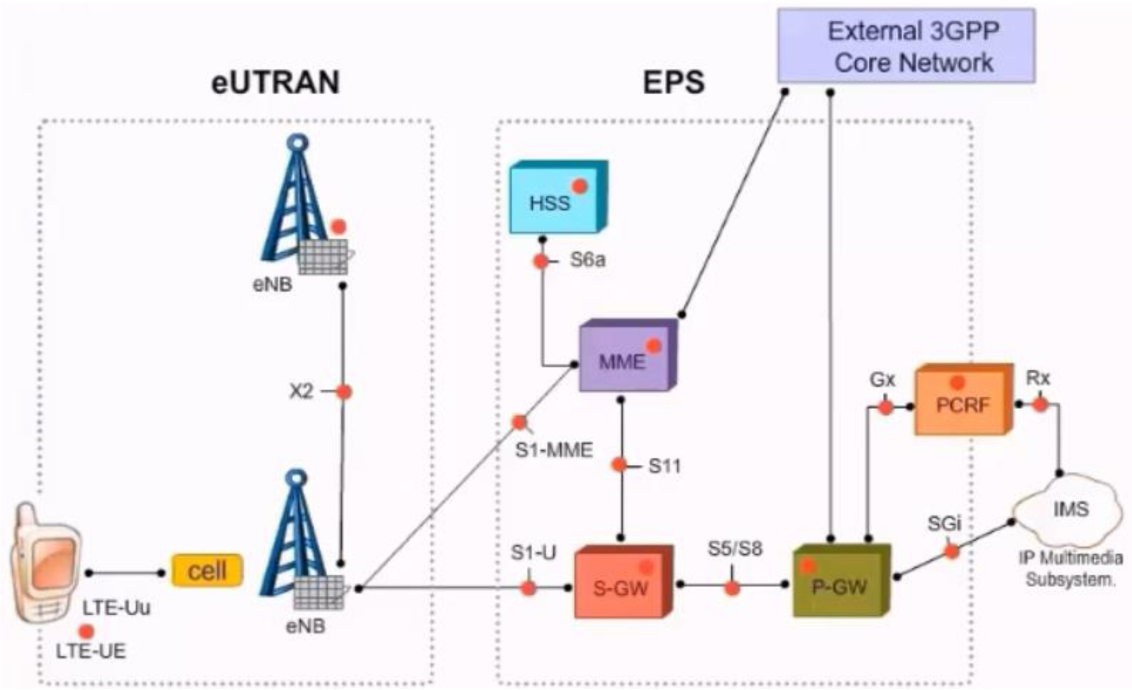
Módulo 1

LTE x 3G x 2G

Feature	LTE Network	3G Network	2G Network
Handset	UE	UE	MS
Radio Element(s)	e Node B	Node B + RNC	BTS + BSC
Circuit Core Elements	None	MSS + MGW	MSC or MSS + MGW
Packet Core Elements	MME + S-GW	SGSN + GGSN	SGSN + GGSN
Subscriber Database	HSS	HLR + VLR or HSS	HLR + VLR

Elementos da rede LTE



LTE-UE é usado por um usuário final para se comunicar com uma rede LTE. Pode ser um celular portátil ou um dongle USB, ou qualquer equipamento conectado ao eNode B mais próximo. A interface de rádio entre o UE e o eNodeB é chamado de Uu. UE é responsável por:

- Gerência de Mobilidade;
- Controle de chamada;
- Gerência de sessão;

- Gerência de identidade;

Interface X2

Principais funções:

- Conexões diretas entre eNB;
- Coordenação de *Handoff* sem envolvimento de *Evolved Packet Core* (EPC);
- Balanceamento de carga.

Evolved Node B (eNB)

- Funções da gerência de recursos de rádio (RRM – *Radio Resource Management*):
  - Controle da configuração de parâmetros de Rádio;
  - Controle de Admissão de Rádio;
  - Controle de Mobilidade de Conexão;
  - Alocação de recursos dinâmicos para *uplink* e *downlink*.
- Compressão do cabeçalho IP e encriptação dos dados do usuário;
- Seleção de MME ao UE;
- Medidas para mobilidade;
- Agendamento e transmissão de paging e broadcast.

Home Subscriber Server (HSS)

- Base de dados permanente do assinante;
- Armazena dados de mobilidade e serviço de cada assinante;
- Contém o Centro de Autenticação;

Interface S6-a

Principais funções:

- Dados de comunicação e autenticação;
- Exclusão e atualização de dados do assinante.

Mobility Management Entity (MME)

- Plano de controle dos elementos da rede em EPC;
- Usado para:
  - Autenticação;
  - Proteção de integridade;
  - Atualização de área de rasteamento;
  - Incluir e excluir assinante;
  - Controle de segurança de rádio;
  - Distribuição de mensagens paging para eNB;
  - Sinalização de nó de controle roaming;

S1-MME

Interface entre S1 e MME

Funcionalidade:

- Auxilia no controle entre S1 e MME.

S11

Principal função:

- Transfere o nível do parâmetro QoS para MME.

S1-U

Funcionalidade:

- Configuração de parâmetros SAE (*System Architecture Evolution*) de plano de tunelamento do usuário.
- Comutação inter eNB durante *handoff*.

Serving SAE Gateway

- Ponto de ancoragem de mobilidade local: Comutação do caminho do plano do usuário para um novo eNB em caso de *handoff*;
- Ancoragem de mobilidade para mobilidade inter-3GPP (padronização);
- Rota de pacotes entre eNB, P-GW e SGSN (*Serving Gateway Support Node*);
- Suporte à intercepção legal.

S5/S8

Transporta os pacotes das configurações de parâmetros EPS entre um P-GW e um S-GW.

Packet Data Network (PDN) SAE Gateway (P-GW)

- Mobilidade entre systemas 3GPP e não 3GPP;
- Aplicação de políticas (PCEF – Policy Enforcement);
- Filtragem de pacotes baseada por usuário;
- Suporte à carregamento e intercepção legal;
- Rota de pacotes entre Serving GW e redes de dados externas;
- Triagem de pacotes (funcionalidade de *firewall*).

SGI

Faz conectividade entre PDN Gateway e IMS (*Internet Protocol Multimedia Subsystem*).

GX

Faz conectividade entre PDN Gateway e PCRF.

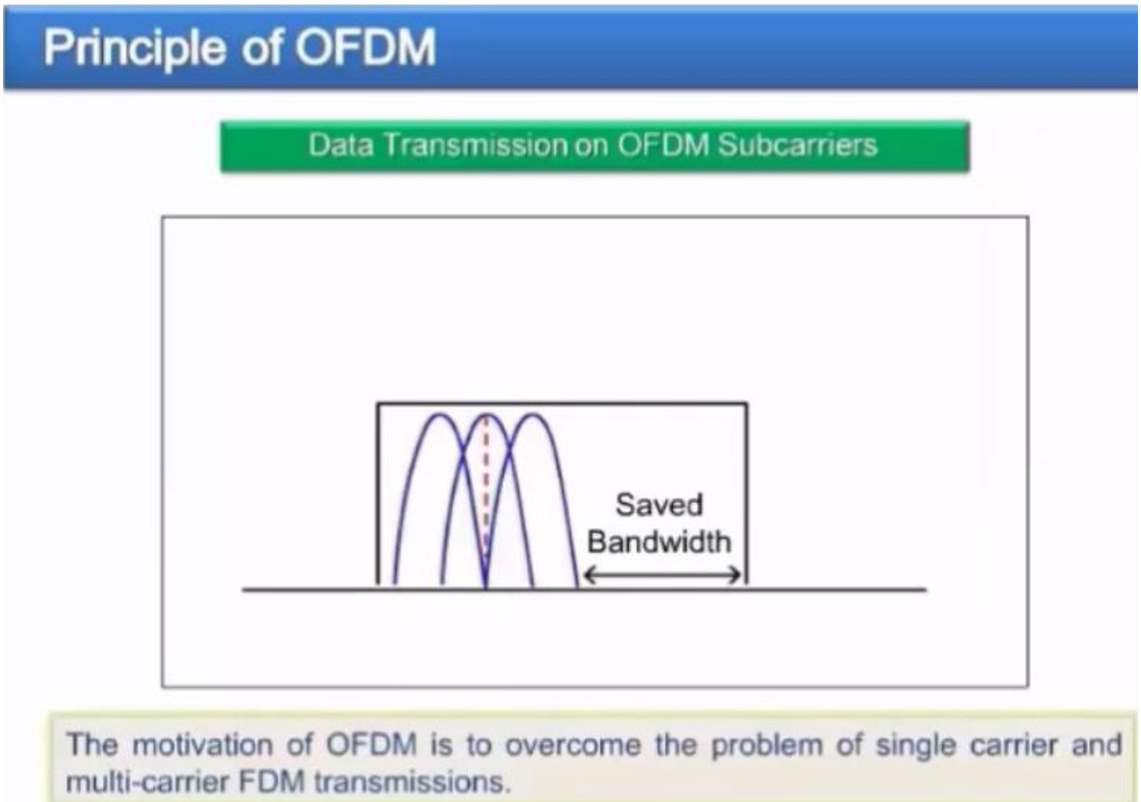
Policy and Charging Rule Function (PCRF)

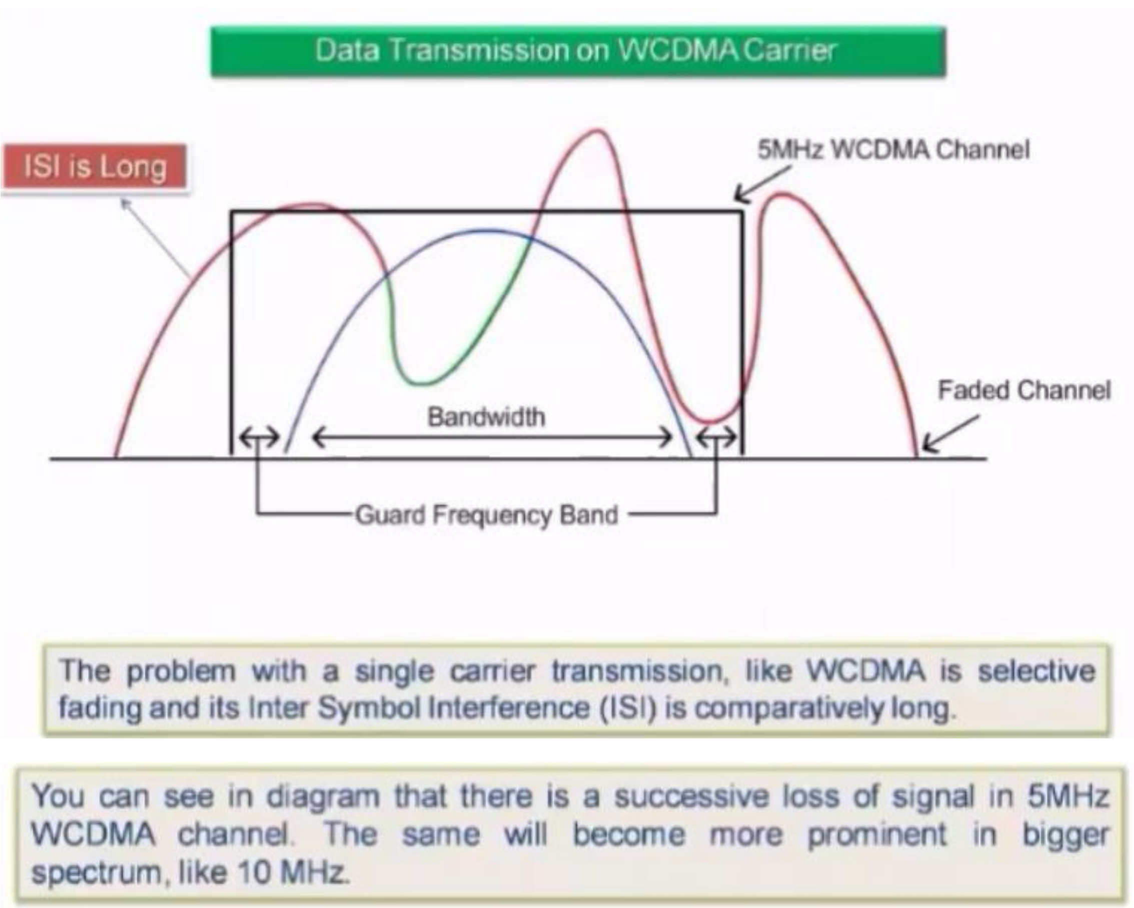
- Política baseada em fluxo e controle de carregamento de decisões;
- *Policy and Charging Enforcement Function* (PCEF) força controle de QoS em nome de PCRF;
- *Bearer Binding and Event Reposting Function* (BBERF) vincula o fluxo aos parâmetros de configuração IP e reporta eventos;
- *Subscriber Profile Repository* (SPR) armazena os perfis dos assinantes;
- *Application Function* (AF) representa aplicações que requerem política dinâmica e controle de QoS.

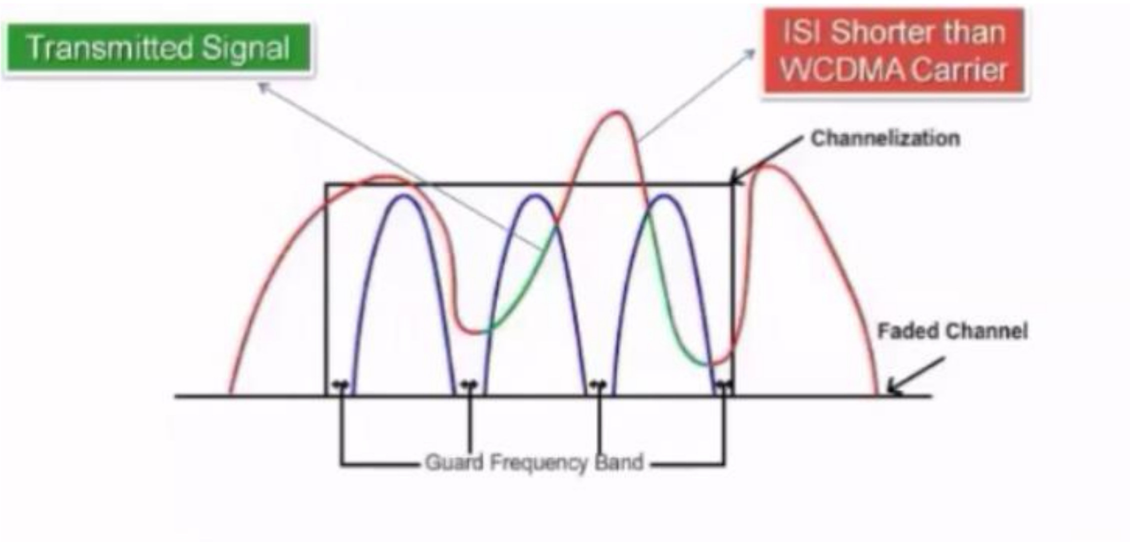
RX

Faz conectividade entre PCRF e IMS.

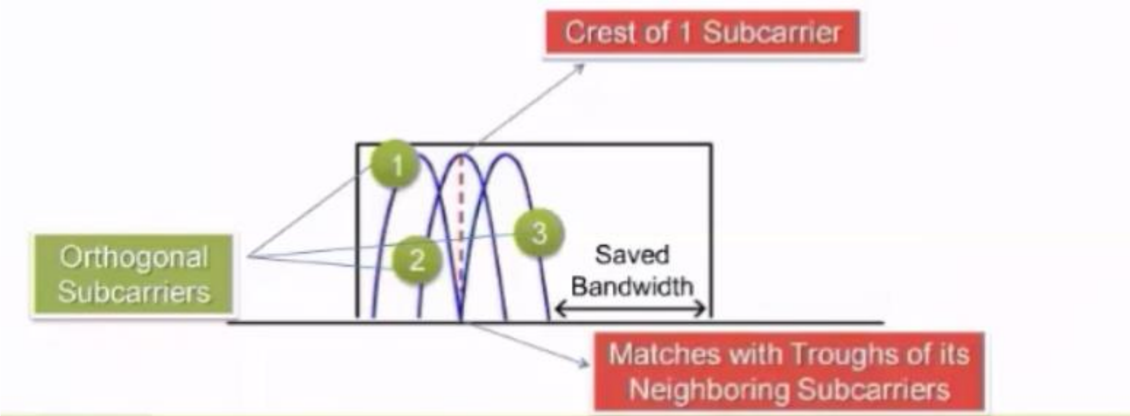
Princípio de OFDM (*Orthogonal frequency-division multiplexing*)



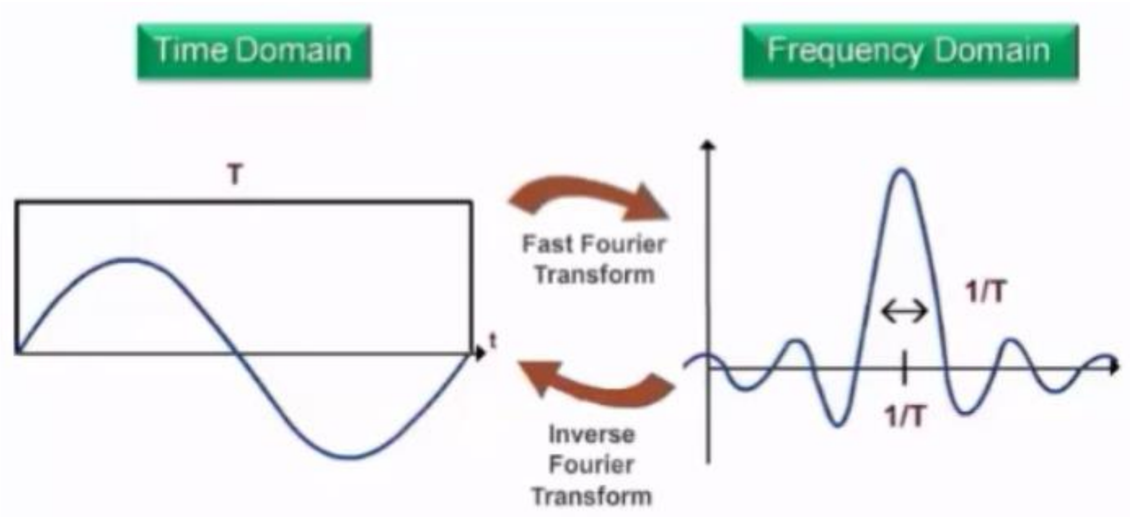




Multi-carrier FDM transmission fading is flat and ISI is shorter but both of them require guard band, which reduces the spectrum efficiency.



To fight the problem of selective fading, ISI, and to utilize the available spectrum efficiently, OFDM technique is used, which spreads the information on number of sub carriers (which are orthogonal to each other) in order to create very narrow band channels. You can see in diagram that the crest of 1 subcarrier matches with troughs of its neighboring subcarriers.



The representation of a subcarrier is done on time domain and frequency domain:

- **Time domain:** It represents how long the symbol lasts on air, and this is inversely proportional to width of the subcarrier.

- **Frequency domain:** It represents the frequency center of the carrier.

To translate a continuous signal from FD to TD, Inverse Fourier Transform (IFT) is used, and for the reverse activity FFT (Fast Fourier Transform) is used.

- **Basic Idea Summary of OFDM:**

  - The channels are divided into multiple subcarriers, to reduce the effect of selective fading and ISI.

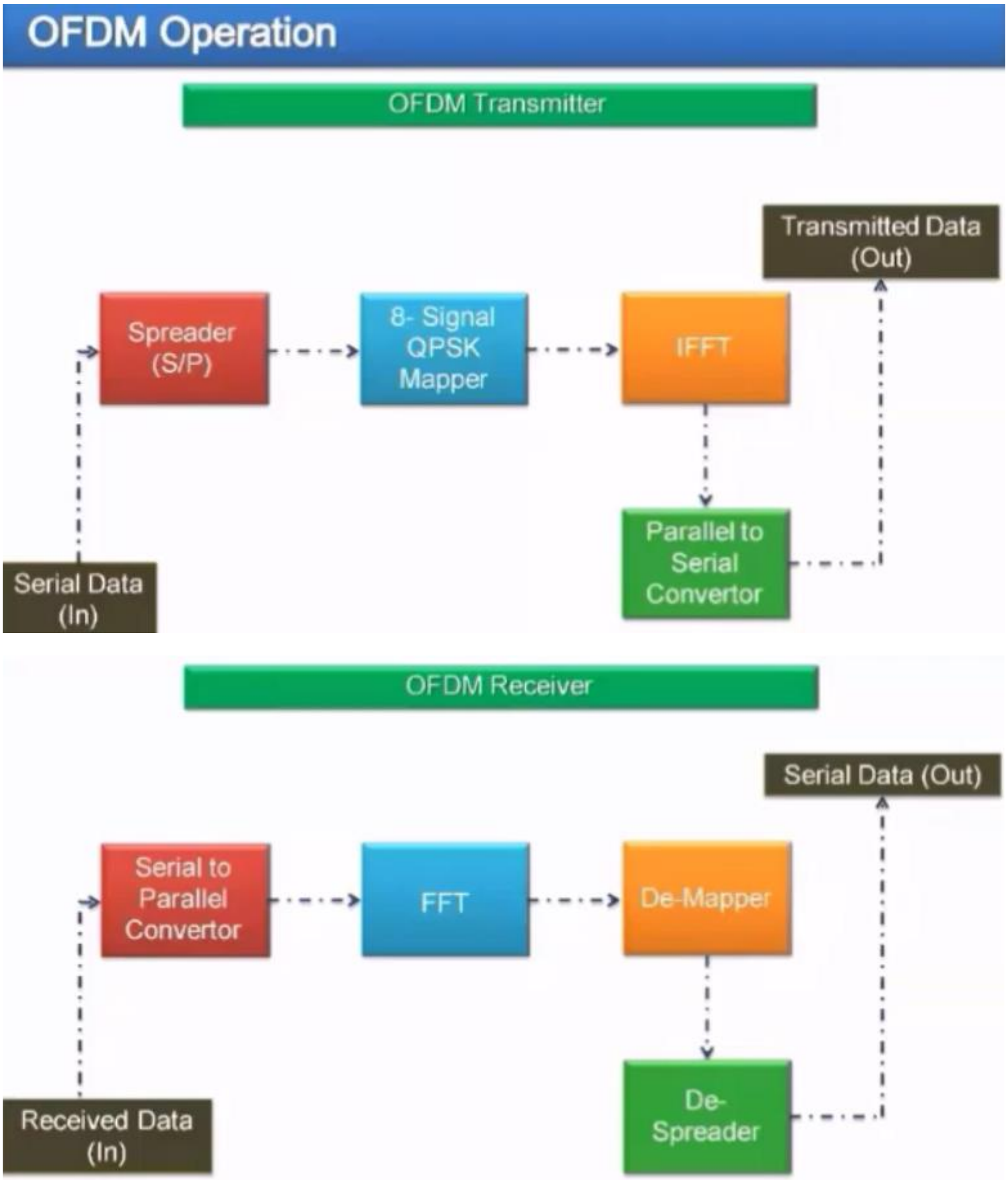
  - The throughput will be sum of the data rates of each individual subcarriers, while the power is distributed to all subcarriers.

  - FFT (Fast Fourier Transform) is used to create the orthogonal subcarriers. The number of subcarriers is determined by the FFT size (by the bandwidth).

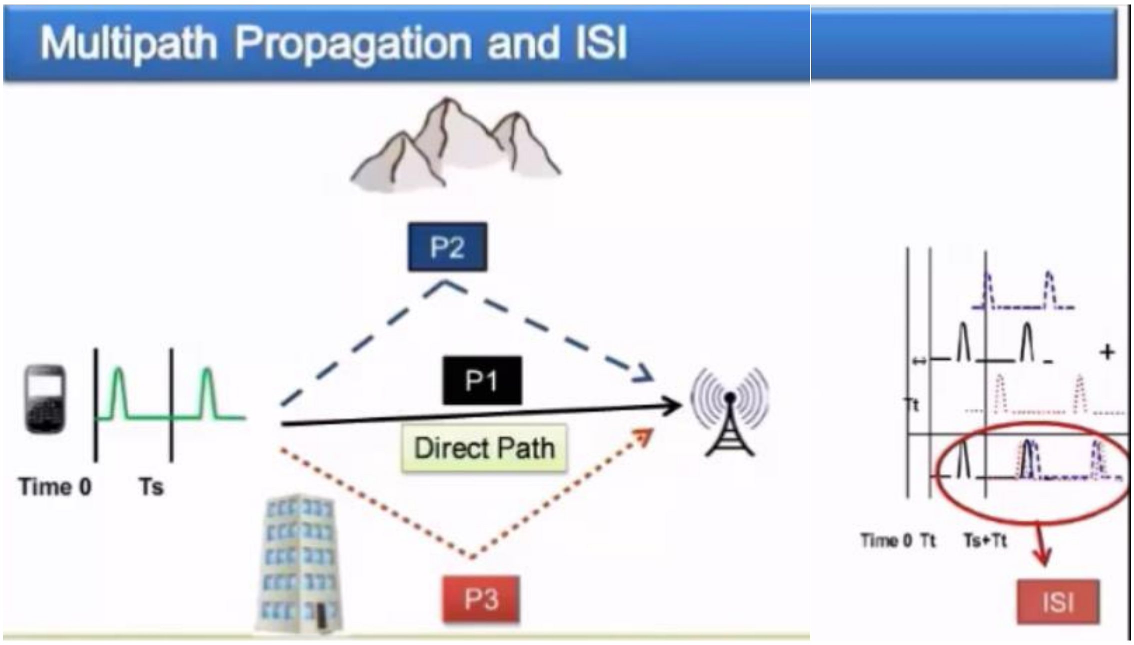
  - In LTE, these subcarriers are separated, by15kHz.

  - To keep high data rate, very short symbol duration is used in OFDM.

- **The OFDM still has to fight with the problem of Multipath propagation.**



OFDM Operation
OFDM Transmitter
Transmitted Data (Out)
Spreader (S/P)
8- Signal QPSK Mapper
IFFT
Parallel to Serial Convertor
Serial Data (In)
OFDM Receiver
Serial Data (Out)
Serial to Parallel Convertor
FFT
De-Mapper
De-Spreader
Received Data (In)

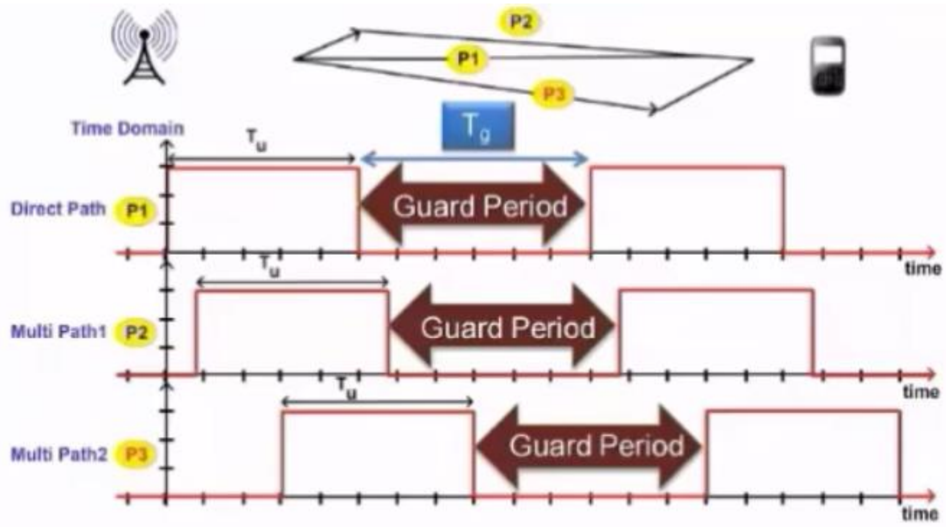


In multi path propagation, signal takes two or more different paths, and reaches receiver with the delayed version of the same signal.

As the signal goes through a direct path and also, an alternate path, the final signal after convergence creates a problem of Inter Symbol Interference.

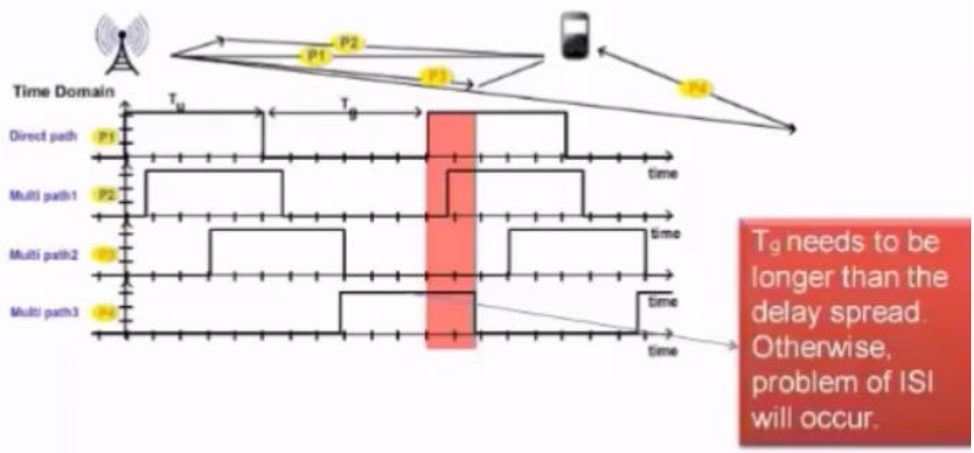
This multipath signal, is due to atmospheric ducting, ionospheric reflection and refraction. Also, reflection from water bodies and terrestrial objects, such as mountains and buildings.

Please take a note that one of the main objective, while designing the 3GPP LTE radio was, to simplify the design of LTE receivers, which can fight the problem of ISI, due to multipath propagation, without keeping much load of DSP processing and capacity.



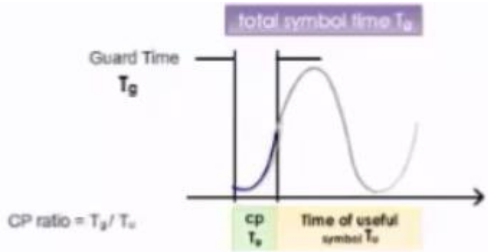
Introduce a Guard Period (T_g) after the pulse. T_g needs to be long enough, so as to capture all the delayed multipath signals. In order to use T_g i.e. no transmission period, Cyclic Prefix is transmitted.

Cyclic Prefix



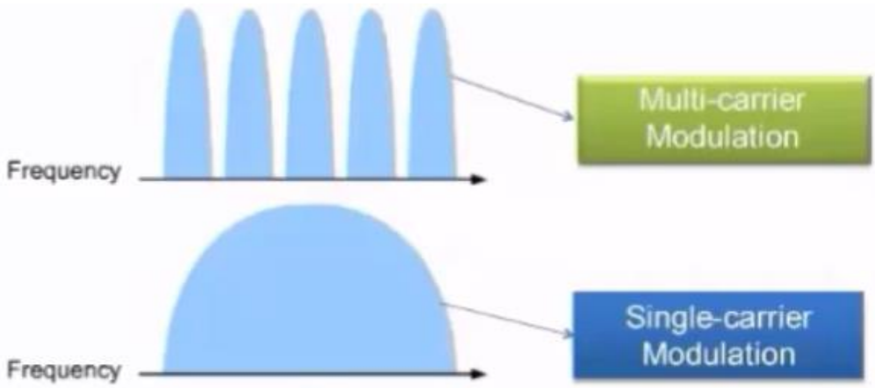
In-spite of not sending any information on the guard time, a cyclic prefix is transmitted.

Cyclic Prefix - Types



LTE has used two types of cyclic prefix, one for normal cell having the duration of 4.67µs and is used for small cells with short multipath delay profile and other one is called as extended CP which is designed for use with large cells with long delay profiles having a CP duration of 16.67µs.

Multi-Carrier Modulation

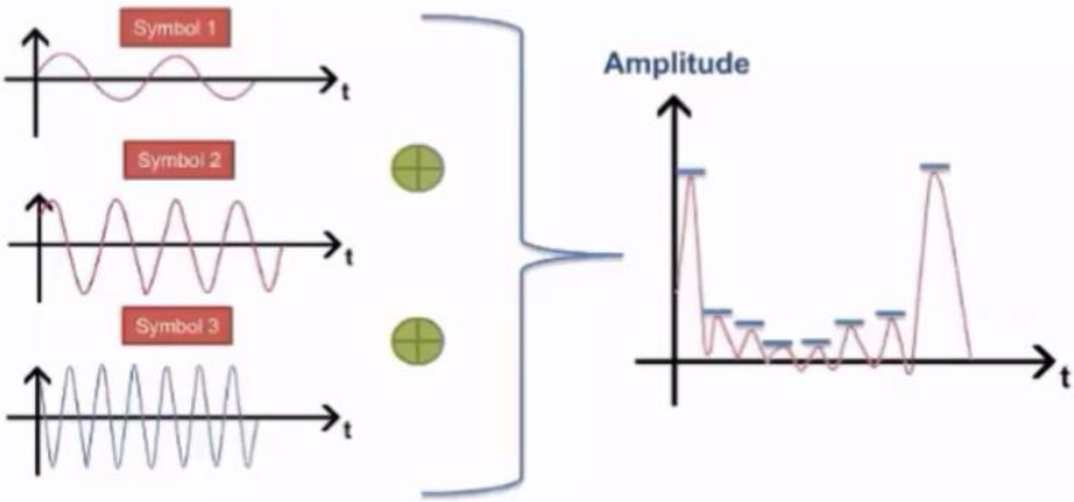


Multi-Carrier modulation is one of the technique in OFDM where the multiple carriers are transmitted and modulated in parallel. This increases the bit-rate, keeping the advantages of smaller carrier size and reduced Flat fading, as compared with the coherent bandwidth of wireless channel and it has reduced inter-symbol interference handling via cyclic prefix or cyclic suffix.

OFDMA Symbol

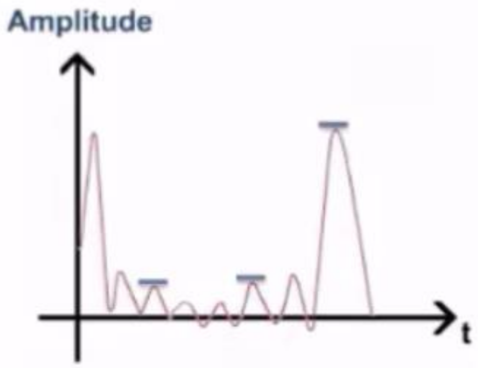
- OFDMA is an extension of the OFDM technique, to allow multiple user transmissions. It is used in other systems, like Wi-Fi, DVB and WiMAX.
- In this technique, the available subcarriers are distributed to different users.
- The cyclic prefix added in the symbols, add an overhead, into the utilization of a subcarrier.
- OFDMA symbol is the time period occupied by the modulation symbols, on all subcarriers. It represents all the data being transferred, in parallel at a point of time.
- OFDM symbol duration, including CP, is approximately 71.4 µs (*), which is long enough, when compared with 3.69 µs, for GSM and 0.26µs, for WCDMA.
- Time period for symbol or user data, T_u, without considering CP, is 66.67µs (1/15kHz).

Peak-to-Average Power Ratio in OFDMA



The overall transmission power of all subcarriers is the sum of all subcarriers combined together. Since the number of subcarriers are huge, for example, 300 for 5MHz channel, the Peak to Average Power (PAPR) has very large range values.

Peak-to-Average Power Ratio in OFDMA



When the peaks have larger values, this PAPR will have greater range of different power levels.

To handle this situation, we need Power Amplifiers which can be managed on a enodeB, but not in a UE because it will require higher amount of UE battery power, which will be very expensive to handle on a UE.

Pros:

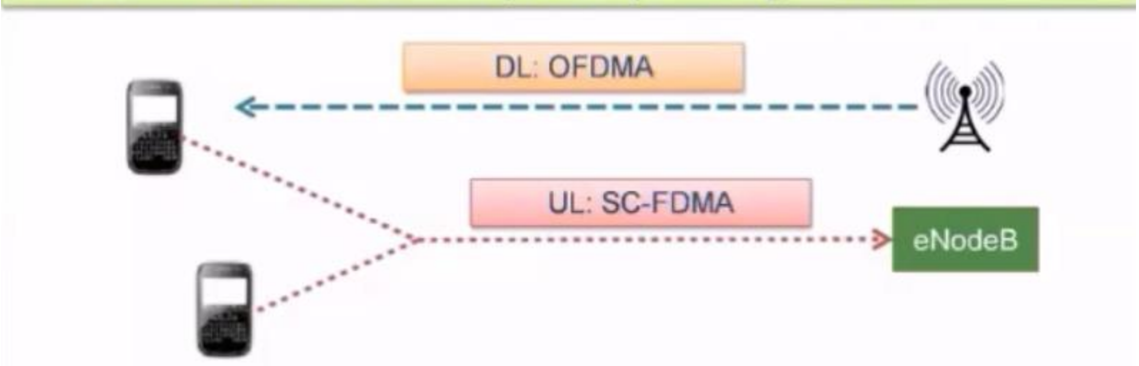
- High spectral efficiency, and little interference (ISI), between channels
- Robust in multi-path environments, thanks to Cyclic Prefix
- Favourable to MIMO techniques
- Using spatial multiplexing, OFDMA offers high potential for throughput gain
- Low complexity, due to efficient implementation of FFT module
- Less sensitive to time synchronization errors

Cons:

- Severe High PAPR (Peak to Average Power Ratio)
- Small subcarrier spacing makes it more sensitive to frequency offset (subcarriers may interfere each others)

SC-FDMA Signal & Limitations of Single Carrier

Single Carrier Frequency Domain Multiple Access (SC-FDMA) or DFT-Spread OFDMA (DFT-SOFDMA) technique is chosen by 3GPP for uplink multiple access in LTE over OFDMA to facilitate efficient power amplifier design in the UE.

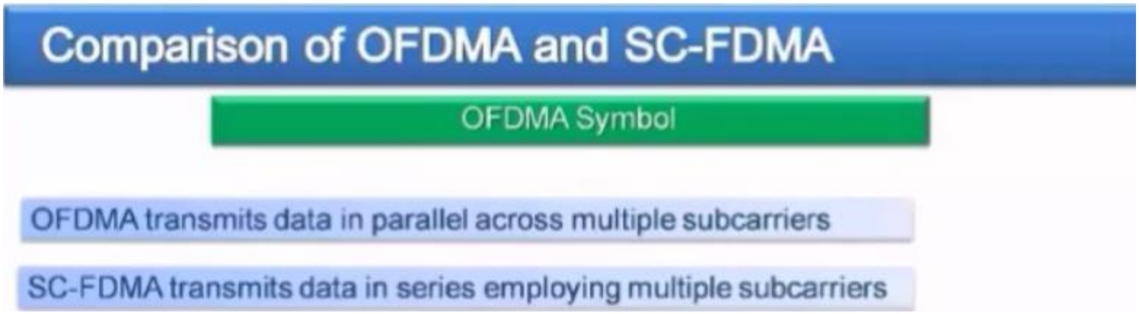


PAR?

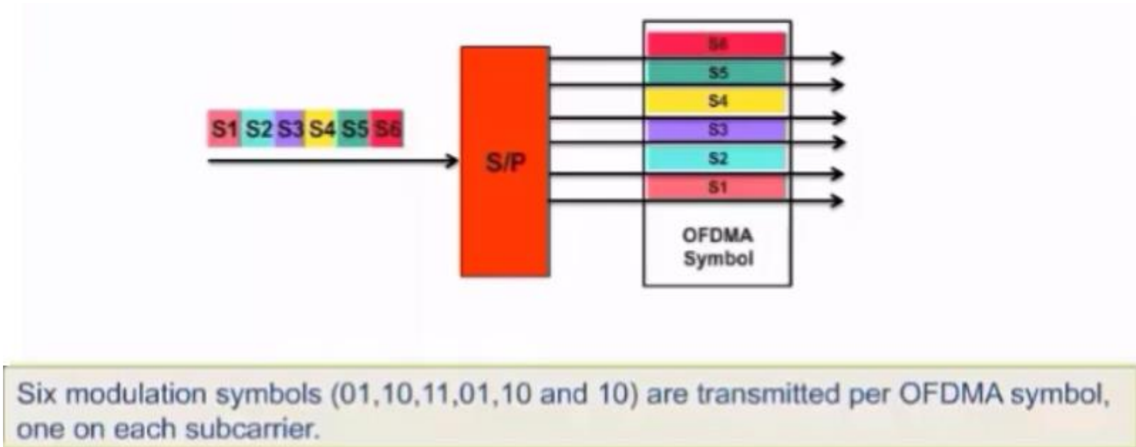
It is a special variant of OFDM that reduces the PAPR. It Combines the PAR of single-carrier system, with the multipath resistance and flexible subcarrier frequency allocation, offered by OFDM.

The DFT spreading of modulation symbols, reduce the PAPR, between 6...9 dB, compared to OFDMA.

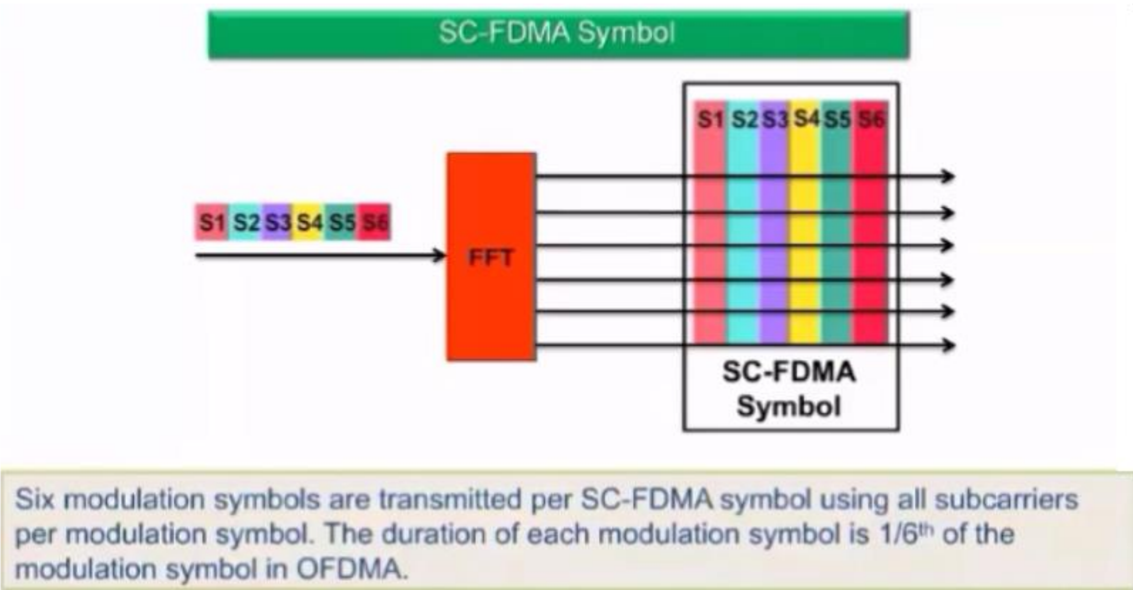
A reduction in PAPR, means lower RF hardware requirements, (power amplifier) which will help in saving the UE battery life, to a great extent.



Exemplo



Exemplo:



OFDMA Parameters

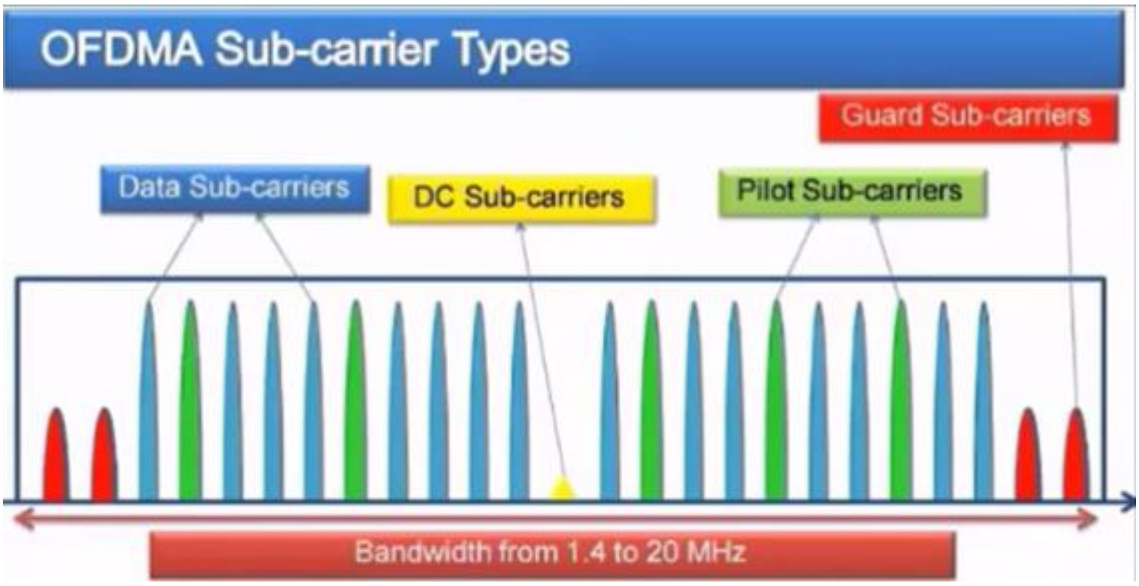
1. **Scalable Bandwidth:** LTE has scalable bandwidth option of 1.4, 3, 5, 10, 15 and 20 MHz. Higher BW means higher peak data rate, bigger capacity and low physical layer overheads.
2. **Sub carrier spacing:** (Δf = 15 KHz) for both OFDMA and SC-FDMA and the symbol time, Tsymbol = 1/ Δf = 66.7 µs.
3. **The number of Subcarrier Nc:** Nc x Δf = BW. LTE use 10% channel BW as guard band (to avoid out band emissions). If BW = 20MHz -> Transmission BW = 20-2 = 18 MHz. Therefore, no. of sub carriers, Nc = 18MHz/15KHz = 1200 subcarriers.
4. **FFT (Fast Fourier Transform) size Nfft:** It has to be a power of 2 to speed up the fft operations. Since the BW = 20 MHz has 1200 sub-carriers, which is not a power of 2, so the number having next power of 2 is 2048, which is the Nfft. The rest 2048-1200 = 848 are padded with zeros.
5. **Sampling frequency Fs:** Fs = Nfft x Δf. For BW 20 MHz, Fs = 2048 x 15KHz = 30.72 MHz, equivalent to 3.84*8 (sampling rate is a multiple of chip rate 3.84 of UMTS and HSPA to keep the same clock timings between the two technologies).

OFDMA Parameters: Table

OFDMA Parameters

Spectrum Allocation	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Sub-carrier Spacing	15 KHz					
Sampling Frequency	1.92 MHz (1/2 x 3.84)	3.84 MHz	7.68 MHz (2 x 3.84)	15.36 MHz (4 x 3.84)	23.04 MHz (6 x 3.84)	30.72 MHz (8 x 3.84)
Number of Sub-carriers FFT Size	128	256	512	1024	1536	2048
Number of Useful Sub-carriers	72 (73)	180 (181)	300 (301)	600 (601)	900 (901)	1200 (1201)

The most frequently used, is spectrum allocation of 5 MHz.



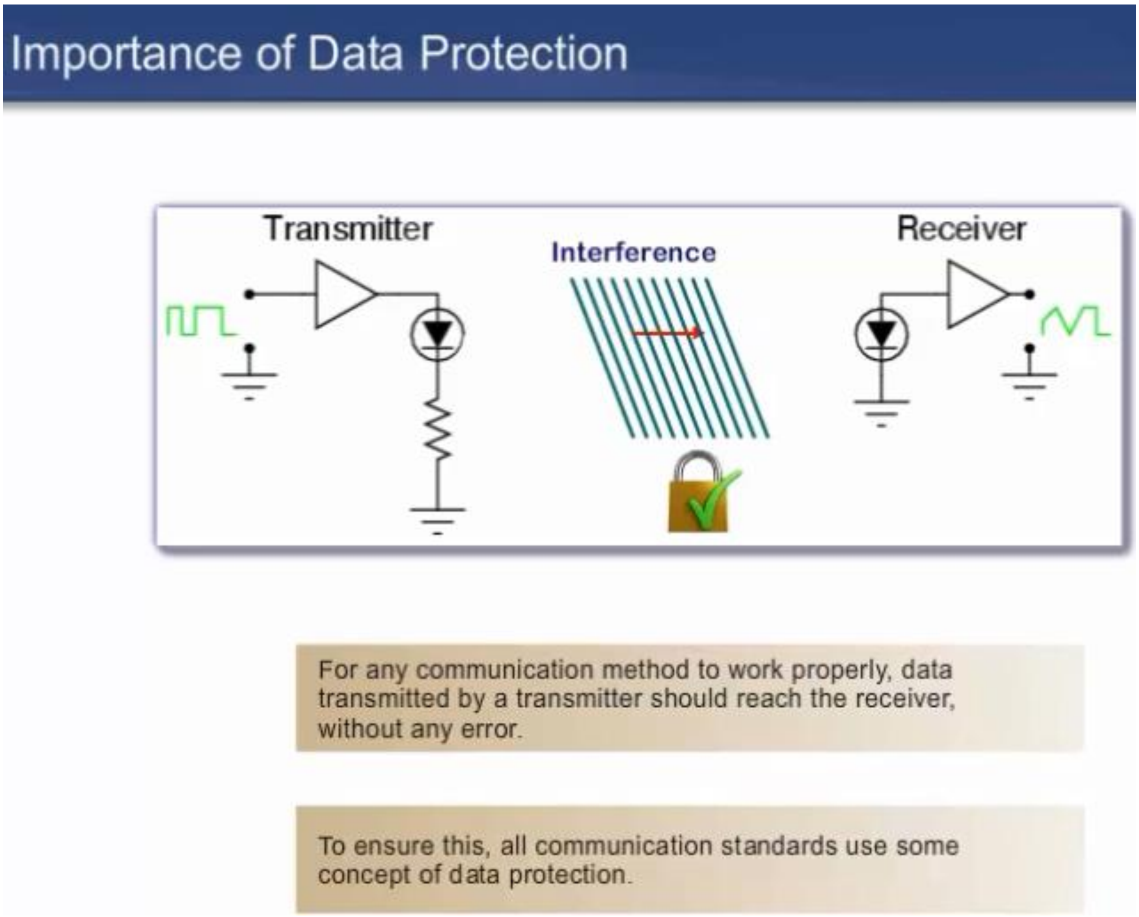
The sub-carriers used in LTE are:

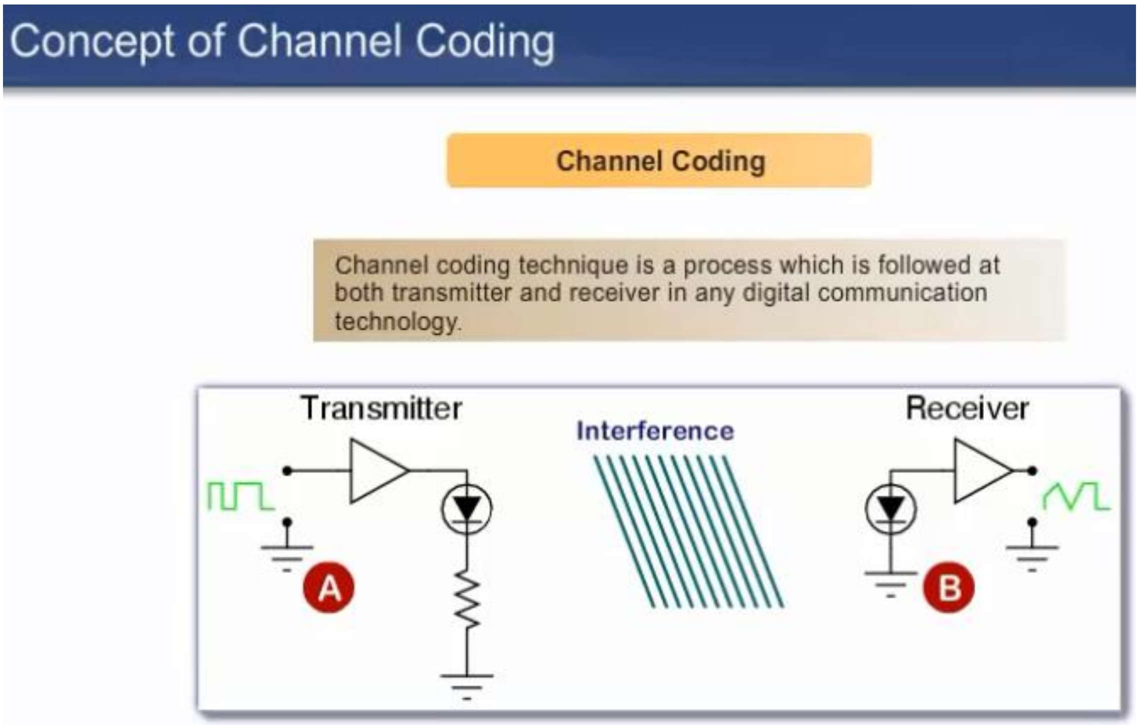
- Data Sub-carrier
- Pilot Sub-carrier
- DC Sub-carrier
- Guard Sub-carrier

Direct current SC have no info but used by UE to locate the center of OFDM frequency band.

Pilot sub-carrier reference is used to make measurements.

Adição de bit de paridade extra para detecção de erro e correção





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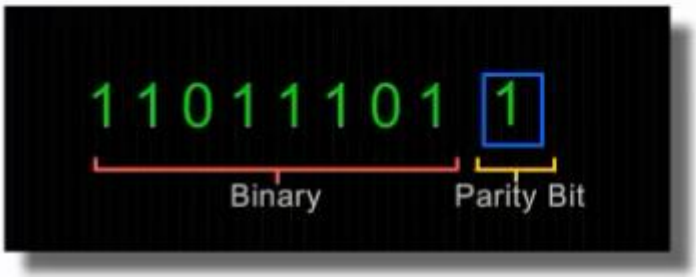
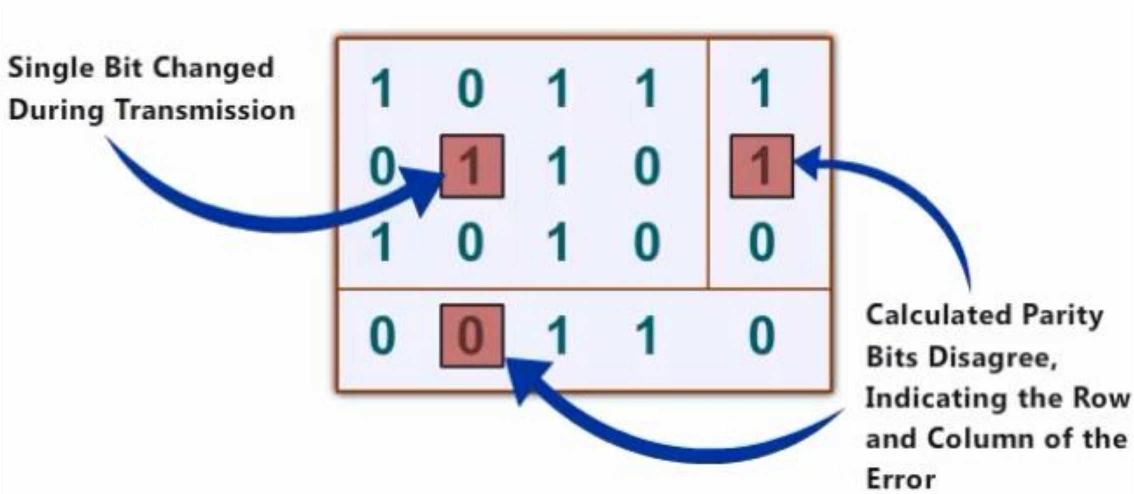




There are two types of coding algorithms:

- Block Codes
- Convolutional Codes

There are two different policies to make use of channel coding:

- Automatic Repeat Request (ARQ)

  System will ask for a re-transmission of data, in case any error is identified in the received data.

- Forward Error Correction (FEC)

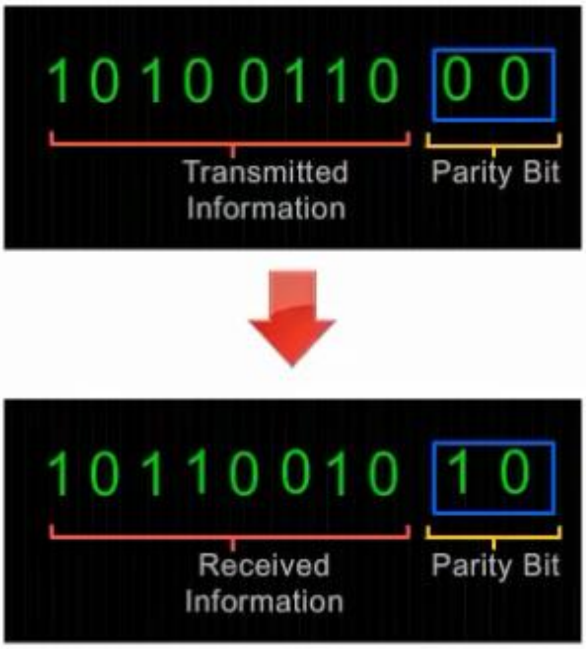
  System will fix the error prone data, if the errors are identified at the time of reception of digital data.

Forward Error Correction (FEC)

The concept of FEC was brought in by the American mathematician Richard Hamming, who invented the first FEC code in 1950 and was named as Hamming (7, 4) codes.

FEC Technique:

Used for controlling and correcting the data transmitted over any unreliable medium or on a noisy channel like wireless medium.



Advantage:

- Removes call for a reverse channel for data re-transmission.

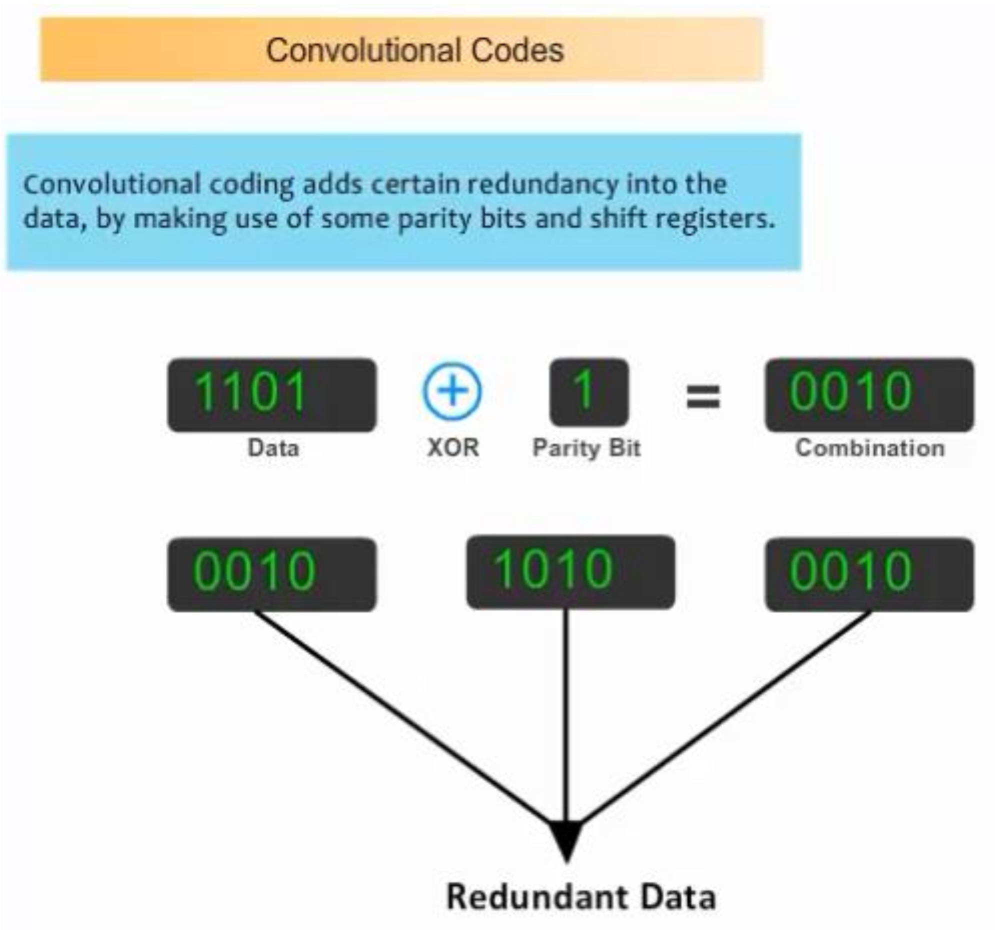
Disadvantage:

- An overhead to the available bandwidth.

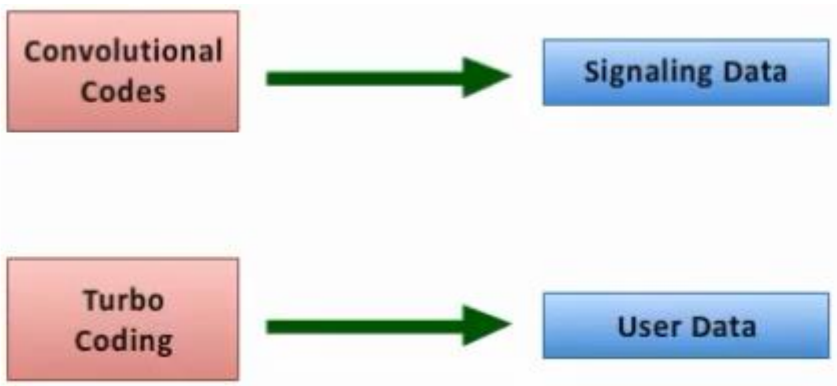
Different Methods of FEC: Convolutional Codes

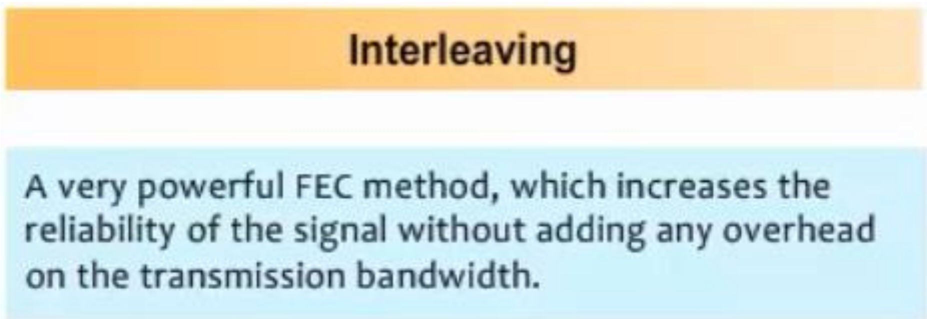
Different types of FEC methods used in LTE are:

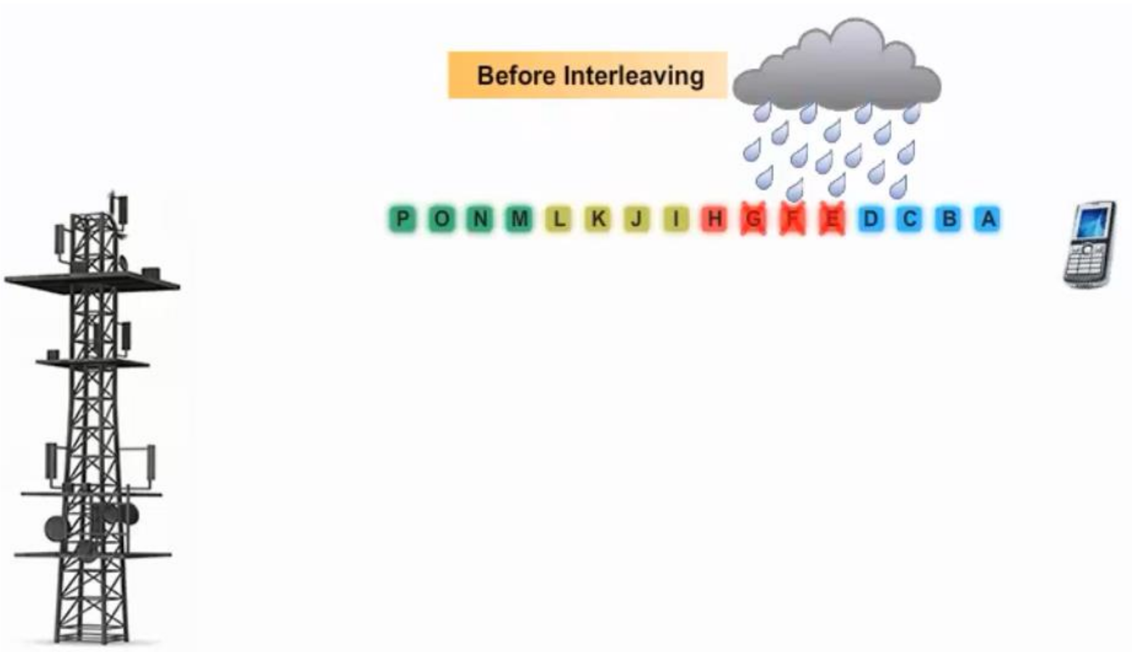
- Convolution coding for the signaling data
- Interleaving
- Turbo coding for the user data



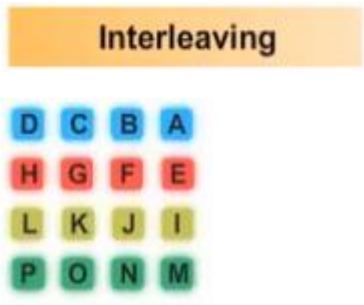
Quando diferente 1, igual 0. Enviado várias vezes para ver se há algum erro

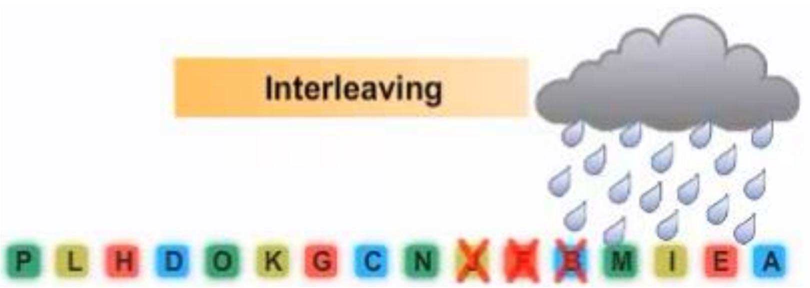


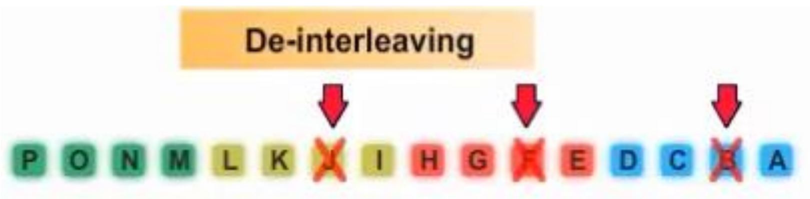




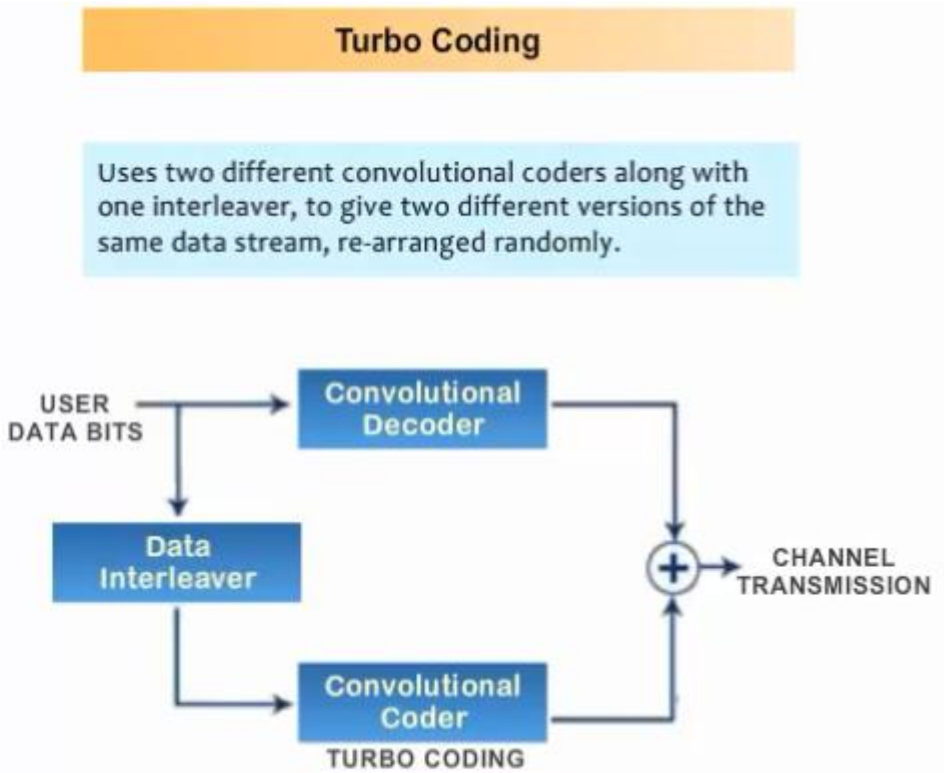
Não é possível recuperar os dados originais.

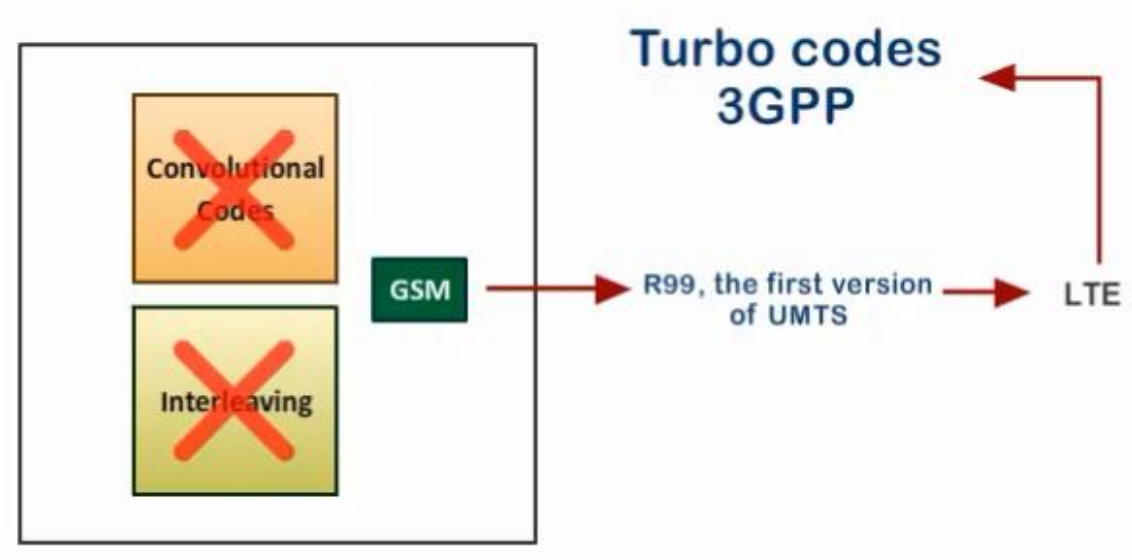






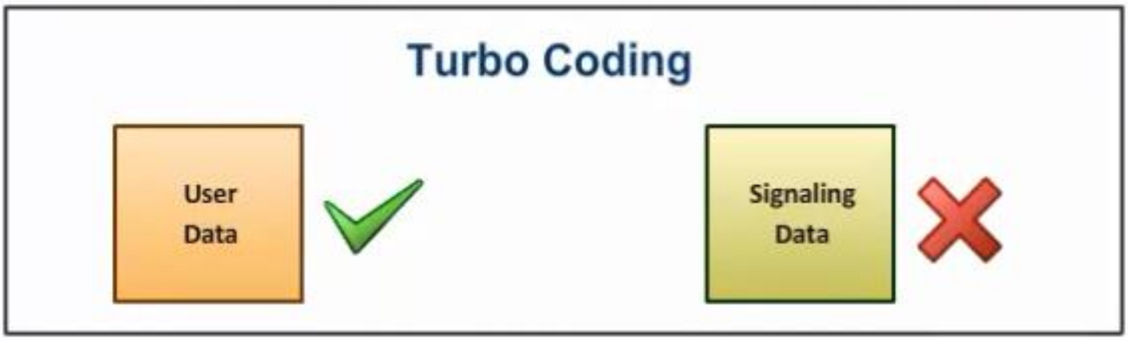
Erros não são consecutivos. Probabilidade de recuperação de arquivos é muito maior.

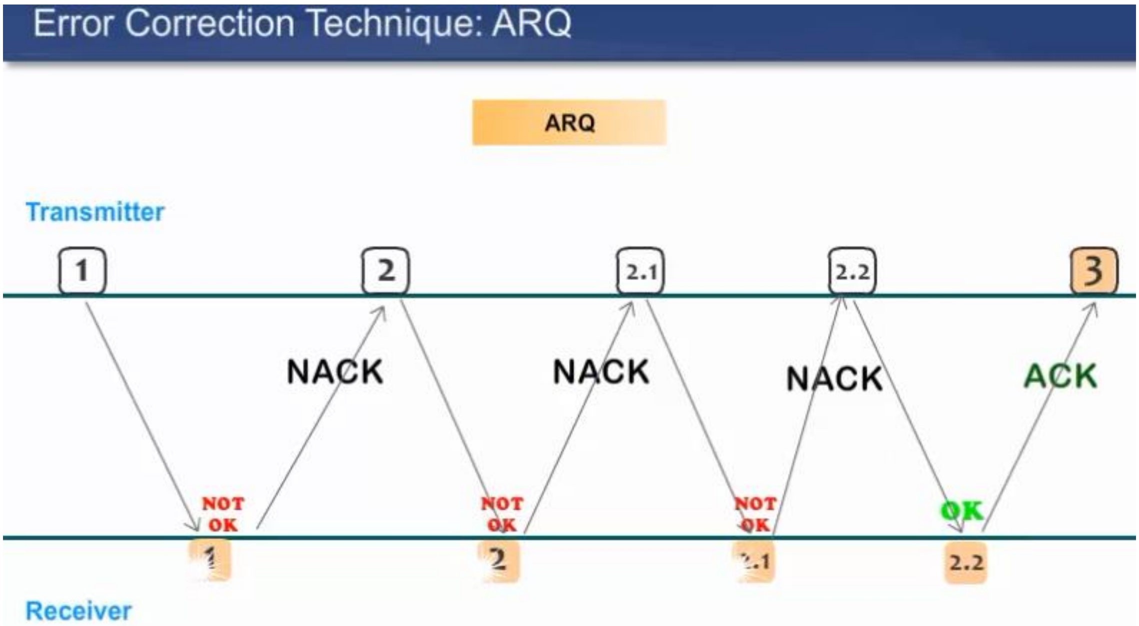




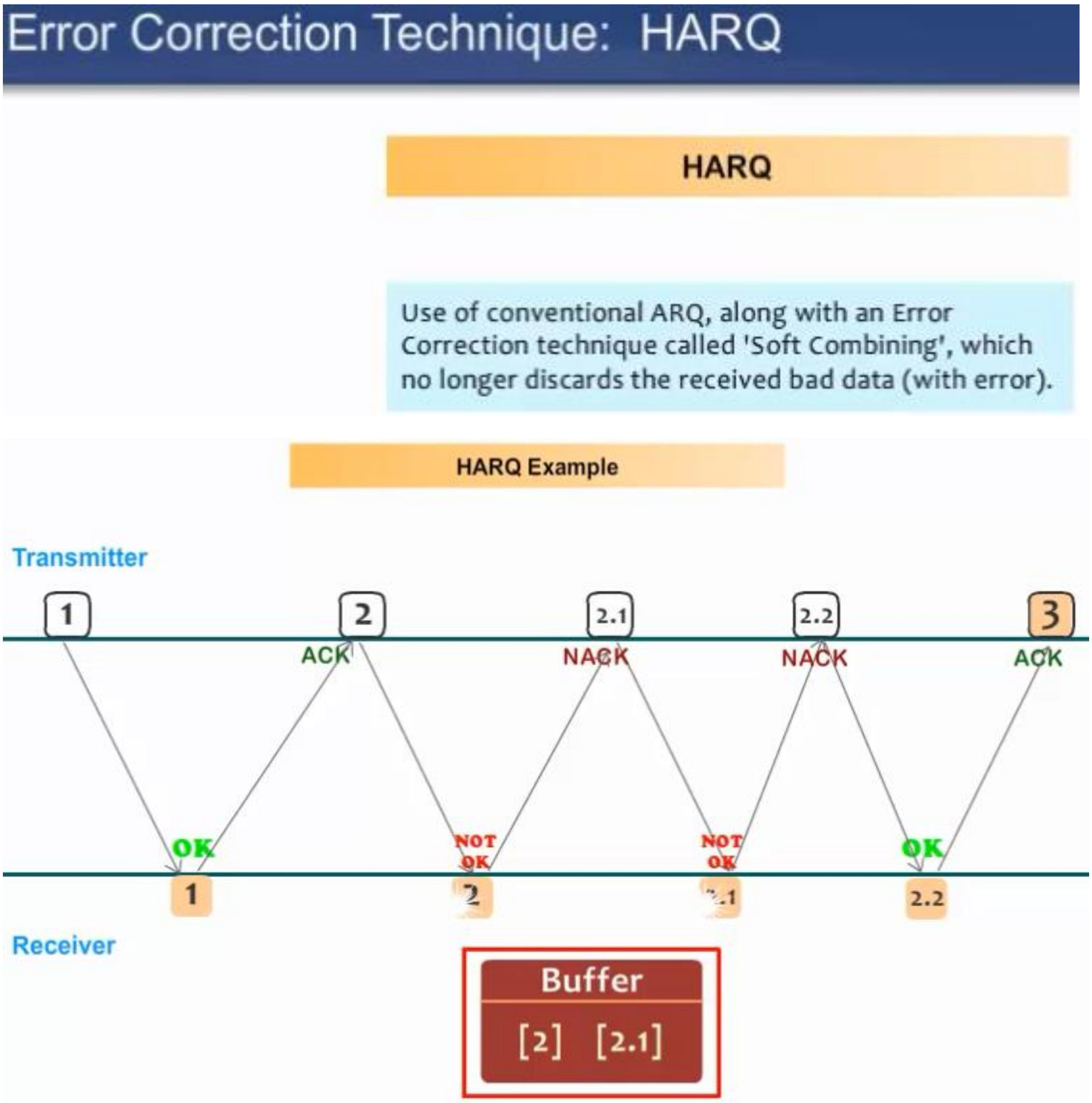
Turbo code não mudou no LTE.

Tubo coding adiciona um delay extra.

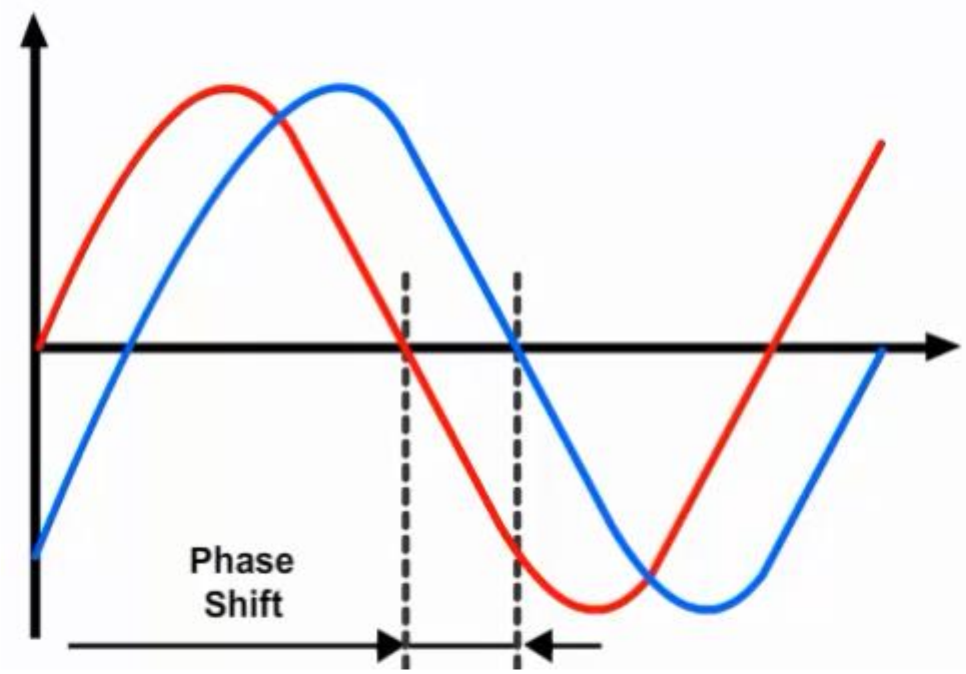




Descarta arquivos com erros.



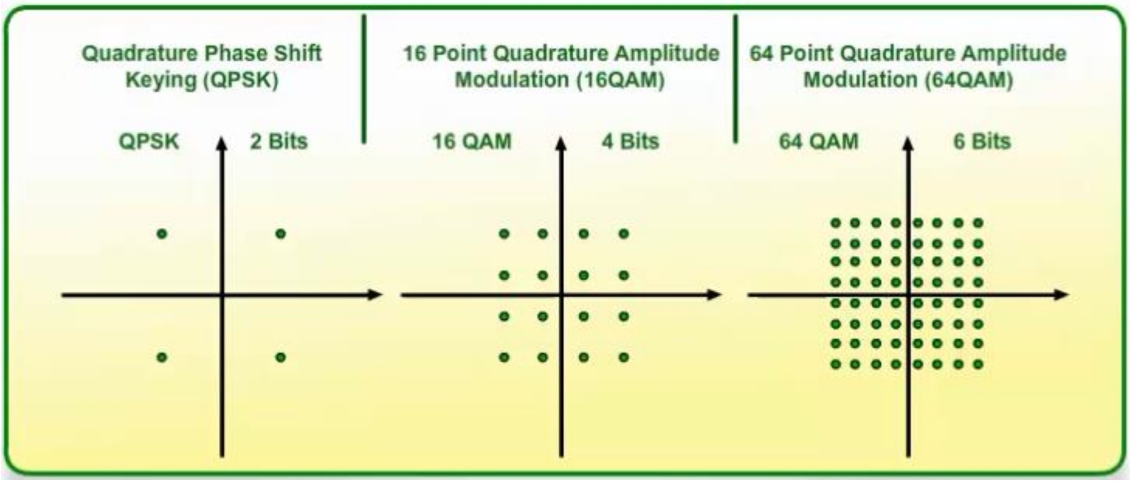
Modulation Schemes Used in LTE



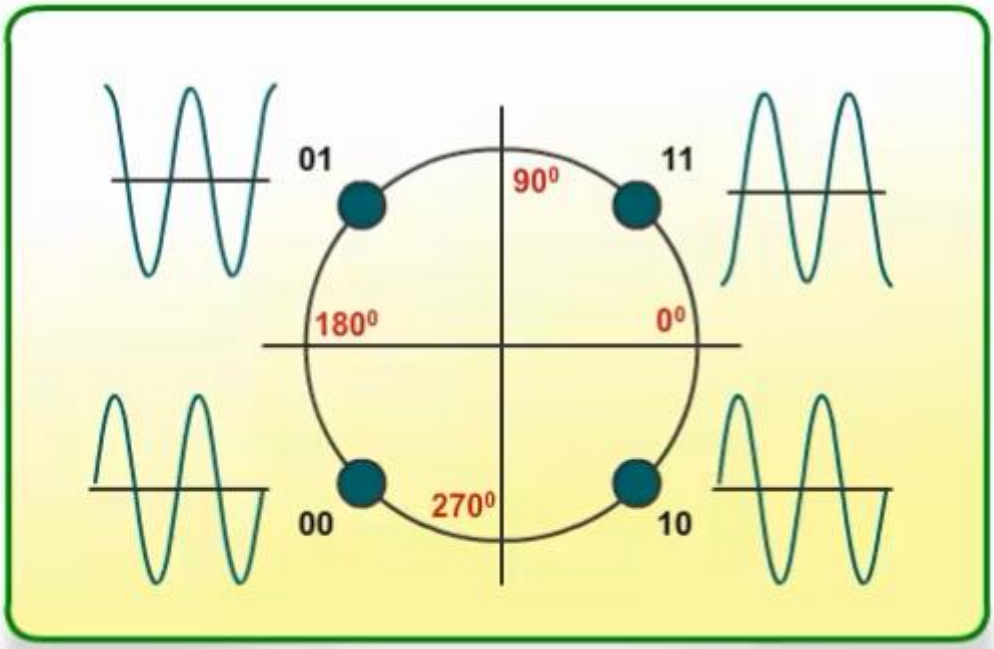
PSK + Amplitude Keying = Quadrature Amplitude Modulation (QAM)

Modulation Schemes Used in LTE

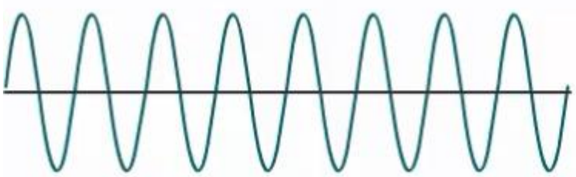
Some of the forms of PSK that are used in LTE network are:



QPSK



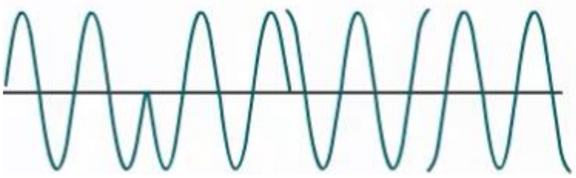
Carrier



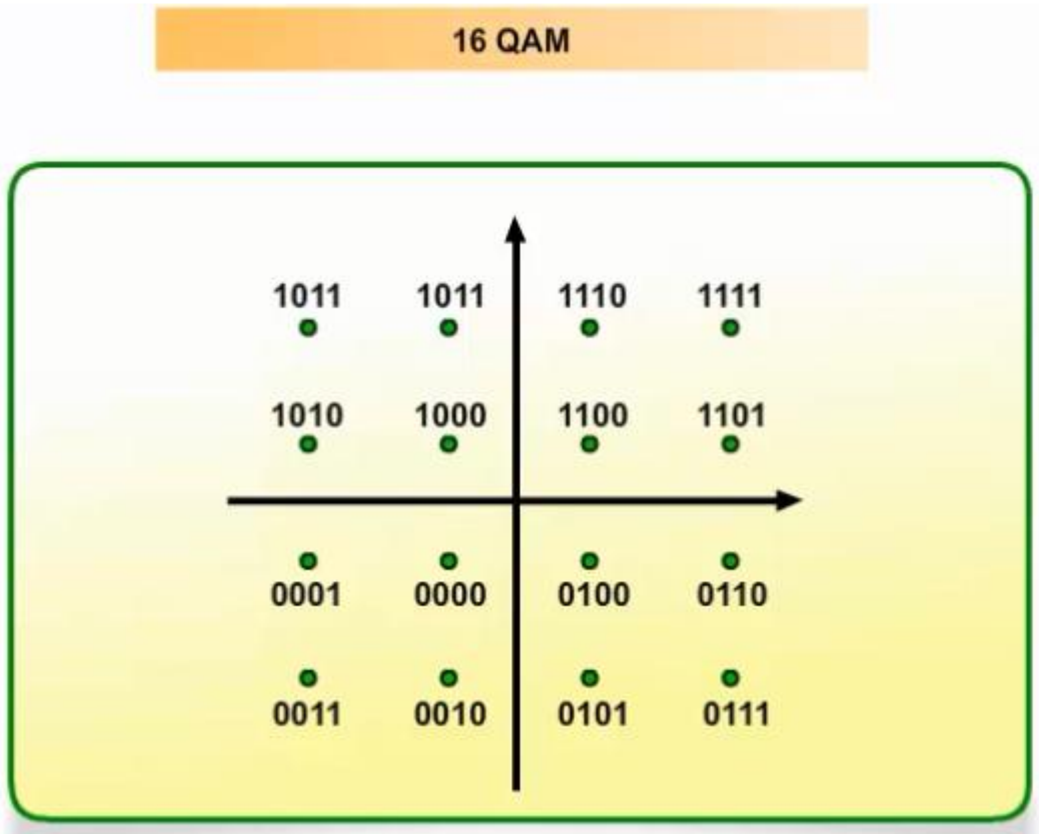
Modulating value from two bits

0 (00)	2 (10)	1 (01)	3 (11)

Modulating Result



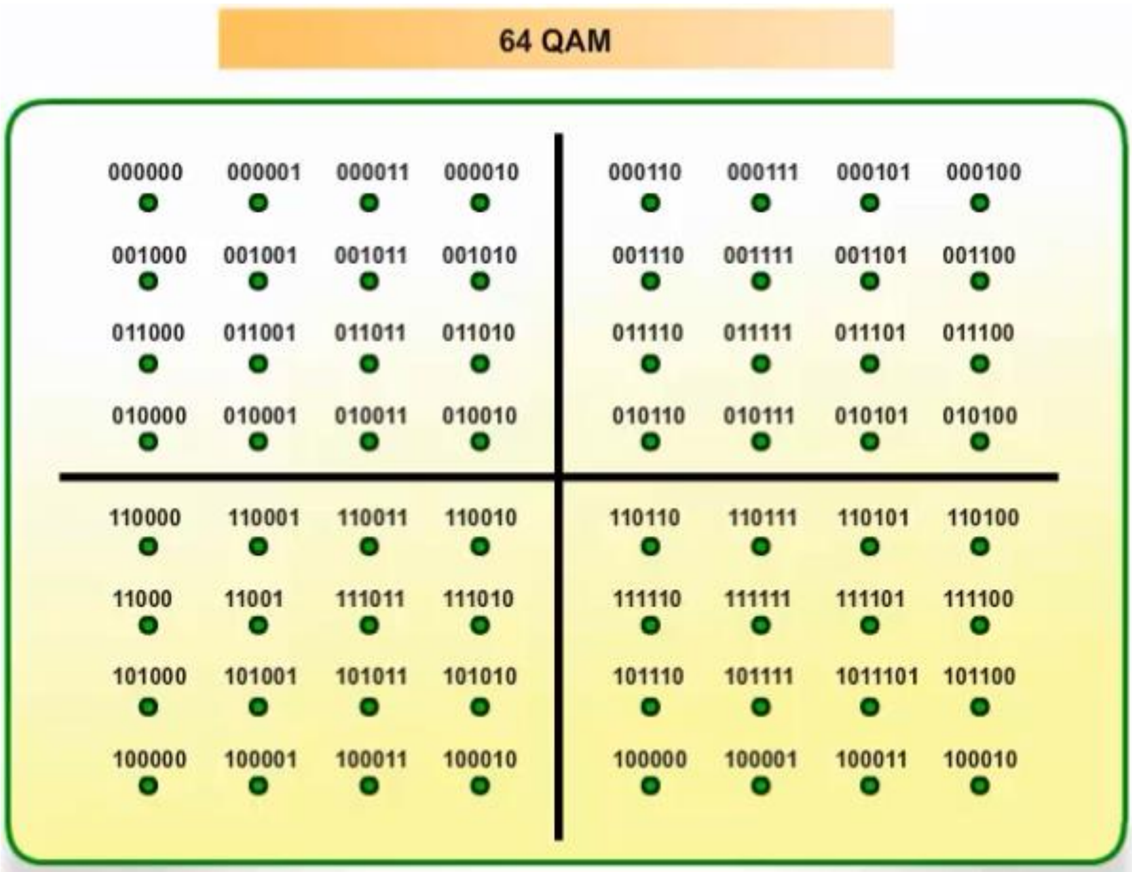
In QPSK, each adjacent symbol differs by only one bit, and hence sometimes it is also known as quaternary or quadriphase PSK or 4-PSK.



Less Robust than QPSK

Requires good radio conditions SNR

More Robust than 64 QAM



2^6=64

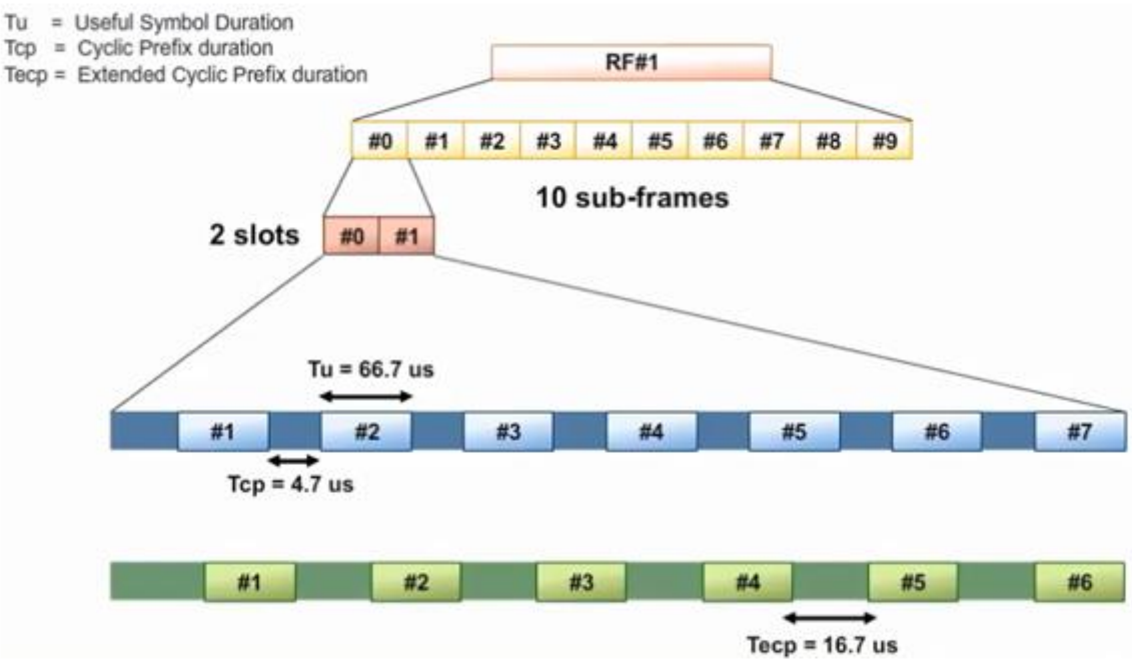
A escolha do tipo de modulação depende da qualidade do canal.

Frame Structure in LTE

RF#1 – 10 ms

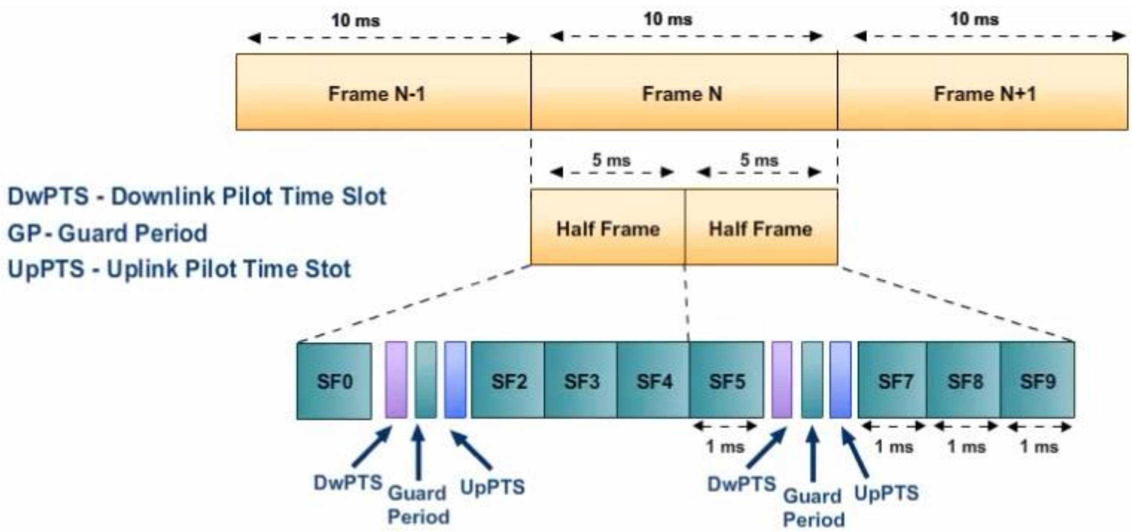
Radio Frame – 1 ms cada

7 símbolos ou 6 símbolos (extendido)



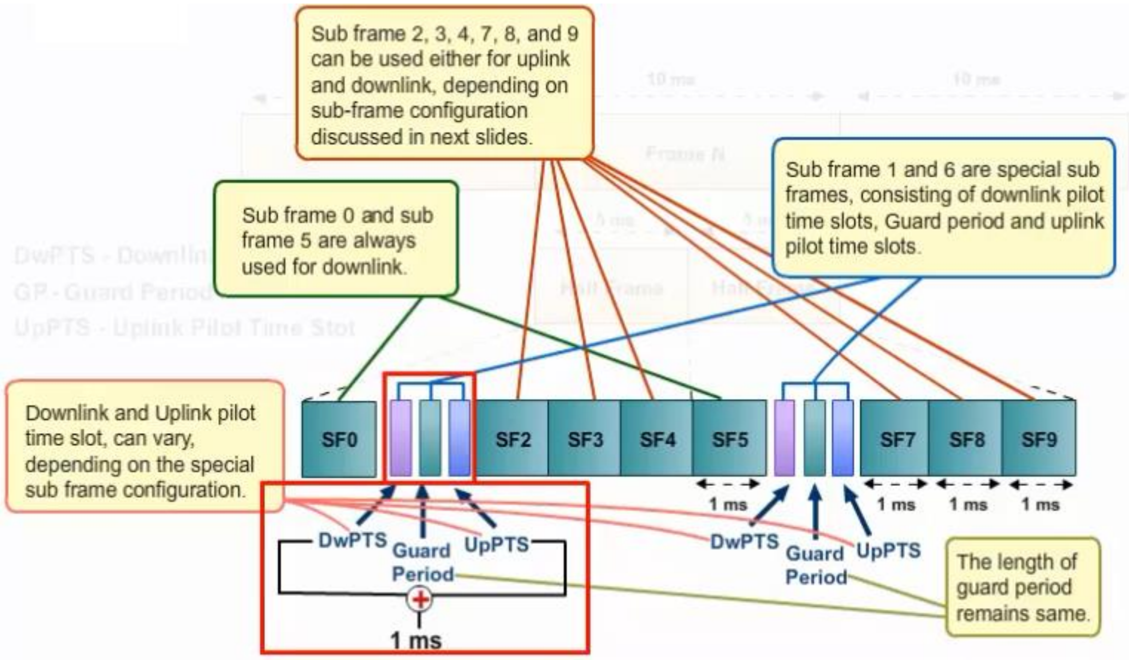
TDD- Type 2

The frame structure for the type 2 frames used on LTE TDD is some what different.



Upload 250 Mb,

Download 25 Mb.



Sub Frame Configuration

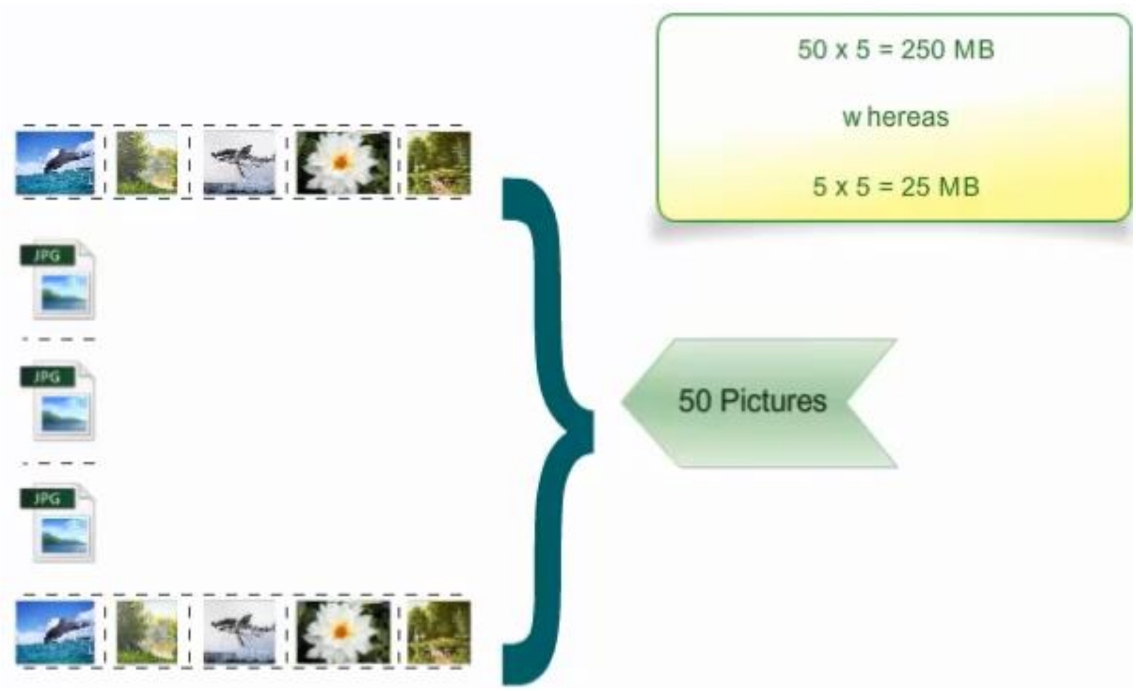
Up/Down Link Config	Down to UP link Switch Periodicity	SUBFRAME NUMBER									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

D/U is a subframe for Downlink/Uplink transmission and S is a "special" subframe used for a guard time.

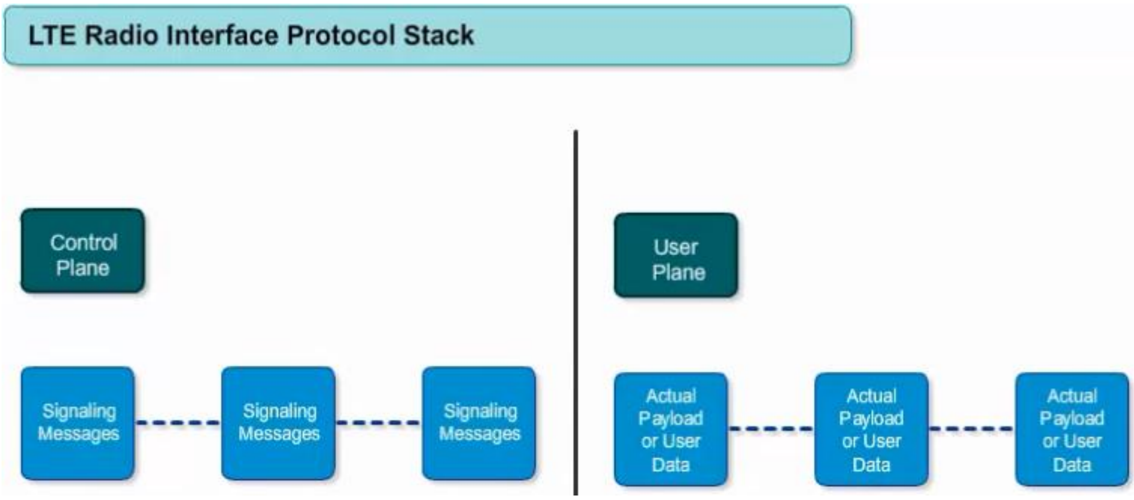
The advantages of TDD are typically observed in situations where:

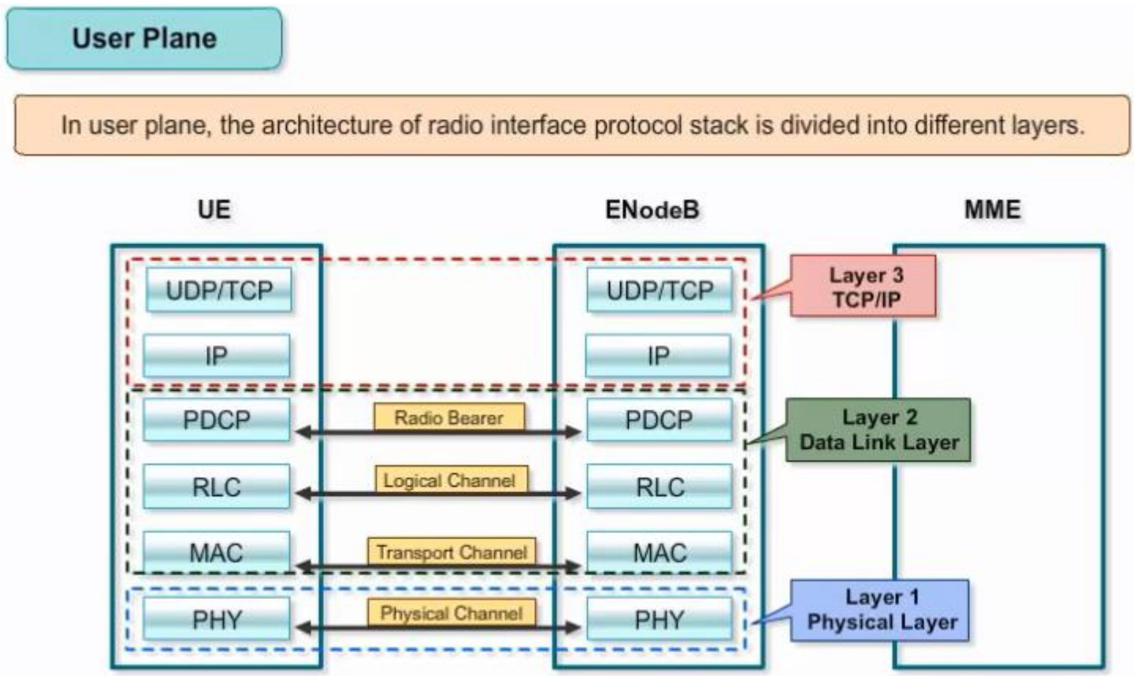
Upload 250 Mb,

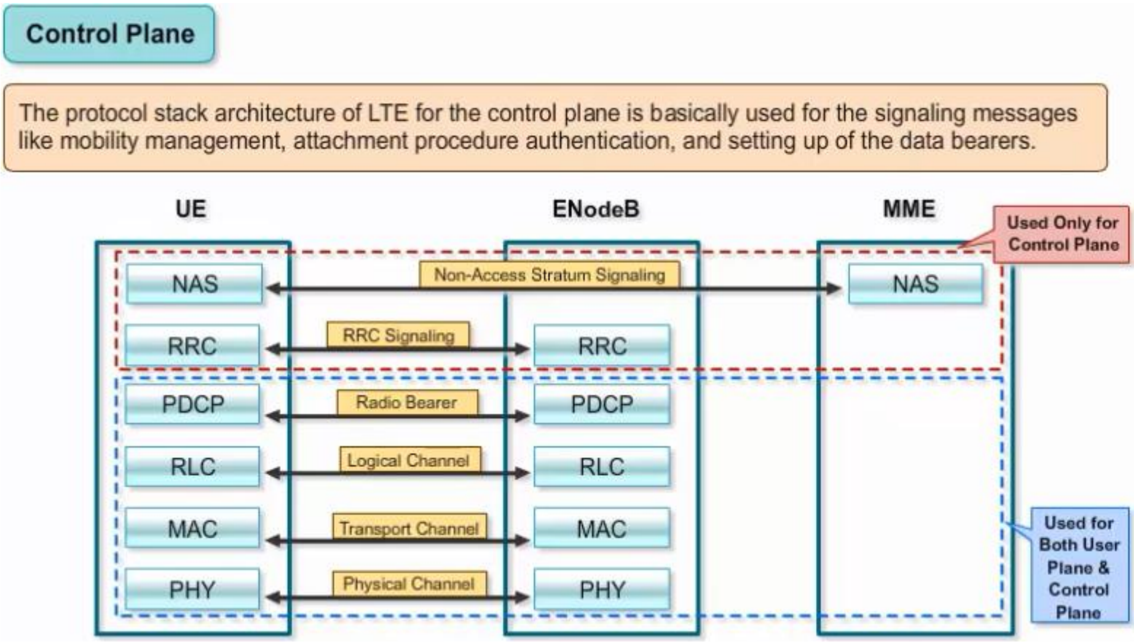
Download 25 Mb.



Radio Interface Protocol Stack Of LTE:



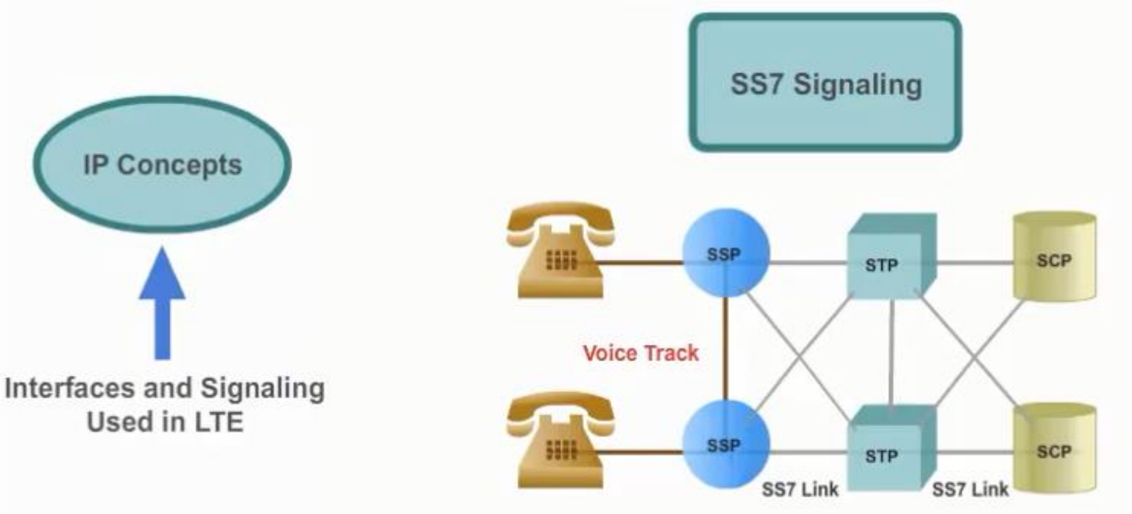




Módulo 4

Concept of S1 and X2 Interface

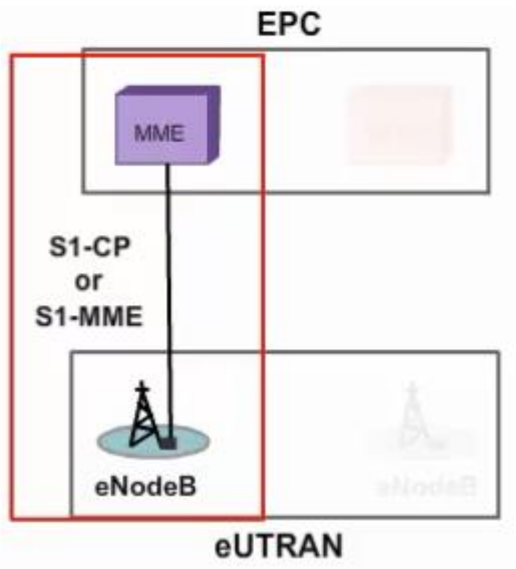
All interfaces, and signaling used in LTE, are based on IP concepts. This is mainly to overcome the dependency, on the legacy SS7 signaling, which was used in GSM.



S1 is an interface between the E-UTRAN and EPC, which connects each other logically.

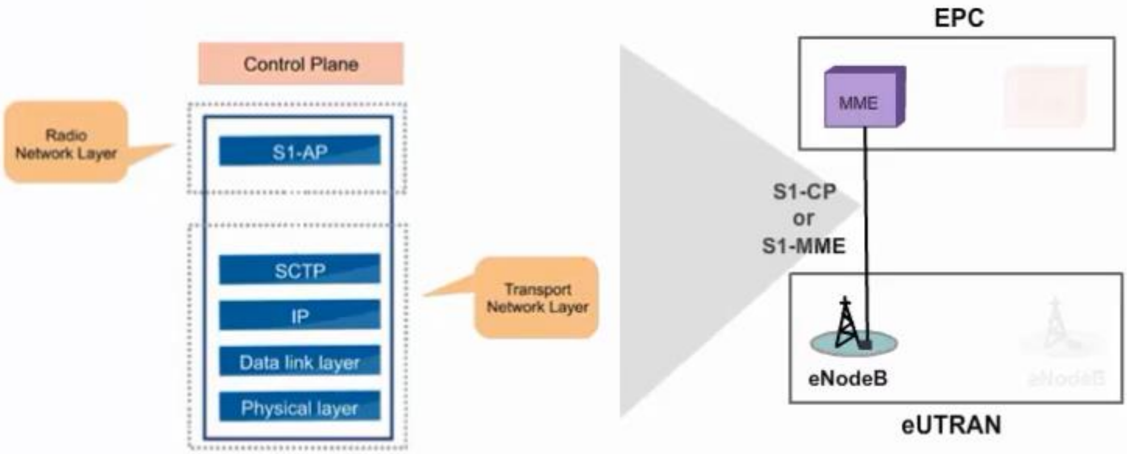
The S1 interface is divided into two planes:

- S1-Control plane, which connects the eNB with the MME for control signaling. This interface is also called as S1-MME interface.



Protocol Structure of S1-C or S1-MME:

S1 Interface in LTE is many-to-many interface.



Protocol Structure of S1- MME Interface

S1AP is the signaling protocol that MME use to manage :

- **Initial UE context setup**
- **Bearer Setup, modification and release**
- **The access stratum or radio network security functions.**
- **Paging and Mobility**

S1AP is carried over SCTP and IP to provide reliable transmission over the S1 interface.

Stream Control Transmission Protocol (SCTP) is a new reliable, message-oriented transport-layer protocol. Which works like TCP and provides the guaranteed delivery of data.

One SCTP connection exists for each MME-eNodeB relation.

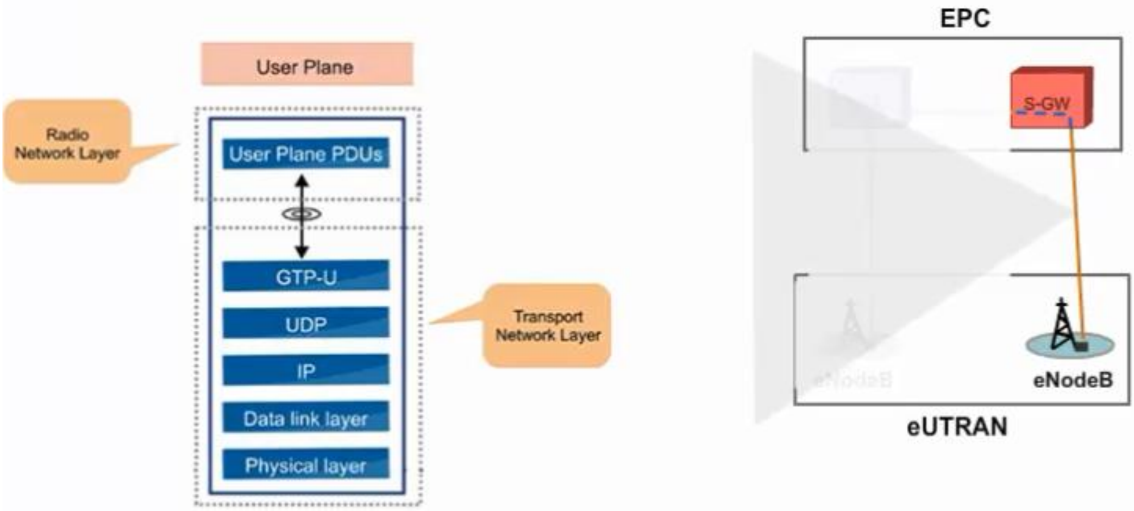
The usage of Physical layer L1, Data Link Layer L2 and L3 are same with the only difference is to choose IP version like IPv4 or IPv6 as per the requirement.

Protocol Structure of S1-C or S1-MME:

The other part of S1 interface, is called as S1-User or S1-U, which is a logical connection between eNB and the S-GW (Serving Gateway).

Protocol Structure of S1-U:

This interface uses GTP-U over UDP/IP protocol, which is common with the existing UMTS system.

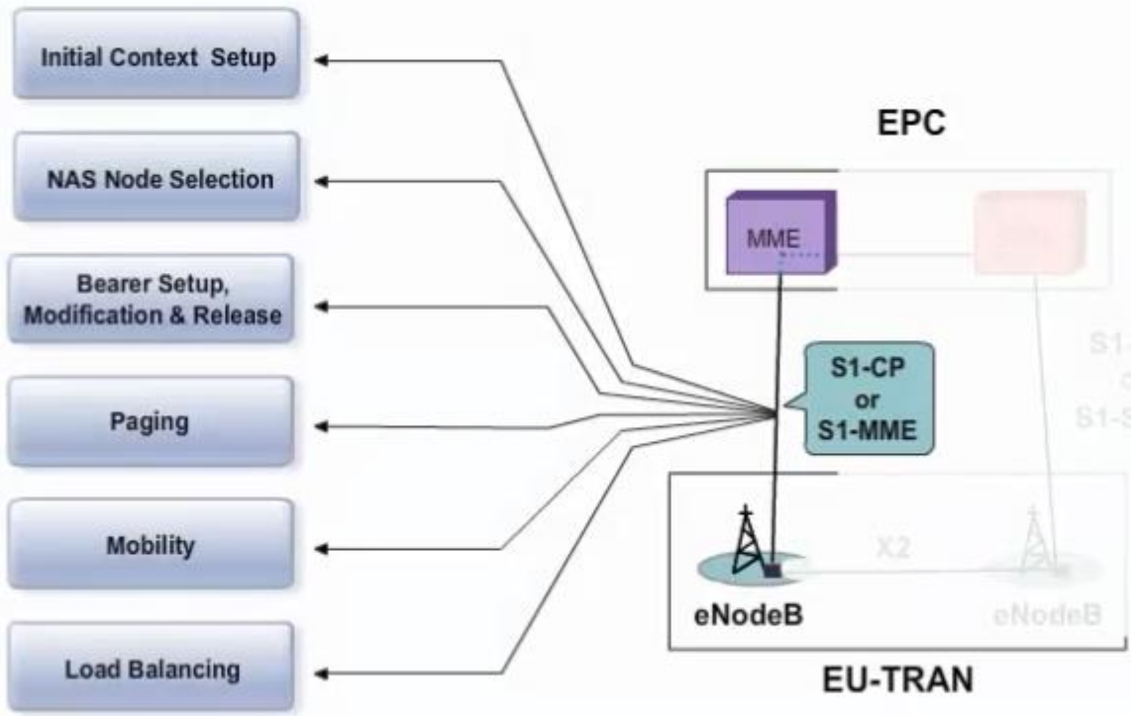


Protocol Structure of S1- U Interface

It provides the non-guaranteed data delivery, between eNB and S-GW, but it is relatively simple protocol that allows many tunnels between each endpoints.

The transport bearer is acknowledged only the GTP tunnel end points, and the endpoint IP address, like source and destination IP address, and Tunneling Endpoint ID (TEID).

S1 Interface Functions



Initial Context Setup

The first step in the S1-C interface is to create a Transport Network Layer (TNL) with an SCTP association.

This starts with the initiation of MME selection, by the eNodeB, after which a SCTP connection can be built between one eNodeB and one MME.

NAS Node Selection

As soon as the UE enters, the resource pool area, it has to select a MME to which it will remain connected, for all its communication needs, in the network, till the time it is in that pool area, or it remains in that active mode.

Bearer Setup, Modification & Release

All these functions are done on S1 interface, independently, for each setup request. GTP-U tunnel endpoints need to be defined.

Also, every bearer needs to be treated separately in the network.

Paging

Paging is a mechanism, to wake the UE up, in case of the idle mode, since in the idle mode, the UE is not required to keep connection with the eNB it is connected to, and this procedure is done on the S1 interface only.

Mobility

The S1 interface provides the mobility procedure for Intra LTE mobility where the serving eNB and the target eNB belongs to two different MMEs, and it also provides the mobility procedures for Inter LTE/RAT mobility like, LTE to UMTS handovers.

Load Balancing

Load balancing in case some MME is overloaded in certain time of the day, or a new MME is being installed or removed from the system. We need to purposefully balance the load in all the MMEs in the pool evenly.

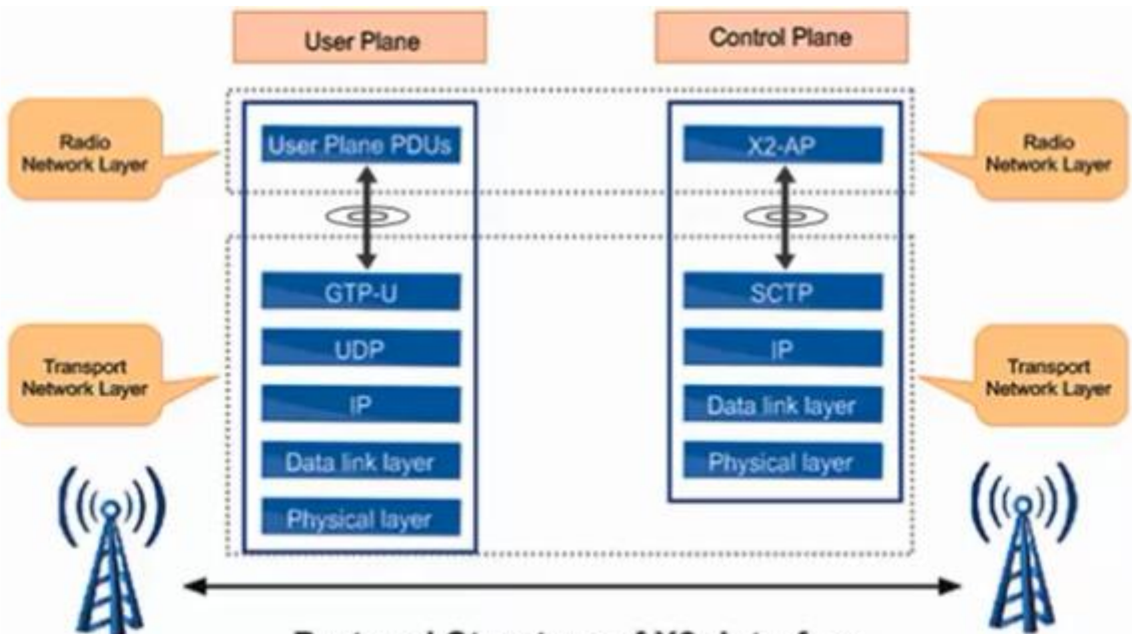
Or if some MME wants to forcefully offload itself, it may be done on the idle UE first and then maybe on the connected UEs'.

X2 User Plane & Control Plane Protocol Structure

The protocol structure of X2 interface is also similar to S1 interface, and is also divided into two parts, user plane and control plane.

PDUs are mapped on GTP-U protocol, which doesn't guarantee delivery but is simple to implement.

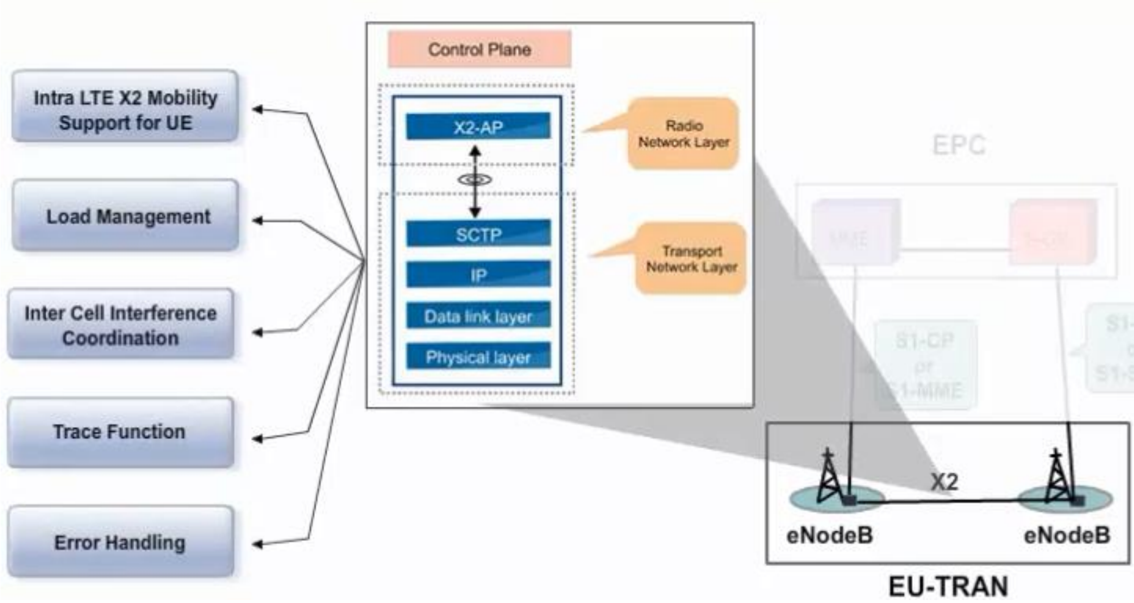
X2-AP is mapped on the SCTP protocol, for the control plane, which ensures guaranteed delivery of packets.



Protocol Structure of X2- Interface

The purpose of using same protocols between S1 and X2 interface is to simplify the operations, involving data forwarding.

X2 Interface Functions



Intra LTE X2 Mobility Support for UE

X2 based mobility provides a mechanisms of handovers between two eNodeBs without involving the core network.
These handover are much faster than S1 based handovers since the handover is directly performed between the two eNBs. The core network is only informed once the handover is successful so that the MME keeps the updated UE context.

Please note, the pre requisites for X2 based mobility support are:

- Both the eNodeB need to be connected to same MME and SGW.
- There has to be a direct connection on the X2 interface between the two eNodeB.

Load Management

This is a very important feature in LTE self-optimization process, in which the overall system capacity and the capabilities are improved, by detecting an imbalance between different eNBs.

The X2 interface will automatically transfer the load, from a heavily overloaded eNB to the other eNB, which is not that overloaded.

Now the question is, how the system will do that by comparing the load, and changing the handover and reselection parameters, like thresholds and hysteresis margin, after reaching which the handover events triggered.

Inter Cell Interference Coordination

This is also known as the uplink interference management.

For example, if you move away from the eNB, the UE is required to transmit the information with a higher power, to remain connected to the eNB, even if the eNB is not overloaded, the high power of UE will still create problem in the neighboring cells.

So, in this case also, we need to use a mechanism to shift those high power UEs to the other eNBs, if required, to maintain the overall balance of the system.

Trece Function

This is a very important feature, which will provide the history information of the number of eNBs last visited by the UE and the amount of time, the UE has spent on one or more eNBs.
This will help network, to decide upon UE speed and to configure the handover parameters accordingly.

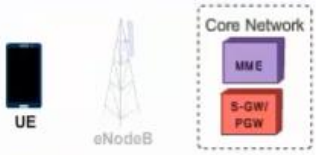
The network has an option to configure the history information required from the UE, to keep an overall balance in the system.

Error Handling

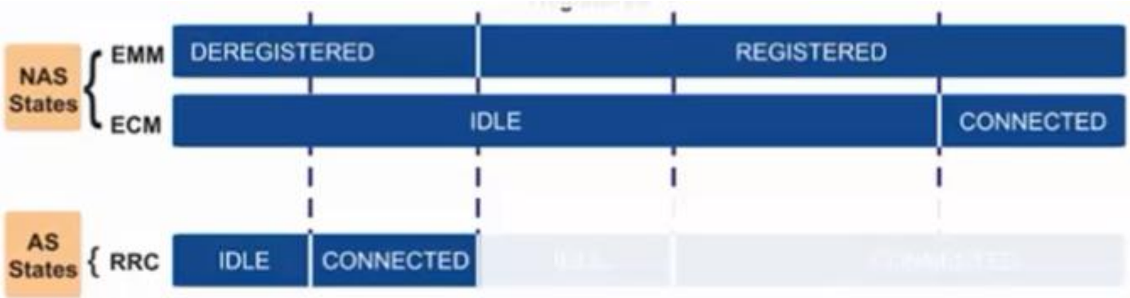
The X2 interface also performs some general error indication functions, which are required for the lossless handovers and the data transfers.

All Possible NAS and AS States in LTE

Different Access and Non Access Stratum States in LTE



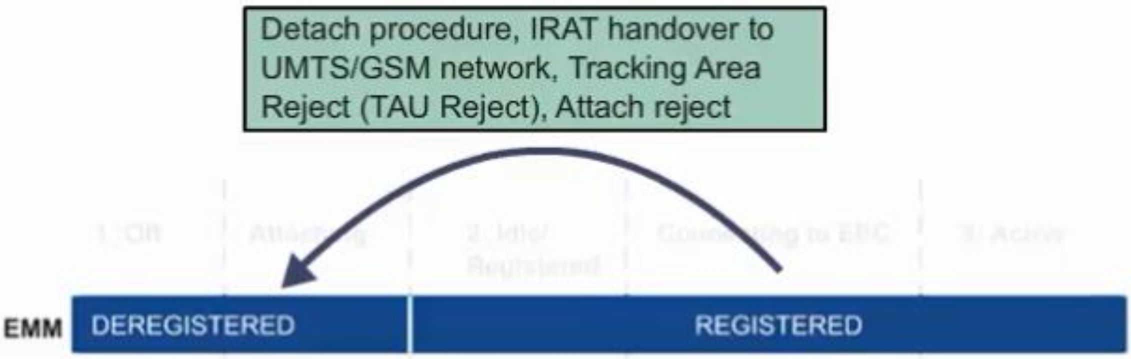
- RRC represents connection of UE with access network or with an eNB.
- EMM represents connection of UE with the MME.
- ECM represents the connection of UE and the EPC for the transfer of actual data.



EMM (EPS Mobility Management) States

In the EMM DEREGISTERED state, the MME holds no valid location information for the UE. The UE is not reachable by a MME, as the UE location is not known.

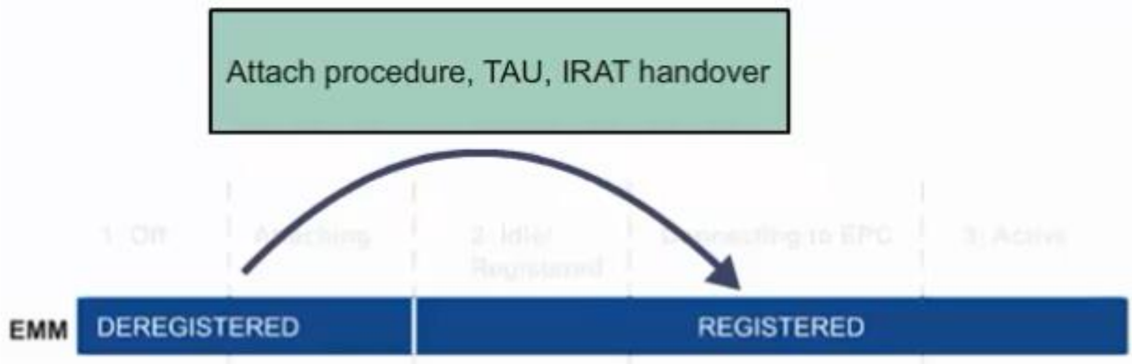
In the EMM-DEREGISTERED state, some UE context can still be stored in the UE and MME, to avoid running an Authentication Key Aggreement (AKA) procedure during every Attach request.



In the EMM-REGISTERED state, the UE can receive services that require registration in the EPS.

The UE location is known in the MME to at least an accuracy of the tracking area list allocated to that UE

In the EMM-REGISTERED state, the UE shall always have at least one active connection



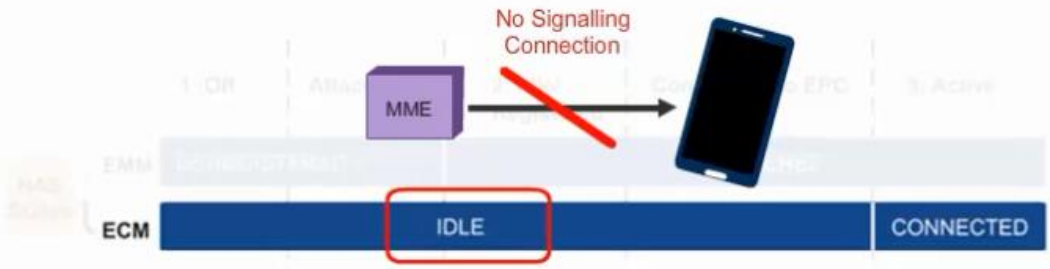
ECM States:

These states represent the connections between the UE and the EPC (Evolved Packet Core) including the information which network keeps in case of full fledge connectivity

ECM (EPS Connection Mobility) States

ECM Idle:

In ECM-IDLE state, there exist no signaling connection between UE and the MME.
But, UE can still be tracked on the tracking area basis, if it is in the EMM registered mode.
The UE can move in the network area, by keeping limited connectivity, by doing tracking area updates (TAU).

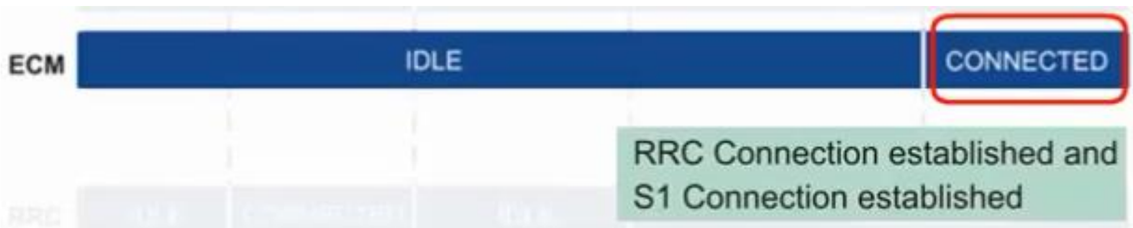


ECM Connected:

This state represents the full connectivity of the UE, with the network.

It means that there will be an active RRC connection, between the UE and EUTRAN, and one active S1 connection between the UE and MME, by an eNodeB.

Now, the connection of a UE to the network will be on the cell of an eNodeB, and the mobility will be managed by the handovers, not by the TAU.



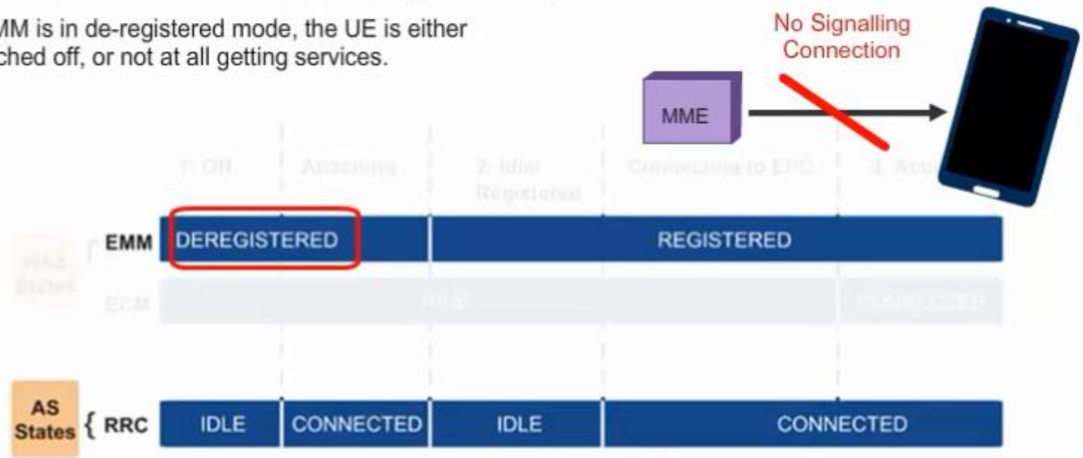
RRC (Radio Resource Control) States

RRC (Radio Resource Control) States

RRC Idle:

In RRC idle mode the EMM can be in, deregistered or registered mode.

If EMM is in de-registered mode, the UE is either switched off, or not at all getting services.

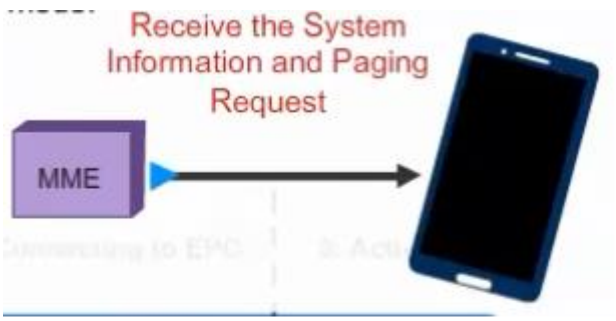


NAS and AS states in LTE

RRC_IDLE:

- PLMN Selection;
- Broadcast of System Information;
- Paging;
- Cell Re-selection Mobility;
- No RRC Context Stored in the eNB

In case EMM is in registered mode, then the UE in RRC idle mode can receive the system information and can listen for the paging request, in case it is required.

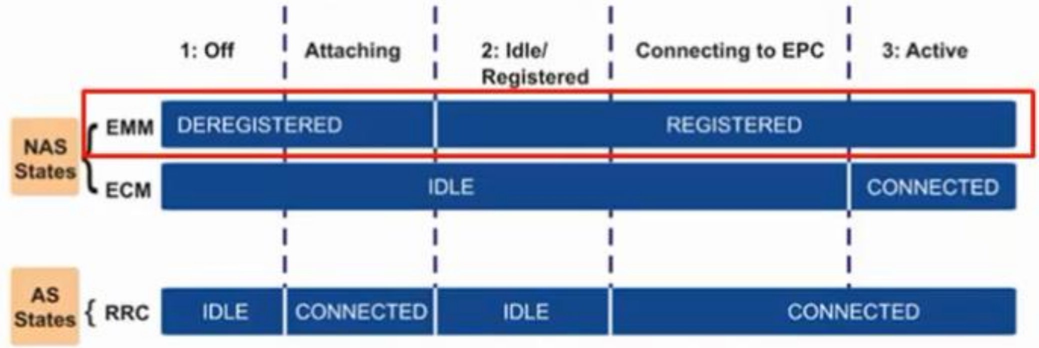


RRC Connected:

In RRC connected mode, the information kept in the UE is known to the network, up to the cell level, in an eNode B.

Also, the UE has the uplink resources available with it, to communicate with the network.

For the actual user data to transfer all RRC, EMM and ECM, have to be, in connected or registered mode.



NAS and AS states in LTE

RRC_CONNECTED:

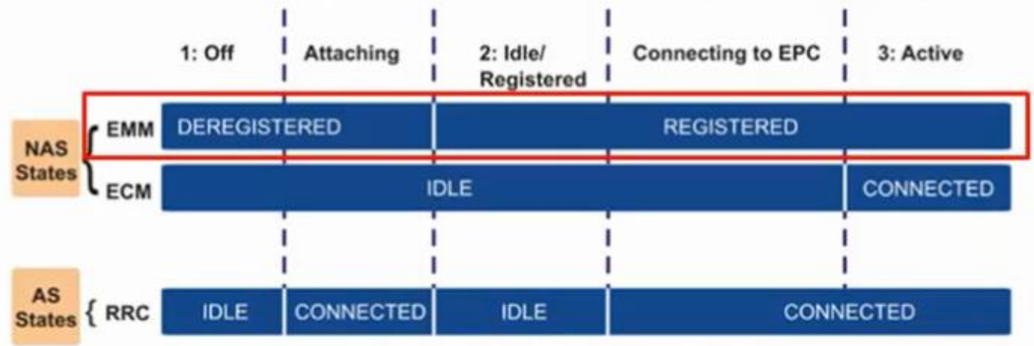
- UE has an E-UTRAN-RRC Connection;
- E-UTRAN knows the Cell, the UE belongs to;
- Network can Transmit and/or Receive Data to/from UE;
- Neighbor Cell Measurements;

RRC Connected:

In RRC connected mode, the information kept in the UE is known to the network, up to the cell level, in an eNode B.

Also, the UE has the uplink resources available with it, to communicate with the network.

For the actual user data to transfer all RRC, EMM and ECM, have to be, in connected or registered mode.



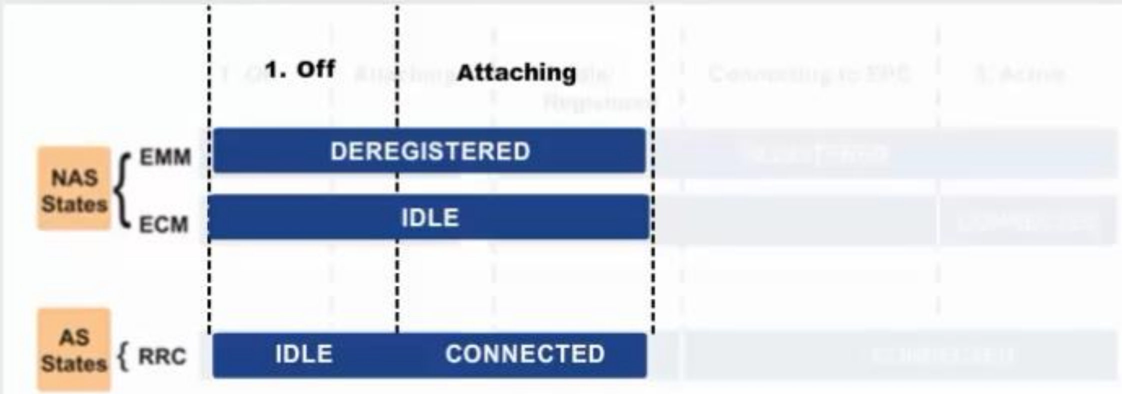
NAS and AS states in LTE

RRC_CONNECTED:

- UE has an E-UTRAN-RRC Connection;
- E-UTRAN knows the Cell, the UE belongs to;
- Network can Transmit and/or Receive Data to/from UE;
- Neighbor Cell Measurements;

UE States in LTE

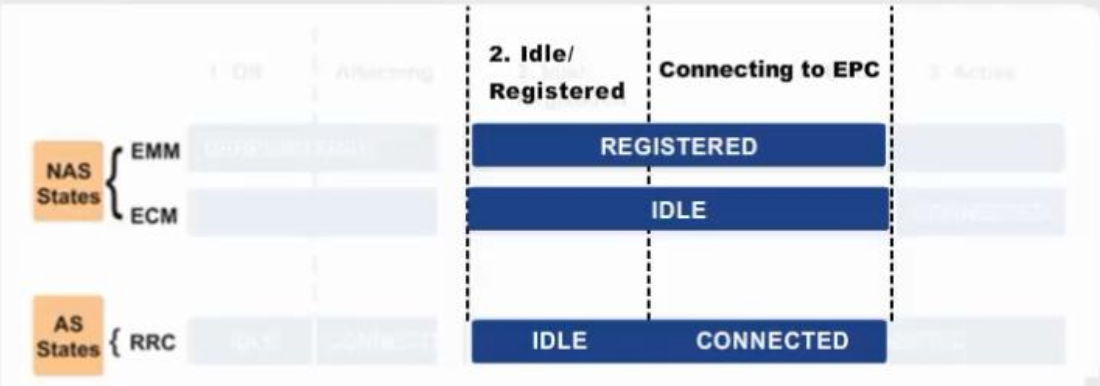
- Used as power up, when the mobile terminal is not known to the network.
- Before any further communication, the mobile terminal needs to register with the network, using the random-access procedure.



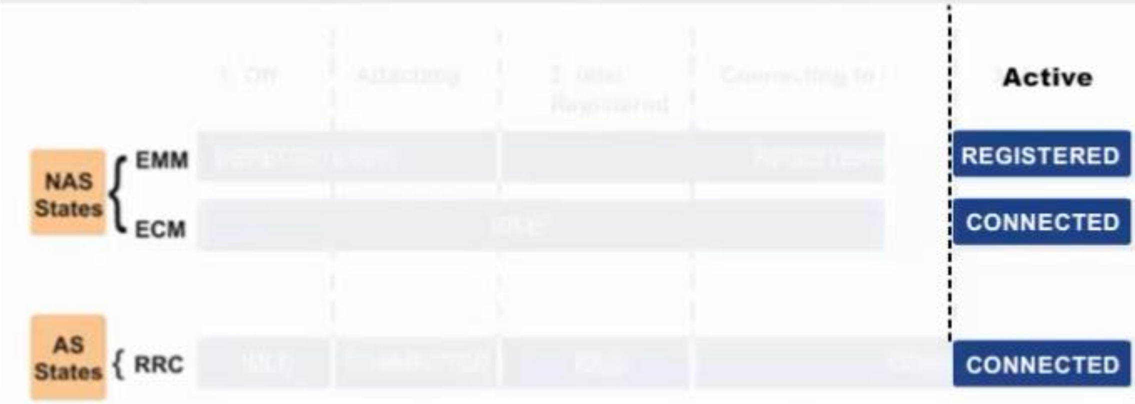
NAS and AS states in LTE

LTE_IDLE

- Low activity state, to reduce battery consumption.
- The only uplink transmission activity that may take place is random access, to move to LTE_ACTIVE
- In the downlink, the mobile terminal can periodically wake up, in order to be paged for incoming calls
- The network knows at least the group of cells, in which paging of the mobile terminal is to be done.

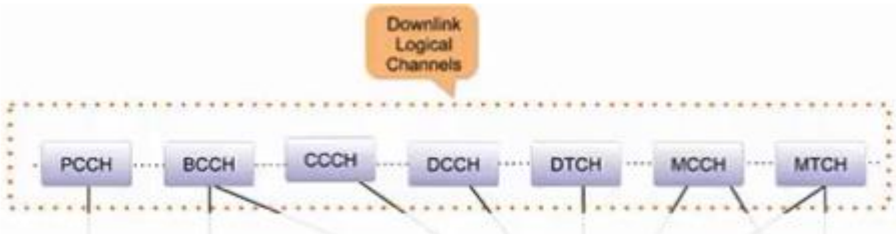


- Mobile terminal is active, with transmitting and receiving data.
- **IN_SYNC:** Uplink is synchronized with eNodeB.
- **OUT_SYNC**
  - Uplink is not synchronized with eNodeB.
  - Mobile terminal needs to perform a random-access procedure, to restore uplink synchronization.



NAS and AS states in LTE

LTE Channels and Signals: Downlink



Logical Channels:

These are the channels which help us to know the kind of information, we are trying to send.

Logical channels in LTE are broadly classified into:

- **Control Channels**
- **User Channels**

Different type of logical control channels are:

- **Paging Control Channel (PCCH):**

  This control channel is used for paging information when searching a UE on a network.

- **Broadcast Control Channel (BCCH):**

  This control channel provides system information to all mobile terminals connected to the eNodeB.

- **Common Control Channel (CCCH):**

  This channel is used for random access information, e.g. for actions including setting up a connection.

- **Dedicated Control Channel (DCCH):**

  This control channel is used for carrying user-specific control information, e.g. for controlling actions including power control, handover, etc.

- **Multicast Control Channel (MCCH):**

  This control channel is used for Information needed for multicast reception.

Traffic channels:

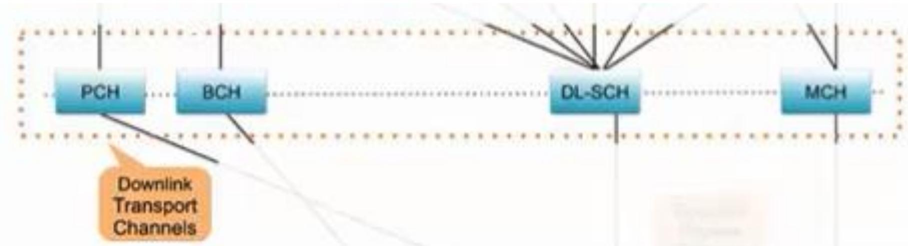
These LTE traffic channels carry the user-plane data:

- **Dedicated Traffic Channel (DTCH):**

  This traffic channel is used for the transmission of user data.

- **Multicast Traffic Channel (MTCH):**

  This channel is used for the transmission of multicast data.



Transport channels define how and with what type of characteristics the data is transferred by the physical layer.

Transport Channels are distinguished by the ways in which the transport channel processor manipulates them.

- **Paging Channel (PCH) :**

  To convey the Paging information

- **Broadcast Channel (BCH) :**

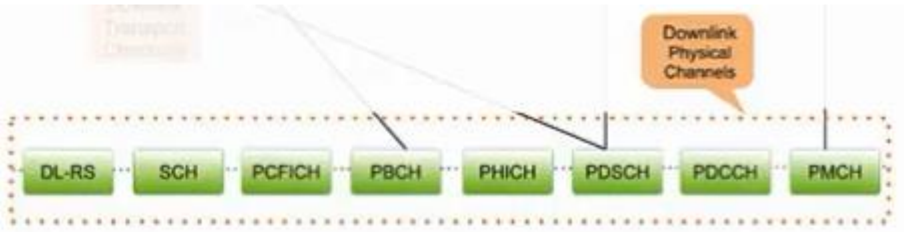
  This LTE transport channel maps to Broadcast Control Channel (BCCH) for broadcasting the vital information about the network in the form of Master Information Block or MIB

- **Downlink Shared Channel (DL-SCH):**

  This transport channel is the main channel for downlink data transfer. It is used by many logical channels.

- **Multicast Channel (MCH):**

  This transport channel is used to transmit MCCH information to set up multicast transmissions.



A Physical Channel are defined by the physical resources, used for Transmitting the data. The physical layer of LTE channels are divided into physical channels, and physical signals, a distinction can be made between:

- **The physical channels are mapped to transport & logical channels that carries information from the upper layer.**
- **The physical signals, does not carry information but are used for Synchronization or measurement.**

The Downlink physical channels are:

- **Physical Downlink Shared Channel (PDSCH):**

  It is a shared channel used to carry user data of radio & core network, system information (BCH), paging message etc.

- **Physical Downlink Control Channel (PDCCH):**

  It is a shared signaling channel to carry the allocation of the resources on PDSCH.

- **Physical Broadcast Channel (PBCH):**

  It is the channel used to broadcast the system information.

- **Reference Signals (DL-RS):**

  The reference signal in LTE is used to represent the cell specific power of an enodeB. Which is similar to the CPICH power UMTS cell.

- **Downlink Synchronization Signal (SCH):**

  There are two Downlink synchronization signals - a primary synchronization signal or PSS and a secondary synchronization signal or SSS. Both consists of a predefined code sequence used for cell detection and initial time and frequency synchronization.

- **Physical Control Format Indicator Channel (PCFICH):**

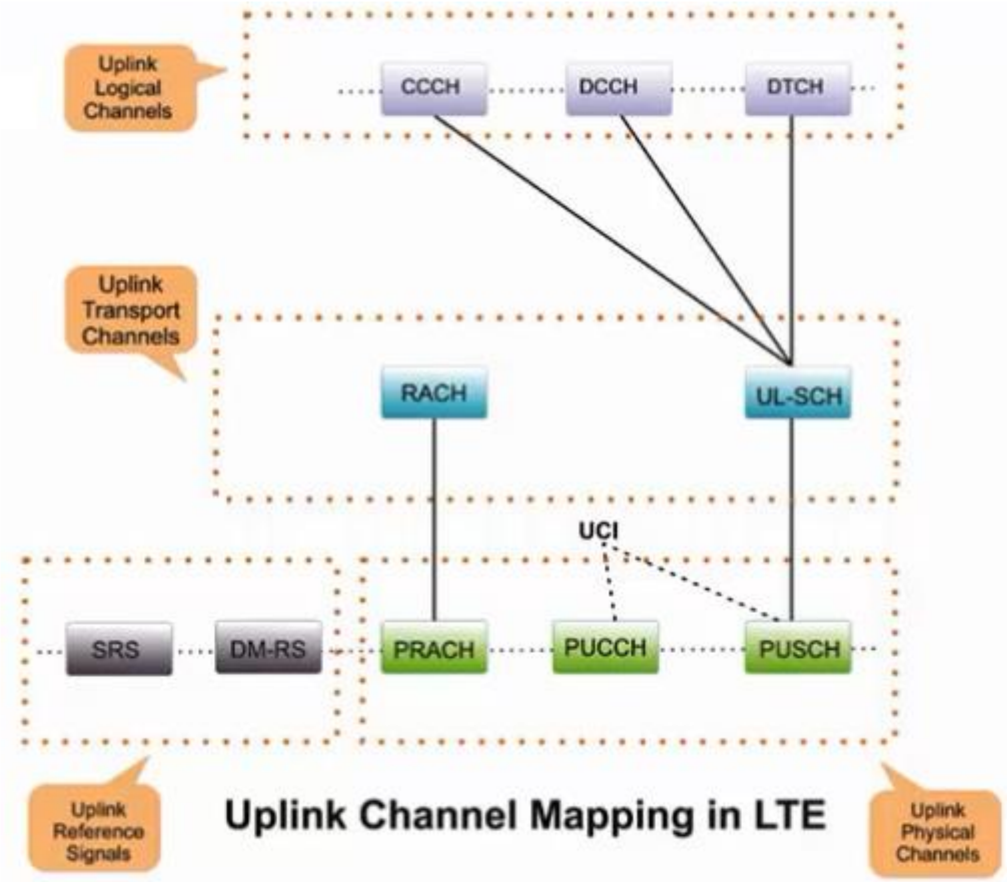
  The PCFICH is like the PDCCH which is a pure physical layer control channel. It indicates how many OFDM symbols are used to encode the PDCCH information.

- **Physical Hybrid ARQ Indicator Channel (PHICH) :**

  This signal is used to report the Hybrid Automatic Repeat Request (HARQ) status. It carries the HARQ ACK/NACK signal indicating whether a transport block has been correctly received. The HARQ indicator is 1 bit long signal where - "0" indicates ACK, and "1" indicates NACK.

Modulation Schemes Used in LTE

The LTE uplink channels are also divided into hierarchal structure of logical, transport and physical channel:



In the transport layer the Uplink has two different transport channels:

- **Random Access Channel (RACH):** This is used for random access procedure, which is used by the User Equipment to ask for the initial access on the network.
- **Uplink Shared Channel (UL-SCH):** This transport channel is the main channel for uplink data transfer. It is used by many logical channels.

Following are the uplink physical channels and signals.

Uplink Physical Signals

- **Demodulation Signals:**
  - This signal is used for channel estimation in the eNodeB receiver, to demodulate control and data channels. This is similar to the reference signal of the uplink.
- **Sounding Reference Signals:**
  - This signal provides uplink channel quality estimation, which is the basis for the Uplink scheduling decisions. This is similar to Channel Quality indicator CQI in Downlink.

Uplink Physical Channels:

- **Physical Random Access Channel (PRACH):**

  Which carries the random access information.
- **Physical Uplink shared channel (PUSCH)**

  Which is used to carry the uplink shared channel information.
- **Physical uplink Control Channel (PUCCH)**

  Which is used to carry the control information required.

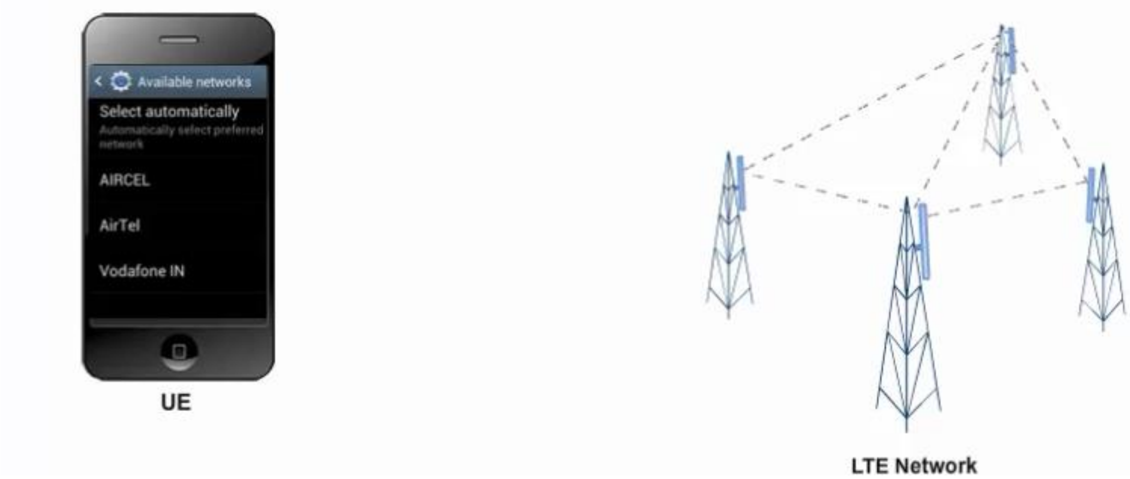
UCI or Uplink Control information is carried by the PUCCH and PUSCH on the physical layer. UCI carry mainly three types of information.

- Scheduling Request
- Hybrid Automatic Repeat Request (HARQ Indication)
- Channel Quality Indicator (CQI)

Módulo 5

Random Access

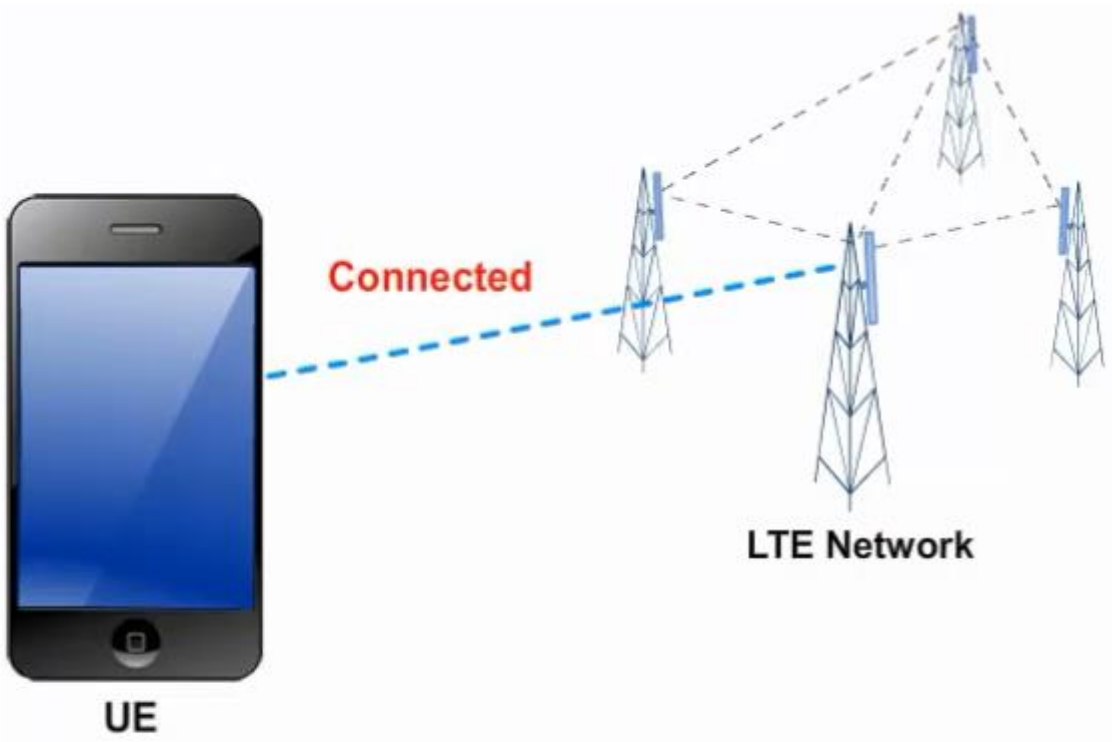
A UE can connect with an available LTE network only if its Uplink is synchronized with the LTE network. For this, LTE uses Random Access (RA) technique.



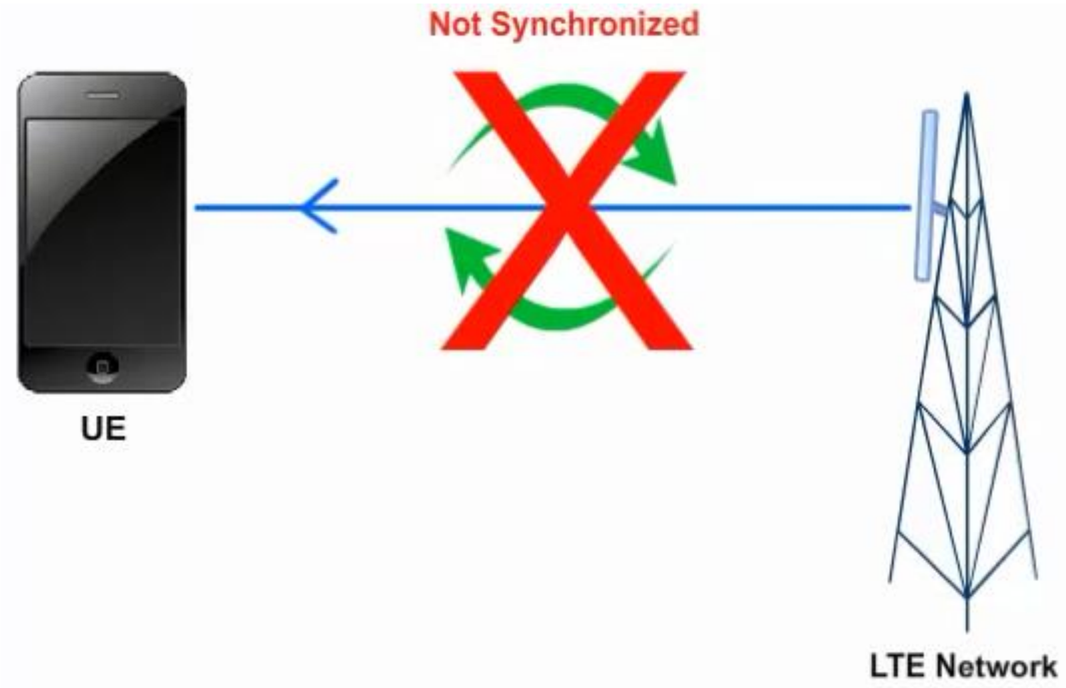
The RA procedure is used in the following cases:

- Initial Access
- RRC Connected
- Handover

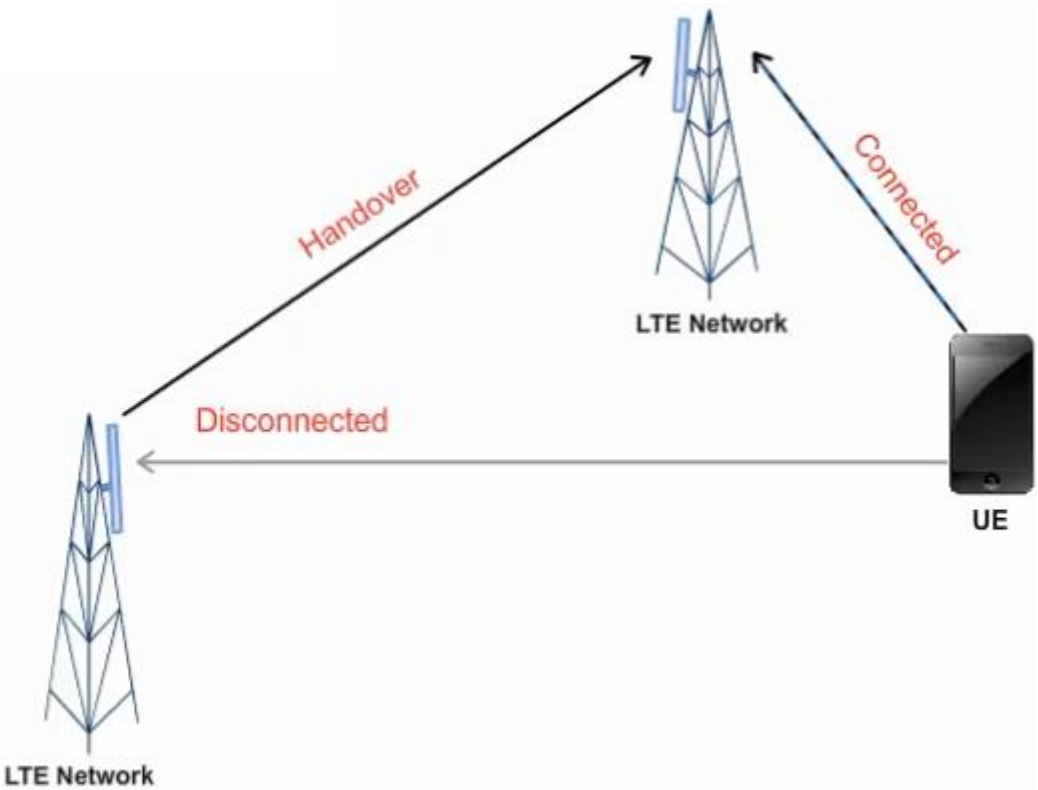
Initial Access

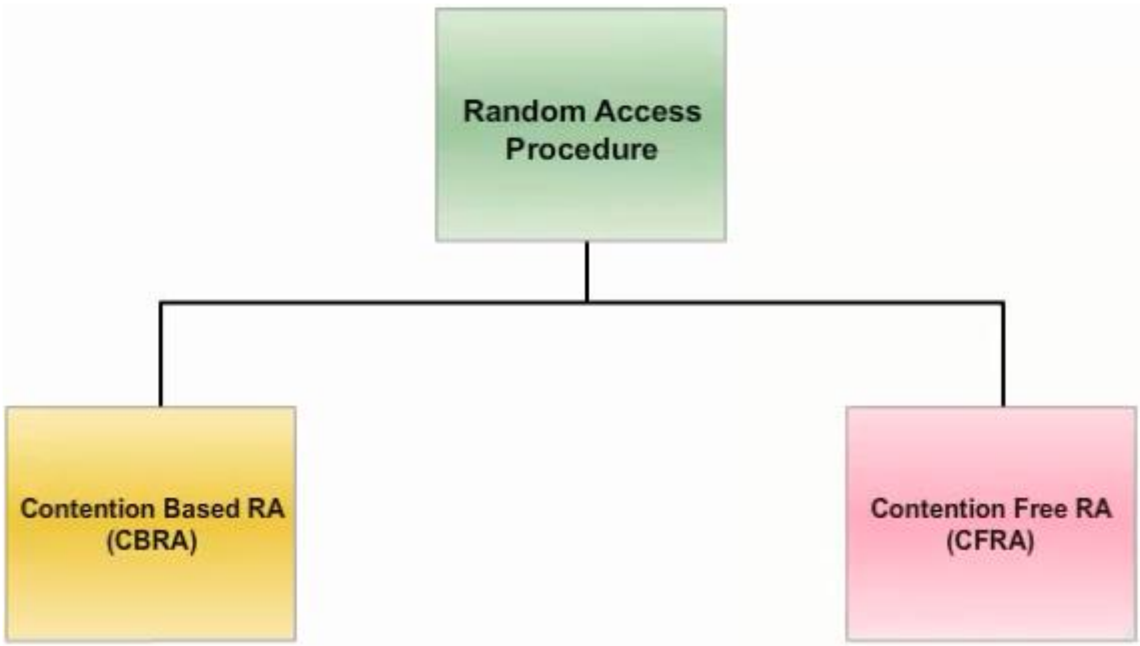


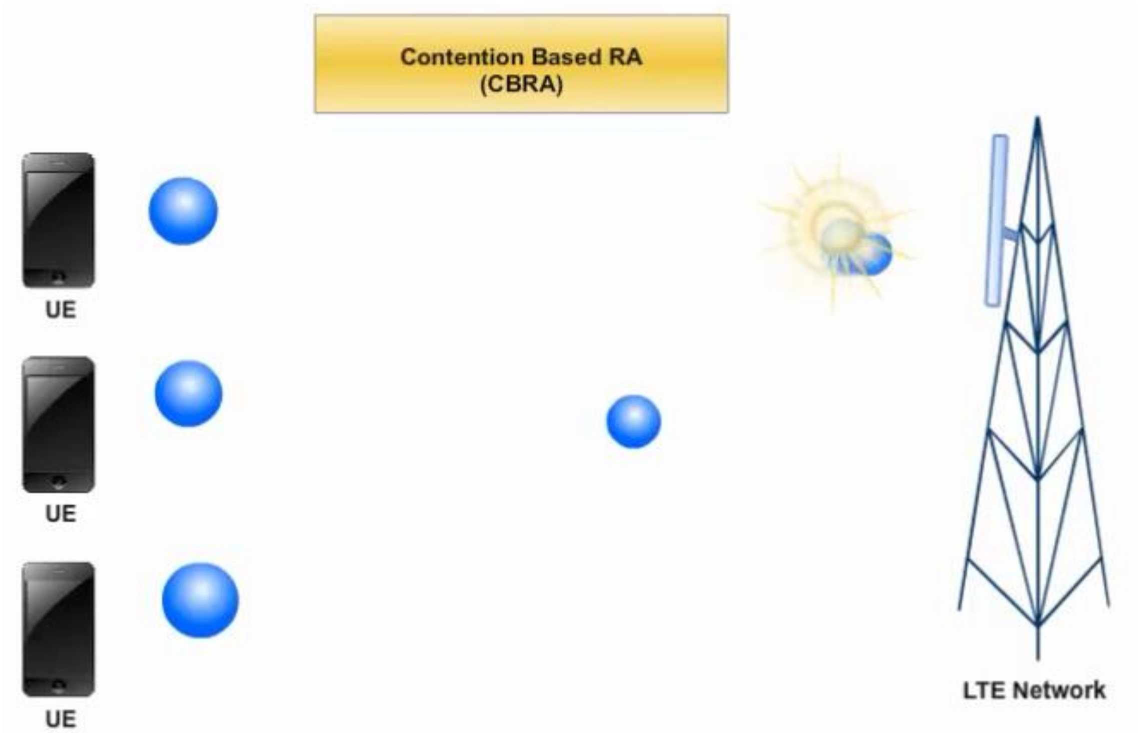
RRC (Radio Resource Control) Connected


Not Synchronized
UE
LTE Network

Handover

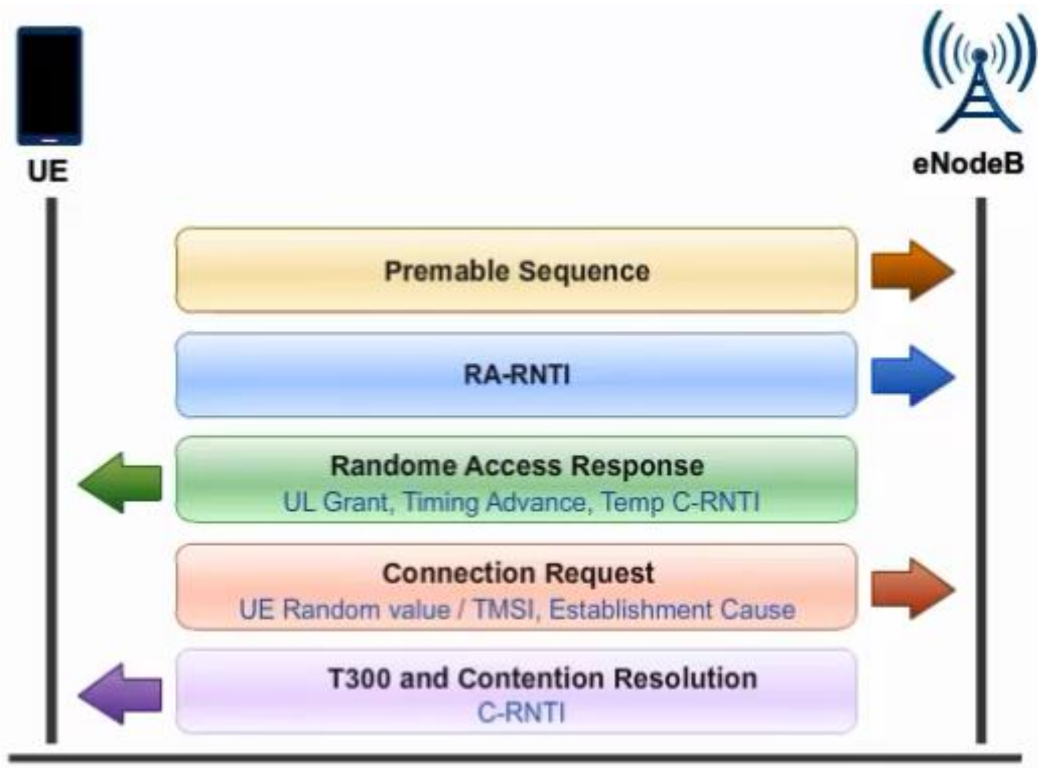

Handover
Connected
LTE Network
Disconnected
UE
LTE Network


Random Access Procedure
Contention Based RA (CBRA)
Contention Free RA (CFRA)


Contention Based RA (CBRA)
UE
UE
UE
LTE Network

Contention Based Random Access (CBRA) Procedure

The CBRA procedure consists of four steps.



Step 1:

- UE selects a preamble sequence.
- UE gives its identity to the LTE network.
- UE sends the preamble again if it does not receive any response from the LTE network.

Step 2:

- eNodeB sends a Random Access Response message to the UE on Physical Downlink Shared Channel (PDSCH).
- The RAR message contains the following information:
  - A temporary Cell ID named C-RNTI
  - One Timing Advance value
  - One UL Grant
  - Optional back-off indicator

Step 3:

- The UE sends an RRC connection request message to eNodeB along with a UE ID.
- UE is identified by the C-RNTI it was given in the preceding step.
- This message contains an establishment cause, which is the reason UE wants to connect to the LTE network.

Step 4:

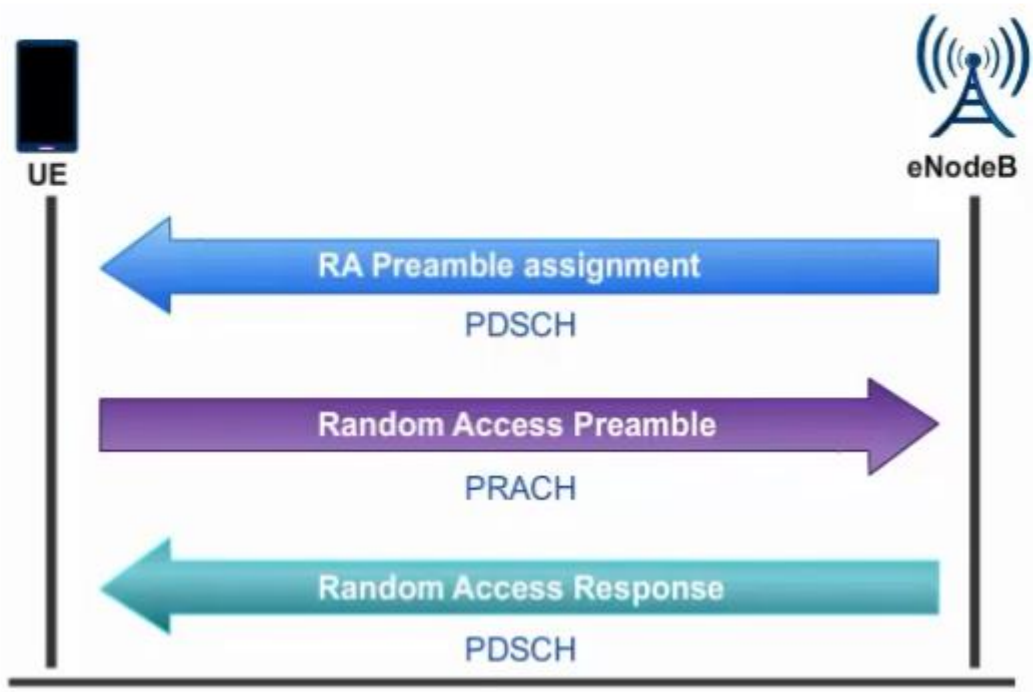
- The following two timers gets activated:
  - **T300:** It defines the amount of time the UE needs to wait for the RRC connection message it has sent in the preceding step. When the T300 timer expires, the RA process starts from the first step.
  - **Contention Resolution Timer:** It is similar to the T300 timer but if it expires, the RA procedure needs to start from the third step.

Contention Free Random Access (CFRA) Procedure

The CFRA procedure is always initiated by eNodeB.

Since the entire process in this procedure is controlled by eNodeB, it does not have any chance of collision.

This procedure consists of three steps.



Step 1:

- The RA preamble is assigned to the UE by the eNodeB via dedicated signaling over PDSCH in DL.

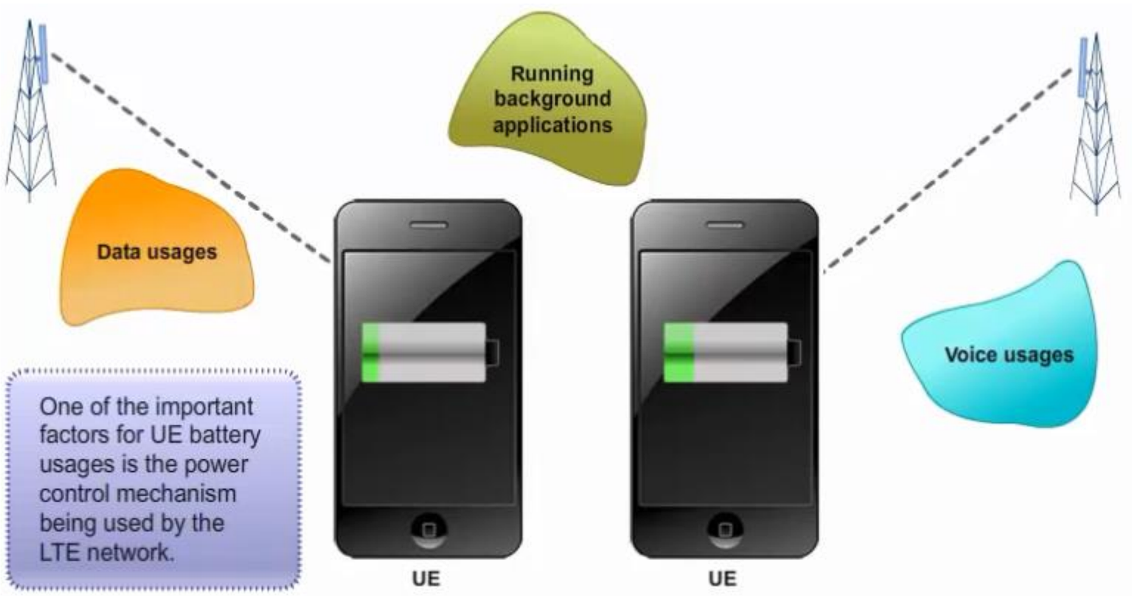
Step 2:

- The UE transmits the assigned non-contention RA preamble to eNodeB on PRACH.

Step 3:

- eNodeB sends a RA response (RAR), which is identified by using RA-RNTI. If the UE finds the same RA preamble ID in RAR, the UE considers that the RA is successful.

Power Control



Como controlar inteligentemente a potência transmitida?

Use a very high gain amplifier

Só funciona se o transmissor e o receptor estão em uma distância razoável. Se a distância for muito próxima. A força do sinal pode saturar o receptor.

How would you handle this situation?

To handle this situation, you can tune down the transmitter amplifier power.

Embora, esta sintonia manual só funciona quando a distância entre o transmissor e o receptor não muda.

What if the distance and channel condition, such as humidity, precipitation, and buildings, between the transmitter and the receiver changes very often?

Use Power Control mechanism

Power Control is an intelligent method of selecting the transmit power of any given node (UE or eNodeB) in the LTE network to achieve good performance.

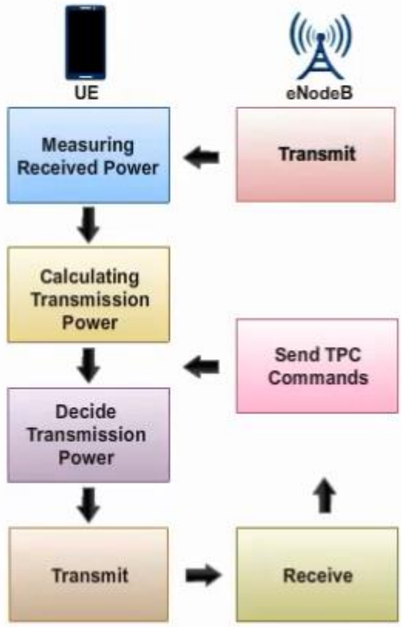
Different types of power control mechanism used in the LTE network are:

- **Closed Loop Power Control**
- **Open Loop Power Control**

Closed Loop Power Control

Process followed in the Closed Loop Power Control mechanism:

- Transmitter sends a signal to receiver.
- Receiver measures the power of the signal sent by the transmitter.
- If the sent power is too low, the receiver sends a special command saying increase the power and if the sent power is too strong, the receiver sends another command saying decrease the power.



In closed loop power control mechanism:

- The transmitter can change its output dynamically.
- The type of command used is called Transmit Power Control (TPC).

Closed loop power control mechanism is used in all kind of mobile communication technologies, such as CDMA, WCDMA, and LTE.

Open Loop Power Control

Baseado em sistema de *feedback*

What if providing feedback is not possible?

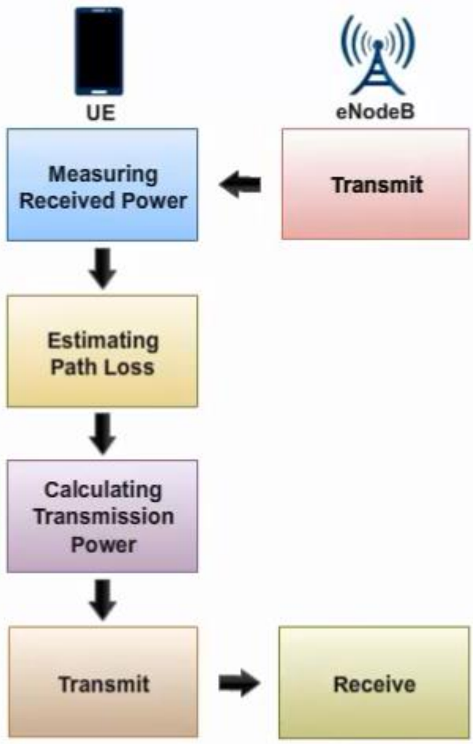
Por exemplo:

If you just turned on your UE and it has to send some signal to an LTE network. How would the UE decide the strength of power signal sent for the first time?

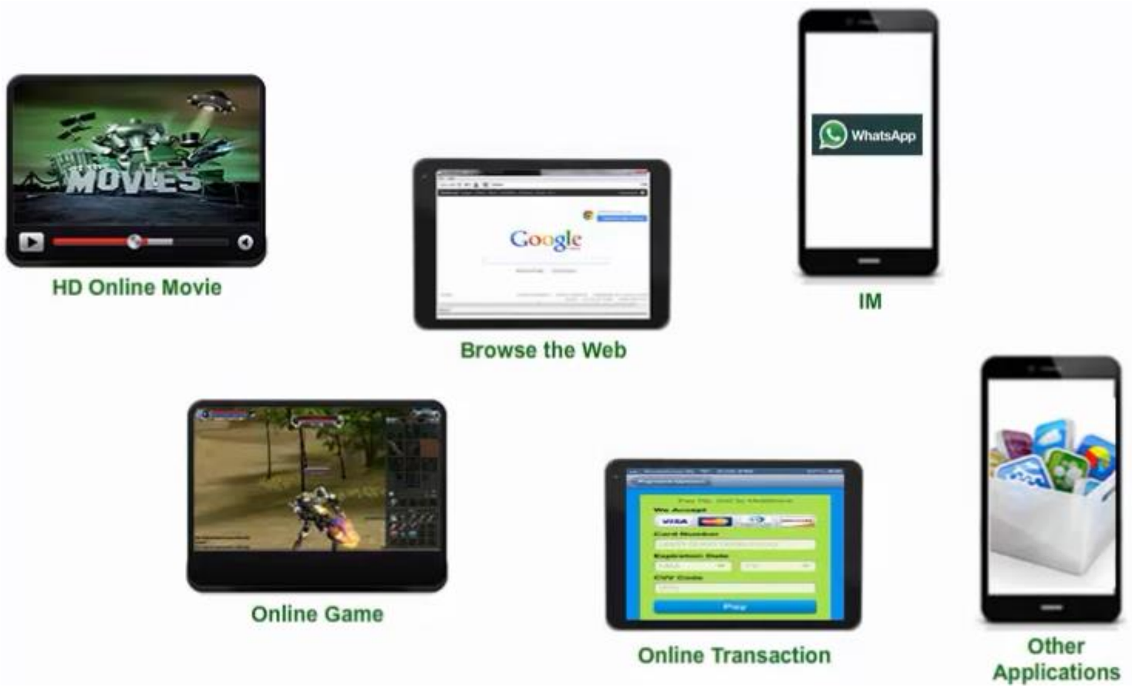
Use open loop power control mechanism

In open loop power control mechanism:

- LTE network transmits reference signals with a fixed power value along with the information about the reference signal it transmits.
- The LTE network transmits the maximum allowable power that a UE can transmit.
- The UE decodes the reference signal coming from the LTE network and estimates the path loss between the UE and the LTE network.
- The UE calculates how much power is allowed to be transmitted from the available information.



Multiple Inputs Multiple Outputs (MIMO)



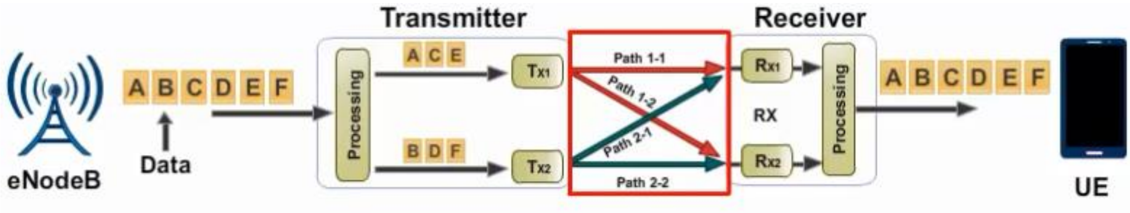
High-Speed Internet

How will be the bandwidth demand of users met, if there is a spectrum crunch?

Use Multiple Input Multiple Output (MIMO) technology

The MIMO technique:

- Is used to generate more data throughput from the existing bandwidth.
- Provides better signal performance and higher data rates.
- Has been included as an integral part of LTE.



Uses of multiple antennas in MIMO provides the following benefits:

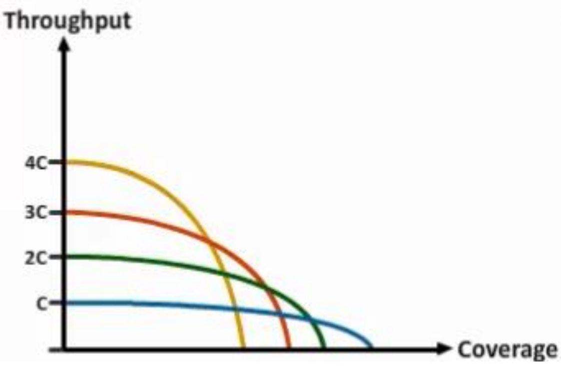
- Reliable operation in poor signal conditions
- Greater system capacity
- Increased data rates for individual users

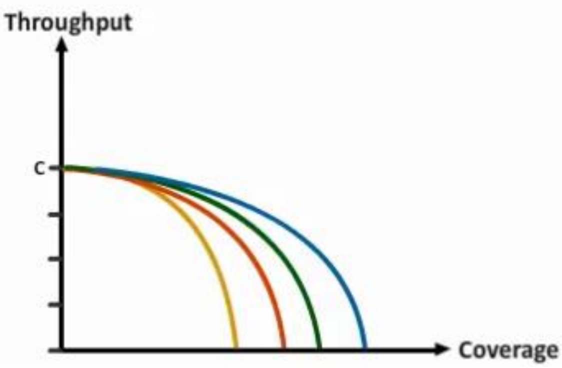
Basic Terminologies used in MIMO techniques are:

- Transmission Layer
- Spatial Multiplexing
- Rank
- PMI Pre-coding Matrix Indicator
- Beamforming

Transmission Layer

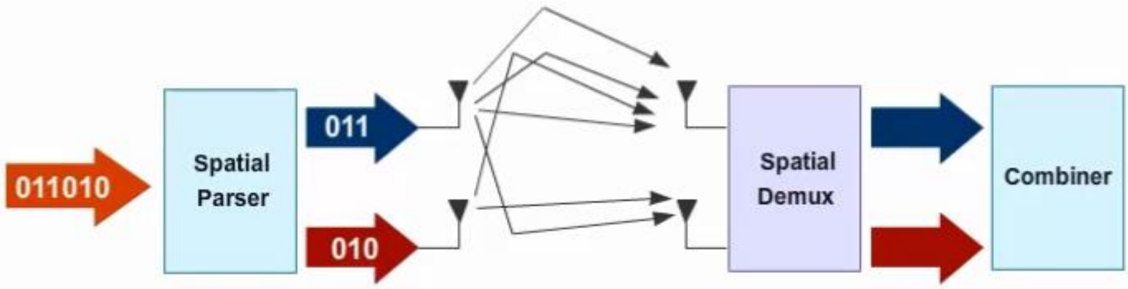
Transmission layer determines the maximum number of antenna stream that can be used to transmit signal streams.
If the same signal stream is being transmitted from all the antenna streams (Transmission Layers), coverage is enhanced but has no impact on the throughput.
However, if the different signal streams are transmitted from the antenna streams, throughput is increased





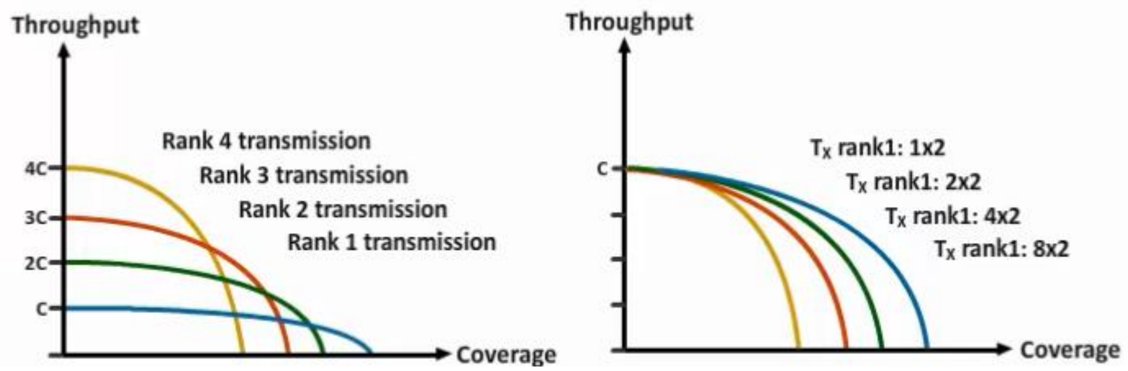
Spatial Multiplexing

Spatial multiplexing creates a number of independent transmission channels between the transmitter and the receiver, which enables multiple different signal streams to be transmitted simultaneously. These signal streams are then reconstructed separately by the UE. This technique increases the data throughput available for an individual user or multiplex data from different users.



Rank

Rank represents the number of different signal streams sent. In LTE, Rank 1 means that the same signal stream is sent from all four antennas and Rank 4 means that different signal streams are sent from all four antennas.

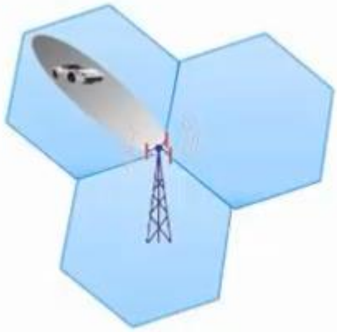


PMI Pre-coding Matrix Indicator

This is a feedback provided by the UE to indicate which kind of coding from a predefined code book the eNodeB should use, which is known to both UE and eNodeB. This feedback is used to determine the optimum precoding matrix for the current channel conditions.

Beamforming

Beamforming is used to improve the coverage area of single UE or a group of UEs. For this, the coverage pattern is changed by creating a constructive interference only between different transmission layers where the UE may also provide a feedback to the eNodeB to improve its coverage area. This can be done by changing the spatial layer and rank to provide better coverage to the UE, based on the feedback provided by the UE about the channel conditions it is experiencing.



Transmission Modes

The following table displays the transmission modes with their description.

TM1	Single Antenna
TM2	Transmit Diversity
TM3	Open Loop Spatial Multiplexing
TM4	Closed Loop Spatial Multiplexing
TM5	Multi User MIMO
TM6	Closed Loop Single Layer Precoding
TM7	Linear Array Beamforming

TM1: Single Antenna

This transmission mode is used in the most basic type of wireless links. In this mode, single data stream is transmitted by using one antenna and received by one or more antennas. Hence, no spatial multiplexing is used in this transmission mode. It is also referred to as Single Input Single Output (SISO) or Single Input Multiple Output (SIMO) depending upon the number of antennas used.

TM2: Transmit Diversity

In this transmission mode, same data streams are transmitted from multiple antennas, each with different coding or frequency resources. Same data is obtained after decoding the streams. This mode increases the coverage area but not increases the data rate.

TM3: Open Loop Spatial Multiplexing

In this transmission mode, two data streams are transmitted over two or more antennas. This transmission mode does not require any feedback, which provides support to fast moving UEs. This transmission mode provides a better throughput.

TM4: Closed Loop Spatial Multiplexing

This transmission mode is similar to the open loop spatial multiplexing, but as the name suggests, it has feedback incorporated to close the loop. A tight PMI feedback is required to provide the instantaneous channel conditions to the eNodeB. Therefore, this mode is not feasible for the fast moving UEs, but it provides a better throughput.

TM5: Multi User MIMO

This transmission mode is similar to close loop spatial multiplexing with the difference being that each spatial layer serves a distinct UE and no PMI feedback is required. The different spatial layers are used for serving different UEs. This type of transmission mode does not increase the throughput of a single user. However, it increases the overall number of users being served.

TM6: Closed Loop Single Layer Precoding

In this transmission mode, the antenna configurations are similar to TM4, but instead of transmit diversity, this mode uses the spatial multiplexing to create a Beamforming effect, which provides a 1 or 2 dB gain over TM2: Transmit Diversity. In addition, as no PMI feedback is required, it is not suitable for fast moving UEs.

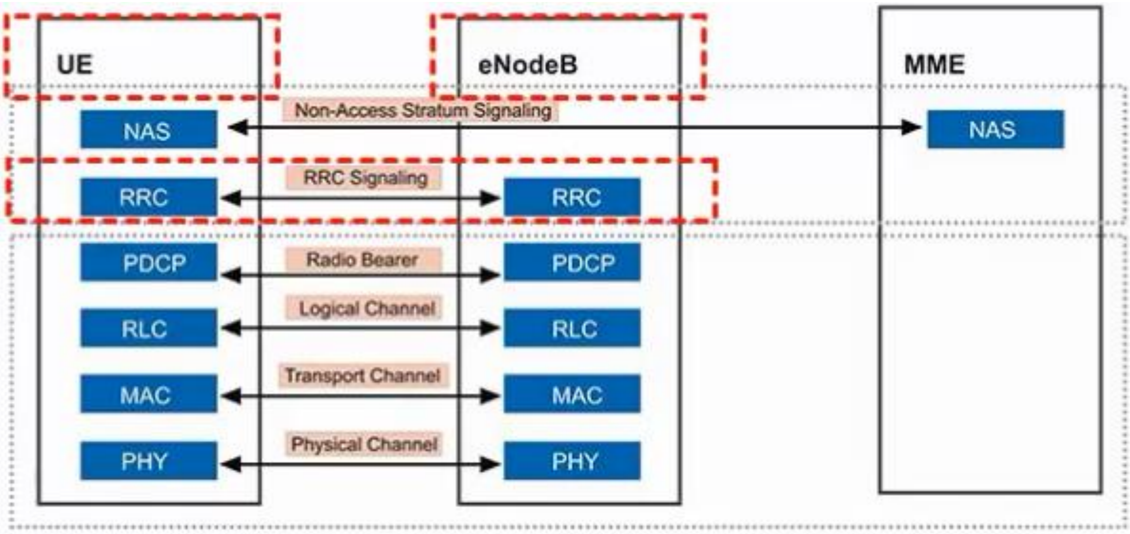
TM7: Linear Array Beamforming

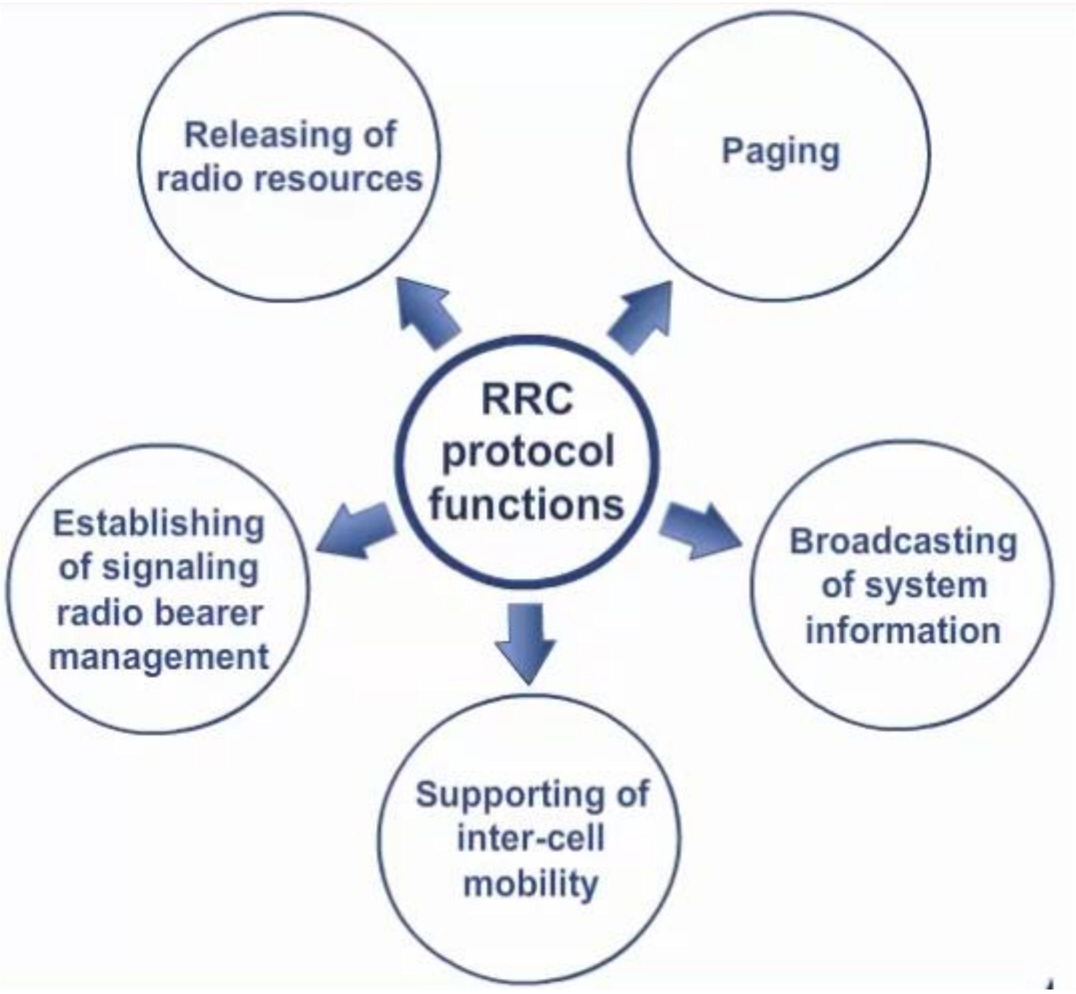
This transmission mode is also a rank 1 mode, which is based on beamforming technique (to focus on a particular area) by using an array of linear antenna. It reduces interference and increases capacity as the specific UE will have a beam formed in their particular direction.

Introduction

Network Resources

The complete process from managing of the available radio resources to controlling, assigning, sharing, and distributing the existing radio resources among the users or entities of the wireless network is known as Radio Resource Management (RRM).





RRC Functions and Procedures

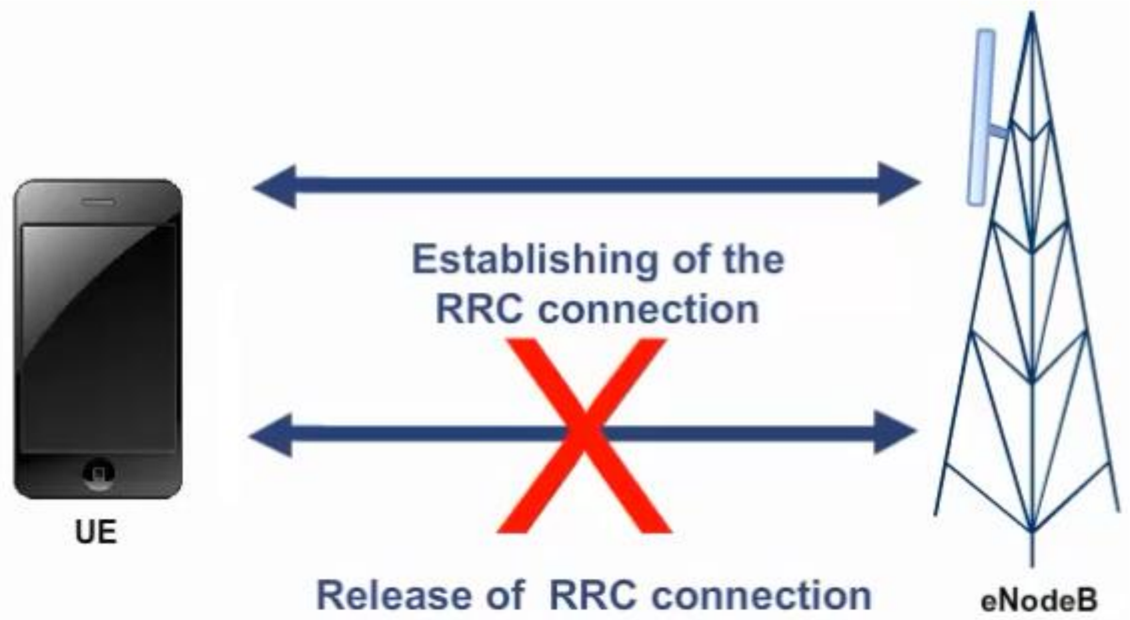
RRC functions can be categorized into the following tasks:

Broadcast of System Information

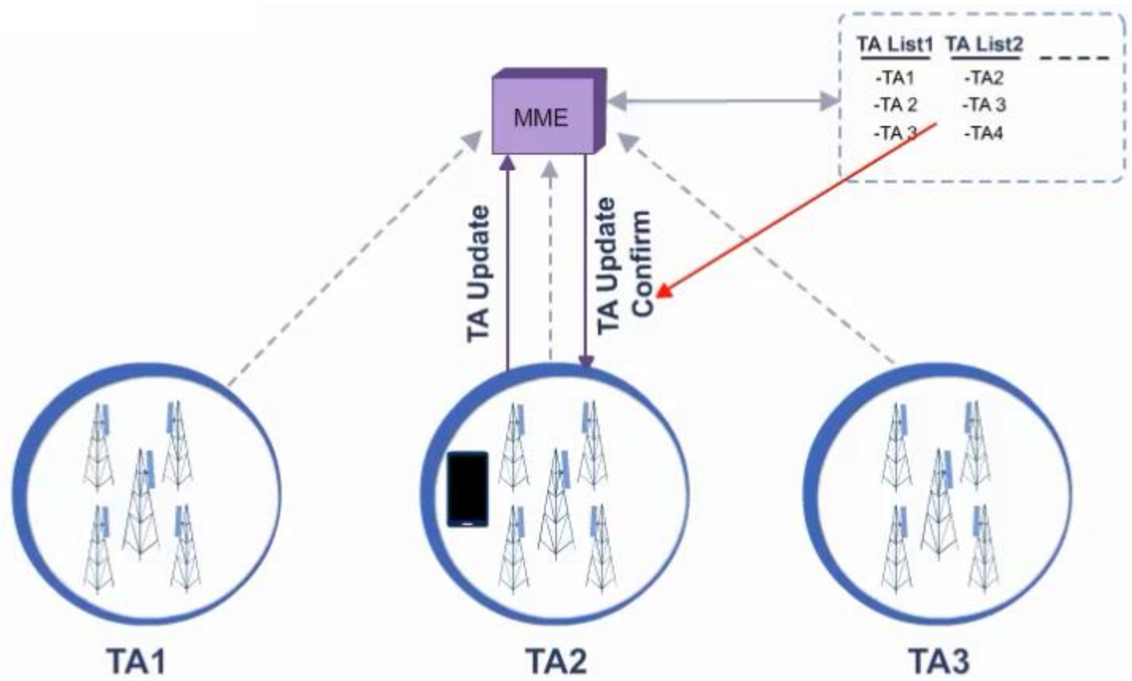
- It includes information related to the Non-Access-Stratum (NAS) as well as the Access-Stratum (AS).
- Includes information applicable for UEs in RRC_IDLE state, such as cell selection/reselection parameters and neighboring cell information.
- Includes information application for UEs in RRC_CONNECTED state, such as common channel configuration information.

Paging

Radio Resouce Control (RRC) Connection Management



Mobility Management



TA = Tracking Area

Important RRC Messages

Before the random access procedure, UE needs to read the system broadcast information, which helps the UE to perform cell selection or reselection, and read the PLMN ID and other broadcast information.

To provide all this system information to the UE, LTE has divided this system information into the following two parts:

- Master Information Block (MIB)
- System Information Block (SIB)

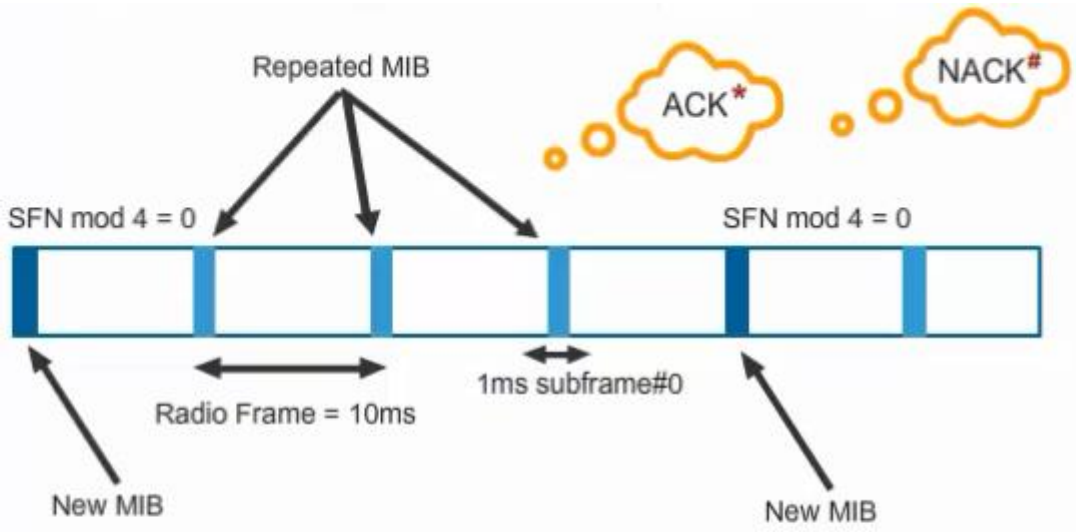
Master Information Block (MIB):

- Contains some of the most important and frequently transmitted parameters, which are needed by the UE to get other information from eNodeB.
- Is the first thing that a UE needs to read after it establishes downlink synchronization.
- The transmission of MIB is done on BCCH logical channel → BCH transport channel → PBCH physical channel.
- It contains:
  - DL-bandwidth
  - System Frame Number (SFN)
  - Physical Hybrid ARQ Indicator Channel (PHICH) configuration

DL – Number of resources and blocks.

SFN – Helps in synchronization and access at time reference.

PHICH – Used to carry ACK and NACK from the uplink data.



System Information Block (SIB):

- The second part SIB transmits significant information that helps the UE in accessing an eNodeB and performing eNodeB re-selection.
- SIBs are of 13 types.
- SIBs are transmitted on BCCH → DL - SCH → PDSCH channel.
- In an LTE network, MIB, SIB-1, and SIB-2 are the most important and mandatory information to be transmitted for any cell to provide the services to the UE.
- All other SIBs are optional, and they can be scheduled dynamically based on the scheduling information given in SIB-1.

SIBs	Function
SIB-1	Contains information related to cell access and scheduling of other SIBs
SIB-2	Contains information related to channel configuration and RACH
SIB-3	Contains information required for intra-frequency, inter-frequency, and I-RAT cell re-selections
SIB-4	Contains information required for INTRA-frequency neighboring cells (E-UTRA)
SIB-5	Contains information required for INTER-frequency neighboring cells (E-UTRA)
SIB-6	Contains information required for INTER-RAT (UTRAN cells)
SIB-7	Contains information required for re-selection to INTER-RAT (GERAN cells)
SIB-8	Contains information required for re-selection to INTER-RAT (CDMA2000)
SIB-9	Contains information related to Home eNodeB (FEMTOCELL)
SIB-10	Contains information for an Earthquake and Tsunami Warning System (ETWS) primary notification
SIB-11	Contains information for an Earthquake and Tsunami Warning System (ETWS) secondary notification
SIB-12	Contains Commercial Mobile Alert Service (CMAS) information
SIB-13	Contains Multimedia Broadcast Multicast Service (MBMS) control information

SIB-1 contains information required by the UE to access a cell. It includes:

- The PLMN information
- Cell ID
- Tracking Area Code (TAC)
- Cell selection information
- Frequency band indicator
- Scheduling information of other SIBs

SIB-1 has a fixed scheduling, which is broadcasted after every 80ms and the same is repeated after every 20ms.

SIB-2 is considered as the most important SIB in the LTE network. The information that it contains helps in implementing the protocol stack and troubleshooting. It contains the following important information:

- Power control configuration, such as PUSCH/PUCCH
- RACH configuration, which helps UE in starting the random access procedure
- Timers and other RRC information without which the UE will not be able to initiate a attach procedure
- Initial preamble power and Max HARQ retransmission
- Paging configuration

SIB-3 contains information required for intra-frequency, inter-frequency, and I-RAT cell re-selections parameters, such as cellReselectionInfoCommon, cellReselectionServingFreqInfo, intraFreqCellReselectionInfo, neighCellConfig and p_Max. However, this information is not applicable in all scenarios.

SIB-4 contains E-UTRA information required for Intra-LTE intra-frequency cell selections, such as neighbor cell list, black cell list, and physical cell ID.

SIB-5 contains E-UTRA information required for Intra-LTE inter-frequency cell re-selection, such as neighbor cell list, cell reselection priority, carrier frequency, and the threshold used by the UE while reselecting a higher or lower priority frequency than the current serving frequency.

SIB-6 contains information required for INTER-RAT (UTRAN cells) cell re-selection, such as carrier frequency list, cell re-selection priority, minimum required Rx level, threshold used by UE while re-selecting a higher or lower priority frequency than the current serving frequency, and cell re-selection timer value for UTRAN.

SIB-7 contains information required for IRAT cell-reselection to INTER-RAT (GERAN cells), such as carrier frequency info list, cell-reselection priority, minimum required Rx level, threshold used by the UE while re-selecting a higher/lower priority frequency than the current serving frequency, and cell-reselection timer.

SIB-8 contains information required for re-selection to INTER-RAT (CDMA2000) systems.

SIB-9 contains information related to Home eNodeB (FEMTOCELL) like a hnb_name. FEMTOCELL is a small base station used in residential area or by small businesses.

SIB-10 contains information for an Earthquake and Tsunami Warning System (ETWS) primary notification. ETWS is a public warning system. Here, paging system is used to inform the ETWS capable UEs in RRC_IDLE and RRC_CONNECTED modes to listen to SIB-10 and SIB-11.

SIB-11 contains information for an Earthquake and Tsunami Warning System (ETWS) secondary notification.

SIB-12 contains information related to Commercial Mobile Alert Service (CMAS) notification. The CMAS notification contains high emergency situations and is defined for three categories, presidential alerts, threat alert, and AMBER alerts (Used in child abduction and endangered situation).

SIB-13 contains information required to acquire the Multimedia Broadcast Multicast Service (MBMS) control information associated with one or more MBSFN areas.

Paging

The paging procedure is required in any of the following cases:

- Transmit paging information to a UE in RRC_IDLE mode.
- Inform UEs in RRC_IDLE and RRC_CONNECTED mode about a system information change.
- Inform UEs about an ETWS primary or secondary notification.
- Inform UEs about a Commecial Mobile Alert Service (CMAS) notification.

- Paging is a procedure in which the UE can reconnect to the LTE network, if required. Otherwise, it can remain in RRC_IDLE mode to save the battery.
- UEs use Discontinuous Receive (DRx) when in RRC_IDLE mode in order to wake up at regular intervals to check for paging messages.
- To better understand paging, let us know about Paging Occasion (PO) and Paging Frame (PF).

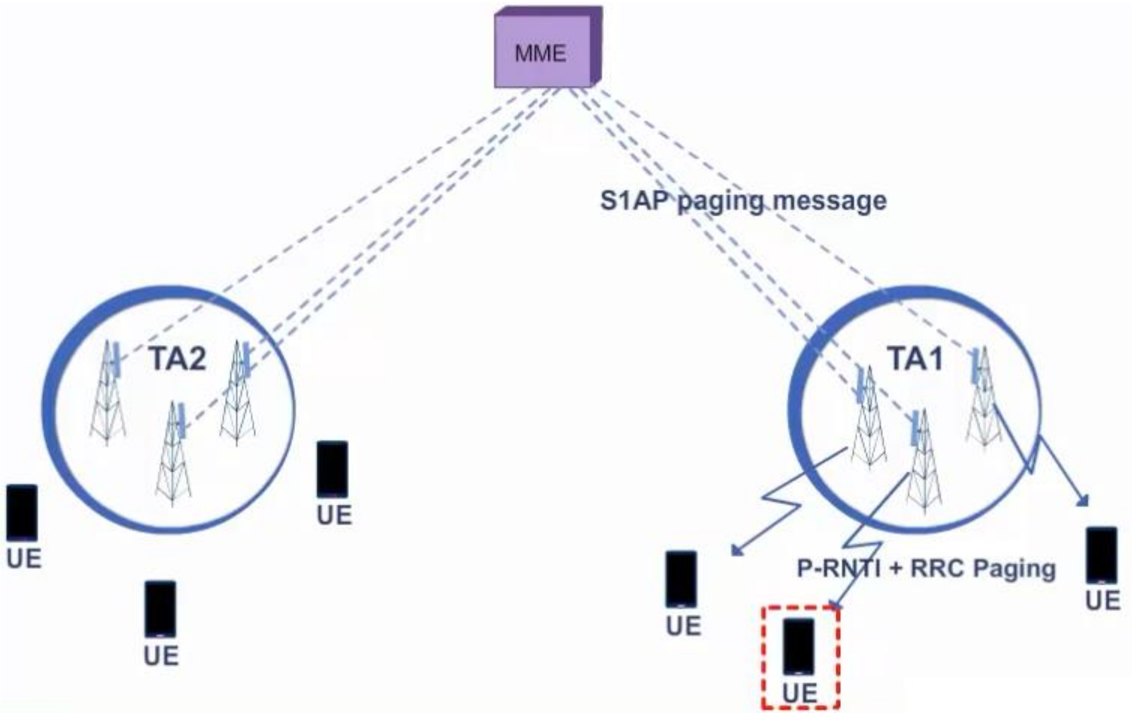
Paging Occasion

- It is a subframe where P-RNTI is transmitted on PDCCH addressing the paging message for the UE.
- There is always one paging occasion for each UE in a DRx cycle.
- P-RNTI is a random number, which the UE searches for.
- After finding its P-RNTI, UE decodes the PDCCH information. Otherwise, it goes back into the RRC_IDLE state.

Paging Frame

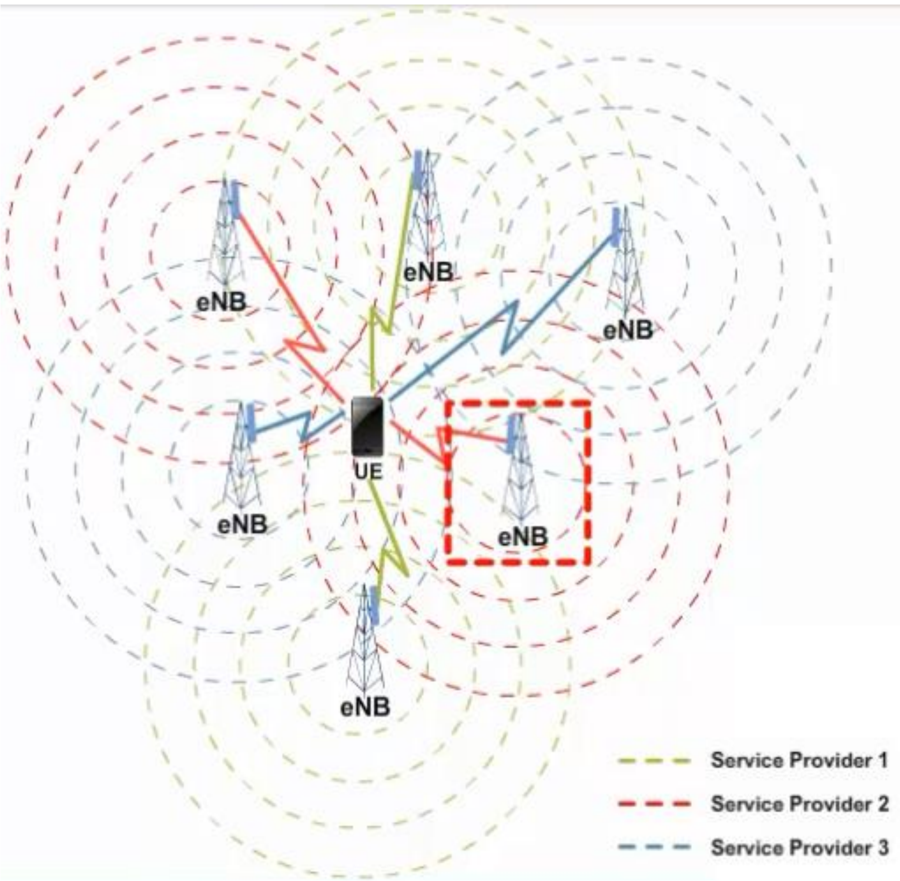
- It is a Radio Frame in which the UE looks for the paging message.
- One paging frame can contain one or multiple paging occations.

Paging Procedure



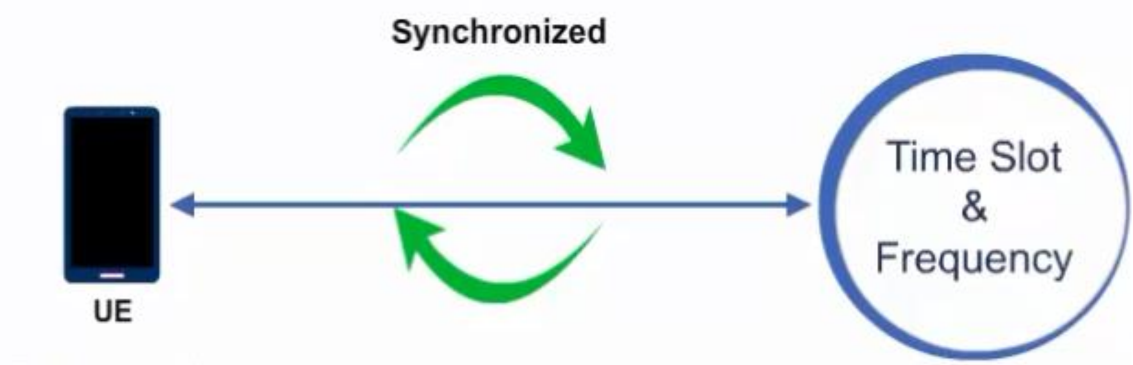
Paging response.

Cell Search Procedure



Which specific eNodeB the UE has to camp on?

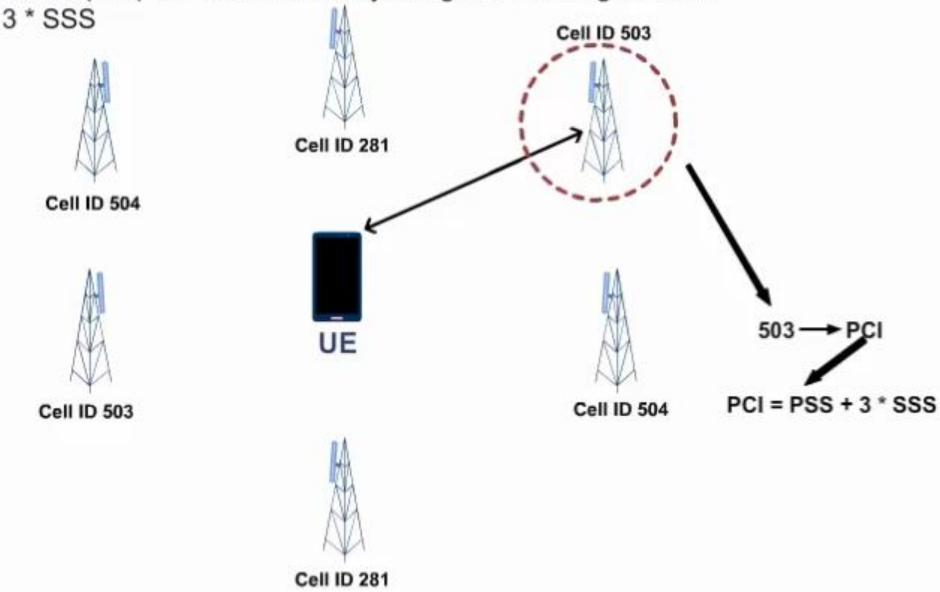
The UE needs to go through a specific decision-making process to pick up a specific eNodeB to camp on. This specific process is called as cell search process.



CELL ID : 2473

- LTE uses hierarchical cell search procedure, which is identified by 504 different cell ID's. This is divided into 168 unique physical cell layer ID or Secondary Synchronization Signal (SSS).
- SSS contains 3 physical cell layer IDs or Primary Synchronization Signal (PSS).

- In LTE network, PSS and SSS are periodically transmitted from eNodeB.
- The physical cell ID (PCI) can be identified by using the following formula:
  PCI = PSS + 3 * SSS

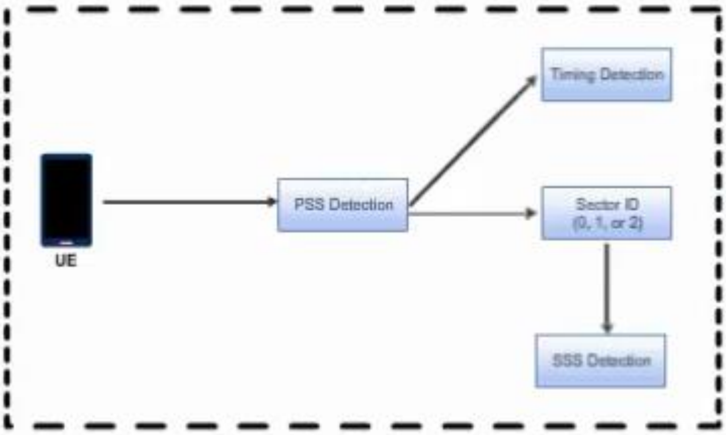


Some of the situations where a UE needs to go through the cell search process are:

- When you first time switch on a phone
- When you power off your phone and then power it on
- When you switch your phone to Airplane mode, and then switch back to normal mode

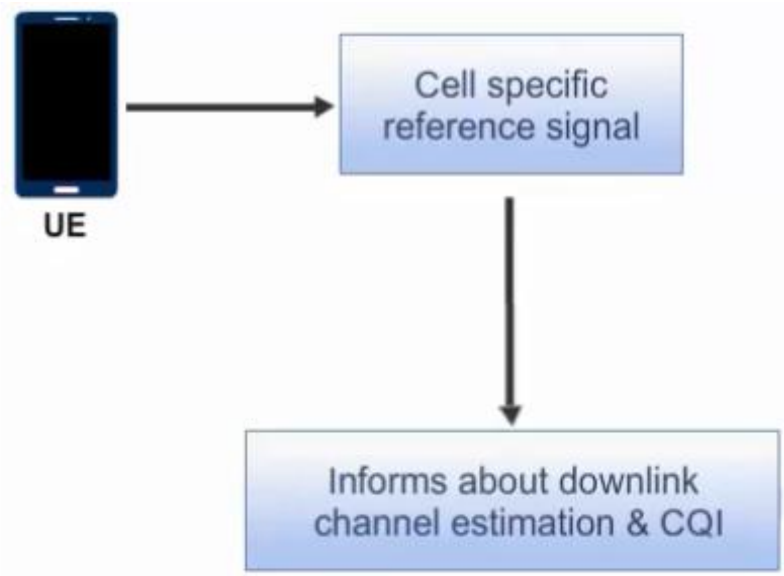
Now, let us understand the cell search procedure into the following three steps:

Step 1:



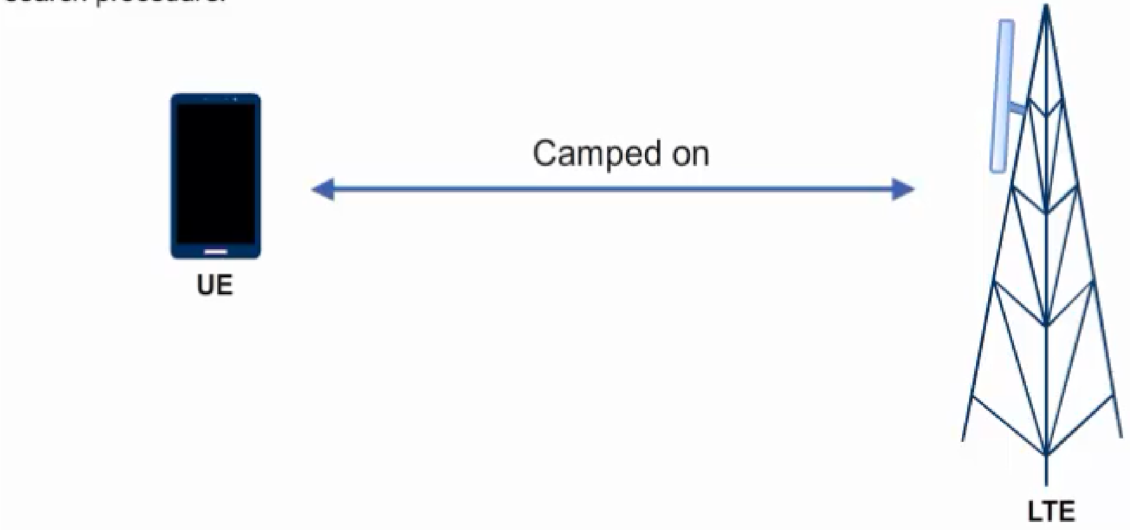
- Using this PSS and SSS, UE finds out the physical cell ID.

Step 2:

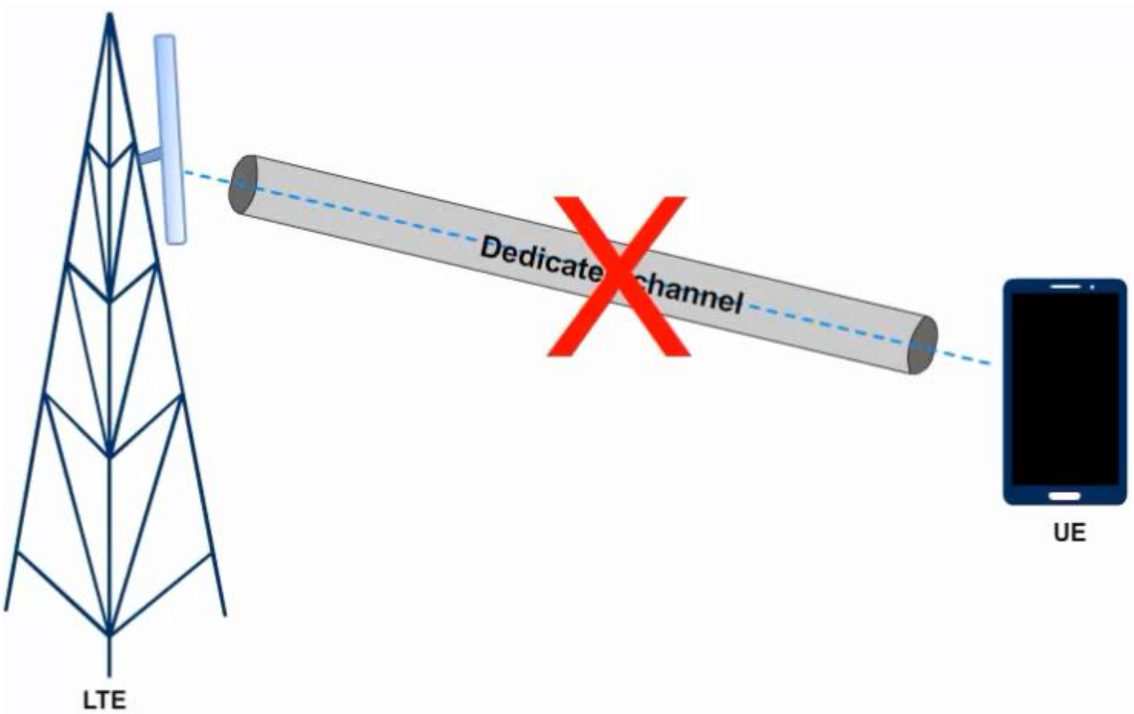


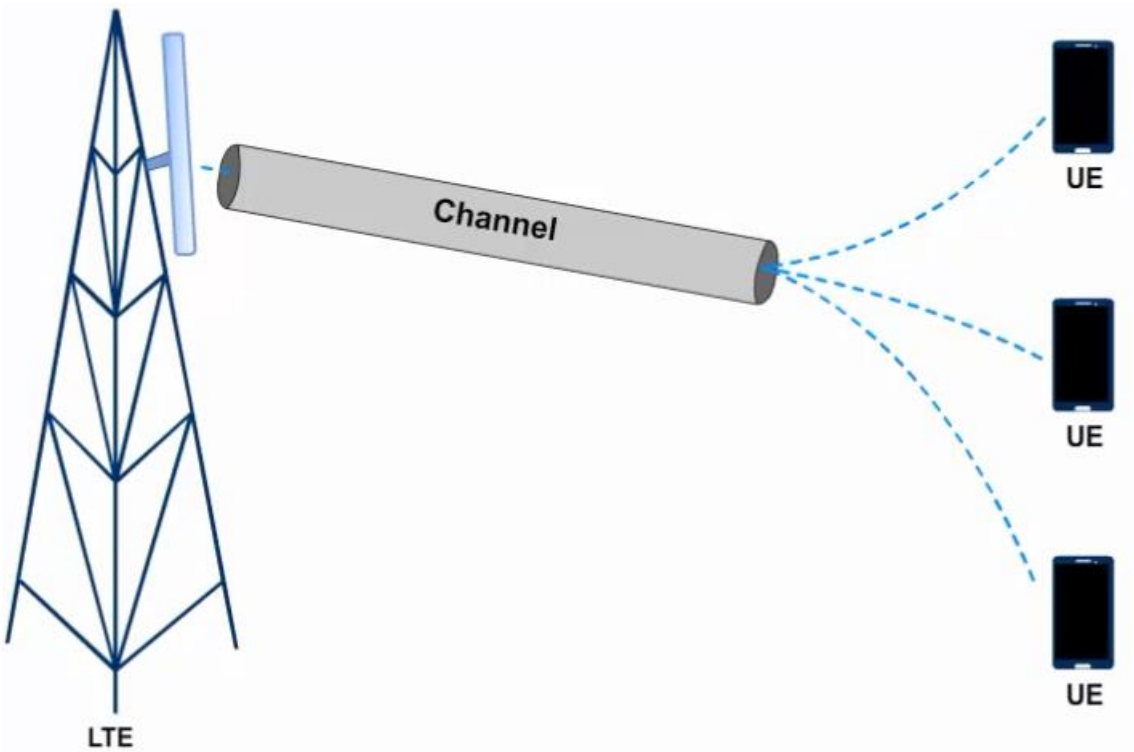
Step 3:

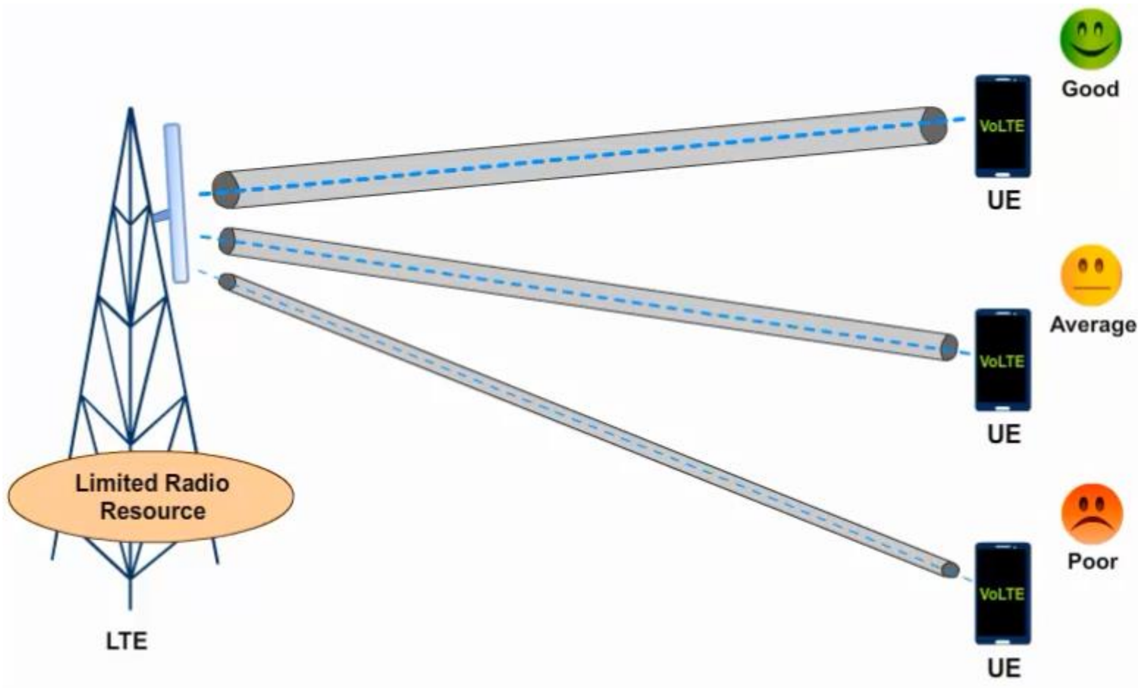
In the final step, UE reads the system information: MIB, SIB1, and SIB2, required for the cell search procedure.



Scheduling in LTE

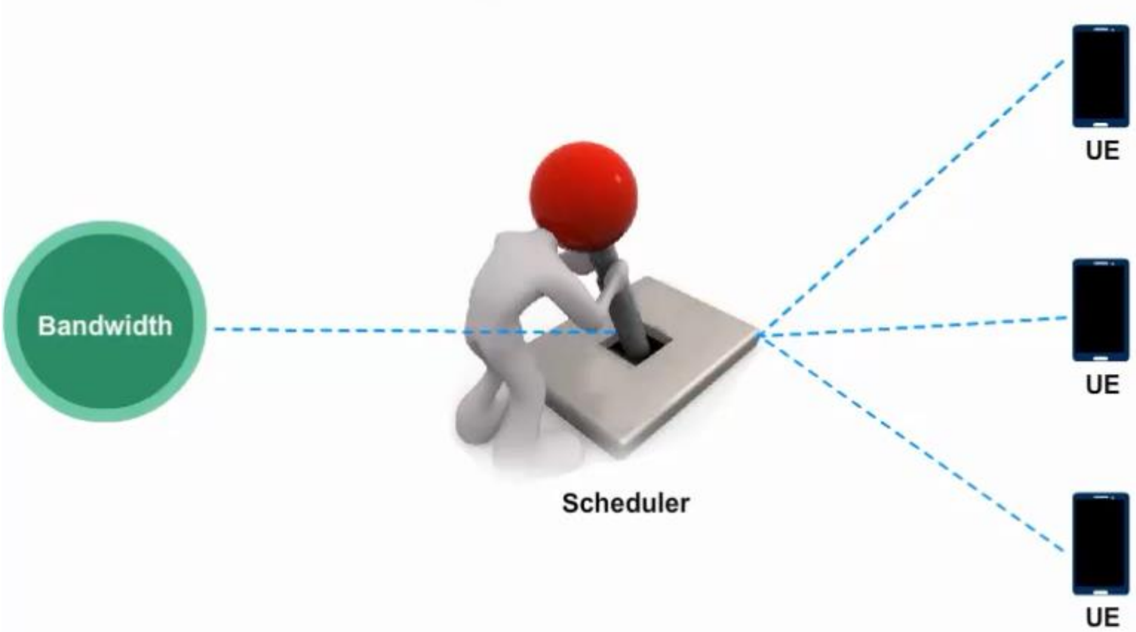

Dedicated channel
UE
LTE

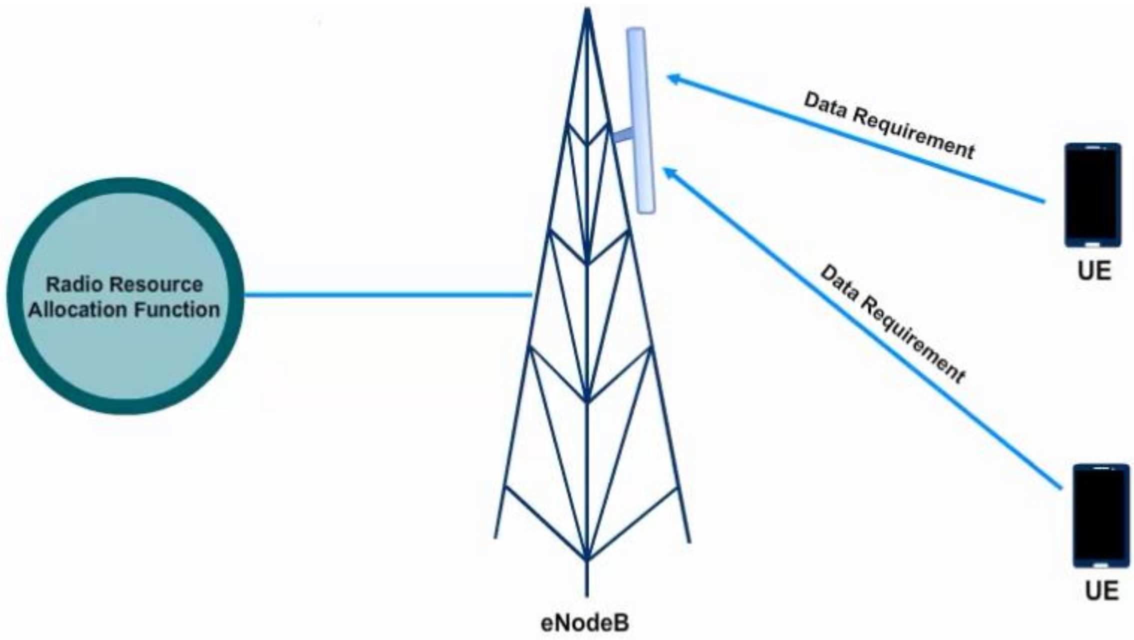

Channel
UE
UE
UE
LTE



Radio Resources

For this, LTE network uses a technique called as scheduling.





Data Requirement -> Data Delivered

However, before studying scheduling in detail, let us first understand some basic terminologies.

Bearer

It is like a virtual tunnel that carries data in an LTE network.

In addition, it defines the way transmitted data needs to be treated when it travels in the LTE network.

This treatment is done in consideration of the priority of data delivery.

This priority depends on two factors, provided services and user profiles.

For example, some services, such as VoLTE, require guaranteed bit-rate whereas with some services, such as the Web browsing, bit rate can be compromised.

Similarly, there may be some privileged users to whom higher data rates need to be provided.

- In simple words, you can say that bearers are sets of network parameters that define data specific treatment.
- In LTE, the following two types of bearers are available:
  - Default Bearer
  - Dedicated Bearer

Default Bearer

Each default bearer has its own IP address and a UE can have multiple default bearers each with a unique IP address.

With this bearer, speed and quality of service may vary depending on the network usage and time of the day.

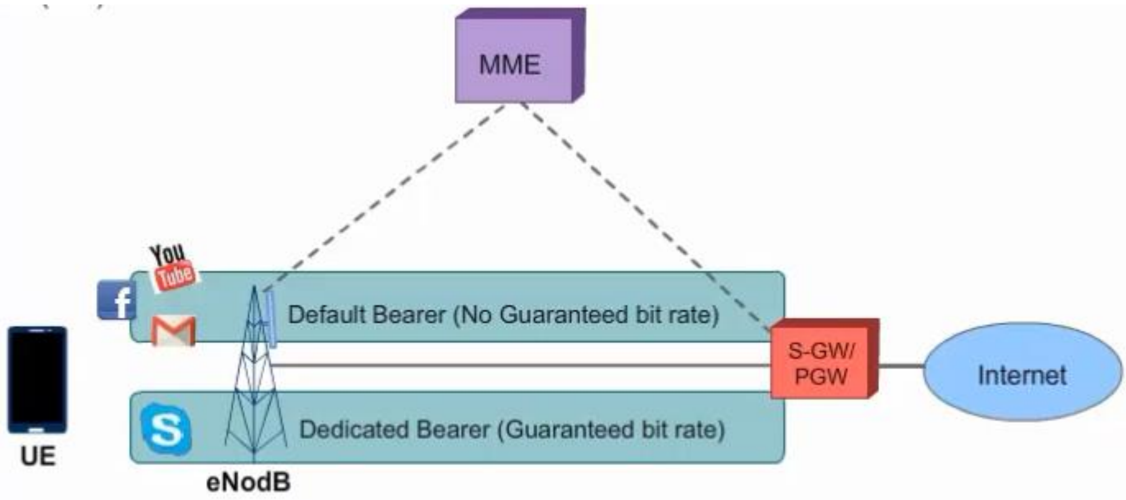
What is the need of a dedicated bearer when each UE already has a default bearer?

What if you need guaranteed bit-rate which is not supported with the default bearer?

Dedicated Bearer

Dedicated bearer is useful in maintaining high voice quality and improving user experience, which is a need for VoLTE.

To assign special rule of treatment to specific data or services, the service providers use a Traffic Flow Template (TFT).



GBR (Guaranteed Bit Rate):

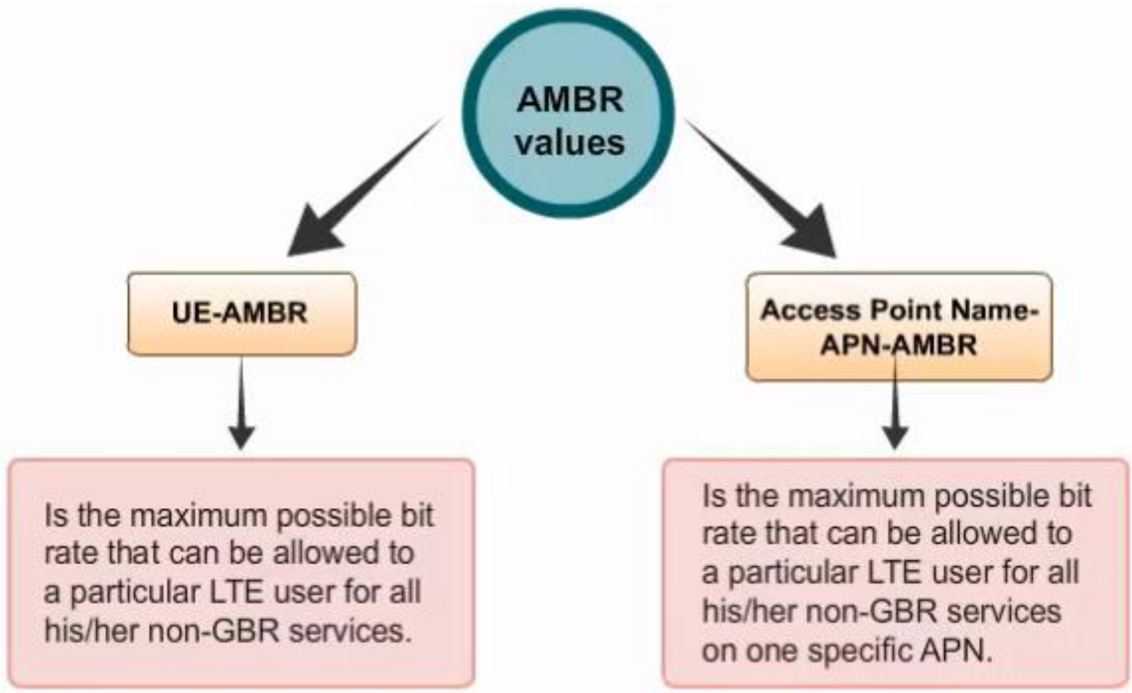
- It is the minimum guaranteed bit rate that is requested by a service or an application.
- It is separately specified for both, uplink and downlink, transmission.
- Its bit rate is pre-determined and associated with the bearer. However, bit rates can be increased based on the availability of resources.
- A GBR bearer is generally used for VoLTE (Voice Over LTE).
- Basically, a GBR bearer is established based on demand as it blocks the resources used for data transmission.
- In addition, GBR ensures that congestion-related packet loss will not occur while transmission.

Non-Guaranteed Bit Rate (Non-GBR):

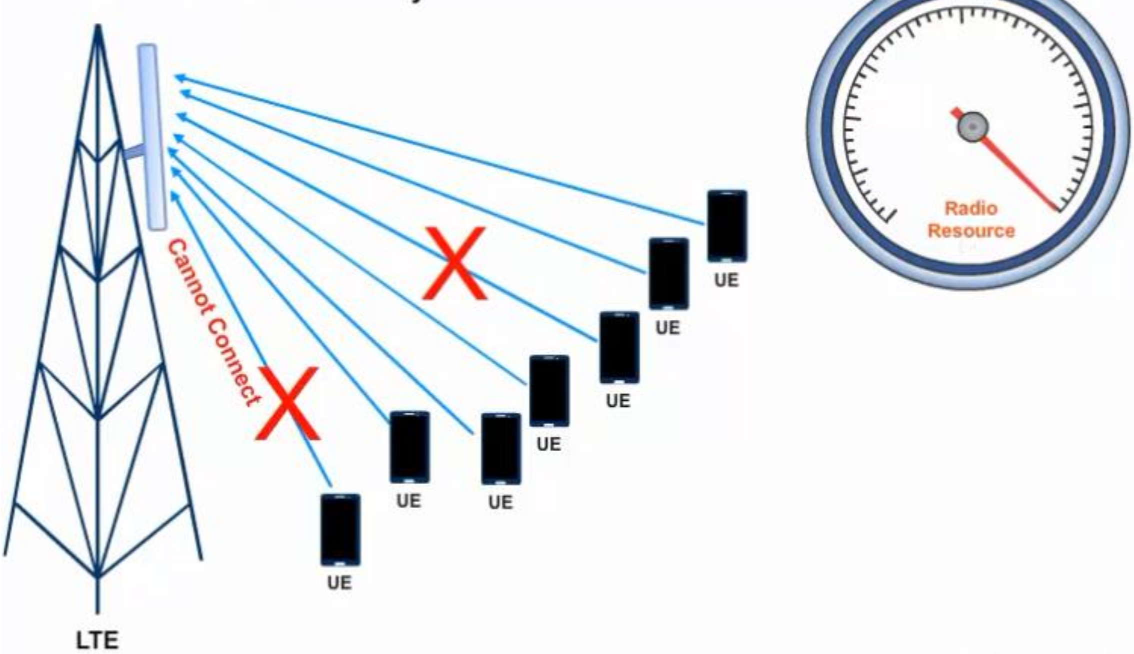
- This bearer does not provide any minimum guaranteed bit rate like a GBR bearer and is prone to packet loss due to congestion.
- It does not block any specific transmission resource at any point of time as done by the GBR bearer.

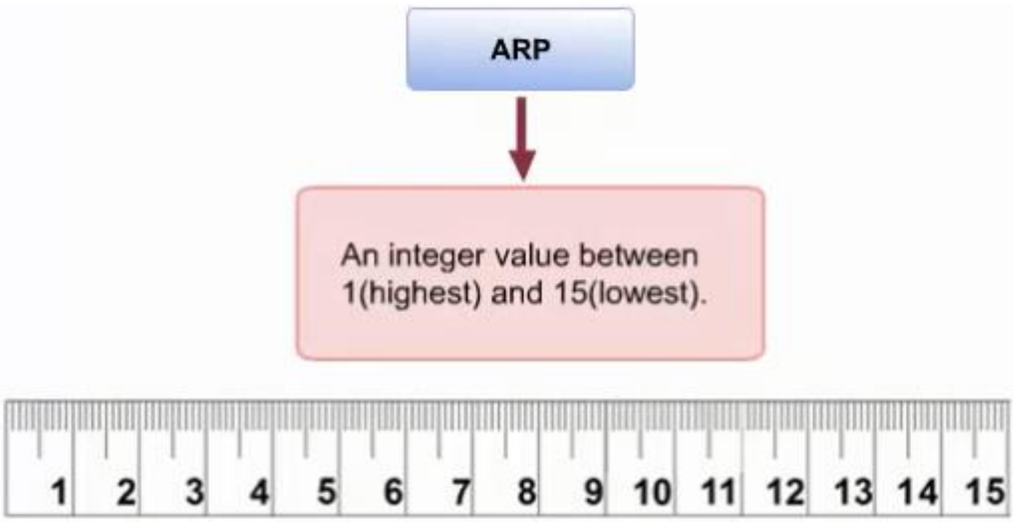
Aggregated Maximum Bit Rate (AMBR)

- It defines the maximum possible bit rate that can be allocated to a specific LTE user.
- It is defined only for non-guaranteed bit rate services preventing from taking-over all the available bandwidth.



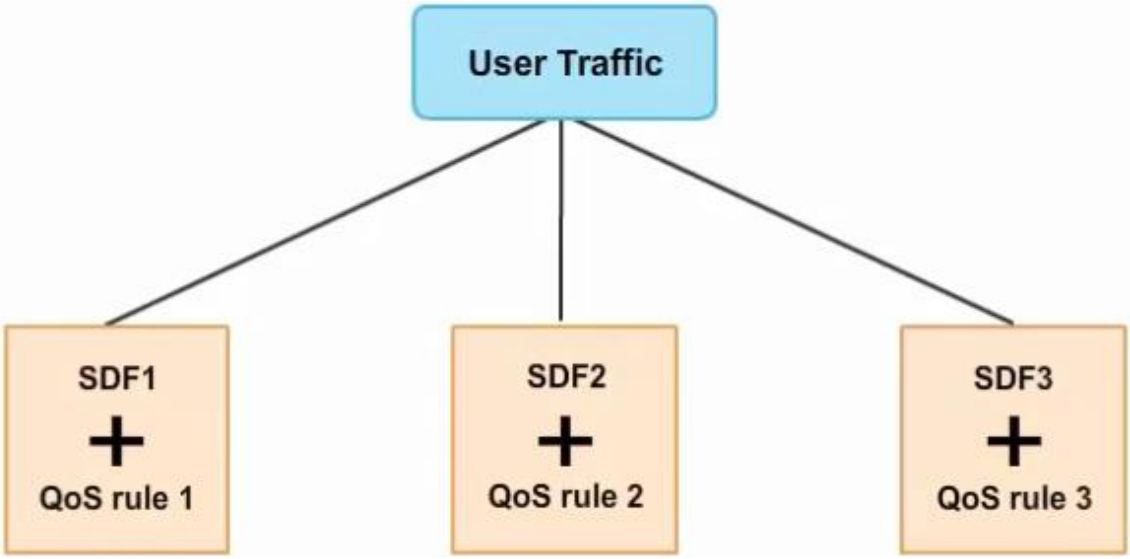
Allocation and Retention Priority





Quality of Service (QoS):

- To define the priorities for different users or services, LTE network has defined Quality of Service (QoS).



Quality of service Class Identifier (QCI):

- The QoS performance characteristics of each IP packet are indicated by using an integer from 1 to 9 known as QoS Class Identifier (QCI).

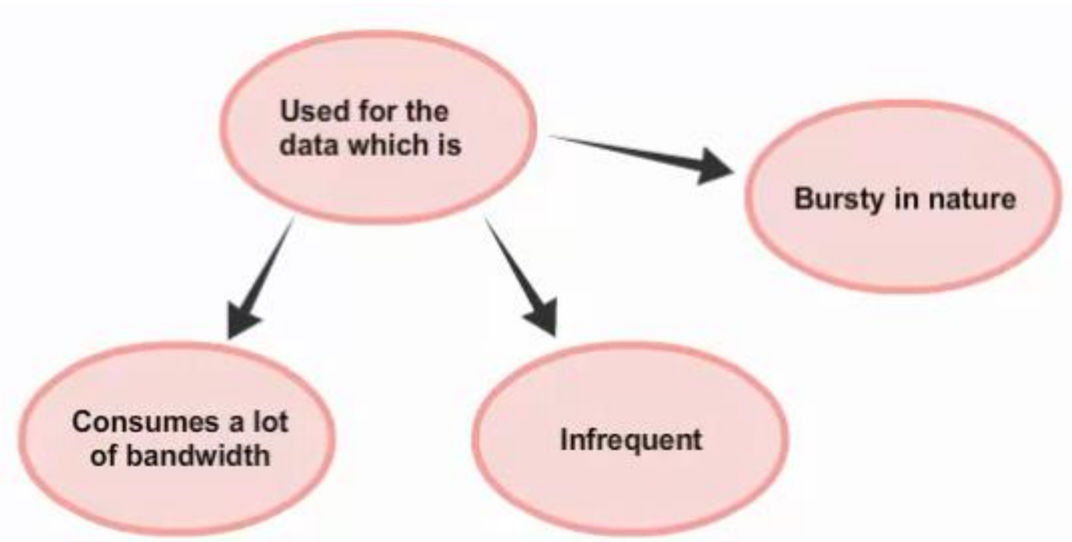
QCI	Bearer Type	Priority	Packet Delay	Packet Loss	Example
1	GBR	2	100 ms	10^{-2}	VoIP call
2		4	150 ms	10^{-3}	Video call
3		3	50 ms		Online Gaming (Real Time)
4		5	300 ms	10^{-6}	Video streaming
5	Non-GBR	1	100 ms		IMS Signaling
6		6	300 ms		Video, TCP based services e.g. email, chat, ftp etc
7		7	100 ms	10^{-3}	Voice, Video, Interactive gaming
8		8	300 ms	10^{-6}	Video, TCP based services e.g. email, chat, ftp etc
9		9			

For scheduling, various algorithms are used.

The currently used scheduling algorithms in the LTE network are:

- Dynamic Scheduling
- Persistent Scheduling
- Semi-persistent Scheduling

Dynamic Scheduling



Example:

Web surfing, Video Streaming, FTP, etc.

- Best suited for the situation where the payload is much more than the control information, such as video streaming.
- Less suited for the real time streaming applications, such as VoLTE, where data is sent in short bursts while at regular intervals.

Persistent Scheduling

What type of scheduling should be used where the amount of data is less and occurs in a fixed interval of time?

Reduces the overhead of control information drastically.

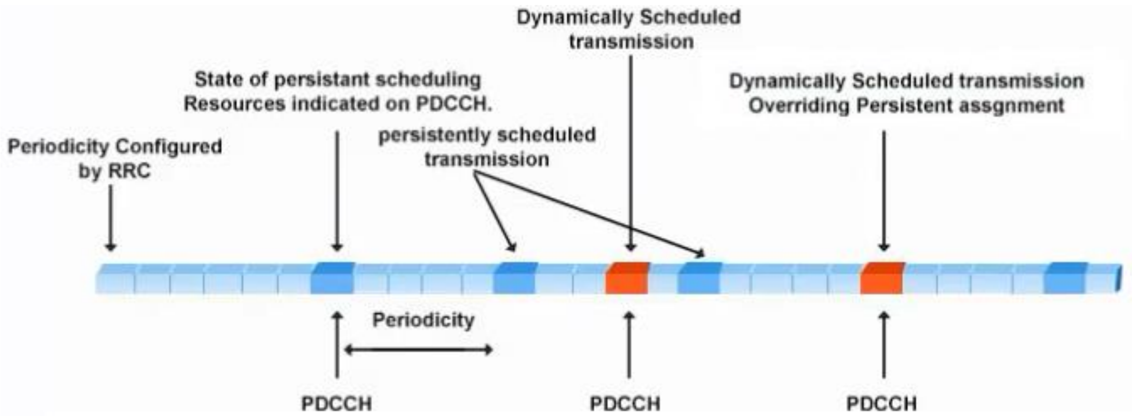
Semi-persistent Scheduling

In persistent scheduling, the control information is sent on a regular interval.

What if any of the data is lost in between the next coming period and you need to retransmit that data?

Use semi-persistent scheduling

- Semi-persistent scheduling is the special case of persistent scheduling in which the eNodeB can assign a predefined set or chunk of resources to the VoLTE service with an interval of 20ms.
- In addition, the UE is not required to check for resources in every sub-frame.
- However, the eNodeB can change the time interval on PDCCH, if required.
- If some data is lost in between the two intervals of persistent scheduling and retransmission of data is required; the control information may also change since PDCCH have priority.
- The control information of persistent scheduling may also get override.



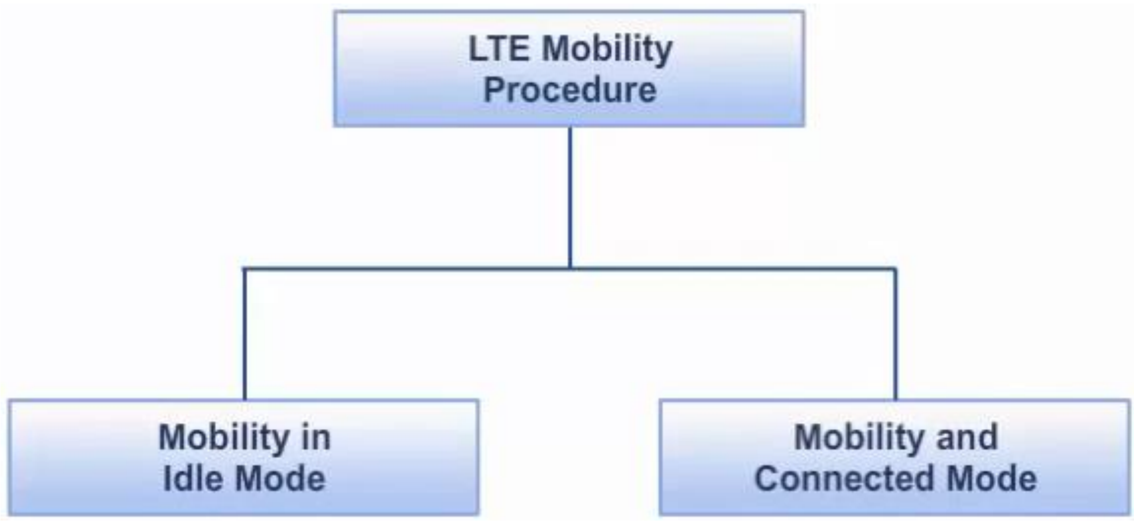
Mobility in LTE

Same kind of service, anywhere, anytime.

- The LTE network has been designed to ensure seamless services for the moving users.
- When a user moves from one location to another location, LTE network keeps the tracking of the location of users.

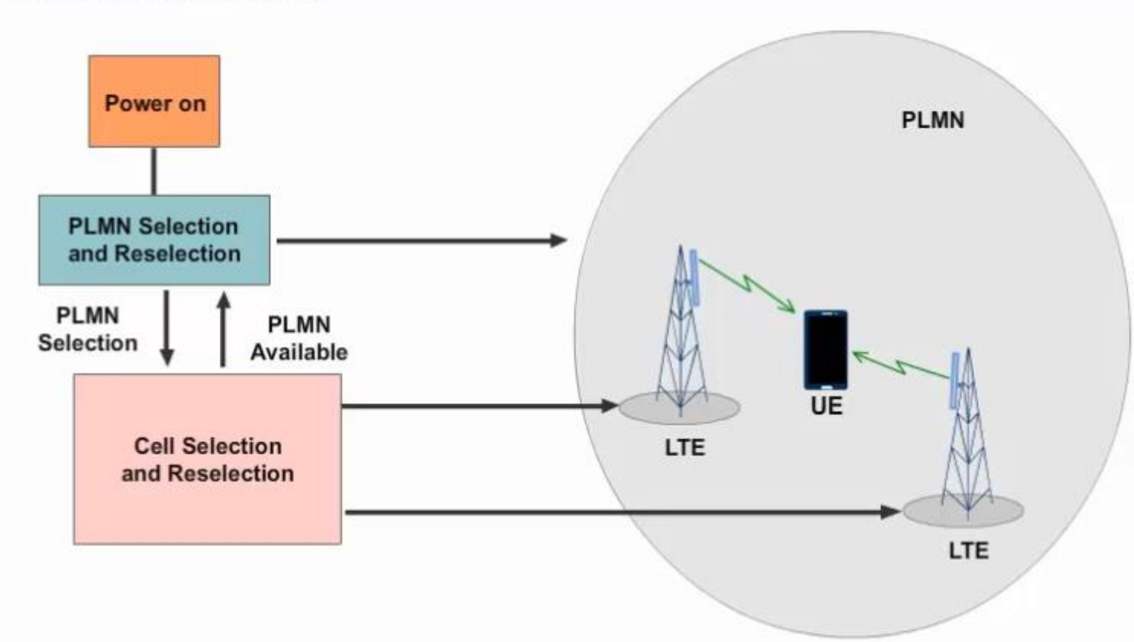
Mobile Management Entity (MME):

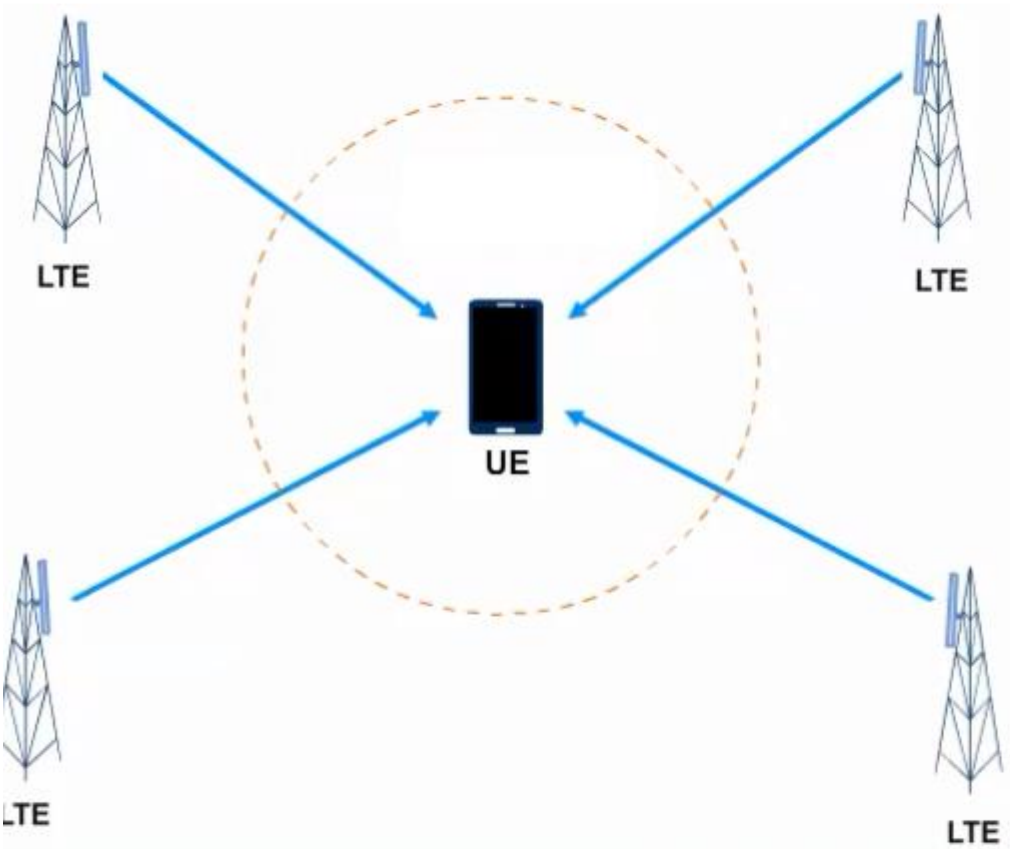
- It does the entire mobility management function of the LTE network.



In LTE idle mode, mobility is maintained by the means of:

Cell Selection Procedure





Measure Signal Strength/Quality

Measure RSRP & RSRQ

Camped on

The UE is allowed to camp on a cell only when:

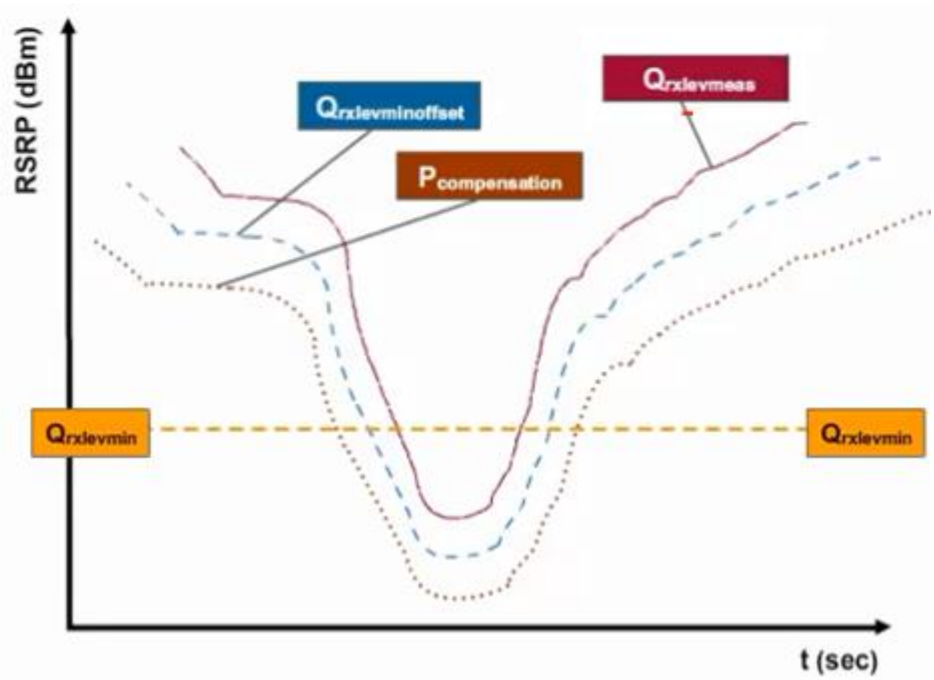
Cell selection receive level value (Srxlev) > 0

+

Cell selection quality value (Squal) > 0

Srxlev and Squal are computed based on the following equations:

$$Srxlev = Q_{rxlevmeas} - (Q_{rxlevmin} + Q_{rxlevminoffset}) - P_{compensation}$$



$Q_{rxlevmeas}$ It is the measured receive level value for the cell (RSRP).

$Q_{rxlevmin}$

It is the minimum required receive level in the cell (dBm). It is obtained from SIB1.

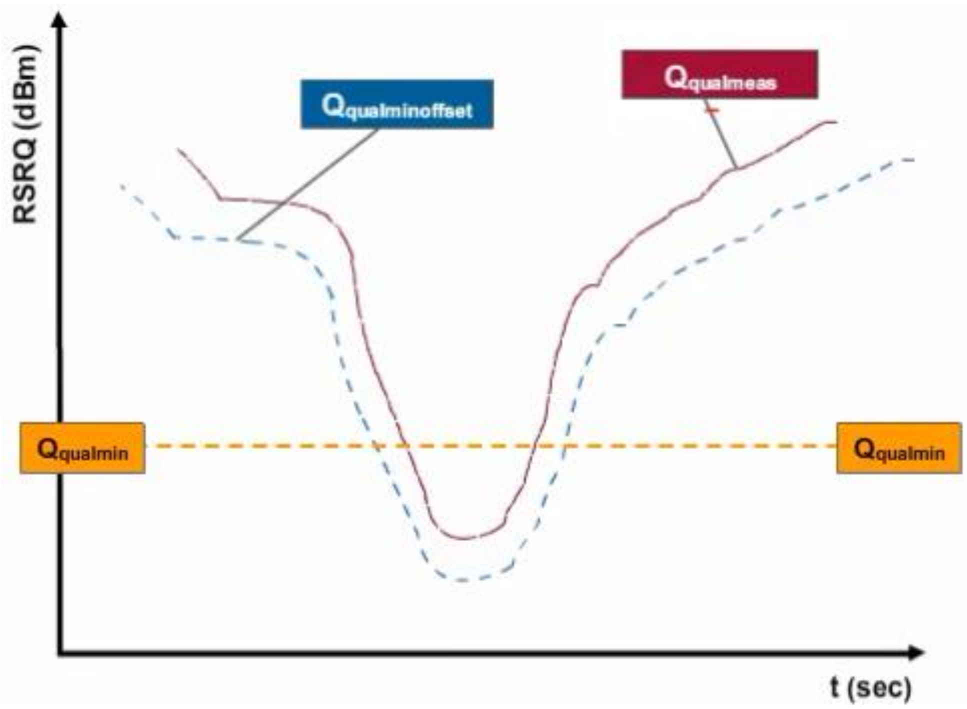
$Q_{rxlevminoffset}$

It is an offset to $Q_{rxlevmin}$ that is only taken into account as a result of a periodic search for a higher priority PLMN while camped normally in a Visitor PLMN (VPLMN). It is obtained from SIB1.

$P_{compensation}$

It is the maximum function calculated from P_{EMAX}-P_{UMAX}. Where, P_{EMAX} is the maximum transmit power level a UE is allowed to use in the cell and P_{UMAX} is the maximum transmit power of the UE.

$$\text{Squal} = Q_{qualmeas} - (Q_{qualmin} + Q_{qualminoffset})$$



$Q_{qualmeas}$ It is the measured cell quality value (RSRQ).

$Q_{qualmin}$

It is the minimum required quality level in the cell (dBm). It is obtained from SIB1.

$Q_{qualminoffset}$

It is an offset to $Q_{qualmin}$ that is only taken into account as a result of a periodic search for a higher priority PLMN while camped normally in a Visitor PLMN (VPLMN). It is obtained from SIB1.

Mobility in LTE Idle Mode

Cell Reselection Procedure

These criteria can be explained by using the following equations:

Rs = Qmeas,s + Qhyst,s
Rn = Qmeas,n – Qhyst,n

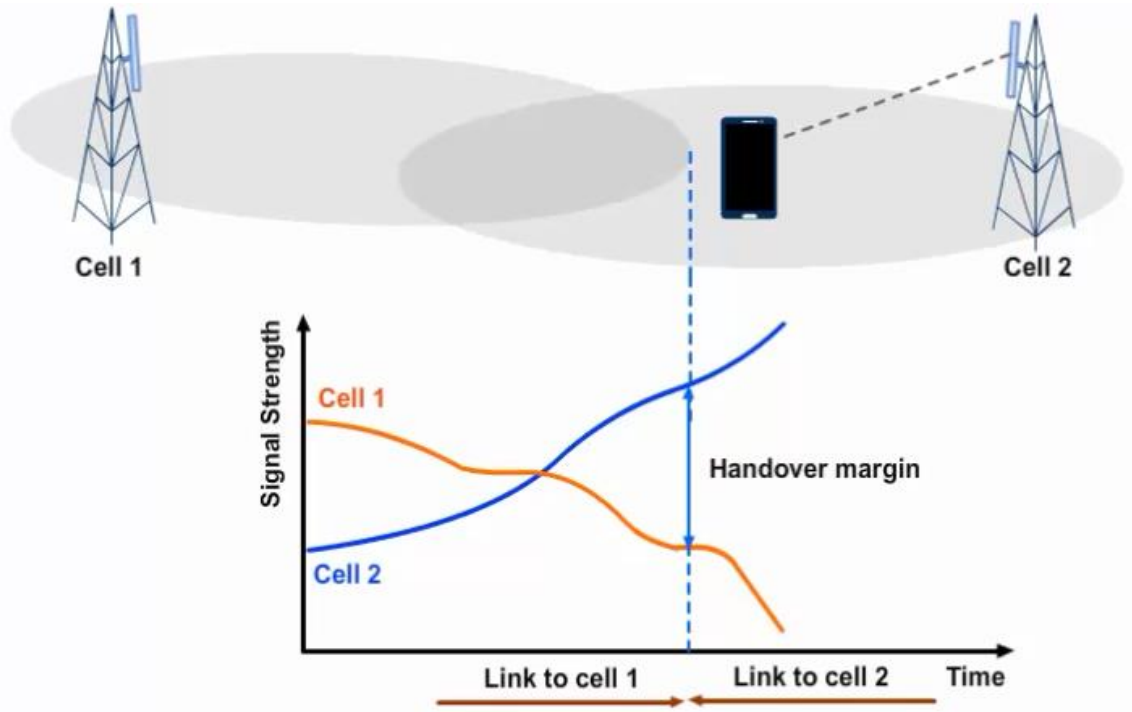
If Rn > Rs, then cell reselection can be done.

Where, Qmeas,s & Qmeas,n are RSRP Measurements.

The UE will reselect the new cell, if the above conditions are met for a time interval, tReselection.

For example, if the UE remains in the cell selected mode for at least this amount of time to get rid of fast moving ping pong situation.

Mobility in LTE connected Mode (Events)



To measure the signal strength of cells, 3GPP defines several predefined set of measurement report to be performed by the UE.

These predefined measurement report types are called Events.

The handover events are listed in the following table.

Event Type	Description
A Type Events: Intra and Inter Frequency Events	
Event A1	When Serving cell becomes better than given (an absolute) threshold
Event A2	When Serving cell becomes worse than given (an absolute) threshold
Event A3	When Neighbor cell becomes an amount of offset better than serving cell
Event A4	When neighbor cell becomes better than (an absolute) threshold
Event A5	When Serving cell becomes worse than (an absolute) threshold1 and neighbor cell becomes better than (an another absolute) threshold2
B Type Events: Inter RAT Events	
Event B1	When Inter RAT neighbor cell becomes better than (an absolute) threshold
Event B2	When serving cell becomes worse than (an absolute) threshold1 and inter RAT neighbor cell becomes better than (another absolute) threshold2

Mobility in LTE connected Mode

Broadly, we will be discussing X2 based handovers, S1 based handovers and Inter Radio Access Technology (IRAT) handovers in this module.

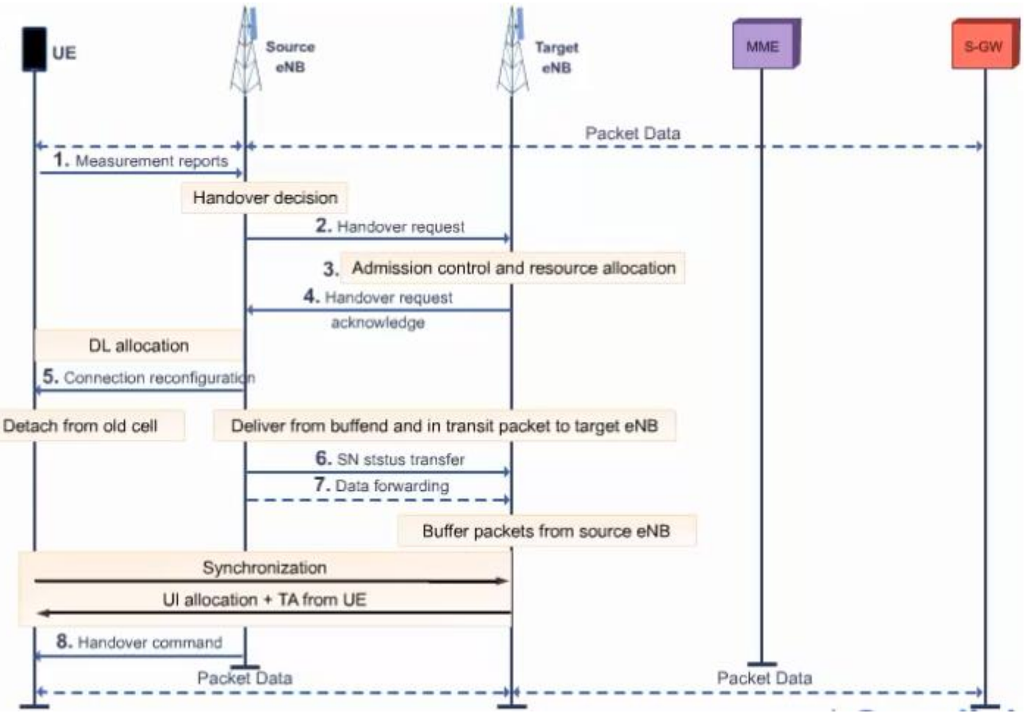
X2-based Handover

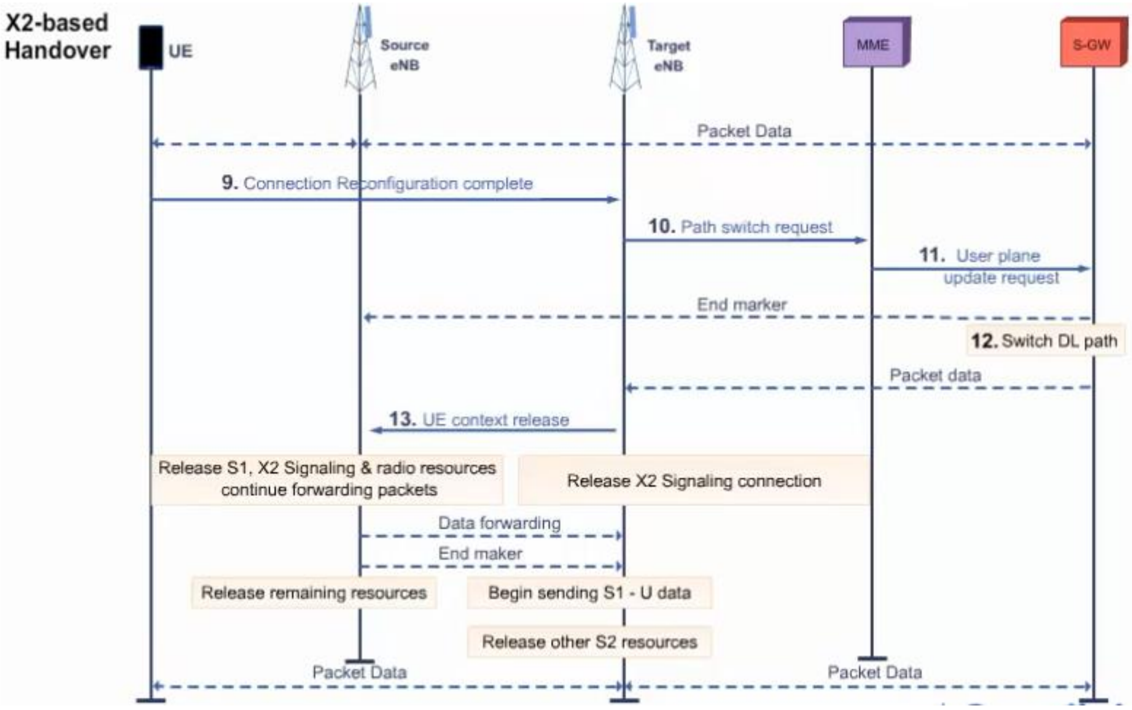
- This handover is normally used for the inter-eNodeB handover.
- It is a handover between two eNodeBs that are connected with the same MME.
- In addition, there has to be a direct connection between both the eNodeBs on x2-interface.

S1-based Handover

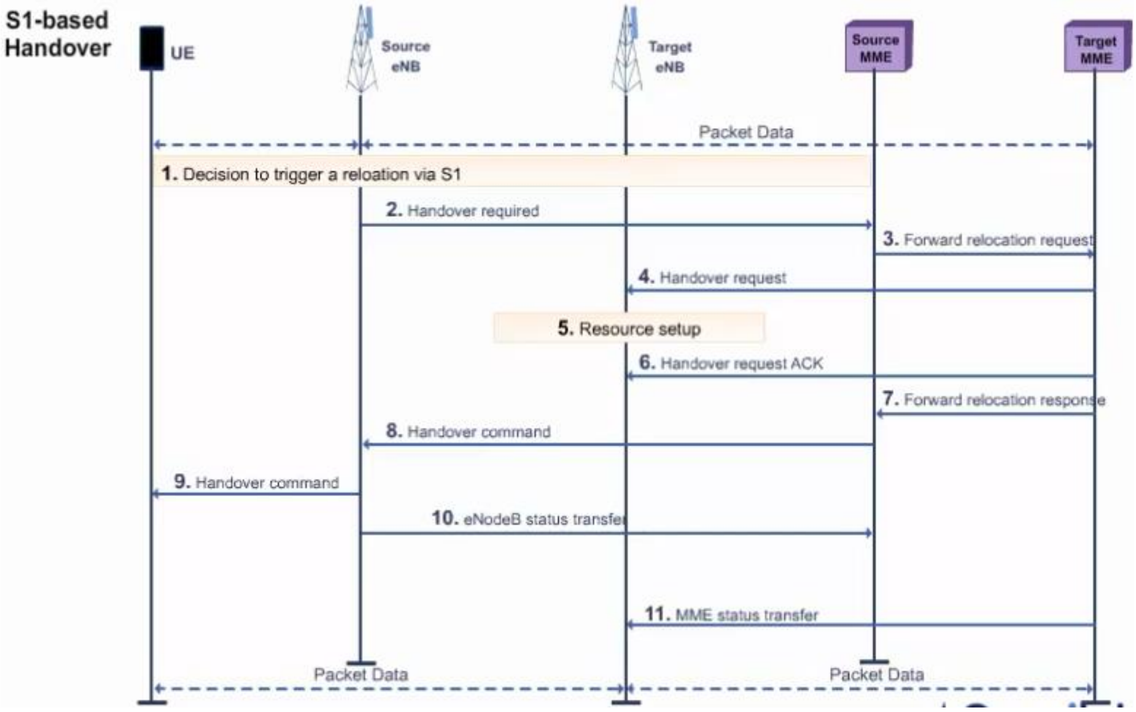
- This handover is used for inter eNB handover where X2 connectivity is not available.
  Or, when both eNBs are connected with different MMEs.

X2-based Handover

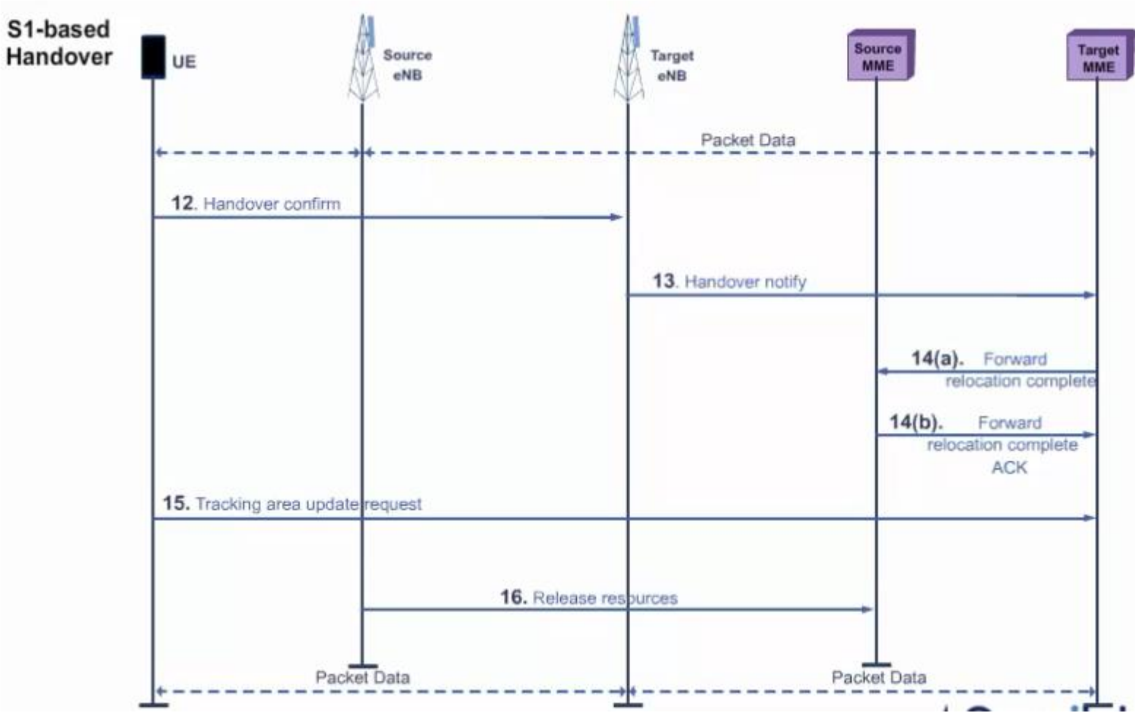


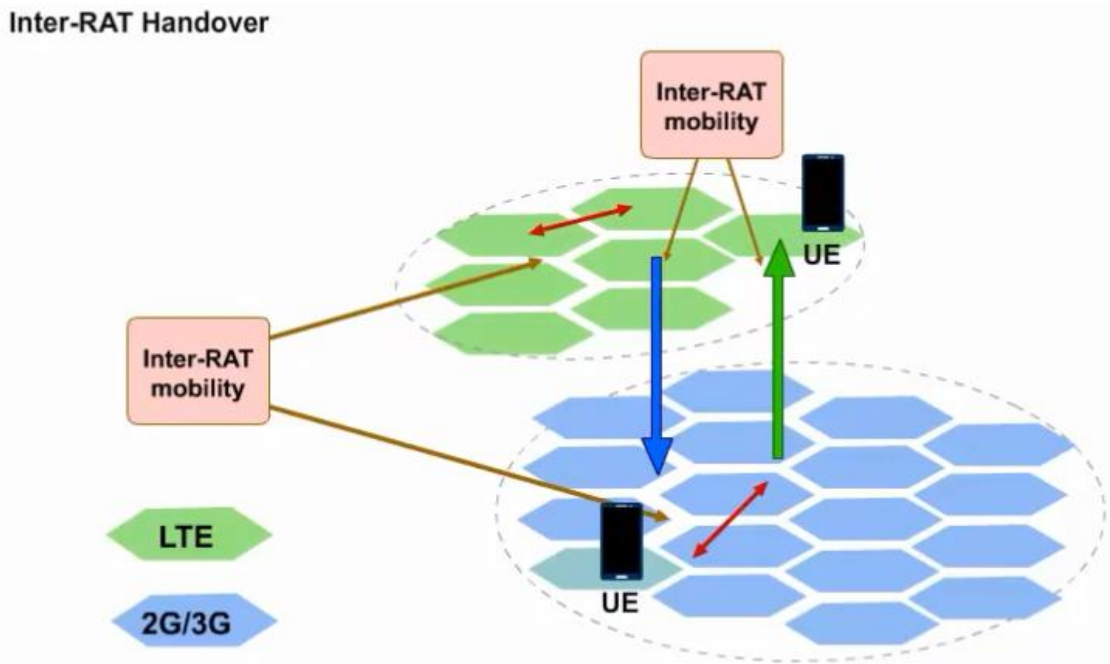


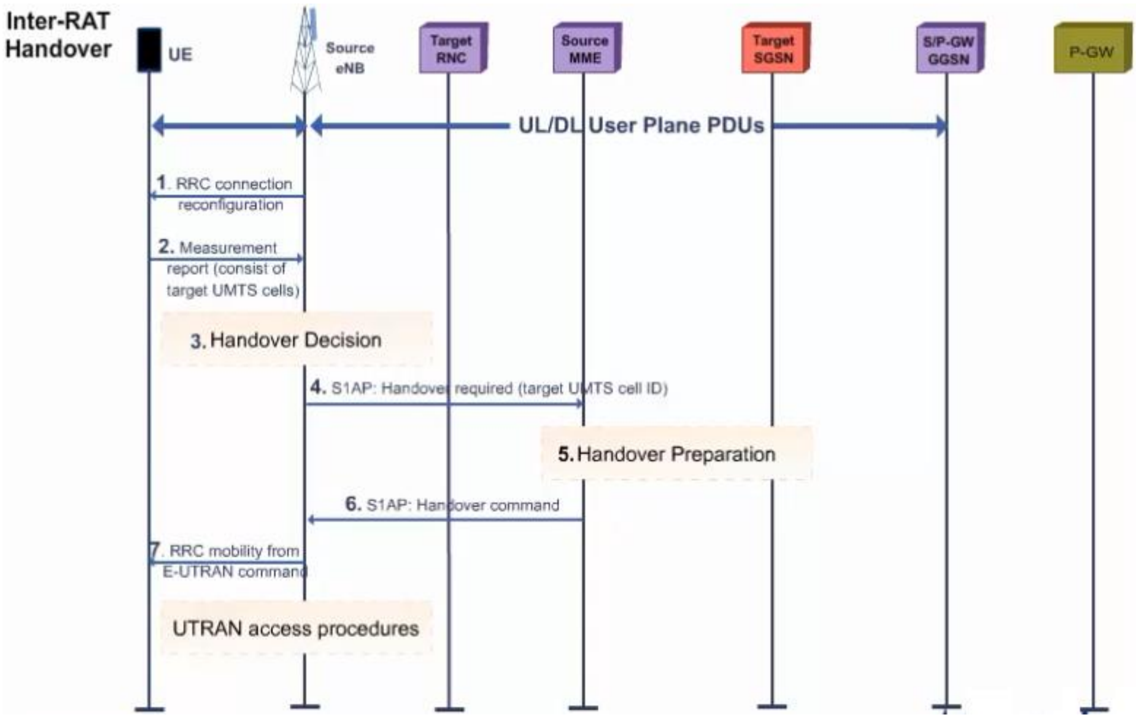
X2-based Handover
UE
Source eNB
Target eNB
MME
S-GW
Packet Data
9. Connection Reconfiguration complete
10. Path switch request
11. User plane update request
End marker
12. Switch DL path
Packet data
13. UE context release
Release S1, X2 Signaling & radio resources continue forwarding packets
Release X2 Signaling connection
Data forwarding
End maker
Release remaining resources
Begin sending S1 - U data
Release other S2 resources
Packet Data
Packet Data



S1-based Handover
UE
Source eNB
Target eNB
Source MME
Target MME
Packet Data
1. Decision to trigger a reloation via S1
2. Handover required
3. Forward relocation request
4. Handover request
5. Resource setup
6. Handover request ACK
7. Forward relocation response
8. Handover command
9. Handover command
10. eNodeB status transfer
11. MME status transfer
Packet Data
Packet Data


S1-based Handover
UE
Source eNB
Target eNB
Source MME
Target MME
Packet Data
12. Handover confirm
13. Handover notify
14(a). Forward relocation complete
14(b). Forward relocation complete ACK
15. Tracking area update request
16. Release resources
Packet Data
Packet Data


Inter-RAT Handover
Inter-RAT mobility
UE
Inter-RAT mobility
LTE
UE
2G/3G


Inter-RAT Handover
UE
Source eNB
Target RNC
Source MME
Target SGSN
S/P-GW GGSN
P-GW
UL/DL User Plane PDUs
1. RRC connection reconfiguration
2. Measurement report (consist of target UMTS cells)
3. Handover Decision
4. S1AP: Handover required (target UMTS cell ID)
5. Handover Preparation
6. S1AP: Handover command
7. RRC mobility from E-UTRAN command
UTRAN access procedures