DATA FLOW, RADIO RESOURCE MANAGEMENT, AND MOBILITY MANAGEMENT

MODULE 5

Chapter 10

- **Module – 5**
- **Radio Resource Management and Mobility Management:**
- PDCP overview, MAC/RLC overview, RRC overview
- Mobility Management, Inter-cell Interference Coordination
- (Sec 10.1 – 10.5 of Text).
- L1, L2

BEARER SERVICE

- **Bearer Service** or **data service** is a service that allows transmission of information signals between network interfaces.
- These services give the subscriber the capacity required to transmit appropriate signals between certain access points, i.e. user network interfaces.

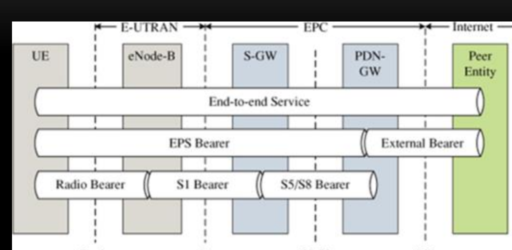
EPS BEARER SERVICE ARCHITECTURE

- LTE is a packet-switched network from end to end that is designed primarily for high-speed data services.
- To efficiently support the varying QoS requirements of different IP applications, LTE uses the concept of a *bearer* as the central element of QoS control.
- Each EPS (Evolved Packet System) bearer (*bearer* for short) is defined between the Packet Data Network Gateway (PDN-GW) and the UE
  - It maps to a specific set of QoS parameters such as data rate, latency, and packet error rate.

EPS BEARER SERVICE ARCHITECTURE

- Applications with very different QoS requirements such as e-mail and voice can be put on separate bearers that will allow the system to simultaneously meet their QoS requirements.
- The end-to-end connectivity through the network is made via the bearer service

EPS BEARER SERVICE ARCHITECTURE



EPS BEARER SERVICE ARCHITECTURE…

Broadly, the bearers can be divided into two classes:

1. Guaranteed Bit Rate (GBR) bearers
2. Non-GBR bearers

GUARANTEED BIT RATE (GBR) BEARERS

- These bearers define and guarantee a minimum bit rate that will be available to the UE.
- Bit rates higher than the minimum bit rate can be allowed if resources are available.
- GBR bearers are typically used for applications such as voice, streaming video, and real-time gaming.

NON-GBR BEARERS

- These bearers do not define or guarantee a minimum bit rate to the UE.
- The achieved bit rate depends on the system load, the number of UEs served by the eNode-B, and the scheduling algorithm.
- Non-GBR bearers are used for applications such as web browsing, e-mail, FTP, and P2P file sharing.

QCI- QoS Class Identifier

Each bearer is associated with a QoS Class Identifier (QCI), which indicates the priority, packet delay budget, acceptable packet error loss rate and the GBR/non-GBR classification.

DEFAULT BEARER AND DEDICATED BEARER

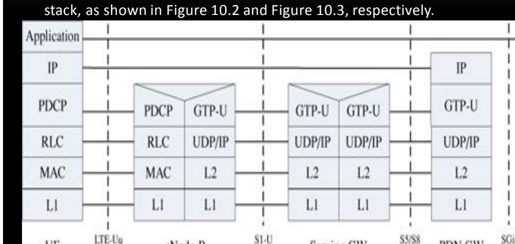
- ***DEFAULT BEARER***
  - One EPS bearer is established when the UE connects to a Packet Data Network (PDN), and that remains established throughout the lifetime of the PDN connection to provide the UE with always-on IP connectivity to that PDN.
- ***DEDICATED BEARER***
  - Any additional EPS bearer that is established to the same PDN is referred to as a The core network handles the establishment and modification of the dedicated bearer.

STANDARDIZED QOS CLASS IDENTIFIERS (QCIS) FOR LTE

QCI	Resource Type	Priority	Packet Delay Budget (ms)	Packet Error Loss Rate	Example Services
1	GBR	2	100	10^{-2}	Conversational voice
2	GBR	4	150	10^{-3}	Conversational video (live streaming)
3	GBR	3	50	10^{-3}	Real-time gaming
4	GBR	5	300	10^{-6}	Non-conversational video (buffered streaming)
5	Non-GBR	1	100	10^{-6}	IMS signaling
6	Non-GBR	6	300	10^{-6}	Video (buffered streaming), TCP-based (e.g., WWW, e-mail, chat, FTP, etc.)
7	Non-GBR	7	100	10^{-3}	Voice, video (live streaming), interactive gaming
8	Non-GBR	8	300	10^{-6}	Video (buffered streaming), TCP-based (e.g., WWW, e-mail, chat, FTP, etc.)
9	Non-GBR	9	300	10^{-6}	

PROTOCOL ARCHITECTURE BETWEEN THE UE AND THE CORE NETWORK

- The protocol architecture in LTE between the UE and the core network is divided into the user plane protocol stack and the control plane protocol stack, as shown in Figure 10.2 and Figure 10.3, respectively.



- **Figure:** User plane protocol stack.

CONTROL PLANE PROTOCOL STACK.

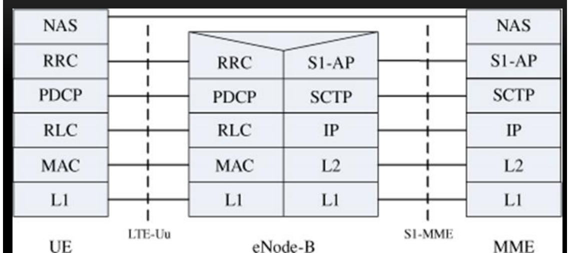
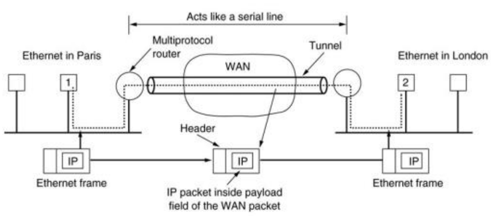


Figure: Control plane protocol stack.

USER PLANE AND CONTROL PLANE

- ***The user plane*** ***is responsible*** for transporting IP packets carrying application-specific data from the PDN-GW to the UE.
- This is done by encapsulating the IP packets in an Evolved Packet Core (EPC)-specific protocol and tunneling them from the PDN-GW to the eNode-B using the ***GPRS Tunneling Protocol (GTP).***
- From the eNode-B the packets are transported to the UE using the Packet Data Convergence Protocol (PDCP).

Tunneling a packet from Paris to London.



Problem: Here source and destination are on same type of network but there is different kind of network in between.

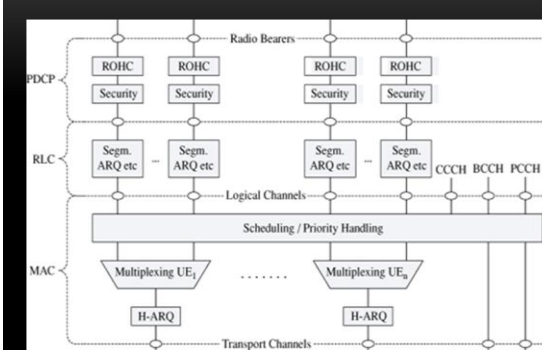
Solution: Tunneling

- ***Control plane*** ***is used for transporting*** signaling between the Mobility Management Entity (MME) and the UE.
- The type of signaling handled over the control plane is typically related to
  - *Bearer management*
  - *QoS management, and*
  - *Mobility management including functions such as handover and paging.*

WHY IS GTP USED IN LTE?

- It provides mobility.
- When UE is mobile, the IP address remains same and packets are still forwarded since tunneling is provided between PGW and eNB via SGW
- Multiple tunnels (bearers) can be used by same UE to obtain different network QoS
- Main IP remains hidden so it provides security as well
- Creation, deletion and modification of tunnels in case of GTP-C

LAYER 2 STRUCTURE FOR DOWNLINK



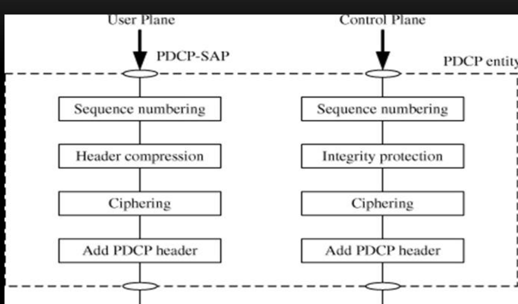
LAYER 2 STRUCTURE FOR DOWNLINK

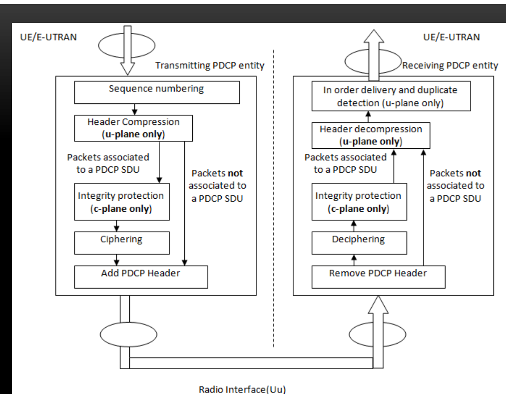
- In LTE, Layer 2 of the protocol stack is split into the following sublayers:
  1. Medium Access Control (MAC)
  2. Radio Link Control (RLC)
  3. PDCP
- Radio bearers are mapped to logical channels through PDCP and RLC sublayers.
- The Service Access Point (SAP) between the physical layer and the MAC sublayer provides the transport channels that are used by the physical layer to provide services to the MAC.

PDCP OVERVIEW

- A PDCP entity is associated either with the control plane or with the user plane depending on which radio bearer it is carrying data for.
- Each radio bearer is associated with one PDCP entity, and each PDCP entity is associated with one or two RLC entities
- depends on the radio bearer characteristic (uni-directional or bi-directional) and the RLC mode.
- PDCP is used only for radio bearers mapped on DCCH and DTCH types of logical channels.

PDCP FUNCTIONS FOR THE USER PLANE AND THE CONTROL PLANE





THE MAIN SERVICES AND FUNCTIONS OF THE PDCP SUBLAYER

for the user plane

1. Header compression and decompression of IP data flows with the **RObust Header Compression (ROHC) protocol**
2. Ciphering and deciphering of user plane data
3. In-sequence delivery and reordering of upper-layer PDUs at handover
4. Buffering and forwarding of upper-layer PDUs from the serving eNode-B to the target eNode-B during handover
5. Timer-based discarding of SDUs in the uplink

THE MAIN SERVICES AND FUNCTIONS OF THE PDCP SUBLAYER

For the control plane:

- 1. Ciphering and deciphering of control plane data
- 2. Integrity protection and integrity verification of control plane data
- 3. Transfer of control plane data

PDCP PDU

- The PDCP PDUs can be divided into two categories:

1. The PDCP data PDU is used in both the control and user plane to transport higher-layer packets.

Conveys either:

✓ user plane data containing a compressed/uncompressed IP packet

or

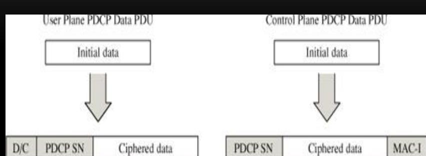
✓ control plane data containing one RRC message and a Message Authentication Code for Integrity (MAC-I) field for integrity protection

PDCP PDU…

2. The PDCP control PDU is used only within the user plane to ***convey a PDCP status report*** during handover and ***feedback information*** for header compression.

PDCP control PDU ***does not carry any higher-layer SDU*** but rather is used for peer-to-peer signaling between the PDCP entities at two ends.

PDCP PDU…

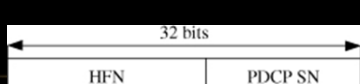


HEADER COMPRESSION

- The header compression protocol in LTE is based on the RObust Header Compression (ROHC)
- PDCP entities are configured by upper layers to use header compression, which is only performed on user plane data.
- The requirement for header compression comes from the fact that all the services in LTE are IP-based, and are based on the framework of IP and other related IETF protocols.
- There are multiple header compression algorithms, called ***profiles***, defined for the ROHC framework.
- Each profile is specific to the particular network layer, transport layer, or upper-layer protocol combination, e.g., TCP/IP and RTP/UDP/IP.

INTEGRITY AND CIPHERING

- The security-related functions in PDCP include **integrity protection** and **ciphering.**
- A PDCP PDU counter, denoted by the parameter COUNT, is maintained and used as an input to the security algorithm.
- The format of COUNT is shown in Figure, which has a length of 32 bits and consists of two parts:
  - ➢ the Hyper Frame Number (HFN) and the PDCP SN.
- The SN is used for reordering and duplicate detection of RLC packets at the receive end.



MAC/RLC OVERVIEW

- The RLC layer performs segmentation and/or concatenation on PDCP PDUs based on the size indicated by the MAC.
- RLC also reorders the RLC PDUs once they are received out of order possibly due to H-ARQ processes in the MAC layer.
- The RLC layer also supports an ARQ mechanism, which resides on top of the MAC layer H-ARQ and is used only when all the H-ARQ transmissions are exhausted and the RLC PDU has not yet been received without errors

DATA TRANSFER MODES

- Functions of the RLC layer are performed by RLC entities.
- Each RLC entity can be operated in three different modes:
  1. the Transparent Mode (TM)
  2. the Unacknowledged Mode (UM)
  3. the Acknowledged Mode (AM).

THE TRANSPARENT MODE (TM)

- The TM mode is the simplest one.
- The RLC entity ***does not add any RLC header to the PDU*** and no data segmentation or concatenation is performed.
- This mode is suitable for ***services that do not need retransmission*** or are not sensitive to delivery order.
- Only RRC messages such as broadcast system information messages and paging messages use the TM mode.
- The TM mode is not used for user plane data transmission.
- The RLC data PDU delivered by a TM RLC entity is called the TM Data (TMD) PDU.

THE UNACKNOWLEDGED MODE (UM)

- The UM mode provides in-sequence delivery of data that may be received out of sequence due to the H-ARQ process in MAC, but no retransmission of the lost PDU is required.
- This ***mode can be used by delay-sensitive and error-tolerant real-time applications, such as VoIP.***
- The DTCH logical channel can be operated in the UM mode, and the RLC data PDU delivered by an UM RLC entity is called the UM Data (UMD) PDU. .
- The receiving UM RLC entity performs duplicate detection, reordering, and reassembly of UMD PDUs.

THE ACKNOWLEDGED MODE (AM)

- The AM mode is the most complex one, which requests retransmission of missing PDUs in addition to the UM mode functionalities.
- **It is mainly used by error-sensitive and delay-tolerant applications.**
- An AM RLC entity can be configured to deliver/receive RLC PDUs through DCCH and DTCH.
- An AM RLC entity delivers/receives the AM Data (AMD) PDU and the STATUS PDU indicating the ACK/NAK information of the RLC PDUs.

THE ACKNOWLEDGED MODE (AM)…

- The operation of the AM RLC entity is similar to that of the UM RLC entity, except that it supports retransmission of RLC data PDUs.
- The receiving AM RLC entity can send a STATUS PDU to inform the transmitting RLC entity about the AMD PDUs that are received successfully and that are detected to be lost.

PURPOSE OF MAC AND RLC LAYERS

The main services and functions of the RLC sublayer include

i. • Transfering/receiving PDUs from upper layers, i.e., from RRC for the CCCH logical channel or from PDCP for other cases
ii. • Error correction through ARQ (only when the RLC is operated in the AM mode)
iii. • Concatenation, segmentation, and reassembly of RLC SDUs (only for UM and AM data transfer)
iv. • Re-segmentation of RLC data PDUs (only for AM data transfer)
v. • In-sequence delivery of upper-layer PDUs (only for UM and AM data transfer)
vi. • Duplicate detection (only for UM and AM data transfer)
vii. • Protocol error detection and recovery
viii. • RLC SDU discard (only for UM and AM data transfer)
ix. • RLC re-establishment

Purpose of MAC and RLC Layers….

- LTE defines two MAC entities: one in the UE and one in the eNode-B.
- The exact functions performed by the MAC entities are different in the UE from those performed in the eNode-B.
- The main services and functions of the MAC sublayer include
  1. • Mapping between logical channels and transport channels
  2. • Multiplexing/demultiplexing of MAC SDUs belonging to one or different logical channels into/from the same transport block
  3. • Scheduling for both downlink and uplink transmission

Purpose of MAC and RLC Layers….

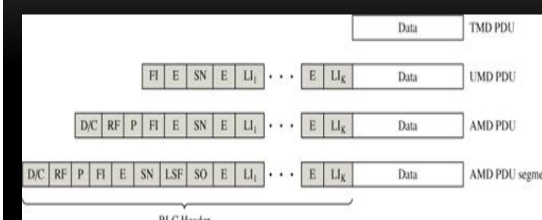
4. • Error correction through H-ARQ, which has tight interaction with ARQ in the RLC layer and will be discussed later in this section
5. • Priority handling between logical channels of one UE or between UEs by means of dynamic scheduling
6. • Transport format selection, i.e., the selection of the Modulation and Coding Scheme (MCS) for link adaptation
7. • Padding if a MAC PDU is not fully filled with data

PDU HEADERS AND FORMATS

RLC PDU FORMATS

- RLC PDUs can be categorized into RLC data PDUs and RLC control PDUs.
- RLC data PDUs are used by TM, UM, and AM RLC entities to transfer upper-layer PDUs, called the TM Data (TMD) PDU, the UM Data (UMD) PDU, and the AM Data (AMD) PDU, respectively.
- On the other hand, RLC control PDUs are used for peer-to-peer signaling between the AM RLC entities at the two ends for ARQ procedures.

RLC PDU FORMATS



Formats of RLC Data PDUs

RLC PDU Formats…

- The TMD PDU only consists of a Data field, as no RLC header is added.
- The RLC headers are different for UMD PDU and AMD PDU, but they contain common fields including:
- **Framing Info (FI) field:** indicates whether a RLC SDU is segmented at the beginning and/or at the end of the Data field.
- **Length Indicator (LI) field:** indicates the length in bytes of the corresponding Data field element present in the UMD or AMD PDU.
- **Extension bit (E) field:** indicates whether a Data field follows or a set of E field and LI field follows.

RLC PDU FORMATS…

- **SN field:** indicates the sequence number of the corresponding UMD or AMD PDU.
- It consists of 10 bits for AMD PDU, AMD PDU segments, and STATUS PDUs, and 5 bits or 10 bits for UMD PDU.
- The PDU sequence number carried by the RLC header is independent of the SDU sequence number, i.e., the PDCP sequence number.

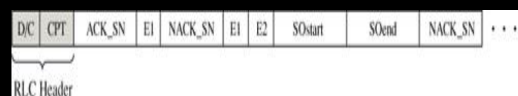
RLC PDU FORMATS…

- For AMD PDU and AMD PDU segments, additional fields are available:
- **Data/Control (D/C) field:** indicates whether the RLC PDU is an RLC Data PDU or an RLC Control PDU.
- **Re-segmentation Flag (RF) field:** indicates whether the RLC PDU is an AMD PDU or an AMD PDU segment.
- **•Polling bit (P) field:** indicates whether the transmitting side of an AM RLC entity requests a STATUS report from its peer AM RLC entity.

RLC PDU FORMATS…

The STATUS PDU

- The STATUS PDU is used by the receiving AM RLC entity to indicate the missing portions of AMD PDUs.
- **• Control PDU Type (CPT) field:** indicates the type of the RLC control PDU, and in Release 8 the STATUS PDU is the only defined control PDU.
- **• Acknowledgment SN (ACK_SN) field:** indicates the SN of the next not received RLC Data PDU, which is not reported as missing in the STATUS PDU.



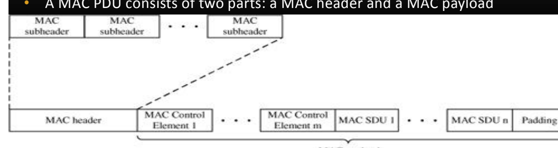
The format of STATUS PDU.

RLC PDU FORMATS…

- **Extension bit 1 (E1) field:** indicates whether a set of NACK_SN, E1, and E2 follows.
- **• Extension bit 2 (E2) field:** indicates whether a set of SOstart and SOend follows.
- **• Negative Acknowledgment SN (NACK_SN) field:** indicates the SN of the AMD PDU (or portions of it) that has been detected as lost at the receiving side of the AM RLC entity.
- **• SO start (SOstart) field and SO end (SOend) field:** together indicate the portion of the AMD PDU with SN = NACK_SN that has been detected as lost at the receiving side of the AM RLC entity.

MAC PDU FORMATS

- The MAC layer receives data from RLC as MAC SDUs, and passes the MAC PDUs to PHY.
- A MAC PDU consists of two parts: a MAC header and a MAC payload



- The MAC payload consists of zero or more MAC SDUs, zero or more MAC control elements, and optional padding
- the MAC PDU header consists of one or more MAC PDU subheaders, while each subheader corresponds to either a MAC SDU, a MAC control element, or padding.
- Therefore, both the MAC SDU and the MAC header are of variable sizes.

MAC SUB-HEADER

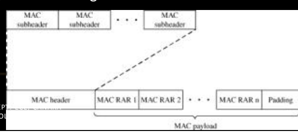
- The format of a typical MAC subheader is shown above which contains five different fields.
- **• "R" field:** It is currently reserved always set to "0."
- **• "E" field:** It is an extension field as a flag indicating if more fields are present in the MAC header.
  - If it is set to "1," another set of at least R/R/E/LCID fields follows; otherwise, either a MAC SDU, a MAC control element, or padding follows.

MAC SUB-HEADER….

- **• "LCID" field:** This Logical Channel ID (LCID) field identifies the logical channel instance of the corresponding MAC SDU or the type of the corresponding MAC control element or padding.
- **• "F" field:** This format indicates the size of the Length field.
- **• "L" field:** This Length field indicates the length of the corresponding MAC PDU or MAC control element in bytes.

MAC RANDOM ACCESS RESPONSES (MAC RAR)

- The MAC payload consists of one or more MAC Random Access Responses (MAC RAR) and optional padding.
- Each MAC RAR is of fixed size and consists of four fields, described as follows:
  - • **Reserved Bit:** It is set to "0."
  - • **Timing Advance Command:** It indicates the index value used to control the amount of timing adjustment that UE has to apply. It is of 11 bits.
  - • **UL Grant:** It indicates the resources to be used on the uplink, and is of 20 bits.
  - • **Temporary C-RNTI:** This field indicates the temporary identity that is used by the UE during random access. The size is 16 bits.

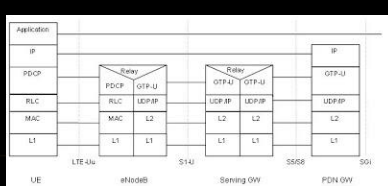


ARQ PROCEDURES

- To better support upper-layer services, LTE applies a dynamic and efficient two-layer retransmission scheme:
  1. A fast H-ARQ protocol with low latency and low overhead feedback in the MAC layer and
  2. A highly reliable selective repeat ARQ protocol in the RLC layer.
- The H-ARQ protocol is responsible for handling transmission errors by performing retransmissions based on H-ARQ processes with incremental redundancy or chase combining, which is handled by the PHY layer.
- The ARQ protocol in the RLC layer is to correct residual H-ARQ errors, mainly due to the error in H-ARQ ACK feedback.
- ARQ procedures are only performed in the AM transfer mode by an AM RLC entity and unlike H-ARQ, the latency associated with the RLC layer ARQ is much larger.

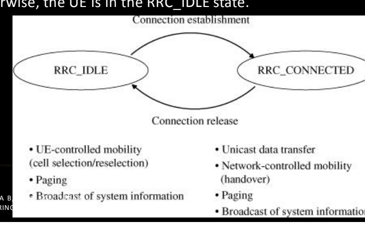
RRC OVERVIEW

- The RRC layer takes care of RRC connection management, radio bearer control, mobility functions, and UE measurement reporting and control.
- It is also responsible for broadcasting system information and paging.



RRC STATES

- Compared to UMTS, which has four RRC states, LTE has only two states: RRC_IDLE and RRC_CONNECTED.
- This simplifies the RRC state machine handling and the radio resource management, which controls the RRC state.
- A UE is in the RRC_CONNECTED state when an RRC connection has been established;
- otherwise, the UE is in the RRC_IDLE state.



RRC STATES…

- **In the RRC_IDLE state**, the UE can receive broadcasts of system information and paging information.
- There is no signaling radio bearer established, so there is no RRC connection.
- the mobility control is handled by the UE, which performs neighboring cell measurements and cell selection/reselection.

RRC STATES…

- **In the RRC_CONNECTED state**, the UE has an E-UTRAN RRC connection and a context in the E-UTRAN, so it is able to transmit and/or receive data to/from the network (eNode-B).
- The UE monitors control channels (PDCCH) associated with the shared data channel to determine if data is scheduled for it.
- The UE can also report channel quality information and feedback information to the eNode-B to assist the data transmission.
- In the RRC_CONNECTED state, the network controls mobility/handover of the UE, while UEs provide neighboring cell measurement information.

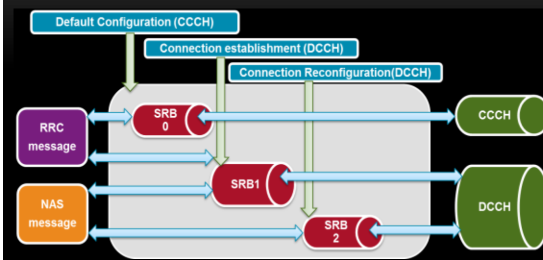
RRC FUNCTIONS

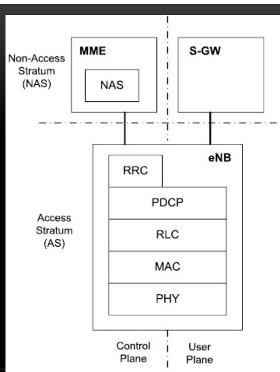
SIGNALLING RADIO BEARERS (SRB)

- SRBs are defined as radio bearers that are used only for the transmission of RRC and NAS messages.
- There are three different SRBs defined in LTE
  1. SRB0 is for RRC messages using the CCCH logical channel.
  2. SRB1 is for RRC messages and NAS messages prior to the establishment of SRB2, all using the DCCH logical channel.
  3. SRB2 is for NAS messages, using DCCH logical channel.
     - SRB2 has a lower-priority than SRB1 and is always configured by the E-UTRAN after security activation

RRC FUNCTIONS

SIGNALLING RADIO BEARERS (SRB)





LTE Advanced Protocol Stack

MAIN FUNCTIONS OF THE RRC PROTOCOL.

Broadcast of system information, which is divided into the Master Information Block (MIB) and a number of System Information Blocks (SIBs).

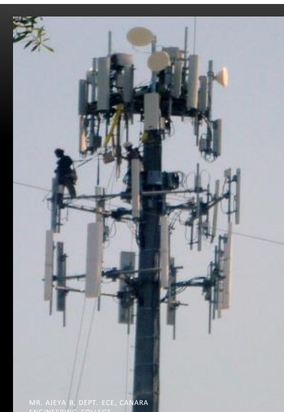
- The MIB includes a limited number of the most essential and most frequently transmitted parameters that are needed to acquire other information from the cell, and is transmitted on the BCH logical channel.
- SIBs other than SIB Type 1 are carried in System Information (SI) messages.
- SIB Type 1 contains parameters needed to determine if a cell is suitable for cell selection as well as information about the time-domain scheduling of the other SIBs.
- SIB Type 1 and all SI messages are transmitted on DL-SCH.

MAIN FUNCTIONS OF THE RRC PROTOCOL….

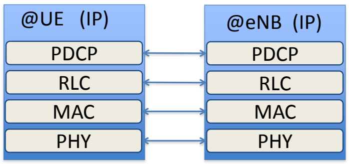
RRC connection control includes procedures related to the establishment, modification, and release of an RRC connection, including paging, initial security activation, establishment of SRBs and radio bearers carrying user data, radio configuration control and QoS control, and recovery from the radio link failure.

Measurement configuration and reporting includes establishment, modification, and release of measurements, configuration, and (de-)activation of measurement gaps, and measurement reporting for intra-frequency, inter-frequency, and inter-RAT (Radio Access Technology) mobility.

Other functions include transfer of dedicated NAS information and non-3GPP dedicated information, transfer of UE radio access capability information, and support of self-configuration and self-optimization.



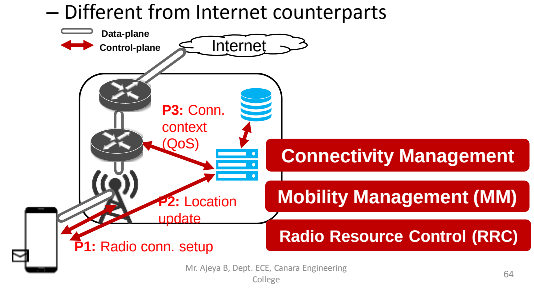
Data-Plane Protocols: IP + lower layers



- **Packet Data Convergence Protocol (PDCP)** – header compression, radio encryption
- **Radio Link Control (RLC)** – Readies packets to be transferred over the air interface
- **Medium Access Control (MAC)** – Multiplexing, QoS

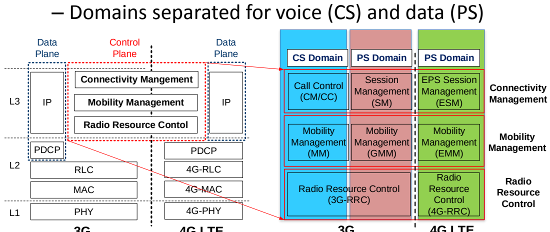
Control-Plane Protocols

- Control utilities: mobile network specific
  - Different from Internet counterparts

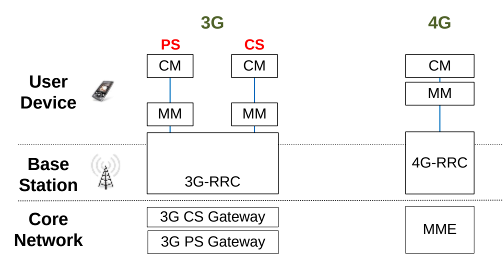


Control-Plane Protocols in 4G/3G

- Variants for same/similar control functions
  - Hybrid 4G/3G systems
  - Domains separated for voice (CS) and data (PS)

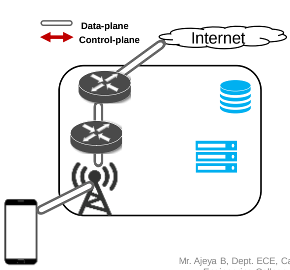


Distributed Operations: Device, base station, core networks

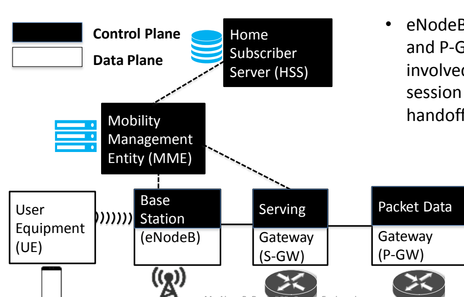


Put Them Together

- Setting up data service in 4G

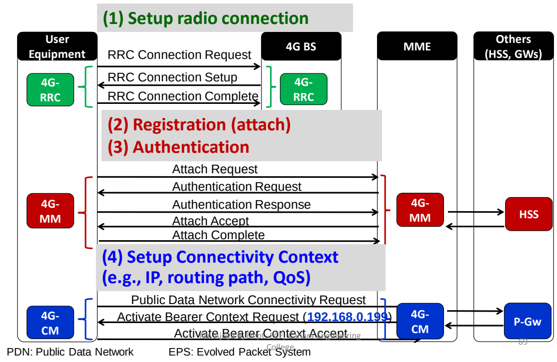


Data and Control Planes in LTE



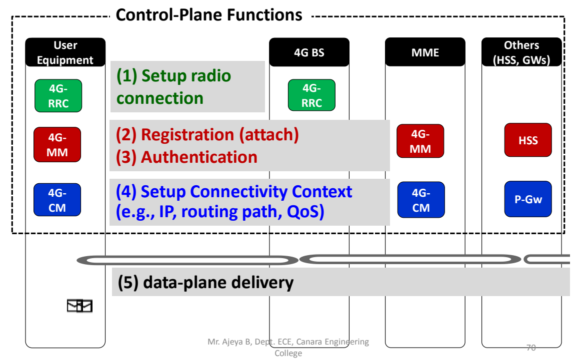
- eNodeB, S-GW and P-GW are involved in session setup, handoff, routing

Setting Up Data Service in 4G



PDN: Public Data Network EPS: Evolved Packet System

Setting Up Data Service in 4G



MOBILITY MANAGEMENT

LTE mobility management functions can be categorized into two groups:

1. Mobility within the LTE system (intra-LTE mobility)
2. Mobility to other systems such as other 3GPP systems (e.g., UMTS) and non-3GPP systems (inter-RAT mobility).

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MOBILITY MANAGEMENT

- Intra-LTE mobility can happen either over the S1 interface or over the X2 interface.
- When the UE moves from one eNode-B to another eNode-B within the same Radio Access Network (RAN) attached to the same MME, the mobility takes place over the X2 interface.
- when the UE moves from one eNode-B to another that belongs to a different RAN attached to different MMEs or if the two eNode-Bs are not connected over an X2 interface, then the mobility takes place over the S1 interface.
- The inter-RAT mobility essentially uses the S1-mobility with the only difference being that in this case the PDCP context is not continued and the UE needs to re-establish its session once it moves to the target non-LTE system.

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S1 MOBILITY

- S1 mobility is very similar to the UMTS Serving Radio Network Subsystem (SRNS) relocation procedure and consists of THREE steps
  1. Preparation phase
  2. Execution phase
  3. Completion phase

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S1 MOBILITY….

- 1. **Preparation Phase**:
- Once a decision has been made for a handover and a target MME and eNode-B have been identified, the network needs to allocate resources on the target side for the impending handover.
- The MME sends a handover request to the target eNode-B requesting it to set up the appropriate resources for the UE.
- Once the resources have been allocated at the target eNode-B, it sends a handover request ACK to the MME.
- Once this message is received by the MME, it sends a handover command to the UE via the source eNode-B.

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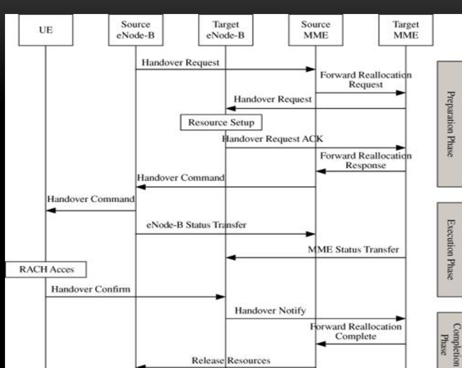
S1 MOBILITY….

- 2. **Execution Phase**:
- Once the UE receives the handover command, it responds by performing the various RAN-related procedures needed for the handover including accessing the target eNode-B using the Random Access Channel (RACH).
- The RAN-related procedures of a handover are discussed in detail later in this section.
- While the UE performs the handover, the source eNode-B initiates the status transfer where the PDCP context of the UE is transferred to the target eNode-B.
- The source eNode-B also forwards the data stored in the PDCP buffer to the target eNode-B.
- Once the status and data have been transferred to the target eNode-B and the UE is able to establish a Radio Access Bearer (RAB) on the target eNode-B, it sends the handover confirm message to the target eNode-B.

S1 MOBILITY…

- 3. **Completion Phase**:
- When the target eNode-B receives the handover confirm message, it sends a handover notify message to the MME.
- The MME then informs the source eNode-B to release the resources originally used by the UE.

MOBILITY MANAGEMENT OVER THE S1 INTERFACE.



X2 MOBILITY

- The mobility over the X2 interface is the default mode of operation in LTE unless an X2 interface is not available between the source and target eNode-Bs.
- When this is the case, the mobility over S1 interface is triggered as mentioned in the previous section.
- Mobility over the X2 interface also consists of three steps
  1. **Preparation Phase**
  2. **Completion Phase**
  3. **Execution Phase**

X2 MOBILITY…

- 1. **Preparation Phase**:
- Once the handover decision has been made by the source eNode-B, it sends a handover request message to the target eNode-B.
- The target eNode-B upon receipt of this message works with the MME and S-GW to set up the resources for the UE.
- In the case of mobility over X2 interface, it is possible to set up resources on a per-RAB basis, which implies that upon the completion of the handover the UE will have the same RABs at the target eNode-B with the same set of QoS as it had on the source eNode-B.
- This process makes the handover quick and seamless and the UE is not required to set up the RAB with the target eNode-B once the handover is completed.
- The target eNode-B responds to the source eNode-B with a handover request ACK once it is ready.

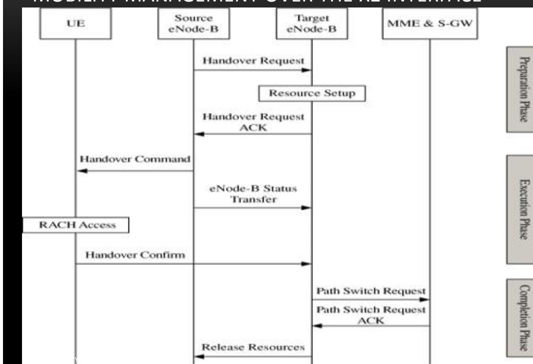
X2 MOBILITY…

- **Execution Phase**:
- Upon receiving the handover request ACK, the source eNode-B sends a handover command to the UE.
- While the UE completes the various RAN-related handover procedures, the source eNode-B starts the status and data transfer to the target eNode-B.
- This is done on a per-RAB basis for the UE.

X2 MOBILITY…

- **Completion Phase**:
- Once the UE completes the handover procedure, it sends a handoff complete message to the target eNode-B.
- Then the target eNode-B sends a path switch request to the MME/S-GW and the S-GW switches the GTP tunnel from the source eNode-B to the target eNode-B.
- When the data path in the user plane is switched, the target eNode-B sends a message to the source eNode-B to release the resources originally used by the UE.

MOBILITY MANAGEMENT OVER THE X2 INTERFACE



X2 MOBILITY…

- In the case of X2 mobility, the source eNode-B can select a lossless handover for one or more of the RABs.
- In this case, both the PDCP-processed and PDCP-unprocessed packets are sent to the target eNode-B during the status transfer.
- The PDCP-processed packets are the data packets that have been transmitted by the source eNode-B to the UE but the UE has not yet acknowledged the receipt of such packets.
- On the other hand, PDCP-unprocessed packets are the packets buffered by the PDCP layer that are yet to be transmitted by the source eNode-B.

X2 MOBILITY…

- In LTE there is an additional feature called *selective retransmission*
  - which is enabled where the target eNode-B may not retransmit the PDCP-processed packets that were forwarded but were acknowledged by the UE after the status transfer was initiated.

RAN PROCEDURES FOR MOBILITY

- RAN-related mobility management procedures happen between the UE and the eNode-B or between the UE and the MME in order to enable the UE to handover from one eNode-B to another.
- These procedures can be classified into two distinct cases:
  1. Mobility in the RRC_IDLE state and
  2. Mobility in the RRC_CONNECTED state
- The mobility management in these two RRC states was designed to be consistent, i.e., to prevent the ping-pong between two eNode-Bs when the UE undergoes RRC state transitions and also to be applicable in a host of different scenarios such as network sharing, country border, and home deployment (femto cells).

- In LTE, like other radio access technologies, **radio link quality is the primary measure** that is used in intra-frequency handover, i.e., the UE selects the eNode-B with the best radio link quality.
- In LTE, the radio link quality is indicated by the **Reference Signal Received Power (RSRP)** for an LTE cell and by the Reference Signal Code Power (RSCP) for a UMTS cell.
- Selecting the eNode-B/Node-B with the best radio link quality is optimum from both an interference management and a battery life point of view.
- However, for inter-frequency handover and/or inter-RAT handover, radio link quality is not the primary measure on which the handover is based.

- Other factors such as UE capability, call type, QoS requirements, and other policy-related aspects are also included in the handover decision process.
- The *measurement report* from the UE, which contains the radio link measurement for the neighboring eNode-B, is the primary mechanism used by the network to trigger and control a handover procedure.
- The serving eNode-B provides the UE with the list of the neighboring cells and the frequencies that it ought to measure and report when a measurement report is requested.

INTRA-LTE HANDOVER

five events that trigger measurement reporting:

- • **Event A1**: The serving cell radio link quality becomes better than an absolute threshold.
- • **Event A2**: The serving cell radio link quality becomes worse than an absolute threshold.
- • **Event A3**: The neighbor cell radio link quality becomes better than an offset relative to the serving cell.
- • **Event A4**: The neighbor cell radio link quality becomes better than an absolute threshold.
- • **Event A5**: Serving cell radio link quality becomes less than an absolute thresh-old and the neighbor cell radio link quality becomes better than another absolute threshold.

FOR INTER-RAT HANDOVER

there are two events that can trigger a measurement report:

- • **Event B1**: Neighbor cell radio link quality on a different RAT becomes better than an absolute threshold.
- • **Event B2**: Serving cell radio link quality becomes worse than an absolute threshold and the neighbor cell radio link quality on a different RAT becomes better than another threshold.

- For all these events the E-UTRAN can specify a *timeToTrigger* parameter, which is the amount of time each of these events must be satisfied before a measurement report is triggered.
- This *timeToTrigger* parameter is chosen to prevent the UE from ping-ponging between eNode-Bs, which can happen if no such parameter is used.
- The RAN mobility management in LTE had been designed to trigger a measurement report whenever there is a significant change in the radio link quality even if it is for the better.

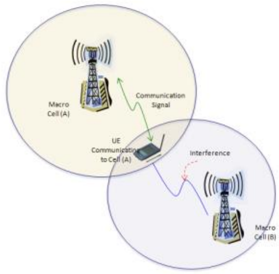
PAGING

- Paging is a connection control function of the RRC protocol.
- The Paging message is used to inform the UEs in the RRC_IDLE or RRC_CONNECTED state about a system information change and/or about an Earthquake and Tsunami Warning System (ETWS) notification.
- The UE in the RRC_IDLE state also monitors a Paging channel to detect incoming calls.

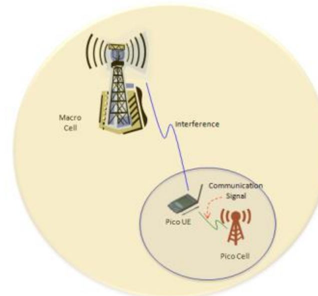
INTER-CELL INTERFERENCE COORDINATION

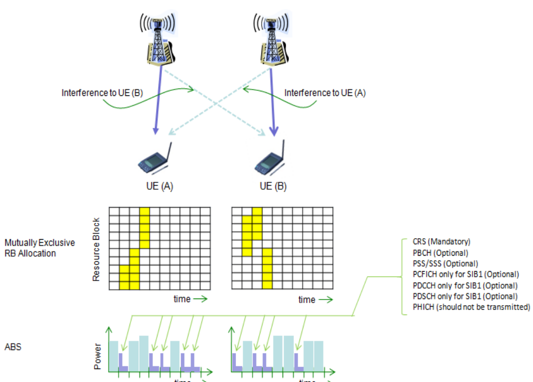
- In cellular networks, each UE suffers Inter-Cell Interference (ICI) due to frequency reuse in other cells.
- Conventional cellular networks by design are interference-limited: if they were not, it would be possible to increase the spectrum efficiency by lowering the frequency reuse or increasing the average loading per cell.
- To meet the spectrum efficiency target, LTE will be deployed with universal frequency reuse, i.e., the same spectrum will be reused in each cell.
- This will cause a high level of ICI, especially for UEs at the cell edge.
- Meanwhile, LTE also has a mandate to increase cell edge throughput.
- Therefore, ICI control techniques must be applied.

•Case 1 : UE is in cell boundary of a cell.
•In this case, the signal from neibour cell can act as interferer. In this case, signal strength from serving cell tends to be very weak and at the same time SNR would be very poor not only because of the weak serving cell signal but also because of the interference.



- Case 2 : UE is under a coverage of a femto or pico cell. In this case, the Macro cells around those pico/femto cell or other pico/femto cell can act as interferer. In this case, the signal strength from serving cell may not be such a weak, but SNR tend to be poorer due to the interference.





INTER-CELL INTERFERENCE COORDINATION
DOWNLINK

- In the downlink, there are three basic approaches to mitigate ICI:
  1. **ICI randomization**
  2. **ICI cancellation**
  3. **ICI coordination/avoidance**

INTER-CELL INTERFERENCE COORDINATION
DOWNLINK

ICI randomization

- This is achieved by scrambling the codeword after channel coding with a pseudo-random sequence.
- With cell-specific scrambling, ICI from neighboring cells is randomized, and then interference suppression is achieved thanks to the processing gain provided by the channel code.
- Without scrambling, the channel decoder might be equally matched to interfering signals as to the desired signals on the same radio resource.
- ICI randomization has been applied in systems such as UMTS.

INTER-CELL INTERFERENCE COORDINATION
DOWNLINK

ICI cancellation

- If a UE is able to decode the interfering signals, it can regenerate and then subtract them from the desired signal.
- This can be achieved with a multiuser detector at the UE.
- However, to decode the interfering signal from neighboring cells, the UE needs to know its transmission format, which is not available as the UE cannot decode the PDCCH from neighboring cells.
- Alternatively, ICI cancellation can also be performed in the spatial domain.
- Linear spatial interference cancellation with statistical knowledge of interference channels is a practical option for ICI cancellation, but application in the downlink is limited by the capability and the number of antennas at UEs.

INTER-CELL INTERFERENCE COORDINATION
DOWNLINK

ICI coordination/avoidance

- This is achieved by applying restrictions to the downlink resource management in a coordinated way between neighboring cells.
- The restrictions can be on time/frequency resources or transmit power used at each eNode-B.
- It requires additional inter-eNode-B communication and UE measurements and reporting.

ICI COORDINATION/AVOIDANCE

- ICI coordination/avoidance can be either ***static or semi-static***, with different inter-eNode-B communication requirements and different performance.

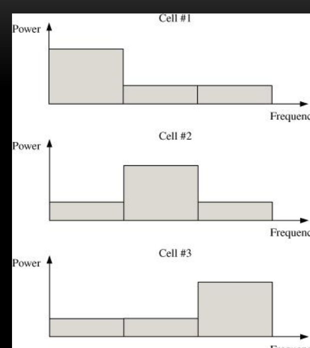
1. Static ICI coordination/avoidance

- This is mainly done during the cell planning process and does not require frequent reconfiguration.
- Static coordination strategy requires no or little inter-eNode-B signaling, but there is performance limitation as dynamic characteristics such as cell loading or user distributions are not taken into consideration.

ICI COORDINATION/AVOIDANCE…

2. Semi-static ICI coordination/avoidance

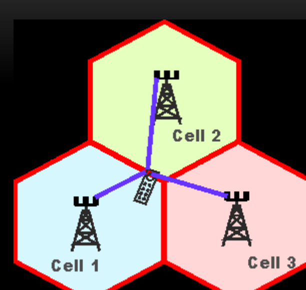
- Semi-static coordination typically requires reconfigurations on a time-scale of the order of seconds or longer, and inter-eNode-B communication over the X2 interface is needed.
- The information exchanged between neighboring eNode-Bs can be transmission power and/or traffic load on different resource blocks.
- By considering such information at neighboring eNode-Bs, ICI suppression is more efficient.

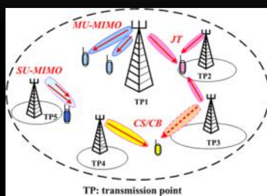


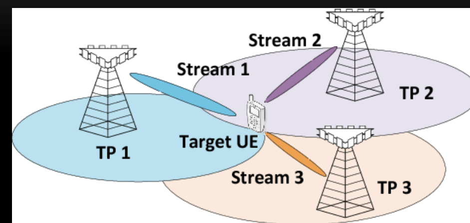
Possible downlink power levels of three neighbouring cells.
Edge users in each cell would be allocated to the higher power levels.

COORDINATED MULTI-POINT TRANSMISSION

- In LTE-Advanced, to further improve cell-edge performance, advanced techniques with more sophisticated coordination will be developed for ICI mitigation.
- One such technique is called Coordinated Multi-Point (CoMP) transmission/reception.
- Downlink CoMP transmission implies dynamic coordination among multiple geographically separated transmission points.
- It can be deployed in the form of coordinated scheduling and/or beamforming, or multicell joint transmission, which is essentially the same as the networked MIMO.







COORDINATED MULTI-POINT TRANSMISSION…

- CoMP with joint transmission theoretically can eliminate all the ICI and transfer the cellular network from an interference-limited system to a noise-limited system.
- However, there are many practical issues associated with CoMP transmission. It is a type of dynamic ICI coordination.
- Deploying it will have great impacts on radio-interface specifications, such as feedback and measurement mechanisms from the UE, inter-eNode-B signaling, and downlink control and reference signal design.

UPLINK

- The basic approaches for uplink ICI mitigation are as follows:

ICI randomization Similar to the downlink, ICI randomization in the uplink is achieved by scrambling the encoded symbols prior to modulation.

- Instead of cell-specific scrambling as used in the downlink, UE-specific scrambling is used in the uplink as ICI comes from multiple UEs in neighboring cells.

ICI cancellation ICI cancellation is more applicable in the uplink than in the downlink, as the eNode-B has higher computational capability and usually more antenna elements.

Uplink power control Power control is an efficient way to suppress ICI in the uplink. Fractional Power Control (FPC) is used in LTE.

ICI coordination/avoidance Similar coordination techniques discussed for downlink can be applied in the uplink, such as FFR.

UPLINK…

- To assist uplink ICI coordination, two messages are defined in LTE that can be exchanged over the X2 interface between eNode-Bs for power allocation and user scheduling:
  1. Interference Overload Indicator (OI) and
  2. High Interference Indicator (HII).
- OI indicates physical layer measurements of the average uplink interference plus noise for each PRB, based on which eNode-Bs can adjust uplink power to suppress ICI.
- HII indicates which PRBs will be used for cell-edge UEs in a certain cell. Neighboring cells may then take this information into consideration when scheduling their own users to avoid high interference.

COORDINATED MULTI-POINT RECEPTION

- Similar to the downlink, CoMP reception will be developed for uplink in LTE-Advanced.
- This means coordinated reception at multiple eNode-Bs of transmitted signals from multiple geographically separated UEs in different cells.
- In contrast to downlink, uplink CoMP reception is expected to have very limited impact on the radio-interface specifications.
- As uplink scheduling is performed at the eNode-B, coordinated inter-cell scheduling can be applied to control ICI, which, however, will have impact on radio-interface specifications.

END OF MODULE 5

QoS architecture

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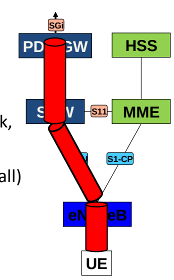
QoS MATTERS IN CELLULAR

- Overprovisioning is difficult
  - Resources are scarce (few 10s of MHzs)
  - Equipment and spectrum expensive
  - You need to use well what you have
- Everything is more complicated
  - Due to the wide-area radio delays are higher
  - Primary application is delay sensitive
- Money
  - People are (somewhat more) willing to pay
  - There is an infrastructure to charge
  - Service and price differentiation happens

Bearers

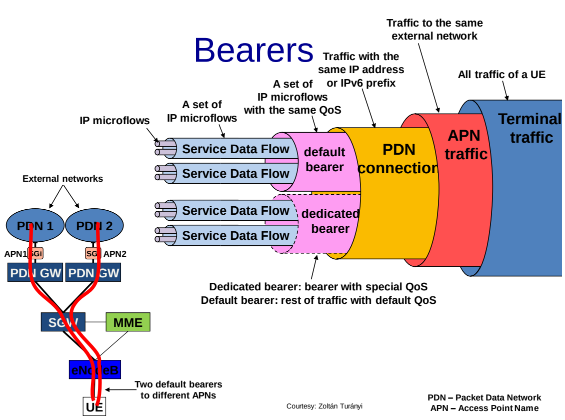
- A bearer is a L2 packet transmission channel
  - ...to a specific external Packet Data Network,
  - ...using a specific IP address/prefix,
  - ...carrying a specific set of IP flows (maybe all)
  - ...providing a specific QoS.
- In 2G/3G also known as "PDP Context"
- Bearer setup is explicitly signaled
  - In LTE one bearer is always set up at attachment



Courtesy: Zoltán Turányi

See more in: 23.107 QoS concept and architecture

Bearers



Courtesy: Zoltán Turányi

PDN – Packet Data Network
APN – Access Point Name