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Report on LTE

File Name	Interim Report LTE.docx
Revision	V1
Date	April 2011
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7.1 History

7.1.1 Cellular Networks

The concept of cells was developed by Bell labs of the ISA in 1947. It allowed the capacity of the network to be increased substantially by dividing the coverage into small cells each with its own base station operating at a different frequency. Given that cells will have the same overall throughput capacity, cells in densely populated area will be of a reduced size whereas cells in more rural locations could span many kilometres.

7.1.2 First Generation Systems

The first commercial mobile networks were analogue and arrived in the 1980s. These developed independently and there was no global standard.[719]

- AMPS – Analogue Mobile Phone System – Used in America
- TACS – Total Access Communication System – Europe
- NMT – Nordic Mobile Telephone – Europe
- J-TACS – Japanese Total Access Communication System – Japan & Hong Kong

One advantage that these analogue systems had over their digital successor GSM was its range which made it ideal for sparsely populated areas

7.1.3 Second Generation Systems (2G)

Global **S**ystem for **M**obile communication (GSM) was developed collaboratively by companies working under the European Technical Standards Institute (ETSI). This was a digital, voice connection oriented system which allowed roaming across European countries. The first GSM network was launched in 1991 in Finland.

GSM uses Time Division Multiple Access (TDMA) to divide the carrier frequency into slots for individual phones use.

GSM has become the dominant standard for mobile telecommunications, offered in over 218 countries worldwide and having a coverage of over 80% of the world, with active GSM – *3GSM* subscriptions exceeding 4.5 billion [712, 713].

General Packet Radio Service (GPRS) was an enhancement to GSM standard developed by the 3rd Generation Partnership Project (3GPP). The class of a GPRS phone determines the speed at which data can be transferred. The class refers to the number of timeslots available for transmission of data. The maximum speed GPRS is 48K (for 5 Slots). [712]

Enhanced Data rates for GSM Evolution (**EDGE)** achieves higher data throughput by using more slots and higher encoding rate (8PSK) (i.e. 3 bits per symbol) giving a transmission rate of up to 473Kbits^{-1}. [712]

Evolved EDGE achieves even higher rates through, among other things, higher order modulation (16QAM and 32QAM) rates. Edge like GPRS will reduce its modulation and coding scheme according to the quality of the radio signal. [712]
GPRS and EDGE are a best effort service (i.e. there is no guaranteed quality of service as in a switched circuit). Several subscribers share the same bandwidth. I have experienced data rates as low as 25 Kbits^{-1} while connected to EDGE in spite of there being excellent signal quality.

7.1.4 Third Generation Systems (3G)

To offer third generation (3G) technologies, the 3GPP group developed Universal Mobile Telecommunication System (UMTS). UMTS is set up as part of the International Mobile Telecommunication (IMT) and its task is to specify the requirements of 3G technologies. UMTS has a completely new designed radio access network introducing Wideband Code Division Multiple Access *(WCDMA) [719]*.Currently, the 3GPP group has evolved UMTS in Releases 5, 6 and 7.

Release	Functional freeze	Main UMTS feature of release
Rel-99	March 2000	Basic 3.84 Mcps W-CDMA (FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	December 2007	HSPA+ (64QAM downlink, MIMO, 16QAM uplink) LTE and SAE feasibility study
Rel-8	December 2008	LTE work item – OFOMA/SC-FDMA air interface SAE work item – new IP core network Further HSPA improvements

Table 701: Evolution of the Universal Mobile Telecommunications (UMTS) specifications. Source [714] (Note: The Table does not include advance in GSM specification i.e. EDGE and EDGE+)

Mobile operators had to build entirely new networks and license entirely new frequencies (2100MHz), especially to achieve high-end data transmission rates of up to 2mbits^{-1} for stationary or near stationary users and 384kbits^{-1} for mobile users.

The UK Government scooped £22bn from the sale of licences for 3G. Many commentators view that the mobile operators paid too much for their licenses and left them without the funds to invest in their networks, leaving companies like Vodafone with the challenge of generating £600 pounds from each subscriber just to cover their £6bn 3G license costs.

High Speed Downlink Data Access (HSDPA) is an enhancement to 3G and is part of UTMS standards since release 5. High downloads speeds of 14Mbits^{-1} are achieved through higher order modulation 64QAM, reduced radio frame lengths and new functionalities within the radio networks [708].

HSDPA+ an evolution of HSPA was specified resulting from studies in Release 7 which added multiple input/ multiple output (MIMO) antenna capability and 16QAM (Uplink)/ 64QAM (Downlink) modulation.

In reality the speeds, observed by UK consumers is considerably lower. BBC News reported that consumers in towns in Britain were receiving between 1.7-3.6 Mbits^{-1} for their down link connections.

With the advent of I-phones, tablets and other such sophisticated mobile devices and applications there is a requirement for ever higher bandwidth.

7.2 Long-Term-Evolution

7.2.1 LTE Introduction

The Long-Term-Evolution (LTE) project was started in November 2004 by 3GPP to develop a standard for the next generation cellular mobile technology. The first version of LTE is documented in Release 8 of the 3GPP Specifications.

The LTE stated requirements [711, 719] included

- Increased user data rates – *100Mbps^{-1} downlink, 50Mbits^{-1} uplink*
- Reduced connection time and plane latency – *<100ms connection time, <10ms two way radio round trip.*
- Lower cost per bit through spectral efficiency
- Simplified network architecture
- Greater flexibility in use of spectrum
- Seamless mobility – *sustained connections at speeds up 350km/h (for high speed trains)*
- Reasonable power consumption for user equipment.

LTE which involves the evolution of the Universal Terrestrial Radio Access Network (E-UTRAN) has been accompanied by a parallel 3GPP project called System Architecture Evolution (SAE) an all new IP packet based network known as Evolved Packet Core (EPC). Together LTE and SAE are referred to as the Evolved Packet System (EPS). However, in literature depending on the context, long term evolution LTE is often used to apply to both the LTE and SAE.

Another misnomer is that LTE is often referred to by suppliers, consumers and in the news as a 4th Generation (4G) systems. However LTE does not meet the International Mobile Telecommunication – Advanced (IMT-Advanced) specifications for 4G technologies. LTE-Advanced, is aimed to meet these standards.

LTE has been developed as an evolution of existing 3G technologies. This allows for a simplified, less expensive upgrade from the existing network technology.

7.2.2 LTE and SAE

LTE and SAE were developed to support packet switched services rather than circuit switched services as was the case in the earlier models on cellular networks. This trend to focus on data rather than voice started with 3G. LTE and SAE is entirely Internet Protocol based. In contrast to GSM and 3G where the User Equipment (UE) was allocated temporarily an IP address for data transmissions, in LTE the UE is permanently allocated an IP address. (In GSM and 3G the UE could be reached over circuit switched network). In LTE, without an IP address the UE cannot be reached.

At High level, LTE the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) consists of evolved NodeB (eNB) or base station whereas the evolved packed network consists of several logical nodes.

- PDN-Gateway (P-GW). The Packet Data Network Gateway is responsible for IP address allocation for the User Equipment (UE) as well as the Quality of Service (QoS) enforcement.
- Serving Gateway (S-GW). All user packets are transferred via the serving gateway. It serves as the anchor for bearers as users move from eNodeB to eNodeB (i.e. Base Station to Base Station)
- Mobility Management Entity (MME).

7.2.3 LTE Quality of Service

LTE is implemented on IP based network. The importance for Quality of Service (QoS) when sharing resources between critical and non-critical data transfer is very high. Applications like VoIP do not tolerate delayed packets where application like email would be perfectly happy with a best effort service.
Release 8 offers a classed based QoS concept for delivering real time and non-real time traffic, with current and future QoS in mind. A network initiated QoS system is implemented offering control based on Guaranteed Bit Rate (GBG) and Non-Guaranteed Bit Rate (Non-GBG) [714].

7.2.4 LTE Radio Architecture

Downlink and OFDM

New Radio Spectrum cannot be invented only used more efficiently. On the downlink LTE uses Orthogonal Frequency Division Multiple Access (OFDMA). This is a variant of Orthogonal Frequency Multiplexing (OFDM). In OFDM carriers are made orthogonal by the use of a Fourier Transform. This allows for a large number of closely spaced orthogonal carriers that can be transmitted in parallel.

Each subcarrier is modulated using QSPK, 16QAM or 64QAM (providing 2, 4 and 6 bits per symbol). Link adaptation is used to determine data rate or error probabilities by adapting modulation and channel coding schemes to current channel conditions.

OFDMA is more efficient than Wideband Code Division Multiple Access (WCMA) used in UMTS 3G. The European Telecommunications Standards Institute (ETSI) first looked at OFDM for GSM back in the late 1980s however, the processing power required to perform the many Fast Fourier Transforms (FFT) operations at was too expensive. In 1998 the 3GPP seriously considered OFDMA for 3G UMTS but the decision went in favour of WCDMA. Today, cheap computing power has made OFDMA viable [714, 719].

Uplink and SC-FDMA

One of the main disadvantages of OFDMA is the high Peak Power to Average ratio of the signal. This requires powerful amplifiers for the sending device making it unsuitable for user equipment. This led the 3GPP to choose Single Carrier Frequency Division Multiple Access (SC-FDMA) for the uplink. Having an efficient (energy) transmission scheme ensures that the mobile devices with little power available are both efficient and cost effective. [710,714]

MIMO

To increase throughput, LTE uses spatial multiplexing, a technology that uses two multi-antenna transmissions: Transmit Diversity and Multi-stream Transmission. At both network and user level, Multi-stream Transmission uses multiple antennas in order to provide increased peak data rate. This is achieved by simultaneous transmissions over a single radio link. Multilayer antenna solutions also generate High peak rates, for example 2x2 or 4x4 multiple in multiple out (MIMO). Extended coverage is achievable by beam forming.

Multi User scheduling

The eNodeB is responsible for managing the resources for both the uplink and down link channels. The objective is to fulfil the expectations of many users while meeting the QoS requirements of their applications.
Two extremes of scheduling are opportunistic scheduling and fair scheduling. Opportunistic scheduling attempts to maximise the data transferred by the entire network whereas fair scheduling pays more attention to the latency for each user rather than total data achieved through the network.

7.3 LTE Advanced

Even though LTE is a high speed data network it does not meet the standards set by IMT-Advanced for 4G technology.

Release 10 from 3GPP, a project known as Long-Term-Evolution-Advanced (LTE-Advanced) is designed to be 4G technology meeting IMT-Advanced requirements.

The 3GPP LTE-Advanced will

- Enhanced Data rates –
  - peak data rates of $1Gbs^{-1}$ downlink and $500mbs^{-1}$ low mobility
  - and $100Mbs^{-1}$ high mobility
- LTE Advanced should be able to aggregate non contiguous carriers (a bandwidth of 100MHz is likely to be required to achieve $1Gbs^{-1}$ downlink, this spectrum may not be found contiguously)
- High order spatial multiplexing (MIMO) up to eight transmit aerials and for receive aerials at the enodeB
- Coordinated MIMO schemes involving multiple cells to improve overall spectral efficiency.

- The use of relays nodes to improve data rates to edge of cell users
- Backwards compatibility, mobility between LTE-Advanced, LTE, GSM/EDGE, HSPA and CDMA200.

7.4 Implementation of LTE and 4G

7.4.1 First implementation of LTE

Nordic carrier TeliaSonera deployed what it claims are the world's first two commercial LTE networks in December 2009 in Stockholm and Oslo, offering maximum throughput speeds of 100Mbits/s. Ericson provided Swedish network whereas the Norwegian kit was provided by Chinese vendor Huawei.[715]

7.4.2 Strategies for implementing LTE

It is envisaged that carriers will adopt several strategies for implementing LTE. Some will implement data over LTE while using the older 3G and 2G networks for voice. Nearly all of them will have a fall back strategy of fall back HSDPA and EDGE for areas where no LTE coverage

7.4.3 Comparison of LTE with other technologies

In the 3G and HSDPA world service providers always prefer the customer to connect to their WI-FI hotspots in preference to their 3G and HSDPA networks. This gives an indication of the relative costs and performance of proving these services. It is unlikely that the cost model will change even with the introduction of LTE. Wide area license radio spectrum is likely always to be at a premium.

Probably more interesting, is to compare LTE with WiMAX. The initial release of WiMAX was not mobile but with the release of IEEE 802.16e, WiMAX gained mobile capabilities. A comparison of the technologies and the business model is given in section 9.2.

7.4.4 Sale of 4G licenses in the UK

On 22nd March 2011, Ofcom the telecoms regulator launched a consultation on how best to sell off the rights to the next generation of mobile wireless networks. [717,718]

There are two blocks of frequency to be sold off. One block in 2.6 GHz band and the other in the lower frequency of 800MHz band a spin off from the migration from analogue to digital TV. The bandwidth being sold off is 80% more than what was sold in 3G auction in 2000. [718]

It is unlikely that that the Government will raise the £22 billion it raised through the sale of 3 G licenses. The German auction of 4G licences last year raised 4.3Bn Euros as against the 50bn Euros it raised from the sale of 3G licenses in 2000 .[716]

Most telecoms analyst believe that mobile providers over paid for 3G licences in 2000 [701,702,703,704,705]

7.5 Conclusion

Provided LTE and LTE Advanced live up to the hype and deliver the throughput in the specifications, they will radically change the way we conduct our working and social lives. The high data speed they will offer, will allow businesses to have more mobile and remote work force.

With the integration of high speed mobile devices into cars, it will allow better traffic management (Even with today's technology, Honda was able to open up its navigation systems after the Japanese earthquake to show what routes in northern Japan were open). Integration of LTE into vehicle entertainments systems will provide the ability for video conferencing, sharing of data and other collaborative activities.

Investment is essential to LTE and LTE-advanced. The Mobile operators must over pay for their 4G licences.

LTE provides an upgrade path from the currently deployed 3G and 2G Technologies

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