Abstract: The topic Circuit Switched Fall-Back in theory & practice showcases how network operators in India are now providing 4G LTE network to the users. Most of the operators like Airtel, Idea, Vodafone in India are providing only data services via 4G LTE and are using the legacy networks like 3G and 2G to provide voice services. This topic covers the information of how the switching happens, when a 4G LTE user makes a call or receives one, from 4G LTE to legacy network 3G and how a device turns back to the LTE after a voice session. In addition it also covers few introductory topics on LTE and Voice over LTE overview. Though there are a large number of articles covering theoretical background of the same topic, I, as a new attempt, tried to investigate and produce the information of the stages through which switching really happens.

Key words: CSFB, VoLTE, 4G LTE, 4G in India.

1. Introduction:

Long-Term Evolution (LTE) is a standard for high-speed wireless communication for mobile phones and data terminals. It is based on the Global System for Mobile communications (GSM) and Universal Mobile Telecommunication System (UMTS) network technologies, increasing the capacity and speed using a different radio interface together with core network improvements. The standard is developed by the 3GPP (3rd Generation Partnership Project) and is specified in its Release 8 document series, with minor enhancements described in Release 9. LTE is the upgrade path for carriers with both GSM/UMTS networks. The different LTE frequencies and bands used in different countries will mean that only multi-band phones will be able to use LTE in all countries where it is supported. LTE is commonly marketed as 4G (fourth generation) LTE, but it does not satisfy the technical criteria of a 4G wireless service, as specified in the 3GPP Release 8 and 9 document series, for LTE Advanced. However, due to marketing pressures and the significant advancements, ITU (International Telecommunication Union) later decided that LTE together with the aforementioned technologies can be called 4G technologies.[1]

VoLTE Overview:
Let’s first have a look at different VoLTE techniques.[2][10][11]

SVLTE (Simultaneous Voice and LTE)
User Equipment (UE) here supports both LTE (data) and legacy networks (circuit service) simultaneously. Strength is No interworking is needed between LTE and legacy, it is faster than CSFB, and (Voice + LTE data) is possible. Weakness is High battery consumption (as device uses both services simultaneously). The first to launch this type of VoLTE are CDMA2000 operators in Korea.

CSFB (Circuit Switch Fall-Back)
In CSFB UE falls back to a legacy network for voice service. Strengths are low battery consumption and simple UE structure (cost down). Drawbacks are interworking needed between LTE and legacy, Delay for switching system, and (Voice + LTE data) is impossible. Most of the operators in India and other parts of the world are now implementing CSFB for VoLTE.

VoLTE (Voice over LTE)
It supports Voice call on LTE network and is advantageous as it requires minimum battery energy, simple UE structure (cost down), faster than CSFB, (Voice + LTE data) is possible. Weaknesses are it requires IMS (IP Multimedia Subsystem) system, complex core network, National Wide network coverage. Most of the LTE operators are preparing to launch this technology.

SRVCC (Single Radio Voice Call Continuity):
It is a Technology for transferring VoLTE call to the legacy (3G/2G) CS network while the call is in progress to. It is specified 3GPP Release10.

2. CSFB in Theory

The Circuit Switched Fall-Back is a short term solution for providing voice services to the Fourth generation (4G) Long Term Evaluation (LTE) users by relying on the existing 2G/3G network. Since Voice over LTE in India is being provided...
through legacy networks, when a user camped on 4G makes a voice call the UE sends an Extended Service Request to Mobility Management Entity (MME). On receiving the ESR MME orders e-Node B to redirect the call to the legacy network 2G/3G [3]. The e-Node B to which the User Equipment (UE) is connected to then sends a LTE connection release message to the UE, the UE then tries to establish a connection with an existing legacy network. If connection is successful the voice call is established if not call cannot be established. Now let us look in detail how the things happen.[4][5]

The Preparation Phase

Switching between networks is possible as the device, when turns ON and connects to the LTE, requests the LTE to register its presence in the existing Legacy networks and the registration in the Legacy networks is done on behalf of the mobile equipment by MME. For registration of the mobile equipment the MME has to inform the MSC Location Area Identity (LAI) in which the mobile equipment is currently ‘theoretically’ located. Since this is only a theoretical value, it has to be computed out of the Tracking Area Identity (TAI) which is the current location identity in LTE. In practice this creates a dependency between the TAI and the LAI, i.e, the location areas that describe a group of base stations in 2G/3G and LTE must be configured in a geographically similar way so that fallback works later when required.[4] [5]

The Execution Phase: Mobile-Terminated call

When a Voice call arrives at the MSC for a Subscriber it signals the incoming call via SGs interface to the MME which in its eyes is a 2G or 3G SGSN. From here a notification is sent to the mobile device. From the MSC point of a view this a legacy procedure that already exists. If the mobile is in RRC connected state, the MME can forward the request immediately. If the mobile device wants to take the call it sends, it signals to the MME that it would like to be handed over to the 2G or 3G network on which it could receive the call. The MME then informs e-Node B that the mobile has to be handed over to the 2G or 3G network.

If there is any packet data session going on the time of handover, the standard contains two options on how to proceed: Either the data transfer is suspended or the packet-switched connection is handed over to the 2G or 3G network. This is possible only for UMTS as most 2G networks are not able to handle data and voice connections simultaneously. If the mobile is in RRC Idle state when the voice call is signaled, the MME has to page the mobile device to re-establish radio contact. Once contact has been re-established, it forwards the information about the call. Since there is no ongoing data transfer at this time, no handover of the IP connection is needed as the mobile can re-establish the packet-switched connection by itself once it is in 2G or 3G network.

The e-Node B has the possibility to request 2G or 3G measurements from the device to have a better idea as to which cell to handover the mobile to, or it can do so blindly by sending it information about a preconfigured cell. Once the mobile device is in the 2G or 3G cell, it answers to the initial paging via the legacy cell. In case the MME has made a mistake and the legacy cell is in a location area different from where the device was registered in the preparation phase, the specification also contains a mechanism to first perform a location update and the reroute the waiting voice call inside the same MSC or even to an entirely different MSC. [4][5]

The Execution Phase: Mobile-Originated Call

This procedure is similar to the mobile-terminated call example above. [5]The difference is that no paging is sent by the network, unlike in the case if an incoming call, and there is no paging response to the MSC after the device is in the legacy cell.[4]

3. CSFB in practice

Circuit Switched Fall-Back technique in practice involves a series of events before and after. Let us look at what happens in practice. “All the events shown in this paper are the ones recorded at the base station using a TEMS investigator.”[7]

When the device is switched ON:

![Events](image)

The mobile device gets connected to the predefined network LTE, in case of no LTE coverage the best legacy network available would be connected. For Circuit Switched Fall-Back to happen there should exist a legacy network.

Idle mode:

In this mode the mobile device is only connected to the LTE but no service is being used. As the name says the device continues to be idle until a service is requested or initiated. In Idle mode no radio resource connection exists.
Cell re-selection:
For the mobile device to refresh its connection or to register and establish a connection with the coverage it has to perform Cell re-selection in which it tries to connect to a cell providing the best coverage. It has to be noted that cell re-selection is a continuous process and is necessary to keep the mobile device connected to the best signal transmitting base station.

RRC connection request:
Since for any type of communication to happen a path is to be established between the two points, which in this case are mobile device and base station, RRC connection serves the purpose it acts like a path between mobile device and e-Node B enabling the device to have data or voice information to be able to receive on the path. Hence an RRC connection request is made to the e-Node B.

RRC connection establishment:
If the RRC connection request response from the e-Node B is positive RRC connection is established or else another attempt is made by making a request again until connection is established.

Dedicated mode:
Once the RRC connection request is registered and connection is established mobile device switches to Dedicated mode in which a radio resource connection is established between the mobile device and e-Node B. In Dedicated mode the mobile device is said to be assigned a traffic channel.

PS Attach:
As LTE is a packet switched network, the mobile device hangs on to a PS network.[7]

RA update:
The mobile device informs its current position to the e-Node B, since it is connected to the network after switching ON. This event also occurs when the mobile device enters a different cell or new cell.

Whenever an LTE user makes a call there would be a series of events that happen and get registered at the base station which in this case is a e-Node B.[7]

CSFB call attempt:
Since LTE network operators here in India use Circuit Switched Fall-Back to provide voice services to the users, call attempt made by an LTE user is referred to as CSFB call attempt. From here the process of switching from LTE network to legacy network starts.

Call setup:
A request is made by the device for call setup to the LTE.

eUTRAN RRC connection release:
Since operators provide only data services on LTE for the originating call to be served, already established RRC connection between eUTRAN and the mobile device is released allowing it to connect to the legacy network later.

Idle mode:
After a call is made, although UMTS allows simultaneous voice and data sessions but it is to be noted that simultaneous sessions during call setup cannot be served, the device is forced to Idle mode. Once the call is established simultaneous voice and data sessions are allowed and any previous data sessions that were ongoing during call setup are re-established.

Cell re-selection:
With the RRC connection release from LTE network now mobile device starts finding a new cell and starts Cell re-selection in existing legacy network. For the mobile device to refresh its connection or to register and establish a connection with the coverage it has to perform Cell re-selection in which it tries to connect to a cell providing the best coverage. It has to be noted that cell re-selection is a continuous process and is necessary to keep the mobile device connected to the best signal transmitting base station.
UTRAN RRC connection request:
Since for any type of communication to happen a path is to be established between the two points, which in this case are mobile device and base station, RRC connection serves the purpose it acts like a path between mobile device and Node B enabling the device to have data or voice information to be able to receive on the path. Hence an RRC connection request is made to the Node B.

UTRAN RRC connection establishment:
If the RRC connection request response from the Node B is positive RRC connection is established or else another attempt is made by making a request again until connection is established.

Dedicated mode:
Once RRC connection request is registered and connection is established mobile device switches to Dedicated mode in which a radio resource connection is established between the mobile device and Node B. In Dedicated mode the mobile device is said to be assigned a traffic channel.

Call attempt:
With WCDMA resource channel assigned the device now makes Call attempt.

Measurement report:
The user equipment has to send a report of its transmission power, signal quality and power it received. Since there is a change of the network that is serving the mobile device some changes are required in transmission powers to have a good QOS and effective communication.

Routing area update:
As now the mobile device is being served by a legacy network, which is a 3G network in this case, the device has to again inform the Node B its current location for further processes like handovers to be successful. The device using the routing area information it informed the LTE informs its Location area to the serving legacy network.

CSFB Call setup:
Call setup process after the device is switched back to a legacy network.

CSFB call established:
If the call setup is successful and the call is answered by the called subscriber the call made is established.

Measurement Reports:
While the call is being spoken user equipment keeps sending Measurement reports frequently for efficient communication.

How does the UE return to LTE once call ends?
Let us now look at the events that occur as a mobile device returns to LTE after voice session ends. During this transition alike during the call setup no data sessions can take place. [7]

RRC connection release:
Very soon the call ends RRC connection established for voice session to carry on is released by the Node B (UTRAN).

Idle mode:
For a shorter duration device sets into the idle mode as it now needs a few milli seconds of time to switch back.

Cell re-selection to eUTRAN:
Since LTE is the predefined network the mobile device automatically falls back to it as soon as voice session ends and as a step in that direction it first performs Cell re-selection and tries to connect to the cell providing the best LTE signal around. For the mobile device to refresh its connection or to register and establish a connection with the coverage it has to perform Cell re-selection in which it tries to connect to a cell providing the best coverage. It has to be noted that cell re-selection is a continuous process and is necessary to keep the mobile device connected to the best signal transmitting base station.


**eUTRAN RRC connection request:**  
Since for any type of communication to happen a path is to be established between the two points, which in this case are mobile device and base station, RRC connection serves the purpose it acts like a path between mobile device and e-Node B enabling the device to have data or voice information to be able to receive on the path. Hence an RRC connection request is made to the e-Node B.

**eUTRAN RRC connection establishment:**  
If the RRC connection request response from the e-Node B is positive RRC connection is established or else another attempt is made by making a request again until connection is established. Once the connection is established the mobile device enters Dedicated mode.

**Dedicated mode:**  
Once RRC connection request is registered and connection is established mobile device switches to Dedicated mode in which a radio resource connection is established between the mobile device and e-Node B. In Dedicated mode the mobile device is said to be assigned a traffic channel.

**When a call is terminated:**  
A terminated call is an incoming call to a user.\[7\]

**Idle mode:**  
Since the user is now not using any of the services the device is in idle mode.

**Dedicated mode:**  
As the call to the user arrives at the MSC it asks e-Node B to hand over the mobile device to a legacy network. As soon as the handover happens, the device is assigned a radio connection and it enters the Dedicated mode.

**CSFB call attempt:**  
The mobile device called is informed about the call.

**RRC connection establishment:**  
If the user accepts the call incoming, then RRC connection is established by the Node B.

**Call setup:**  
Once the RRC connection is established the call is setup.

**Measurement reports:**  
For effective communication and satisfactory QOS the mobile device keeps sending measurement reports of transmitted and received powers.

**Location Area update:**  
For the handovers to be successful the mobile keeps updating its location area information to the Node B as it moves.

**4. Note:**

When there is a requirement of a Handover “Radio Link Addition” event happens in SHO case. In it an extra radio resource connection is reserved from a different Node B which is one of the active set of base stations that are serving the mobile at that moment.

**5. Conclusion:**

The downside of this solution is introduction of delay due to the procedure execution. This delay varies based on the Mobile Originating call, in this case the delay is around 4.97 seconds, or the Mobile Terminating call, in this case the delay is around 2.84 seconds. Furthermore Circuit Switched Fall-Back requires introduction of new interfaces between LTE and legacy 2G or 3G network especially between MSC- MME/SGSN and S-GW-SGSN in order to perform combined registration and paging process. If a GSM network is used for the voice call, no packet-switched services can be used during the conversation as most GSM networks do not support the dual transfer mode (DTM) functionality for simultaneous voice and data transmission. In addition if the DTM is supported, data rates will be very low compared to those in the LTE network.

If a UMTS network is used for a voice call, it is optionally possible to move on ongoing data session from LTE to UMTS during the fallback procedure. However this takes additional time.

Footnote is the benefit of using the CSFB technology is that the operators can use their existing 2G or 3G networks infrastructure for providing voice calls.[8][9]

**6. Abbreviations and Definitions**

Long Term evolution: is a standard for high-speed wireless communications for mobile phones and data terminals and is commercially marketed as 4G LTE.

2G/3G/4G: generations in mobile communication.
VoLTE: is an acronym for Voice over LTE, which is based on the IP Multimedia Subsystem (IMS) network.

User Equipment (UE): is any device used directly by an end-user to communicate. It can be a handheld telephone, a laptop computer equipped with a mobile broadband adapter, or any other device.

Mobility Management Entity (MME): plays an important role in LTE architecture and is the main signaling node in the Core Network.

e-Node B (evolved Node B): is the evolution of the element Node B in UMTS. It is the hardware that is connected to the mobile phone network that communicates directly wirelessly with mobile handsets (UEs), like a base transceiver station (BTS) in GSM networks.

Mobile Switching Center (MSC): is the primary service delivery node for GSM/CDMA, responsible for routing voice calls and SMS as well as other services (such as conference calls, FAX and circuit switched data).

Serving GPRS Support Node (SGSN): is a main component of the GPRS network, which handles all packet switched data within the network, e.g. the mobility management and authentication of the users. The SGSN performs the same functions as the MSC for voice traffic.

Radio Resource Control (RRC): is a protocol used in UMTS and LTE on the Air interface. It handles the control plane signaling between the User Equipment (UE) and the Radio Access Network (UTRAN or E-UTRAN).

Universal Mobile Telecommunications System (UMTS): is a third generation mobile cellular system for networks based on the GSM standard.

Internet Protocol (IP): is a set of rules for sending data across a network.

Cell: is the geographical area covered by a cellular telephone transmitter.

Base Station: is a fixed point of communication for customer cellular phones on a carrier network.

Node B: is a term used in UMTS networks equivalent to the BTS (base transceiver station) in GSM.

Quality of service (QOS): is the overall performance of a telephony or computer network, particularly the performance seen by the users of the network.

Handover: refers to the process of transferring an ongoing call or data session from one channel connected to the core network to another channel.

Soft handover (SHO): refers to a feature used by the CDMA and W-CDMA standards, where a cell phone is simultaneously connected to two or more cells (or cell sectors) during a call.

SGW (Serving Gateway): forwards and routes packets to and from the e-Node B and packet data network gateway (PGW).

PGW (Packet Data Network Gateway): The PDN Gateway provides connectivity from the UE to external packet data networks by being the point of exit and entry of traffic for the UE.

References:

[7] TEMS Investigator