Performance of CS Fallback from LTE to UMTS

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ABSTRACT

Circuit Switched Fallback (CSFB) is the most commonly used method to support voice services over Long Term Evolution (LTE) networks today, as the deployment of IP Multimedia Subsystem (IMS) is still in its infancy. In this article, we discuss the performance of CSFB voice traffic redirection from LTE to UMTS using data from live commercial networks. The key factors impacting CSFB call setup delay are highlighted. Data from multiple cell geometries including stationary and mobility conditions are presented for Mobile Originated (MO) calls towards landlines, Mobile Terminated (MT) calls from landlines and Mobile-to-Mobile (M2M) CSFB calls. Analysis results in well optimized deployments show that on an average, MO/MT call-setup time for CSFB from LTE to UMTS is around 1 sec greater than legacy UMTS. However, the results can vary depending on the network configuration and the conditions of the measurement. To illustrate the optimization of CSFB performance in real networks, we also highlight the principal call set up optimization and implementation factors impacting CSFB call setup delay and success rates. This article demonstrates that in well optimized networks, CSFB to UMTS call setup success rates can be very close to those achieved in the legacy UMTS systems.

INTRODUCTION

Traditionally, voice services have been provided over circuit switched (CS) networks in wireless systems. But LTE is a purely packet switched (PS) system and, thus, requires the deployment of IMS in the operator's Core Network to integrate voice services and to ensure Quality of Service and adequate charging mechanisms. However, most commercial systems today do not have IMS integrated in the Core Network. This prevents the deployment of voice services over LTE (VoLTE). Since voice service is a major source of revenue for operators, LTE network operators require an alternative path to allow early LTE deployment with enhanced PS services without sacrificing voice quality. CSFB is an intermediate solution in the short term and an alternative service in the long term to support voice services in LTE. CSFB is standardized by 3GPP and allows capable LTE devices to utilize CS services through several legacy voice networks – in particular UMTS [1]. Therefore, it is important to understand CSFB performance in terms of relative call setup delays and call setup success rates as compared to the original call setup performance in legacy 2G/3G networks. This article concentrates on CSFB to legacy UMTS systems.

The article layout is as follows: we summarize the CSFB call setup procedure. It also describes network architecture requirements and discusses the key differences between establishing a legacy CS call in 3G (UMTS) and a CSFB call in LTE. We explain the typical configuration of the LTE/UMTS networks from which CSFB performance data was collected. It also provides an overview of the test locations and data collection procedure. We present CSFB call setup delay performance statistics from live commercial network deployments including MO calls to landlines, MT calls from land-lines and M2M calls in different scenarios. In addition, call setup delay budget analysis from Access Stratum (AS) and Non Access Stratum (NAS) perspectives are included to provide insights into possible optimizations at different stages of the CSFB call setup procedure. We discuss the most common CSFB call setup failure cases and recommended approaches to deal with such scenarios from a network optimization, configuration and implementation perspective. Finally, we summarize the main observations of CSFB performance in current LTE deployments.

SYSTEM ARCHITECTURE AND CSFB PROCEDURES

CSFB capable devices are multi-technology devices that support combined registration procedures to LTE and UMTS networks. Figure 1a shows the required inter-working between UMTS and LTE networks to provide CSFB services. The Mobility Management Entity (MME) in the LTE network requires updates to support the SGs interface connecting it to the Mobile Switching Center (MSC) in UMTS for combined registration and paging processing of CS domain services [1, 6]. The S3 interface connecting the MME with the Serving GPRS Support Node

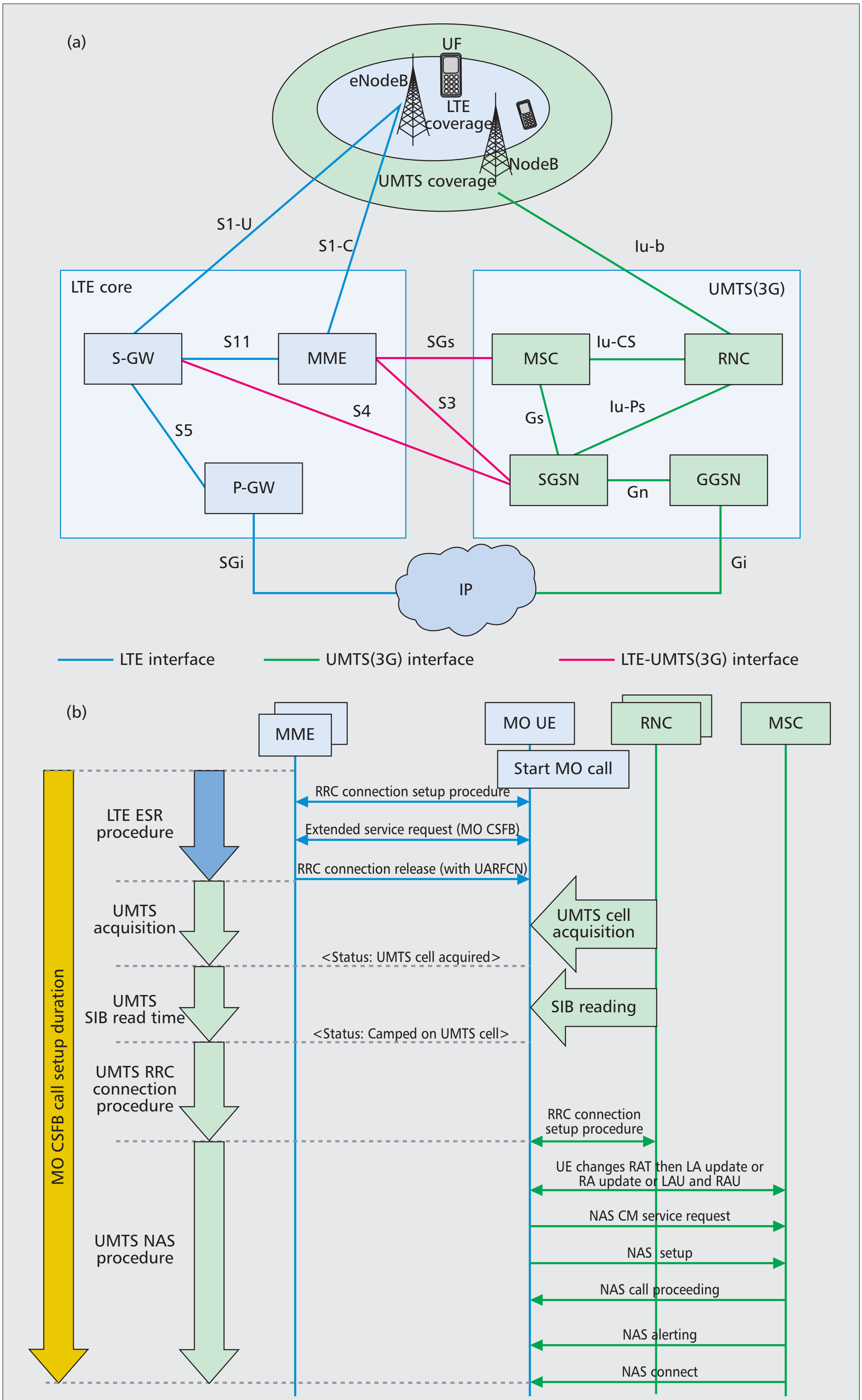

Figure 1. *a) CSFB network architecture; b) is an abstraction of the CSFB related procedures required to establish a CS call from LTE. For simplicity, the MME block in the figure includes the eNodeB, S-GW and P-GW components that are part of the LTE network. Similarly, the RNC block includes the NodeB and the SGSN components that are part of the 3G UMTS network.*

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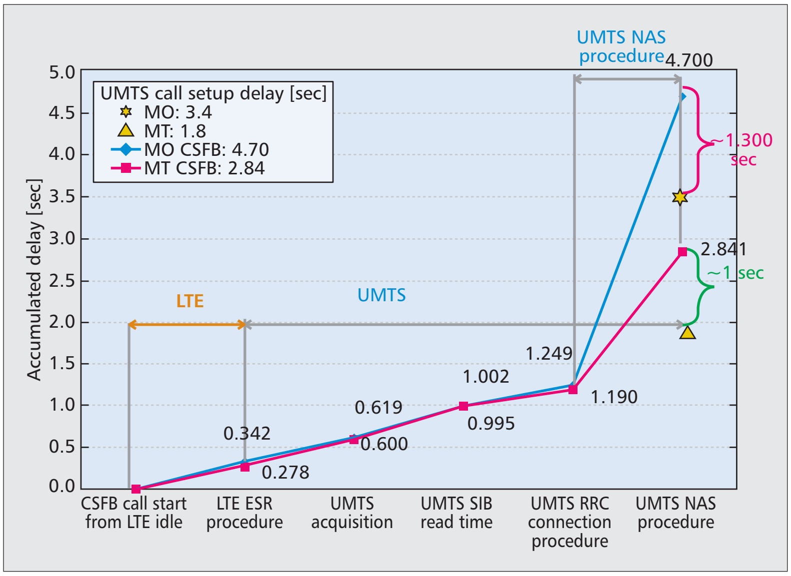

Figure 2. *Mobile to land-line CSFB call setup from RRC IDLE (redirection).*

(SGSN) and the S4 interface connecting the LTE Serving Gateway (S-GW) with the UMTS SGSN are also required to enable signaling and PS data context transfers between LTE and UMTS [1].

Once a CSFB capable User Equipment (UE) is registered in both the LTE and UMTS networks, and it moves inside LTE coverage, the MME and MSC are updated with the (paging) location of the UE through a combination of Tracking Area (TA) and Location Area (LA) Update procedures. This information is used to update the Home Subscriber Server (HSS) for PS and CS paging of the UE. Furthermore, if Idle Mode Signaling Reduction (ISR) is not supported, whenever the UE reselects between LTE and UMTS, it initiates a combined Tracking Area Update (TAU) procedure in LTE or a combined Routing Area Update (RAU) procedure in UMTS [2].

From an execution perspective, CSFB can occur due to MO voice calls, MT voice calls or M2M voice calls. From an LTE Radio Resource Control (RRC) perspective, these calls could take place while the UE is in LTE RRC IDLE state (no active session) or RRC CONNECTED state (with an active session). To maintain the perception of "Always-on connectivity" in LTE during a CSFB call, in addition to establishing the required CS voice call in the target 2G/3G system, CSFB requires the transfer of the PS data context from LTE to the 3G network [1], as opposed to simply setting up the voice call.

Figure 1b is an abstraction of the CSFB related procedures required to establish a CS call from LTE. For simplicity, the MME block in the figure includes the eNodeB, S-GW and P-GW components that are part of the LTE network. Similarly, the RNC block includes the NodeB and the SGSN components that are part of the 3G UMTS network.

After the mobile user originates a CSFB call, the Non Access Stratum (NAS) layer at the UE issues an Extended Service Request (ESR) that needs to be conveyed to the MME. In order to facilitate this, an LTE RRC connection needs to be set up between the UE and the eNodeB (required only if the CSFB call is initiated from RRC IDLE state in LTE).

After the MME receives the ESR, authentication and security procedures might be required before the MME informs the eNodeB to redirect the call to UMTS. Alternatively, instead of a redirection, the MME could trigger a CSFB through PSHO (PS Handover).

If redirection is used, the UE receives the LTE RRC Connection Release with UMTS redirection information from the serving eNodeB. Thereafter, the UE goes into RRC IDLE state in LTE and attempts to acquire the specified frequency in UMTS. After the UE acquires a suitable UMTS cell, it establishes a UMTS RRC connection.

A UE that was in Evolved Packet System (EPS) Session Management (ESM) active state and was redirected to UMTS performs the Routing Area Update procedure. This triggers the relocation of bearer contexts to the target resource in the SGSN of UMTS [2]. The SGSN then initiates the set up of PDP Contexts, mapping each EPS bearer that was previously established in LTE to a corresponding UMTS bearer. Finally, the SGSN completes the procedure by sending a Routing Area Update accept message to the UE.

In parallel or in a sequence, a conventional UMTS CS call setup procedure is performed in the legacy 3G UMTS network as defined through Non Access Stratum Connection Management (CM) signaling (See Service Request, Setup, Call Proceeding, Alerting and Connect messaging in Fig. 1b).

Network Configuration and Data Collection

Multiple deployed LTE networks with CSFB functionality in North America, Europe and Asia were considered for this study. In general, the selected networks had a single LTE frequency that overlapped multiple UMTS frequencies in the same geographical area. Most of the selected networks deployed CSFB as defined in LTE Rel8, although Rel9 enhancements were also deployed in some clusters. In these networks, a large sample size of MO, MT, M2M CSFB calls and legacy UMTS calls were attempted using commercially available LTE smartphones. For legacy UMTS calls, the phones were reconfigured to disable LTE, so that only legacy UMTS calls were initiated. For all CSFB calls, the phones were verified to be in LTE/UMTS coverage before a CSFB call was initiated. After a CSFB call was released, a generous 20 sec wait time was allowed to ensure the phones camp again in LTE in the majority of cases. In order to study a wide range of conditions, the data was collected in multiple stationary near cell conditions with average LTE Reference Signal Received Power (RSRP) of –66dBm, and UMTS Received Signal Code Power (RSCP) of –50dBm and in stationary cell-edge conditions with average RSRP of –110 dBm and RSCP = –90dBm. Measurements in mobility conditions (typically the most challenging) were also collected to analyze CSFB Performance. In some cases, the number of CSFB calls attempted exceeded 1000 calls per location. These calls were typically divided into batches of around 100 calls at different times of the day across the week. Such a large sample size was important to obtain statistically significant performance results and capture specific issues described in this article that negatively impacted CSFB call setup delay and success rate. During the tests, mobile log data was saved from the mobile application and the phone modem, including both LTE and UMTS protocol information as well as various LTE and UMTS radio access and core network elements. Performance results in terms of call setup delays and call setup failures that reflect user experience were obtained from analysis of both UE and radio/core network logs.

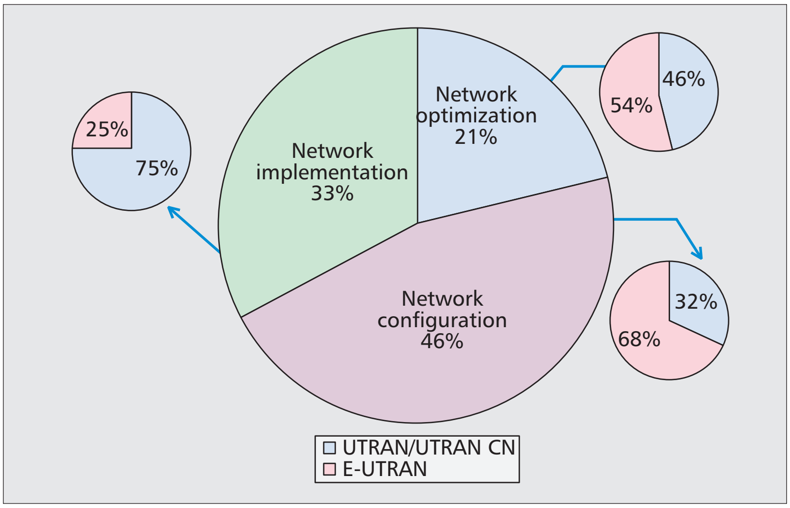

Figure 3. *Summary of CSFB call setup failure causes in an initial CSFB deployment.*

CSFB Call Setup Delay

Call setup delay definitions can vary based on the deployment, the called entity type and NAS signaling handling during the call setup procedure. In most deployments, measuring NAS signaling delay from "NAS CM Service Request" to "NAS ALERTING" message serves the purpose for MO CSFB calls. However, in some deployments, the NAS ALERTING message is sent to the calling party before the core network entity establishes connection to the called party (i.e., it provides an early ring back tone to the calling party). In such deployments, the MO call setup measurements should be considered to "NAS CONNECT" message, which is only sent after the voice path to the called entity is established. In the latter case, the time required by the calling party to answer the call should be discounted from the call setup statistics for a fair comparison. For MT CSFB calls, call setup delay is usually measured from the time the mobile receives a Paging Request to the time a "NAS ALERTING" message is received. The breakdown for these NAS procedures is illustrated in Fig. 1b.

CSFB Call Setup Delay from LTE in IDLE State

The call setup delay budget in near cell conditions, including all intermediate steps for MO and MT CSFB calls from a typical commercial CSFB deployment is shown in Fig. 2. It starts with the UE in LTE IDLE mode and presents the average cumulative delays for the entire call setup procedure. "LTE ESR Procedure" in Fig. 2 is the time the UE spends to establish LTE RRC connection to send the ESR message and receive a redirection to UMTS message. After this, the UE acquires a UMTS cell in the step labeled "UMTS Acquisition" and then starts reading System Information Broadcast (SIB) messages, labeled as "UMTS SIB Read and Camp time." Finally, the UE starts RRC connection procedures in the UMTS network, labeled "UMTS RRC Connection Procedure." After this stage, NAS messaging is exchanged between the UE and UMTS core network for the completion of the CS call setup (PS context transfer happens during the RAU procedure, as described in previous sections).

It can be inferred from Fig. 2 that the measured call setup time for MT CSFB calls is shorter than for MO CSFB Calls. Call setup delay measurement from the MT UE starts after the called UE receives the paging request from the network, although the NAS interaction between the network and the originating party could occur before the page was received by the terminating UE. Hence, for MO calls, the UE perceives the NAS procedure while interacting with the called party as an extra call setup delay. For MT calls, the required NAS procedures between the calling party and the allocation of call resources at the MSC are transparent to the MT UE.

The CSFB call setup delay in cell edge conditions compared to the delay presented in Fig. 2 could be up to 0.6 seconds longer for both CSFB and UMTS legacy calls in a well optimized UMTS network. In general, the total CSFB call setup excess delay compared to UMTS legacy calls for MO and MT land-line calls is expected to be approximately 1 sec in commercial networks with LTE Rel8 capabilities and drop to around 0.5 sec for networks/devices supporting SIB skipping and LTE Rel9 based UMTS SIB tunneling.

CSFB Call Setup Delay During LTE Active Session

CSFB call setup during LTE active session differs in two aspects from the CSFB from LTE in IDLE state. Firstly, the UE does not need to establish RRC connection in LTE since it is already in RRC CONNECTED state. Secondly, the UE has to continue with its LTE PS active data session in UMTS. Hence, in parallel to establishing the CS voice call path, the transfer and activation of an LTE PS session needs to be completed in UMTS.

Although starting the call from LTE RRC CONNECTED saves some portion of the CS call setup time compared to CSFB from LTE Idle, concurrently transferring and activating

		Excess delay to Legacy [sec]	
Call Type	Legacy (UMTS) [sec]	CSFB (Rel8)	CSFB (Rel9)
MO to Land-Line	3.4	1.3	0.5
MT from Land-Line	1.8	1	0.5
Mobile to Mobile	6.5	2	1

Table 1. *Average call setup times in live networks.*

Delay Source	% of excess delay relative to best call	Possible Optimization
SIB Read Time in UMTS	36	Increase the periodicity of mandatory UMTS SIBs; introduce SIB tunneling and SIB skipping
Paging Delay in LTE	15	LTE DRX cycle settings: Tradeoff call setup time vs. battery life
Core Network Delay	14	Optimize NAS message handling for concurrent CS/PS multi-RAB establishment
WCDMA Access	9.5	Optimize WCDMA layer, especially RACH parameters
LTE Access	6.8	Tune LTE RACH parameters, ensure good LTE coverage

Table 2. *Possible optimizations for CSFB call setup delay.*

both PS and CS RABs into UMTS might incur additional delays at the NAS layer. This is particularly noticeable if NAS layer messaging is not handled efficiently.

For CSFB calls during an LTE active session, in addition to measuring CS call setup delay, it is necessary to measure PS data interruption time. In a CSFB deployment where the core network prioritizes CS establishment over PS during the multi-RAB procedure in UMTS, the CS establishment delays are similar to those presented in Section A. PS data interruption time with typical LTE Rel8 CSFB with redirections and without ISR is around 5 sec, as measured from the time the last Radio Link Control (RLC) PDU is received from LTE to the first RLC PDU received from UMTS. This long data interruption can be reduced to a few hundreds of milliseconds by enabling LTE to UMTS PS handover instead of using redirection for the CSFB call.

After a CSFB call is released in UMTS, network operators prefer that the UE returns to LTE as soon as possible. In the absence of UMTS to LTE PS handover support, current commercial deployments rely on priority based Inter-RAT cell reselection or fast return via network based UMTS to LTE redirection. Depending on parameter settings for the state transition and DRX timers, the inter-RAT cell reselection approach could allow the UE to return to LTE approximately 10 sec after CS and PS activity ceased in the UMTS network. Using the network UMTS to LTE redirection approach, if the CSFB call was attempted from LTE IDLE state, returning to LTE takes only around 0.5 sec.

MOBILE-TO-MOBILE CSFB PERFORMANCE

M2M CSFB performance is the most challenging situation from the call setup delay perspective. In M2M CSFB calls, after successful redirection to UMTS, the MO UE sends a CM Service Request in UMTS to the source MSC, the MT UE receives the page for the CSFB call in LTE and inititates MT CS fallback procedures. Hence, the time spent in the MO NAS procedure includes the end-to-end MT call setup delay caused by the required paging and resource establishment at the MSC.

Therefore, in the M2M scenario, the amount of delay due to any suboptimal implementation is almost double because it includes both the MO and MT procedures. Moreover, mobility conditions of both CSFB devices introduce additional factors such as handovers and abrupt Radio Frequency (RF) variations during the CSFB call establishment, which impact CSFB call setup delay statistics.

Call setup time for M2M CSFB calls in LTE Rel8 and during mobility conditions is around 2 sec greater than M2M calls on legacy UMTS networks. Results reported in this article represent the average delay for more than 200 M2M calls in the most challenging coverage area of an operator deployment. With Rel9 enhancements and the same average conditions, this difference is expected to be close to 1 sec.

Table 1 summarizes the CSFB call setup performance results from previous sections. Call setup times for legacy UMTS CS calls and the excess delay encountered for MO/MT/M2M CSFB calls are shown for comparison. Average performance numbers in Table 1 are based on data collected from well optimized LTE and UMTS commercial networks with reasonable RF conditions. Higher excess delays could be measured in suboptimal networks.

CSFB CALL SETUP DELAY OPTIMIZATION

In initial CSFB deployments, call setup time can vary widely and a number of calls may experience excessive delays. Optimizing CSFB setup delay requires an understanding of the shortest call setup time that can be achieved on the network and the root cause of excessive delays. By comparing the shortest CSFB call setup time to the average, the total opportunity for optimization can be quantified. Then the delay budget differences for each CSFB call stage need to be analyzed to identify specific optimization opportunities in the call setup. Table 2 summarizes a sample of common optimization opportunities for live CSFB networks.

The technique used to compute the statistics in Table 2 involved collecting all the high call setup delay samples, and breaking down the call flow to segments to identify the source of excess delay. A large sample set of calls (1000+) in a commercially deployed CSFB network is considered.

Category	Network	Issue Description
Network Optimization Related Issues	LTE Radio Access	–Continuous RACH failures –Missed Pages –HO Failures and Ping-pongs
	UMTS Radio Access	–RRC Connection Procedure Failures –Maximum RLC retransmissions –Physical layer Radio Link Failures (RLF)
	Core Network	–LAU related failures
Network Configuration Related Issues	LTE Radio Access	–LTE Radio link or TAU procedure failures –LTE Idle mode reselection failures and missed CSFB pages
	UMTS Radio Access	–Cell Update Recovery Timer Value
	Core Network	–High paging intervals and infrequent paging causing call failures
Network Implementation Related Issues	LTE Radio Access	–Improper handling of CSFB calls during Intra-frequency HOs –Tracking Area Update Procedure Issues
	UMTS Radio Access	–Lack of support for CS call recovery via Cell Update Recovery Support –Race conditions during CS and PS Security Mode Procedures
	Core Network	–Failures in Inter-System Paging and Interworking (MSC-MME) issues –Sporadic RRC Connection Releases during NAS signaling procedures

Table 3. *Possible optimizations for CSFB call setup delay.*

CSFB calls involve interaction between LTE and UMTS radio access and core networks. The lack of suitable radio access planning, RF optimization and interference management or poor inter-working of both networks can lead to a variety of issues.

In general, CSFB call setup delay can be optimized in three different areas:
- RF and parameter optimizations in UMTS and LTE
- Introduction of available CSFB enhancements (i.e., support of Inter-RAT PSHO in both LTE/UMTS directions, SIB skipping, SIB tunneling, ISR or inclusion of the Primary Scrambling Codes of the UMTS target cell in redirection messages).
- Improvements on NAS message handling and inter-working of LTE and 3G core networks (i.e., efficient handling of NAS messaging at the UE and network to provide adequate CS and PS call setup tradeoffs for the concurrent procedure of establishing both PS and CS).

CSFB Call Setup Failure Rate

This section provides an insight on CSFB call setup failure rate and an overview of different reasons that may cause higher than expected failure rates as observed in live CSFB networks. The key associated issues have been categorized into three general areas:
- Network Optimization
- Network Configuration
- Network Implementation

In general, when driving along routes with the highest frequency of CSFB failures, initial CSFB to UMTS commercial deployments show up to 3 percent CSFB call setup failures. CSFB failures across the network are around 1–2 percent, which indicates the CSFB failure rate is close to that of legacy UMTS deployments.

Network Optimization Related CSFB Failures

CSFB calls involve interaction between LTE and UMTS radio access and core networks. The lack of suitable radio access planning, RF optimization and interference management or poor inter-working of both networks can lead to a variety of issues, as listed in Table 3.

Suboptimal UL LTE coverage (i.e., LTE planning) can lead to LTE Random Access Channel (RACH) procedure failures. RACH failures may result in initial registration or Tracking Area Update (TAU) failures. TAU failures can indirectly result in missing pages for the duration the UE is not able to update its location. Poor DL LTE coverage can also lead to paging failures. On the other hand, excessive cell overlap can lead to excessive HO, both of which can result in CSFB call failures.

CSFB call setup failures are also observed due to UMTS optimization related issues. Blind redirection from LTE to UMTS is the most common mechanism in today's CSFB deployments. Therefore, in areas of poor UMTS RF coverage or high load/interference, there is a risk CSFB call setup may encounter failures due to physical layer problems or failed RRC Connection procedures.

An emphasis should be placed on UMTS frequency layers that receive CSFB calls, with additional care taken to ensure that DL/UL load on those frequencies is carefully managed and the load is distributed across CSFB target carriers.

Careful planning of LA/MSC boundaries is required. Lack of suitable UMTS CN planning with regards to LA/MSC boundaries may result

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in serving MSC changes during a CSFB call setup procedure and can cause call setup failures.

NETWORK CONFIGURATION RELATED CSFB FAILURES

Table 3 lists some typical cases where improper LTE/UMTS and core network configuration can lead to CSFB call setup failures. Some LTE initial deployments do not have intra-frequency measurements configured during TAU procedures. LTE measurements during TAU procedures ensure that the UE completes a HO to the best cell immediately and avoids MO/MT CSFB call setup failures.

In some initial deployments, LTE networks schedule SIB messages do not contain useful neighbor cell information (e.g. SIB4) [4]. In this scenario, while the UE waits to collect such LTE SIBs, and if suboptimal RF conditions are encountered, this unnecessary delay may cause LTE cell reselection failures, which result in missed pages and MT CSFB call failures.

Inadequate UMTS CN configuration also impacts call setup performance. If the MSC timer (waiting for ESR after LTE page) is not properly set in relation to the DRX cycle setting in LTE, UEs may miss LTE pages, leading to failed MT CSFB calls. This is especially true when UEs are in suboptimal RF conditions and the MSC uses a large re-paging interval with a few retries. Setting the MSC Paging retry timer interval and count carefully based on the LTE Idle Mode DRX cycle is recommended.

NETWORK IMPLEMENTATION RELATED CSFB FAILURES

Table 3 lists some suboptimal network implementations and lack of certain feature support in LTE and UMTS that can result in CSFB failures.

In mobility scenarios, CSFB call setup failures are a possibility during Intra-frequency handovers. In some of these scenarios, when HO execution is ongoing, CSFB issues might be observed due to MME implementation. In particular, if the MME receives a rejection to a UE Context Modification Request message with a CS Fallback indicator from the eNodeB with an indication that an X2/S1 handover is in progress, the MME shall resend the UE Context Modification Request with CS Fallback indicator to the target eNodeB. This ensures that the LTE RRC Connection Release message with redirection can be sent through the new cell when the HO is complete, or to the source eNodeB if the HO is deemed to have failed [3]. If the MME does not perform this action, CSFB establishment during HO execution is prone to failure.

Another issue in mobility conditions that leads to CSFB failures is associated with the network releasing the RRC connection before receiving an RLC ACK for the TAU complete message. This causes MT CSFB call setup failure because the MME cannot page the UE unless the TAU and LAU procedures are completed. Similarly, in UMTS, CS and PS domain Security Mode Command (SMC) procedure implementation can also lead to CSFB call setup failures when RLC ACK is not received for CS SMC before PS SMC is sent. In general, eNodeBs and RNCs should provide sufficient delay to ensure receipt of RLC ACKs from UEs for prior signaling messages before sending any subsequent message. Additionally, some RNC implementations do not support Cell Update (CU) procedures for the CS domain, although they still enable a T314 timer for re-establishing a DCH (Dedicated Channel) in case of an RLF during the CSFB call setup procedure. Hence, the UE would initiate multiple Cell Update procedures (recovery technique) without receiving a confirmation, which significantly delays transmission of the RRC Connection Request. Support for such recovery procedures for CS calls can increase the probability of establishing a CSFB call in challenging RF conditions (especially in mobility).

When the UE is moving between multiple LA boundaries and across MSCs, poor interaction between the MME and MSCs can result in MT CSFB call setup failures. This could cause the target MSC to release the Iu-CS connection (Fig. 1a) resulting in the UMTS network releasing the RRC connection, which eventually results in a CSFB call setup failure. Therefore, tight timing synchronization between the MSC and MME is required and precise handling of corner cases/race-conditions is needed.

Figure 3 illustrates typical causes for CSFB to UMTS call setup failures in early CSFB deployments. While the exact distribution can vary from one CSFB capable network to another, depending on various factors, similar trends have been observed in various deployments. It should be noted that network configuration related issues can be fixed relatively early by conducting careful audits, while network implementation issues (RAN/CN) can sometimes take longer to address. Fixing optimization related issues depends on the size and nature of the deployment, although it can be addressed on an on-going basis with consistent efforts. Typically, in early deployments, once network configuration and network implementation related issues are addressed, network optimization related issues such as LTE RACH failures, TAU failures, UMTS RRC Connection failures (coverage, congestion, etc.) are commonly the cause of the CSFB call setup failures. In general, by carefully resolving the issues presented, CSFB to UMTS call setup success rate can be brought very close to the legacy UMTS network performance of around 99 percent or better.

CONCLUSIONS

CSFB performance in live commercial networks has been presented in this article. In an adequately optimized LTE Rel8 network, MO/MT CSFB call setup delay is around 1 sec longer than the corresponding legacy CS calls in UMTS. This difference can be reduced to around 0.5 sec with LTE Rel9 enhancements. The call setup delay of an MO/MT CSFB call with an existing data session is expected to have similar delay relative to CSFB calls from LTE without the data session (assuming that the UMTS Core Network prioritizes CS over PS setup procedures). Statistics for the most challenging M2M CSFB case in mobility conditions have also been presented. In the M2M scenario, the MO UE (calling party) perceived delay is double the delay observed for MO calls to land lines, while the MT UE (called party) perceived delay is similar to that of MT to land-line. The longer call setup delay perceived in the MO UE case is because the MO UE NAS procedure is completed only after the MT UE completes the end-to-end CSFB procedure. The M2M CSFB call setup delay with LTE Rel8 in challenging mobility conditions is around 2 sec greater than the legacy UMTS call setup time. However, in a reasonably well optimized Rel9 deployed network, this difference can be reduced to around 1 sec. The time taken for a UE to return from UMTS to LTE after a CSFB call is also discussed and measured to be around 10 sec using inter-RAT reselection and around 0.5 sec using UMTS to LTE redirection. The article also presented a CSFB call setup delay optimization methodology and briefly explored possible optimization options. These methodologies span from network optimization approaches to NAS message handling, and the utilization of Release 9 CSFB features such as UMTS SIB tunneling, ISR and/or UE specific and network changes directed to improve CSFB call setup delay.

CSFB call setup failure analysis has also been discussed in this article. A large variety of CSFB call failure scenarios were explored and we provided details about CSFB call setup failures from Network Optimization, Network Configuration and Network Implementation perspectives. A typical distribution of issues leading to CSFB call setup failures observed in early deployments were presented for reference. In general it has been found that with careful optimization, CSFB to UMTS call setup success rates can be comparable to the performance of legacy UMTS networks.

Typically, in early deployments, once network configuration and network implementation related issues are addressed, network optimization related issues such as LTE RACH failures, TAU failures, UMTS RRC Connection failures are commonly the cause of the CSFB call setup failures.

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