4G LTE Technologies: System Concepts

CK Toh, PhD, Chief Technology Advisor, ALICO Systems Inc., Torrance, CA, US

ABSTRACT

Recently, we have witnessed the roll out of LTE (Long Term Evolution, or so called 4G) services from major US telcos, such as VERIZON, AT&T, T-Mobile, etc. These broadband wireless services claim to surpass current 3G cellular networks, paving the way to true wide area mobility, multimedia services while on-the-go and greater interactivity. In this white paper, we present the technical aspects of Long Term Evolution, its architecture, and its differences with earlier 3G systems.

INTRODUCTION

Over the years, there have been consistent improvements in the design of cellular networks. The advancement is necessary in order to cope with increasing number of users, increasing level of traffic (voice, data, etc.,), and increasing level of sophisticated but useful applications on mobile devices. The quest for higher bandwidth, faster connection times, and seamless handoffs, a scalable solution prompted engineers to seek better solutions. Various standardization organizations have taken efforts to work on specific agenda, providing an open forum for ideas, contributions, and convergence to agreed technical specifications. The ITU, IEEE, 3GPP, WWRF, etc., held regular meetings to address these issues and they are mostly well attended by key industry players.

Conventionally, we see the cellular network as **a 3-layer system**, comprising the **core**, the **edge**, and the **access** subsystems. The **core** is the heart of the network system. Essentially, it is the high end switch or a collection of such switches where perform very fast high speed switching, handoffs, and also perform the necessary signaling, traffic control and management, and interaction with essential databases (such as location, AAA, etc). Hence, the core subsystem is mostly controlled and policed by the telcos. Core subsystems contain the intelligence concerning traffic utilization, users' profile, systems up and down time, etc. To provide round-the-clock services, telcos monitor the core subsystem daily and regularly gather statistics for performance evaluation and improvement purposes.

The **edge subsystem** (also commonly known as the edge node) consists of a node that specifically acts as the interface between the core subsystem and the access subsystem. The edge node has a wired connection to the core node and a wired connection to the access node.

It is called the edge because it is the node furthest away from the core (wired network) and closest to the access (wireless part) node.

The **access subsystem** (also commonly known as the access node or base station or radio station) consists of a node that specifically acts as an interface between the wired networks (via the edge node) and the wireless networks. It has an interface that provides wireless coverage and connectivity (depending on the radio technologies used) to mobile terminals within its coverage range. Access nodes support both uplink and downlink communications and such communications may be asymmetric in nature. Multiplexing techniques are frequently used to support multiple users within a wireless cell. Advanced modulation and equalization techniques help to boost data rates, increase reliability, and improved on error control. Access nodes can also provide security features to ensure that only legitimate users can access the code network. Access nodes are scattered about an area to provide sufficient air coverage, with overlapping cells. Overlapping cells are needed to ensure smooth handoffs of mobile calls as the users migrate from one location to another. Hence, access subsystem fulfills the role of fixed and mobile convergence.

LTE Evolution: 3GPP Release 10 is higher peak rates and provision of relaying solutions. Higher data rates are further achieved through carrier aggregation, spectrum aggregation and additional antennas (up to 8 antennas downlink, 4 antennas uplink), achieving 3Gbps peak data rate uplink and 1.5Gbps downlink.

LTE is an all-IP based Network: It supports both IPv4 and IPv6. LTE is different from 3G by these aspects:

- Use of OFDM technology
- Use of MIMO technology
- A new System Architecture Evolution (SAE)

LTE Advance Radio Technology: Use of MIMO, OFDM, SIMO, TDD, FDD, Channel Coding and GSA. Downlink is OFDMA (Orthogonal Frequency Division Multiple Access), uplink is SC-FDMA (Single Carrier-Frequency Division Multiple Access) or also known as DFTS-OFDM. Advanced antenna solutions provide more signal diversity, beam-forming capability and multi-layer transmissions (through MIMO). There is considerable flexibility in the use of spectrum for LTE. LTE can work on new and existing bands and over FDD and TDD. In terms of link adaptation, LTE can use QPSK, 16QAM or 64QAM modulation schemes and it performs channel coding to provide robustness against poor channel conditions (ie., build redundancy into the bits). The 15KHz tones provide a long symbol time, resulting in robustness against multipath propagation and time dispersion issues. MIMO provides transmit diversity, receive diversity, and spatial multiplexing characteristics. These greatly boost transmission performance. European operators will use 2.6GHz band. Reusing GSM bands for LTE is possible. LTE can be used in both TDD and FDD modes. LTE provides flexible channel bandwidth: the smallest being 1.4MHz, followed by 3, 5, 10, 15, and 20 MHz.

LTE SAE (System Architecture Evolution): SAE essentially moves some of the core network functions to the edge (periphery) to achieve a "flatter" network and lower latency. SAE provides different advantages over 3G architectures, such as: (a) improved data capacity, (b) all-IP architectures, (c) reduced latency, and (d) reduced operation and capital costs. SAE uses a common gateway node, an all-IP based systems (with IP-based protocols), an MME (mobility management entity) and a radio access network and core network functional split. The main element of LTE SAW is the EPC (Evolved Packet Core). The EPC connects to several eNodeBs.

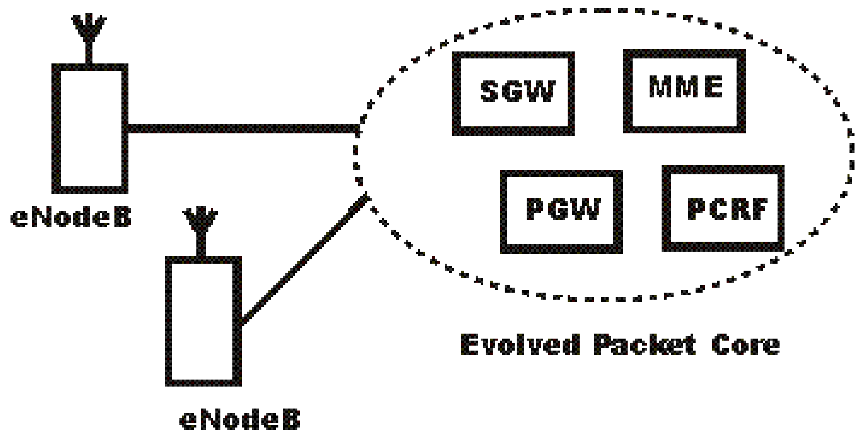

Fig: Elements of EPC – Evolved Packet Core

Within the EPC, there are 4 elements. MME handles intra-LTE handoffs, bearer activation and de-activation, and interacts with HSS to authenticate user. Hence, MME provides control plane functionality. The SGW (Serving Gateway) is a data plane element for the magaing of user plane mobility and acts as the gateway between RAN (Radio Access Network) and the Core Network. When mobile station move across areas served by different eNodeBs, the SGW serves as the anchor point, ensure continuity of data path. The third element is the PGW (PDN Gateway) which provides connectivity to the mobile station to external PDN (Packet Data Networks). The PCRF (Policy & Charging Rules Function) detects service flow, and enforces charging policy.

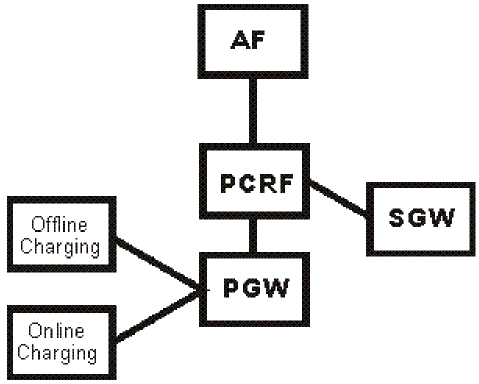

Fig: Interactions of PGW with PCRF, and Charging.

Compared to the 3G UMTS / WCDMA with UTRAN, in LTE SAE, the RNC (Radio Network Controller) and radio resource management is moved to the base stations. Such base stations are also called the eNodeB or eNB. eNB are connected to the core network gateway via a S1 interface while eNBs can be connected to other eNBs in a mesh manner via an X2 interface. This rich interconnection provides faster handoff of connections during roaming by mobile stations. The radio resource control handled by the eNB includes: (a) admissions control, (b) load balancing, and (c) mobility control (handoff decisions).

3G LTE Specification: Earlier LTE specifications are shown in the table below. Different modulation schemes can be used and mobility rate can be as high as vehicular speeds.

PARAMETER	DETAILS
Peak downlink speed 64QAM (Mbps)	100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
Peak uplink speeds (Mbps)	50 (QPSK), 57 (16QAM), 86 (64QAM)
Data type	All packet switched data (voice and data). No circuit switched.
Channel bandwidths (MHz)	1.4, 3, 5, 10, 15, 20
Duplex schemes	FDD and TDD
Mobility	0 - 15 km/h (optimised), 15 - 120 km/h (high performance)
Latency	Idle to active less than 100ms Small packets ~10 ms
Spectral efficiency	Downlink: 3 - 4 times Rel 6 HSDPA Uplink: 2 -3 x Rel 6 HSUPA
Access schemes	OFDMA (Downlink) SC-FDMA (Uplink)
Modulation types supported	QPSK, 16QAM, 64QAM (Uplink and downlink)

Voice over LTE (VoLTE): Mobile operators receive over 80% of their revenues from SMS and voice traffic, which implies that operators want LTE to support Voice differently than just using VoIP. VoLTE utilizes IMS (IP Multimedia Subsystem). VoLTE was developed by a collaboration of over 40 operators, including Verizon, AT&T, Nokia, and Alcatel-Lucent. VoLTE is an IMS-based specification. 3 new signaling interfaces are defined in VoLTE: (a) UNI, (b) Roaming R-NNI, and (c) Interconnection I-NNI.

LTE Security: SIM is one of the key elements of GSM security. The SIM allows one to keep the identity of the subscriber in an encrypted manner. In LTE, UMTS Subscriber Identity Module was introduced (USIM) which has similar functionality as the GSM SIM.

4G LTE = IMT-A = LTE-A: Is the new 4G technology. As shown in the table below, LTE-A can provide as much as 10x the speed (both uplink and downlink) of LTE. In addition, latency is also lower.

	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE	LTE ADVANCED (IMT ADVANCED)
Max downlink speed bps	384 k	14 M	28 M	100M	1G
Max uplink speed bps	128 k	5.7 M	11 M	50 M	500 M
Latency round trip time approx	150 ms	100 ms	50ms (max)	~10 ms	less than 5 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8	Rel 10
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10	
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA	OFDMA / SC-FDMA

WiMax is the other alternative to LTE-A, but WiMax is less appealing compared to LTE-A. LTE-A will use OFDMA and MIMO technologies, with more antenna additions. LTE-A utilizes carrier aggregation technique to boost transmission capacity. IMT-A sets the maximum channel bandwidth as 100MHz.

LTE-CoMP: LTE-A includes LTE-CoMP (co-ordinated multipoint) which turns inter-cell interference into useful signal. LTE-CoMP refers to the dynamic coordination of transmission and reception among different base stations.

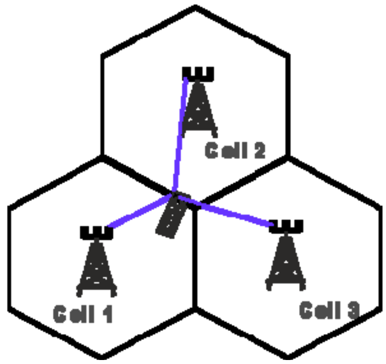

Figure: LTE-CoMP allows multiple eNBs coordination

LTE-CoMP allows the mobile at the edge of a cell to be served by 2 or more eNBs to impove signal transmission and reception thereby increasing throughput especially under cell edge situations. Intelligence is added to LTE-CoMP such that multiple simultaneous transmission of user data from multiple eNBs to a single mobile station and the dynamic cell selection with data transmission from a single eBN.

LTE-A Relaying: Its purpose is to enhance wireless coverage and capacity. One of the hard issues is dealing with poor signal conditions at cell edges. LTE relays actually demodulate and decode the received signal, apply any necessary error correction and then retransmit an entirely new signal. This “relay” provides a clean signal to be propagated out again. A mobile station actually talks to the relay node, which in turn communicates with an eNB, hence the term “relay”. Relay nodes are fixed elements, they do not move unlike the mobile station.

4G LTE Coverage & Services: We will now look at the 4G LTE providers in the USA, i.e., VERIZON and AT&T. Verizon claims that its’ 4G LTE coverage include over 175 cities and supports over 186 million users in the USA. Verizon identifies several applications of 4G LTE, such as transportation, emergencies, distribution, health care, utility industries, construction sector, financial services, manufacturing, etc. For mobile broadband devices, Verizon charges $30/month for 2GB. Verizon LTE smart phones operate at the LTE 700 MHz band, with CDMA 1xEVDO/3G at 800 and 1900 MHz band.

As shown in the figure, most 4G markets are targeted at the east coast of USA, in particular, major cities where population concentration is important. Also, Verizon 3G coverage has been predominantly covering the whole of USA, with the exception of some rural areas.

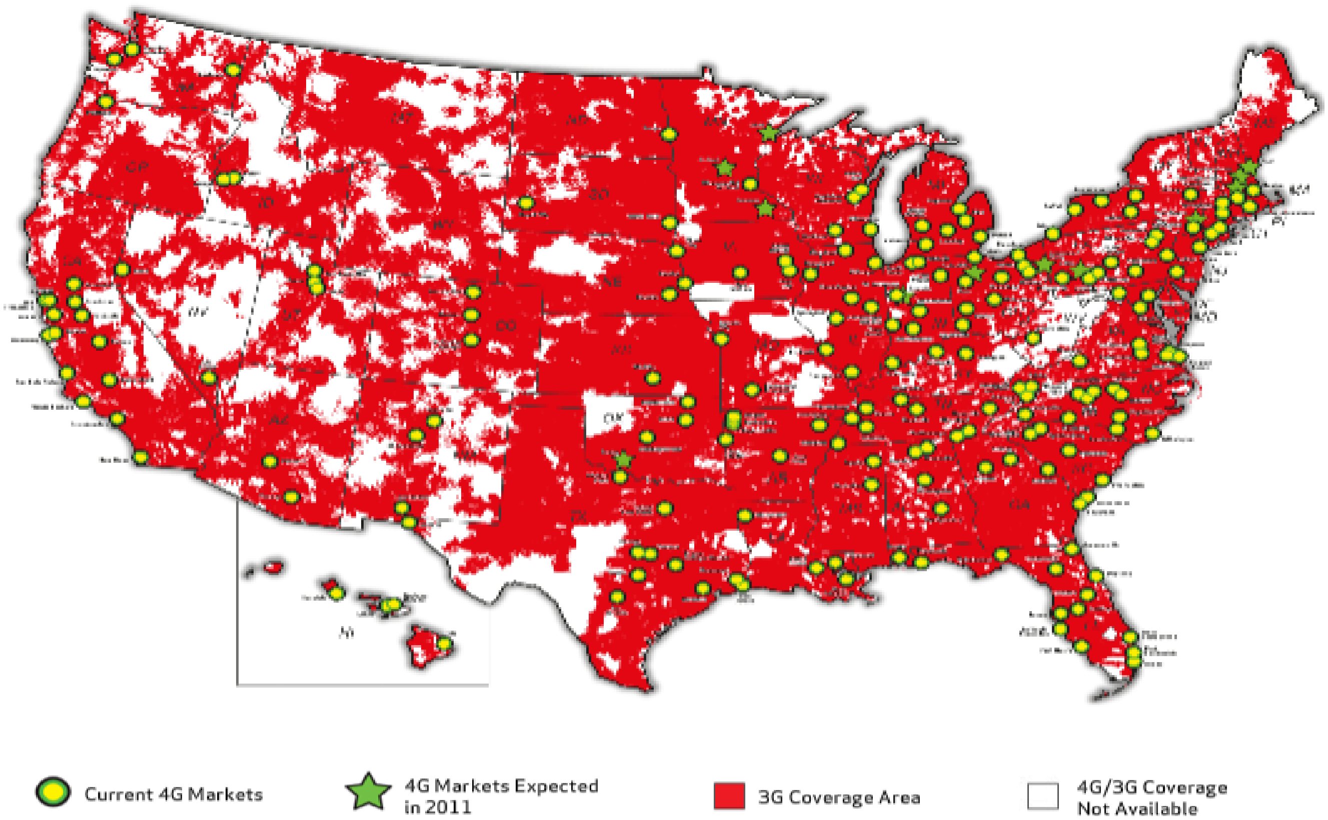

Fig: 3G and 4G Wireless Coverage in USA (Source: Verizon)

AT&T 4G LTE, on the other hand, has been launched in 9 cities and planned to service 70 million users. In AT&T's service definition, 3G (also known as mobile broadband) refers to HSPA, while 4G refers to HSPA+ and the true 4G refers to 4G LTE. Hence, 4G in AT&T's definition does not imply LTE technology.

AT&T 4G devices include those from HTC, Samsung, Blackberry, etc. AT&T 4G LTE services include "talk –while-surf", i.e., enabling concurrent voice and data operations over the high speed communication pipe. AT&T also emphasizes the fallback to HSPA+ when users move to areas without LTE coverage.

As shown below, AT&T LTE services mostly reside on east coast cities. Mobile users in California will not be able to enjoy 4G LTE services as yet. The AT&T based HTC tablet, for example, supports 4G (i.e., HSPA+) at the 850/1900/2100 MHz band and LTE at 700MHz band. Most of the 4G devices are backward compatible, i.e., they support GSM/GPRS/EDGE at 850/900/1800/1900 MHz bands.

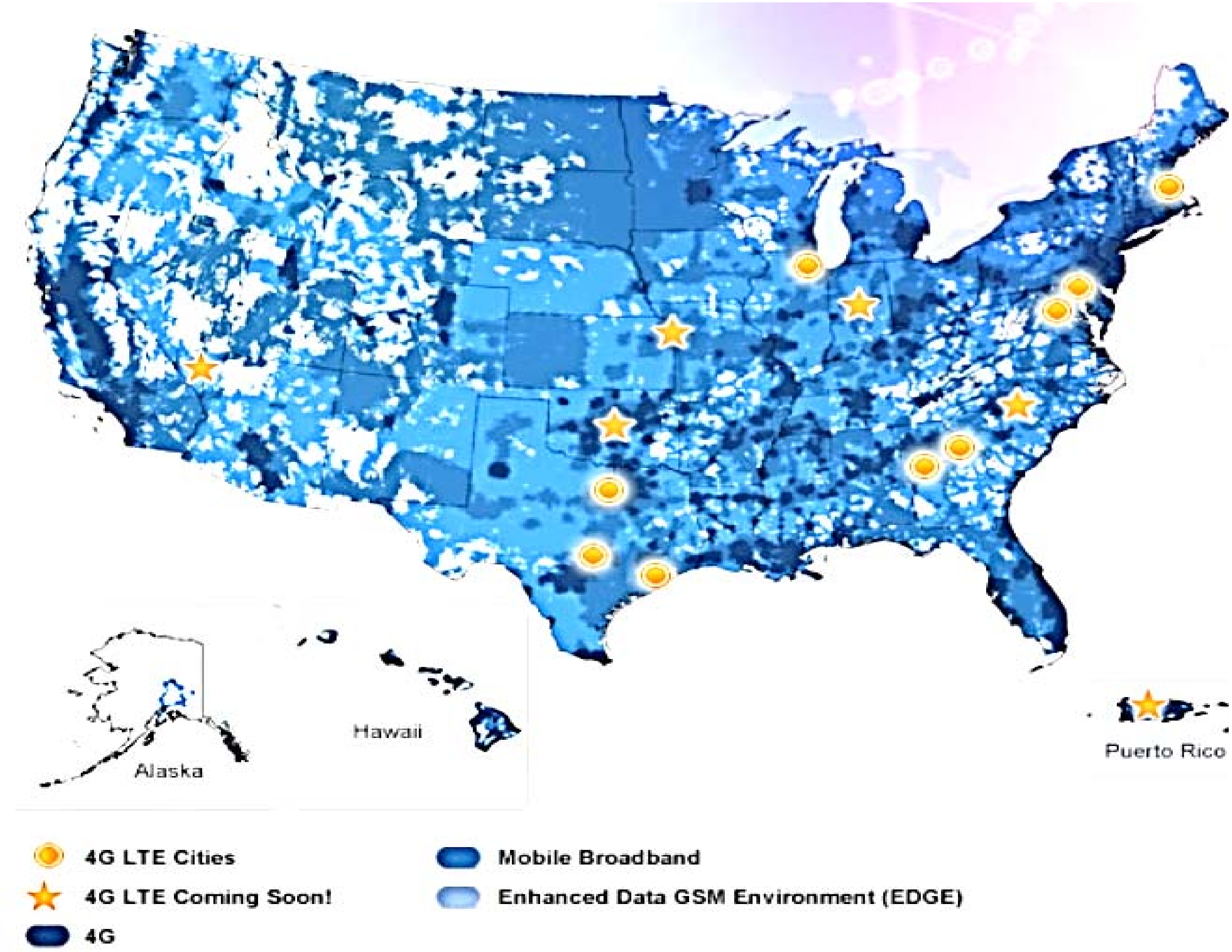

Fig: 3G and 4G Wireless Coverage in USA (Source: AT&T)

CONCLUSION

The adoption, deployment, and usage of 4G LTE technologies are now in full swing. Major telecoms operators are offering such services. Consumers have readily jumped the queue to acquire 4G phones and services. The provision of high speed and low latency features will certainly empower smart-phone and mobile-device users to run sophisticated applications (social networks, maps, banking, search, etc.,) in addition to our normal voice calls, SMS and MMS. The top 8 wireless carriers in USA are: Verizon, AT&T, Sprint Nextel, T-Mobile, Clearwire, MetroPCS, US Cellular, and Leap Wireless.

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