



# Circuit-switched fallback.

# The first phase of voice evolution for mobile LTE devices.

White Paper

In collaboration with:



## LTE Growth and Challenges

The 3GPP Long Term Evolution (LTE) high-speed, high-capacity data standard for mobile devices is on its way to becoming a globally deployed standard. Launched commercially in late 2009, first quarter 2012 deployment and planning worldwide has expanded as reflected in Figure 1.

As an all-IP, data-only transport technology using *packet switching*, LTE introduces challenges to satisfying established quality of service expectations for *circuit-switched mobile telephony* and *SMS* for LTE-capable smartphones, while being served on the LTE network.

Two general approaches have been taken to address the dichotomy between packet switched (PS) data and circuit switched (CS) voice networks: *dual radio* solutions and *single radio* solutions. Dual radio solutions use two always-on radios (and supporting chipsets), one for packet switched LTE data and one for circuit switched telephony, and as a data fallback where LTE is not available. Dual radio solutions have emerged for LTE-CDMA2000 network interworking, driven by time-to-market pressures. Single radio solutions use one radio to handle both types of traffic, and use network signaling to determine when

to switch from the PS network to the CS network. This solution is universally accepted for LTE-3GPP network interworking solutions and is the focus of this paper.

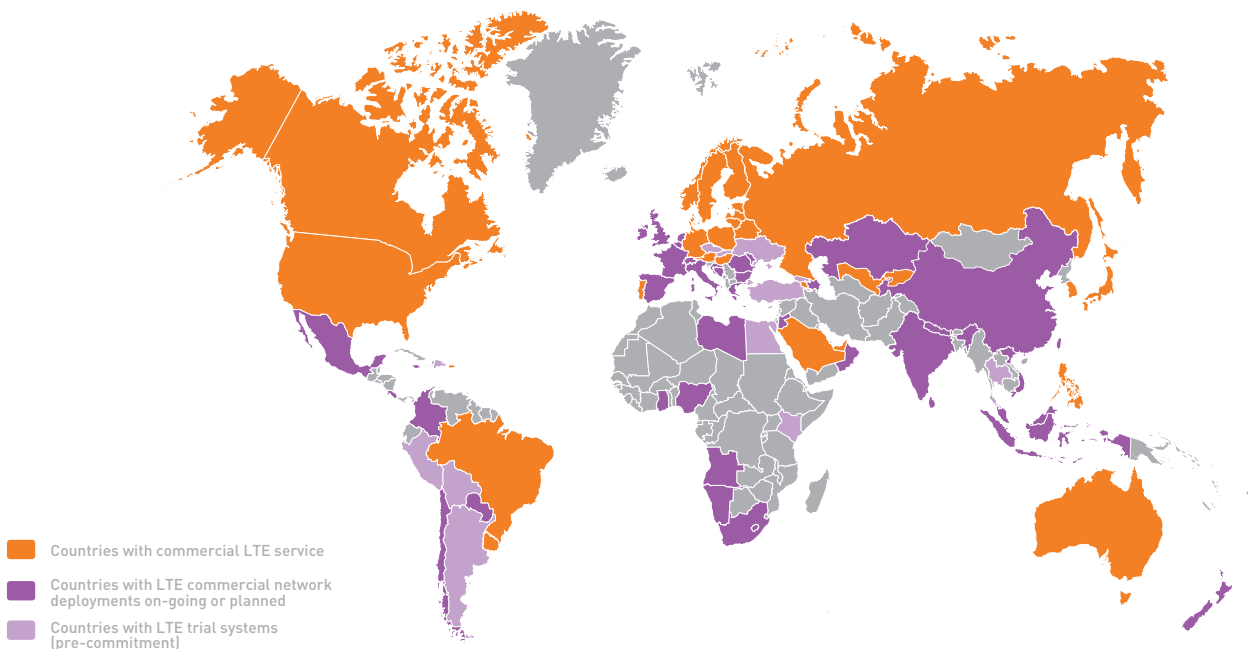
With circuit-switched fallback, when the user's device is operating in LTE (data connection) mode and a call comes in, the LTE network pages the device. The device responds with a special service request message to the network, and the network signals the device to move (fall back) to 2G/3G to accept the incoming call. Similarly for outgoing calls, the same special service request is used to move the device to 2G/3G to place the outgoing call.

While CSFB enables single radio voice solutions for LTE handsets, the switching requirements impose some technical challenges, for which solutions—described in detail below—have been developed.

CSFB addresses the requirements of the first phase of the evolution of mobile voice services, which began on commercial scale in 2011. CSFB is the solution to the reality of mixed networks today and throughout the transition to ubiquitous all-LTE networks in the future phases of LTE voice evolution.

**Figure 1**

First quarter 2012 LTE deployments and plans.



## The 3 phases of LTE voice and communication services evolution

The handling of voice traffic on LTE handsets is evolving as the mobile industry infrastructure evolves toward higher—eventually ubiquitous—LTE availability. Central to the enablement of LTE smartphones is to meet today’s very high expectation for mobile user experience and to evolve the entire communications experience by augmenting voice with richer media services.

This voice evolution can be characterized into three major phases, summarized in Figure 2.

In the first phase, currently under way, all voice traffic is handled by legacy Circuit-Switched (CS) networks, while data traffic is handled by LTE Packet-Switched (PS) networks—when and where available—and by 2G/3G networks as a fallback in non-LTE areas. Single radio solutions use CSFB to switch between LTE and 2G/3G access modes. CSFB has become the predominant global solution for voice and SMS interoperability in early LTE handsets, primarily due to inherent cost, size and power advantages of single radio solutions on the device

side. In 2011, CSFB has commercially launched in several regions around the world, and is the first step toward subsequent LTE voice evolution phases, which are also based on single radio solutions.

The second phase in LTE voice evolution introduces native VoIP on LTE (VoLTE) along with enhanced IP multimedia services such as video telephony, HD Voice and Rich Communication Suite (RCS) additions like instant messaging, video share and enhanced/shared phone-books. This phase also uses a single radio solution with Single Radio Voice Call Continuity (SRVCC) that seamlessly maintains voice calls as mobile users move between LTE and non-LTE coverage areas. CSFB continues to be deployed during phase 2, to provide voice services for roamers and CSFB only devices.

The third phase converges the enhanced capacity and services of all-IP networks (Voice and Video over IP and RCS) for continuous coverage across the broader range of network access methods, including LTE, 3G/HSPA and WiFi, with interoperability across operators and legacy telephony domains.

**Figure 2**  
The 3 phases of LTE voice evolution.



## The network architecture of CSFB

The legacy 2G/3G network and the LTE network co-exist in mixed networks, residing between the mobile customer’s User Equipment (UE) and the common core network, where an MME (Mobility management Entity) is serving users while in LTE access, while for 2G/3G an SGSN (Serving GPRS Support Node) is serving users when utilizing data services and an MSC Server (Mobile Switching Center Server) when utilizing voice services. The MSC Server connects to the carrier’s telephony network. To support CS Fallback signaling and SMS transfer for LTE devices, the MME connects to the MSC Server.

The architecture in Figure 3 shows a simplified view of the parallel LTE and 2G/3G networks.

The interface (SGs) between the MSC Server and the LTE Mobile Management Entity(MME) enables the user’s device to be both CS and PS registered while on the LTE access network. This interface also enables the delivery of CS pages via the LTE access, as well as SMS, without having the device leave LTE.

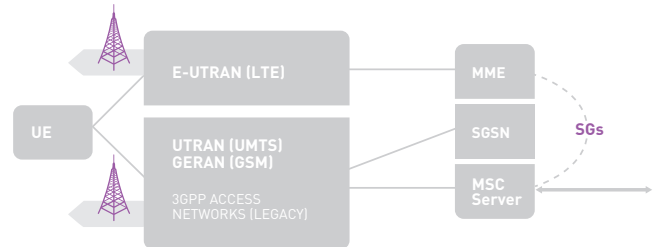
With the default LTE data network connection in operation, a mobile terminating (incoming) CS voice call triggers a page via LTE to the user’s device, as shown in Figure 4.

This page initiates CSFB, as the device sends an extended service request to the network to transition to 2G/3G, as shown in Figure 5.

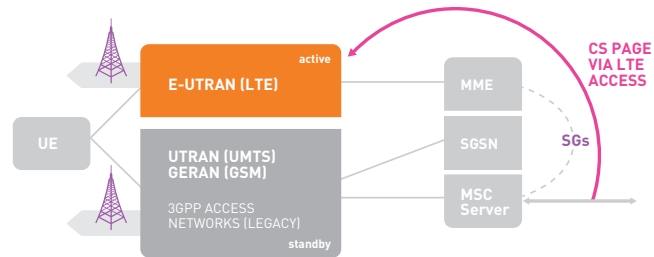
Once transitioned, the legacy call setup procedures are followed to setup the CS call. Mobile originating (outgoing) calls follow the same transition from LTE (PS) to 2G/3G (CS), except for the paging step, which is not needed. In 3G networks, PS data sessions can also move for simultaneous voice and data services. In 2G networks, PS data sessions may be suspended until the voice call ends and the device returns to LTE, unless the 2G network supports dual transfer mode (DTM), which permits simultaneous voice and data.

When the voice call ends, the device returns to LTE via idle mode or connected mode mobility procedures, as shown in Figure 6.

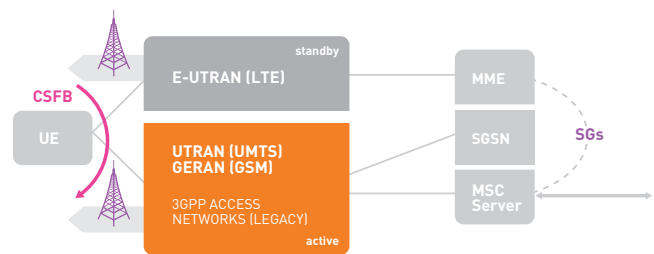
**Figure 3**  
EPS and legacy 3GPP packet core networks.



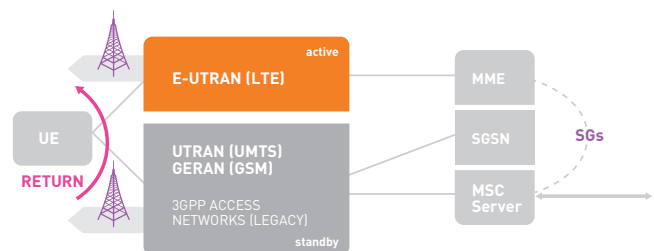
**Figure 4**  
Incoming voice call: CS page via LTE.



**Figure 5**  
Circuit-switched fallback.



**Figure 6**  
Return to LTE after voice call.



## Voice network acquisition

When the user's device is paged via LTE with an incoming call, or when the user initiates an outgoing call, the device switches from LTE to 2G/3G. Acquisition of the 2G/3G network and setup of the call can employ one of two procedures: *handover* or *redirection*.

In the *handover* procedure, the target cell is prepared in advance and the device can enter that cell directly in connected mode. Inter-Radio Access Technology (IRAT) measurements of signal strength measurements may be required while on LTE in this procedure, prior to making the handover.

In the *redirection* procedure, only the target frequency is indicated to the device. The device is then allowed to pick any cell on the indicated frequency, or may even try other frequencies/RATs if no cell can be found on the target frequency. Once a cell is found, the device initiates normal call setup procedures. IRAT measurements of signal strength are not needed prior to redirection. Consequently, CSFB with redirection may require less time to identify the best cell compared to the handover procedure.

Redirection-based CSFB has variations with differing call setup speeds:

- With *Release 8 Release with Redirection—Basic*, the device follows 3GPP Release 8 procedures and reads all the System Information Block (SIB) messages prior to accessing the target cell.

- With *Release 8 Release with Redirection—SIB Skipping (3G)*, the device follows 3GPP release 8, but only reads the mandatory SIBs 1, 3, 5 and 7, skipping all other SIBs prior to access. In this case, the neighbor information in SIB11 is delivered to the UE via measurement control messaging once the UE is in connected mode on the target cell. This approach can be either implicitly supported by the UE and the network, or explicitly through Deferred Measurement Control Reporting (DMCR) signaling.

- With *Release 9 Enhanced Release with Redirection—SI Tunneling*, the device follows 3GPP release 9, where SIB information can be tunneled from the target Radio Access Network (RAN) via the core network to the source RAN and be included in the redirection message sent to the device. This can avoid reading any SIBs on the target cell.

The predominant solutions deployed today are based on Release 8 Release with Redirection—SIB Skipping, in order to achieve good call setup times, good reliability, and simplify deployments. It is anticipated that Release 9 Enhanced Release with Redirection will be deployed in the near future. At this time, there is not as much push for handover-based CSFB since both Release 8 Release with Redirection—SIB Skipping and Release 9 Enhanced Release with Redirection—SI Tunneling have largely addressed any call setup time issues that may have existed with the Basic Release with Redirection solution.

## Outgoing call setup time

The additional steps in switching from LTE to 3G networks for voice calls, expectably, incur a penalty in call setup times.

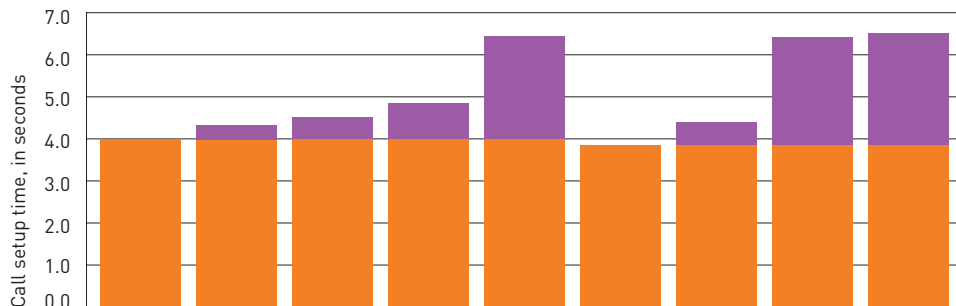
For mobile-originated (outgoing) voice calls, measurements of call setup times have been collected in live 3G networks with commercial infrastructure, averaged over a variety of good and poor radio conditions. Call setup times for 2G have been measured with lab testing, since adequate field data has not yet been captured.

Outgoing call setup times for 3G and 2G using the different handover and redirection procedures outlined above are summarized in Figure 7.

For 3G, handover-based CSFB has the lowest outgoing call setup time penalty (+0.4 seconds, +9% above legacy 3G). Handover avoids SIB reading and access delays altogether, but requires 0.3 seconds for IRAT measurements while on LTE. Redirection-based Release 9 SI Tunneling has only a slightly higher penalty (+0.5 seconds, +13%), by not reading SIBs at all. The optimized Release 8 Skip SIBs methods takes only slightly longer (+0.9 seconds, +22% vs. legacy), since reading the mandatory—but lower periodicity—SIBs 1, 3, 5 and 7 takes only about 0.3 seconds. The highest call setup time penalty (+2.5 seconds, +63% vs. legacy) is incurred with Release 8 Basic, because it takes about two seconds to read all the SIBs prior to access. SIB11/12 messages can be very large depending on the number of neighbors, which can result in segmentation.

**Figure 7**  
Mobile-Originated (Outgoing) Call Setup Times, LTE to 3G CSFB by Setup Method, with Comparisons to Legacy 3G. All units in seconds.

	UMTS				GSM				
	Handover	Redirection		GERAN Legacy	Redirection		Handover		
		Rel-8 / Rel 9	Rel 9		Rel-8	Rel 9		Rel-8 / Rel 9	
		SI Tunnel	Skip SIBs	Basic		SI Tunnel	Basic		
LTE Idle to connected transition	0.1	0.1	0.1	0.1		0.1	0.1	0.1	
Service Request for CSFB	0.2	0.2	0.2	0.2		0.2	0.2	0.2	
IRAT Measurement	0.3							2.4	
Handover	0.3							0.4	
RRC Release		0.2	0.2	0.2		0.3	0.3		
Tune To & Measure 3G Cells		0.2	0.2	0.2					
Read MIB & SIBs	0.2		0.4	2.0			2.0		
Camp on Cell/Channel Assignment		0.1	0.1	0.1	0.4	0.4	0.4		
3G RRC Connection Setup	0.3	0.3	0.3	0.3					
NAS / E2E Procedures	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	
<b>Total</b>	<b>4.0</b>	<b>4.4</b>	<b>4.5</b>	<b>4.9</b>	<b>6.5</b>	<b>3.9</b>	<b>4.5</b>	<b>6.6</b>	
<b>Difference vs. Legacy</b>		0.4 9%	0.5 13%	0.9 22%	2.5 63%	3.9	0.6 14%	2.6 65%	2.7 68%



For 2G, redirection-based Release 9 SI Tunneling—with a +0.6 second (+14%) penalty vs. legacy 3G—significantly outperforms handover-based CSFB (+2.6 seconds, +65%) for outgoing call setup time. Release 9 Basic setup time (+2.6 seconds, +65%) is essentially equivalent to handover-based CSFB. The difference in 2G handover-based CSFB is due to the much higher IRAT measurement time of 2.4 seconds, about eight times the 0.3 seconds required for 3G, caused by less efficient synchronization and cell identification. The difference in 2G redirection-based Release 8 is the 2 seconds required to read system information blocks, and since, unlike 3G, none of the long-periodicity SIBs are expendable, the SkipSIB option is not available.

So for 3G, handover and one or more of the redirection options appear capable of acceptable performance. For 2G, only redirection-based Release 9 SI Tunneling offers outgoing call setup times that do not compromise the user experience.

## Incoming call setup time

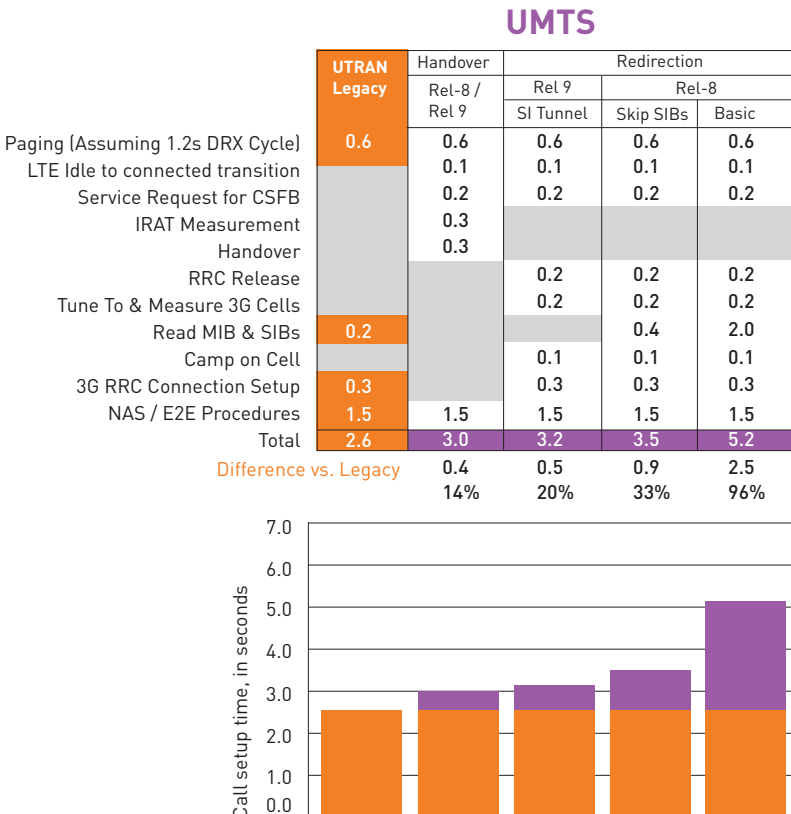
For mobile terminated (incoming) voice calls, measurements of call setup times have also been collected in live 3G networks with commercial infrastructure, averaged over a variety of good and poor radio conditions.

Incoming call setup times using the different handover and redirection procedures outlined above are summarized in Figure 8.

As was the case for outgoing calls on 3G, the best CSFB incoming call setup time performance comes with handover-based call setup, but it is only slightly faster than redirection-based Release 9 SI Tunneling. Please note that for the incoming calls, the NAS delay is shorter because it doesn't include the paging delay and the setup delay on the outgoing device.

**Figure 8**

Mobile-Terminated (Incoming) Call Setup Times, LTE to 3G CSFB by Setup Method, with Comparisons to Legacy 3G. All units in seconds.



One option to reduce CSFB call setup time is to shorten the LTE DRX paging cycle time. This gain in incoming call setup time comes at the cost of power consumption, since a shorter DRX paging cycle requires additional paging resources and, as a result, higher idle mode power consumption.

Focusing on real world user experiences, comparisons of incremental call setup time for CSFB over legacy 3G call setups time should be evaluated in light of the normal range of 3G call setup times. The less-than-a-second CSFB call setup increments—in the handover method and the two faster redirection methods—may not noticeably impact the user-perceptible experience, since they fall within the range or pre-existing 3G call setup times, and are more influenced by local signal strength and network conditions than CSFB call setup time penalties.

## Data interruption time

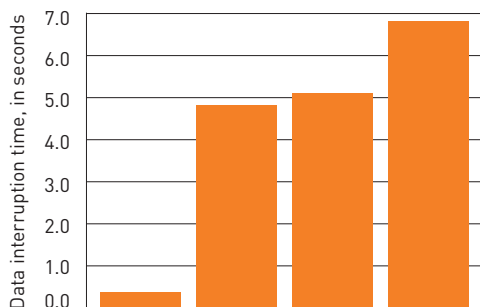
If a user is in an active PS data session (e.g., streaming media) when a voice call is initiated, the inter-RAT transition and routing area update will interrupt the data transfer. The interruption time will depend on the mobility mechanism, as summarized in Figure 9.

Using handover-based CSFB, the data stream interruption time of 0.3 seconds is unlikely to be noticeable. The user experience impact of the much higher 5 second data stream interruption in the redirection-based Release 9 SI Tunneling and Release 8 Skip SIBs methods may be mitigated in practice by the fact that user attention will already be diverted to initiating an outgoing call or receiving an incoming call.

**Figure 9**  
Data Interruption Time by Voice Call Setup by Setup Method.  
All units in seconds.

**UMTS**

	Handover	Redirection		
	Rel-8 / Rel 9	Rel 9	Rel-8	
		SI Tunnel	Skip SIBs	Basic
Handover	<b>0.3</b>			
RRC Release		0.2	0.2	0.2
Acquisition on UTRAN		0.2	0.2	0.2
Read MIB & SIBs			0.4	2.0
Camp on Cell		0.1	0.1	0.1
Connection Setup		0.3	0.3	0.3
Optional RAU Procedure		4.0	4.0	4.0
<b>Total Data Interruption Time</b>	<b>0.3</b>	<b>4.8</b>	<b>5.1</b>	<b>6.8</b>





## Call setup reliability

Another key issue for the voice call user experience is call setup reliability—the ability to successfully establish an incoming or outgoing call on the first attempt, or within a time frame that doesn't indicate call setup failure. The target is to at least match legacy performance, which is in the 98% range.

With CSFB switching between LTE and 3G networks, there are two primary challenges to call setup success: changes in IRAT conditions between measurement and acquisition (for handover-based CSFB), and mismatches between LTE and 3G geographic signal coverage areas that require server-side updates.

### Changing IRAT conditions for handover-based CSFB

With handover-based CSFB, IRAT measurements can change between the time the measurement is taken using LTE and the time 3G voice network acquisition is attempted. In that time, the cell identified and prepared for handover may become unavailable, resulting in connection failure, as visualized in Figure 10.

**Figure 10**

Target cell handover failure.



In handover-based CSFB, the measurement is performed before—on average of 0.3 seconds before, as shown in Figures 7 and 8 above—the IRAT transition. If the IRAT conditions change negatively, there is a higher probability of handover failure, especially in high mobility situations. Historical experience has already shown somewhat higher failure rates with inter-frequency handover or IRAT handover (e.g. 3G to 2G), suggesting that delays between IRAT measurement and network acquisition can increase setup failures.

In contrast, redirection-based CSFB can be expected to deliver higher call setup reliability than handover-based CSFB, simply because redirection-based CSFB takes the IRAT measurement immediately before attempting access on the identified cell. Since the Release 9 SI Tunneling and Release 8 Skip SIBs redirection-based CSFB methods have only slightly higher call setup *times*, their higher call setup *reliability* has guided the general industry trend to rely on redirection-based CSFB approaches.

The reliability of redirection-based CSFB call setup has been tested using device traces in field testing on live 3G networks, and no call setup failures were observed out of more than 160 calls, covering both good and bad RF conditions for redirection-based CSFB to UMTS. These results point to call setup reliability on par with legacy call setup reliability. Similar traces collected on the network side showed redirection-based CSFB reliability in the 99% range, on par with UMTS legacy performance. Test data for handover-based CSFB reliability has not yet become available, due to its limited use to date.

### LTE to 3G cell handover time

With different frequencies having different terrain propagation and structure penetration characteristics, as well as potentially different fixed antenna sites, LTE and 3G radio access patterns for any given location are never identical. Consequently, uncertainty about which 3G cell is the best target for switchover from an LTE cell is unavoidable, simply because LTE cells can overlap two or more 3G cells, as visualized in Figure 11.

These mismatches between LTE and 3G geographic signal coverage areas can introduce substantial setup delays due to Mobile Switching Center (MSC) servers needing to update user locations in their originating LTE cell Tracking Areas (TA) and their destination 3G cell Location Areas (LA), as visualized in Figure 12.

If CSFB switching is done from an LTE cell in one TA to a 3G cell in another LA (where the user's device is not registered), a new Location Area Update (LAU) must be done prior to executing connection setup. This LAU procedure can add a one to two second delay to setup time, depending on the load on the network. The example in Figure 12 assumes that 3G coverage is better than LTE, however the problem applies equally in the opposite case.

In the more extreme case, this LTE to 3G cell switch may occur in an MSC Server "border" area, where the LTE to 3G switch involves a change of MSC Server. In this situation, both the LAU and the Home Location Register (HLR) update must occur between different MSC Servers prior to connection setup. This Mobile Terminated Roaming Retry procedure can add a four to five second delay to setup time, depending on network loads.

These substantial call setup delays affect the user experience noticeably, and may be judged as call setup failures rather than acceptable as delays.

#### Network architecture to address cell mismatch

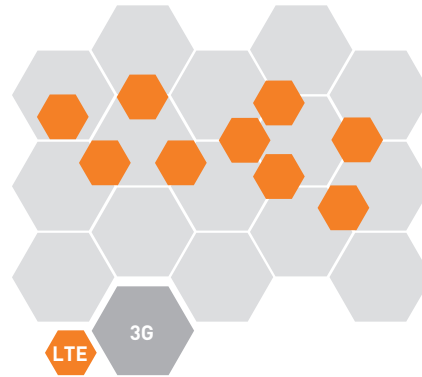
To address the setup delays and setup failure risks in MSC "border" areas, as well as eliminate the LAU delay time, MSC Pool architecture can be deployed.

MSC Pool architecture, also known as lu/A-Flex, conforms to the 3GPP Release 5 specifications for connection of Radio Access Network (RAN) nodes to multiple Core Network (CN) nodes. With MSC Pool architecture, all MSC Servers within a pooled area serve all cells in the pool, eliminating MSC "borders" and the time delay of inter-MSC LAUs within the pool. Such a pooled architecture serving a broader area can be visualized as in Figure 13.

MT Roaming Forwarding (MTRF) can also be used as a complement to MSC Pool architecture.

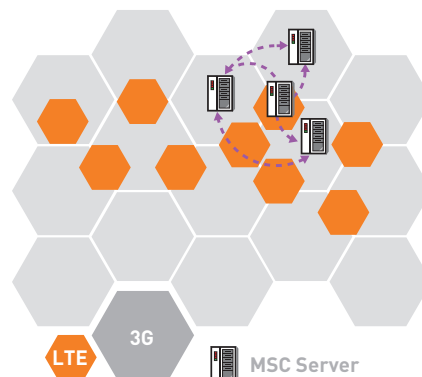
**Figure 11**

LTE/3G overlap.



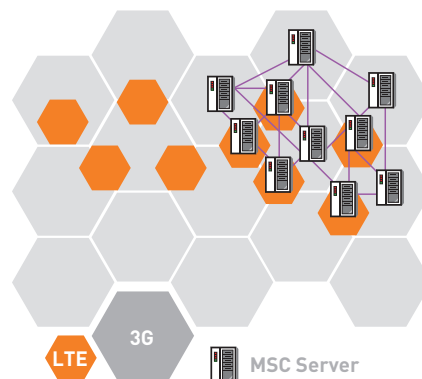
**Figure 12**

LTE to 3G cell switching uncertainty.



**Figure 13**

MSC pool architecture.



MTRF is a newer version of the MT Roaming Retry (MTRR) standard and it solves the MSC border issue by forwarding calls directly from the old MSC to the new MSC in case a fallback is done over an MSC border. MTRF has the advantage over MTRR of not needing inter-operator agreements and not rerouting calls back to the GMSC for a second HLR interrogation. This makes MTRF more reliable and easier to deploy.

Even with MSC Pooling, MTRF may be needed between MSC Pools or in areas where MSC Pool architecture is not deployed.

MSC Pool architecture has a better success rate than using MTRF alone, since MTRF requires additional inter-MSC location updates, HLR location updates and forwarding procedures to handle CSFB calls across MSC "borders." MSC Pool architecture also eliminates the need for MTRF within the pooled area for terminating CSFB calls.

## Conclusions

CSFB is the first step in enabling mainstream LTE handsets with the cost, size and battery life advantages of single-radio solutions to LTE data in combination with 2G/3G voice (and data fallback, in non-LTE areas).

The single-radio solution is also the pathway to later phases of LTE voice evolution that add additional operator network capacity gains and user experience enhancements.

CSFB network upgrades provide a first step towards VoLTE with SRVCC, the next phase of LTE voice evolution. Even as VoLTE is initially launched, VoLTE handsets will continue to require CSFB for roaming.

While several options are available to address the call setup time and reliability issues introduced by the single-radio solution, the evidence gathered to date suggests the following as solutions for handsets and supporting network infrastructure in the current phase of LTE evolution:

- Redirection-based CSFB using Release 9 SI Tunneling, for both 3G and 2G. The measured sub-second call setup penalties should fall within the range of legacy user experience, and can be improved (for incoming calls) with DRX paging cycle optimization. The slight call setup time advantage of handover-based CSFB for 3G does not appear to justify its deficiencies relative to call setup reliability under changing IRAT conditions.
- MSC Pool architecture, in combination with MT Roaming Forwarding, to deliver satisfactory call setup times and success rates across the broadest range of network conditions.

*This whitepaper has been developed in collaboration with Ericsson, where Ericsson has provided input to, and reviewed, the overall network aspects of the paper.*

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