LONG TERM EVOLUTION

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About :

Antonis Hontzeas has been In the forefront of the Telecommunications industry for twenty years. Tenure includes positions ranging from design and technical management up to and including executive positions dealing with solution management and strategic marketing management.

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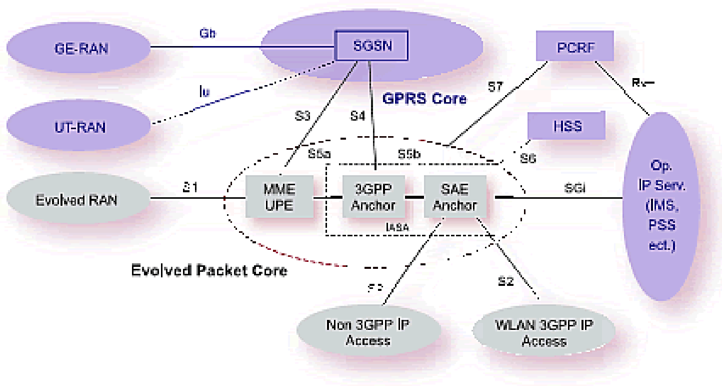
Long Term Evolution

LTE (Long Term Evolution) or *3G Long Term Evolution* is the evolution of mobile cellular communications technology towards a full edge to edge broadband ip network, and is introduced in 3rd Generation Partnership Project (3GPP) Release 8.

The aim of this 3GPP project is to further develop the *Universal Mobile Telecommunications System* (UMTS) standard and provide an enhanced user experience and simplified technology for next generation mobile broadband. Scientists and design engineers from more than 60 operators, vendors and research institutes have teamed up to realise this radio access standardization effort.

Much of the 3GPP Release 8 standard will be oriented towards upgrading UMTS to 4G mobile communications technology, and an all-IP flat architecture system.



LTE targets requirements of next generation networks including downlink peak rates of at least 100Mbit/s, uplink rates of 50 Mbit/s and RAN (Radio Access Network) round-trip times of less than 10ms. LTE supports flexible carrier bandwidths, from 1.4MHz up to 20MHz as well as both FDD (Frequency Division Duplex) and TDD (Time Division Duplex).

LTE further aspires to improve considerably spectral efficiency, lowering costs, improving services, making use of new spectrum and refarmed spectrum opportunities, and better integration with other open standards. The resulting architecture is referred to as **EPS** (Evolved Packet System) and comprises the **E-UTRAN** (Evolved UTRAN) on the access side and **EPC** (Evolved Packet Core) via the System Architecture Evolution concept (**SAE**), on the core network side.

LTE advantages include high throughput, low latency, plug and play from day one, FDD and TDD in the same platform, superior end-user experience and simple architecture resulting in low operating expenditures (OPEX). LTE will also support seamless connection to existing networks, such as GSM, CDMA and WCDMA. However LTE requires a completely new RAN and core network deployment and is not backward compatible with existing UMTS systems.

The standard includes:

- *Peak download rates* of 326.4 Mbit/s for 4x4 antennas, 172.8 Mbit/s for 2x2 antennas for every 20 MHz of spectrum.
- *Peak upload rates* of 86.4 Mbit/s for every 20 MHz of spectrum.
- *5 different terminal classes* ranging from a voice centric class up to a high end terminal that supports the peak data rates. All terminals will be able to process 20 MHz bandwidth.
- *At least 200 active users* in every 5 MHz cell. (i.e., 200 active data clients)
- *Sub-5ms latency* for small IP packets.
- *Increased spectrum flexibility*, with spectrum slices as small as 1.5 MHz .and as large as 20 MHz. W-CDMA requires 5 MHz slices, leading to some problems with roll-outs in

countries where the 5 MHz spectrum is already allocated to 2 - 2.5G legacy GSM and cdmaOne. The 5 MHz chunks also limit the amount of bandwidth per handset.

- *Optimal cell size of 5 km*, 30 km sizes with reasonable performance, and up to 100 km cell sizes supported with acceptable performance.
- *Co-existence with legacy standards* (users can transparently start a call or transfer of data in an area using an LTE standard, and should coverage be unavailable, continue the operation without any action on their part using GSM/GPRS or W-CDMA-based UMTS or even 3GPP2 networks such as cdmaOne or CDMA2000) .
- *Support for MBSFN* (Multicast Broadcast Single Frequency Network). This feature can deliver services such as MBMS using the LTE infrastructure, and is a competitor to DVB-h.

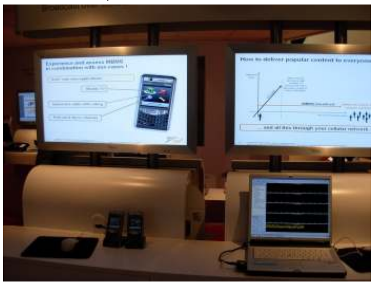
A large amount of the work is aimed at simplifying the architecture of the system, as it evolves from the existing hybrid (packet and circuit switching) network, to an all-IP flat architecture system.

Why LTE ?

Why is the cellular industry reconsidering the overall architecture of the GSM based mobile communication system after only a decade from the introduction of the very first 3G/UMTS networks?

This is a common question and the chief answer has to do with the fact that the world is very different today that it was ten years ago. Fixed broadband connectivity is now ubiquitous with multi-megabit speeds available at reasonable cost to customers and business users via DSL, fiber and cable connections.
Broadband is part of today's mobile customer experience. This shift in user perception is demonstrated by the rapid increase in the uptake of WCDMA and HSPA networks worldwide. As of January 2009, there are over 4 billion wireless subscribers and over 254 operators in more than 110 countries supporting WCDMA.

In January 2009 237 operators had commercially launched HSPA in 105 countries and over 70% of HSDPA networks supported 3.6 Mbps (peak) or higher, and over 34 % of HSDPA networks supported 7.2 Mbps (peak) or higher. There were 66 commercial HSUPA systems commercially launched in 47 countries.



The natural counterpart to HSDPA, HSUPA boosts mobile uplink speeds as high as 5.8 Mbit/s. This provides a valuable complement for operators wishing to introduce mobile broadband services demanding greater capacity and speed on both uplink and downlink. An example of this is Voice over IP (**VoIP**), where voice calls are delivered over the Internet or other IP networks in a packet-based session.
Furthermore, other technologies have matured since UMTS was first commercialised in 2001.

Mobile WiMAX which was accepted by ITU as the sixth radio access method for IMT-2000 (IMT-2000O FDMA TDD WMAN) is being deployed by operators in Asia-Pacific and the Americas.
Some European carriers have expressed interest in deploying the technology as a complement to their current 3G/UMTS operations. The acceptance of mobile WiMAX as a part of IMT-2000 opens up the possibility of operators deploying the technology in

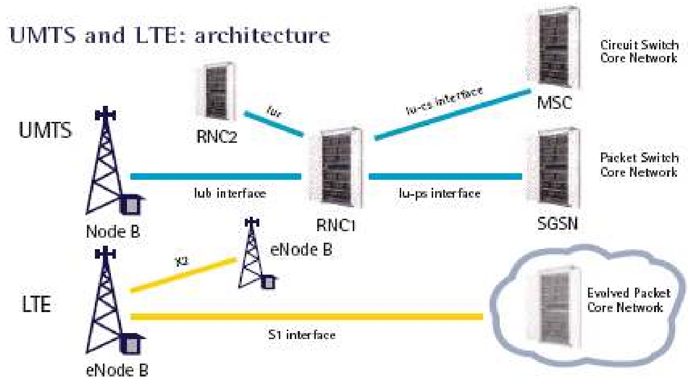
their existing licensed 3G/UMTS spectrum allocations.

Operators are thus presented with a choice of technologies to provide their customers with wireless broadband services. This will allow them either to compete with fixed operators or to provide broadband services in areas where the fixed infrastructure does not exist and would be too expensive to deploy.

Against this backdrop, LTE offers compelling attractions for incumbent UMTS/HSPA operators such as the ability to re-use significant portions of their existing infrastructure, together with re-use existing spectrum assets. While LTE looks firmly to the future, it does so with a Return of Investment (**ROI**) approach.

As a result, LTE will allow operators to generate fresh sources of value from their existing network investments while enjoying the significant economies of scale that flow from participation in the world’s biggest and most successful family of evolving cellular systems that are specified by 3GPP.

Flat Architecture



A characteristic of next generation networks is that all connectivity and session control relies on TCP/IP. Since different functional domains can now communicate and interact easily, the result is a richer communications experience including enhanced voice, video, messaging services and advanced multimedia solutions.

In 2004, 3GPP proposed Transmission Control Protocol/Internet Protocol (TCP/IP) as the future for next generation networks and began feasibility studies into All IP Networks (AIPN). Proposals developed included recommendations for 3GPP Release 7(2005), which acts as the foundation of higher level protocols and applicatons which form the LTE concept. These recommendations are part of the 3GPP System Architecture Evolution (**SAE**). Some aspects of All-IP networks, however, were already defined as early as release 4.

3GPP is defining IP-based, flat network architecture as part of the *System Architecture Evolution* (SAE) effort. 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. The main component of the **SAE** architecture is the **Evolved Packet Core** (**EPC**), also known as **SAE Core**. The EPC will serve as equivalent of GPRS networks (via the **Mobility Management Entity**, **Serving Gateway** and **PDN Gateway** subcomponents).

The subcomponents of the EPC are:

- *MME (Mobility Management Entity*): The MME is the key control node for the LTE access network. It is responsible for idle mode UE (User Equipment) tracking and paging procedure including retransmissions. It is involved in the bearer activation/deactivation process and is also responsible for choosing the SGW for a UE at the initial attach and at time of intra-LTE handover involving Core Network (CN) node relocation. It is responsible for authenticating the user (by interacting with the HSS). The Non-Access

Stratum (NAS) signaling terminates at the MME and it is also responsible for generation and allocation of temporary identities to UEs. It checks the authorization of the UE to camp on the service provider's Public Land Mobile Network (PLMN) and enforces UE roaming restrictions. The MME is the termination point in the network for ciphering/integrity protection for NAS signaling and handles the security key management. Lawful interception of signaling is also supported by the MME. The MME also provides the control plane function for mobility between LTE and 2G/3G access networks with the S3 interface terminating at the MME from the SGSN. The MME also terminates the S6a interface towards the home HSS for roaming UEs.

- *S-GW (Serving Gateway):* The SGW routes and forwards user data packets, while also acting as the mobility anchor for the user plane during inter-eNB handovers and as the anchor for mobility between LTE and other 3GPP technologies (terminating S4 interface and relaying the traffic between 2G/3G systems and PDN GW). For idle state UEs, the SGW terminates the DL data path and triggers paging when DL data arrives for the UE. It manages and stores UE contexts, e.g. parameters of the IP bearer service, network internal routing information. It also performs replication of the user traffic in case of lawful interception.
- *P-GW (PDN gateway):* The PDN GW provides connectivity to the UE to external packet data

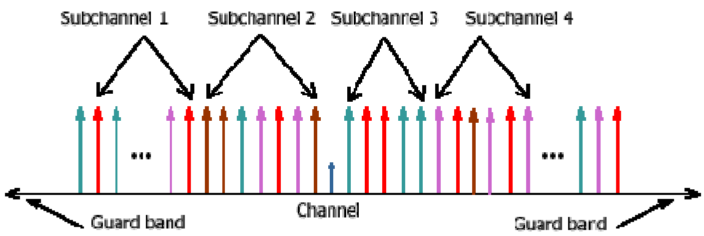
networks by being the point of exit and entry of traffic for the UE. A UE may have simultaneous connectivity with more than one PDN GW for accessing multiple PDNs. The PDN GW performs policy enforcement, packet filtering for each user, charging support, lawful interception and packet screening. Another key role of the PDN GW is to act as the anchor for mobility between 3GPP and non-3GPP technologies such as WiMAX and 3GPP2 (CDMA 1X and EvDO).

Radio

The Release 8 air interface, **E-UTRA** (Evolved UTRA, the E- prefix being common to the evolved equivalents of older UMTS components) would be used by UMTS operators deploying their own wireless networks. It's important to note that Release 8 is intended for use over any IP network, including WiMAX and WiFi, and even wired networks.

The proposed E-UTRA system uses **OFDMA** for the downlink (tower to handset) and Single Carrier FDMA (**SC-FDMA**) for the uplink and employs **MIMO (Multiple Input – Multiple Output)** with up to four antennas per station. The channel coding scheme for transport blocks is turbo coding couple with a contention-free quadratic permutation polynomial (QPP) turbo code internal interleaver.

Orthogonal Frequency-Division Multiple Access (**OFDMA**) is a multi-user version of the popular Orthogonal frequency-division multiplexing (OFDM) digital modulation scheme. Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users as shown in the illustration below. This allows simultaneous low data rate transmission from several users.



OFDMA Advantages:

- *Flexibility of deployment* across various frequency bands with little needed modification to the air interface.
- *Averaging interferences* from neighboring cells, by using different basic carrier permutations between users in different cells.
- *Interferences within the cell* are averaged by using allocation with cyclic permutations.
- *Orthogonality* in the uplink by synchronizing users in time and frequency.
- *Single Frequency Network* coverage, where coverage problem exists and gives excellent coverage.
- *Adaptive carrier allocation* in multiplication of 23 carriers = nX23 carriers up to 1587 carriers (all data carriers).
- *Frequency diversity* by spreading the carriers all over the used spectrum.
- *Time diversity* by optional interleaving of carrier groups in time.
- Optimal cell capacity through adaptivity to the highest modulation a user can use. Less carriers means higher gain per carrier (up to 18dB gain for 23 carrier allocation instead of 1587 carriers), and increase in overall cell capacity.

Recognised disadvantages of OFDMA:

- *Higher sensitivity* to frequency offsets and phase noise.
- *Asynchronous data communication* services such as web access are characterized by short communication bursts at high data rate.
- *The complex OFDM electronics*, including the FFT algorithm and forward error correction is constantly active independent of the data rate. This results in inefficient power consumption even though the FFT algorithm may hibernate during certain time intervals.
- *The OFDM diversity gain* and resistance to frequency-selective fading may partly be lost if very few sub-carriers are assigned to each user, and if the same carrier is used in every OFDM symbol. Adaptive sub-carrier assignment based on fast feedback information about the channel, or sub-carrier frequency hopping, is therefore desirable.
- *Co-channel interference processing* from neighbouring cells is more complex in OFDM than in CDMA. It would require dynamic channel allocation with advanced coordination among adjacent base stations.
- *Fast channel feedback information* and adaptive sub-carrier assignment is more complex than CDMA fast power control.

Characteristics and principles of operation

Adaptive user-to-subcarrier assignment is achieved from received channel condition feedback. If the assignment is done sufficiently fast, this further improves the OFDM robustness to fast fading and narrow-band cochannel interference, and makes it possible to achieve even better system spectral efficiency.

Different number of sub-carriers can be assigned to different users, in view to support differentiated Quality of Service (QoS), i.e. to control the data rate and error probability individually for each user.

OFDMA resembles code division multiple access (CDMA) spread spectrum, where users can achieve different data rates by assigning a different code spreading factor or a different number of spreading codes to each user.

OFDMA can be seen as an alternative to combining OFDM with time division multiple access (TDMA) or time-domain statistical multiplexing, i.e. packet mode communication. Low-data-rate users can send continuously with low transmission power instead of using a "pulsed" high-power carrier. Constant delay, and shorter delay, can be achieved.

OFDMA can also be described as a combination of frequency domain and time domain multiple accesses, where the resources are partitioned in the time-frequency space and slots are assigned along the OFDM symbol index as well as OFDM sub-carrier index.

OFDMA is considered as highly suitable for broadband wireless networks, due to advantages including scalability and MIMO-friendliness, and ability to take advantage of channel frequency selectivity.

In spectrum sensing *cognitive radio*, OFDMA is a possible approach to filling free radio frequency bands adaptively.

Single-carrier FDMA (**SC-FDMA**) is frequency-division multiple access scheme. It is a multi-user version of Single-carrier frequency domain equalization (SC-FDE) modulation scheme. SC-FDE can be viewed as a linearly precoded OFDM scheme (LP-OFDMA) or as a single carrier multiple access scheme. One prominent advantage over conventional OFDM and OFDMA is that the SC-FDE and LP-OFDMA/SC-FDMA signals have lower peak-to-average power ratio (PAPR) because of its inherent single carrier structure.

Just like in OFDM, guard intervals with cyclic repetition are introduced between blocks of symbols in view to efficiently eliminate time spreading (caused by multi-path propagation) among the blocks. In OFDM, fast Fourier transform (FFT) is applied on the receiver side on each block of symbols, and inverse

FFT (IFFT) on the transmitter side. In SC-FDE, both FFT and IFFT are applied on the receiver side, but not on the transmitter side. In SC-FDMA, both FFT and IFFT are applied on the transmitter side, and also on the receiver side.

In OFDM as well as SC-FDE and SC-FDMA, equalization is achieved on the receiver side after the FFT calculation, by multiplying each Fourier coefficient by a complex number. This helps combat frequency-selective fading and phase distortion.

In SC-FDMA, multiple access is made possible by inserting silent fourier-coefficients on the transmitter side before the IFFT, and removing them on the receiver side before the IFFT. Different users are assigned to different fourier-coefficients (sub-carriers).

The use of OFDM, a system where the available spectrum is divided into many thin carriers, each on a different frequency, each carrying a part of the signal, enables E-UTRA to be much more flexible in its use of spectrum than the older CDMA based systems that dominated 3G. CDMA networks require large blocks of spectrum to be allocated to each carrier, to maintain high chip rates, and thus maximize efficiency. Building radios capable of coping with different chip rates (and spectrum bandwidths) is more complex than creating radios that only send and receive one size of carrier, so generally CDMA based systems standardize both.

Standardizing on a fixed spectrum slice has consequences for the operators deploying the system: too narrow a spectrum slice would mean the efficiency and maximum bandwidth per handset suffers; too wide a spectrum slice implies deployment issues and spectrum cramming with legacy systems. This became a major issue in the US roll-out of UMTS over W-CDMA, where W-CDMA's 5 MHz requirement often left no room in some markets for operators to co-deploy it with existing GSM standards.

LTE supports both FDD and TDD mode. Each mode has its own frame structure within LTE and these are aligned with each other meaning that similar hardware can be used in the base stations and terminals to allow for economy of scale. The TDD mode in LTE is aligned with TD-SCDMA as well allowing for coexistence. **Ericsson** demonstrated at the MWC 2008 in Barcelona for the first time in the world both LTE FDD and TDD mode on the same base station platform.

Downlink

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.

In the time domain you have a radio frame that is 10 ms long and consists of 10 sub frames of 1 ms each. Every sub frame consists of 2 slots where each slot is 0.5 ms. The subcarrier spacing in the frequency domain is 15 kHz. Twelve of these subcarriers together (per slot) is called a resource block so one resource block is 180 kHz. 6 Resource blocks fit in a carrier of 1.4 MHz and 100 resource blocks fit in a carrier of 20 MHz.

Supported modulation formats on the downlink data channels are QPSK, 16QAM and 64QAM.

For MIMO operation, a distinction is made between single user MIMO, for enhancing one user's data throughput, and multi user MIMO for enhancing the cell throughput.

In MIMO systems, a transmitter sends multiple streams by multiple transmit antennas. The transmit streams go through a matrix channel which consists of multiple paths between multiple transmit antennas at the transmitter and multiple receive antennas at the receiver. Then, the receiver gets the received signal vectors by the multiple receive antennas and decodes the received signal vectors into the original information. Spatial multiplexing techniques makes the receivers very complex, and therefore it is typically combined with orthogonal frequency-division multiplexing (OFDM) or with Orthogonal Frequency Division Multiple Access (OFDMA) modulation, where the problems created by multi-path channel are handled efficiently.

Uplink

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.

Supported modulation formats on the uplink data channels are QPSK, 16QAM and 64QAM.

If virtual MIMO / Spatial division multiple access (SDMA) is introduced the data rate in the uplink direction can be increased depending on the number of antennas at the base station. With this technology more than one mobile can reuse the same resources.

Spectrum

LTE and WIMAX each have their own benefits and are suited to address different target market segments.WiMAX is primarily TDD (Time-Division-Duplex) and will address operators that have unpaired spectrum whereas LTE is FDD (Frequency-Division-Duplex) and will address operators that have paired spectrum. TDD allows the up-link and down-link to share the same spectrum, whereas FDD has the up-link and down-link transmit on different frequencies.

Advanced Wireless Services (AWS)

In September 2006 the FCC completed an auction of AWS licenses ("Auction No. 66") in which the winning bidders won a total of 1,087 licenses. In the spirit of the U.S. government's free-market policies, the FCC does not usually mandate that specific technologies be used in specific bands. Therefore, owners of AWS spectrum are free to use it for just about any 2G, 3G or 4G, technology. This is the foundation of the tech neutrality concept.
This spectrum uses 1.710-1.755 GHz for the uplink and 2.110-2.155 GHz for the downlink. The 90 MHz of spectrum is divided into six frequency blocks labeled A through F. Blocks A, B, and F are 20

megahertz each and blocks C, D, and E, are 10 megahertz each. The FCC wanted to harmonize its "new" AWS spectrum as closely as possible with Europe's UMTS 2100 band. However, the lower half of Europe's UMTS 2100 band almost completely overlaps with the U.S PCS band, so complete harmonization wasn't an option. Given this constraint, the FCC harmonized AWS as much as possible with the rest of the world. The upper AWS band aligns with Europe's UMTS 2100 base transmit band, and the lower AWS band aligns with Europe's GSM 1800 mobile transmit band.

700 MHz

In the U.S. this includes 62 MHz of spectrum broken into 4 blocks; Lower A (12 MHz), Lower B (12 MHz), Lower E (6 MHz unpaired), Upper C (22 MHz), Upper D (10 MHz). These bands are highly prized chunks of spectrum and a tremendous resource: the low frequency is efficient and will allow for a network that doesn't require a dense buildout and provides better in-building penetration than higher frequency bands.

In 2005, the President of the U.S. signed the Digital Television Transition and Public Safety Act of 2005 into law, designating February 17, 2009 as the date that all U.S. TV stations must complete the transition from analog to digital broadcasts, vacating the 700 MHz radio frequency spectrum, and thereby making it fully available for new services. The upper C block will have "open access" rules. In the FCC's context "open access" means that there will be "no locking and no blocking" by the network operator. That is, the licensee must allow any device to be connected to the network as long as the device is compatible with, and will not harm the network (i.e., no “locking”), and the licensee cannot impose restrictions against content, applications, or services that may be accessed over the network (i.e., no “blocking”).

The upper D block will include a Public/Private Partnership obligation. As part of the 700 MHz FCC decision, the commercial license owner will combine this asset with an additional 10 MHz of adjacent spectrum licensed to a national Public Safety Broadband Licensee (PSBL), creating a public-private partnership. In exchange for constructing and operating the shared network to Public Safety specifications, the D Block commercial licensee will gain access to spectrum, on a secondary basis, held by the PSBL to provide it with additional capacity to furnish non-priority communications services to commercial subscribers.

Indications are strong that in Europe and much of the rest of the world, the so-called digital dividend – the freeing up of spectrum brought about by the switch from analog to digital TV- will also allow a significant amount of spectrum to be carved out for wireless broadband in the UHF band. While the details of the digital dividend outside of the U.S are still being debated, the expectation is that allocations will align with, or as closely as possible with the U.S. allocations in order to facilitate Global Roaming.

Refarming GSM 900 MHz

The 900 MHz band is the most ubiquitous and the most harmonized worldwide wireless telecommunication spectrum band available today. It also has the benefit of increased coverage and subsequent reduction in network deployment costs compared to deployments at higher frequencies, making it a highly strategic spectrum band. Furthermore, 900MHz offers improved building penetration and is particularly well suited to supporting those regions that have a predominantly rural population. The ongoing subscriber migration from GSM to UMTS taking place in over 150 countries worldwide is relieving pressure on the GSM900 networks and is starting to free up some spectrum capacity in that band. Consequently, many operators are evaluating the potential for deploying UMTS (HSPA/HSPA+) in this GSM900 band. On the other hand a number of operators are considering keeping that freed-up GSM spectrum until LTE becomes available in the beginning of 2010.From a planning perspective, UMTS deployments require a full 5 MHz of spectrum to be freed up before being deployed in that band. Additionally, the availability of mobile devices able to support 900 MHz is not planned until 2010 and counting. In contrast, LTE will be able to be deployed in spectrum bands as small as 1.25MHz and it provides good initial deployment scalability as it can be literally “squeezed” in as the GSM spectrum is freed-up, and grow as more spectrum becomes available. These factors reduce the time advantage of deploying UMTS (HSPA/HSPA+) in the 900 MHz band.In addition, with the improved spectrum efficiency, LTE deployment in the 900 MHz band would bring the highest capacity benefit and also provide operators the ability to deploy an LTE network with greater coverage at a much reduced cost compared to higher frequency spectrum hence provide a good mobile broadband data countrywide layer. Finally, deploying LTE in 900MHz can also bring the additional cost and logistic benefits of being able to deploy LTE at existing GSM sites as the coverage of GSM/LTE in 900MHz should be very similar.It is unlikely that operators in Europe would shut down their GSM networks as GSM still provides the backbone of voice communication and global roaming. GSM networks with EDGE or future E-EDGE upgrades do provide a good data sub-layer to hand over to, when, initially, LTE coverage will not available. The most likely scenario is that LTE at 900 MHz could run alongside GSM900 for a 5-10 year period after which time a GSM shutdown might be considered. The willingness of operators to commit to refarming 900 MHz will in many cases hinge on discussions at the EU level on the continuing legal applicability of the GSM Directives. Based on recent development, it now looks like the EU Parliament has endorsed the refarming of GSM spectrum paving the way for potential deployments of LTE into 900MHz.

IMT Extension Band

WRC-2000 identified three additional bands for terrestrial IMT-2000 including 2500-2690 MHz. As a result, starting in 2008, as much as 140 MHz of IMT2000 FDD expansion spectrum will be allocated in Europe; 2500-2570 MHz for uplink and 2620- 2690 MHz for downlink. Additionally up to 50 MHz (2570 MHz-2620 MHz) will be allocated as an unpaired TDD band. As a globally common band plan, this spectrum band will also enable economies of scale and global roaming. It is likely that LTE will be deployed in the FDD portion of this band due to its benefits as compared to HSPA/ HSPA+. In addition, this band is the only one of 2 bands that offers the unique opportunity for the deploymentof LTE in maximum spectrum bandwidth by providing channels of up to 20 MHz. In that sense, it is largely expected that current mobile operators will try and secure the maximum 20 MHz allocation to provide themwith the ability to support future mobile broadband capacity requirement.

Other Candidate Bands

GSM 1800: Interest from Americas, Asia Pac and some countries in EMEA, especially for the refarming of existing GSM spectrum.

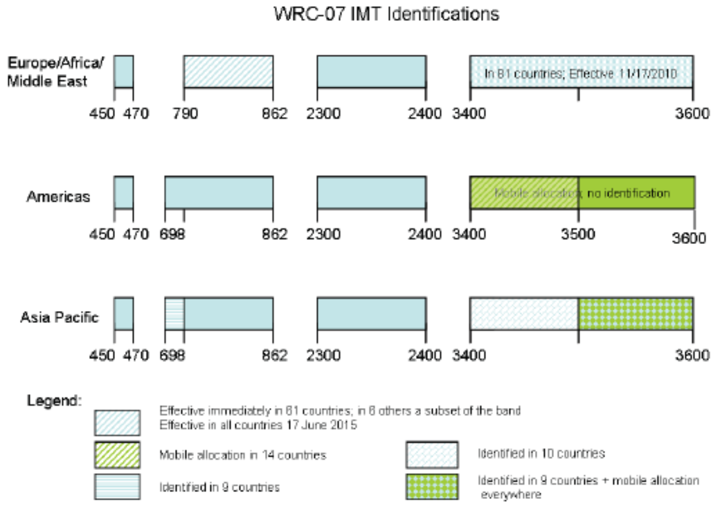
UMTS Core Band 2.1 GHz: This is the core 3-3.5G band for EMEA, AsiaPac & LAC with deployments of networks in over 150 countries. Most operators were awarded 2, 3 and in some limited instances 4 x 5 MHz carriers in this spectrum band. Most operators have so far only used one band, but with mobile data growth and subscriber migration to UMTS/HSPA, it is yet unclear if and how many carriers will be available in that band for LTE services in 2010 - 2012.

PCS 1900: Alternative to core band, which is not available in EMEA. Service providers may refarm this spectrum after the new 700 MHz and AWS spectrum is consumed.

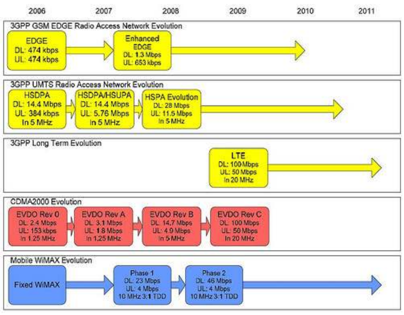
Cellular 850: Refarm this spectrum after the new 700 MHz and AWS spectrum is consumed. Very popular alternative in former Warsaw pact countries that have joined NATO.

Future Spectrum Requirements

ITU (ITU-R M.2078) projects overall spectrum requirements for the future development of IMT-2000 and for IMT-Advanced. The results assert that additional spectrum demand of between 500 MHz and 1 GHz will be needed in all ITU Regions by 2020. This report expresses traffic growth factors of 2 to 3 by 2010 for Europe compared to today. It is clear that existing bands will not be enough for IMT services approximately after the year 2015 and additional bands are needed. In order to deliver a true broadband experience, large blocks of spectrum will need to be identified and allocated. One of the goals of WRC-07 was to identify additional, harmonized, worldwide spectrum, to enable global roaming services while bringing economies of scale to vendors. In this regard, WRC-07 identified the 450-470 MHz and 2300-2400 MHz bands for IMT (which includes both IMT-2000 and IMT-Advanced) on a global basis. In addition, WRC-07 identified portions or all of 698-862 MHz and 3400-3600 MHz. The identification and use of these bands varies from region-to-region and country-to-country as detailed in below. The Final Acts from WRC-07 provide full details on these identifications. WC-07 made positive steps towards making spectrum available for future LTE deployments. In particular, WRC-07 began the process of migrating broadcast spectrum in the 698-806 MHz band to mobile applications. The next steps will be working with individual countries to ensure spectrum is recovered and licensed for mobile systems at a national or regional level around the world. In addition, achieving an internationally harmonized band plan for use of the spectrum is also important.

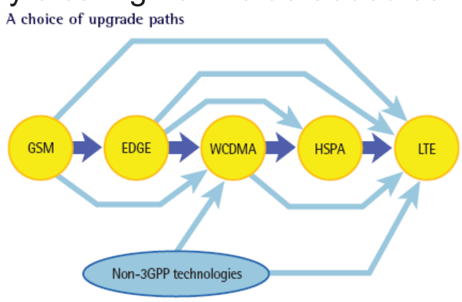


NETWORK EVOLUTION



In parallel with its advanced new radio interface, realising the full potential of LTE requires an evolution from today's hybrid packet/circuit switched networks to a simplified, all-IP (Internet Protocol) environment. From an operator's point of view, the pay-off is reduced delivery costs for rich, blended applications combining voice, video and data services plus simplified interworking with other fixed and wireless networks.

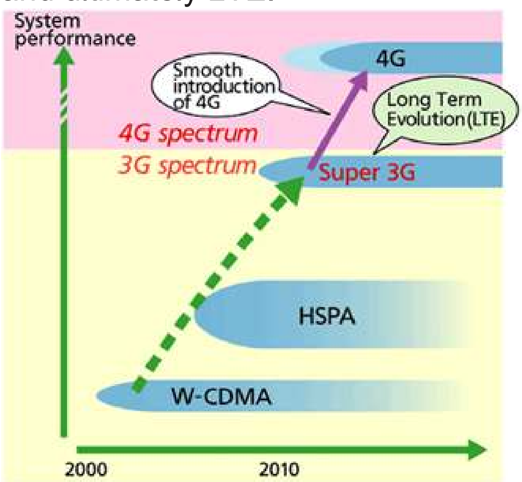
By creating new value-added service possibilities,



LTE provides a smooth evolutionary path for operators deploying all 3GPP and non-3GPP technologies.

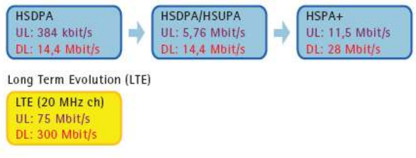
LTE promises long-term revenue stability and growth for around two hundred mobile operators that are already firmly committed to the UMTS/HSPA family of 3G systems. Just as

importantly, it provides a powerful tool to attract customers who are provided with an increasing number of technology options for broadband connectivity on the move.
Based on the UMTS/HSPA family of standards, LTE will enhance the capabilities of current cellular network technologies to satisfy the needs of a highly demanding customer accustomed to fixed broadband services. As such, it unifies the voice-oriented environment of today's mobile networks with the data-centric service possibilities of the fixed Internet. Another key goal of the project is the harmonious coexistence of LTE systems alongside legacy circuit switched networks. This will allow operators to introduce LTE's all-IP concept progressively, retaining the value and preserving the ROI of their existing voice-based service platforms while benefiting from the performance boost that LTE delivers for data services. 3GPP proposed migrating towards an all-IP core network as early as Release 4, hinting at what would become a prominent feature of later UMTS/HSPA releases
and ultimately LTE.



The concept of 'Long Term Evolution' for today's 3G/UMTS standard was discussed in detail in 2004, when a RAN (Radio Access Network)

Evolution Workshop in Toronto accepted contributions from more than 40 operators, manufacturers and research institutes (including 3GPP members as well as non-member organisations). Contributors offered a range of views and proposals on the evolution of the UTRAN (Universal Terrestrial Radio Access Network).



Uplink and downlink data rates compared for HSPA and LTE.

Following the Toronto workshop, in December 2004, 3GPP launched a feasibility study in order "*to develop a framework for the evolution of the 3GPP radioaccess technology towards a high-data-rate, low-latency and packet-optimised radio -access technology*". In other words, the study would map out specifications for a radio access network (RAN) capable of supporting the broadband Internet user experience we already enjoy in today's fixed networks – with the addition of full mobility to enable exciting new service possibilities.

Today, specifications for LTE are encapsulated in 3GPP Release 8, the newest set of standards that defines the technical evolution of 3GPP mobile network systems.

Release 8 succeeds the previous iteration of 3G standards – Release 7 – that includes specifications for HSPA+, the 'missing link' between HSPA and LTE. Defined in 3GPP Releases 7 and 8, HSPA+ allows the introduction of a simpler, 'flat', IP-oriented network architecture while bypassing many of the legacy equipment requirements of UMTS/HSPA.

Peak data rates with HSPA+ are 28 Mbit/s on the downlink and 11.5 Mbit/s on the uplink using 2x2 MIMO (Multiple-Input Multiple-Output) antenna techniques and 16QAM (Quadrature Amplitude Modulation). However, HSPA+ can further boost data rates up to 42 Mbit/s on the downlink and 23 Mbit/s on the uplink using 2x2MIMO and 64QAM, a combination that is part of Release 8.
As such, HSPA+ slots neatly between the already impressive performance of HSPA (with its theoretical downlink performance of up to 14.4 Mbit/s) and LTE that promises rates of 300 Mbit/s in the downlink and 75 Mbit/s in the uplink forevery 20 MHz of paired spectrum.

SERVICES

Through a combination of very high downlink (and uplink) transmission speeds, more flexible, efficient use of spectrum and reduced packet latency, LTE promises to enhance the delivery of mobile broadband services while adding exciting new value-added service possibilities.

But what does this mean in terms of operator revenues and subscriber growth in a market where broadband connectivity is rapidly becoming commoditised?

An overarching objective for LTE is the stabilisation and reversal of steadily declining ARPU (Average Revenue per User) that is characteristic of many mobile markets.

A study conducted in 2007 for the UMTS Forum, compared the services supported by today's mobile network technologies with the richer service possibilities that LTE enables through higher downlink speeds and reduced latency for packet-based services.

For consumers, this enriched user experience will be typified by the large-scale streaming, downloading and sharing of video, music and rich multimedia content. All these services will need significantly greater throughput to provide adequate quality of service, particularly as users' future expectations will be increased by the growing popularity of other high-bandwidth platforms like High Definition TV transmission. For business customers it will mean high-speed transfer of large files, high-quality videoconferencing and secure nomadic access to corporate networks.

Similarly, LTE brings the characteristics of today's 'Web 2.0' into the mobile space for the first time. Alongside secure e-commerce, this will span real-time peer-topeer applications like multiplayer gaming and file sharing.

In addition, the study considered a distinct set of services that do not have clear analogies in today's fixed network environment. These include 'machine to machine' (M2M) applications and the large-scale exchange of community based projects.

Service category	Current environment	LTE environment
Rich voice	Real-time audio	VoIP, high quality video conferencing
P2F messaging	SMS, MMS, low priority e-mails	Photo messages, IM, mobile e-mail, video messaging
Browsing	Access to online information services, for which users pay standard network rates. Currently limited to WAP browsing over GPRS and 3G networks	Super-fast browsing, uploading content to social networking sites
Paid information	Contentforwhich users pay over and above standard network charges. Mainly text-based information.	E-newspapers, high quality audio streaming
Personalisation	Predominantly ringtones, also includes screensavers and ringbacks	Realtones (original artist recordings), personalised mobile web sites
Games	Downloadable and online games	A consistent online gaming experience across both fixed and mobile networks
TV/ video on demand	Streamed and downloadable video content	Broadcast television services, true on-demand television, high quality video streaming
Music	Full track downloads and analogue radio services	High quality music downloading and storage
Content messaging and cross media	Peer-to-peer messaging using third party content as well as interaction with other media	Wide scale distribution of video clips, karaoke services, video-based mobile advertising
M-commerce	Commission on transactions (including gambling) and payment facilities undertaken over mobile networks	Mobile handsets as payment devices, with payment details carried over high speed networks to enable rapid completion of transactions
Mobile data networking	Access to corporate intranets and databases, as well as the use of applications such as CRM	P2P file transfer, business applications, application sharing, M2M communication, mobile intranet/ extranet

Classification of mobile services that will be enabled or enriched in an LTE environment.

LTE ADVANCED

Being defined as a 3G technology LTE does not meet the requirements for 4G also called *IMT Advanced* as defined by the International Telecommunication Union such as peak data rates up to 1 Gbit/s. The ITU has invited the submission of candidate Radio Interface Technologies (RITs) following their requirements as mentioned in a circular letter.

The mobile communication industry and standardisation organisations have therefore started to work on 4G access technologies such as LTE Advanced. At a workshop in April 2008 in China 3GPP agreed the plans for future work on Long Term Evolution (LTE) a first set of 3GPP requirements on LTE Advanced has been approved in June 2008. Besides the peak data rate 1 Gbit/s that fully supports the 4G requirements as defined by the ITU-R, it also targets faster switching between power states and improved performance at the cell edge. Detailed proposals are being studied within the working groups.

Proposed Features:

- *Backward compatibility* with LTE and 3gpp legacy systems.
- *Peak data rate* 1 Gbps DL and 500 Mbps UL.
- *BW about 70 MHz* in DL and 40 MHz in UL.
- *C plane latency* from Idle with IP address to Connected less than 50 ms and U plane latency shorter than 5 ms towards RAN, taking into account 30% retransmissions (FFS).
- *Cell edge throughput* twice that of LTE.
- *3 times higher* average user throughput than LTE.
- *3 times more* spectral efficient than LTE.
- *Support of scalable BW* and spectrum aggregation.
- *Peak spectrum efficiency* 30 bps/Hz in DS and 15 bps/Hz in UL.

Technology proposals

The proposals could roughly be categorized into:

- *UE Dual TX antenna solutions* for SU-MIMO and diversity MIMO scalable system bandwidth exceeding 20 MHz, potentially up to 100MHz.
- *Local area optimization* of air interface.
- *Nomadic / Local Area network* and mobility solutions.
- *Flexible Spectrum Usage.*
- *Cognitive Radio.*
- *Various concepts* for Relay Nodes.
- *Automatic and autonomous* network configuration and operation.
- *Enhanced precoding* and forward error correction.
- *Interference management* and suppression.
- *Asymmetric bandwidth* assignment for FDD.
- *Hybrid OFDMA* and SC-FDMA in uplink.
- *UL/DL inter eNB* coordinated MIMO.

As can be seen most of the proposals address the PHY layer.

Support of larger bandwidth in LTE Advanced

In 4G, bandwidths up to 100MHz are foreseen to provide peak data rates up to 1 Gbps. In general OFDM provides simple means to increase bandwidth by adding additional subcarrier. Since Release 8 UE capabilities only support 20MHz bandwidth, the scheduler must consider a mix of terminals. Due to a fragmented spectrum the available bandwidth might also be not contiguous. To ensure backward compatibility to current LTE the control channels such as synchronisation, broadcast or PDCCH/PUCCH might be needed per 20MHz. Some of the main challenges for 100 MHz terminals are:

- *Availability of RF* filter for such an large bandwidth and bandwidths of variable range
- *Availability of Analog Digital Converter* with such a high sampling rate and quantization resolution
- *Increased decoding complexity* e.g. for channel decoding and increased soft buffer size

Minimum changes to the specifications will be required if Resource Allocation, MIMO, Link Adaptation, HARQ etc are done per 20MHz. The scheduler must operate across the bandwidth and there will be a larger number of transport blocks per transmission time interval. Currently the Frequency Division Duplex (FDD) schemes as defined for LTE in Release 8 are limited to operate in a fully symmetric allocation of paired spectrum. This makes it difficult to find suitable FDD spectrum allocations and also cannot efficiently support asymmetric traffic. For LTE Advanced more flexible bandwidth allocations are currently being considered.

LTE Advanced will be standardised in the 3GPP specification Release 10 and will be designed to meet the 4G requirements as defined by ITU. Amongst others 4G technologies must support various bandwidth allocations up to 100MHz and shall support peak data rates up to 1 Gbps for stationary terminals. LTE Advanced, which is likely to be the first true 4G technology, will be a smooth evolution of the LTE standard will be based on same principles. Work on the requirements is already progressing in 3GPP while work on technology proposals is expected to go on for some time within the working groups. Several changes on the physical layer can be expected to support larger bandwidths with more flexible allocations and to make use of further enhanced antenna technologies. Coordinated base stations with coordinated scheduling, coordinated MIMO or interference management and suppression will also require changes on the network architecture.

Strategic Marketing Perspective

Long Term Evolution has been, directly or indirectly, about 14 years in the making when the cellular industry decided to slowly, but surely, abandon the circuit switched global title/ISDN/SS7 network (which had been around in one way or another since the beginning of the 1940s) and migrate to an all ip framework (GSM- GPRS-3G (incl. HSPA)-SAE/LTE - 4G LTE Advanced).

A number of LTE promotional materials state that LTE gives equivalent fixed line and better voice service. This kind of positioning does injustice to mobile communication technologies and generates unrealistic expectations.

Mobile throughput and quality will never be able to compete with state of the art fixed and should not be positioned to. Fixed technology propagates within a controlled environment (ex. a wire) while mobile technology (propagation based) is always challenged by nature (propagation effects etc…). If LTE boasts 100 Mbps downlink and 50 Mbps uplink, fixed can deliver via fiber 100Gbps symmetrical. If mobile reaches 100 Gbps (which will require a good portion of spectrum), then fixed will top 100 Tbps.

Mobile technologies should be marketed for the benefit that they add, i.e. that they offer mobility with an adequate infrastructure to accommodate the required services with resilience and certainty. ***Mobility*** is the key word and not ***Compare***.

LTE goes a long way in offering mobility based broadband services. In addition, the flattened network will make it more manageable and less expensive to maintain. The fact that it rests (finally) on a common architecture/protocol (ip) implies that it can eventually align its roadmaps with other ip based systems, including an ip based fixed network (implying an eventual technical convergence to a common core network for fixed/mobile systems).

LTE does not go a long way in opening up the network to accommodate third party initiatives, even though the IMS subsystem will indeed provide APIs to independent approved software developers. LTE is still very much a telecom network and not an open network as many from the other side of the fence would've hoped. The fact that LTE is an IMS based network (implying SIP based central core network control) implies limited accommodation of peer advancements and surrogate based technologies which are emerging rapidly and accelerating the evolution at the edge of the network.

Summary

Most operators will upgrade their packet core network (SGSN, GGSN etc…) towards the *Evolved Packet Core* functionality (initially this will be a pure software upgrade but eventually, once the CS functionality is totally removed, this will be replaced by high capacity routing mechanisms). These boxes will then be replaced by high capacity high speed dumb *ip routers* and the mobility intelligence will reside in servers. This means that voice call handling (which will be ip based) will be nothing more than another software application and *pcm based* communication will be, at least for mobile technology, a thing of the past.