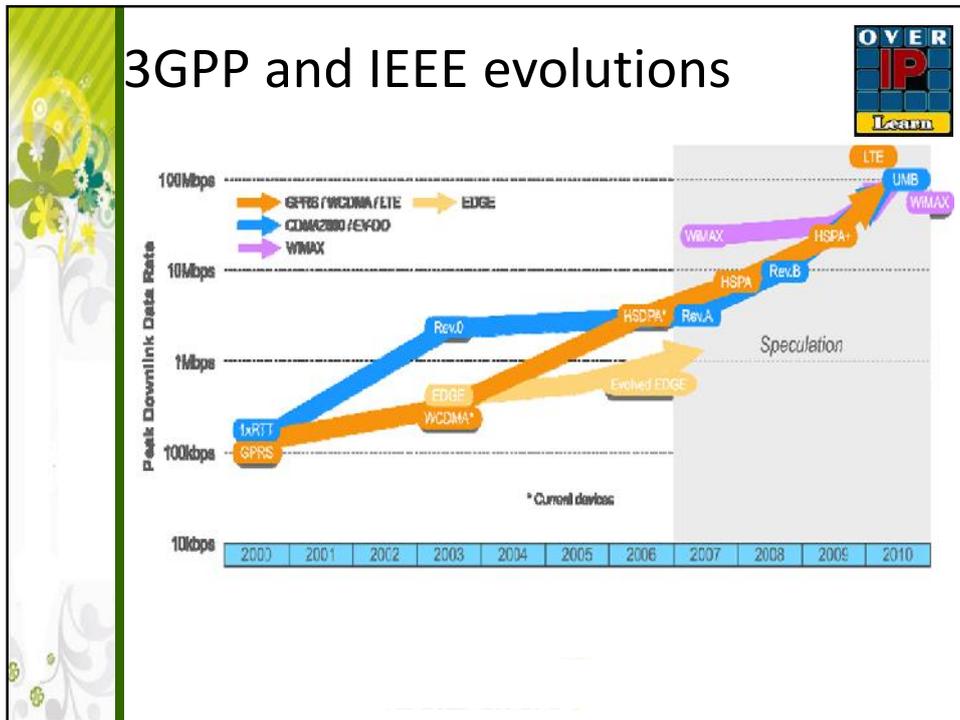




Course Contents



- **Historical vision**
- LTE Capabilities
- System architecture



- ## 3GPP evolution
- **1G (Early 1980s)**
 - Analog speech communications.
 - Analog FDMA.
 - Ex: AMPS
 - **2G: Started years ago with GSM: Mainly voice**
 - Digital modulation of speech communications.
 - Advanced security and roaming.
 - TDMA and narrowband CDMA.
 - Ex: GSM, IS-95 (cdmaOne), and PDC
 - **2.5G: Adding Packet Services: GPRS, EDGE**
 - **3G: Adding 3G Air Interface: UMTS**
 - **3G Architecture:**
 - Support of 2G/2.5G and 3G Access
 - Handover between GSM and UMTS technologies
 - **3G Extensions:**
 - HSDPA/HSUPA
 - IP Multi Media Subsystem (IMS)
 - Inter-working with WLAN (I-WLAN)
 - **Beyond 3G:**
 - Long Term Evolution (LTE)
 - System Architecture Evolution (SAE)
 - Adding Mobility towards I-WLAN and non-3GPP air interfaces

3GPP2 evolution



- CDMA2000 1X (1999)
- CDMA2000 1xEV-DO (2000)
- EV-DO Rev. A (2004): VoIP
- EV-DO Rev. B (2006): Multi-carrier
- Ultra Mobile Broadband (UMB), f.k.a. EV-DO Rev.C
 - Based on EV-DO, IEEE 802.20, and FLASH-OFDM
 - Spec finalized in April 2007.
 - Commercially available in early 2009.

IEEE 802.16 Evolution



- **802.16 (2002)**: Line-of-sight fixed operation in 10 to 66 GHz
- **802.16a (2003)**: Air interface support for 2 to 11 GHz
- **802.16d (2004)**: Minor improvements to fixes to 16a
- **802.16e (2006)**: Support for vehicular mobility and asymmetrical link
- **802.16m (in progress)**: Higher data rate, reduced latency, and efficient security mechanism

Beyond 3G



- International Mobile Télécommunications (IMT)-2000 introduced global standard for 3G.
- Systems beyond IMT-2000 (IMT-Advanced) is set to introduce evolutionary path beyond 3G.
- Mobile class targets 100 Mbps with high mobility and nomadic/ local area class targets 1 Gbps with low mobility.
- 3GPP and 3GPP2 are currently developing evolutionary/ revolutionary systems beyond 3G.
 - 3GPP Long Term Evolution (LTE)
 - 3GPP2 Ultra Mobile Broadband (UMB)
- IEEE 802.16-based WiMax is also evolving towards 4G through 802.16m.

Beyond 3G



- Release 99 (Mar. 2000): UMTS/WCDMA
- Rel-5 (Mar. 2002): HSDPA
- Rel-6 (Mar. 2005): HSUPA
- Rel-7 (2007):
DL MIMO, IMS (IP Multimedia Subsystem),
optimized real-time services (VoIP, gaming, push-to-talk).
- Long Term Evolution (LTE)
 - 3GPP work on the Evolution of the 3G Mobile System started in November 2004.
 - Standardized in the form of Rel-8.
 - Spec finalized and approved in January 2008.
 - Target deployment in 2010.
- LTE advanced



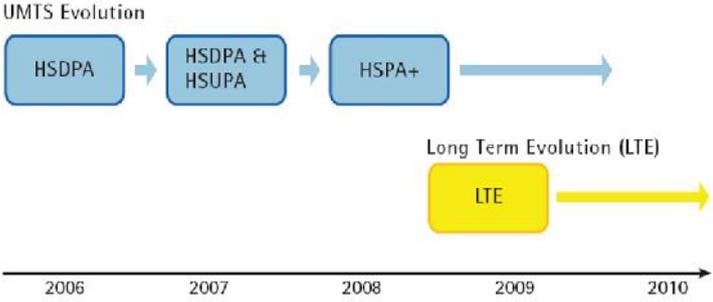
Course Contents

- Historical Vision
- **LTE Capabilities**
- System architecture



3G evolution

UMTS Evolution



```
graph LR; HSDPA[2006] --> HSUPA[2007]; HSUPA --> HSPAplus[2008]; HSPAplus --> LTE[2009];
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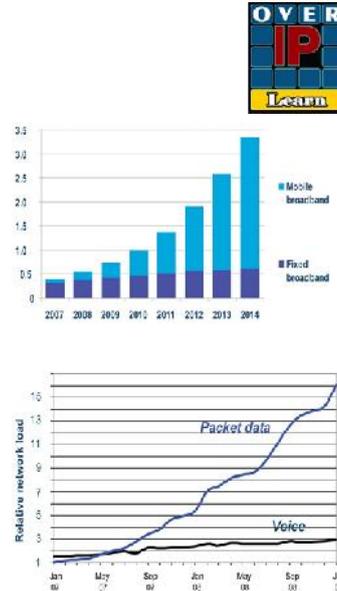
Long Term Evolution (LTE)

2006 2007 2008 2009 2010

Evolution timeframe for planned 3GPP systems.

Why LTE

- **Need for PS optimized system**
 - Evolve UMTS towards packet only system
- **Need for higher data rates**
 - Can be achieved with HSDPA/HSUPA
 - and/or new air interface defined by 3GPP LTE
- **Less processor load cost**
 - Less number of transitions between different states will lead definitely to less processor load
- **Need for high quality of services**
 - Use of licensed frequencies to guarantee quality of services
 - Always-on experience (reduce control plane latency significantly)
 - Reduce round trip delay (\rightarrow 3GPP LTE)
- **Need for cheaper infrastructure**
 - Simplify architecture, reduce number



LTE Defined Data Rates

- **Downlink**
 - 100Mbps theoretical
- **Uplink**
 - 50Mbps theoretical
- Generally we can say the downlink rate relative to HZ 5 bits/s/HZ and for Uplink 2.5bits/s/HZ



LTE duplexing and accessing



- **Duplexing Methods**
 - FDD
 - UL and DL can reach the peak traffic simultaneously
 - TDD
 - UL and DL can not reach the peak traffic simultaneously
- **Accessing techniques**
 - OFDMA for the DL
 - SC-FDMA for the UL

Modulation and coding



- **Adaptive Modulation and Coding**
 - DL Modulations: QPSK, 16-QAM and 64-QAM modulation
 - UL Modulations: QPSK and 16-QAM
 - Turbo code

Modulation coding		Peak bit rate per sub-carrier/bandwidth combination				
		72/1.4 MHz	180/3.0 MHz	300/5.0 MHz	600/10 MHz	1200/20 MHz
QPSK 1/2	Single stream	0.9	2.2	3.6	7.2	14.4
16QAM 1/2	Single stream	1.7	4.3	7.2	14.4	28.8
16QAM 3/4	Single stream	2.6	6.5	10.8	21.6	43.2
64QAM 3/4	Single stream	3.9	9.7	16.2	32.4	64.8
64QAM 5/6	Single stream	5.2	13.0	21.6	43.2	86.4
64QAM 3/4	2 × 2 MIMO	7.8	19.4	32.4	64.8	129.6
64QAM 4/4	2 × 2 MIMO	10.4	25.9	43.2	86.4	172.8

Modulation coding		Peak bit rate per sub-carrier/bandwidth combination				
		72/1.4 MHz	180/3.0 MHz	300/5.0 MHz	600/10 MHz	1200/20 MHz
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16QAM 3/4	Single stream	2.6	6.5	10.8	21.6	43.2
16QAM 4/4	Single stream	3.5	8.6	14.4	28.8	57.6

LTE Maximum Latency (1-2)



- **For control Plane**
 - The delay of changing the mobile mode from the active to non active and vice versa
 - If the terminal was in the idle mode it needs 100msec
 - If the terminal was in the dormant it needs 50msec
- **For User Plane**
 - Time the terminal takes to transmit small packets to the RAN and Vice versa is 5 msec

LTE Maximum Latency (2-2)



- **What is the idle mode**
 - Terminal unknown for the RAN
 - No Radio resources assigned
- **What is the dormant mode**
 - Terminal is known for the RAN
 - No Radio resources assigned

LTE theoretical Capacity



- **Active Mode**
 - At 5MHz BW the Cell can support 200 users simultaneously.
 - At BW more than 5 MHz the Cell can support up to 400 Simultaneously terminal.
- **IDLE Mode**
 - Can support more than 400 Users at the same time



LTE System Performance targets(1-2)

- **User throughput**
 - 95% from the users will take average throughput
 - 5% will be little bit smaller than the average
- **Spectrum efficiency**
 - It define high spectrum efficiency Bits/MHZ/Cell
- **Coverage**
 - 5 Km with high throughput
 - 30 Km with low throughput
 - 100Km with very low throughput



LTE System Performance targets(2-2)

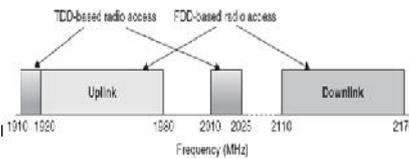
- **Mobility**
 - 0-15km/ hour the more better subscriber behavior.
 - 120 km/ hour the accepted behavior.
 - 350 km/ hour very low data rate and data throughput.
- **Enhanced MBMS**
 - Up to 16 multimedia channels per just one carrier



LTE deployment aspects



- **Flexible spectrum**
 - The carrier could be 1.25 MHz, 1.6 MHz, 2.5 MHz, 5MHz, 10MHz, 15MHz or 20 MHz
 - Can use the IMT2000 Band
 - 1910-1920 and 2010-2025 at the TDD Band
 - 1920- 1960 FDD UL and 2110-2170 FDD DL
- **Stand alone**
- **Coexisted with WCDMA and GSM**
 - HO from LTE to GSM 500msec for NRT and 300 for RT and the same for GSM

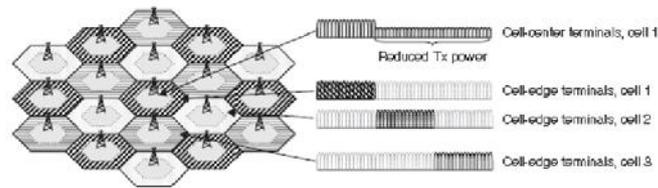


Interference handling



- **LTE Frequency Reuse Pattern**

- Generally it is equal to 1
- IIC (Inter cell interference coordinator) is used to reduce the interference and make the reuse for cell outer area >

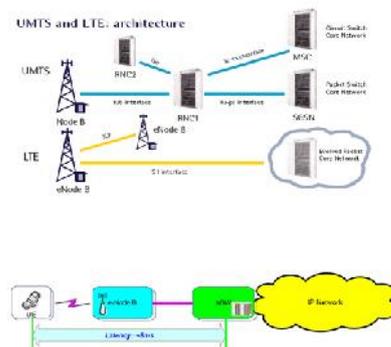


Architecture and Migration



- **LTE RAN agreed on the following**

- Packet bearer support
 - Real Time
 - Conversational
- Reduce the number of the new interfaces
 - NO RNC
 - NO CS-CN
- Reduce the single point of failure
 - NO RNC
- Separate the treatment of different types of traffic (O&M, Control and Data) to utilize the BW
- Reduce the variable delay and Jitter (TCP/IP)
- Agreed QoS between Transmitting end and receiving end
- No SHO or Macro diversity
- MIMO and Tx diversity techniques used



Complexity



- Easy design
- Less complex
- No redundant feature
- Minimize Cost and maintain system performance
 - Low complexity
 - Low power consumption

LTE Services (1-2)



Service category	Current environment	LTE environment
Rich voice	Real-time audio	VoIP, high quality video conferencing
P2F messaging	SMS, MMS, low priority e-mails	Photo messages, IM, mobile e-mail, video messaging
Browsing	Access to online information services, for which users pay standard network rates. Currently limited to WAP browsing over GPRS and 3G networks	Super-fast browsing, uploading content to social networking sites
Paid information	Content for which users pay over and above standard network charges. Mainly text-based information.	E-newspapers, high quality audio streaming
Personalisation	Predominantly ringtones, also includes screensavers and ringbacks	Realtones (original artist recordings), personalised mobile web sites
Games	Downloadable and online games	A consistent online gaming experience across both fixed and mobile networks
TV/ video on demand	Streamed and downloadable video content	Broadcast television services, true on-demand television, high quality video streaming
Music	Full track downloads and analogue radio services	High quality music downloading and storage services

LTE Services (2-2)



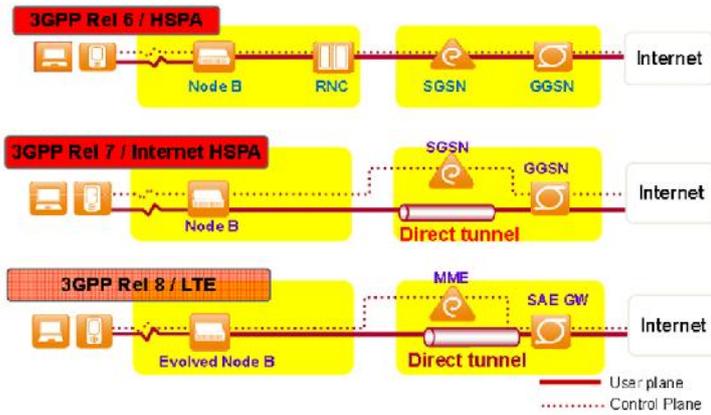
Service category	Current environment	LTE environment
Content messaging and cross media	Peer-to-peer messaging using third party content as well as interaction with other media	Wide scale distribution of video clips, karaoke services, video-based mobile advertising
M-commerce	Commission on transactions (including gambling) and payment facilities undertaken over mobile networks	Mobile handsets as payment devices, with payment details carried over high speed networks to enable rapid completion of transactions
Mobile data networking	Access to corporate intranets and databases, as well as the use of applications such as CRM	P2P file transfer, business applications, application sharing, M2M communication, mobile intranet/extranet

Course Contents



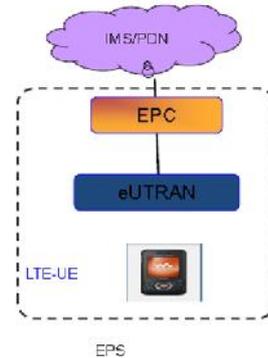
- Historical Vision
- LTE Capabilities
- **System architecture**

Network architecture Evolution

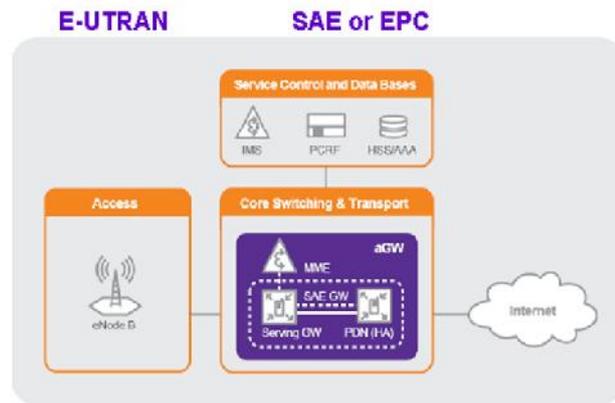


3GPP-LTE Architecture High level (1-2)

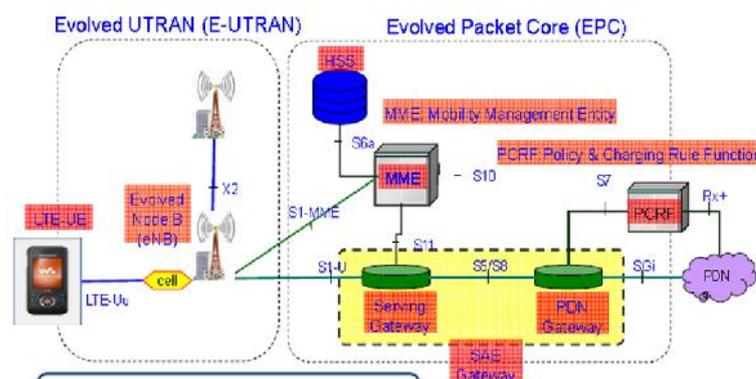
- LTE/SAE architecture is driven by the goal to optimize the system for packet data transfer.
- No circuit switched components
- New approach in the inter-connection between radio access network and core network
- The EPS architecture is made up of an EPC (Packet Core Network, also referred as SAE) and an eUTRAN Radio Access Network (also referred as LTE)
- The CN provides access to external packet IP networks and performs a number of CN related functions (e.g. QoS, security, mobility and terminal context management) for idle (camped) and active terminals
- The RAN performs all radio interface related functions



3GPP-LTE Architecture High level (2-2)



SAE Network Architecture



Main references to architecture in 3GPP specs:
TS23.401, TS23.402, TS36.300

Evolved UTRAN



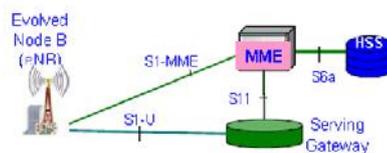
- It is the only network element defined as part of EUTRAN
- It replaces the old Node B / RNC combination from 3G
- It terminates the complete radio interface including physical layer.
- It provides all radio management functions
- An eNB can handle several cells.
- To enable efficient inter-cell radio management for cells not attached to the same eNB, there is an inter-eNB interface X2 specified. It will allow to coordinate inter-eNB handovers without direct involvement of EPC during this process.

eNB Functions
Inter-cell RRM: HO, load balancing between cells
Radio Bearer Control: setup, modifications and release of Radio Resources
Connection Mgt. Control: UE State Mgmt. MME-UE Connection
Radio Admission Control
eNode B Measurements: Collection and evaluation
Dynamic Resource Allocation (Scheduler)
IP Header Compression/de-compression
Access Layer Security: ciphering and integrity protection on the radio interface
MME Selection at Attach of the UE
User Data Routing to the SAE GW
Transmission of Paging Message coming from MME
Transmission of Broadcast Info (System info, MBMS)

EPC (1-5)



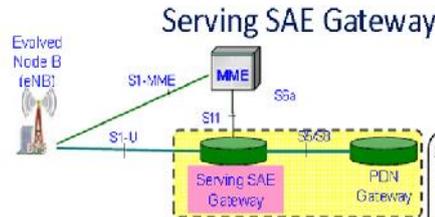
Mobility Management Entity (MME)



- It is a pure signaling entity inside the EPC.
- SAE uses tracking areas to track the position of idle UEs. The basic principle is identical to location or routing areas from 2G/3G.
- MME handles attaches and detaches to the SAE system, as well as tracking area updates
- Therefore it possesses an interface towards the HSS (home subscriber server) which stores the subscription relevant information and the currently assigned MME in its permanent data base.
- A second functionality of the MME is the signaling coordination to setup transport bearers (SAE bearers) through the EPC for a UE.
- MMEs can be interconnected via the S10 interface

MME Functions
Control plane NE in EPC
Non-Access-Stratum (NAS) Security (Authentication, integrity Protection)
Idle State Mobility Handling
Tracking Area updates
Subscriber attach/detach
Signaling coordination for SAE Bearer Setup/Release
Radio Security Control
Trigger and distribution of Paging Messages to eNB
Roaming Control (S6a interface to HSS)
Inter-CN Node Signaling (S10 interface), allows efficient inter MME tracking area updates and attaches

EPC (2-5)



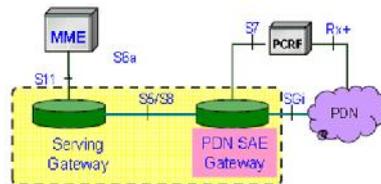
- The serving gateway is a network element that manages the user data path (SAE bearers) within EPC.
- It therefore connects via the S1-U interface towards eNB and receives uplink packet data from here and transmits downlink packet data on it.
- Thus the serving gateway is some kind of distribution and packet data anchoring function within EPC.
- It relays the packet data within EPC via the S5/S8 interface to or from the PDN gateway.
- A serving gateway is controlled by one or more MMEs via S11 interface.

Serving Gateway Functions
Local mobility anchor point: Switching the user plane path to a new eNB in case of Handover
Mobility anchoring for inter-3GPP mobility: This is sometimes referred to as the 3GPP Anchor function
Idle Mode Packet Buffering and notification to MME
Packet Routing/Forwarding between eNB, PDN GW and SGSN
Lawful Interception support

EPC (3-5)



Packet Data Network (PDN) SAE Gateway



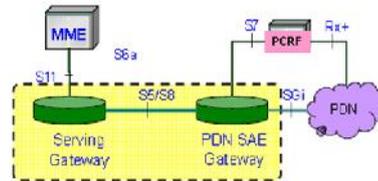
- The PDN gateway provides the connection between EPC and a number of external data networks.
- Thus it is comparable to GGSN in 2G/3G networks.
- A major functionality provided by a PDN gateway is the QoS coordination between the external PDN and EPC.
- Therefore the PDN gateway can be connected via S7 to a PCRF (Policy and Charging Rule Function).

PDN Gateway Functions
Mobility anchor for mobility between 3GPP access systems and non-3GPP access systems: This is sometimes referred to as the SAE Anchor function
Policy Enforcement (PCEF)
Per User based Packet Filtering (i.e. deep packet inspection)
Charging & Lawful Interception support
IP Address Allocation for UE
Packet Routing/Forwarding between Serving GW and external Data Network
Packets screening (firewall functionality)

EPC (4-5)



Policy and Charging Rule Function (PCRF)



PCRF: Policy & Charging Rule Function

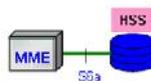
- QoS policy negotiation with PDN
- Charging Policy: determines how packets should be accounted

- The PCRF major functionality is the Quality of Service (QoS) coordination between the external PDN and EPC.
- Therefore the PCRF is connected via Rx+ interface to the external Data network (PDN)
- This function can be used to check and modify the QoS associated with a SAE bearer setup from SAE or to request the setup of a SAE bearer from the PDN.
- This QoS management resembles the policy and charging control framework introduced for IMS with UMTS release 6

EPC (5-5)



Home Subscriber Server (HSS)



HSS Functions

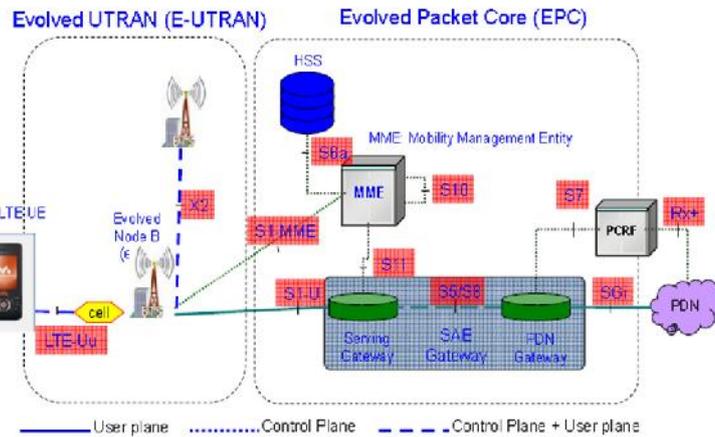
- Permanent and central subscriber database
- Stores mobility and service data for every subscriber
- Contains the Authentication Center (AuC) functionality.

- The HSS is already introduced by UMTS release 5.
- With LTE/SAE the HSS will get additionally data per subscriber for SAE mobility and service handling.
- Some changes in the database as well as in the HSS protocol (DIAMETER) will be necessary to enable HSS for LTE/SAE.
- The HSS can be accessed by the MME via S6a interface.

Interfaces



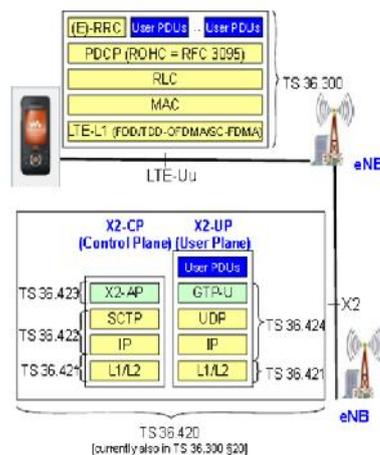
LTE/SAE Network Interfaces



UTRAN interfaces



LTE Radio Interface and the X2 Interface



LTE-Uu
Air interface of EUTRAN
Based on OFDMA in downlink and SC-FDMA in uplink
FDD and TDD duplex methods
Scalable bandwidth 1.4MHz to currently 20 MHz
Data rates up to 100 Mbps in DL
MIMO (Multiple Input Multiple Output) is a major component although optional.

X2
Inter-eNB interface
Handover coordination without involving the EPC
X2AP: special signalling protocol
During HO, Source eNB can use the X2 interface to forward downlink packets still buffered or arriving from the serving gateway to the target eNB.
This will avoid loss of a huge amount of packets during inter-eNB handover.

EPC Interfaces (1 – 5)



S1-MME & S1-U Interfaces

S1-MME

Control interface between eNB and MME

S1flex allows 1 eNB to connect to several MME

MME and UE will exchange non-access stratum signaling via eNB through this interface.

E.g. if a UE performs a tracking area update the TRACKING AREA UPDATE REQUEST message will be sent from UE to eNB and the eNB will forward the message via S1-MME to the MME.

S1AP: S1 Application Protocol

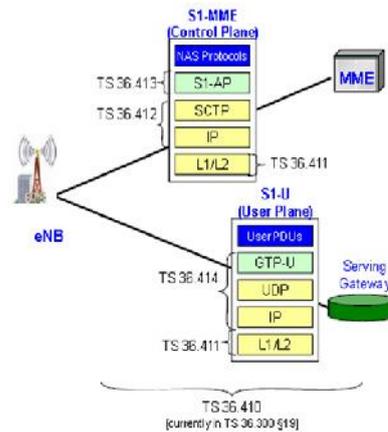
S1-U

User plane interface between eNB and serving gateway.

It is a pure user data interface (U=User plane).

S1flex-U also supported: a single eNB can connect to several Serving GWs.

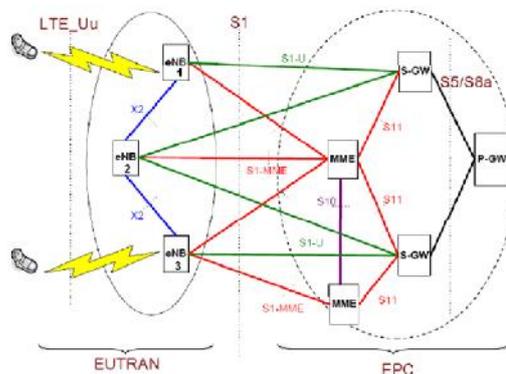
Which Serving GW a user's SAE bearer will have to use is signaled from the MME of this user.



EPC Interfaces (1 – 5)



EUTRAN & EPC connected with S1-flex



Several cases

eNB 1 Single S1-MME
Single S1-U

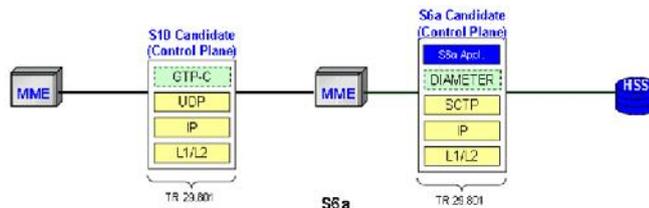
eNB 2 Single S1-MME
Multiple S1-U → S1Flex-U

eNB 3 Multiple S1-MME → S1Flex
Single S1-U

EPC Interfaces (2 – 5)



S10 & S6a Interfaces



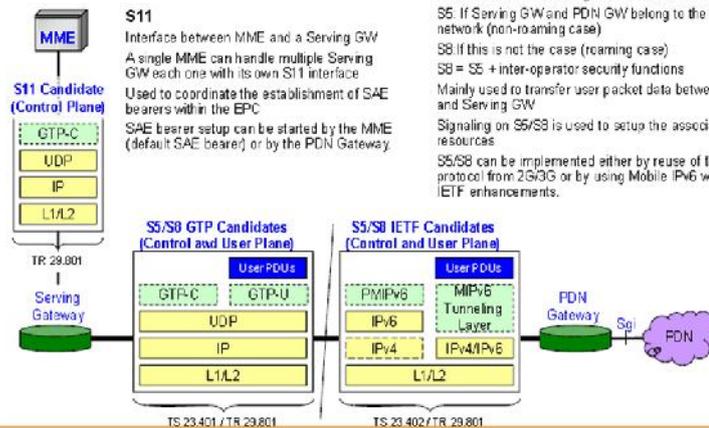
S10
 Interface between different MMEs
 Used during inter-MME tracking area updates
 The new MME can contact the old MME the user had been registered before to retrieve data about identity (IMSI), security information (security context, authentication vectors) and active SAE bearers (PDN gateways to contact, QoS, etc.)
 Obviously S10 is a pure signaling interface, no user data runs on it.

S6a
 Interface between the MME and the HSS
 The MME uses it to retrieve subscription information from HSS (handover/tracking area restrictions, external PDN allowed, QoS, etc.) during attaches and updates
 The HSS can during these procedures also store the user's current MME address in its database.

EPC Interfaces (3 – 5)



S11 & S5/S8 Interfaces



S11
 Interface between MME and a Serving GW
 A single MME can handle multiple Serving GW each one with its own S11 interface
 Used to coordinate the establishment of SAE bearers within the EPC
 SAE bearer setup can be started by the MME (default SAE bearer) or by the PDN Gateway.

S5/S8
 Interface between Serving GW and PDN GW
 S5: If Serving GW and PDN GW belong to the same network (non-roaming case)
 S8: If this is not the case (roaming case)
 S8 = S5 + inter-operator security functions
 Mainly used to transfer user packet data between PDN GW and Serving GW
 Signaling on S5/S8 is used to setup the associated bearer resources
 S5/S8 can be implemented either by reuse of the GTP protocol from 2G/3G or by using Mobile IPv6 with some IETF enhancements.

EPC Interfaces (4 – 5)



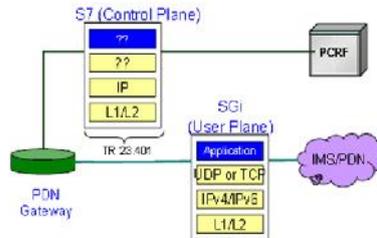
S7 & SGi Interfaces

S7

Interface between PDN GW and PCRF (Policy and Charging Rule Function)

It allows:

- the PCRF to request the setup of a SAE bearer with appropriate QoS
- allows the PDN GW to ask for the CoS of an SAE bearer to setup
- to indicate EPC status changes to the PCRF to apply a new policy rule.



SGi

Interface used by the PDN GW to send and receive data to and from the external data network

It is typically either IPv4 or IPv6 based

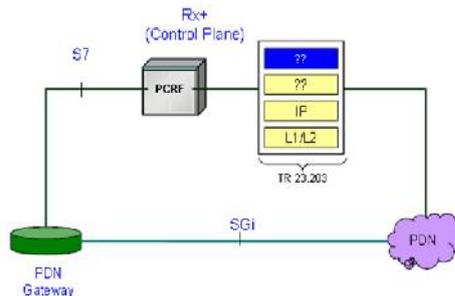
Downlink data coming from the external PDN must be assigned to the right SAE bearer of the right user by analysis of the incoming packet's IP addresses, port numbers, etc.

This interface corresponds to the Gi interface in 2G/3G networks

EPC Interfaces (5 – 5)



Rx+ Interface

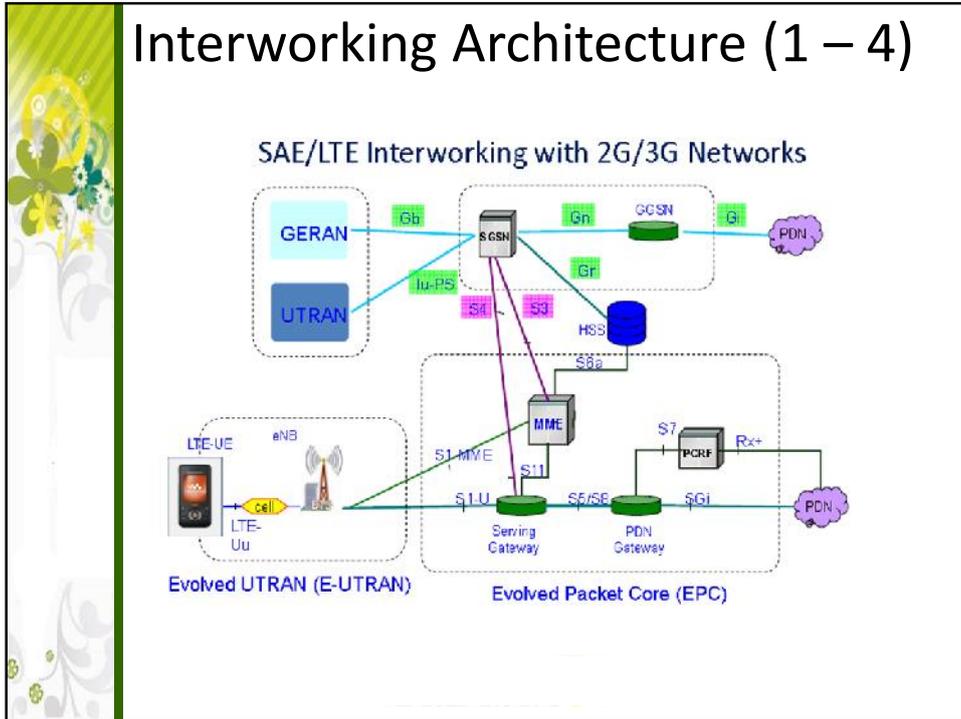


Rx+

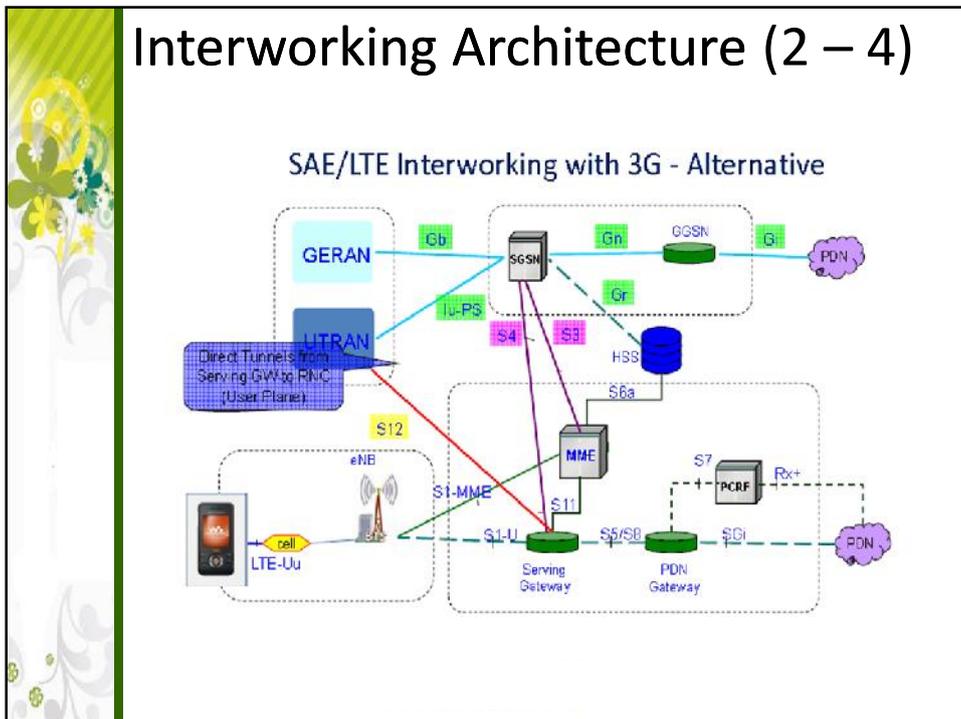
Interface between PCRF(Policy & Charging Rules Function) and the external PDN network/operators IMS

Standardized in 3GPP TS 23.203.

Interworking Architecture (1 – 4)

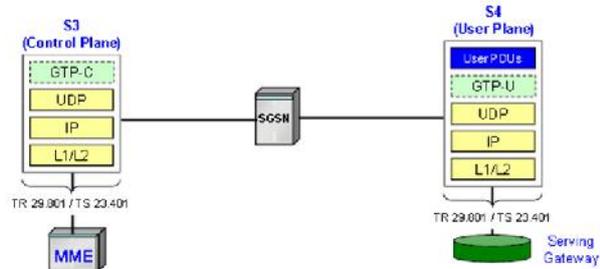


Interworking Architecture (2 – 4)



Interworking Architecture (3 – 4)

S3 & S4 Interfaces



S3/S4

Interfaces between EPC and 2G/3G packet switched core network domain

They would allow inter-system changes between SAE and 2G/3G

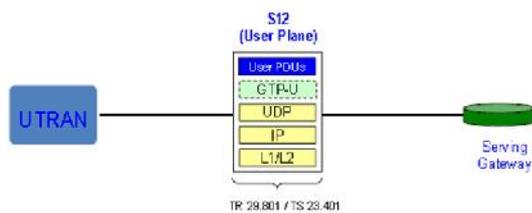
The S3 is a pure signalling interface used to coordinate the inter-system change between MME and SGSN

The S4 is the user plane interface and it is located between SGSN and Serving SAE GW.

This would allow to either forward packet data from EUTRAN via Serving SAE GW to SGSN (and then to GGSN) or from 2G/3G RAN to SGSN to Serving SAE GW to PDN GW.

Interworking Architecture (4 – 4)

S12 Interface



S12

Interfaces between EPC and 3G Radio access network

It would allow inter-system changes between SAE and 3G

The S12 is the user plane interface used for tunneling user data directly between the Serving SAE GW and the UTRAN.

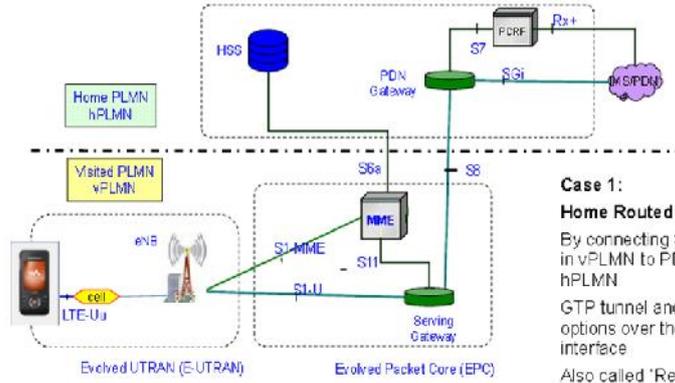
This would allow to forward packet data from 3G RAN to Serving SAE GW to PDN GW.

It is based on the Gn interface between the SGSN and the GGSN and so uses the GTP-U protocol.

Roaming Architecture (1 - 3)



LTE/SAE Roaming Architecture – Case 1



Case 1: Home Routed Traffic
 By connecting Serving GW in vPLMN to PDN GW in hPLMN
 GTP tunnel and MIPv6 options over the S8 interface
 Also called "Remote Breakout"

Roaming Architecture (2 - 3)

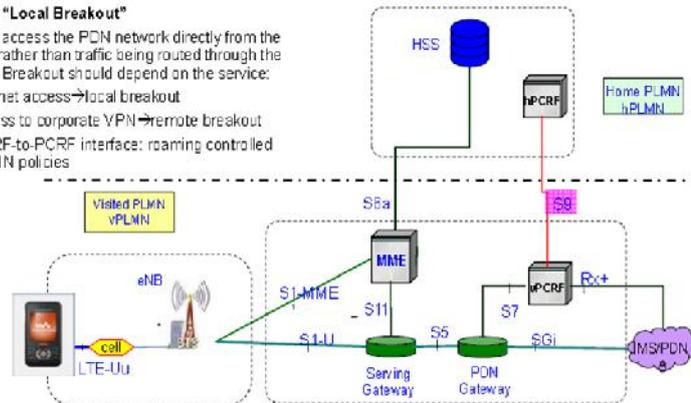


LTE/SAE Roaming Architecture – Case 2

Case 2: "Local Breakout"

UE can access the PDN network directly from the vPLMN rather than traffic being routed through the hPLMN. Breakout should depend on the service:

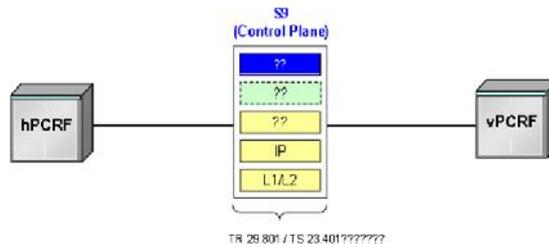
- i.e. internet access → local breakout
- i.e. access to corporate VPN → remote breakout
- S8: PCRF-to-PCRF interface: roaming controlled by hPLMN policies



Roaming Architecture (3 - 3)

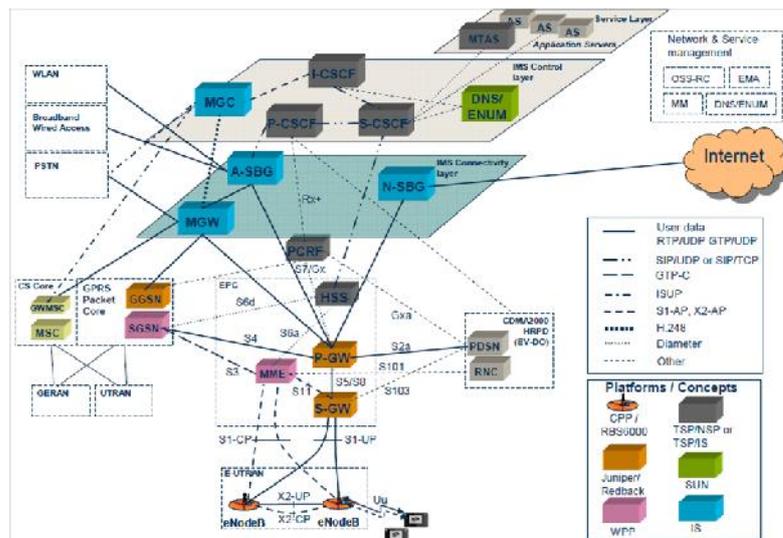


S9 Interface



S9
 Interfaces between the hPCRF and the vPCRF used in roaming cases.
 It is used for enforcement in the VPLMN of dynamic control policies from the HPLMN.

Overall LTE system Architecture





Thank You



LTE Key Technologies

Prepared By: RF Team

AbdelRahman Fady & Mohamed Mohsen



Course Contents

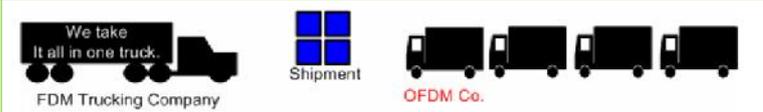
- Accessing Techniques for DL & UL
- Multiple antenna techniques(MIMO)
- Scheduling, Link Adaptation and HARQ
- Traffic Cases



OFDM(Orthogonal Frequency Division Multiple Access)

- OFDM is a type of Multi-Carrier Transmission.
- OFDM is a special case of FDM Technology.
- It is a way of FDM but with the condition of orthogonality
- OFDM is the DL Accessing Technique for LTE.



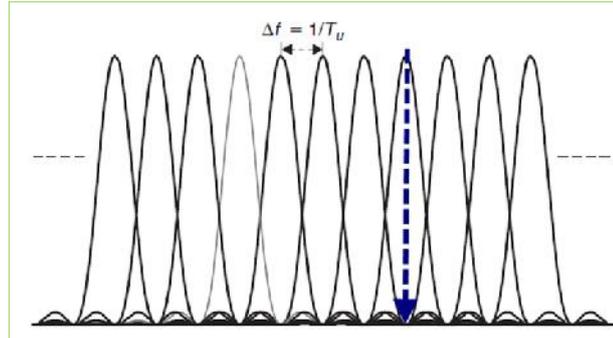


Think About the benefits?

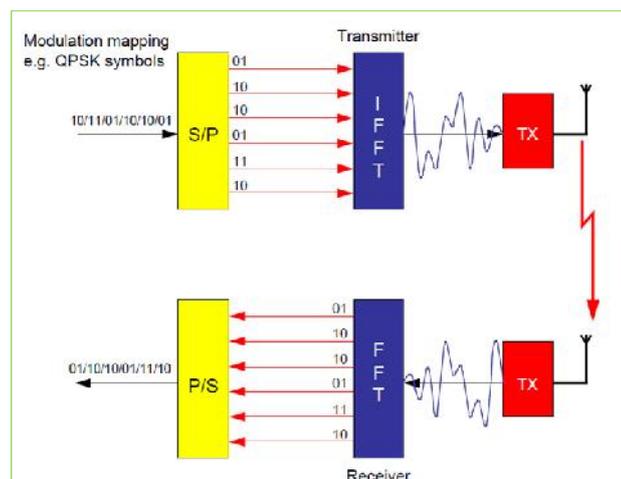
OFDM Frequency Structure



- The idea of OFDM is to divide the BW into group of orthogonal sub-carriers
- Sub-carrier spacing is the inverse of Ts(Symbol Time)ensure orthogonality
- Considering Ts=66.7 Microsec So we have sub-carrier spacing=15 KHz



OFDM TX/RX Block Diagram

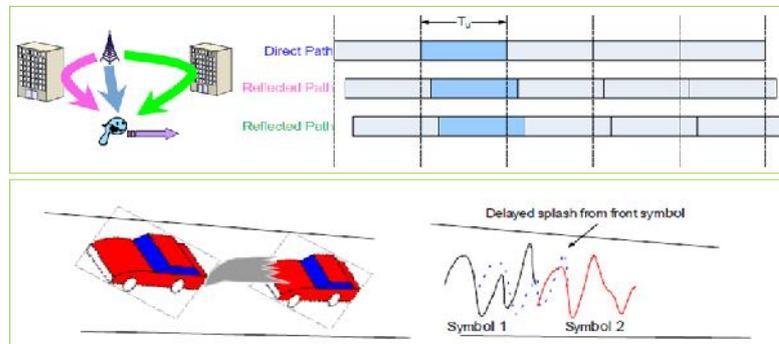


Advantages and Disadvantages of OFDM

- **Key OFDM Advantages**
 - Increased Spectral Efficiency
 - Robustness to Multipath Fading
 - Scalable Bandwidth Allocation
- **Disadvantages**
 - High Peak to Average Power Ratio (PAPR)
 - Sensitive to Frequency and Timing Errors
 - Guard Band Requirement
 - Inter Symbol interference and inter Carrier Interference

Inter Symbol and inter Carrier interference

- Inter Symbol interference comes from delay spread of Multi-Path fading

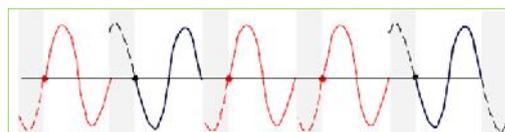
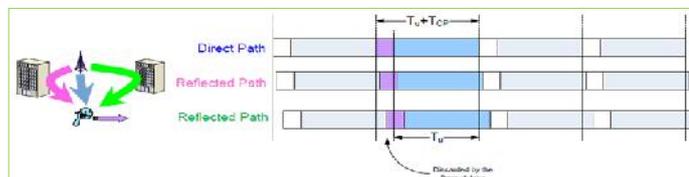


Inter Symbol and inter Carrier interference

- Inter Carrier interference comes from Doppler shift effect
- The most important part of the symbol to be protected is the front part as it carries the phase change.
- The solution of this problem is to add a CP(Cyclic Prefix).

Cyclic Prefix insertion

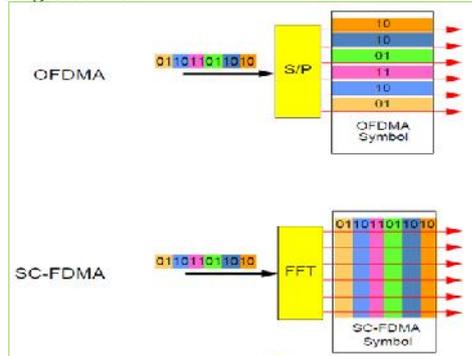
- The idea of Cyclic Prefix is to copy the symbol end in the front to protect the phase information.
- Cyclic Prefix is removed before de-modulation.
- The disadvantage of this is reducing the symbol rate (T_s/T_s+T_{cp}).



SC-FDMA

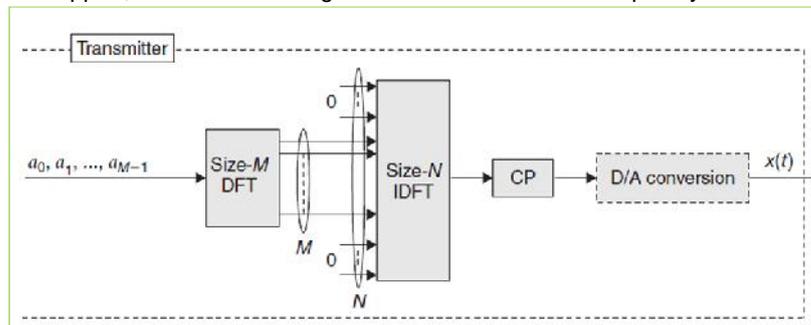


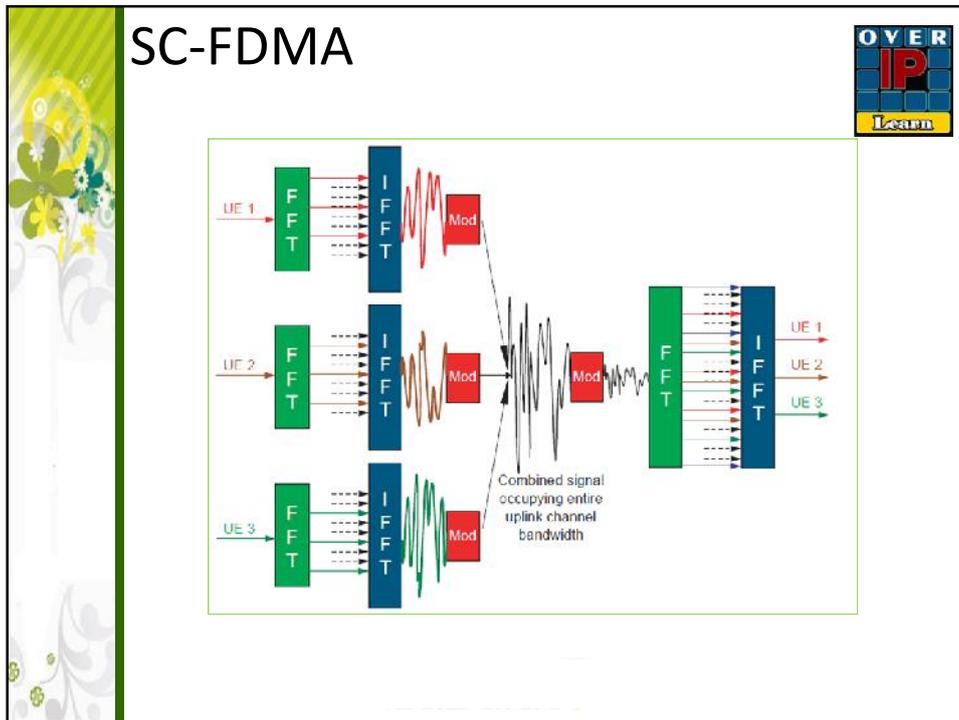
- SC-FDMA is used as an Uplink Access Technique.
- SC-FDMA is a solution for the PAPR occurred in OFDM.
- OFDM transmits data in parallel among different sub-carriers while SC-FDMA transmits data in series among different sub-carriers grouped as single carrier.



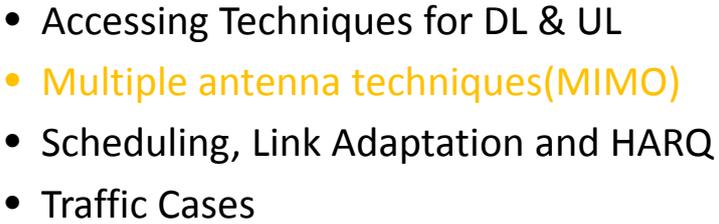
SC-FDMA

- the nominal bandwidth of the transmitted signal will be $BW = M/N \cdot f_s$.
- M the instantaneous bandwidth of the transmitted signal can be varied, allowing for flexible bandwidth assignment.
- Furthermore, by shifting the IDFT inputs to which the DFT outputs are mapped, the transmitted signal can be shifted in the frequency domain





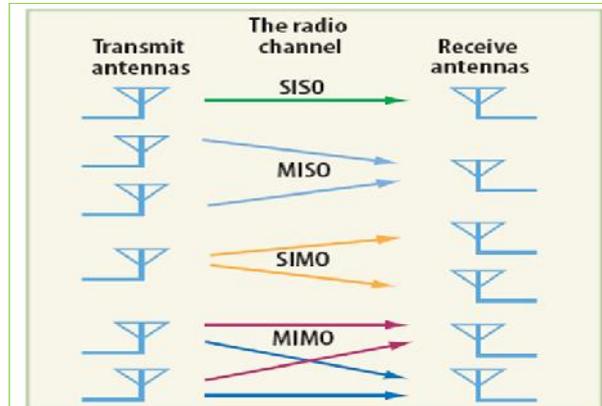
Course Contents



- Accessing Techniques for DL & UL
- Multiple antenna techniques(MIMO)
- Scheduling, Link Adaptation and HARQ
- Traffic Cases

OVER
IP
Learn

Historical Overview



1. These diagrams show different single- and multiple-antenna techniques.

Historical Overview



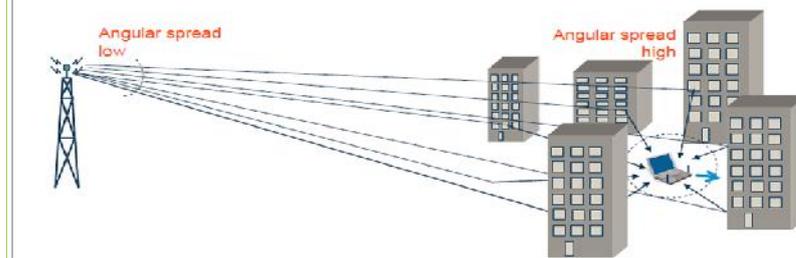
- Multi antenna systems is the use of multiple receive and/or transmit antennas
- If one transmitting and many receiving, is called SIMO(single input multi output)
- If many transmitting and one receiving, is called MISO(multi input single output)
- If many transmitting and many receiving, is called MIMO(multi input multi output)
- Multi antenna techniques are used to increase system performance including capacity, coverage, QoS.

Idea of MiMO



- MiMO makes benefit of channel Multipath fading.
- The two antennas must have “low fading correlation” in order to create different channel paths.
- MIMO Can't perform well in a non Multi-path environment.

- Angular spread at base station side typically much lower than at the terminal side
 - Beamforming at base station side beneficial
 - Easier to obtain low spatial correlation at terminal side (shorter antenna distance than at base station)



MIMO Main benefits



- MIMO has two main benefits either:
 - 1) Improving SINR in case of Low SINR
 - 2) Sharing SINR in case of High SINR
- MIMO Achieves these Main benefits through certain modes of operation:
 - 1) TX Diversity(Open Loop or Closed Loop)
 - 2) RX Diversity(MRC & IRC)
 - 3) Beam Forming
 - 4) SU-MIMO & MU-MIMO(Spatial Multiplexing)

MIMO Channel Model



- To be able to understand the MIMO main operations we have to understand the Channel model in case of MIMO
- MIMO adds a new dimension besides time and frequency called spatial domain
- We would consider a 2x2 MIMO as an example

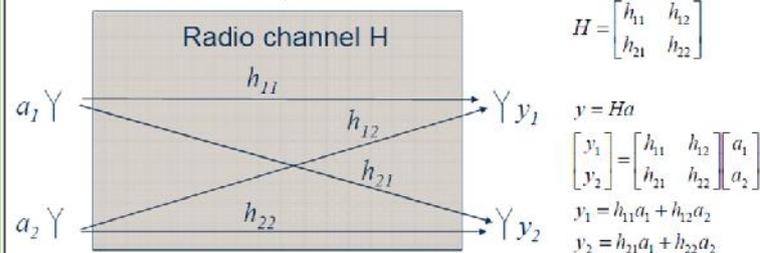
MIMO Channel Model



- y : received signal, a : transmitted signal on antenna port, h : radio channel transfer function

$$a \text{ } \Upsilon \xrightarrow{h} \Upsilon y = ha$$

- With MIMO, the radio channel transfer function becomes a matrix, H



Important Definitions

- Channel Rank: is the number of independent paths that can be created in the channel
- TX Rank: is the Min of (N_t, N_r) where N_t is the No. of TX Antennas and N_r is the number of RX antennas
- Channel rank = TX Rank >>>> Why?!
- PMI: pre-coder Matrix indicator that it is calculated at the mobile from RS(Reference Symbols) and reported to the eNB to perform required signal processing

TX Diversity Open & Closed Loop

- Open loop means there is no knowledge about channel conditions
- Open loop TX Diversity is done by transmitting same code word from different antenna ports
- It is done by either STBC(Space Time Block coding) or SFBC(Space Frequency Block Coding)
- Closed loop is when there is feedback about channel condition, CSI(Channel State Information) is reported
- Closed loop is called “ Beam Forming”

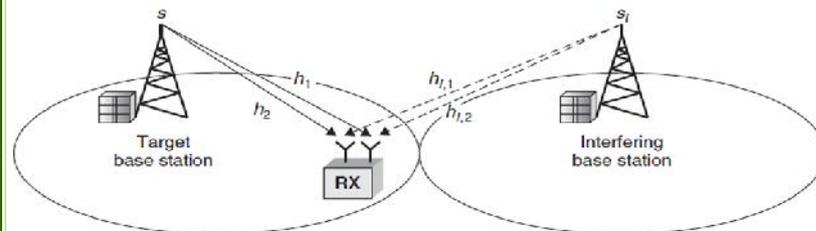
Beam Forming

- The idea of beam forming is to direct the antenna radiation pattern towards a certain group of users in a certain place
- This is done by multiplying by a certain pre-coding Matrix calculated from user feedback about the channel spatial characteristics
- Beam Forming increases the SINR and decreases the interference
- It is not used till now in any operator

RX Diversity



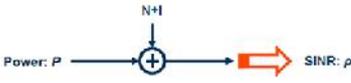
- RX Diversity is done through either MRC(Maximum Ration Combining) or IRC(interference Rejection Combining)
- MRC when channel is mainly impaired by noise
- IRC when channel is mainly impaired by interference
- IRC is a kind of Beam Forming ?!!



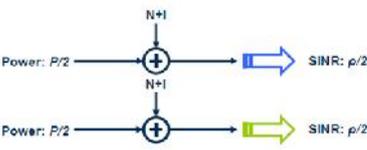
Spatial Multiplexing



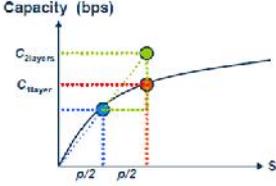
Single layer



Two layers



- High SINR saturates single layer throughput
- SINR "shared" among layers
- Ideally, multiple layers better ($C_{2layers} > C_{1layer}$)
- In practice, MIMO may be worse due to
 - Inter stream cross-talk => lowers MIMO SINR:s
 - SINR imbalance



High SINR => greater chance multiple layers is better!

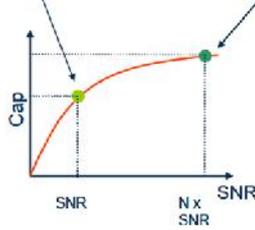
Spatial Multiplexing



Without MIMO

Single stream Rx/Tx processing,
Multiple Rx and/or Tx antennas

$C \sim \log(1+SNR)$ $C \sim \log(1+N \times SNR)$

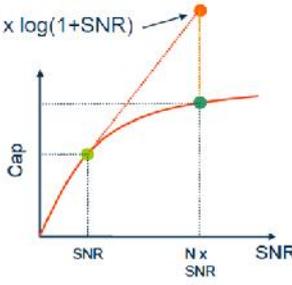


Low SNR: approx linear increase in rate
High SNR: logarithmic increase in rate

With MIMO

Multistream Rx/Tx processing,
Multiple Rx and Tx antennas

$C_{mimo} \sim N \times \log(1+SNR)$



Share SNR between streams =>
Linear increase in rate

SU-MIMO & MU-MIMO

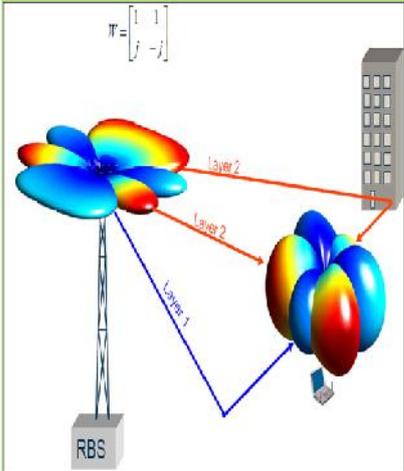


- SU-MIMO is used in downlink where the two created layers are used with a single user so the gain is in the average user Throughput.
- MU-MIMO is used in uplink as the UE can't transmit with two antennas simultaneously, so the two created layers are used to serve two different users.

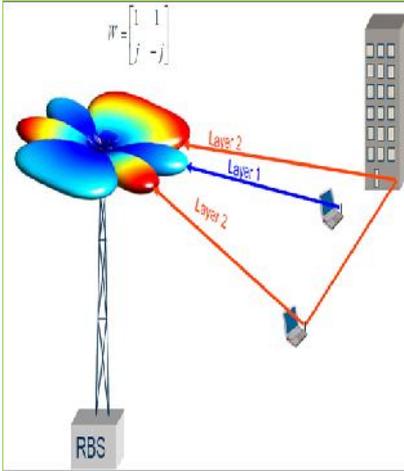
SU-MIMO & MU-MIMO



$\mathbb{W} = \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix}$



$\mathbb{W} = \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix}$





Course Contents

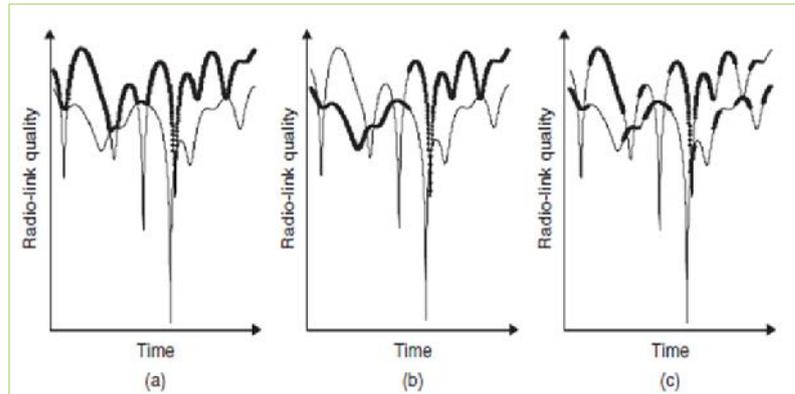
- Accessing Techniques for DL & UL
- Multiple antenna techniques(MIMO)
- **Scheduling, Link Adaptation and HARQ**
- Traffic Cases



Channel dependent Scheduling

- Scheduling in LTE is fast scheduling done every TTI(1ms)
- Scheduling is the most important function in the eNB
- Trade off between Fairness and Throughput while satisfying the required QoS
- Scheduling has three main types:
 - 1) MAX C/I
 - 2) Round Robin
 - 3) Proportional fair

Channel dependent Scheduling

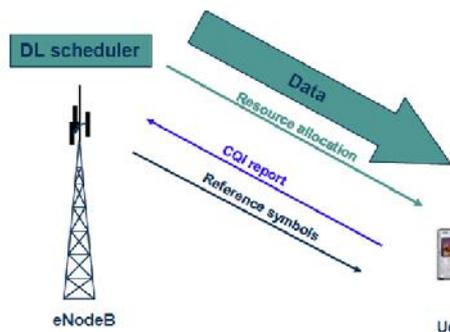


What it is (a),(b) & (c) ?

DL Scheduling



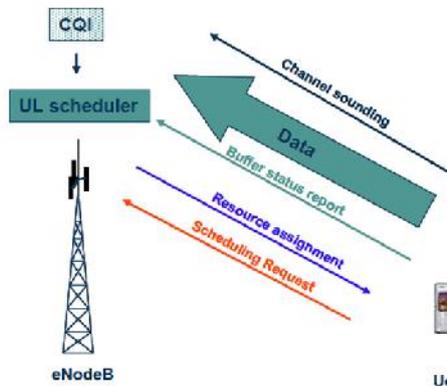
- Ue provides a Channel Quality Report (CQI) based on DL reference symbols
- Scheduler assigns resources per RB based on QoS, CQI etc.
- Resource allocation is transmitted in connection with data
- Many details remain open in 3GPP



UL Scheduling

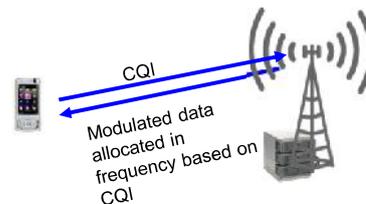


- Ue request UL transmission via "scheduling request"
- Scheduler assigns initial resources without detailed knowledge of buffer content
- More detailed buffer status report may follow in connection with data
- Either D-SR on PUCCH or RA-SR on RACH



LTE Channel Quality Indicator (CQI)

- Indicates the DL channel quality as experienced by the UE
- UE proposes eNB and optimum MCS so BLER is on target
 - CQI not only considers time domain but also frequency domain. CQI reference resource:
 - **Time:** Defined by a single sub-frame
 - **Frequency:** Defined by PRB corresponding to the band to which the derived CQI value related
 - ‘**Meaning of CQI reporting**’ (for periodic and aperiodic):
 - **Wideband CQI:** Referred to the complete system BW
 - **Sub-band CQI:** value per sub-band (certain # of RB) that is configured by higher layers



DL Link adaptation

Optimizing air interface efficiency

- Motivation of link adaptation:** Modify the signal transmitted to and by a particular user according to the signal quality variation to improve the **system capacity** and **coverage reliability**.
 - If SINR is good then higher MCS can be used -> more bits per byte -> more throughput.
 - If SINR is bad then lower MCS should be used (more robust)
- The selection of the modulation and the channel coding rate is based:
 - Downlink data channel: CQI report from UE
 - Downlink common channel (PDCCH)
 - Uplink: BLER measurements

MCS/TBS Selection

- Based on CQI Status, Appropriate MCS and TBS index is selected based on SINR value (3GPP Standard measurements)
- After MCS and ITBS selection Transport Block - code word Throughput and PRB can be mapped and scheduled in DL

Only a subset of the complete table (3GPP TS 36.213 specifies 110 columns)

MCS Index	Modulation Order	TBS Index
M_{cs}	Q_m	T_{cs}
0	2	0
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	2	10
11	2	11
12	2	12
13	2	13
14	2	14
15	2	15
16	2	16
17	2	17
18	2	18
19	2	19
20	2	20
21	2	21
22	2	22
23	2	23
24	2	24
25	2	25
26	2	26
27	2	27
28	2	28
29	2	29
30	2	reserved
31	2	reserved

Modulation Order
 2 0 QPSK
 4 0 16QAM
 6 0 64QAM

High MCS corresponds to high throughput

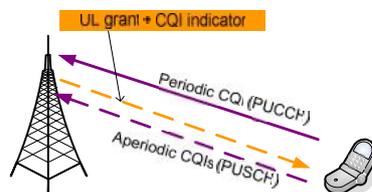
T_{cs}	N_{cs}									
	1	2	3	4	5	6	7	8	9	10
0	16	32	56	88	120	152	176	208	224	256
1	24	48	80	112	144	176	208	224	256	288
2	32	64	112	160	208	256	288	320	352	384
3	40	80	144	208	256	320	352	384	416	448
4	48	96	176	240	304	352	400	448	496	544
5	56	112	208	288	352	416	464	512	560	608
6	64	128	240	336	400	464	512	560	608	656
7	72	144	272	384	448	512	560	608	656	704
8	80	160	304	432	512	576	624	672	720	768
9	88	176	336	480	560	624	672	720	768	816
10	96	192	368	528	608	672	720	768	816	864
11	104	208	400	576	656	720	768	816	864	912
12	112	224	432	624	704	768	816	864	912	960
13	120	240	464	672	752	816	864	912	960	1008
14	128	256	496	720	800	864	912	960	1008	1056
15	136	272	528	768	848	912	960	1008	1056	1104
16	144	288	560	816	896	960	1008	1056	1104	1152
17	152	304	592	864	944	1008	1056	1104	1152	1200
18	160	320	624	912	992	1056	1104	1152	1200	1248
19	168	336	656	960	1040	1104	1152	1200	1248	1296
20	176	352	688	1008	1088	1152	1200	1248	1296	1344
21	184	368	720	1056	1136	1200	1248	1296	1344	1392
22	192	384	752	1104	1184	1248	1296	1344	1392	1440
23	200	400	784	1152	1232	1296	1344	1392	1440	1488
24	208	416	816	1200	1280	1344	1392	1440	1488	1536
25	216	432	848	1248	1328	1392	1440	1488	1536	1584
26	224	448	880	1296	1376	1440	1488	1536	1584	1632
27	232	464	912	1344	1424	1488	1536	1584	1632	1680
28	240	480	944	1392	1472	1536	1584	1632	1680	1728
29	248	496	976	1440	1520	1584	1632	1680	1728	1776
30	256	512	1008	1488	1568	1632	1680	1728	1776	1824
31	264	528	1040	1536	1616	1680	1728	1776	1824	1872

UL Link adaptation

The eNB measures the uplink channel quality and orders the UE to use a specific modulation and coding scheme (MCS) based on this. Other parameters may also be taken into account, such as *UE power headroom, scheduled bandwidth, buffer content and acceptable delay*.

Sounding Reference Signal (SRS)

Used by network to be able to estimate the channel quality of uplink channels for different UE in order to be able to apply dependent UL link adaptation and scheduling for different UEs.



HARQ Operation



- LTE Can Recover PDU errors at two layers: RLC & MAC
- MAC introduces H-ARQ solution at MAC layer to recover any error in the physical layer
- UE Combines all of the retransmission to increase probability of successfully reception
- The number of simultaneous H-ARQ operations depends on Mobile category
- If the number of HARQ Retransmission is reached the RAB is released

QoS Handling



QCI	Type	Priority	Packet Delay Budget	Packet Error Rate	Service Example
1	GBR	2	100ms	10 ⁻²	Conversational Voice
2	GBR	4	150ms	10 ⁻³	Conversational Voice
3	GBR	3	50ms	10 ⁻³	Real time gaming
4	GBR	5	300ms	10 ⁻⁶	Real time video
5	Non GBR	1	100ms	10 ⁻⁶	IMS signaling
6	Non GBR	6	300ms	10 ⁻⁶	Video with buffer
7	Non GBR	7	100ms	10 ⁻³	Voice, Video, Interactive Gaming
8	Non GBR	8	300ms	10 ⁻⁶	Video, TCP (HTTP, E-mail, FTP etc)
9	Non GBR	9	300ms	10 ⁻⁶	Video, TCP (HTTP, E-mail, FTP etc)

QoS Handling



EPS Bearer QoS depends on the **resource type: GBR or Non-GBR**

- A **Default EPS Bearer** is always Non-GBR
- A **Dedicated EPS Bearer** can be GBR or Non-GBR

EPS QoS Parameters

- QoS Class Identifier (QCI)
- Allocation/Retention Priority (ARP)
- Guaranteed Bit Rate (GBR), Maximum Bit Rate (MBR)
 - GBR Bearers only - (Uplink/Downlink)
- Per UE/APN Aggregate MBR (UE-AMBR, APN-AMBR)
 - Non-GBR Bearers only - (Uplink/Downlink)

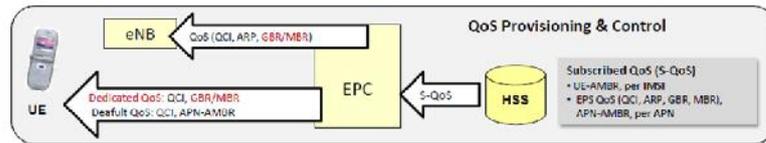
APN = Access Point Name

GBR QoS

- QCI
- ARP
- GBR
- MBR

Non-GBR QoS

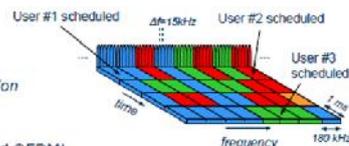
- QCI
- ARP
- APN-AMBR
- UE-AMBR



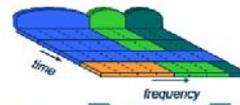


Main LTE Key Feature ... reminder

- Downlink: Adaptive OFDM and OFDMA
 - Channel-dependent scheduling and link adaptation in time and frequency domain



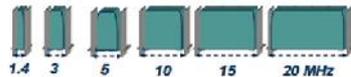
- Uplink: SC-FDMA with dynamic bandwidth (Pre-coded OFDM)
 - Low PAPR → Higher power efficiency
 - Reduced uplink interference (enables intra-cell orthogonality)



- Multi-Antennas, both RBS and terminal
 - MIMO, antenna beams, TX- and RX diversity, interference rejection
 - High bit rates and high capacity



- Flexible bandwidth
 - Possible to deploy in 6 different bandwidths up to 20 MHz



- Harmonized FDD and TDD concept
 - Maximum commonality between FDD and TDD

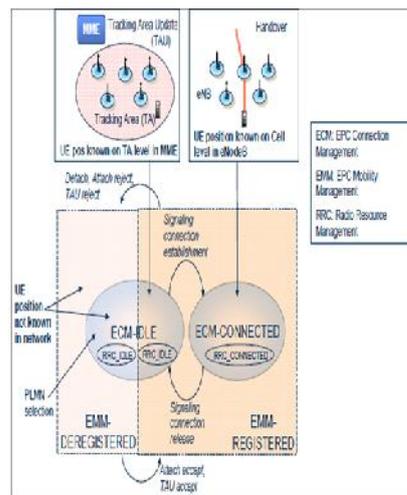


- Minimum UE capability: BW = 20 MHz

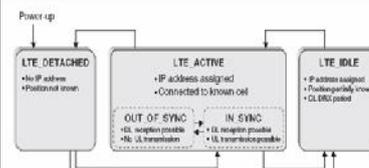
Main LTE Frequency bands

E-UTRA Band	Uplink (UL)		Downlink (DL)	
	FUL_low	FUL_high	FUL_low	FUL_high
1	1920 MHz	1980 MHz	2110 MHz	2170 MHz
2	1850 MHz	1910 MHz	1930 MHz	1990 MHz
3	1710 MHz	1785 MHz	1805 MHz	1880 MHz
4	1710 MHz	1755 MHz	2110 MHz	2155 MHz
5	824 MHz	849 MHz	869 MHz	894 MHz
6	830 MHz	840 MHz	875 MHz	885 MHz
7	2500 MHz	2570 MHz	2620 MHz	2690 MHz
8	880 MHz	915 MHz	925 MHz	960 MHz
9	1749.9 MHz	1784.9 MHz	1844.9 MHz	1879.9 MHz
10	1710 MHz	1770 MHz	2110 MHz	2170 MHz
11	1427.9 MHz	1452.9 MHz	1475.9 MHz	1500.9 MHz
12	698 MHz	716 MHz	728 MHz	746 MHz
13	777 MHz	787 MHz	746 MHz	756 MHz
14	788 MHz	798 MHz	758 MHz	768 MHz

Protocol states and mobility

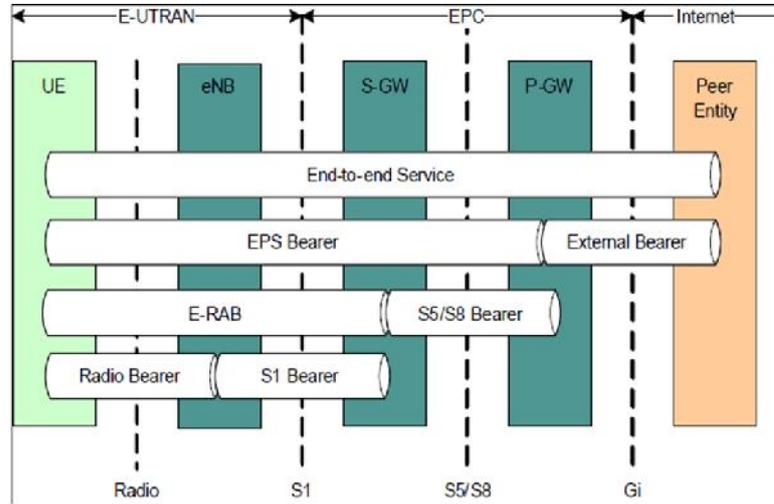


One of the main LTE advantages is minimizing number of states transitions that led to huge saving in processor load.

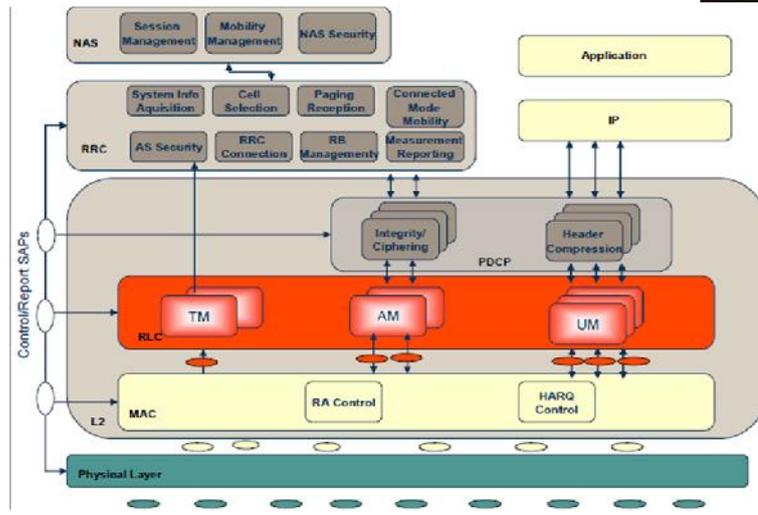


TAU: tracking area update occurs when LTE-Ue change its tracking area while it is in idle mode.
Handover: done through x2 or S1 and it is controlled totally by e-NodeB.

LTE bearer concept



UE protocol stack (1-3)





UE protocol stack (2-3)

- RRC Layer

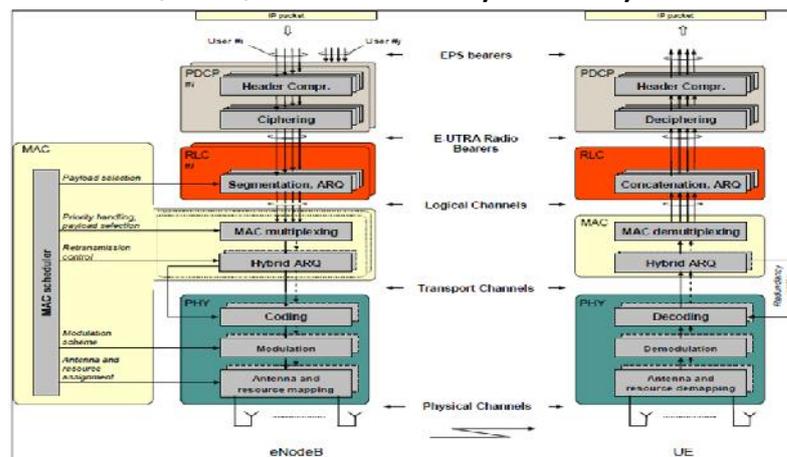
- System information
- Cell Selection / Reselection
- Connection control
 - Paging
 - RRC connection establishment
 - Security activation
 - RRC connection reconfiguration
 - RRC connection re-establishment
 - RRC connection release
 - Radio link failure related actions
- Measurement Control
 - Measurement configuration
 - Measurement reporting
- Mobility Management
 - Inter/Intra E-UTRA mobility
 - Mobility from E-UTRA
 - Handover to E-UTRA
- Other procedures
 - DL Direct Transfer
 - UL Direct Transfer
 - UE capability transfer
 - Protocol error handling



UE protocol stack (3-3)



- PDCP, RLC, MAC and Physical Layers



UE Categories



Category	1	2	3	4	5
DL peak rate	10	50	100	150	300
UL peak rate	5	25	50	50	75
Max DL mod	64QAM				
Max UL mod	16QAM			64QAM	
Layers for DL spatial mux.	1	2		4	

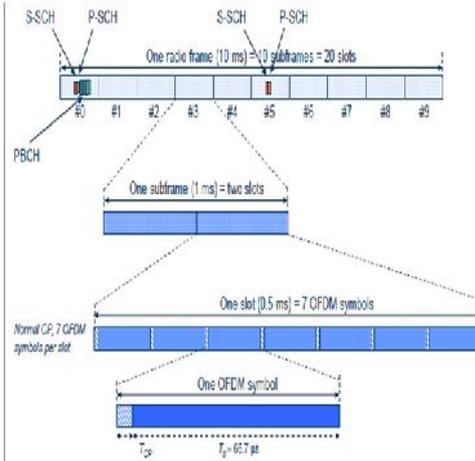
- All UEs support 4 Tx antennas at eNodeB
- Soft buffer sizes under discussion
- MBMS is a separate capability
- FDD, HD-FDD and TDD are independent capabilities

Time domain Structure



- LTE Duplexing Mode
 - FDD
 - In FDD there are 2 different time domain structures, one for Uplink and one for downlink
 - TDD
 - In TDD there is single time domain structure shared between UL and DL
 - Peak LTE data rate couldn't be achieved through TDD.

General time Domain structure



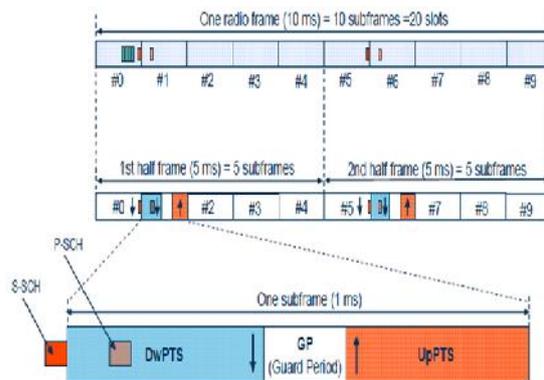
- PBCH sent in subframe #0, slot 1, symbol 0-3 over 4 consecutive radio frames (40 ms)

- SCH sent in subframe #0 and #5, slot 0 and 10, symbol 5-6 (4-5 in case of extended CP)

CP_Normal duration is $\approx 4.7 \mu s$

CP_Extended duration is $\approx 16.7 \mu s$

TDD time domain structure (1-3)



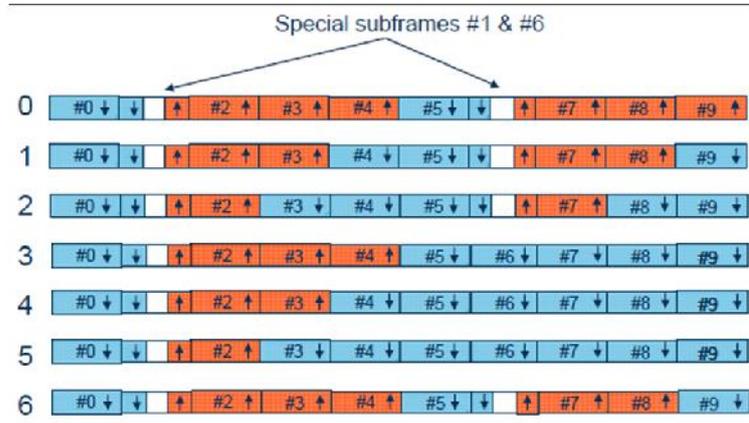
- DL to UL switch point in special subframe #1 and #6 only

- Other subframes allocated to UL or DL

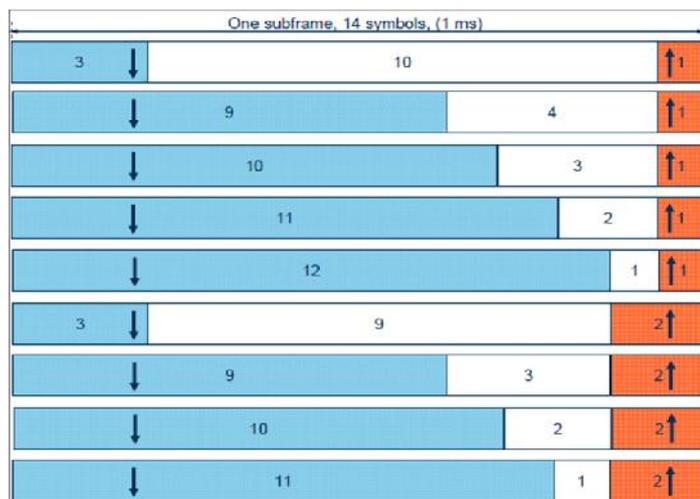
- Sum of DwPTS, GP and UpPTS always 1 ms

- Subframe #0 and #5 always DL Used for cell search signals (S-SCH)

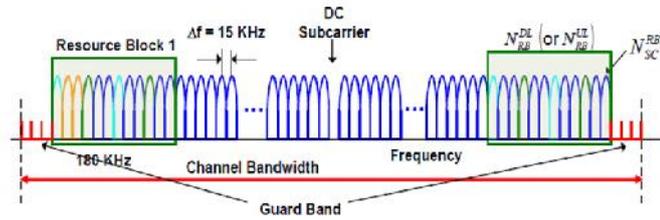
TDD time Domain structure (2-3)



TDD time Domain structure (3-3)



Frequency Domain structure



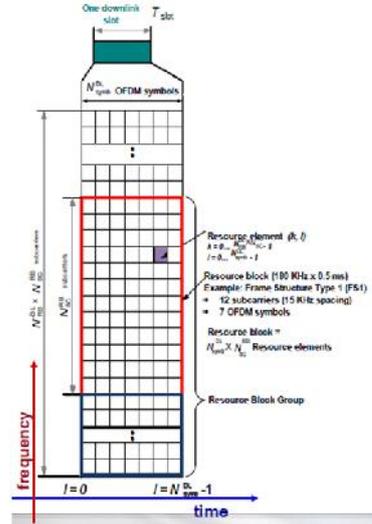
- Δf : Subcarrier spacing
 - 15 KHz in normal cases
 - 7.5 KHz in MBSFN transmission
- DC Subcarrier: Direct Current subcarrier at center of frequency band
- $F_s = N_{fft} \times \Delta f$ Sampling frequency
 - Where N_{fft} is the IFFT size
- $BW = N_{used} \times \Delta f$ Actual needed BW
 - Where N_{used} is the actual number of used subcarriers

Frequency Domain Configurations

Channel Bandwidth [MHz]	1.4	3	5	10	15	20
N. of Occupied Subcarriers including DC (N_{sc})	73	181	301	601	901	1201
FFT Size (N)	128	256	512	1024	1536	2048
Sampling Rate [MHz]	1.92 $\frac{1}{2} \times 3.84$	3.84	7.68 2×3.84	15.36 4×3.84	23.04 6×3.84	30.72 8×3.84
N. of Resource Blocks (N_{RB})	6	15	25	50	75	100

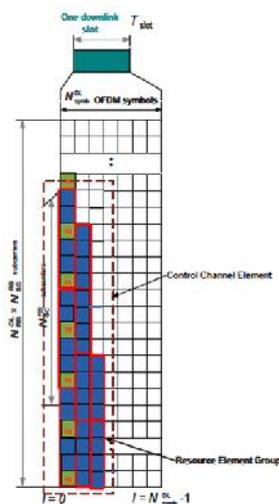
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Resources grid (1-2)



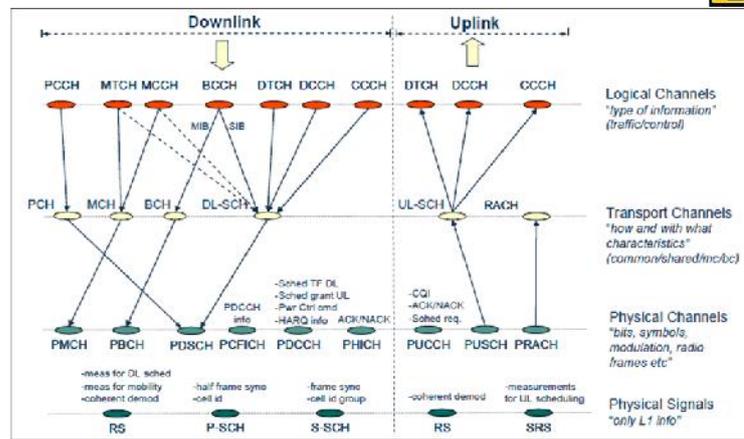
- **Resource Element (RE)**
One element in the time/frequency resource grid. One subcarrier in one OFDM/FDM symbol for DL/UL.
- **Resource Block (RB)**
Minimum scheduling size for DL/UL data Channels Physical Resource Block (PRB) [180 kHz x 0.5 ms]
- **Resource Block Group (RBG)**
Group of Resource Blocks Size of RBG depends on the system bandwidth in the cell

Resources grid (1-2)



- **Resource Element Group (REG)**
Groups of Resource Elements to carry control information. 4 or 6 REs per REG depending on number of reference signals per symbol, cyclic prefix configuration. REs used for DL Reference Signals (RS) are not considered for the REG.
- **Control Channel Element (CCE)**
Group of 9 REGs form a single CCE. 1 CCE = 36 REs usable for control information. Both REG and CCE are used to specify resources for LTE DL control channels.
- **Antenna Port**
One designated reference signal per antenna port. Set of antenna ports supported depends on reference signal configuration within cell.

LTE Channels



LTE Logical Channels (1-2)



Control Channels

- **Broadcast Control Channel (BCCH):** A downlink channel for broadcasting system control information.
- **Paging Control Channel (PCCH):** A downlink channel that transfers paging information. This channel is used when the network does not know the location cell of the UE.
- **Common Control Channel (CCCH):** This channel is used by the UEs having no RRC connection with the network. CCCH would be used by the UEs when accessing a new cell or after cell reselection.
- **Multicast Control Channel (MCCH):** A point-to-multipoint downlink channel used for transmitting MBMS scheduling and control information from the network to the UE, for one or several MTCHs. After establishing an RRC connection this channel is only used by UEs that receive MBMS.
- **Dedicated Control Channel (DCCH):** A point-to-point bidirectional channel that transmits dedicated control information between a UE and the network. Used by UEs having an RRC connection.



LTE Logical Channels (2-2)



Traffic Channels

- **Dedicated Traffic Channel (DTCH):** A Dedicated Traffic Channel (DTCH) is a point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.
- **Multicast Traffic Channel (MTCH):** A point-to-multipoint downlink channel for transmitting traffic data from the network to the UEs using MBMS.



LTE Transport Channels



Downlink:

- **Broadcast Channel (BCH):** A low fixed bit rate channel broadcast in the entire coverage area of the cell. Beam-forming is not applied.
- **Downlink Shared Channel (DL-SCH):** A channel with possibility to use HARQ and link adaptation by varying the modulation, coding and transmit power. The channel is possible to broadcast in the entire cell and beam-forming may be applied. UE power saving (DRX) is supported to reduce the UE power consumption. MBMS transmission is also supported.
- **Paging Channel (PCH):** A channel that is broadcasted in the entire cell. DRX is supported to enable power saving.
- **Multicast channel (MCH):** A separate transport channel for multicast (MBMS). This channel is broadcast in the entire coverage area of the cell. Combining of MBMS transmissions from multiple cells (MBSFN) is supported.

Uplink:

- **Uplink Shared channel (UL-SCH):** A channel with possibility to use HARQ and link adaptation by varying the transmit power, modulation and coding. Beam-forming may be applied.
- **Random Access Channel (RACH):** A channel used to obtain timing synchronization (asynchronous random access) and to transmit information needed to obtain scheduling grants (synchronous random access). The transmission is typically contention based. For UEs having an RRC connection there is some limited support for contention free access.



Physical channels (1-15)

Downlink

- Physical Downlink Shared Channel (PDSCH)**
 - transmission of the DL-SCH transport channel
- Physical Control Format Indicator Channel (PCFICH)**
 - indicates the PDCCH format in DL
- Physical Downlink Control Channel (PDCCH)**
 - DL L1/L2 control signaling
- Physical Hybrid ARQ Indicator Channel (PHICH)**
 - DL HARQ info
- Physical Broadcast Channel (PBCH)**
 - DL transmission of the BCH transport channel.
- Physical Multicast Channel (PMCH)**
 - DL transmission of the MCH transport channel.
- Reference Signals (RS)**
 - support measurements and coherent demodulation in downlink.
- Primary and Secondary Synchronization signals (P-SCH and S-SCH)**
 - DL only and used in the cell search procedure.

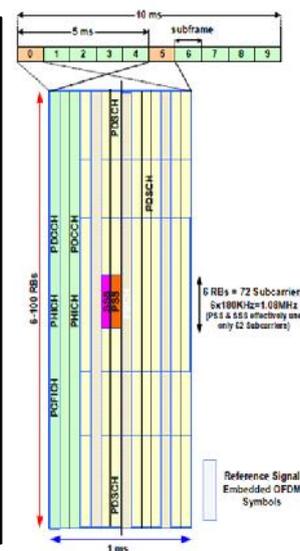
Uplink

- Physical Uplink Control Channel (PUCCH)**
 - UL L1/L2 control signaling
- Physical Uplink Shared Channel (PUSCH)**
 - transmission of the UL-SCH transport channel
- Sounding Reference Signal (SRS)**
 - supports UL scheduling measurements
- Physical Random Access Channel (PRACH)**
 - UL transmission of the random access preamble as given by the RACH transport channel.
- Physical signals**
- Reference Signals (RS)**
 - support measurements and coherent demodulation in uplink

Physical channels (2-15)

•PSS and SSS Functions

- Frequency and Time synchronization**
 - 1- Carrier frequency determination
 - 2- OFDM symbol/subframe/frame timing determination
- Physical Layer Cell ID determination**
 - 1- Determine 1 out of 504 possibilities
- Primary Synchronization Signals (PSS)**
 - 1- Assists subframe timing determination
 - 2- Provides a unique Cell ID index (0, 1, or 2) within a Cell ID group
- Secondary Synchronization Signals (SSS)**
 - 1- Assists frame timing determination
 - 1.1- M-sequences with scrambling and different concatenation methods for SF0 and SF5)
 - 2- Provides a unique Cell ID group number among 168 possible Cell ID groups



Physical channels (3- 15)

• PBCH Function

- 1- Carries the primary Broadcast Transport Channel
- 2- Carries the Master Information Block (MIB), which includes:

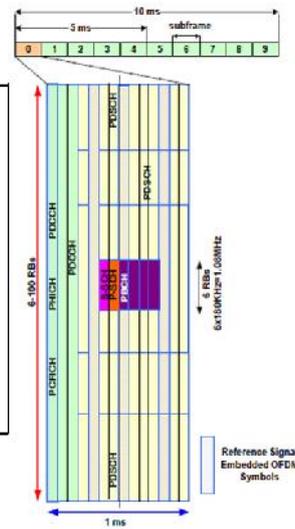
- 2.1- Overall DL transmission bandwidth
- 2.2- PHICH configuration in the cell
- 2.3- System Frame Number
- 2.4- Number of transmit antennas (implicit)

• Transmitted in

- 1- **Time:** subframe 0 in every frame , 4 OFDM symbols in the second slot of corresponding subframe
- 2- **Frequency:** middle 1.08 MHz (6 RBs)

• TTI = 40 ms

- 1- Transmitted in 4 bursts at a very low data rate
- 2- Same information is repeated in 4 subframes



Physical channels (4- 15)

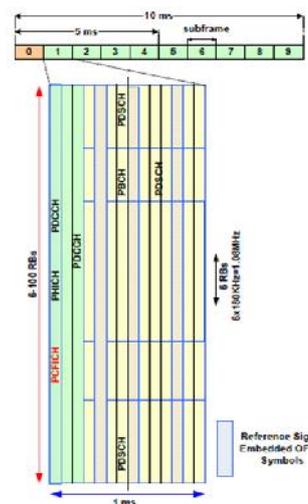
PCFICH Function

- 1- Carries the Control Format Indicator (CFI)
- 2- Signals the number of OFDM symbols of PDCCH:

- 2.1- 1, 2, or 3 OFDM symbols for system bandwidth > 10 RBs
- 2.2- 2, 3, or 4 OFDM symbols for system bandwidth > 6-10 RBs
- 2.3- Control and data do **not** occur in same OFDM symbol

3- Transmitted in:

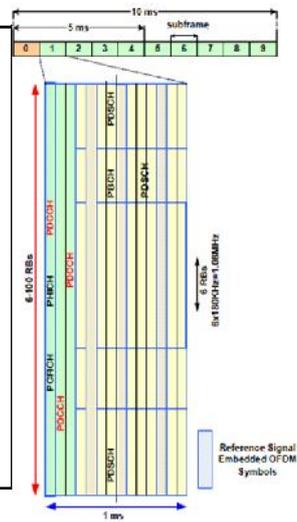
- 3.1- Time: 1st OFDM symbol of all subframes
- 3.2- Frequency: spanning the entire
 - 4 REGs -> 16 REs
 - Mapping depends on Cell ID



Physical channels (5- 15)

PDCCH Function

- **Used for:**
 - DL/UL resource assignments
 - Multi-user Transmit Power Control (TPC) commands
 - Paging indicators
- **CCEs are the building blocks for transmitting PDCCH**
 - 1 CCE = 9 REGs (36 REs) = 72 bits
 - The control region consists of a set of CCEs, numbered from 0 to N_CCE for each subframe
 - The control region is confined to 3 or 4 (maximum) OFDM symbols per subframe (depending on system bandwidth)
- **A PDCCH is an aggregation of contiguous CCEs (1,2,4,8)**
 - Necessary for different PDCCH formats and coding rate protections
 - Effective supported PDCCH aggregation levels need to result in code rate < 0.75



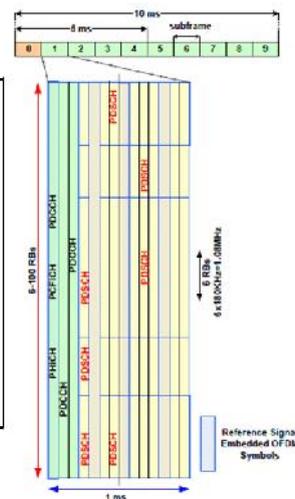
Physical channels (6- 15)

PDSCH function

- **Transmits DL packet data**
 - One Transport Block transmission per UE's code word per subframe
 - A common MCS per code word per UE across all allocated RBs
 - Independent MCS for two code words per UE
 - 7 PDSCH Tx modes

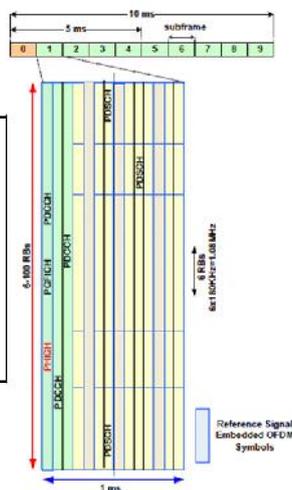
Mapping to Resource Blocks (RBs)

- Mapping for a particular transmit antenna port shall be in increasing order of:
 - First the frequency index,
 - Then the time index, starting with the first slot in a subframe.



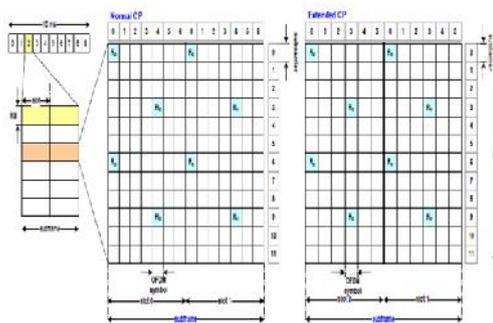
Physical channels (7- 15)

PHICH function
 Used for ACK/NAK of UL-SCH transmissions
 Transmitted in:
Time
 –Normal duration: 1st OFDM symbol
 –Extended duration: Over 2 or 3 OFDM symbols
Frequency
 –Spanning all system bandwidth
 –Mapping depending on Cell ID
FDM multiplexed with other DL control channels
Support of CDM multiplexing of multiple PHICHs



Physical channels (8- 15)

RS transmission in single antenna scenario



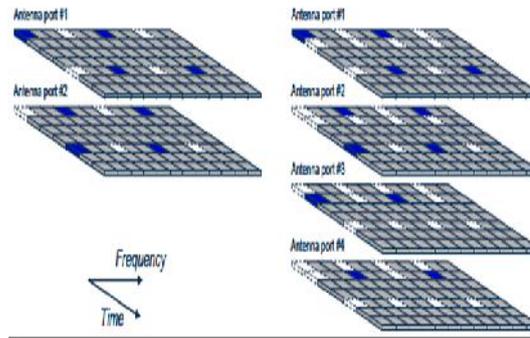
Cell-specific reference signals
 – Sequence is a product of 1 of 3 orthogonal sequences
 1 of 168 pseudo-random sequences
 – $3 \times 168 = 504$ different sequences 504 different cell identities .
Used for
 – coherent demodulation in the UE
 – channel-quality measurements for scheduling
 – measurements for mobility

Reference signal transmission scheme

- Transmitted on 2 OFDM symbols each time slot with 6 OFDM sub-carriers spacing

Physical channels (9- 15)

RS transmission in Multiple antenna scenario



Cell-specific reference signals

– Sequence is a product of 1 of 3 orthogonal sequences
 1 of 168 pseudo-random sequences
 – $3 \times 168 = 504$ different sequences
 504 different cell identities .

Used for

- coherent demodulation in the UE
- channel-quality measurements for scheduling
- measurements for mobility

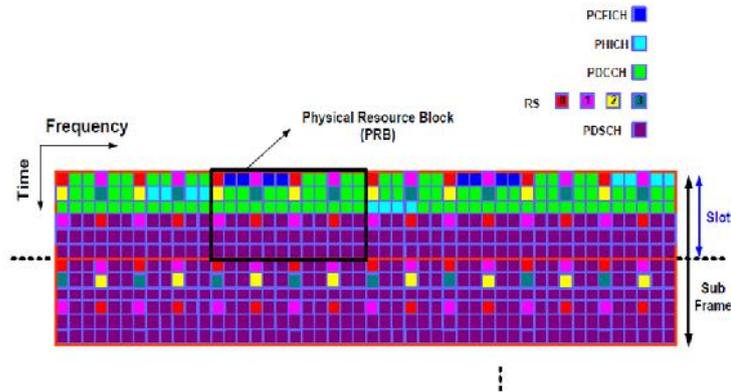
Reference signal transmission scheme

- Transmitted on 2 OFDM symbols each time slot with 6 OFDM sub-carriers spacing

Physical channels (10- 15)



Example of Frame Structure Type 1 (extended CP) transmission



Physical channels (11- 15)



Uplink – physical channel

Physical Uplink Control Channel (PUCCH)

- UL L1/L2 control signaling
 - ACK/NACK
 - RA, PMI, CQI
 - SR

Physical Uplink Shared Channel (PUSCH)

- transmission of the UL-SCH transport channel

Sounding Reference Signal (SRS)

- supports UL scheduling measurements

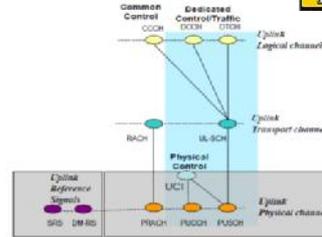
Physical Random Access Channel (PRACH)

- UL transmission of the random access preamble as given by the RACH transport channel.

Physical signals

Reference Signals (RS)

- support measurements and coherent demodulation in uplink



Uplink - transport channels

- **Uplink Shared channel (UL-SCH):** A channel with possibility to use HARQ and link adaptation by varying the transmit power, modulation and coding. Beam-forming may be applied.

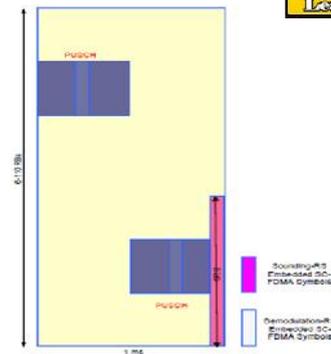
- **Random Access Channel (RACH):** A channel used to obtain timing synchronization (asynchronous random access) and to transmit information needed to obtain scheduling grants (synchronous random access). The transmission is typically contention based. For UEs having an RRC connection there is some limited support for contention free access.

Physical channels (12- 15)



Sounding Reference signal

- Not associated with transmission of PUSCH or PUCCH
- Purpose: Uplink channel quality estimation feedback to the Uplink scheduler (for Channel Dependent Scheduling) at the eNodeB
- Transmitted in time/frequency depending on the SRS bandwidth and the SRS bandwidth configuration (some rules apply if there is overlap with PUSCH and PUCCH)



SRS multiplexing:

- Done with CDM when there is one SRS bandwidth, and FDM/CDM when there are multiple SRS bandwidths.

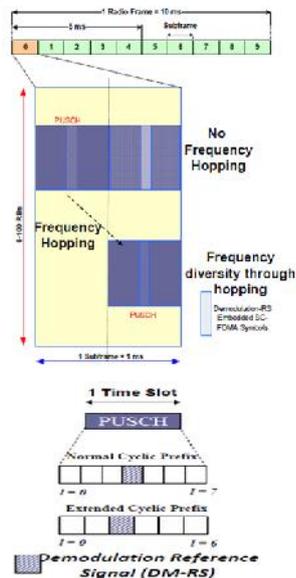
Physical channels (13- 15)

PUSCH

- UL Data
- ACK/NAK for DL data
- CQI/PMI/RI

Demodulation Reference signal

- Associated with transmission of PUSCH or PUCCH
- Purpose: Channel estimation for Uplink coherent demodulation/detection of the Uplink control and data channels
- Transmitted in time/frequency depending on the channel type (PUSCH/PUCCH), format, and cyclic prefix type

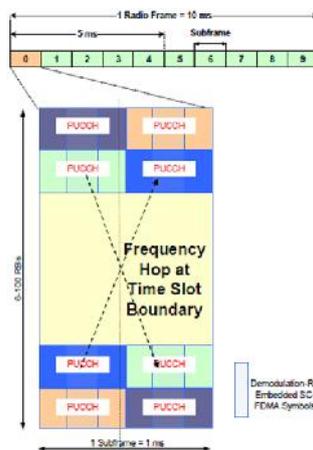
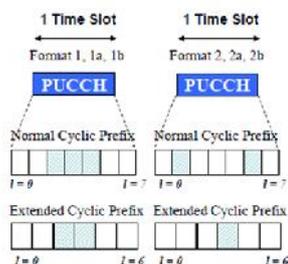


Physical channels (14- 15)



PUCCH

- ACK/NAK for DL data
- Scheduling Request
- CQI/PMI/RI

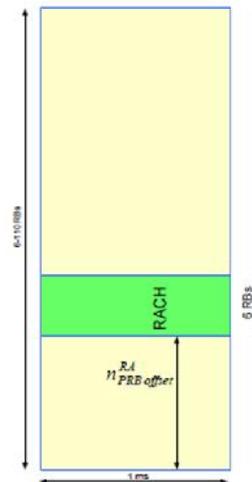


Physical channels (15- 15)



The preamble format determines the length of the Cyclic Prefix and Sequence.

- FDD has 4 preamble formats (for different cell sizes).
- 16 PRACH configurations are possible.
- Each configuration defines slot positions within a frame (for different bandwidths).
- Each random access preamble occupies a bandwidth corresponding to 6 consecutive RBs.

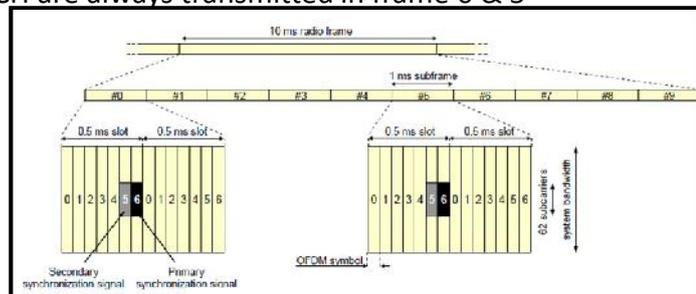


Thank You



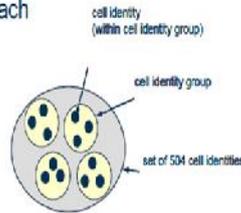
Cell Search Procedure-1/2

- Cell search is done to obtain downlink synchronization with cell to detect the BCCH
- There are two synchronization channels P-SCH & S-SCH
- Synchronization Channel (SCH) always occupies only 63 (62 + DC carrier which is not used) sub-carriers in the center of the available spectrum Why?!
- SCH are always transmitted in frame 0 & 5



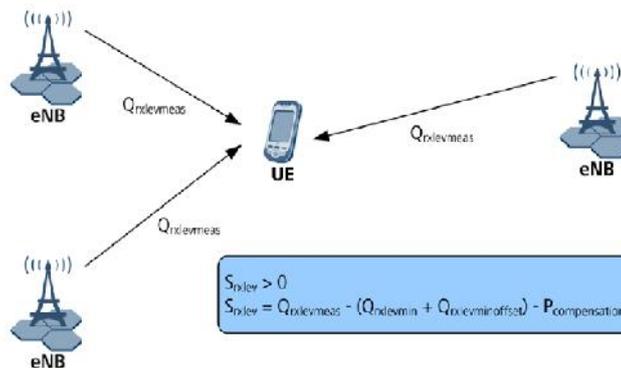
Cell Search Procedure-2/2

- 168 cell identity groups with 3 identities each
 - 168×3=504 cell identities
 - identity within cell identity group
 - ➔ orthogonal RS sequence
- Step 1 – primary synchronization signal
 - 3 different sequences possible
 - to 'break the SFN channel'
 - Used to determine (at least) 5 ms timing
 - Used to determine identity within cell identity group
- Step 2 – secondary synchronization signal
 - 168 different sequences possible
 - Used to determine frame timing
 - Used to determine cell identity group



Cell Selection-1/2

Cell Selection



Cell Selection-2/2



Parameter	Description
Qrxlevmeas	Received RS level
Qrxlevmin	Minimal Required Rx level (dBm) in SIB1
Qrxlevminoffset	Offset to Srxlev, relative with PLMN priority. QrxlevminOffset is only applied when a cell is evaluated for cell selection as a result of a periodic search for a higher priority PLMN while camped normally in a VPLMN in SIB1
Pcompensation	$\max(P_{\text{Maximum allowed power}} - P_{\text{UE MAX Output Power}}, 0)$, where $P_{\text{Maximum allowed power}}$ is sent in SIB1

Cell Re-Selection-1/4

Intra Frequency Measurement

- If the intra frequency measurement triggering threshold is not configured, the UE performs intra frequency measurements always.
- If the intra frequency measurement triggering threshold is configured:
 - $S_{rxlev} > S_{intraSearch}$, the UE does not perform intra frequency measurement
 - $S_{rxlev} \leq S_{intraSearch}$, the UE performs intra frequency measurement

Cell Re-Selection-2/4

Inter Frequency/RAT Measurement

- For the neighbors with higher priority
 - The UE always perform inter frequency /RAT measurement
- For the neighbor with lower or equal priority
 - If the threshold is not configured, the UE always perform inter frequency/RAT measurement
 - If the threshold is configured :
 - When $S_{rxlev} > S_{NonIntraSearch}$, UE does not perform inter frequency/RAT measurement
 - When $S_{rxlev} \leq S_{NonIntraSearch}$, UE perform inter frequency /RAT measurement

Cell Re-Selection-3/4

Intra Frequency/Same Priority Cell Reselection Decision



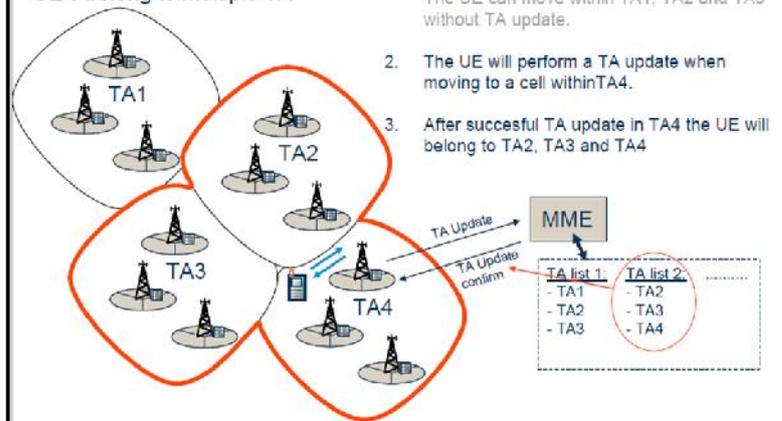
Cell Re-Selection-4/4

Inter-RAT/Inter Frequency High Priority Cell Reselection Decision

- For the high priority cells, the UE perform cell reselection if the following conditions are met :
 - In "reselection time", "Srxlev" of a neighbor is higher than "ThreshXHigh"
 - More than one second has elapsed since the UE camped on the serving cell.

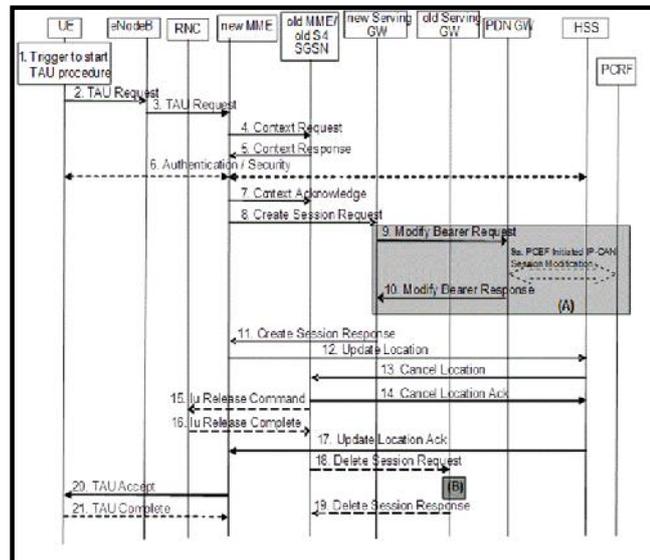
TA(Tracking Area)update-1/2

UE's belong to multiple TA



1. UE belongs to TA1, TA3 and TA2. The UE can move within TA1, TA2 and TA3 without TA update.
2. The UE will perform a TA update when moving to a cell within TA4.
3. After successful TA update in TA4 the UE will belong to TA2, TA3 and TA4

TA(Tracking Area)update-2/2



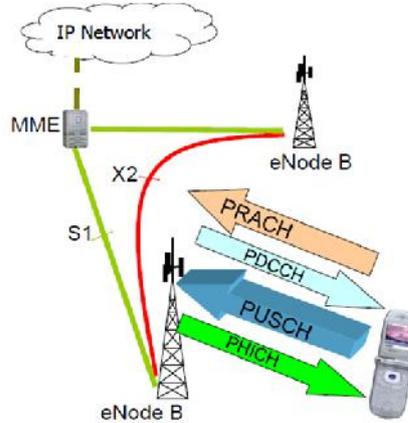
Paging

- UEs in RRC_IDLE mode use DRX to receive paging messages in order to reduce power consumption. The eNodeB may have to buffer the paging message until a UE's paging occasion occurs.
- The time positions of paging messages are fixed on the Uu interface, which are indicated by the Paging Frames (PFs) and Paging Occasion (PO) subframes. One PF is one radio frame, which may contain one or multiple Pos. One PO is a subframe where the Paging Radio Network Temporary Identifier (P-RNTI) is contained. The PO is transmitted over the PDCCH. UEs read paging messages over the Physical Downlink Shared Channel (PDSCH) according to the P-RNTI.
- The PF number and PO subframe number can be calculated according to the IMSI of the UE, DRX cycle, and number of PO subframes in a DRX cycle. Frame numbers are stored in the SI related to the DRX parameters of the UE. When the DRX parameters change, PF number and PO subframe number change accordingly.

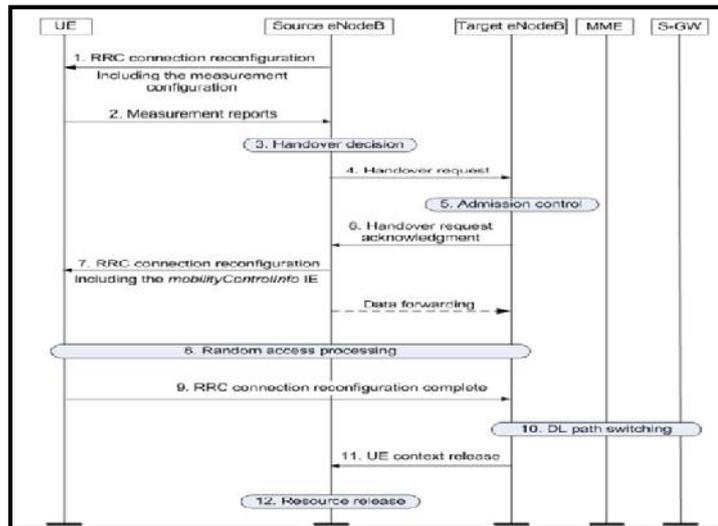
RACH Procedure



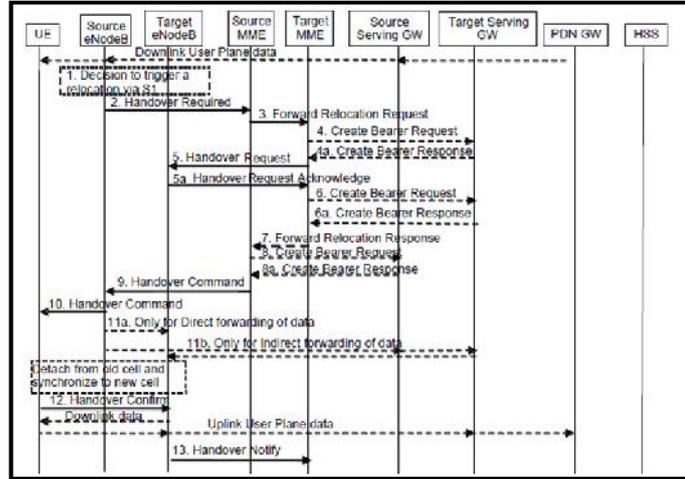
1. Either network indicates specific PRACH resource or UE selects from common PRACH resources.
2. UE sends random access preambles at increasing power.
3. UE receives random access response on the **PDCCH** which includes assigned resources for PUSCH transmission.
 - Physical Resource Blocks (PRB) and Modulation and Coding Scheme (MCS)
4. UE sends signaling and user data on **PUSCH**



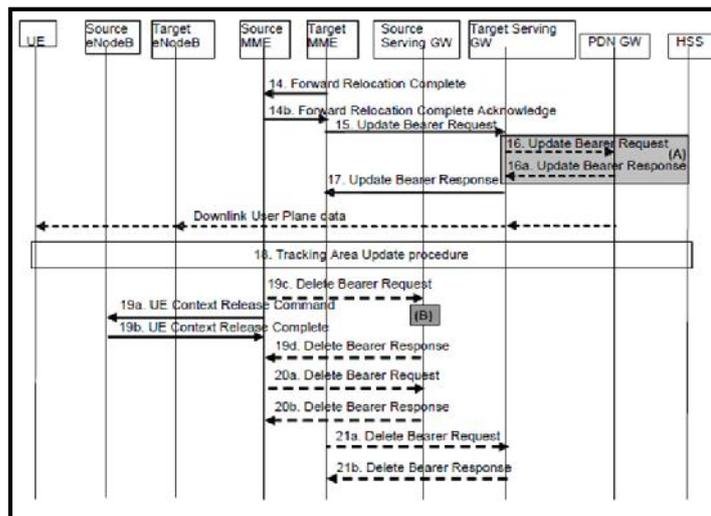
Mobility-X2 Handover



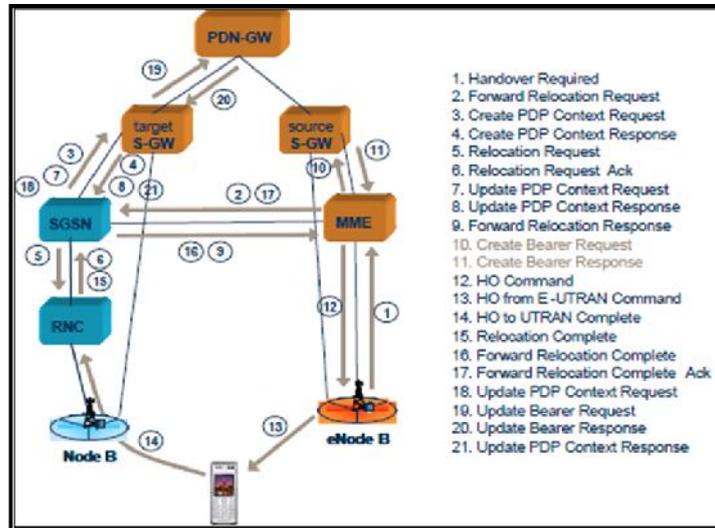
Mobility-S1 Handover-1/2



Mobility-S1 Handover-2/2



Mobility-IRAT Handover



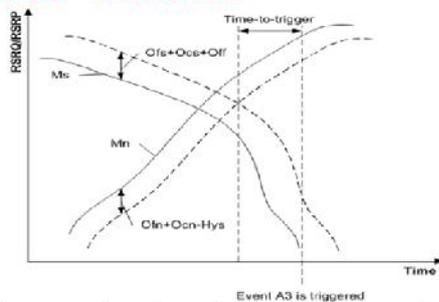
Handover Events



Events	Threshold	Action
A1	Signal quality in the serving cell is higher than a specified threshold	The eNodeB stops inter-frequency or inter-RAT measurements.
A2	Signal quality in the serving cell is lower than a specified threshold	The eNodeB starts inter-frequency or inter-RAT measurements
A3	Signal quality in at least one intra-frequency neighboring cell is higher than that in the serving cell	Source eNodeB sends an intra-frequency handover request.
A4	Signal quality is higher than a specified threshold in at least one inter-frequency neighboring cell	Source eNodeB sends an inter-frequency handover request.
B1	Signal quality is higher than a specified threshold in at least one inter-RAT neighboring cell	source eNodeB sends an inter-RAT handover request.

Handover Events-A3

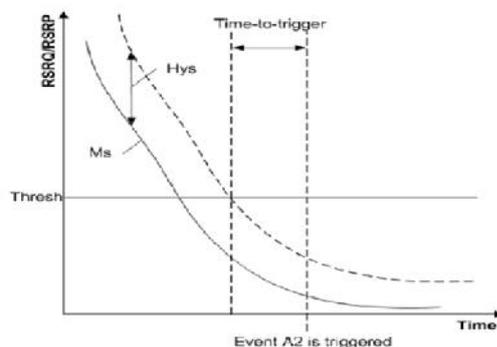
Handover Decision



- Intra-frequency handover is triggered by event A3, which is reported in event-triggered periodical reporting mode.
 - Enter condition: $Mn + Ofn + Ocn - Hys > Ms + Ofs + Ocs + Off$
 - Leave condition: $Mn + Ofn + Ocn + Hys < Ms + Ofs + Ocs + Off$

Handover Events-A3

Event A2 Triggering Algorithm



- Enter condition: $Ms + Hys < \text{Specific Threshold}$
- Leave condition: $Ms - Hys > \text{Specific Threshold}$



Thank You