GSM-UMTS Network Migration to LTE

LTE and 2G-3G Interworking Functions

February 2010

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SCOPE

This paper reviews key considerations for introducing LTE technology into an existing GSM-UMTS network. LTE is an IP-based wireless technology that will drive a major network transformation as the traditional circuit-based applications and services migrate to an all-IP environment. LTE will open the door to new converged multimedia services; however, introducing complex voice and multimedia applications into a wireless network is not a trivial task. Introducing LTE will require the support and coordination between a complex ecosystem of application servers, devices/terminals and interaction with existing technologies.

This paper discusses functionality and steps GSM-UMTS network operators may use to effectively evolve their networks to LTE.

1 INTRODUCTION

Existing 2G-3G wireless operators, including AT&T, China Telecom, China Mobile, NTT DoCoMo, Telecom Italia, T-Mobile Germany and USA, Verizon and Vodafone, have all made announcements indicating LTE as their preferred wireless technology for the future.[1]

With such powerful endorsements, one might expect that LTE will be taking the wireless industry by storm. However, similar to its North American technology predecessors, the realization of LTE will require a multi-year effort. In North America, migrations from AMPs to TDMA to GSM to UMTS have spanned multiple years with existing technologies remaining intact for extended periods of time.

For example, the first commercial launch of UMTS in North America occurred in July 2004.[2] More than four years later, by the end of 2008, UMTS base station deployments in North America were yet to surpass that of GSM.[3]

In a similar fashion, market analysts expect a protracted ramp to LTE. Despite the first LTE trial systems going on-air in 2010, Gartner projects that by the end of 2012, LTE base station deployments will still account for less than 1 percent of the total North American 3rd Generation Partnership Project (3GPP) and 3GPP2 wireless base station infrastructure.[3]

Dell'Oro makes similar projections, predicting that LTE base stations will remain well under 10 percent of the total worldwide 3GPP and 3GPP2 by the end of 2013.

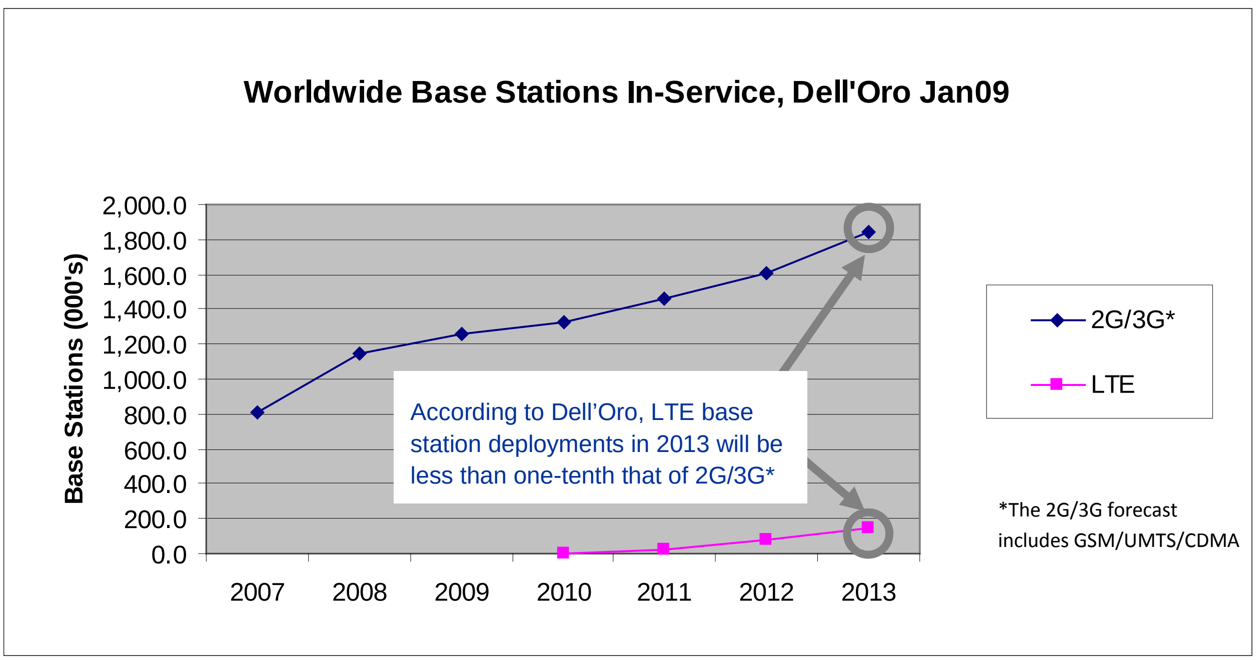


Figure 1.[4]

[1] *HSPA+ Delivers Smooth Transition to LTE,* 3G Americas, 24 July 2008.
[2] *AT&T Wireless Launches Commercial 3G Services Powered by Nortel Networks*, UMTS Forum, 20 July 2004.
[3] *Forecast: Mobile Network Infrastructure, Americas, 2006-2012 (4Q08 Update),* Gartner.

The point of these statistics is not to dispel the widely held notions that LTE will become the dominant wireless technology of the future, but rather to illustrate the inevitability that LTE must coexist with existing wireless technologies during its rise to pre-eminence.

Operators planning an LTE deployment will need to consider the implications of utilizing LTE in an ecosystem comprising 2G, 3G, and future "4G" wireless technologies. It will be years before LTE RF coverage replicates that of GSM, GPRS and UMTS. Therefore, operators planning an LTE deployment will need to offer multi-technology devices with networks that allow mobility and service continuity between GSM, GPRS, UMTS and LTE.

This paper identifies some of the possible challenges and solutions for enabling interaction of LTE with GSM, GPRS and UMTS networks.

[4] *Mobility Forecast Tables*, Dell'Oro Group, January 2009.

2 OPERATOR STRATEGIES FOR AN LTE DEPLOYMENT

Operator strategies for an LTE deployment can be classified into three main categories:

1. Data-only services on LTE
2. Data-only services on LTE with 2G-3G voice
3. Voice and data services on LTE.

To de-risk their LTE deployments, operators may incorporate one or more of these strategies at different times. Thus, the three strategies are not diametric to one another, but rather build upon their predecessor(s).

For example, a logical progression for an operator might be to initially deploy data-only services for LTE subscribers and then evolve to offer voice using the existing 2G-3G system. Another operator may offer LTE data services with voice services on the 2G-3G network and then later migrate their voice traffic to LTE. Alternatively, yet another operator may decide to jump straight to the third strategy, offering all voice and data services on LTE without ever deploying the first two options.

It is highly unlikely an operator would deploy any of the three strategies in reverse order. It should also be noted that 3GPP standards for LTE do not intrinsically support voice calls. Rather, LTE is a wireless data, "all-IP" technology for which voice services have largely been an afterthought in the Release 8 3GPP standards.

The following section discusses these three main LTE deployment strategies as well as some of their sub-strategies.

2.1 DATA-ONLY SERVICES

To simplify their network evolution to LTE as it pertains to voice services, some operators will begin LTE deployments offering only data services. Dell'Oro has projected, "While in its early years of deployment, LTE will primarily be a data-only service, used for high-speed mobile broadband (rather than for voice)…"[5]

The advantage of a data-only strategy is that it allows operators to quickly deploy LTE access without the requirement of a voice core solution. Operators can gain deployment and operational experience with LTE prior to adding the complexity of voice and its extensive regulatory requirements.

A "data-only" offering implies that the LTE subscriber base will be targeted at customers who want wireless dongles, netbooks, air cards and/or similar devices.

INTEROPERABILITY WITH 2G-3G DATA

When choosing to offer LTE data-only services, operators will need to decide whether the LTE data system should include mobility with the existing 2G-3G data network. Operators will need to decide whether to offer LTE-only capable devices or whether to offer LTE dongles and cards that also support GPRS/EDGE and/or UMTS-HSPA.

[5] *Mobility 5-Year Forecast Report*, Dell'Oro, January 2009.

As LTE networks are deployed, initial LTE RF coverage may be limited. Therefore, it is expected that most 2G-3G operators will choose to allow mobility with their existing data systems to extend the coverage footprint. As Dell'Oro points out, "… other than early adopters, operators must support enough coverage of their LTE networks to entice subscribers to migrate away from mobile 3G service to LTE."[5]

Extending the coverage footprint can be achieved by offering wireless dongles, netbooks and air cards that not only support LTE but also support GPRS/EDGE and/or UMTS-HSPA. Though subscribers may not be able to achieve the same data rates outside of LTE coverage, providing devices that are both LTE and GPRS/UMTS capable will provide coverage parity with the existing solution with increased data rates in LTE zones.

2.2 DATA-ONLY SERVICES ON LTE WITH 2G-3G VOICE

Voice will continue to be a major revenue generator for wireless operators. To appeal to the largest portion of their subscriber base, operators deploying an LTE network will eventually need to offer voice services in conjunction with their data offerings. Similar to the data-only strategy, using 2G-3G voice with data services on LTE/EDGE/UMTS enables the quick deployment of LTE access without the need for an entirely new voice core solution.

Operators wishing to deploy LTE data with GSM-UMTS voice services need only to implement the CS-Fallback solution and corresponding SGs interface documented in 3GPP TS 23.272.

At a high level, CS-Fallback allows devices tuned to the LTE access network to receive pages forwarded by the 2G-3G core network. If the call is accepted the device will "fallback" to the GSM-UMTS network to terminate and process the call. In a similar fashion, mobile originations also fallback to GSM-UMTS RF coverage for call processing.

In addition to being used for voice services, CS-Fallback may also be used to provide other CS-domain services such as CS UDI video, SMS, LCS and USSD.

2.3 VOICE AND DATA SERVICES ON LTE

LTE is a wireless data all-IP access technology. LTE does not specify the core network for voice services but rather relies on other core network technologies to deliver this functionality. 3GPP Release 8 standards provide mechanisms such as CS-Fallback, Single Radio Voice Call Continuity (SRVCC) Handover, etc., that LTE systems may utilize to interact with existing voice core networks. Further definition of the aforementioned mechanisms as well as additional evolution in the standards (for functions such as emergency location services) are required for a successful voice over LTE implementation.

As standards for voice services over LTE mature, such as VoLTE, and as the migration of 2G-3G subscribers to LTE occurs, offering voice services on LTE alone may be deferred. Hybrid approaches involving interaction between LTE and 2G-3G systems are expected in the short term.

Several approaches are being pursued to provide voice and advanced services over LTE and are discussed in the following sections.

2.3.1 IP MULTIMEDIA SUBSYSTEMS (IMS)

IMS is an SIP-based (Session Initiation Protocol) session and service control platform that enables delivery of multimedia applications across a broadband wireline or wireless network. Because LTE is a wireless data “all-IP” technology, LTE is able to provide the broadband connectivity IMS requires for delivering SIP-based services (such as voice).

IMS was first introduced in the 3GPP Release 5 standards and predates the development of LTE by nearly seven years.[6] To incorporate IMS into an LTE ecosystem, the IMS and LTE network standards have been enhanced to include multiple new functions and nodes such as the MSC Enhanced for SRVCC HO, SCC AS, MSC Enhanced for ICS, etc. Additionally, 3GPP Release 9 standards address critical functions such as the handling of emergency location services (which in Release 8 requires the use of CS-Fallback).

Ten years of industry contributions have resulted in an extensive set of IMS standards. Vendors and operators seeking to implement IMS, VoIP and SMS in LTE have been faced with the challenge of identifying the minimum set required for implementing voice, supplementary services and SMS in LTE. To address this challenge, operators and equipment providers created the One Voice Initiative. One Voice (first released in November of 2009) accomplished the following: it identified the minimum mandatory set of requirements, and identified choices for options such that the end-to-end LTE ecosystem could readily build to the initial capability across the UE, eUTRAN, ePC and IMS.

On February 15, 2010, the One Voice Initiative was adopted by GSMA under the moniker of Voice over LTE (VoLTE). With its introduction, GSMA’s Voice over LTE (VoLTE) initiative had the backing of more than 40 organizations from across the mobile ecosystem, including many of the world’s leading mobile operators, handset manufacturers and equipment vendors.

By aligning upon the VoLTE/One Voice initiative, industry members foster an end-to-end LTE ecosystem. Such a standards-based ecosystem ensures the subscriber continues to enjoy in LTE (as they have in GSM/UMTS) a wide variety of handsets and the ability to roam globally while retaining both their voice and broadband data services in LTE.

Because standards for voice services over LTE using IMS are still maturing and the movement of 2G-3G subscribers to LTE will occur over time, offering voice services over LTE with a full IMS architecture may come later than initial data offerings over LTE. Solutions such as CS-Fallback, hybrids of Voice over LTE and 2G-3G systems, or optimized-IMS solutions (i.e. solutions based on IMS standards that extend beyond and/or optimize IMS standards) are expected in the interim.

2.3.2 VOLGA

Though still in the early phases of development, Voice over LTE via Generic Access (VoLGA) is intended to provide mobile operators with the ability to deliver voice and messaging services over LTE access networks based on the existing 3GPP Generic Access Network (GAN) standard. By using a consistent 3GPP GAN standard for GSM, UMTS and LTE, VoLGA has the ability to provide mobile subscribers with a nearly consistent set of voice, SMS and other circuit-switched services as they transition between 3GPP access technologies. The ability to leverage existing 2G-3G core network assets and operating

[6] 3GPP Release 5, which introduced IMS, was frozen in March of 2002; 3GPP Release 8, which introduced LTE, was first ratified in March of 2009 but continues to receive updates.

paradigms is a key advantage of the proposed VoLGA approach. However, there is some concern among operators and vendors that ubiquitous roaming, a key success factor for wireless services, will be difficult if not impossible without a single common industry view of how voice services should be addressed in LTE.

The VoLGA solution requires a VoLGA Access Network Controller (VANC) be added to the existing GSM-UMTS voice core. A VANC is a modified 3GPP Generic Access Network Controller (GANC) that supports circuit-switched services over LTE by creating an IP tunnel while providing the appearance of an A interface to 2G-3G core network nodes.

In 3GPP, the VoLGA method is referred to as Circuit Switch over Packet Switch (CSoPS). It should be noted that 3GPP has declined to give priority to the CSoPS concept in both Release 8 and Release 9. Work on CSoPS within 3GPP (formally documented as alternative 2 in 23.879) was stopped at the March 2009 SA plenary.

An independent VoLGA Forum was established to generate VoLGA specifications and support outside of 3GPP. It is unclear whether VoLGA will gain sufficient backing in the industry to achieve the widespread adoption that is needed for this concept to be successful. As of February 2010, the VoLGA Forum is comprised of 19 participating companies, most of which are vendors.[7] Thus, the VoLGA solution and other VoLGA considerations are not a focus in the remaining sections of this paper.

[7] VoLGA Forum Participating Companies, http://www.volga-forum.com/members.php.

3 SUBSCRIBER EXPECTATIONS

When it comes to LTE wireless services, subscribers likely will expect their LTE devices to work as well or better than their existing 2G-3G devices for both voice and data services while providing new mobile aware multimedia applications. They will want telephony to function as they are already accustomed and they will want new services to function in intuitively obvious ways. This is a tall order for carriers themselves as well as the Radio Access Network (RAN), the core, the application plane and the terminal. This section explores these and other subscriber expectations and examines how LTE will be deployed to meet those challenges.

A subscriber's perception of the overall value of the service provided is referred to as Quality of Experience (QoE). QoE takes into consideration every factor that contributes to overall user perception and may include factors such as speed, bandwidth, feature set, coverage area, mobility, cost, personalization and choice.

To provide QoE that meets subscriber expectations, the following will be critical for most LTE systems:

- The LTE phone must provide high data throughput with low latency
- The LTE system must provide transparency and parity of services
    - The LTE phone must provide features, functionality and performance equivalent or better than predecessor wireless technologies
- The LTE phone must provide seamless service and an "always on" experience
    - The LTE phone must provide service all the time, albeit some of the time the service may not be better than 2G-3G
    - Ongoing voice services and features must be maintained while travelling from LTE service zones to 2G-3G coverage areas
    - The network must interoperate across operators and provide full roaming capabilities
    - The user must be able to initiate a session and obtain information or services at a moment's notice
    - The user must be able to have data sent to them without their initiation
- The system must be able to support various plan options providing different service sets, data rates, etc., to coincide with various subscriber fees
    - The quality of service provided must match what the user paid for
    - Sufficient information should be provided to the user to know when high quality service is and is not possible
- The system should be able to offer new and/or enriched services

3.1 HIGH DATA THROUGHPUT AND LOW LATENCY

The wireless environment is challenging with respect to consistent service quality. Buildings and other geographical features along with interference from other sources create areas of low signal strength and high noise where service may be challenging. In addition, Raleigh fading causes significant changes in performance of the air interface for both voice and data. Fortunately, users have an intuitive understanding of this problem and have some tolerance for variability. Users do look for “bars” on their phones and adjust their expectations of call quality according to what they see. Of course, users are happier when they get better service in more locations, but the expectation of a wireless system includes some acceptance that it is not perfect everywhere.

LTE provides greater spectral efficiency than previous technologies. It couples this increase in efficiency with additional spectrum. Initially, this will provide a very good QoE (with improved data rates and lower latencies), similar to landline broadband. As LTE becomes more popular, there will be more competition amongst users for the spectrum and more interference. It will be necessary to deploy additional capabilities to retain the high QoE for a rapidly expanding number of users. Fortunately, this need will come hand-in-hand with the revenue growth from these subscribers.

Several techniques are available to provide higher QoE. These involve improving user throughput directly, improving throughput by improving spectral efficiency and reducing latency. Techniques include:

Use of OFDM technology. Orthogonal Frequency Division Multiplexing (OFDM) along with other air interface innovations offer lower latency connections as well as increased spectral efficiency, particularly in the uplink.

More advanced levels of MIMO. Additional receive and transmit paths increase the signal to interference ratio (i.e. increase the spectral efficiency). Using 4x2 MIMO in critical areas will increase network capacity to support a high QoE for more users.

Network MIMO (planned with the introduction of LTE Advanced in 3GPP Release 10). Network MIMO uses multiple base stations to provide diverse transmission paths to a user. This makes use or advances in available computational power in the network to increase capacity via improvement in signal to interference ratio.

Home NodeB, Pico Cells and Small Cell Radii. It is well understood that smaller cells increase capacity by reusing the spectrum more frequently in the spatial domain. Cost-effective technology advances are allowing affordable support for much smaller cell sizes in critical high traffic areas.

Higher-order modulation (made practical partly by smaller cells). Where the signal-to-interference ratios permit, high-order modulation techniques allow the transmission of more data within a given amount of spectrum. By using smaller cell radii, it can be practical to enable high-order modulation in hotspots.

Flexible spectrum carrier configurations. LTE supports a wide range of carrier widths including 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz. This allows a service provider to fully use the available spectrum aggregated into a single radio carrier providing higher peak data rate capabilities and lower latencies than previous 3G technologies.

Flatter Architecture. The network core for LTE (called the Evolved Packet Core – EPC) has been designed to minimize mobility-specific processing elements to lower the overhead and packet processing bottlenecks. Fewer hops reduce end-to-end latency and simplify network operations.

3.2 TRANSPARENCY AND PARITY OF SERVICES

When migrating from a 2G-3G capable device to a device that also supports LTE, users will expect to have access to the same services that they enjoy today (termed “service parity”), and they will expect those services to work in a way to which they have become accustomed (termed “service transparency”), independent of the access technology. In short, users will not want to re-learn existing features or lose functionality on their new devices.

LTE will empower some services that may not operate as well, or even not at all, on 2G networks. However, the converse should not be true. The LTE system will need to meet and/or exceed the 2G-3G system capabilities.

3.2.1 TRANSPARENCY AND PARITY FOR DATA

Existing data services that currently operate in 2G or 3G networks will typically operate transparently or with better performance in an LTE environment. LTE provides higher data throughputs, which will speed up most network-based applications. Thus, transparency and parity of existing data services is generally not a concern for operators migrating from 2G-3G networks to LTE.

Carriers will offer new data services that may not perform well on slower (e.g. 2G) networks. The user will, therefore, observe enhanced operation of some features when using LTE. Some applications that require low latency and/or high speeds may be restricted to operation on LTE.

3.2.2 TRANSPARENCY AND PARITY FOR VOICE

Voice continues to be an essential wireless application. For basic voice services, LTE VoIP will be provided in a transparent way to existing GSM-UMTS circuit voice. There has been ongoing work to ensure that a larger set of voice services and mid-call services operate transparently between circuit voice and VoIP. As discussed later in this white paper, basic voice calls can be handed over to circuit using SRVCC HO technology. Considerations for achieving service continuity are addressed in section 5.3.2.

3.2.3 TRANSPARENCY AND PARITY FOR SMS

Short Message Service (SMS) is used both for user messages and updates to terminals. SMS messages can be delivered to LTE devices by 1) IMS and SIP; or 2) utilizing existing infrastructure and tunnelling SMS messages from the MSC to the MME over the SGs interface.

The advantage of the second method is that it allows delivery of SMS prior to the introduction of IMS and/or avoids the need to upgrade the SMS infrastructure after IMS is introduced.

3.3 SEAMLESS SERVICE AND AN ALWAYS-ON EXPERIENCE

An important aspect of QoE is to have high quality service available all the time in all places. Despite the desire to rapidly deploy LTE, it will take time for LTE to reach the coverage level enjoyed with 2G-3G systems. Since LTE cannot be made instantly available everywhere, it will be necessary to complete the coverage area by providing interoperability with the existing 2G & 3G networks.

To provide a seamless experience, operators will need to deploy active handover for voice, data and multimedia services. The following section discusses mechanisms that may be incorporated to facilitate active mode handover between LTE and 2G-3G systems. It also discusses the option to perform idle mode handover.

3.3.1 SEAMLESS SERVICE FOR DATA

A service provider introducing LTE will likely already have an existing 2G and/or 3G infrastructure in place. And, because they will not have ubiquitous LTE coverage on day one, the initial deployment of the more advanced technology will have to present itself to the user as a higher speed extension to their existing mobile data products.

From the perspective of the mobility service provider, a user should have as similar as practical an experience with the network whether the radio is 2G-3G or LTE (of course, later air interface will be much faster). If the user is mobile or under varying RF conditions that force radio technology re-selection in the UE, the connection to the packet network should always remain “up” and under no circumstances, should there be a reassignment of IP address that can “break” sessions that are running. Mild packet loss may be acceptable if it occurs for very short periods of time so that the higher layer protocols or the application layer can recover without any noticeable adverse effect to the user experience.

To accomplish this seamless interoperability across the radio access technologies, not only are devices that support LTE as well as 2G-3G packet data required, but packet core network support is also critical.

Three mechanisms that may be used in the packet core network to achieve near seamless interworking of packet services between LTE and legacy 3GPP 2G-3G include:

1. Using the S-GW as a mobility anchor for all 3GPP radio technologies as described in Release 8 TS 23.401 Clause 5.5.2
2. Making the MME appear to the legacy 2G-3G network as just another SGSN as documented in Annex D of TS 23.401
3. Using a technique for simultaneous Routing Area (RA) and Tracking Area (TA) registration known as Idle-Mode Signaling Reduction or ISR

Each of these three mechanisms is defined in greater detail in section 5.1 of this white paper. It should be noted that the mechanisms for packet switch handover do not apply to interworking between LTE packet voice (VoIP) and the 2G-3G CS core.

WHY NETWORK SUPPORT IS CRITICAL FOR SEAMLESS DATA SERVICE

To understand why network support is critical, consider the simplest UE-based implementation of Inter-Radio Access Technology (I-RAT) Hand-Over (HO). Such an implementation is based on the concept of an unattached UE monitoring for multiple radio technologies and selecting the “best available” radio. If coverage for the currently attached radio drops, the UE simply reselects and reattaches to whatever better coverage is available. The problem with this approach is that since a new IP address will be issued at network attach time, there is no guarantee the UE will continue using the same IP address. As a consequence, all application layer sessions will have to be destroyed and reconnected. In some cases, as with web browsing, the impact will be minimal. In other cases, as with VPNs and video streaming, the entire session will need to be rebuilt.

Network assisted Packet-Switched HO (PS HO) will allow the network to use UE measurement data to assist in the process. Network control of the HO will indicate to the UE when to redirect to the preferred RAT. Further, network signaling will ensure that PDP contexts (2G-3G) and EPS bearers (LTE) are mapped to each other across RATs and between the 2G-3G packet core and the Evolved Packet Core (EPC). Sections 5.1.1 and 5.1.2 review two methods that have been established in standards for achieving the seamless HO between 2G-3G radios and LTE.

3.3.2 SEAMLESS SERVICE FOR VOICE

Subscribers require continuity of voice service between LTE and 2G-3G for both active and idle mode roaming. This is supported by LTE, and there are three deployment scenarios to consider:

1. LTE provides data only service and the 2G-3G network is used for voice.
2. Voice on LTE is provided by VoIP IMS
3. Voice is provided on LTE via CSoPS (Circuit Switch over Packet Switch)

The following sections examine each of these cases.

3.3.2.1 SEAMLESS VOICE COVERAGE WHEN LTE IS USED ONLY FOR DATA

Initially, LTE deployments will provide data-only service. When the UE is a data card for a PC, no voice coverage is needed. It is expected that LTE-enabled data and voice terminals will be deployed prior to universal voice coverage on LTE. In this environment it will be necessary to provide both interoperation of data capabilities and provide the user a good experience when voice is covered on 3G and data is provided with LTE. This is accomplished via Circuit-Switched Fallback as described in 3GPP 23.272.

Circuit-Switched Fallback works in the following ways:

1. For outgoing calls, the UE initiates the proper transition to the 3G network and then can proceed with normal 3G voice call initiation
2. For incoming calls the network pages the UE over LTE. This begins a procedure with the network and UE to transition the UE to 3G (or 2G) to receive the call. If there is an active data session, it can be brought over to the 3G network.

As shown in the reference architecture in Figure 2, there is an SGs interface from the MSC to the MME to accomplish the paging function. The S3 interface from the MME to the SGSN shown in the figure facilities the continuation of an active data session while the UE transitions from LTE to 3G.

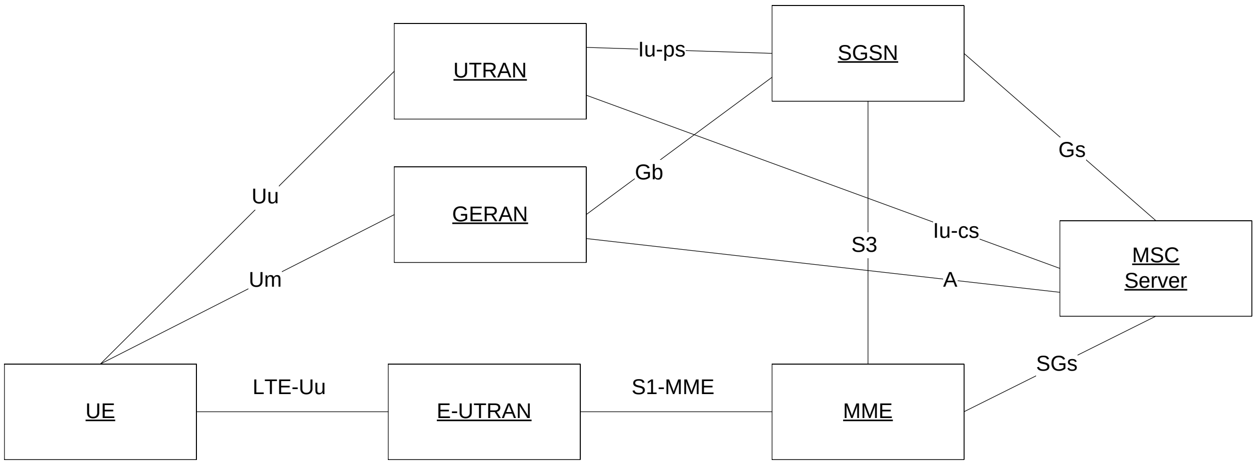


Figure 2.[8]

The SGs interface can also be used to provide support of SMS delivery over LTE. An SMS Center is connected to the 3G MSC over a map interface. The MSC server can deliver SMS messages over LTE via the SGs interface to the MME. This SMS functionality does not need a full MSC; it requires only a simplified MSC Server.

3.3.2.2 SEAMLESS VOICE COVERAGE FOR LTE VOIP

Since 3G networks generally use circuit voice and LTE networks are packet-based, it is necessary to provide mobility between the Circuit and Packet domain for voice services. The SRVCC feature provides this capability for both active and idle mode mobility. Calls will be seamlessly delivered to either the LTE or 2G-3G network according to where the user is currently active. If a user is active on a call and leaves LTE coverage, SRVCC allows that call to be handed over to the 2G-3G network without disruption. For facilitating session transfer, the 2G-3G MSC must be upgraded with SRVCC capabilities, which includes support of the Sv interface as shown in Figure 3.

[8] *CS Fallback in EPS Architecture*, Figure 4.2-1, 3GPP TS 23.272 V8.2.0 (2008-12).

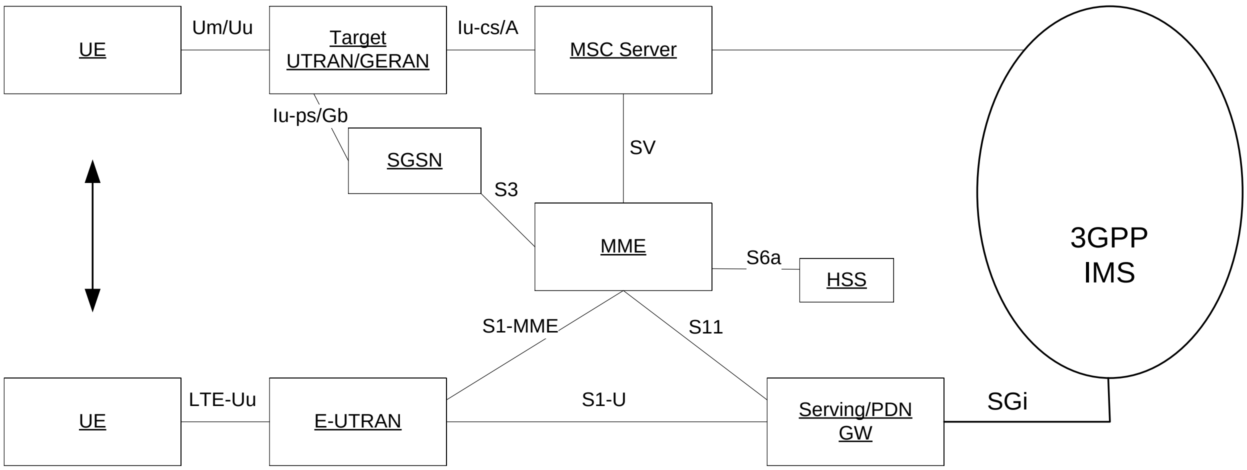


Figure 3.[9]

When a voice handover between the LTE (IMS) domain and the 2G-3G (circuit) domain is required, the Sv is used to trigger the MSC to initiate the SRVCC transfer. As described in TS 23.216, the Enhanced MSC Server initiates the session transfer procedure to IMS and coordinates it with the CS handover procedure to the target cell. 3GPP TS 23.216 has the complete call flow in Section 6.

SRVCC supports the concurrent transfer of a packet bearer if the target network is 3G or a 2G network able to support concurrent voice and data.

If VoIP is used on 3G, then a voice call may be handed over to a 3G packet network without using SRVCC. This is accomplished via PS HO as discussed in section 3.3.1.

3.3.2.3 SEAMLESS VOICE COVERAGE WHEN USING CS OVER PS

VoLGA supports handovers from LTE to the GSM-UMTS network using some of the SRVCC capabilities previously described. When the E-UTRAN detects the need for a handover based on measurements reports received from the mobile device, it sends a Handover Required message to the MME, initiating the process. The MME, in turn, informs the VANC that a handover is required by sending it an SRVCC PS-to-CS Request message over the Sv interface. The VANC converts this request into a CS Handover Request and sends it over to the MSC instructing it to prepare for handover. Once the preparations have been completed, the MSC informs the VANC that it is ready for handover. The VANC notifies the MME, which then commands the UE, via the E-UTRAN, to handover to the GERAN/UTRAN. With the completion of the handover, the VANC clears all the resources used by the call and instructs the MME to do the same by sending it the SRVCC PS-to-CS Complete Notification. At this point, the VANC may also deregister the UE and release the VoLGA signaling bearer.

[9] 3GPP TS 23.216.

As with the IMS solution described previously, if a data session is concurrently active with the voice call, it may either be handed over to the GSM-UMTS network or suspended, depending on the characteristics of the network.

3.3.3 ALWAYS-ON EXPERIENCE

Users are becoming accustomed to an always-on experience. They expect to obtain information or services at a moment's notice and to have data sent to them without their initiation.

An example of a user terminated data service is SMS. Providing an always-on experience, especially for terminating services puts significant stress on a 3G network. In order to provide an always-on experience for SMS users, 3G networks rely upon paging technology from the circuit service infrastructure. This is specific for SMS and not readily applicable for generic data services. It is challenging for 3G networks to provide generic always-on data service because the allocation or holding of a code (to be able to receive data) consumes non-trivial resources.

LTE makes the rapid allocation and de-allocation of data resource significantly more granular, rapid, and less resource consumptive. This will allow service providers to provide a true always-on experience. With LTE, it becomes practical to efficiently support a large number of users who may be fairly active without sending large amounts of data. Many human-to-human and machine-to-machine always-on use cases produce this kind of traffic model.

3.4 CHOICE OF SERVICE LEVELS

Current 3G deployments do not typically offer subscribers Quality of Service (QoS) choices for data. Today, subscribers are limited to "best effort" data. As such, subscribers perceive QoS and QoE as the same concept; but in LTE networks, QoS is a key focus area. With the introduction of LTE, operators will have the ability to offer subscribers service plans with differentiated QoS levels. The following section explains the QoS concept and how it is achieved in an LTE network.

QoS is the ability to negotiate a service level agreement and having the terms of that agreement reliably fulfilled. In layman's terms, it is the ability to buy what you want and get what you paid for. The concept is familiar to users, they deal with offers for various grades of landline internet service, they understand getting the number of simultaneous TV channels they paid for and they understand paying for the number of simultaneous phone calls they can have (they may think of this as telephone "lines"). Users will be frustrated if they do not see a good correlation between what they pay for and what they get.

Part of the migration to LTE will include the addition of an architecture for managing and providing QoS that will meet the user's expectations and the service provider's interest in monetizing the level of service provided.

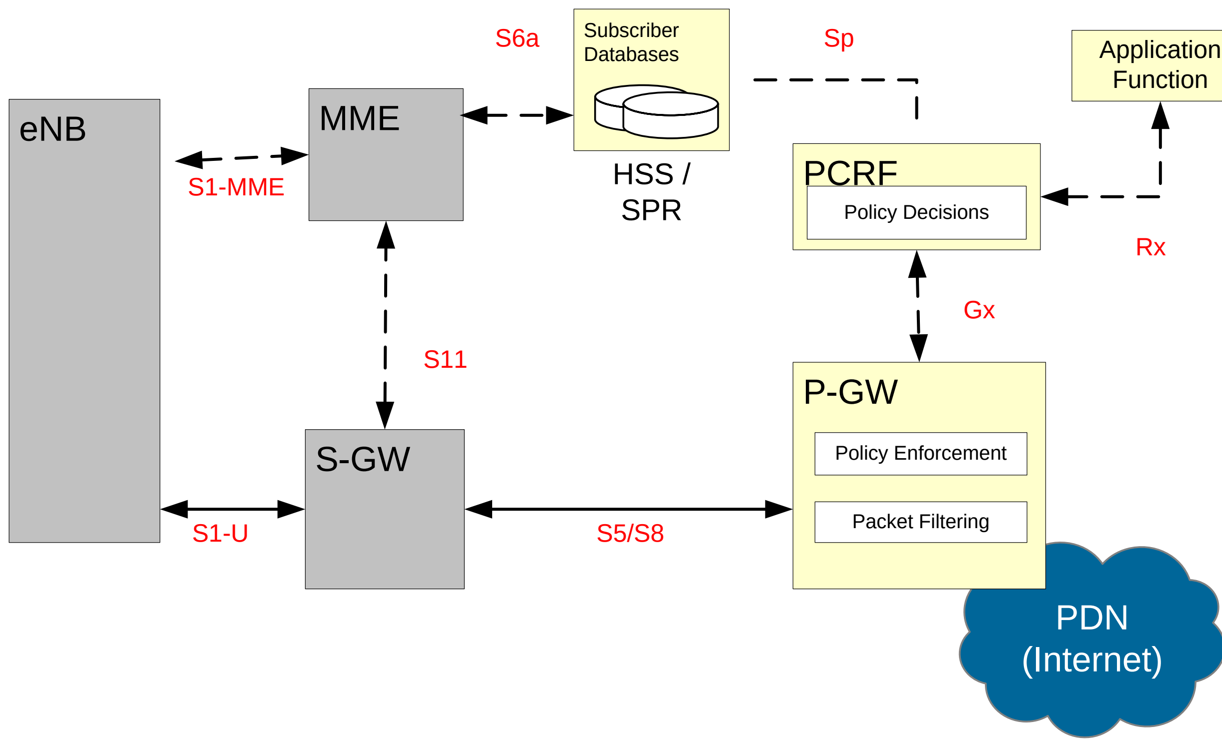


Figure 4.

Policy is introduced into the network via a Policy Charging and Rules Function (PCRF) as shown in Figure 4. This provides a decision point to allow or disallow QoS requests. Decisions can be made based on user subscription (i.e. the Sp interface to the HSS/SPR), the application function (i.e. the Rx interface to the application function), or user requests. The policy is enforced via policy enforcement and packet filtering in the P-GW.

The policy and charging functions are closely aligned. Recall that the intent of a QoS system is to enable the service provider to sell and the subscriber to buy whatever QoS is desired. A policy purpose is not to block users from gaining service grades; it is to enable a market for higher qualities or service.

3.5 NEW AND ENRICHED SERVICES

LTE will enable services requiring high throughput rates (such as video services), low latency (such as gaming), and high quality of service (such as real time video conferencing). IMS is expected to be one of the primary vehicles for delivering new services.

4 OPERATOR EXPECTATIONS AND CONSIDERATIONS

An important consideration of any operator migrating to LTE is that they meet the subscriber's expectations as discussed in Section 3. In addition to meeting subscriber expectations, however, operators will have their own incremental set of needs and expectations. Some of these operator needs may be of little interest to large portions of the operator's customer base or may be completely transparent to the subscriber but are no less crucial to a successful LTE deployment and business model. The following section addresses a number of expectations and considerations operators will encounter when migrating from a GSM-UMTS network to LTE.

4.1 DEVICE CONSIDERATIONS

While device selection will be strongly driven by subscriber preferences when selecting which devices to offer to their customer base, LTE service providers will need to take into account several factors that may otherwise be over-looked by their consumers. Critical factors include the need for multi-mode devices, multi-band devices, dual stack IPv4/IPv6 capabilities, and features such as SRVCC HO and/or CS-Fallback. All of these considerations are discussed below.

4.1.1 MULTI-MODE DEVICES

As mentioned previously in this white paper, it will be a number of years before LTE RF coverage matches that of existing 2G-3G systems. In order to provide subscribers equivalency or better coverage than their existing service, operators will not only need to build a network infrastructure that allows 2G-3G and LTE coexistence, they will need to offer devices with multi-mode capabilities.

Devices that support GSM-HSPA-LTE will provide the subscriber with the greatest ability to acquire service across the largest coverage area. Thus, multi-mode devices will largely be necessary with the introduction of LTE to appeal to early technology adopters and a large portion of the subscriber base.

4.1.2 MULTI-BAND DEVICES

There are several RF band classes defined for LTE as shown in *Appendix B*. To protect revenues and provide optimal LTE coverage, it is important for carriers to have access to a vibrant ecosystem of terminals that include support for multiple bands.

Roaming charges can be a significant expense and/or revenue generator for operators. Operators with mixed spectrum bands will require multi-banded terminals. Operators will need multi-band devices to support both their spectrum and their roaming partners' spectrum.

As shown in *Appendix B*, many of the bands being used for early LTE deployment are confined to specific geographic regions. For example, wireless operators in Europe and Asia use different frequency bands than those used in North America. Depending upon the country and carrier, European and Asian carriers use the 900 MHz band (GSM), 1800 MHz band (DCS) and/or 2100 MHz (W-CDMA) frequency bands. In North America, the 700 MHz (700), 800 MHz (Cellular), 1700/2100 MHz (AWS), and 1900 MHz (PCS) frequency bands are used.

It should be noted that even before considering the technical RF challenges of multi-band devices, terminals face technical RF challenges working in some of the individual bands. The 700 MHz band is of special interest to North American operators and presents several potential challenges:

- Band class 12 (700 MHz A+B+C) has a narrow duplex gap (the UL-to-DL frequency separation) of only 12 MHz as measured from band edges, which poses filter and duplexing challenges.
- Band class 12 also has strict interference constraints upon interference with TV CH 51 reception (in the adjacent block).
- Band Classes 12 and 17 both face interference associated with adjacent broadcast services in the Lower D-block (MediaFLO) and E-block.

It is essential that the industry quickly drives a robust supporting chipset ecosystem (RF and baseband) upon which the single- and multi-band terminals will depend. Associations will work with government regulators toward harmonization of spectrum bands. Carriers with common spectrum and/or known roaming agreements will work together to help the wireless industry increase efficiencies of scale and scope in order to drive terminal availability, efficiency and access with their required operating bands.

4.1.3 IPV4 AND IPV6

Migration to LTE carries with it the implied transition to IPv6. The 3G Americas white paper, *IPv6 Transition Considerations for LTE and Evolved Packet Core*, discusses this in some depth. The deployment of LTE will put greatly increased demands upon IP addresses. There will be many more devices and some of these devices will be connected to a higher fraction of the time. Devices using VoIP will stay connected (and, hence, retain their IP Addresses) all of the time. This creates an IP address exhaustion problem that will be addressed, at least in part, by the use of IPv6.

It is expected that IPv6 addresses will be used for VoIP and other push services. It is also expected that IPv4 addresses will be needed for some time for Internet access. Windows XP and existing Mac OS devices are compatible only with IPv4 and this creates a need for IPv4 within the connecting LTE UE. The need for both IPv4 and IPv6 (for always-on, VoIP, and push services) leads to dual stack devices as discussed in the white paper.

Since the IP address exhaustion cannot be fully addressed by IPv6, it is expected that many carriers will have to use NAT for IPv4 addresses.

The 3G Americas white paper also discusses the use of IPv6 to IPv4 http-proxy (NAT-PT) to support IPv6-only devices.

4.1.4 OTHER CRITICAL DEVICE CAPABILITIES

This paper has identified several capabilities within the network to support seamless operation across 2G-3G and LTE. In order for these network features to function, the UE must also support these features. They include:

- Seamless voice handover between LTE and 3G requires support for SRVCC capabilities within the handset.
- UE support is also needed for the previously mentioned CS-Fallback. The reader will recall that CS-Fallback is a method for providing 3G voice service on a terminal that supports LTE data.
- Voice terminals operating in LTE will be required to have location capabilities for LTE. Existing Assisted Global Positioning System (AGPS) methods will be supplemented by downlink observed time of arrival location technology. This will be required to meet the FCC mandates for location accuracy with 911 calls.

- LTE terminals, including data cards, will have to support SMS. SMS is used for both user messaging, terminal updates and Over-the-Air Activation.

It should be noted that a terminal that supports VoLGA defined voice services also requires an entirely new set of capabilities not found in existing 3G terminals or an LTE IMS-capable terminal.

4.2 SATISFYING REGULATORY REQUIREMENTS

A fundamental requirement of any network deployment is that the system adheres to government regulations. Though government regulations differ from country to country, three requirements that are pervasive throughout the world include Lawful Intercept, TTY-TDD and Emergency Services.

The following section discusses considerations for lawful intercept in both a data and voice over LTE context and discusses considerations for Emergency Services in an LTE network.

4.2.1 LAWFUL INTERCEPT FOR VOICE

Satisfying Lawful Intercept (LI) requirements is a key criterion for new products and architectures to be viable in the market. Network operators, access providers and service providers must all satisfy LI requirements by capturing certain information and making it available to law enforcement monitoring facilities. If a product does not satisfy LI requirements, its deployment will be blocked. The following paragraphs describe some of the challenges involved in supporting LI for IMS voice. These challenges are being addressed in IMS standards independent of the access environment.

- **Customization.** LI includes a broad range of service interactions and its requirements are often country-specific.
- **Transparency.** LI must be performed without the targeted users and associated users noticing any difference in the behavior of their services.
- **Jurisdictional boundaries.** In the IMS architecture, users access services through the S-CSCF in their home networks. This presents new considerations for a visited network to apply LI to a roamer. To capture content in both the session control and bearer planes, the visited network and the home network must both perform LI. LI solutions must be mindful of jurisdictional boundaries, especially when it is across national boundaries.
- **Correlation.** IMS services can be provided by application servers that receive SIP messages from the S-CSCF when filter criteria are met. These application servers will have to support LI. Similarly, the various types of media servers that exist in IMS (e.g. conference servers) will also have to support LI. The growth in both the number and types of nodes in IMS compared to 2G and 3G voice networks will present additional considerations for LI provisioning and the correlation of LI reports.
- **Legacy interfaces.** In the U.S., LI in the CS domain uses ISUP trunks to pass bearer information (voice content) to LI monitoring centers and this is unlikely to change. Because SIP is the only call control protocol supported in IMS, use of a gateway node (an interworking function) to access these trunks is anticipated.
- **Service awareness.** Capturing VoIP packets in the Evolved Packet Core incurs challenges with service interactions. For example, LI requirements include capturing the voice content of a call that was *redirected* by an LI target that is no longer involved the call. If user A calls user B and is forwarded or transferred to user C, and user B is an LI target, then the A-C call must be

monitored. In the CS domain, B's gateway or serving MSC has access to the bearer plane of the A-C call. But in IMS, a new solution will need to be devised, as B's S-CSCF has no control over the bearer plane in the A-C call and, in most SIP implementations of call forwarding and call transfer, does not remain in the control plane of the A-C call.

4.2.2 TTY-TDD

TTY-TDD is an existing regulatory service that provides communications for speech and hearing impaired subscribers using existing widely deployed TTY-TDD devices. This service is used for both emergency and normal service. For normal service it is used both directly between users with TTY devices and via free service centers which perform translation. This service must interwork with the PSTN.

4.2.3 EMERGENCY SERVICES

In Release 8, LTE-capable devices must rely on the existing 2G-3G voice core to provide emergency services. IMS in Release 8 does have the ability to identify an emergency number and instruct the terminal to instead place the call in the CS domain (TS 23.167). The reason for this fallback is that 3GPP is finalizing the following capabilities:

- How to support E911 for a terminal that has not registered (analogous to CS support for a SIM-less, IMEI-only emergency call)
- How to provide location information
- How to give E911 calls priority over non-emergency calls
- How to support E911 in restricted areas (for example, where roaming is not allowed)

These issues are to be addressed in Release 9 and the solutions will propagate back into Release 8 so that E911 calls can be carried over LTE. This also means supporting the handover of emergency calls from LTE to 2G-3G CS. Also, because emergency services are local in nature, the Release 9 proposal includes detecting emergency calls within the P-CSCF so that they can be routed to an E-CSCF (Emergency CSCF) and from there to a local emergency center, either through the Mm interface to an external IP Multimedia Network, or through an Mi or Mg interface to a BGCF or MGCF that connects to the CS domain.

In the U.S., E911 Public Safety Answering Points (PSAPs) are accessed via both ISUP and MF trunks. The legacy equipment for the latter has existed for many years and will remain in place for quite some time. SIP is the call control protocol supported in IMS. Therefore, it will be necessary to use a gateway node (an interworking function) to complete emergency calls over these trunks.

4.3 OPERATIONS EFFICIENCY

A key necessity for any network operator is the ability to operate their network efficiently. The following section identifies two important network activities that operators should consider when migrating from a GSM-UMTS network to LTE. The first deals with increased automation in managing the radio access network while the second deals with efficiently activating new subscribers.

4.3.1 SELF-OPTIMIZING NETWORKS

The wireless industry is deploying LTE to support a wide variety of applications requiring high data rates and high signaling rates that translate to stringent QoS requirements. The deployment of a large number of base stations (eNBs), femtos and Home-eNBs will result in a highly complex network with several parameters that need to be set and fine-tuned. In a heterogeneous environment, the dynamic operating parameters of base stations will change even more rapidly. Technology suppliers must provide solutions that will allow wireless networks to, first and foremost, serve consumers in the most efficient manner possible, and second, to fully capitalize on the vastly greater capabilities of LTE technology. In current network operations, live network measurements are fed back to tune the initial design parameters. However, this feedback is typically manual, labor-intensive and slow. The result is often suboptimal performance. Automation does exist within the network and it works well for scheduling algorithms, power control, etc. With proper design, automation can be extended to other network operations with significant resulting operational and performance benefits.

3GPP TR36.902 is one of the key specifications that addresses the issue of Self-Organizing or Self-Optimizing Networks (SONs). SONs automatically configure and optimize networks to minimize operational effort and improve network performance. SONs offer a vision in which base stations automatically interact with each other and with the core network to perform self-organizing functions.

SON comprises three key aspects: self-configuration, self-optimization and self-healing. 3GPP TS36.902 has defined several functional areas in SON to realize these objectives. The self-configuration aspect of SON aims to support plug and play operation of new eNB elements. The corresponding 3GPP TS36.902 functional areas include automated configuration of Physical Cell Identity and Automatic Neighbor Relation function. The self-optimization aspect of SON aims to mitigate quality degradations by optimizing network parameters under interference and overload conditions. The corresponding features in 3GPP TS 36.902 include: load balancing between eNBs, handover parameter optimizations, static and dynamic interference control to improve cell edge throughput, capacity and coverage optimization, Random Access Channel optimization and Energy Savings. The self-healing aspect of SON aims to achieve automatic fault identification based on UE measurements of the radio quality that are then used for cell outage compensation.

SON algorithms can be implemented in a centralized, distributed or hybrid architecture. In a centralized architecture, the SON functions would be supported through a centralized management at EMS and local management at eNB. The goal is to eventually push all SON functionality to eNB, with information exchange between the eNBs over the X2 interface. This allows higher degree of automation of LTE networks, so that resources for the management plane are not continuously re-planned when the LTE network is gradually deployed.

For an operator, the network is their key investment that is the basis of their revenue. Therefore, for the vision of SON to be realized with LTE, it is important that the following operational objectives be achieved:

1. The operator must have strong confidence in the proposed automation processes under highly unpredictable conditions, while minimizing risk and effort. Automation provides them with a path to maximize their network performance with minimum effort, and minimum cost.
2. The operator must reserve the ability to keep manual control of the system, on demand.
3. The implementation of SON for LTE must take into account existing 2G-3G operations.

SON will begin by automating lower-level operational functions (e.g. eNodeB plug and play configuration), thereby freeing up operational resources to focus upon higher-value, higher-complexity issues such as capacity and coverage optimization. SON mechanisms will allow an operator to focus on strategic management of the network rather than day-to-day management, thereby enabling operations to move up the value chain.

4.3.2 SIM PROVISIONING AND OVER-THE-AIR ACTIVATION

Depending on their LTE services strategy, operators will have to update the Universal Identity Cryptographic Computer (UICC) to offer IMS services and may choose to change the way they update their UICCs at time of activation from a push mechanism to a pull mechanism.

In existing 3GPP systems, consumers receive their UICCs with all the necessary information already provisioned so they can be functional on the network. However, some operators update the UICCs to refresh the USIM and ISIM at the time of first attachment to the network during a process commonly known as Over-the-Air (OTA) activation. Currently, the OTA activation delivers the new file updates via a push mechanism relying on the SMS bearer with SMS Type Data Download. With the OTA activation, the ISIM is populated with the IMS Private Identity (IMPI) and IMS Public Identities (IMPUs), without which the IMS services cannot be delivered.

In the LTE environment, SMS can either be delivered via the SGs interface or become an SIP service that relies on IMS for delivery. The current OTA activation is impacted by the choice of delivery of SMS.

SMS TUNNELING OVER THE SGS INTERFACE

With SMS tunneling over the SGs interface, the SMS service remains available regardless of the IMS availability itself. Therefore, operators can continue to perform OTA activation via the push mechanism relying on SMS. This mechanism enables OTA activation over the 2G-3G circuit, 2G-3G packet (with the SG interface) and LTE networks.

SMS AS A SIP SERVICE

With SMS available only as a SIP service relying on IMS, the UICC OTA activation for remote ISIM provisioning cannot rely on the SMS bearer. One solution is to change the OTA UICC activation from a push mechanism to a pull mechanism based on IP. With a pull mechanism, the UICC initiates the OTA activation when it is available on the network, pulling information from the OTA server to update its applications, including the ISIM. IP-based pull OTA has been standardized over HTTPS by GlobalPlatform; it is being standardized by ETSI; and it requires devices that support the Bearer Independent Protocol (BIP).

4.4 EFFICIENT MIGRATION

In addition to meeting subscriber expectations, satisfying regulatory requirements, selecting devices that meet their objectives, and ensuring operational efficiencies can be achieved, operators will also need to create a build-out plan that makes efficient use of available resources and provides for a smooth deployment. The following section discusses spectrum considerations as well as considerations for reusing antennas, access equipment, core network equipment and back-office infrastructure.

4.4.1 SPECTRUM CONSIDERATIONS

The Digital Dividend spectrum initiative, spectrum clearing and refarming combined with advances in the spectral efficiency of cellular technology, offer wireless operators increased capacity (support for more subscribers) while enhancing subscriber experiences and making many new types of services a possibility.

Spectrum is a highly sought after and valuable commodity amongst the cellular network operator community. Furthermore, the availability and acquisition of licensed spectrum also presents a real barrier to entry for potential operators. As a result, there is often fierce competition to secure additional spectrum when it becomes available. The increasing rate of adoption and rising traffic over wireless technologies may mean that available spectrum becomes over-subscribed in a relatively short period.

The above scenario will likely increase the urgency to allocate new spectrum for LTE and the refarming of existing spectrums. The refarming of spectrum is difficult as the spectrum is still in use by a large numbers of subscribers.

Eventually mature markets may choose to phase-out GSM and refarm spectrum for LTE. LTE presents a unique opportunity for in-band migration made possible by its scalable bandwidth. With the refarming of 1.4 MHz (seven timeslots) of GSM, a baseline LTE system can be deployed. While such a system would obviously not deliver the full benefits of LTE deployed in a 10 MHz or 20 MHz channel, it does, however, present a credible and scalable migration path.

An important consideration for operators deploying cellular systems is the increasing number of bands and the corresponding support from infrastructure and device vendors. The fundamental system design and networking protocols remain the same for each band; only the radio baseband radioelements of the radios may have to change. It is possible that the baseband can support multi-technology and this would mean more powerful onboard processing capabilities with implications for cost. A multi-band radio would be an ideal solution.

Given the global nature and economic significance of the cellular industry, decisions made concerning new spectrum allocation and harmonization will undoubtedly have profound and lasting consequences. Regulators should ensure that new spectrum is harmonized and coordinated on a regional or global basis while ensuring that the technology can be used efficiently and without causing interference to other spectrum users.

4.4.2 ANTENNA SHARING AND ACCESS EQUIPMENT REUSE

It is always preferable to install separate antennas and separate RF feeder paths when installing new services. This recommendation maximizes system performance, minimizes the impact on existing systems, eliminates interaction during network optimization, minimizes interference and simplifies Operations, Administration and Management (OA&M).

2G-3G wireless operators must install several antennas for each Base Transceiver Station (BTS). Because the sites for these antennas are often leased and local zoning boards require variances and permits to install the antenna towers, the acquisition of zoning variances represents significant legal expenditure. Also, the leases sometimes must be renegotiated and new variances approved before new antennas can be added to existing antenna systems.

As with most technology changes, mechanical, structural and wind loading analysis must be conducted before new RF feed lines and new antennas can be added to existing tower structures. Analysis may indicate that the antenna mast structure must be reinforced before the new antennas may be added.

BTS Antenna Sharing can save the cost and time expended on these efforts. Antenna sharing techniques represent a tradeoff of the costs and limitations of adding new feeders and antennas, against the costs of combining equipment, RF performance and OA&M impacts. This section presents a brief outline of the possibilities for addressing antenna and RF feeder sharing, investigating RF performance and OA&M impact, as well as spectral considerations to minimize intersystem interference.

4.4.2.1 ANTENNA SHARING TECHNIQUES

Antenna sharing techniques can be divided into two primary categories: Multi-Band and Co-Band. 2G-3G wireless operators may already be using a combination of antenna sharing techniques to combine GSM and UMTS. This could complicate proposals for the addition of LTE.

MULTI-BAND

Multi-Band techniques combine the transmit/receive signals of separate BTS operating in different frequency bands.

Multi-Band techniques use filter combiners and multi-band antennas to combine signals from the BTS operating in different frequency bands (example: Cellular 850 and PCS1900.) This technique may involve the replacement of existing single band antennas with dual or multiple band antennas as well as the mounting and cabling additional combiners (example: dual band diplexers.)

CO-BAND

Co-Band Techniques combine the transmit/receive signals of separate BTS operating in the same frequency band.

Co-Band techniques may be subdivided into two subcategories: Receive Path-Only sharing, and Transmit/Receive Path sharing.

Co-Band Receive Path-Only sharing techniques require that each BTS have access to a separate antenna to process transmit signals. The receive signals from each of these antennas are shared between the BTS. This technique is quite simple and easy to implement as it involves only the sharing of low level receive signals.

Co-Band Transmit/Receive Path sharing involves the combination of transmit signals from separate BTS operating in the same frequency band as well as the sharing of receive path signals. These combiners are usually mounted in a separate frame and can be quite expensive and may require frequency guard bands which cannot be used for wireless service.

4.4.2.2 ANTENNA SHARING PERFORMANCE CONSIDERATIONS

Antenna sharing techniques reduce the time, cost and complexity of adding more antennas to a mast structure; however, these benefits must be balanced with performance considerations.

Network Optimization: Systems that share antennas also share the antenna pattern and coverage. This means that moving the tilt or azimuth of the antenna to optimize one system will affect the shared system.

Receive Path Noise Figure: Systems that share receive paths between multiple BTS will incur some increase in the receive path Noise Figure (NF) as well as some degradation in receive path Input 3rd order Intercept Point (IIP3.) Typically IIP3 is traded off such that NF is degraded by no more than 1 dB.

Transmit Path Insertion Loss: Combining transmit signals will typically cause a path loss increase of less than 1 dB due to the insertion loss of the filter combiners and inter-cabinet cabling. This is usually considered acceptable to gain the benefits of antenna sharing.

Spectral considerations to minimize PIM: Antenna sharing techniques that combine multiple transmit signals must consider 3rd order Passive Intermodulation (PIM) products generated in the Antenna and RF Feeder. PIM products that fall within the receive band of a shared BTS may cause interference reducing quality of service.

Certain frequency band combinations are susceptible to generating third order PIM products within a corresponding receive band. Without careful frequency planning, these PIM products can fall in corresponding receive bands and significantly degrade the receiver sensitivity of the shared system. In these instances it will be necessary to restrict the frequencies used by shared systems to prevent receiver desensitization.

4.4.3 CORE NETWORK AND BACK-OFFICE REUSE

It is often desirable for operators introducing LTE to their GSM-UMTS networks to reuse as much of their existing core network, back-office, and existing Fault, Configuration, Accounting, Performance and Security (FCAPS) as possible. Mechanisms for reuse come in many different forms and are highly vendor dependent.

Proponents of equipment reuse may point to the highly distributed nature of IMS and the complexity that comes with introducing multiple nodes and interfaces. The highly distributed nature of IMS creates powerful abilities including home control, multiple vendor support, and powerful new features. This power comes at a cost in complexity with respect to interfaces and nodes. This must be managed to have a deployable system. Furthermore, IMS provides great power with open interfaces. This also comes at a cost in deployment complexity and increasing node count. Combinations of IMS nodes may be employed to reduce the number of interfaces and the complexity.

Consolidation of IMS nodes and/or the reuse of back office systems provide a low cost, low-risk VoLTE solution with the following benefits:

- Reduces operations complexity by combining nodes.
- Provides a low risk alternative by simplifying network provisioning, engineering and management.
- Maximizes network performance by reducing the number of external interfaces.
- Minimizes any risks associated with a full back office conversion.
- Expedites LTE deployment while the 3GPP IMS Standards are maturing and IMS networks are being built out. This can also be viewed as a stepping stone until full IMS network deployment.

5 SOLUTION DESCRIPTIONS AND ANALYSIS

Previous sections of this paper identified critical system functionality (such as Packet-Switched handover, CS-Fallback, and SRVCC Handover) for providing a smooth migration from 2G-3G to LTE networks. The following section discusses these network functions in greater detail.

5.1 SOLUTIONS FOR DATA SERVICES

As previously mentioned in section 3.3.1, there are three mechanisms that may be used in the packet core network to achieve near-seamless interworking of packet services between LTE and legacy 3GPP 2G and 3G include:

1. Using the S-GW as a mobility anchor for all 3GPP radio technologies as described in Release 8 TS 23.401 Clause 5.5.2
2. Making the MME appear to the legacy 2G-3G network as just another SGSN as documented in Annex D of TS 23.401
3. Using a technique for simultaneous Routing Area (RA) and Tracking Area (TA) registration known as “Idle-mode Signaling Reduction” or ISR

5.1.1 PACKET-SWITCHED HANDOVER – RELEASE 8 METHOD DESCRIBED IN TS 23.401

TS 23.401 Clause 5.5.2 defines a general procedure for Inter-RAT handover based on the notion of using the S-GW as a mobility anchor for all 3GPP radio technologies. In order to support this new concept, the SGSNs must be upgraded to support new S3 and S4 interfaces. The specification uses the nomenclature “S4 SGSN” to distinguish the Release 8 SGSNs from the pre-Release 8 SGSNs, which support Gn and Gp interfaces.

The figure below shows the high-level networking view of the Release 8 method. The new S4 interface can be used for “direct forwarding” of data so that down-link packets in-transit while a handover is executed can be sent to the respective radio technology so as to minimize data lost in transit. This feature, along with Idle-Mode Signaling Reduction (ISR) will be the two main advantages of the Release 8 method when compared to the TS 23.401 Annex D method. ISR is discussed in Section 5.1.3.

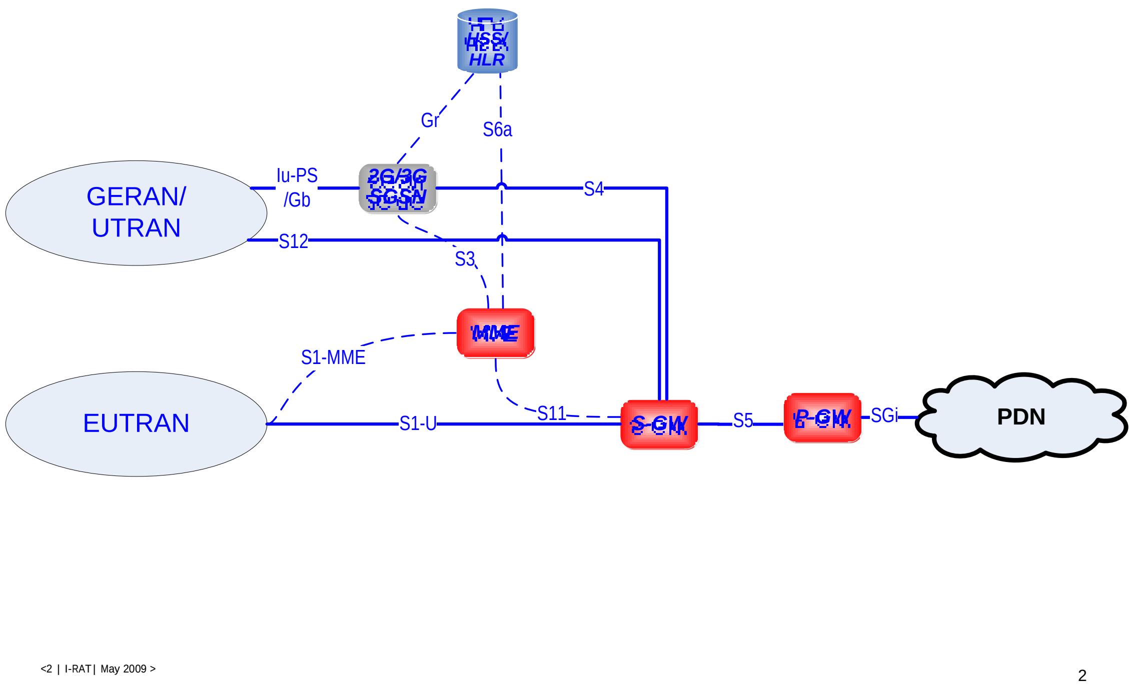


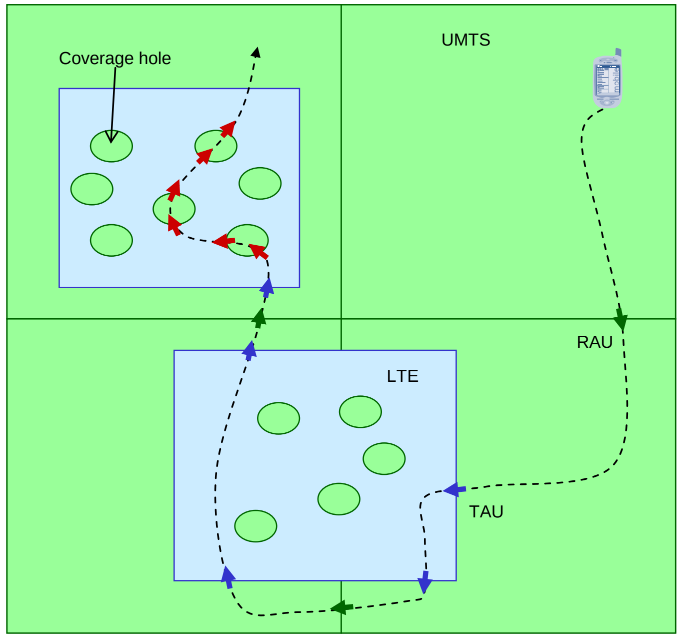
Figure 5.

5.1.2 PACKET-SWITCHED HANDOVER – TS 23.401 ANNEX D METHOD

The Release 8 method of I-RAT interworking requires that the SGSNs in the network be either upgraded to or replaced with Release 4 SGSNs. The basic premise of the Gn/Gp method described in Annex D of TS 23.401 is that an MME appears to the legacy 2G-3G network as just another SGSN; and the P-GW behaves as a GGSN.

5.1.3 IDLE MODE SIGNALING

Early deployment of an overlay LTE may provide “spotty” coverage to a serving area since some cell-sites will get upgraded to LTE whereas others will not (it is assumed that LTE eNBs will be deployed at the same cell tower as the underlay 2G or 3G technology). In this case, when a UE moves from the underlay 2G-3G technology to the overlay LTE technology, the UE will have to perform a TAU procedure, which, if successful, de-registers its presence from the 2G-3G network and registers it with the (preferred) LTE technology in the HSS. When the UE moves from LTE coverage to 2G-3G coverage, it will perform a RAU and deregister from LTE. This will lead to “ping-pong” effects with frequent RAU/TAUs and re-registrations associated to moving UEs in idle-mode (e.g. not generating any revenue) but generating increased signaling traffic. Figure 6 shows the path of a UE that enters a region where there are LTE coverage holes and therefore has to perform TAUs followed by RAUs in successive fashion.



<12 | wp-figure]| April 2009 >

Figure 6.

Figure 6 serves to highlight a fundamental observation that I-RAT ping-ponging occurs when there are mobile (e.g. moving) multi-mode UEs in the network. Datacards are not expected to generate as much ping-ponging because, though multi-mode, they tend not to be mobile.

3GPP proposes a technique for simultaneous RA and TA registration. This technique, known as Idle-Mode Signaling Reduction or ISR, results in no incremental signaling from UEs traversing radio technology boundaries. A UE in ISR-mode will be simultaneously registered in both technologies and will reselect cells in both technologies. A RAU or TAU is triggered only if there has been a change and the UE has moved outside of specified registered TA or RA lists. This benefit of ISR comes at an expense though, and that is that there is incremental paging as now the UE must be paged in both technologies. Because of the need to do simultaneous paging, the architecture that supports ISR must support a common user-plane anchor for both radio technologies. In 3GPP Release 8, this common anchor is provided by the S-GW. Thus, when a packet arrives at the S-GW for an idle mode UE, the S4 and the S11 reference points can be used to request paging initiation in both the MME and SGSN. It is important to note that the 23.401 Annex D method of I-RAT interworking cannot be used to support ISR since the common anchor in that case is a P-GW and paging cannot be initiated from it.

ISR relies on the network being capable to support I-RAT interworking according to 23.401 Release 8 so that the S-GW becomes the mobility anchor for 3GPP technologies. At a minimum, the legacy SGSN has to be upgraded to support S3 and S4 interfaces as well as a new S6d interface into the HSS as shown in Figure 5.

5.1.4 CONCLUSIONS FOR SEAMLESS DATA SERVICE

Service providers may consider deploying two methods of I-RAT interworking. As the number of LTE-capable multi-mode UE grows to be 10 percent to 20 percent of the total population, the Release 8 method has the advantage of eliminating idle-mode signaling through dual RAT registrations but it does require upgrading existing SGSNs to S3/S4 interfaces. The method described in 23.401 Annex D is more practical since it does not require existing SGSNs to be upgraded. However our analysis does suggest a deployment strategy for LTE radio that:

- Proposes high-capacity and highly scalable MMEs be deployed as they can more easily absorb the I-RAT component of increased signaling
- “Fills out” LTE coverage in compact areas, particularly along transit corridors
- Includes planning for extra signaling capacity on legacy SGSNs

Note that I-RAT ping-ponging difficulties will become significant when there is a large enough count of multi-RAT capable mobile UEs (such as smart phones). The data-launch will not need special consideration to I-RAT ping-ponging issues. The reason is that datacards will not be highly mobile (they tend to be used at hotspots) and so will not ping-pong except for fluctuating RF conditions.

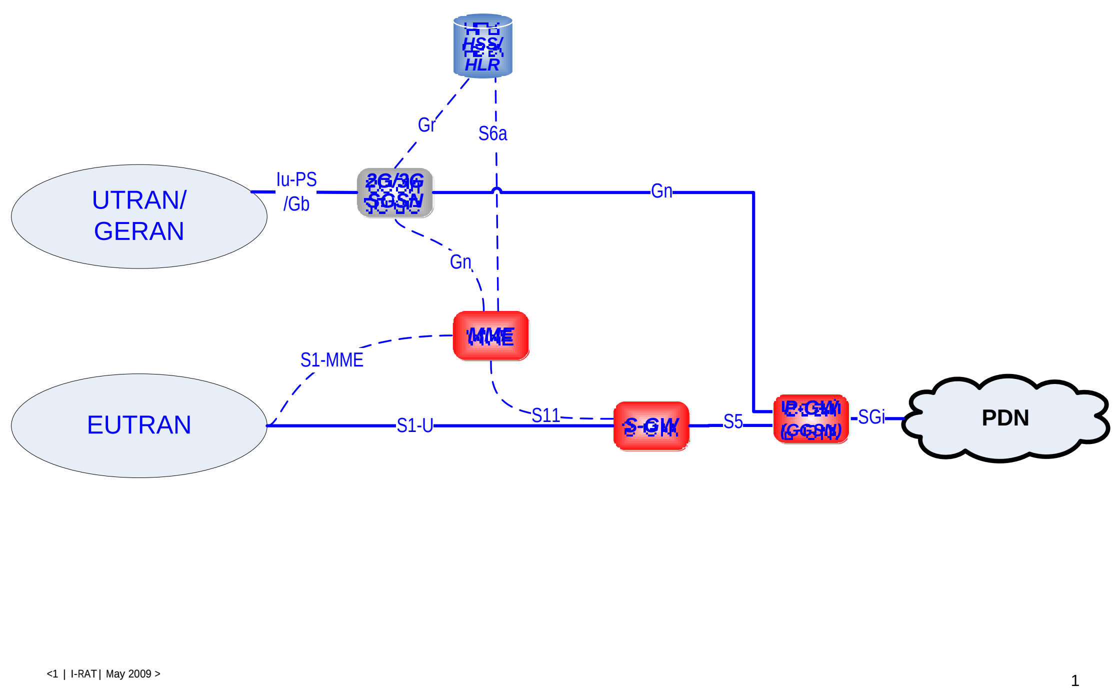


Figure 7.

The important point to observe regarding the Annex D method is that any device making use of LTE will have to use the P-GW as an anchor. Except for regions with no LTE coverage, a multi-mode UE also supporting LTE will attach to the network and use the P-GW/GGSN as the macro-mobility anchor.

5.2 CS-FALLBACK SOLUTION FOR LTE DATA WITH 2G-3G VOICE

During the May 2009 LTE World Summit in Berlin, some operators expressed concern about the lack of support for legacy voice and SMS services in LTE. They also expressed concerns regarding the lack of maturity in IMS deployments and 3GPP standards to deal with the complex needs of LTE voice in a mobile environment.[10]

To address these concerns, 3GPP has developed a mechanism termed CS-Fallback (TS 23.272), which relies on the 2G-3G network to provide voice services. CS-Fallback allows subscribers to transition to a 2G-3G circuit network to receive voice services. Though CS-Fallback introduces a delay in call set-up times, it inherently addresses many other subscriber concerns such as the need for seamless voice and SMS coverage, service transparency, and service parity.

To implement CS-Fallback, operators must offer CS-Fallback capable devices and upgrade their MSCs to support the SGs interface. The SGs interface provides a logical connection between the 2G-3G MSC and LTE MME. It is based on the Gs interface (TS23.0.60), which is implemented between the 2G-3G MSC CS domain and 2G-3G SGSN packet domain.

CS-Fallback procedures can be grouped into three categories:

1. Mobility Management
2. Call Origination and Termination
3. Other Services

CS-Fallback is the default solution for voice. All voice services continue to run in the CS domain.

5.3 IMS-BASED SOLUTIONS FOR VOICE OVER LTE

For the core network, 3GPP has chosen IMS as its next generation services architecture. Therefore, with the potential exception of limited VoLGA deployments, it is expected that most operators will utilize IMS-based solutions to provide voice services over LTE.

IMS has three central principles:

1. Multimedia services use SIP as their session control protocol
2. Multimedia service logic runs in the user's home core network
3. The IMS core network was intended to be access agnostic. However, interaction with existing technologies requires access specific functionality be added to the IMS network.

IMS contains several compelling concepts. But as with most compelling visions, the challenge is in making the transition. This has already been discussed in terms of LTE roll-out scenarios including the use of transitional capabilities such as CS-Fallback, the challenges created by regulatory requirements, and the need for performance improvements. This section will therefore assess the transition to IMS from a broader standpoint.

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[10] *T-Mobile: Voice Discord Threatens LTE*, Unstrung, 26 May 2009.

5.3.1 SRVCC HANDOVER FOR SESSION CONTINUITY

SRVCC Handover is a transitional capability for networks that implement voice services using IMS but which lack complete LTE coverage. SRVCC Handover allows the 2G-3G circuit network to provide a call's bearer path when a user moves out of the LTE coverage area. As stated earlier in this paper, SRVCC is not needed for voice handover or roaming between LTE and 3G PS, as this is accomplished via a PS HO.

The main requirement for SRVCC Handover is to provide service continuity, or at least session continuity. Service continuity means that after an ongoing session has moved to the 2G-3G circuit network, all services continue to function in a way that is transparent to the user. Session continuity means that all sessions are preserved during the handover, even if some of the services are compromised.

While SRVCC Handover usually satisfies continuity requirements, there are scenarios in Release 8 where it drops sessions (lack of session continuity) or reduces service capabilities (lack of service continuity). Some of these scenarios are discussed in previous 3G Americas white papers.

5.3.2 VOICE SERVICES – INTERACTIONS, EQUIVALENCY, TRANSPARENCY, PARITY, INTERWORKING

SRVCC enables a further value-added function, referred to as IMS Centralized Services (ICS), which is a 3GPP standard. With 3GPP ICS, all voice services are centralized in IMS, even when the subscriber is served by a 2G or 3G circuit switch. 3GPP ICS is an optional capability.

When planning centralized services and service continuity between LTE and existing 2G-3G networks, it is critical to consider the full range of services currently being offered and the work needed to replicate the capabilities of existing core networks. An MSC, for example, implements many services for which subscription is not required. These include regulatory services such as LI, E911, Toll-Free Calling, Local Number Portability (LNP), and Wireless Priority Service (WPS). Tones and announcements are widely used to provide progress information during services such as call forwarding, call hold and call waiting. There are many operator-specific services, such as private numbering plans, location-based services, long call duration teardown, call forwarding fraud control, and color ringback tone, some of which are implemented using Customized Applications for Mobile Enhanced Logic (CAMEL). In addition, regardless of how inexpensive network bandwidth becomes, the drive to consume less of it never seems to abate, leading to services like Optimal Routing (OR), Release Link Trunking (RLT) and Transcoder Free Operation (TrFO).

When IMS recasts a service that already exists in 2G-3G, it must provide service transparency, or at least service parity. Service transparency means that the new version of a service provides the same user experience even though its implementation differs. Service parity means that the new version of a service provides a comparable set of capabilities, but the user experience is different and some capabilities may be missing. The IMS services defined thus far usually provide service transparency or, failing that, service parity when Gm mode is available. However, service transparency, parity, and continuity are degraded in CS-only mode.

IMS, SIP and VoIP represent a significant change to the voice network. IMS opens (and therefore specifies) a great many interfaces. Although IMS's large number of open SIP interfaces provides a great deal of flexibility for multi-vendor networks, it also introduces a new level of complexity in the core network. In addition, because IMS is SIP centric, interworking functions are separated from foundational nodes (such as the CSCF) with standardized interfaces. If each of the logical IMS functions is deployed as a separate network node, the complexity of integration can become formidable. Carriers are likely to deploy groupings of these functions to reduce complexity and reduce inter-vendor testing. The benefits of deploying IMS with groupings of functions include:

- Improving capital, maintenance, and operational efficiency
- Simplifying network engineering and provisioning
- Improving messaging latency
- Reducing footprint

Circuit-Switched and previous VoIP technologies will exist for quite some time. IMS-based solutions must provide interworking to existing systems. IMS solution providers may attempt to mimic principles from today's MSCs, which implement services and support numerous protocols on a consolidated platform. Even with such proposed reductions in complexity, the evolution to IMS is significant; carriers have the option to deploy LTE first and IMS later.

6 SUMMARY

This white paper highlighted challenges and solutions for migrating a network from GSM-UMTS to LTE. It reviewed wireless provider strategies for implementing LTE and highlighted critical device and network functionality necessary to insure subscriber and operator expectations are met during the transition period.

Subscribers expect LTE to have equivalence with 3G and offer superior service, speed and applications. Furthermore, seamless coverage including interoperation with 2G-3G is essential. This paper has discussed methods operators will use to meet these challenge.

Though specific subscriber expectations (from higher data rates to parity of services) were discussed in this paper, all expectations were built on the principle that, at a minimum, subscribers will expect their LTE devices to have equivalent if not more capability than predecessor technologies. This includes not only the need to provide new services and better performance with LTE, but also the need to ensure that existing services and seamless coverage footprint are not lost.

To provide interoperation, critical functions for operating a GSM-UMTS/LTE network were discussed. These included functions such as two methods for Packet-Switched Handover, CS-Fallback and the SGs interface, and SRVCC Handover.

LTE and IMS standards continue to mature. The paper has illuminated areas where ongoing work is being done to meet operator and subscriber needs. Key challenges still being addressed by device and RF equipment manufacturers include items such as coping with the narrow duplex gap of the 700 MHz band and dealing with interference associated with adjacent broadcast services for Band Classes 12 and 17. Key challenges still being addressed for providing LTE voice using IMS include items such as session continuity for mid-call services and satisfying government lawful intercept requirements (e.g. dealing with IMS networks spanning jurisdictional boundaries and correlating LI data from multiple network elements).

It should be pointed out that many of the people who successfully implemented 3G overlays to 2G networks are now working on bringing the same success to LTE. In addition, a significant amount of work is ongoing in the 3GPP standards to further assist operators and vendors in successfully introducing LTE to the market place. With such a strong collaborative industry driving towards LTE, there is little doubt that LTE will eventually become as pervasive as its predecessor technologies, GSM and UMTS-HSPA.

APPENDIX A: ACRONYM LIST

3GPP	Third Generation Partnership Project
AGPS	Assisted Global Positioning System
AMPS	Advanced Mobile Phone System
AMR	Adaptive Multi-Rate compression
API	Application Programming Interface
ARPU	Average Revenue Per User
AS	Application Server
BGCF	Breakout Gateway Control Function
BIP	Bearer Independent Protocol
BTS	Base Transceiver Station
CAGR	Compound Annual Growth Rate
CAMEL	Customized Applications for Mobile Enhanced Logic
CAPEX	Capital Expenses
CSoPS	Circuit-Switched over Packet-Switched
CDM	Code Division Multiplexing
CN	Control Network
CPE	Customer premise Equipment
CS	Circuit-Switched
CSFB	CS-Fallback
CTM	Cellular Text Modem
DCH	Dedicated Channel
DCS	Digital Cellular System
E-CSCF	Emergency Call Session Control Function
EDGE	Enhanced Data for GSM Evolution
eNB	Enhanced Node B
ENUM	Telephone Number Mapping from E.164 NUmber Mapping
EPC	Evolved Packet Core; also known as SAE (refers to flatter-IP core network)
EPS	Evolved Packet System is the combination of the EPC/SAE (refers to flatter-IP core network) and the LTE/E-UTRAN
ETSI	European Telecommunication Standards Institute
EUTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network (based on OFDMA)
EV-DO	Evolution Data Optimized or Data Only
FCAPS	Fault, Configuration, Accounting, Performance & Security
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FDS	Frequency Diverse Scheduling
FMC	Fixed Mobile Convergence
GAN	Generic Access Network
GANC	Generic Access Network Controller
GBR	Guaranteed Bit Rate
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio System
GRE	Generic Routing Encapsulation
GSM	Global System for Mobile communications
GTP	GPRS Tunneling Protocol
GTP-U	The part of GTP used for transfer of user data
GTT	Global Text Telephony
GW	Gateway
HLR	Home Location Register
HO	HandOver

HPLMN	Home PLMN
HPCRF	Home PCRF
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access (HSDPA + HSUPA)
HSPA +	High Speed Packet Access Plus (also known as HSPA Evolution or Evolved HSPA)
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTML	Hyper-Text Markup Language
HTTP	Hyper Text Transfer Protocol
HTTPS	Hyper Text Transfer Protocol Secure
IMEI	International Mobile Equipment Identity
IMPI	IMS Private Identity
IMPU	IMS Public Identity
IPTV	Internet Protocol TV
IPV4	Internet Protocol Version 4
IPV6	Internet Protocol Version 6
I-RAT	Inter-Radio Access Technology
ICS	IMS Centralized Services
IM	Instant Messaging
IM-MGW	IMS Media GateWay
IMS	IP Multimedia Subsystem
IN	Intelligent Networking
IP	Internet Protocol
IP-CAN	Internet Protocol Connectivity Access Network
IPSec	Internet Protocol Security
ISIM	IP Multimedia Services Identity Module
ISR	Idle Mode Signaling Reduction
ITU	International Telecommunication Union
kHz	Kilohertz
LCS	LoCation Service
LI	Lawful Intercept
LNA	Low Noise Amplifier
LNP	Local Number Portability (for North America)
LTE	Long Term Evolution
MAC	Media Access Control
Mbps	Megabitz per Second
MF	Multi-Frequency
MGCF	Media Gateway Control Function
MHz	Megahertz
MIM	Mobile Instant Messaging
MIMO	Multiple-Input Multiple-Output
MIB	Master Information Block
MIP	Mobile IP
MMS	Multimedia Messaging Service
MMTel	Multimedia Telephony
MRFC	Multimedia Resource Function Controller
MRFP	Multimedia Resource Function Processor
MMD	Multimedia Domain
MME	Mobility Management Entity
MMS	Multimedia Messaging Service
ms	Milliseconds
MSC	Mobile Switching Center
NAT-PT	Network Address Translation – Protocol Translation
OFDMA	Orthogonal Frequency Division Multiplexing Access (air interface)
OA&M	Operations, Administration and Management
OMA	Open Mobile Architecture

OP	Organizational Partner
OPEX	Operating Expenses
OR	Optimal Routing
OS	Operating System
OTA	Over-the-Air Activation
P-CSCF	Proxy-Call Session Control Function
P-GW	PDN Gateway
PCC	Policy and Charging Convergence
PCS	Personal Communication Service
PCRF	Policy Charging and Rules Function
PDN	Packet Date Network
PDP	Packet Data Protocol
PIM	Passive Iner-Modulation
PLMN	Public Land Mobile Network
PS	Packet-Switched
PSAP	Public Safety Answering Point
QoE	Quality of Experience
QoS	Quality of Service
RA	Routing Area
RAU	Routing Area Update
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Radio Bearer
REL-X	Release ‘99, Release 4, Release 5, etc. from 3GPP standardization
RF	Radio Frequency
RIT	Radio Interface Technology
RLT	Release Link Trunk
S-CSCF	Serving- Call Session Control Function
S-GW	Serving Gateway (LTE)
SAE	System Architecture Evolution also known as Evolved Packet System (EPS) Architecture (refers to flatter-IP core network)
SCC AS	Service Centralization Continuity Application Server
SGs	Reference point between the MME and the MSC for CS Fall Back
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module
SIP	Session Initiated Protocol
SLR	Subscriber Location Register
SMS	Short Message Service
SNS	Social Networking Site
SOA	Service-Oriented Architecture
SON	Self Opitmizing Networks
SRIT	Set of Radio Interface Technologies
SRVCC	Single Radio Voice Call Continuity
SV interface	Interface between the MME and MSC for performing SRVCC Handover
TA	Tracking Area
TAU	Tracking Area Update
TB	Transport Blocks
TCP-IP	Transmission Control Protocol/Internet Protocol
TDD	Time Division Duplex
	Telecommunication Device for Deaf
TDM	Time Division Multiplexing
TDMA	Time Division Multiplexing Access
TISPAN	Telecoms & Internet converged Services & Protocols for Advanced Networks, a standardization body of ETSI
TP	Transport Protocol
TrFO	Transcoder Free Operation

TS	Technical Specification
TSM	Transport Synchronous Module
TTY	TeleTYpe writer
UDI	Unrestricted Digitial Information
UE	User Equipment
UGC	User Generated Content
UICC	Universal Identifier Cryptographic Computer
UL	Uplink
UL-SCH	Uplink Shared Channel
UM	Unacknowledged Mode
UMA	Unlicensed Mobile Access
UMB	Ultra Mobile Broadband
UMTS	Universal Mobile Telecommunication System, also known as WCDMA
UpPTS	Uplink Pilot Time Slot
USB	Universal Serial Bus
USIM	UMTS SIM
USSD	Unstructured Supplementary Service Data
UTRA	Universal Terrestrial Radio Access
UTRAN	UMTS Terrestrial Radio Access Network
VANC	VoLGA Access Network Controller
VCC	Voice Call Continuity
VoIP	Voice over Internet Protocol
VoLGA	Voice over LTE via Generic Access
VPCRF	Visiting PCRF
WCDMA	Wideband Code Division Multiple Access

APPENDIX B: LTE BANDS

FDD				
Operating	**UL Frequency**	**DL Frequency**	**Popular Name**	**Usage**
I (1)	1920 - 1980	2110 - 2170	IMT Core	3G in Japan & EU
II (2)	1850 - 1910	1930 - 1990	PCS 1900	PCS 1900 in Americas***
III (3)	1710 - 1785	1805 - 1880	GSM 1800	DCS in EU
IV (4)	1710 - 1755	2110 - 2155	AWS (US)	AWS in Americas
V (5)	824 - 849	869 - 894	850 (US)	Cellular 850 in Americas
VI (6)	830 - 840	875 - 885	850 (Japan)	Japan
VII (7)	2500 - 2570	2620 - 2690	IMT Extension	Europe & WiMAX
VIII (8)	880 - 915	925 - 960	GSM 900	Extended GSM in EU
IX (9)	1749.9 - 1784.9	1844.9 - 1879.9	1700 (Japan)	Japan
X (10)	1710 - 1770	2110 - 2170	3G Americas	Extended AWS in
XI (11)	1427.9 - 1452.9	1475.9 - 1500.9		Japan
XII (12)	698 - 716	728 - 746	Lower 700	Lower 700 MHz A-B-C
XIII (13) *	777 - 787	746 - 756	Upper 700	Upper 700 MHz C block in
XIV (14) *	788 - 798	758 - 768	700 MHz Public	Public Safety in US **
XVII (17)	734 - 746	704 - 716	Lower 700	Lower 700 MHz B-C
tbd	790 - 862	790 - 862	Digital Dividend	Digital Dividend in EU

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