Performance Analyses of Circuit-Switched Fallback

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ABSTRACT

Circuit switched fallback (CSFB) technology is the most commonly used method to support voice services over long-term evolution (LTE) networks today. In this paper, we discuss the performance of LTE CSFB call flow under handover and redirection procedures. The key factors impacting CSFB call setup delay are highlighted. Analysis results show that redirection-based CSFB is more reliable but handover-based CSFB is incredibly fast.

Keywords

LTE, CSFB, handover, redirection, call setup delay, reliability.

1. INTRODUCTION

In telecommunication, long-term evolution (LTE) is a standard for wireless data communication technology that delivers a high data rate, low latency and packet optimized radio access technology [1, 2]. LTE, however, supports only a packet switched (PS) service while a universal mobile telecommunications system radio access network (UTRAN) supports both of a circuit switched (CS) service and a PS service. In order to provide a CS service in a LTE network, circuit switched fallback (CSFB) technology maybe employed in the LTE network [3-6].

The CSFB process enables all CS services, such as the voice service of user equipment (UE), to be handed over to an access network with a relatively low bandwidth, for example, a global system of mobile communications (GSM) or a universal mobile telecommunications system (UMTS), thereby saving bandwidth resources of an operator. CSFB moves a subscriber from the LTE core network to the CS core network through the SGs interface during call setup (Fig. 1).

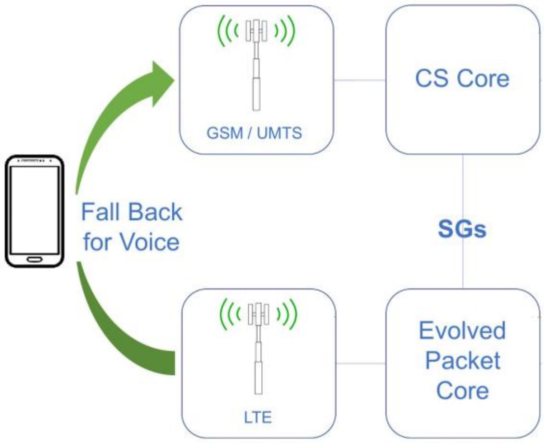

Fig.1. The CSFB architecture

In the existing CSFB technology acquisition of the GSM/UMTS network and the call setup of two procedures can be employed: handover (HO) or redirection (RD) [5-6]. For CSFB RD, UE initiates a call setup from the random access channel. For CSFB HO, UE establishes a call in LTE, and then performs handovers to 3G. The main discriminating factors between the different procedures for CSFB include the complexity of implementation and, more importantly, the call setup delay incurred in using the procedure.

This paper presents a practical performance analysis, including end-to-end assessment of call setup delay under HO and RD procedures of CSFB.

2. ANALYSES

2.1. CSFB Advantages and Disadvantages

Presently, CSFB is the most widely used solution for carrying voice over LTE networks but it is not a true voice over LTE implementation. It involves switching to a 2G or 3G connection before initiating and receiving a circuit switched voice call [5].

To deploy CSFB, there are two options that can be used, as depicted in Fig. 2:

I. Deploy the SGs interface in per mobile switching center (MSC) server pool.

II. Upgrade all existing MSCs to support the SGs interface.

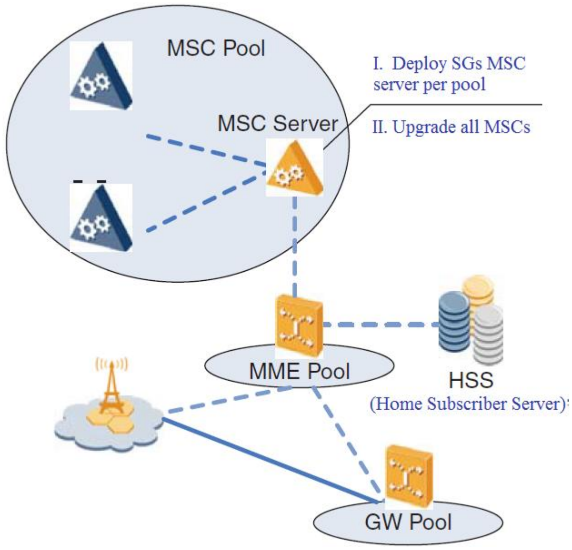

Fig.1. Options for deployment of CSFB

For Solution I, the MSC server and mobility management entity (MME) need to support the SG's interface. Furthermore, it is better to deploy a pair of high capacity MSC servers to provide CSFB service. As for Solution 2, it is mandatory to upgrade all 2G/3G MSC units in the LTE coverage area.

CSFB extends the life of the GSM/UMTS network by enabling it to provide voice services for the LTE network. GSM/UMTS components such as MSCs, CS service platforms, operations support systems, and prepaid/post-paid billing systems are all reused, ensuring a fast and quality rollout of voice services for LTE. No new network elements need to be added, and the required upgrades to the existing network nodes are relatively minor compared to the other options.

Another benefit of CSFB is that it provides complete service and feature transparency with the GSM/UMTS network because the LTE subscriber is redirected to the GSM/UMTS network for all CS services. It also has the ability to carry text messages.

CSFB will be prevalent in the industry for at least next few years but it cannot be a long-term strategy. It has certain disadvantages. CSFB is quite signaling-intensive and fallback may take a while to complete, with estimates placing it at about 0.5 s. In addition, this delay may be increased if the mobile device must conduct measurements to find a suitable GSM/UMTS cell to use and must then perform a location update before being able to originate or answer a call (see Section 2.3). This call setup delay may be enough to be noticed by some LTE subscribers. Sudden data session suspension and call setup delays can lead to poor user experience.

Another disadvantage of CSFB is that, while CSFB supports concurrent voice and data on hand-downs to UMTS and GSM with dual transfer mode (DTM), CSFB does not support concurrent voice and data when handing down to a GSM network without DTM: the PS session is simply suspended.

2.2. RD and HO Issues

In RD procedure, target cell will not be allocating any radio resources upfront. The RD procedure is simply releasing the radio resource control (RRC) connection in LTE and indicating a UTRAN frequency for the UE to be redirected, immediately after the release. RRC connection release is the conventional method of triggering a state transition in LTE from RRC connected to idle mode. The same release message is further utilized for CSFB when the field indicating a RD to UTRAN is signaled. Therefore, the RRC connection release message containing RD information to UTRAN, forces the UE to release the LTE RRC connection followed by immediate RD to the signaled UTRAN's frequency.

The device is then allowed to search for any cell on the signaled UTRAN frequency. If the UE searches the targeted UTRAN frequency and is not able to find a suitable cell, it may try other frequencies, however, adding extra delays to the call setup time. Once a 3G cell is successfully acquired, the device initiates a normal UMTS call setup procedure.

CSFB RD is typically performed without any prior inter-radio access technology (IRAT) measurements on the targeted UTRAN frequency (blind RD). RD without IRAT measurements reduces the call setup delay and depends on the device/network capabilities and the operator's strategy. For example, in certain network topologies where multiple underlying UTRAN frequencies are not being uniformly deployed (or with different UMTS bands), the evolved Node B (eNB) thus instructs the UE to measure the UTRAN cells on the configured frequencies and report their signal strength to the eNB. The eNB later uses the reported UE measurement in selecting the UTRAN frequency to which the UE is redirected. The IRAT cell reporting requires gap measurement and therefore adds extra delays to the setup time.

Another method for CSFB RD is a round-robin RD. IRAT measurements could help to redirect the UE to the less loaded UTRAN frequency, but this is not commonly used due to the delays added to the call setup. When a CSFB is redirected to a highly loaded UTRAN carrier, call setup can fail. Therefore, the UTRAN can follow an RD procedure without IRAT measurement, instead using a round-robin process for each device making a CSFB call. One device is redirected to one of the UTRAN carriers, and the other to the second UTRAN carrier in a round-robin manner. This may offload the UTRAN carriers, expediting the call setup time without compromising the call setup success rate.

CSFB RD has variations with differing call setup speeds:
• Basic, the device follows 3GPP Release 8 procedures and reads all the system information block (SIB) messages prior to accessing the target cell.
• SIB Skipping, the device follows 3GPP release 8, but only reads the mandatory SIB messages, 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 implicitly supported by the UE and the network.
• SI Tunneling, the device can receive SIB information via tunneling from the target radio access network (RAN) via the core network to the source RAN and can be included in the redirection message sent to the device. This can avoid reading any SIBs on the target cell.

In HO procedure, target cell allocates all the required radio resources upfront for the UE to move seamlessly. After the fallback, the device can enter that cell directly in UTRAN connected mode. For the HO decision to be executed stably, the network may have to trigger the device to perform an IRAT HO through gap measurements.

The CSFB procedure starts with the UE sending an extended service request message to the mobility management entity (MME). The service type in this NAS message indicates that an CS call is being initiated, requiring the fallback. The MME notifies the eNB with the UE's context modification request that includes the CS fallback indicator. The eNB then starts the PS HO process to UTRAN. The HO could be blind or non-blind. For non-blind, the eNB configures the target IRAT measurements.

Initially, the UE needs to perform IRAT measurements on the configured UTRAN cells from the LTE connected mode, a process enabling the eNB to execute the IRAT HO. Then, the eNB instructs the UE to execute the HO by sending the mobility from EUTRA command message. The CSFB indicator in this RRC message informs the UE that this procedure is being initiated for CSFB. Once the HO to UTRAN is completed, the UE tunes to the target UTRAN cell, as instructed in the HO message. The UE then initiates the setup of the CS call in UTRAN connected mode, by sending an initial direct transfer message to the radio network controller containing a connection management service request message.

Issues with CSFB can be linked to:
- No coverage on target layer.

If CSFB is completed without measurements then it is possible that the blind RD moves the UE to a layer without coverage. The impact of redirecting towards a layer without coverage is scenario dependent. For example, if the UE is redirected towards UMTS900 but there is only UMTS2100 coverage then the impact is small and the UE selects the UMTS2100 layer with minimal delay. However, if the UE is redirected towards UMTS900 but there is only GSM coverage then the impact is more significant because it takes longer for the UE to move across to the GSM layer.

- Weak coverage on target layer.

If CSFB is completed without measurements then it is possible that the blind RD moves the UE to a weak coverage layer while there are stronger coverage layers available. Redirecting towards a weak coverage layer increases the probability of connection setup failures and connection drops on the target layer.

2.3. Call Setup Delay

Call setup delay is an important metric for CSFB. The call setup delay can be defined as a time interval from the instant the user initiates a connection request until the complete message indicating call disposition is received by the calling terminal [6].

Call setup delays are increased with CS Fallback because the UE first has to make the transition from 4G before call setup can begin on 3G or 2G. The call setup delay is dependent upon the scenario but it is influenced by: whether or not the measurements are completed prior to the transition to 3G or 2G; whether or not the system information is included in the release with redirection message; whether an inter-system handover is completed rather than a release with redirection; whether or not a location area update has to be completed on the target system before call setup can begin.

Testing of call setup times have been provided by CellAdvisor Analyzer in live 3G networks with commercial infrastructure, averaged over a variety of good and poor radio conditions. The testing methodology is described in ETSI TS 101 563 [7].

The test results of the CSBF delay time from LTE to UMTS using different HO and RD (Basic variation) procedures are shown in Table 1. Testing results for various variations of CSFB RD are shown in Table 2. For comparison we would like to mention that in the legacy UMTS systems outgoing average call setup time was 4.2 s, and for incoming call – 2.7 s.

Table 1

Procedures	**Time, s**	
	Outgoing	Incoming
RD without measurements	6.7	5.4
RD with measurements	6.8	5.6
HO without measurements	4.5	3.1
HO without measurements	4.8	3.4

Table 2

Variations	**Time, s**	
	Outgoing	Incoming
Basic	6.7	5.4
SIB Skipping	5.1	3.8
SI Tunneling	4.8	3.4

Analysis results show that on an average, call setup time for CSFB from LTE to UMTS is a few seconds longer than legacy UMTS. However, the results can vary depending on the network configuration and the conditions of the testing. HO CSFB has the lowest outgoing/incoming call setup delay. HO avoids SIB reading and access delays altogether, but requires 0.3 seconds for IRAT measurements while on LTE. The highest call setup delay is incurred with Basic RD variation, because it takes about 2-3 s to read all the SIBs prior to access. SI Tunneling variation has only a slightly higher delay. The measurement increases CSFB call setup time.

2.4. Call Setup Reliability

Call setup reliability or call setup success rate is another important metric for CSFB. Call setup reliability is 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 reliability of CSFB call setup has been tested by 3dB consult using device traces in field testing on live 3G networks.

Our experiments show that the reliability of CSFB calls is still not comparable with legacy CS calls. The root cause is the immature LTE coverage since most of the problems occur when LTE signal strength is low or during the inter-domain switch.

With HO 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. RD CSFB is good in terms of reliability, because it takes the IRAT measurement immediately before attempting access on the identified cell.

3. CONCLUSION

The LTE is the newest mobile technology, designed mainly for high-speed data transfer, having all the chances to replace the existing legacy networks if it can provide voice services similar or even better from the existing. CSFB technology is the most commonly used method to support voice services over LTE networks today. Call setup time for CSFB from LTE to UMTS is a few seconds longer than legacy UMTS, and the reliability of CSFB calls is still not comparable with legacy CS calls. RD CSFB is more reliable but HO CSFB is incredibly fast. The best option with moderate call setup delay and better reliability is RD without measurements with SI Tunneling variation.

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