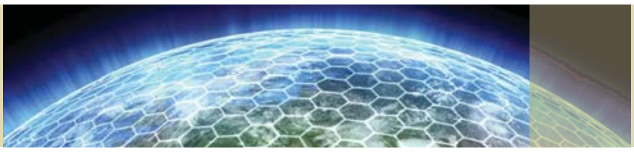

LTE Networks: Evolution and Technology Overview

The long-term evolutionary access technology called LTE (Long Term Evolution) is quickly becoming the network technology of choice for 4G deployments around the world. As user demand for mobile broadband services continues to rise, LTE and its ability to cost-effectively provide very fast, highly responsive mobile data services appears to be the right technology at the right time.

By 2014, Juniper Research predicts revenues from LTE mobile broadband subscribers will exceed $70 billion globally, with 300 million worldwide subscribers by 2015. As of August 2010, according to the Global mobile Suppliers Association (GSA), there are 101 firm LTE network deployments planned or in progress in 41 countries around the world. By the end of 2010, GSA anticipates around 22 LTE networks in commercial service. In addition to these statistics, another 31 operators are currently engaged in various LTE pilot trials and technology tests, which when added to the above translates to 132 operators in 56 countries now investing in LTE.

For many operators, LTE represents a significant shift from legacy mobile systems as the first all-Internet Protocol (IP) network technology and will impact the way networks are designed, deployed, and managed. Mobile operators will need to deal with specific challenges associated with LTE, such as interoperability with legacy and other 4G systems, ensuring end-to-end network QoS and high-quality service delivery, and interaction with IMS for the delivery of multimedia services and voice.

Why LTE?

With LTE, the 3GPP (Third Generation Partnership Project) systems are well positioned to remain competitive for at least the next ten years. LTE's vision of wireless access will result in a comprehensive transition towards a packet-switched-only system that is distinctly non-hierarchical, and which makes wide use of Internet Engineering Task Force (IETF) protocols and practices. LTE is further designed to be interoperable with legacy UMTS systems and offer support for seamless mobility through non-3GPP wireless accesses including, but not limited to, WiMAX, 1x-EVDO, and Wi-Fi.

The LTE access network incorporates state-of-the-art air interface technologies including OFDMA (Orthogonal Frequency Division Multiple Access) and advanced antenna techniques to maximize the efficient use of RF spectrum. It also accommodates several options for frequency bands, carrier bandwidths, and duplexing techniques to effectively utilize the different portions of unused spectrum in different countries and geographies.

Most significantly, the LTE network architecture's evolution to an all-IP architecture enables seamless delivery of applications and services over what were previously two separate and distinct networks. In addition to reducing deployment and operational costs and complexity, the transition to IP enables LTE to support Quality of Service (QoS) for real time packet data services like VoIP and live video streaming.

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Mobile Network Evolution

LTE is a Fourth Generation (4G) mobile network technology. Mobile networks have evolved through a series of innovations to meet the ever-growing demand for wireless services, beginning with the analog cellular networks introduced almost 30 years ago.

First Generation Cellular Networks

All of the First Generation (1G) mobile systems provided voice services based on analog radio transmission techniques. These first generation technologies used Frequency Division Multiple Access (FDMA) which had inherent limitations in the use of radio channels, and used circuit-switched technologies in the network core.

Second Generation Cellular Networks

Second Generation (2G) mobile systems are characterized by digitization and compression of speech. This allowed many more mobile users to be accommodated in the radio spectrum through either time (GSM) or code (IS-95 CDMA) multiplexing.

Third Generation Cellular Networks

Third Generation (3G) cellular networks introduced high-speed data and multimedia connectivity to users. A distinct difference between 2G and 3G technologies was the appearance of a packet data core network, while the access network was shared by circuit and packet domains.

Fourth Generation Networks

The overall goal of Fourth Generation (4G) systems is to provide a converged network compatible with the Next Generation Network (NGN) vision of convergence. This kind of network integrates mobility management, security and QoS management mechanisms for both fixed and mobile broadband accesses, independent of the access technology. Though the Release 8 version of LTE does not strictly meet the ITU's definition of a 4G system, its architecture and underlying technologies provide a solid foundation for the Release 10 (R10) LTE-Advanced system which does describe a fully-compliant 4G system.

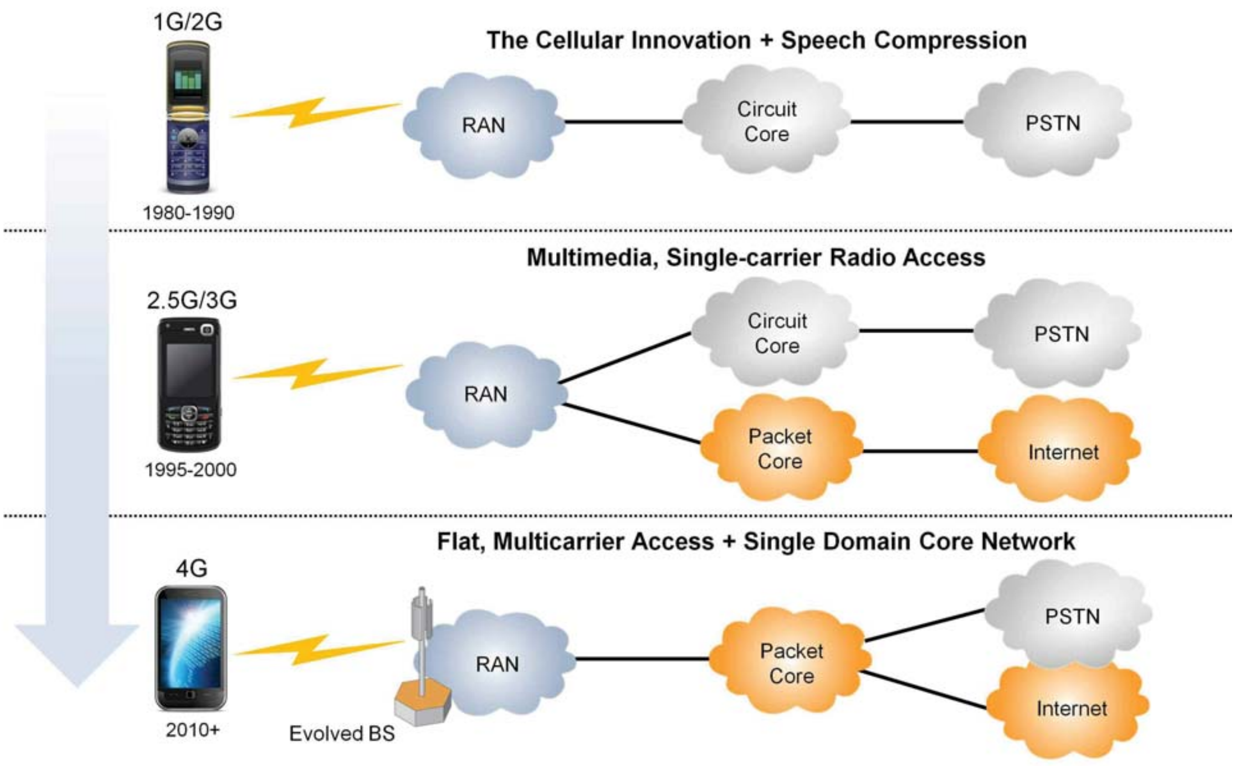

Figure 1. Mobile Network Evolution

3GPP Evolution

3GPP, the body which defined the LTE specifications, has a well established evolutionary scheme that is likely to continue for some time.

Release 99 (R99) defined the original dual-domain UMTS system that supports both circuit-switched voice services and packet switched access.

Release 4 (R4) saw the earliest phase of network IP adoption with the deployment of a bearer-independent circuit-switched architecture that disassociated the telephone switches into media gateways and controllers (soft switches).

Releases 5 through 7 are dominated by techniques to increase the spectral efficiency, and thereby extend the viability of the limited underlying W-CDMA technology. The resulting HSPA+ (High Speed Packet Access, with enhancements) can theoretically achieve peak data rates of 42 Mbps under ideal conditions. In addition to improving spectral efficiency, R5 specifies the initial design of IP Multimedia Subsystem (IMS) – an IP services environment. IP began to proliferate throughout the network with the evolution of interfaces originally delivered on ATM/E1 now being migrated to IP for cost and efficiency purposes.

Release 8 (R8) defines the Long Term Evolution (LTE) system as a break with the past. It marks the start the transition to 4G technologies and networks.

Release 9 (R9) offers enhancements to LTE, including definition of Home eNodeBs for improved residential and in-building coverage.

While first adopters of LTE are working to develop and deploy R8-based LTE systems, work is underway on defining still more improvements to LTE. In particular, the yet to be completed Release 10 (R10) recommendation that defines LTE-Advanced, is a full-featured 4G system which includes 8x8 MIMO, channel aggregation up to 100 MHz, and relay repeaters. It additionally seeks to improve operational efficiencies by supporting a range of self optimizing, self healing capabilities that enable the network to execute tasks that in earlier technologies have been carried out manually.

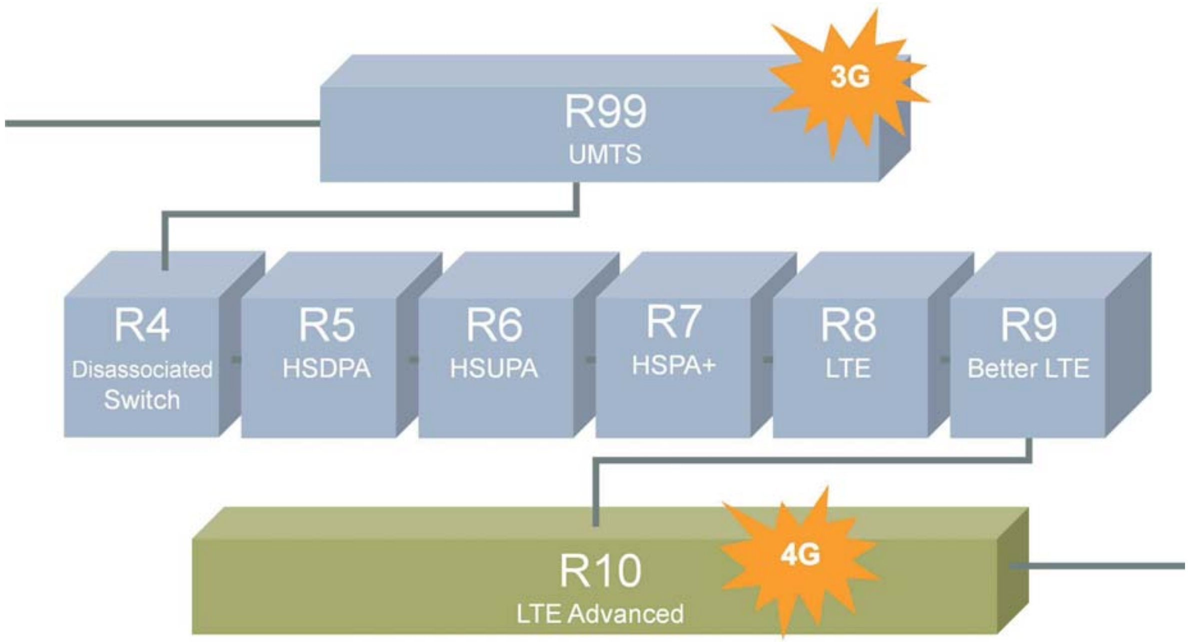

Figure 2. 3GPP Roadmap

LTE Architecture

Figure 3 illustrates the overall LTE architecture, which is marked by the elimination of the circuit-switched domain and a simplified access network. The functional entities depicted in Figure 3 can be physically co-located, or reside in dedicated hardware according to the network operator's needs.

The LTE system is comprised of two networks: the E-UTRAN and the Evolved Packet Core (EPC). The result is a system characterized by its simplicity, a non-hierarchical structure for increased scalability and efficiency, and a design optimized to support real-time IP-based services.

The access network, E-UTRAN is characterized by a network of Evolved-NodeBs (eNBs), which support OFDMA and advanced antenna techniques. Each eNB has an IP address, and is part of the all-IP network. Dedicated radio network controllers, which were present in earlier generation access networks, are not required; the eNBs in LTE collaborate to perform functions such as handover and interference mitigation.

Similarly, the all-IP packet core network enables the deployment and efficient delivery of packet-oriented multimedia services, through the IP Multimedia Subsystem (IMS). This results in lower costs and rapid deployment of new services for network operators.

While there are recognizable parallels to the 3GPP UMTS packet core network, the EPC is a significant departure from the legacy packet core which enables growth in packet traffic, higher data rates, and lower latency, and support for interworking with several wireless access technologies.

From 3G to 4G

The demand for ever-higher data rates, higher capacity, higher user throughput, lower latency, more efficient use of the radio spectrum, and more flexibility fuelled the need for a departure from the inherent limitations of UMTS (and its many evolutions) by, among other things, its CDMA-based air interface. LTE ensures a viable future for mobile broadband by enabling:

1. data rates an order of magnitude higher than single carrier spread spectrum radio can provide (over 300 Mbps downlink and 50 Mbps uplink, compared to 14 Mbps uplink and 5.76 downlink on UMTS HSPA)

2. reduced transit times for user packets (reduced latency), an order of magnitude shorter than can be provided in hierarchical 3G networks (5 ms for data and under 100 ms for signaling)

3. the ability for strict Quality of Service (QoS) control of user data flows with the possibility of these being coupled with various charging schemes

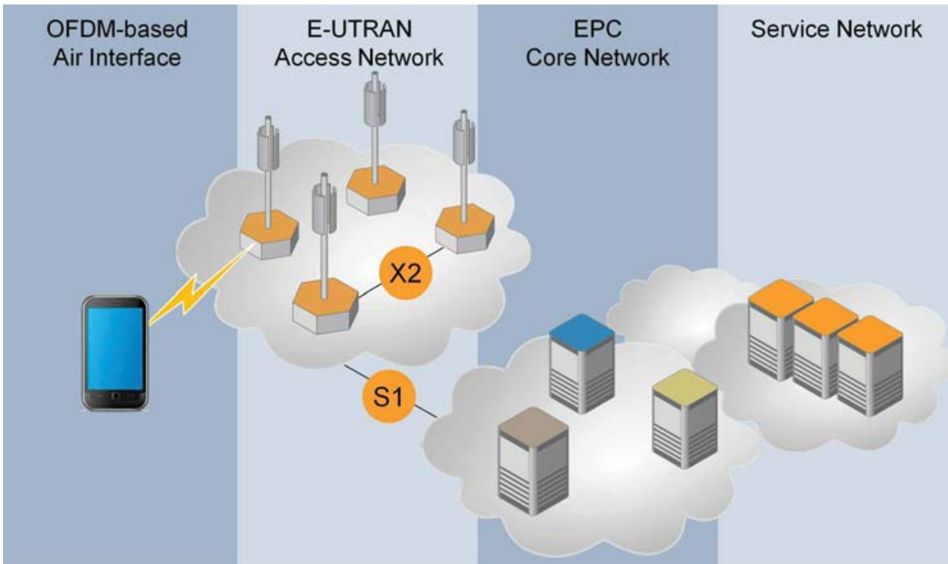

Figure 3. LTE Architecture

The EPC Architecture

LTE's packet domain is called the Evolved Packet Core (EPC). It is a flat all-IP system designed for:

- much higher packet data rates
- significantly lower-latency
- the ability to optimize packet flows within all kinds of operational scenarios having to do with bandwidth rationing and charging schemes
- explicit support for multiple radio access technologies in the interests of seamless mobility, and
- greater system capacity and performance

Six nodes are defined to meet these goals:

MME: Somewhat analogous to the distribution of control and bearer data of the MSC found in 3GPP R4, LTE separates control from bearer in the design of the EPC. The Mobility Management Entity (MME), which supports many functions for managing mobiles and their sessions, also controls establishment of EPS bearers in the selected gateways.

S-GW: The Serving Gateway (S-GW) is responsible for anchoring the user plane for inter-eNB handover and inter-3GPP mobility. An S-GW functionally resembles a 3G SGSN without the mobility and session control features. It routes data packets between the P-GW and the E-UTRAN.

P-GW: The Packet Data Network Gateway (P-GW) acts as a default router for the UE, and is responsible for anchoring the user plane for mobility between some 3GPP access systems and all non-3GPP access systems.

HSS: The Home Subscriber Server is the master data base that stores subscription-related information to support call control and session management entities.

PCRF: The Policy and Charging Control Function (PCRF) is the single point of policy-based QoS control in the network. It is responsible for formulating policy rules from the technical details of Service Date Flows (SDF) that will apply to a user's services, and then passing these rules to the P-GW for enforcement.

ePDG: The evolved Packet Data Gateway (ePDG) is used for interworking with un-trusted non-3GPP IP access systems.

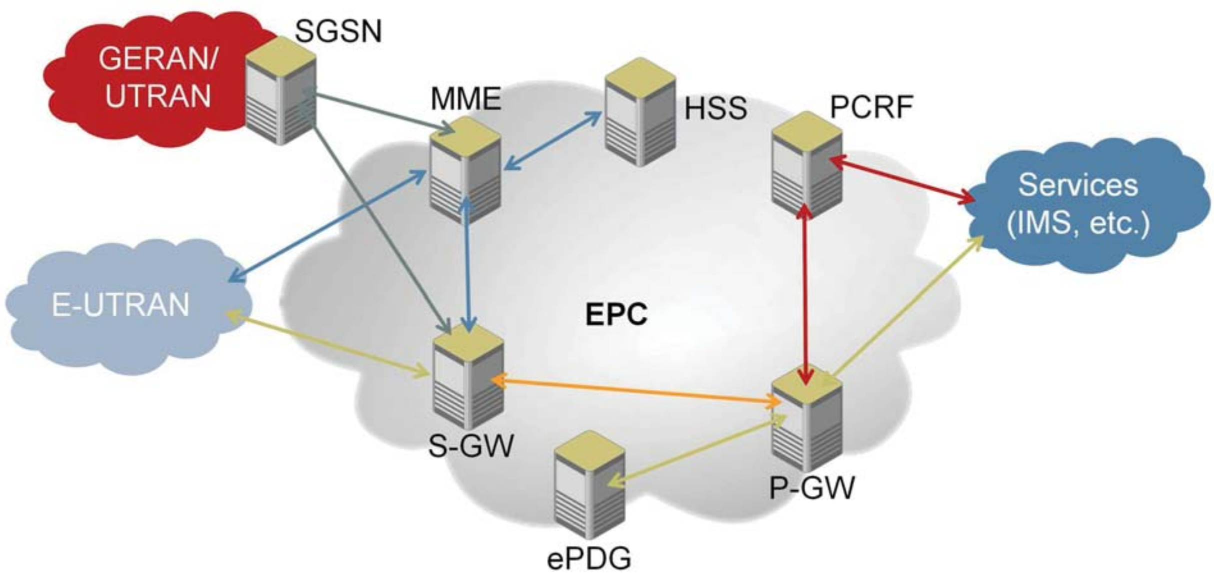

Figure 4. Key EPC Entities

E-UTRAN

The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) implements the LTE access network as a network of eNBs. A key difference between UTRAN and E-UTRAN is the absence of a centralized radio network controller. What were once centrally-coordinated functions are now distributed into the eNBs and the X2 interfaces between them. The eNB is responsible for many functions including:

- Radio Resource Management
- IP header compression and user data encryption
- the scheduling and allocation of uplink and downlink radio resources, and
- coordinating handover with neighboring eNBs

eNBs can communicate with multiple gateways for load sharing and redundancy.

IMS

3GPP has developed a complete service network system for mobile networks, called the IP Multimedia Subsystem (IMS). It is a complete, SIP-based control architecture that includes charging, billing and bandwidth management. As such, it defines its own formal interfaces with the IETF for any protocol extensions.

IMS is intended to occupy the core of tomorrow's converged networks, and is likely to be the chief enabler of accelerated network convergence with the promise of flexible service delivery. Mobile operators will count on LTE to implement cost-effective network changes as preparation for IMS. Deploying SIP-based control architectures on broadband wireless IP-based LTE naturally implies services ought to reside in the IMS.

EPC Interfaces

The key network interfaces (frequently called reference points) in the EPC are shown in Figure 5.

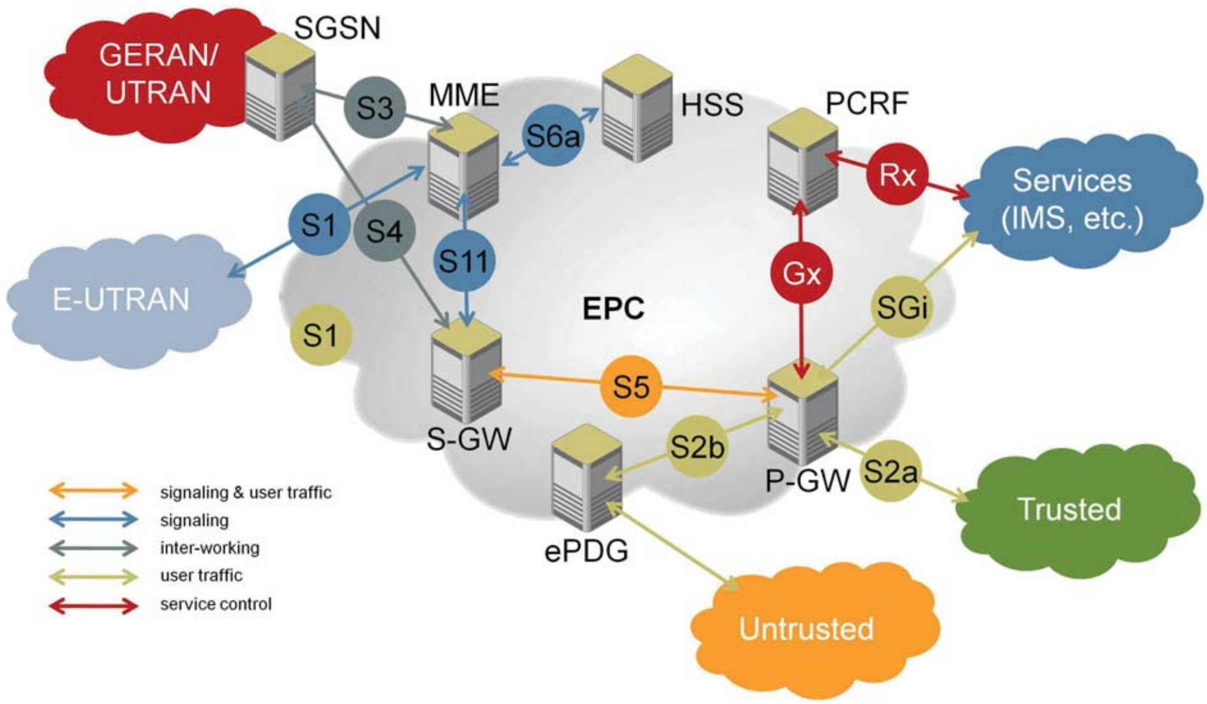

Figure 5. Chief EPC Interfaces

LTE defines several nodes / functions and interfaces, several of which are optional. Figure 5 depicts the subset of nodes and interfaces which are important to understanding the fundamental characteristics of the LTE system.

The **S1-MME** is the reference point for the control plane protocol between the E-UTRAN and the MME.

The **S1-U** is the reference point between the E-UTRAN and S-GW, and uses the GTP-U protocol. This interface supports EPS bearer user plane tunneling and inter-eNB path switching during handover.

The **S5** is the reference point between the S-GW and the P-GW. It uses GTPv2-C and GTP-U to support mobility when the mobile moves out of the scope of the serving gateway. If the P-GW is in a different network (as in roaming scenarios), it is called the **S8** instead.

The **S6a** is the Diameter-based reference point between the MME and the HSS.

The **SGi** is LTE's version of the UMTS's Gi interface between the P-GW and the Packet Data Network (PDN). The PDN may be an external public or private packet data network or an intra-operator packet data network.

The **Rx** is the Diameter-based interface between an Application Function (AF), usually in a Proxy Call Session Control Function (P-CSCF).

The **Gx** is the Diameter-based interface that carries policy rules for the PCRF to the P-GW.

The **S11** is the reference point between the MME and S-GW, and uses GTPv2-C.

The **S2a** is the reference point between the P-GW and any trusted access network that accommodates a user in the interests of seamless mobility.

The **S2b** accommodates a user's packets between the P-GW and an untrusted access network. This kind of inter-working demands a security gateway (ePDG) between the EPC and the untrusted space.

LTE Interoperability

LTE networks will probably exist as hot spots during the early phases of their deployments. This means there will likely be frequent inter-technology handovers between UMTS and LTE. Two interfaces are provided for the interworking.

The **S3** reference point is based on the legacy Gn interface. It lies between the SGSN and the MME where it enables user and bearer information exchanges for inter-3GPP access system mobility.

The **S4** reference point is based on the older GTP-based Gn interface in UMTS, and lies between the SGSN in the GPRS core network and the S-GW.

The preferred way to interwork UMTS with LTE is though a Serving GPRS Support Node (SGSN) upgraded to Release 8. This enhancement deploys the S3 and S4 interfaces that somewhat mimic LTE's strict separation of user data flows from the control plane messages. The relevant interfaces are shown in Figure 5.

Though the protocol stacks are incompatible with each other, LTE supports interworking with legacy 3GPP and non-3GPP networks. The intention is to provide LTE service continuity that is transparent to the access technology. Access independence is one of the requirements of the NGN visions. This independence requires a generic approach, which decouples the NGN core network and its procedures as much as possible from the access technologies.

QoS in LTE

Quality of Service (QoS) is the management of the data traffic in a network. Be it a LAN, WAN, or wireless, packets are subjected to scrutiny and control. Quality of Service is primarily a layer 3 Internet Protocol (IP) concept. It uses tools that have existed since the early days of IP plus some newer tools and protocols that are designed to aid in the provisioning of precisely defined and predictable data transfers in accordance with certain characteristics.

The QoS parameter sets supported within the EPC concern themselves with how packets are handled as they enter, traverse, and leave a network. Adding more bandwidth at the edge of a network may resolve some capacity or congestion problems, but it does not resolve jitter, nor can it fix traffic prioritization problems.

LTE QoS Class Identities

The critical QoS parameter for any EPS bearer is its QoS Class Identity (QCI), which represents the QoS features an EPS bearer should be able to offer for a Service Data Flow (SDF). Each SDF is associated with exactly one QCI. Network operators may pre-configure all QCI characteristics in an eNB, for example, based on their actual characteristics. The parameters they choose to define these determine the allocation of bearer resources in the E-UTRAN.

Each bearer (user data) path in LTE is assigned a set of QoS criteria. Since a user may have services requiring different QoS criteria, additional bearer paths may be added. LTE's identified QCI criteria are listed in Figure 6.

QoS between LTE and other 3GPP systems

Since LTE and UMTS employ different QoS mechanisms, there is a need to be able to map between LTE's QCI parameters for EPS bearers and the four QoS categories and associated parameters of Pre-Release 8 PDP Contexts. The 3GPP recommendations provide rules for mapping QoS definitions between the systems.

QCI	Bearer Type	Application Example	Packet Delay	Packet Loss	Priority
1	GBR	Conversational VoIP	100ms	10^{-2}	2
2		Conversational Video (Live Streaming)	150ms	10^{-3}	4
3		Non-Conversational Video (Buffered Streaming)	300ms	10^{-6}	5
4		Real Time Gaming	50ms	10^{-3}	3
5	NON-GBR	IMS Signaling	100ms	10^{-6}	1
6		Voice, Video, Interactive Games	100ms	10^{-3}	7
7		Video (Buffered Streaming) TCP apps (web, email, ftp) Platinum vs. gold user	300ms	10^{-6}	6
8					8
9					9

Figure 6. LTE QoS-Based Data Flow Specifications and Class Identities (QCI)

EPS Bearers and SDFs

LTE sees any Service Data Flow (SDF) as belonging to one of nine QoS-based data flow specifications listed in Figure 6.

Several 3GPP releases have moved toward a sophisticated multimedia-based policy-oriented environment. LTE offers the promise of policy-based, fixed-mobile convergence for new real-time applications such as VoIP, push-to-talk dispatch, messaging enhanced with video clips, and even two-way video telephony.

LTE PCC

Policy control is the mechanism that allows network operators to control access to the network and services with as fine a resolution as desired. Operators can decide precisely what a subscriber can do, what applications he can use, which ones he cannot use, what kinds of content he can enjoy, and how a service is actually delivered. Policy control depends on rules formulated from the technical details of an SDF. The appropriate policy rules can combine related areas such as control, the user's services, the sense of what a user is willing to pay for a service, and the capabilities of an access network into one functioning unit. Policy control is frequently coupled with charging: Policy and Charging Control (PCC). This allows for the possibility of charging a user for his experience and not just for the number of bits delivered to his handset.

Conclusions

LTE is strongly positioned to lead the evolution in the communications industry for several years. It improves spectral efficiency, simplifies deployment of all-IP real-time services, facilitates integration with non-wireless networks, and supports interworking with legacy wireless technologies. It achieves all of these things through a flat, scalable architecture that is designed to manage and maintain service QoS in a mobile environment with significantly higher data throughput.

Implementing IMS with LTE enables acceleration network convergence with the promise of flexible service delivery. Mobile operators will count on LTE to implement cost-effective network changes as preparation for IMS. Deploying SIP-based control architectures on broadband wireless IP-based LTE is a natural fit for IMS. For operators overlaying existing wireless networks, LTE supports interworking with the legacy 3GPP and non-3GPP wireless accesses, for service continuity that is transparent to the access technology.

To reap the benefits of LTE, network operators will have to face new challenges. Operators must consider migration strategies from legacy 2G/3G networks, reconsider how services are developed, and deploy IP networks which can deliver low latency end-to-end in order to support real-time QoS. This may include interim device strategies, leasing access on 3rd-party IP networks, implementing IMS architectures, and supporting real-time services like VoIP and streaming video over IP. Operators wanting to implement real-time services like VoIP will have to carefully monitor network latency. As these challenges are met and LTE is deployed, operators will recognize significant overall cost savings across the network and significant future revenue opportunities.

About Tektronix Communications:

Tektronix Communications provides network operators and equipment manufacturers around the world an unparalleled suite of network diagnostics and management solutions for fixed, mobile, IP and converged multi-service networks. This comprehensive set of solutions support a range of architectures and applications such as LTE, fixed mobile convergence, IMS, broadband wireless access, WiMAX, VoIP and triple play, including IPTV. Tektronix Communications is headquartered in Plano, Texas.

Learn more about the company's test, measurement and network monitoring solutions by visiting www.tektronixcommunications.com.

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