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4G LTE Cellular Technology: Network Architecture and Mobile Standards

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Abstract—

The earlier evolution of broadband wireless technologies is the consequence of growing demand in the world for best ever mobile Internet access and wireless multimedia applications. This paper explores the network architecture of 4G (4th Generation) and LTE (Long Term Evolution) wireless technologies, the mobile standards used by these technologies and key features. The 4G architecture basically build upon 3G or can say that it is a extension of 3G wireless technology. 4G represents the future of mobile communications in the longer term. In 4G, the majority of the traffic is data and multimedia as opposed to voice only. Data rates in 4G systems will range from 20 to 100 Mbps. Through a common wide-area radio-access technology and flexible network architecture WiMAX and LTE has enabled convergence of mobile and fixed broadband networks. Next fourth generation (4G) mobile technology, promises the full mobility with high speed data rates and high-capacity IP-based services and applications while maintaining full backward compatibility. LTE is not as much a technology as it is the path followed to achieve 4G speeds.

Keywords— 4G, LTE, Wireless Technology, Cellular Network, OFDMA, WiMAX, E-UTRAN, etc.

I. INTRODUCTION

4G is short for Fourth (4th) Generation Technology and it is an attempt to evolve, integrate and amalgamate the current 2G (2nd Generation), 3G (3rd Generation), WLAN (Wireless Local Area Network), broadcast, short-range and fixed wire systems into a single, fully functional, seamless internetwork. 4G Technology is basically the extension in the 3G technology with more bandwidth and services offers in the 3G. 4G have the features of a scalable, flexible, efficient, autonomous, secure and feature-rich backbone to support a multitude of existing and new services and to interface with many different types of networks. It offers fully converged services (voice, data and multimedia) at data rates of up to 100 Mbps and ubiquitous mobile access to a vast array of user devices autonomous networks. Basically, 4G is an improvement and integration of various existing technologies including GSM, GPRS, CDMA, W-CDMA, CDMAone, IMT-2000, Wireless LANs and Bluetooth, etc. The expectation for the 4G technology is the high quality audio/video streaming over end to end Internet Protocol. If the Internet Protocol (IP) multimedia sub-system movement achieves what it going to do, nothing of this possibly will matter. WiMAX or mobile structural design will become progressively more translucent, and therefore the acceptance of several architectures by a particular network operator ever more common. The main features of 4G services of interest to users are application adaptability and high dynamism user's traffic, radio environment, air interfaces, and quality of service. A 4G system must provide capabilities defined by ITU (International Telecommunications Union) in IMT (International Mobile Telecommunications) Advanced. Potential and current applications include amended mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, and 3D television.

II. FOURTH (4TH) GENERATION MOBILE COMMUNICATION

The International Telecommunications Union-Radio communications sector (ITU-R) specified a set of requirements for 4G standards, named the International Mobile Telecommunications Advanced (IMT-Advanced) specification, setting peak speed requirements for 4G service at 100 megabits per second (Mbit/s) for high mobility communication and 1 gigabit per second (Gbit/s) for low mobility communication. Since the first-release versions of Mobile WiMAX (Worldwide Interoperability for Microwave Access) and LTE (Long Term Evolution) support much less than 1 Gbit/s peak bit rate, they are not fully IMT-Advanced compliant, but are often branded 4G by service providers. As opposed to earlier generations, a 4G system does not support traditional circuit-switched telephony service, but all-Internet Protocol (IP) based communication such as IP telephony. The IP Core network has much more stringent requirements and is developed further to support high data rates, provide advanced application services support and manage itself as well as the radio network more efficiently. The spread spectrum radio technology used in 3G systems, is abandoned in all 4G candidate systems and replaced by OFDMA (Orthogonal Frequency Division Multiple Access) multi-carrier transmission and other FDE (Frequency-Domain Equalization) schemes, making it possible to transfer very high bit rates despite extensive multi-path radio propagation. The peak bit rate is further improved by smart antenna arrays for MIMO (Multiple-Input Multiple-Output) communications.

The pre-4G 3GPP (3rd Generation Partnership Project) Long Term Evolution (LTE) technology is often branded "4G-LTE", but the first LTE release does not fully comply with the IMT-Advanced requirements. LTE has a theoretical net bit rate capacity of up to 100 Mbit/s in the downlink and 50 Mbit/s in the uplink if a 20 MHz channel is used and more if MIMO i.e. antenna arrays are used. The physical radio interface was at an early stage named High Speed OFDM Packet Access (HSOPA), now named Evolved UMTS Terrestrial Radio Access (E-UTRA). The first LTE USB dongles do not support any other radio interface. 4G networks provide even higher bitrates and many architectural improvements which are not necessarily visible to the consumer. The current 4G systems that are deployed widely are Evolved High Speed Packet Access (HSPA+), WiMAX and LTE. The latter two are pure packet based networks without traditional voice circuit capabilities. These networks provide voice services via VoIP (Voice over Internet Protocol).

III. NEED AND SCOPE FOR 4G TECHNOLOGY

The use of 4G service will be very similar to that of 3G service even as offering much higher data transfer rates and therefore allowing either more speed intensive applications or more users to experience good speeds whilst only connected through 1 carrier. The 4G aims to:

- 4G Ultra high speed internet access - E-mail or general web browsing is available.
- 4G Data intensive interactive user services - Services such as online satellite mapping will load instantly.
- 4G Multiple User Video conferencing - subscribers can see as well as talk to more than one person.
- 4G Location-based services - a provider sends wide spread, real time weather or traffic conditions to the computer or phone, or allows the subscriber to find and view nearby businesses or friends whilst communicating with them.
- 4G Tele-medicines - a medical provider monitors or provides advice to the potentially isolated subscriber whilst also streaming to them related videos and guides.
- Develop the IMT-2000 CDMA technologies to make more efficient use of the available frequency spectrum.
- Evolve the Cellular Network Architecture to suit high levels of mobility and purely packet-switched data.
- Allow for short-range Ad Hoc networking among wireless devices.
- Make significant advances on the security and scalability.

IV. NETWORK ARCHITECTURE OF 4G

The architecture of the 4G network will more or less resemble the 3G architecture but there are some significant evolutionary changes. Circuit-switching capabilities are redundant in 4G and are thus removed. The MSC (*Mobile Switching Centre)* used previously to service legacy 2G voice traffic is discarded and all voice traffic is treated as packet data at the BS (Base Station). Backward compatibility is maintained by segmenting voice data into packets and routing them through the IP backbone using VOIP (Voice Over IP) technology. A VOIP Gateway is used to connect to PSTN (Public Switched Telephone Network) or ISDN (Integrated Services Digital Network). Another major advancement that 4G makes is the integration of Wireless LANs into the total mobile network. The situation will be similar to what is happening today with wired LANs - the line between a wired WAN and a wired LAN has blurred with the use of same technologies in both (eg. ATM). Similarly, new air interface standards are being developed for high-speed wireless LANs in conjunction with those for the cellular 4G network, which allows wireless LANs to be interconnected to the 4G IP backbone simply via routers with wireless access built-in. All interfaces are air interfaces in this scheme and there is no need for a CM (Control Module) connected to any wired infrastructure. 4G supports ad hoc networking via a more evolved version of a currently existing standard called Bluetooth. The architectural diagram of 4G cellular network is as follows:

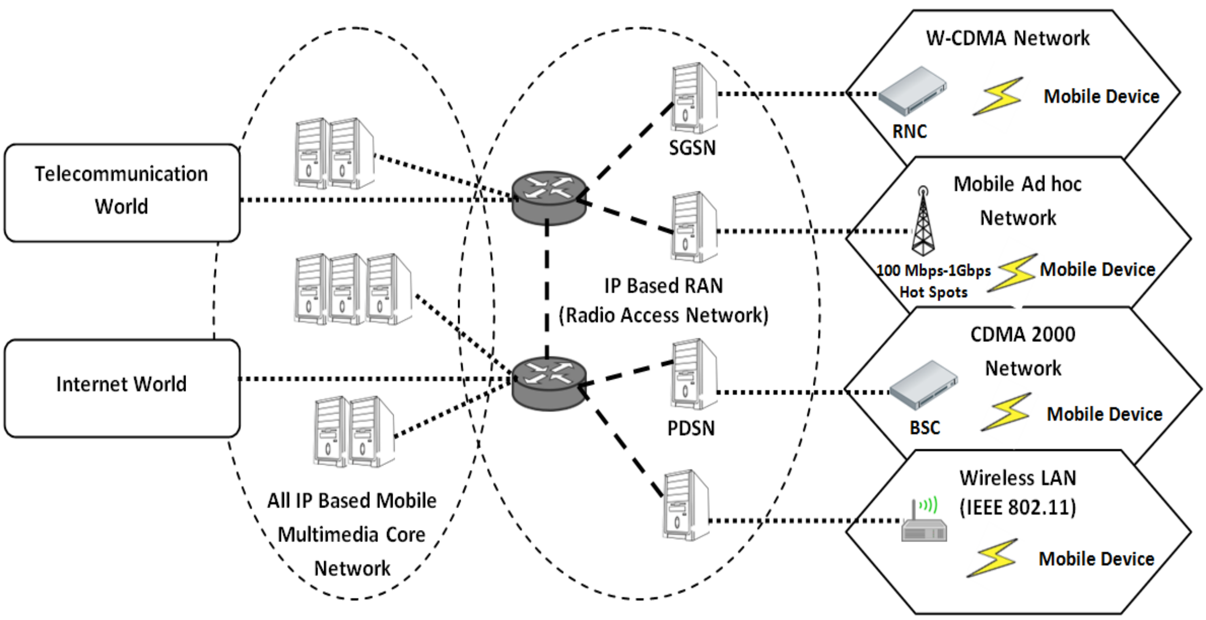

Fig.1. Architecture of 4G Cellular Network

Abbreviation: *PDSN (Packet Data Serving Node), SGSN (Serving GPRS Support Node), RAN (Radio Access Network), RNC (Radio Network Controller), CDMA (Code Division Multiple Access), W-CDMA (Wide Band Code Division Multiple Access), BSC (Base Station Controller)*

The requirements of a 4G core network are: (1) The ability to handle a very high level of multimedia traffic; (2) Advanced mobility management (this involves location management and managing hand-overs); (3) Diversified radio access support (this refers to support for features like various QoS levels and transmission speeds, independent uplink and downlink capacity); (4) Support for a diverse range of applications - i.e support structure for wireless ASPs (Application Service Providers), who are third-party providers of high-level services similar to ASPs in the wired Internet today); (5) Seamless service: the delivery of data must be smooth and not be affected by any transitions in the user's situation like Network-seamless, Terminal-seamless and Content-seamless; and (6) Support for a diverse range of applications - i.e support structure for wireless ASPs (Application Service Providers), who are third-party providers of high-level services similar to ASPs in the wired Internet today).

Geographical Coverage of 4G

4G will provide varied service quality according to distance from dense urban areas. Data rates in rural areas are expected to be lower than those enjoyed in dense urban areas. In the most likely case 4G coverage will extend to metropolitan areas and 3G systems will be utilised beyond them. The reason is partly economical, but cell-sizes also play a role in this. The 4G cell radius will, in general, most likely be smaller because the propagation loss is increased by operating at higher frequencies and at higher transmission bit rates the received signal level threshold must be higher than at lower bit rates, in order to compensate for the greater affect of noise at higher bit rates i.e to receive the signal at an adequate SNR (S*ignal to Noise Ratio).* The Equations that govern cell size:

$$Lp = 38 * \log(d) + 21 * \log(f) + c$$
$$dLb = 10 * \log(B/B0)$$
$$Rr = 1/10 \wedge ((21 * \log(f/f0) + 10 * \log(B/B0)) / 38)$$

Where:
Lp = Propagation Loss, d = Distance, f = frequency, c = constant, dLb = Increase in noise power, B = Bit rate, B0 = Reference Bit Rate, Rr = Relative Cell Radius, f0 = Reference frequency

Greater bit rates as well as higher frequency bands both result in smaller cell size. A cell-size decrease by half will result in 4 times the number of BSs being required to cover the same area. This is a very important consideration because laying down infrastructure incurs the greatest cost to the network providers. Another consequence of this is that cell sojourn time (average time spent within a cell) is reduced and hand-over frequency is increased. 4G will allow for Concatenated Location Registration. If the movement characteristics of a group of MTs are more or less similar their location registrations are concatenated, provided there is a common entity to concatenate with.

Wireless LAN Integration in 4G

One of the major evolutionary steps on the path to 4G is the integration of Wireless LANs so that they can access the IP backbone of a 4G network. A Wireless LAN is an extension to wired LAN where it uses electromagnetic airwaves for communication whereas wired LAN does uses cables. Wireless LAN types include Infrared (IR) Technology, Spread Spectrum Technology, Frequency hopping, Direct sequence and Narrowband Technology. There are several advantages of using WLANs. They enable data to be transmitted over air, thus reducing cabling. WLANs offer productivity, convenience, and cost advantages over traditional wired networks such as increased installation speed, increased simplicity and flexibility, reduced cost-of-ownership and scalability. Also they combine data connectivity with user mobility, increasing flexibility as well as allowing ad-hoc and roaming access within a limited range. Since the 4G core network is basically an IP-based network connecting a Wireless LAN to the 4G backbone is similar in principle to connecting wired LAN in a wired Internet. This is done through a router with a radio transmitter capable of cellular access.

V. NETWORK ARCHITECTURE OF LTE

Long Term Evolution (LTE) is a 4G wireless broadband technology developed by the Third Generation Partnership Project (3GPP), an industry trade group. The LTE technology enabled fast mobile internet connection. Actually, LTE is a path followed to achieve 4G speeds. LTE is a full IP technology used for the mobile broadband services for data transfer and voice calls. Soon it will be used for the Multimedia Broadcast Multicast Service (MBMS). Wireless operators are rapidly expanding their LTE networks to take advantage of additional efficiency, lower latency and the ability to handle ever-increasing data traffic. The core technologies have moved from circuit-switching to the all-IP evolved packet core. Meanwhile, access has evolved from TDMA (Time Division Multiple Access) to OFDMA (Orthogonal Frequency Division Multiple Access) as the need for higher data speeds and volumes as increased. LTE network architecture cab be divided into two sub networks.

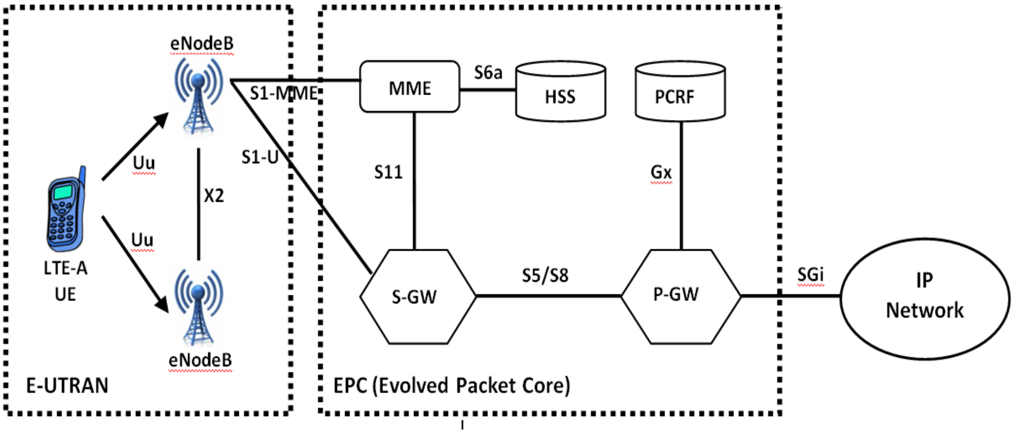

Fig.2. Diagram of LTE Network Architecture.

Abbreviation: *MME (Mobility Management Entity), S-GW (Serving Gateway), HSS (Home Subscriber Server), PCRF (Policy and Charging Rules Function), P-GW (Packet Data Network Gateway), Evolved Universal Terrestrial Radio Access Network (E-UTRAN), EPC (Evolved Packet Core)*

Radio Access Network for LTE

The radio access network is used for wireless radio connection between the mobile phones and antennas from the mobile operator. The radio access network is also called EUTRAN or Evolved Universal Mobile Telecommunications System Terrestrial Radio Access Network. EUTRAN can be also called just LTE (Long Term Evolution). Radio infrastructure is formed of the following nodes:

- **LTE Mobile Terminals:** LTE mobile terminals are the mobile phones and other devices that support the LTE standard.
- **Radio Interface:** Radio interface is a wireless connection between the LTE mobile terminals and eNodeB. It is wireless signals that form the mobile cells.
- **eNodeB:** E-UTRAN Node B or eNodeBs are situated all over the network of the mobile operator. They connect the LTE mobile terminal via radio interface to the core network.

Core Network for LTE

Core Network is the brain of the system. It is formed of telephony switches that enable the different services for the mobile users. Core network devices connect the mobile devices in the mobile network. They also connect the mobile network with the fixed telephony network and internet. The LTE core network is called EPC (Evolved Packet Core) or System Architecture Evolution (SAE). The core network is formed from the five nodes:

- **MME:** Mobility Management Entity or MME is the central control node in the EPC network. It is responsible for mobility and security signalling, tracking and paging of mobile terminals.
- **S-GW:** Serving Gateway or S-GW transports the user traffic between the mobile terminals and external networks. It also interconnects the radio access network with the EPC network. It is connected to the P-GW.
- **P-GW:** PDN (Packet Data Network) Gateway connects the EPC network to the external networks. It routes traffic to and from PDN networks.
- **HSS:** HSS (Home Subscriber Server) is the database of all mobile users that includes all subscriber data. It is also responsible for authentication and call and session setup.
- **PCRF:** PCRF (Policy and Charging Rules Function) is node responsible for real-time policy rules and charging in EPC network.

VI. MOBILE PHONE STANDARDS AND COMPARISON

Global System for Mobile Communications (GSM) and IS-95 were the two most prevalent 2G mobile communication technologies. In 3G, the most prevalent technology was UMTS with CDMA-2000 in close contention. GSM uses TDMA and FDMA for user and cell separation. UMTS, IS-95 and CDMA-2000 use CDMA. WiMAX and LTE use OFDM. Time-Division Multiple Access (TDMA) provides multiuser access by chopping up the channel into sequential time slices. Frequency-Division Multiple Access (FDMA) provides multiuser access by separating the used frequencies. Code-Division Multiple Access (CDMA) uses a digital modulation called spread spectrum which spreads the voice data over a very wide channel in pseudorandom fashion using a user or cell specific pseudorandom code. Orthogonal Frequency Division Multiple Access (OFDMA) uses bundling of multiple small frequency bands that are orthogonal to one another to provide for separation of users. The users are multiplexed in the frequency domain by allocating specific sub-bands to individual users.

The comparison table of mobile phone standards are as follows:

Feature	NMT	GSM	UMTS (3GSM)	IS-95 (CDMA one)	IS-2000 (CDMA 2000)	LTE
Technology	FDMA	TDMA and FDMA	W-CDMA	CDMA	CDMA	OFDMA

Generation	1G	2G	3G	2G	3G	4G
Encoding	Analog	Digital	Digital	Digital	Digital	Digital
Handoff	Hard	Hard	Soft	Soft	Soft	Hard
Voice and Data at the same time	No	Yes GPRS Class A	Yes	No	No EVDO / Yes SVDO	No (Data only: Voice possible though VoLTE or fallback to 2G/3G)

The comparison table of major wireless standards are as follows:

Common Name	Family	Primary Use	Radio Tech	Downstream (Mbit/s)	Upstream (Mbit/s)
UMTS W-CDMA HSPA (HSDPA+ HSUPA)	UMTS/ 3GSM	General 3G	CDMA/ FDD/ MIMO	0.384 14.4	0.384 5.76
HSPA+	3GPP	3G Data	CDMA/ FDD/ MIMO	21 42 84 672	5.8 11.5 22 168
LTE	3GPP	General 4G	OFDMA/ MIMO/ SC-FDMA	100 Cat3 150 Cat4 300 Cat5 (in 20 MHz FDD)	50 Cat3/4 75 Cat5 (in 20 MHz FDD)
Wi-Fi	802.11 (11n)	Mobile Internet	OFDM/ MIMO	288.8 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)	288.8 (using 4x4 configuration in 20 MHz bandwidth) or 600 (using 4x4 configuration in 40 MHz bandwidth)

VII. FEATURES OF 4G TECHNOLOGY

The following key features can be observed in all 4G technologies:

- ***IP Core Network:*** The IP core network will be based on IPv6 (IP Version 6) instead of IPv4. This is more conducive to a large number of devices with IP addresses and also supports mobility far better than its predecessor.
- ***Converged Services:*** A wide range of services will be available to the mobile user conveniently and securely via the 4G Core Network. Personal communications, information systems and entertainment will seem to be merged into a seamless pool of content.
- ***Three Network Layers:*** The Core network may be viewed as consisting of 3 layers - the Transport Network, the Service Middleware and the Applications. The Transport Network is the actual network interconnection and will be configured by routers, as with any IP network.
- ***Devices Compatibility:*** A defining feature of 4G will be the proliferation of a vast array of devices that are capable of accessing the 4G backbone. Wireless capabilities will be embedded into devices that wouldn't even consider today. Not only personal devices like phones, PDAs, laptops, etc. but also sensors, embedded controllers and other specialised equipment.
- ***Ubiquitous Mobile Access:*** 4G aims to provide access to multimedia services anytime anywhere. Improved radio access technology as well as integration of all types of communication networks allows for virtually constant connectivity to the 4G core backbone.
- ***Dependency on Software:*** Advanced software systems are employed for all purposes like network operation, service provision, interfacing and integration, etc. Not only the Core Network but the mobile devices will be highly intelligent as well as re-configurable via software.
- ***Autonomous Networks:*** While user devices are highly intelligent, the core network will also be very sophisticated. It will be capable of managing itself and dynamically adapting to changing network conditions and user preferences for seamless communication. Apart from evolved mobility management, connection control, hand-over mechanisms, etc, dynamic bandwidth allocation will make far more efficient use of the available radio spectrum.
- ***Quality of Service (QoS):*** 4G data rates will between a few Mbps and 100 Mbps, hence the level of service that can be offered is quite tremendous. Apart from 3G services like World Wide Web, Email, and wireless E-commerce this data rate is quite adequate to support the high QoS levels required for high-resolution multimedia traffic, broadcast services, video-conferencing services, ad Hoc networking, alarm notification, sensor data acquisition, etc.

- ***New Feature in LTE:*** LTE enables the maximum data rates of 150 Mbps for download and 75 Mbps for upload. It has the flexible bandwidth of 6 different bandwidths. LTE doesn't have different bearers for voice calls and internet access, it needs to handle the voice calls on completely different way than 2G and 3G networks. The Voice over LTE (VoLTE) is the new features in the LTE describes how the phone calls are handled in the LTE networks.

VIII. CONCLUSIONS

4G LTE is the future of new wireless technology for accessing high bandwidth data for various applications and voice call over VoIP. A major issue in 4G systems is to make the high bit rates available in a larger portion of the cell, especially to users in an exposed position in between several base stations. Certain components such as the circuit-switching elements are removed and Wireless LAN connectivity is added. Mobility control, Location management, Hand-overs, etc have to be performed more efficiently in 4G. LTE is the technological path followed to achieve 4G network speeds.

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