

5.4 Frequency bands for FDD and TDD

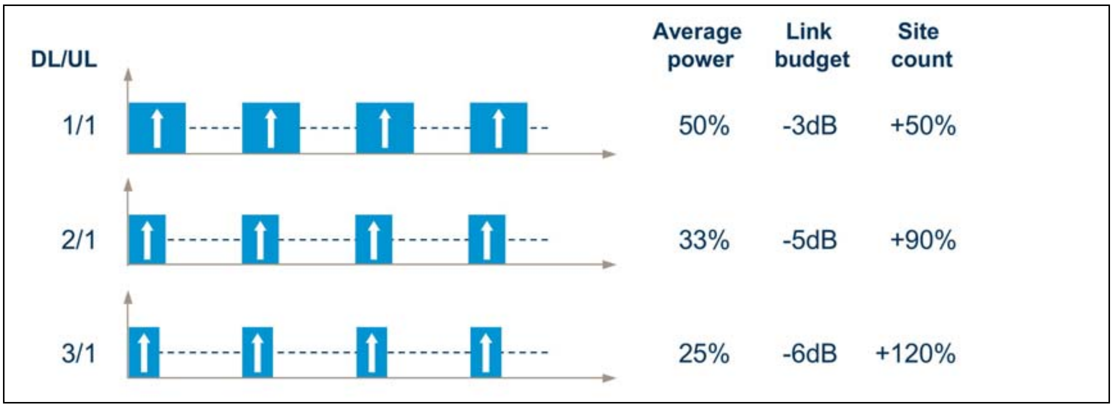
LTE can be used in both paired (FDD) and unpaired (TDD) spectrum. Leading supplier's first product releases will support both duplex schemes. In general, FDD is more efficient and represents higher device and infrastructure volumes, while TDD is a good complement, for example in spectrum center gaps.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

Fact box: FDD and TDD

All cellular systems today use FDD, and more than 90 per cent of the world's mobile frequencies available 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. As an example, if the time split between down- and uplink is 1/1, the uplink is used half of 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.



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



So far, ten different FDD frequency bands and four different TDD frequency bands have been defined in 3GPP that can be used for LTE, as shown in Table 1 [3], [4]. It is likely that more bands will be added to this list such as 700MHz in the US.

FDD Bands

Band	Frequencies UL/DL (MHz)
I	1920 - 1980/2110 - 2170
II	1850 - 1910/1930 - 1990
III	1710 - 1785/1805 - 1880
IV	1710 - 1755/2110 - 2155
V	824 - 849/869 - 894
VI	830 - 840/875 - 885
VII	2500 - 2570/2620 - 2690
VIII	880 - 915/925 -960
IX	1749.9 - 1784.9/1844.9 - 1879.9
X	1710 - 1770/2110 - 2170

TDD Bands

Band	Frequencies UL and DL (MHz)
a	1900 - 1920 2010 - 2025
b	1850 - 1910 1930 - 1990
c	1910 - 1930
d	2570 - 2620

Table 1 FDD (left) and TDD (right) frequency bands defined in 3GPP (June 2007)

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

LTE is defined to support flexible carrier bandwidths from below 5MHz up to 20MHz, in many spectrum bands and for both FDD and TDD deployments. This means that an operator can introduce LTE in both new and existing bands. The first may be bands where it, in general, is easiest to deploy 10MHz or 20MHz carriers (for example, 2.6GHz (Band VII), AWS (Band IV), or 700MHz bands), but eventually LTE will be deployed in all cellular bands. In contrast to earlier cellular systems, LTE will rapidly be deployed on multiple bands.

6 Terminals, modules and fixed wireless terminals

By the time LTE is available, mobile broadband devices will be mass-market products. Industry analyst Strategy Analytics forecasts that by 2010 there will be around half a billion WCDMA phones sold annually and more than two-thirds of them will be HSPA-enabled (October 2006).

Today, most people think about mobile phones when we talk about mobile connections. However in the coming years, devices like notebooks, ultra-portables, gaming devices and video cameras will operate over existing mobile broadband technologies like HSPA and CDMA2000, as well as LTE through standardized PCI Express embedded 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.

Fixed Wireless Terminals (FWTs) are another opportunity to use mobile broadband efficiently. FWTs 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 not is carried over copper cables but through the radio network. FWTs 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. This is a good base for the creation of a healthy ecosystem.

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 legacy 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 that they become both dual mode and dual band.

Stand-alone base stations for LTE will also be simpler to deploy than today's products. Network roll-out and operation & 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 – with low latency.

LTE infrastructure is designed to be as simple as possible to deploy and operate, through flexible technology that can be deployed in a wide variety of frequency bands. LTE offers scalable bandwidths, from less than 5MHz 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. Furthermore, LTE–SAE will interoperate with GSM, WCDMA/HSPA, TD-SCDMA and CDMA.

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

9 Glossary

3GPP: 3rd Generation Partnership Project

3GPP2: 3rd Generation Partnership Project 2

ARIB: Association of Radio Industries and Businesses

ATIS: Alliance for Telecommunication Industry Solutions

AWS: Advanced Wireless Services

CAPEX: Capital Expenditure

CCSA: China Communications Standards Association

CDMA: Code Division Multiple Access

CDMA2000: Code Division Multiple Access 2000

DAB: Digital Audio Broadcast

DSL: Digital Subscriber Line

DVB: Digital Video Broadcast

eHSPA: evolved High Speed Packet Access

ETSI: European Telecommunications Standards Institute

FDD: Frequency Division Duplex

FWT: Fixed Wireless Terminal

GSM: Global System for Mobile communication

HSPA: High Speed Packet Access

HSS: Home Subscriber Server

IEEE: Institute of Electrical and Electronics Engineers

IPTV: Internet Protocol Television

LTE: Long Term Evolution

MBMS: Multimedia Broadcast Multicast Service

MIMO: Multiple Input Multiple Output

MME: Mobility Management Entity

NGMN: Next Generation Mobile Networks

OFDM: Orthogonal Frequency Division Multiplexing

OPEX: Operational Expenditure

PAPR: Peak to Average Power Ratio

PCI: Peripheral Component Interconnect

PCRF: Policing and Charging Rules Function

PDSN: Packet Data Serving Node

PS: Packet Switched

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

TTA: Telecommunications Technology Association

TTC: Telecommunication Technology Committee

TTI: Transmission Time Interval

UTRA: Universal Terrestrial Radio Access

UTRAN: Universal Terrestrial Radio Access Network

WCDMA: Wideband Code Division Multiple Access

WLAN: Wireless Local Area Network

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3. 3GPP TS 25.104 'Base Station (BS) radio transmission and reception (FDD)'
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