Voice over LTE: Status and Migration Trends

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Abstract

Rapid increase in data traffic over cellular network is necessitating deployment of Long Term Evolution (LTE) in the cellular operators networks. While LTE provides efficient data traffic handling and high data rates, it lacks native circuit switched voice capability. The GSM association has standardized IP Multimedia Subsystem (IMS) based VoLTE solution along with Single radio SRVCC for handover. Migration to this solution requires operators to have expensive and complex IMS deployments. This has led to operators leveraging the existing 2G/3G networks with VoLTE methods like Circuit Switched Fallback (CSFB) and Voice over LTE via Generic Access (VoLGA). This paper describes both, the interim and the long-term, solutions for the operators and their respective pro and cons. Future directions in VoLTE research have also been briefly described.

Keywords

VoLTE, Circuit Switched Fall Back, CSFB, Voice over LTE via Generic Access, VoLGA, Single Radio Voice Call Continuity, SRVCC, IMS, IP Multimedia Subsystem, handover, Evolved Packet Core, Evolved UMTS Radio Access Network, MME

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1 Introduction

1.1 LTE Overview

Multimedia applications are driving data usage in the cellular networks. Long Term Evolution (LTE) and its true fourth generation manifestation, Long Term Evolution-Advanced (LTE-A), are technologies that operators are deploying, or planning to deploy, to help them tide over this evolutionary trend. Having evolved from Universal Mobile Telecommunications System (UMTS), the specifications are known as the evolved UMTS Terrestrial Radio Access network (E-UTRAN). The first version of LTE was released by 3GPP as release 8. Table 1 shows different releases since then and their important features [3GPP].

Table 1: LTE releases and their features

Release#	Year	Features
3GPP Release 8	2008	First LTE release as all IP network System Architecture Evolution (SAE). Introduced Orthogonal Frequency Division Multiple Access (OFDMA), Multi In Multi Out (MIMO) and Single Carrier-Frequency Division Multiple Access (SC-FDMA).
3GPP Release 9	2009	Enhanced LTE to interoperate with WiMAX. Introduced femtocells.
3GPP Release 10	2011	LTE-Advanced specifications fulfilling IMT-A requirements. Backwards compatible with Release 8
3GPP Release 11	2012	Advanced IP Interconnection of Services involving national operators and also third party applications. Heterogeneous networks (HetNet) improvements
3GPP Release 12	Planned for 2014	3-D MIMO beamforming, machine type communication and public safety
3GPP Release 13	To be decided	Open

With LTE a move has been made towards a complete IP network consisting of the Evolved Packet Core (EPC), the Radio Access Network (RAN) and the interconnection. The main goal of LTE is to provide a high data rate, low latency and packet optimized radio access technology supporting flexible bandwidth deployments. OFDM, used in downstream, allows simultaneous access by a number of users, MIMO, improves reception by use of multiple antennas and SC-FDMA is used in the uplink to assign radio resources to multiple users. Figure 1 shows the broad architecture of LTE.

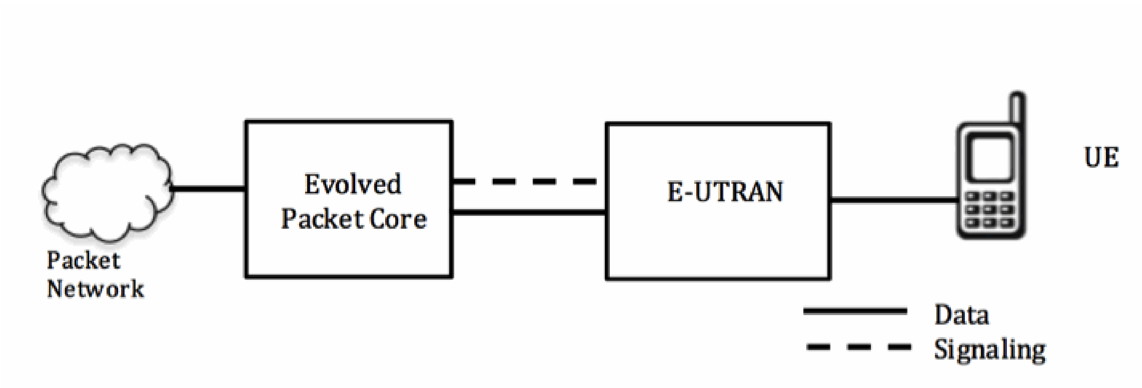


Figure 1 LTE Architecture

The User Equipment (UE) includes functionalities of a Mobile Terminal (MT) that is responsible for call functions, a Terminal Equipment (TE) for data streams and Universal Subscriber Identity Module (USIM). The USIM stores network identity and user information.

The Radio Access Network (RAN) part of the LTE is called the Evolved UMTS Radio Access Network (E-UTRAN). It handles communication between the UE and the Evolved Packet Core (EPC) and consists of the base stations called eNodeBs (eNBs).

The radio related functions include resource management, admission control, mobility control and security. LTE has a flatter architecture because, unlike 3G, there is no Radio Network Controller (RNC) and this feature results in better efficiency. When the UE roams into another eNB area, complete UE state is transferred to the other eNB. Figure 2 shows the important components and interfaces of the E-UTRAN. The eNBs are interconnected through X2 interface and to the MME in the EPC through S1-MME interface and to the Service Gateway (S-GW) through the S1-U interface [alcatel09].

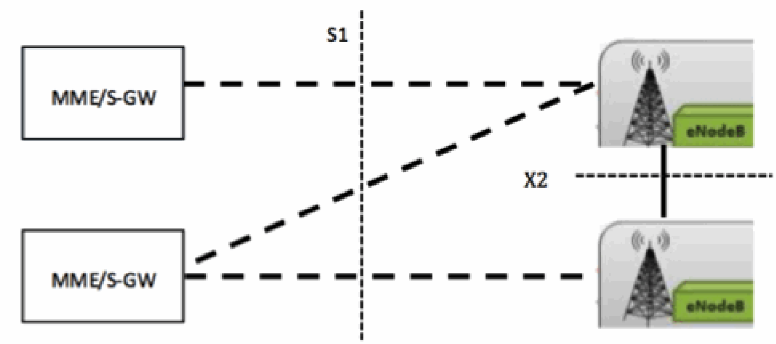


Figure 2 E-UTRAN architecture and interfaces

The Evolved Packet Core (EPC) or System Architecture Evolution (SAE) is the new all-IP core defined by 3GPP in Release 8. It performs, among others, network access control, mobility management, security and network management functions. The subscriber information is stored in the Home Subscriber Server (HSS). The mobility management entity (MME) controls the set-up and release of connections between the user and the packet data network. It also does UE authentication location registration and handover using information from the HSS. The Packet Data Gateway (P-GW) performs the function of GGSN and SGSN of the 3G network i.e. connectivity to the IP network. It communicates with the Packet Data Network (PDN) through the SGi interface. Understandably, it is vested with the work of user authentication, IP address assignment, DHCP functions, QoS, Charging data creation Deep Packet Inspection (DPI). The Serving Gateway (S-GW) routes the data between the base stations and P-GW. Policy and charging functions are handled by The Policy Control and Charging Rules Function (PCRF). It provides flow-based charging functionalities through the Policy Control Enforcement Function (PCEF) implemented in the S-GW [tpoint12]. Figure 3 shows the interaction of these components.

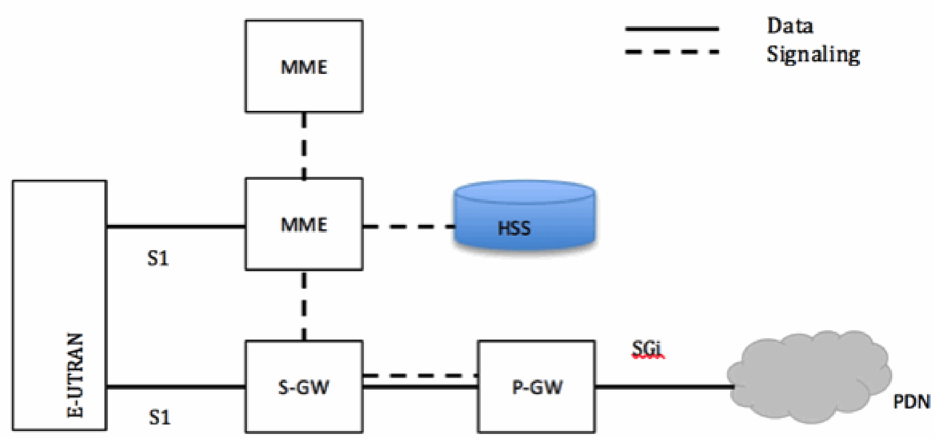


Figure 3 The EPC Architecture

Important technical Specifications of LTE [tpoint12] [ericsson14] The LTE PHY has been designed keeping certain design goals in mind. These are reflected in the important specifications:

Table 2: Specifications of LTE

Feature	Details

Latency	<10 ms from UE to server
Mobility	Upto 350 Km/hr, optimized for 15 km/s
Coverage	Full upto 5 km, slight degradation 5-15 km, operation upto 100 km
Channel Bandwidth (MHz)	1.4, 3, 5, 10, 15, 20
Modulation Schemes	UL: QPSK, 16QAM, 64QAM(optional) DL: QPSK, 16QAM, 64QAM
Multiple Access Schemes	DL: OFDM, UL: SC-FDMA
Modes	TDD and FDD
Multi-Antenna Technology	MIMO, DL: 1x2, 1x2, 2 x 2, 4 x 2, 4 x 4 UL: 1x1.1 x 2, 1 x 4
Peak Data Rate	With 20MHz slot and 4x4 MIMO peak downlink 300 Mbps, Uplink 75 Mbps

The ITU-R IMT-A requires that 4G technologies should downlink data rate of about 1 Gbps and uplink data rate of about 500 Gbps. Thus LTE-A with theoretical downlink/uplink rates of 3Gbps/1.5Gbps is the real 4G [radisys13].

LTE roaming and interworking A subscriber roaming in another network is connected to the E-UTRAN, MME and S-GW of the visited LTE network. To continue getting the contracted home services the subscriber uses the home network P-GW. Using P-GW of the visited network, the visiting subscriber can access the Internet and networks. For interworking with 2G/3G networks, the S-GW acts as the mobility anchor, while the P-GW serves as an anchor allowing seamless mobility to non-3GPP networks such as CDMA2000 or WiMAX [hussain12].

Having seen important aspects of LTE let us now see why providing voice in such advanced networks is an issue.

1.2 Basics of Voice over LTE

To be able to provide good performance at high data rates, LTE has been designed as an all-IP technology. The flip side of this is lack of native circuit-switched (CS) domain voice, which has been the norm so far in the cellular networks. As operators deploy LTE they look for solutions to provide CS voice to their customers. This has resulted in a number of different solutions being proposed and tried. The main methods are Circuit Switched Fallback (CSFB), Voice over LTE over Generic Access network (VoLGA), GSMA VoLTE profile and Single Radio Voice Call Continuity (SRVCC) [alcatel12].

In the initial migratory phase, all voice traffic is expected to be handled by 2G/3G circuit switched networks and data traffic by LTE networks. This phase would see introduction of CSFB, VoLGA or OTT methods for providing voice. The operators decision will be guided by investment and user satisfaction. In the next phase introduction of IP Multimedia Subsystem (IMS) based Voice over IP over LTE (GSMA VoLTE profile) based on GSMA IR.92 standards, may see larger deployment. There is a possibility that these will be further enriched with video services using IMS/MMTel and combined with other enhanced services like presence and location based services, rich communication suite (RCS) and video share services. If this happens, SRVCC is likely to be used for providing call continuity as users move from LTE to non-LTE areas. In the final phase, operators may migrate to full IP networks to take advantage of enhanced capacity, rich communication services, operational efficiencies and inter-RAT interoperability belonging to same or different operators.

During the initial phases operators, who do not have any GSM/UMTS deployment, may offer over the top (OTT) solutions, like Skype, for voice. These solutions may not be able to provide the CS quality and are not native applications on subscribers handsets. Native VoLTE enable prioritization of real time voice and video services, over other data streams, to deliver quality of service levels consistent with user expectations. User expectations regarding roaming, seamless inter-RAT transfer, location information, rich multi-media sharing services, call transfers, conferencing may not be possible to be met with OTT. With the dilemma of multiple technologies in mind, GSMA came up with a solution, which they thought would unify operators. In the next section we will discuss the most prevalent methods and the GSMA profile.

2. VoLTE Architectures and Protocols

On one hand there are operators who have made substantial investments in 2G/3G deployments, on the other there are many who do not have any 2G/3G deployment but have received spectrum for LTE deployment. Then among the existing operators there are those who have not deployed IMS in view of cost or other considerations. It is because of this diversity that many solutions to providing voice over hybrid and pure LTE networks exist. For the same reason, the GSMA specified IMS based VoLTE solution has not caught on. We shall discuss here important techniques that are seeing developmental and deployment efforts [cassey13].

2.1 Circuit Switched Fallback (CSFB)

CSFB has been standardized by 3GPP for providing circuit switched voice services to UE connected to E-UTRAN by reusing GSM/UMTS infrastructure. To deploy this method, the operator should have GSM/UMTS deployment in the LTE coverage areas, or have arrangement with other operators having such deployments. When an LTE subscriber makes or receives a voice call, CSFB hands over the UE to 2G/3G network. This method favors the existing operators who have paid for the spectrum and already invested in 2G/3G infrastructure. New operators with no cellular deployment would have to make expensive arrangements with existing operators. CSFB has become a recommended solution for operators who have not deployed IMS. The EPS CSFB architecture as specii- ed in 3GPP TS 23.272 is given in Figure 4.

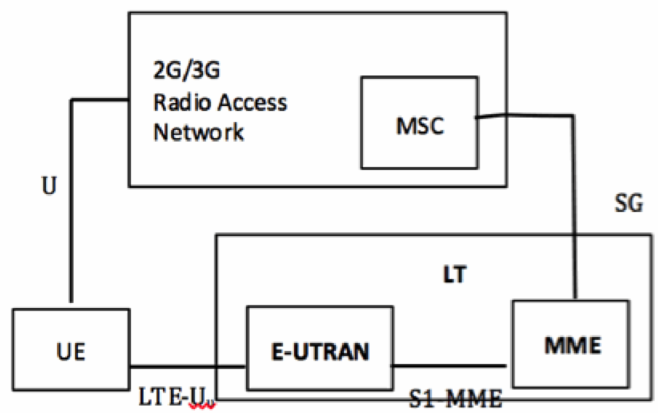


Figure 4 The CSFB Architecture

Both LTE and the legacy network need changes to implement CSFB. It can be seen that there are new SG interfaces between the LTE network (MME) and the MSC of 2G/3G network. These are used for mobility management and paging procedures between Enhanced Packet Service (EPS) and CS domain. Other than this, UE, MME, MSC and E-UTRAN have to support additional functionalities. The UE should support attach to the MME in LTE as well as the MSC in 2G/3G network. The MME requires additional functionality of maintaining the SGs association towards the MSC. The MME also needs to derive the Visitor Location Registrar (VLR) number of the MSC to contact when the UE attaches to the LTE network and also maintain the tracking area lists appropriately. The legacy MSC requires to maintain the combined attached status of the UE and page the UE over SGs association when a paging request for incoming call is received for the UE in LTE. It needs to have support of SMS procedures as provided in 3GPP specification. The eNodeB in E-UTRAN also needs to be updated for forwarding the CS paging requests to the UE, directing it to the target RAT and facilitating the tracking area list management [tekovic13].

Advantages of CSFB:

- Ease of implementation
- The sunk cost in the legacy 2G/3G infrastructure is utilized
- CSFB sustains roaming services

Disadvantages of CSFB:

- Due to delays associated with fallback and recovery, call set up latency is worse than the original 2G/3G networks
- 2G/3G network may not be available in all macro/micro cells of the LTE leading to patchy service
- Operators who do not have legacy deployment cannot implement CSFB
- When switching over to CS voice connection, all LTE data sessions will be dropped

2.2 Voice over LTE via Generic Access (VoLGA)

VoLGA is based on the existing 3GPP Generic Access Network (GAN) standard used by cellular operators to extend coverage of cellular with Wi-Fi offload. GAN standard extends 3GPP coverage by allowing dual mode mobiles, which can access the 3G services over Wi-Fi. The GAN idea is to introduce a gateway between Wifi and 3GPP network, which transfers the signaling between the terminal and the 3GPP network. The purpose of GAN is to extend mobile services over a generic IP access network. With VoLGA operators can integrate LTE stepwise, using 2G or 3G infrastructure. Moving between the two network technologies is fully transparent to the user. The VoLGA is given in Figure 5.

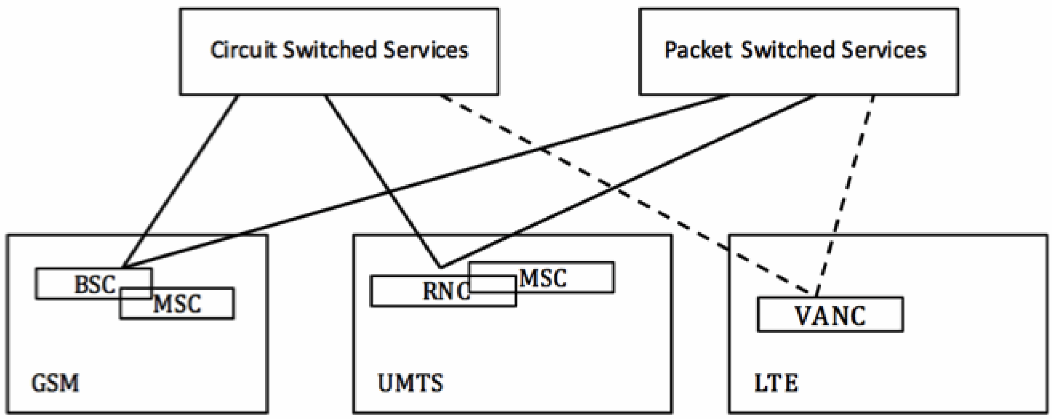


Figure 5 VoLGA Architecture

There are no changes to the existing LTE network, RAN or the MSCs of the legacy network. This allows rapid development even in a multi-vendor MSC environment. All circuit switched services can be used over LTE. To implement VoLGA, a gateway called VoLGA Access Network Controller(VANC) is required. The VANC securely supports the interface to the MSC of a GERAN network or Iu-CS interface to a MSC of UTRAN network and is seen as a Base Station Controller (BSC) by these networks. The VANC has the ability to interact with the LTE network and request QoS for VoLGA voice calls. It connects to the LTE through the SGi interface, which carries both data and signaling traffic to the P-GW towards the Serving Gateway (S-GW) and hence seen as an application function by the SGW/PGW. The VANC also includes a security gateway function that terminates a secure remote access tunnel from each UE providing mutual authentication, encryption and integrity protection for signaling traffic. VoLGA allows for smooth handover of ongoing voice calls to GSM or UMTS when the subscriber leaves the LTE coverage area [stepaniuk10].

Advantages of VoLGA:

- Allows UE to access voice using CS domain and data service using LTE simultaneously
- Unlike CS fallback, the data call is not dropped on handover to CS network
- The VoLGA solution caters to other CS services like SMS
- It doesn't impact existing core network nodes like the MME, the SGSNs or the MSCs
- Emergency and other regulatory services are also supported

Disadvantages of VoLGA:

- It has not been standardized by 3GPP
- It requires a GAN based dual mode terminal with SRVCC capability
- VANC is an additional expense. To support roaming, the visited network also needs to deploy VANCs

2.3 GSMA profile for Voice over LTE

We need to distinguish between Voice over LTE (VoLTE) as a generic term for all methods used for providing voice solutions in an LTE network and the GSMA standardized VoLTE profile. Early adoption of many different methods of providing CS voice in LTE networks prompted GSMA to conduct a year long study to standardize an appropriate method. This was necessary to contain proliferation of incompatible networks, for assuring seamless roaming, nationally and internationally. Widespread use of a single method is also important to generate scale and for service providers and equipment manufacturers. The result was standardization of 3GPP IMS platform to be used for providing voice services over LTE. In February 2010, GSMA released a document called VoLTE Profile. This document specifies a set of minimum functions that any network operator must provide to maintain interoperability. They have described VoLGA and CSFB as intermediate stages with final migration to IMS based VoLTE. Figure 6 gives the important elements of the GSMA VoLTE Architecture.

The IMS registers the UE, carries out authorization and sets up the transmission path between the terminal and itself. Voice call origination and termination are also controlled by IMS. To give the subscribers experience similar to what they got from earlier versions of cellular networks, supplementary services like Caller ID presentation, call waiting, multi-party conferencing are also provided through the IMS.

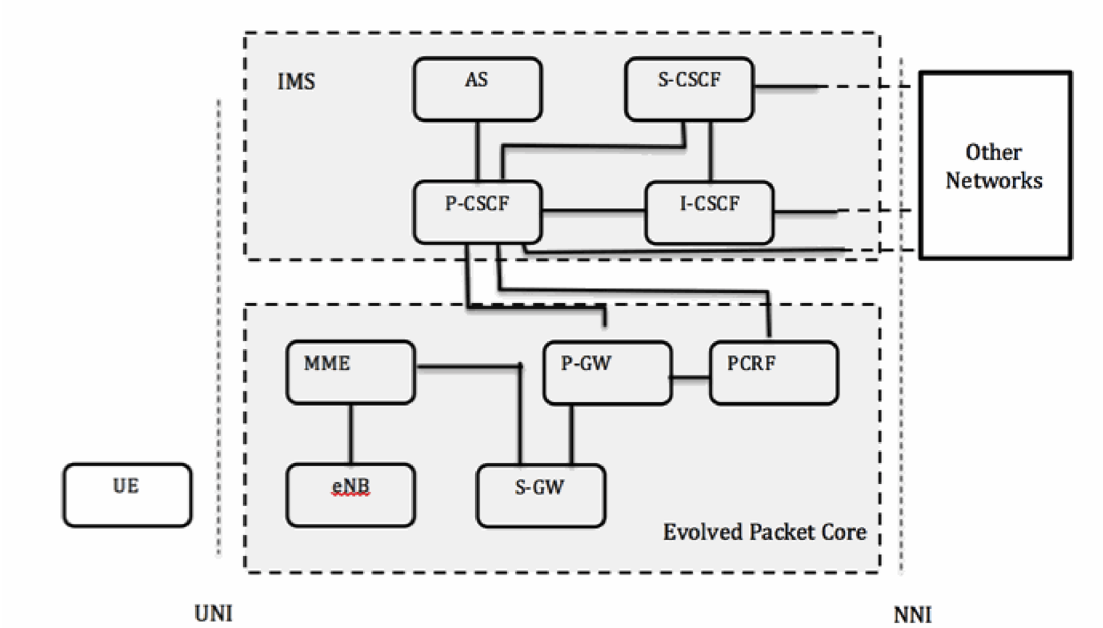


Figure 6 The GSMA VoLTE Architecture

The evolved packet core ~attaches a terminal that is switched on, to an Access Point Name (APN) for getting VoLTE services. The MME, that receives the attach request, conducts location registration using the information in the Home Subscriber Server (HSS) and downloads the subscriber profile. The APN for VoLTE uses a globally shared format and gets a separate bearer for itself. The MME decides the destination P-GW based on the VoLTE APN information and makes a request to set up a bearer between the S-GW and the P-GW. This allows necessary bandwidth to be guaranteed through appropriate QoS control mechanism. For registration, the terminal provides the International Mobile Equipment Identifier (IMEI) and the IMS Communication Service Identifier (ICSI) for service control, charging and other purposes. When the IMS registration request arrives from the terminal via the P-CSCF, the S-CSCF performs registration procedures with the HSS. After the authentication has succeeded, the S-CSCF downloads and stores the service control information of the user from the HSS. Then, the S-CSCF notifies the terminal that the registration has been completed. A separate bearer is established for SIP services. Once LTE attach and IMS registration is over, voice communication can commence [tanaka12].

For meeting the said requirements, VoLTE defines three types of interfaces:

- UNI: The User Network Interface between the UE and the operator's network
- R-NNI: The Roaming Network-to-Network Interface between the home and visited network of a subscriber. Specifications for the NNI, though important for roaming, have not been included in the profile
- I-NNI: The Interconnect Network-to-Network Interface between the networks of the two parties making a call

Handover from LTE to circuit-switched network: GSMA has defined Single Radio Voice Call Continuity (SRVCC) mechanism to handover the calls to CS domain. SRVCC ensures that IMS still remains in control for the duration of the call. Roaming procedures in the CS domain are well established. Emergency calls, regulatory services and revenue sharing are all carried out without any problem. In IMS, user-oriented services are provided from the home-network, which retains the control. The voice/video media breakout point is within the home network [ericsson12].

Single Radio Voice Call Continuity (SRVCC): The GSM profile for VoLTE, might be adopted in the long term as more and more operators deploy IMS in LTE networks. Recently, enhancements have been specified for handing-over ongoing IMS based voice calls to CS networks when the user leaves the UMTS or LTE coverage area during a call. For handover, 3GPP standards TS 23.216, TS 23.237 and TS 24.237 called SRVCC are used. SRVCC facilitates a gradual introduction of the next generation LTE access network into an existing GERAN/UTRAN network infrastructure by enabling a PS to CS handover between E-UTRAN and GERAN/UTRAN domains [Gavrilovic10]. SRVCC is an IMS based solution that involves upgrades to the legacy MSC, MME and the UE. SRVCC satisfies critical requirements for emergency calls. Without SRVCC, operators with gaps or weaknesses in LTE coverage cannot realize the user experience and network efficiency advantages offered by VoLTE until LTE coverage is built out to match the full geographic range of their subscriber service commitments. With SRVCC, operators benefit from fast time to market and the advantage of a solution that works in hybrid as well as LTE networks [qualcomm12].Figure 7 shows the SRVCC architecture.

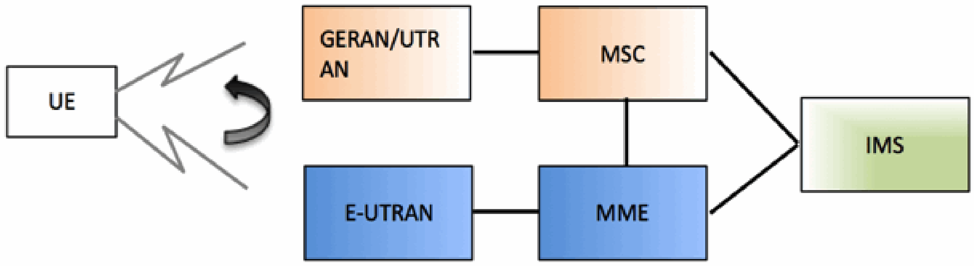


Figure 7 The SRVCC Architecture

The advantage of SRVCC compared to CS fallback is that it is triggered only when the UE is losing the LTE coverage hence the user experiences degradation in QoS for other data connections is only when the UE starts losing coverage. The drawback of SRVCC solution is that it is based on IMS, which is expensive and complex. If LTE is deployed only as very small islands initially then the SRVCC operation might be triggered very frequently bringing the disadvantage similar to the CS fallback.

2.3 OTT Solutions

Over the Top (OTT) solutions refer to the providing voice through third party providers like Skype or Google Talk. These work as application over the existing data service so there will be no changes to the LTE network or the UE thus adding hardly any cost for the operator or the subscriber. For operators who have no 2G/3G deployment, this method is a simple and cost effective way of providing voice. New LTE operators can also use OTT as an interim solution before investing in IMS. There are many drawbacks to OTT. It does not provide any QoS guarantees and the subscribers used to CS experience may not be satisfied with OTT as the main voice offering. The method is not a cellular technology and there is no roaming facility. Calls will drop as the UE moves outside the LTE coverage area. Cellular operators do not prefer this method as revenue sharing arrangements are difficult to negotiate.

3 Seamless VoLTE and Roaming

The present hybrid scenario with GSM, UMTS and GERAN along with LTE deployment is likely to continue for a long time. Even LTE networks operate in different frequencies. In either situation, the mobile subscriber is likely to move out of the 4G LTE coverage during a live voice call. Subscribers would expect such calls to remain connected. In this section we will discuss methods implementing call handover and voice call continuity [paisal10] [samsung13].

3.1 Interoperability among VoLTE architectures

Network interoperability is an important issue for seamless mobility across heterogeneous radio access networks. When the subscriber visits other networks, nationally or internationally, the inter-technology mobility should be transparent to the subscriber. The UE and the network should, therefore, support inter-RAT handover between LTE and various earlier generations networks like UMTS, UTRAN, CDMA 1000 and so on. Media Independent handover (MIH) has been developed by IEEE to enable handover of IP sessions at layer 2 of one radio access technology to another. In case of CSFB technology, voice calls are switched to the 3G network. VoLGA enables the existing core voice network to act as a packet service delivered over the LTE access network. Generic Access Network (GAN) bridges the LTE and UMTS networks. As discussed before, both VoLGA and CSFB are considered to be interim solutions. SRVCC however stands out as it is deemed to be more long-term than the other schemes.

3GPP has standardized IMS based SRVCC as the long-term solution for Inter-RAT handover between LTE and UMTS. Voice calls are anchored in IMS that allow UE to switch between LTE and CS domain legacy network using a single radio. This saves the UE from having expensive multi radio access technology capability. During the period when there is no transmission, UE carries out radio measurements according to the instructions of the eNodeB. When the UE moves from LTE to the UMTS radio access, it informs LTE.

Whenever an SRVCC capable UE is losing LTE coverage, the eNodeB detects it and triggers handover procedure towards the MME. The MME triggers the SRVCC procedure with the 2G/3G MSC using the Sv interface. The MSC signals the target

2G/3G cell and initiates a session with the VoLTE network. The VoLTE network switches the voice session from LTE to 2G/3G CS voice. After switching to 2G/3G CS voice, the MSC notifies the MME. The MME then instructs the UE to hand over from the 4G LTE eUTRAN to 2G/3G, which completes the handover. The call proceeds in UMTS transparently and without interruption. Figure 8 summarizes the SRVCC procedure.

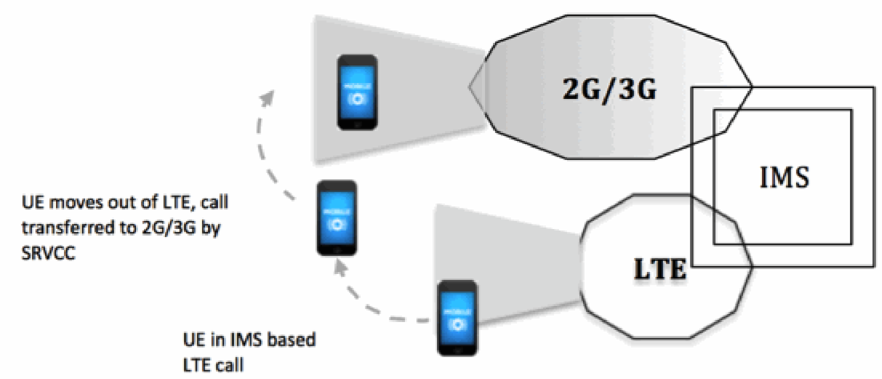


Figure 8 Seamless handover procedure

3.2 Roaming standards

3GPP Release 11 specifies VoLTE roaming and interconnection architecture. It adds standardized necessary functions for implementing roaming and interconnection in a manner similar to existing circuit-switched voice on top of the existing VoLTE roaming and interconnection architecture.

Existing VoLTE Roaming Model: VoLTE is based on IMS, which is an IP-based system implemented using the Session Initiation Protocol (SIP). The present model has an issue that GSMA has proposed to resolve in the future model. In case of international roaming the call from an operator A to an operator B, the voice path and SIP signaling path are not necessarily same. Signaling could go through one or more Internet Exchanges (IPX). In Figure 9 P-CSCF is with operator A while SIP server (S-CSCF and AS) which perform the actual call control are implemented by Operator C. This creates a problem as the IPX operators, in the home network, only carrying voice and no SIP signals are not able to time and charge calls.

i?1/4i?1/4i?1/4

3.3 Roaming Architecture for Voice over IMS with Local Breakout

The problem described in sub-section 3.2 was studied by GSMA and a work item called Roaming Architecture for Voice over IMS with Local Breakout (RAVEL) was agreed upon in Rel 11 VoLTE Roaming Model. RAVEL has agreed on a model similar to the CS network. A new entity called the Transit & Routing Function (TRF) has been introduced, which brings the SIP signals back from the network, where the caller is currently connected (Operator C), to the home network performing call processing(Operator A), and provides an anchor function that routes the voice data and SIP signals over the same path so that the IPX operator can time and charge for the resource usage [ntt13]. Figure 9 shows the RAVEL enhancement.

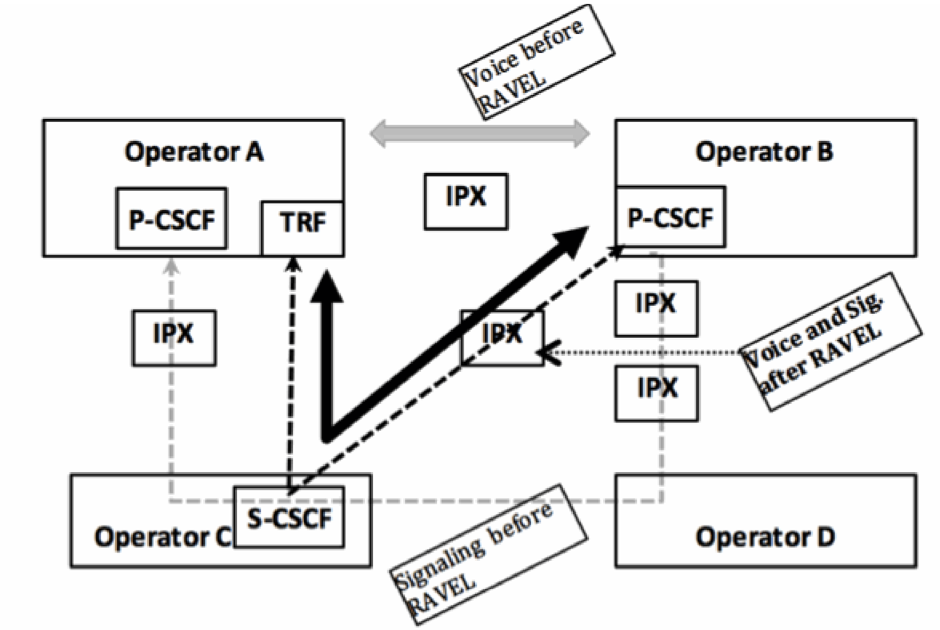


Figure 9 Ravel roaming and interconnection model

4 Performance of VoLTE systems

4.1 Comparative performance of VoLTE systems

The last few sections introduced different methods for providing voice in LTE networks and its continuity for roaming subscribers. In this section we compare these methods based on parameters like cost of deployment, quality of service, deployment scenario and their relative advantages and disadvantages [tabany13].

Cost of providing voice in the LTE network is an important consideration for most operators. There are operators who would prefer one time initial investment on a long-term solution. At the same time, there are other operators who would like to keep initial investment low and in the long-term migrate to a more permanent solution. CSFB requires high investment commitment because it requires all MSCs to be upgraded. As compared to CSFB, VoLGA is less expensive. VoLGA requires GAN and VANC to provide voice over LTE using the legacy wireless network. The GSMA alternative also requires high investment in IMS introduction. While not in the same league as the other solutions, OTT is perhaps the least expensive option to deploy. The operator hardly has to make any investment upfront. However, revenue sharing agreements would need to be negotiated with OTT providers.

UE Cost: UE cost affects mass penetration. CSFB requires the UE to have dual radio capability, which makes the UE expensive. In case of VoLGA, GAN based dual mode UE is required. VoLTE based on IMS requires a UE with VoLTE and SRVCC capabilities. In OTT, there are no special requirements for the UE except having the ability to access the Internet.

QoS: CSFB introduces latency in setting up of voice calls when the calls are handed over from the LTE to the legacy 2G/3G networks. The data quality is also degraded when packet switched to circuit switch handover is required. Moreover, the established LTE sessions would drop when switching from PS to CS. VoLGA connects to the PCRF to provide required QoS and there is no call setup delay. Both voice and data calls can be handled simultaneously. GSMA VoLTE provides carrier-grade QoS and using IMS allows mobile operators to support High Definition(HD) voice calls. OTT does not provide any QoS guarantees, it offers no roaming or rich media services.

Handover: As far as GSMA SRVCC handover is concerned only VoLGA, besides GSMA VoLTE, allows Inter-RAT handover to provide service continuity to LTE users when they move outside an LTE coverage area.

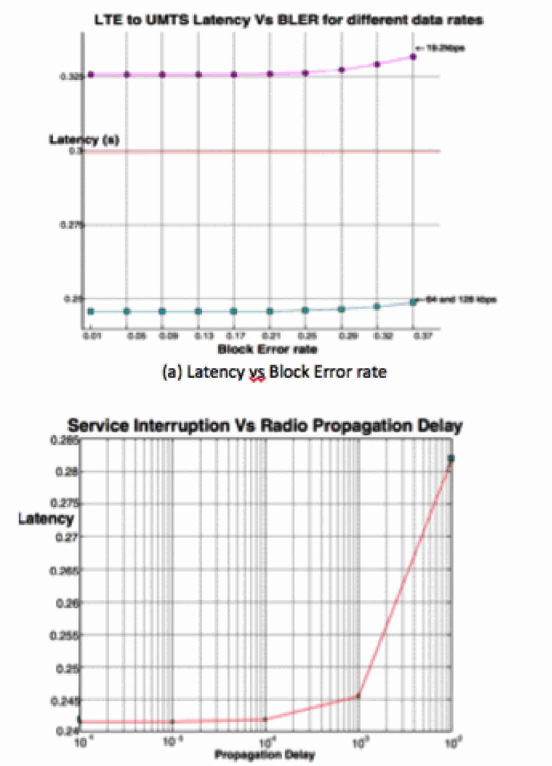
Feasibility of deployment: is an important factor while deciding which method to choose. CSFB and VoLGA require legacy 2G/3G networks in the areas where the operator wishes to deploy LTE and also provide voice services. GSMA VoLTE requires IMS to be deployed, which not many operators have done. For operators who do not have legacy networks and do not wish to invest in IMS, CSFB would be the long-term choice. Operators who would like to maintain their legacy networks could deploy VANC and implement VoLGA. Those operators who have legacy networks and IMS deployment is in the plan, then they could do well to do it early to take advantage of VoLTE and SRVCC all through the migration period and eventually in LTE only networks.

Standards: Operators who wish to only deploy a standardized solution have to be aware that only VoLTE and CSFB have been standardized by 3GPP. At the same time it is important to see whether the method they are selecting has support from more than one big original equipment manufacturer. VoLGA, though not standardized by 3GPP, is supported by Huawei and Alcatel-Lucent.

4.2 Performance of inter-technology mobility and handovers

Whatever the technique deployed, it is important that the required specifications are met so as to ensure customer satisfaction. 3GPP sets the service interruption time for real-time services to switch between LTE and UMTS at 300ms and for non-real time services at 500ms. Service interruption time in inter-RAT handover is the time between the last received transport block on the old frequency and the time the UE starts transmission on the new uplink channel.

Studies have been conducted pertaining to performance of SRVCC handovers and reported in [namakoye11]. Figure 10 gives latency or interruption in service vs the block error rate and the propagation delay under the modeling parameters discussed in the reference. A circuit switched data rate of 64kbps or above, yields an interruption time, which is just below 250ms. As can be seen from [Figure 10 (a)](#), Latency starts increasing beyond 21% block error rate. Latency also rises sharply beyond propagation delay of the order of 10^{-3}([Figure 10 (b)](#)). In both the cases handover process meets the 3GPP requirement of 300 ms.



(a) Latency vs Block Error rate

(b) Latency vs Propagation delay
Figure 11. Latency vs the block error rate and propagation delay
(Source ref: Namakoye11)

5 Challenges of VoLTE

There are many challenges of LTE. While 3GPP has standardized IMS based VoLTE for voice over LTE and SRVCC for call continuity, IMS adoption has been very slow mainly because of the cost issues. Mass deployment of IMS is nowhere in sight putting a question mark on wide adoptability of VoLTE. Among the non-IMS techniques, CSFB introduces call latency as the signaling load on HLR increases. In this section we would discuss the challenges posed by multiplicity of technologies, protocols and implementation scenarios [[anritrsu13](#)].

5.1 Technology challenges

The operators yearn for clarity on standards in supporting voice over LTE. Of the commonly used technologies, CSFB and VoLGA, only the former has been ratified by 3GPP. The operators using VoLGA face the prospect of inter-RAT incompatibility and possible hurdles in migration to GSMA VoLTE. Non-enthusiastic IMS deployment makes it difficult for VoLTE to proliferate. There are many new protocols related to IMS like IPv6, SigComp, IPSec and P-headers that makes matters worse. Integration of the LTE protocol stack with the IMS control layer is to be taken care of and end-to-end IMS signaling must be tested over the LTE access network.

Another issue is implementation of mobility between the packet switched LTE and the circuit switched networks. SRVCC should provide the user experience comparable with the roaming experience in the 2G/3G networks. Regulations in most countries require emergency calls to be provided. While in LTE areas with legacy networks this can continue to be provided over these networks but in LTE areas with no IMS the solution may not be trivial. While there is no easy solution, end-to-end IMS signaling over an LTE transport mechanism, addresses the challenges posed by integration of the LTE protocol stack with the IMS control layer and all its various protocols.

5.2 Implementation challenges

Standards for voice services over LTE based on 3GPP IMS architecture are still maturing. It would take time for the subscriber base on LTE to be anywhere close to 2G/3G networks. It is, therefore, expected that the operators would look for interim solutions before moving on to full-fledged IMS architecture. For operators this makes economic sense. In the interim the operators would deploy CSFB, VoLGA or even OTT solutions. The data may be migrated sooner to the LTE because of built in efficiencies offered by LTE for data operations. New operators who have obtained spectrum from the digital dividend and do not have any legacy networks face difficult situation. If they do not wish to go for OTT solutions for the fear of customer dissatisfaction, they would have to make expensive sharing arrangements with other operators. Even the existing 2G/3G operators who do not have Generic Access Network and do not wish to commit investment in IMS would have to go for CSFB. If the operators have GAN and are prepared to invest in VANC would still have to maintain their legacy networks.

5.3 User satisfaction challenges

Performance of the network for critical real-time services needs to be tested with real-time audio and video quality measurement tools. Network impairment simulation may be carried out to test voice call quality by inserting errors in the application data stream. While moving to more advance technology like LTE, customers expect the service quality to be better than what they get today. While this may be true for data services where customers can see faster video downloads, the same cannot be said for voice services. Depending on the voice over LTE solution deployed by the operator, there may be delay in call set up and degradation in quality. The service providers would therefore face a difficult choice in the short and long term. Since IMS based VoLTE has the support of 3GPP, the operators may be forced to have a roadmap towards full IMS services. The VoLGA forum supports GSMA VoLTE initiative, which recognizes VoLGA as the interim solution.

6 Future Works

A lot of work remains for the standards bodies and research institutions. There is no doubt that the technology to implement Voice-over-LTE (VoLTE) is maturing, but mobile operators won't roll out telephony services in earnest for next couple of years. The main technical concerns are integration with existing operations and business support systems or the lack of these for the new operators. Alternative technologies are also allowing telephony over older networks to coexist with data over LTE.

A new approach that is being tried is the Network functions virtualization (NFV) technology, which could take some pain out of implementation of voice over LTE. Using NFV the operators would be able to create virtual elements of voice over LTE, like EPC and IMS on resources in the cloud. SDN Orchestration mechanisms can then be used to create the required architecture of voice over LTE depending on the existing network scenario. It is being designed to be so versatile that operators would be able to provision and de-provision instances of voice on demand to meet user requirements. Specifically, virtualizing the EPC will let operators automate the authentication and management of subscribers as they access services. Meanwhile, virtualizing the IMS would reduce the cost of VoLTE drastically.

Another area on which research is being carried out is providing voice in LTE- Advanced Heterogeneous Networks (HetNets). LTE-A HetNets use a mix of various sizes of cells. If interference can be controlled in the low power small cells then high spectral efficiency can be achieved. Enhanced inter-cell interference coordination and advanced terminal receivers with interference cancellation (eICIC/IC) has been used to provide high performance in heterogeneous networks in LTE. The LTE Advanced eICIC feature has been standardized in 3GPP Rel. 10. The VoLTE service including features such as Transmission Time Interval (TTI) bundling can coexist with LTE HetNets using eICIC/IC [qualcomm12a].

7 Summary

Migration towards LTE is a foregone conclusion. Both the existing cellular operators and the new ones who received spectrum in the ~digital dividend auction are looking at LTE as the savior technology in the era of exponential increase in data traffic. 3GPP Release 8, 9 and 10 that deal with LTE and LTE-A explain how LTE has been optimized for data transmission. In the process the casualty is circuit switched voice. While there is an option of OTT services, cellular operators are averse to this choice for many reasons and it would also not go down well with subscribers as the main voice offering. The GSMA has standardized 3GPP IMS based VoLTE as the ultimate solution for circuit switched voice and SMS in heterogeneous and pure LTE networks. As this solution is complex and expensive, operators are considering CSFB and VoLGA, atleast in the interim. In this paper we deliberate upon technical details of various VoLTE technologies, their upsides and downsides and the situations in which they could be deployed. Future developments and research in the area of VoLTE has also been discussed.

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List of Acronyms

2G	2nd Generation
3G	3rd Generation
3GPP	3rd Generation Partnership Project
AAA	Authentication, Authorization and Accounting
BLER	Block Error Rate
CDMA	Code Division Multiple Access
CS	Circuit Switched
CSFB	Circuit Switched Fall Back
eICIC	Enhanced inter-cell interference coordination
eNB	eNodeB
EPC	Evolved Packet Core
EPS	Evolved Packet Service
FDD	Frequency Division Duplexing
GAN	Generic Access Network
GERAN	Generic Radio Access Network
GSMA	Global System for Mobile Association
HetNets	Heterogeneous Networks
HLR	Home Location Register
HSS	Home Subscriber Server
ICSI	IMS Communication Service Identifier
IMEI	International Mobile Equipment Identifier
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
IP	Internet Protocol
IPSec	IP Security
ITU	International Telecommunications Union
LTE	Long Term Evolution
LTE-A	Long Term Evolution- Advanced
MIMO	Multi In Multi Out
MME	Mobility Management Entity
MMTel	MultiMedia Telephony
MSC	Mobile Switching Center
NFV	Network Function Virtualization
NNI	Network-to-Network Interface
FDMA	Orthogonal Frequency Division Multiple Access
OTT	Over the Top
P-CSCF	Proxy Call Session Control Function
P-GW	Packet Data Gateway

PCEF	Policy Control Enforcement Function
CRF	Policy Control and Charging Rules Function
PDN	Packet Data Network
PS	Packet Switched
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technolgies
RNC	Radio Network Controller
S-CSCF	Servinc Call Session Control Function
S-GW	Service Gateway
SC-FDMA	Single Carrier Frequency Divisio Multiple Access
SMS	Short Message Service
SRVCC	Single Radio Voice Call Continuity
TDD	Time Division Duplexing
TTI	Transmission Time Interval
UE	User
UMTS	Universal Mobile Telecommunications System
UNI	User Network Interface
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
VANC	VoLGA Access Network Controller
VLR	Visitor Location Register
VoLGA	Voice over LTE via Generic Access
VoLTE	Voice over LTE
WiMAX	Worldwide Interoperability for Microwave Access

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