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).

Data Flow, Radio Resource Management, and Mobility Management

Building on the physical layer procedures discussed in previous chapters, in this chapter we describe higher-layer protocols and mobility management in LTE. Radio re source management and inter-cell interference mitigation techniques will also be discussed in this chapter. However, before discussing higher-layer protocols, we first introduce the concept of bearer for Quality of Service (QoS) control and the protocol architecture of LTE.

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 7. Each radio bearer is associated with one PDCP entity, and each PDCP entity is associated with one or two RLC entities depending on the radio bearer characteristic (uni-directional or bi-directional) and the RLC mode. PDCP is used only for radio bearers mapped on DOCH and DTCH types of logical channels.
The main services and functions of the PDCP sub layer for the user plate and control plane 5 shown in Figure 1 are as follows.

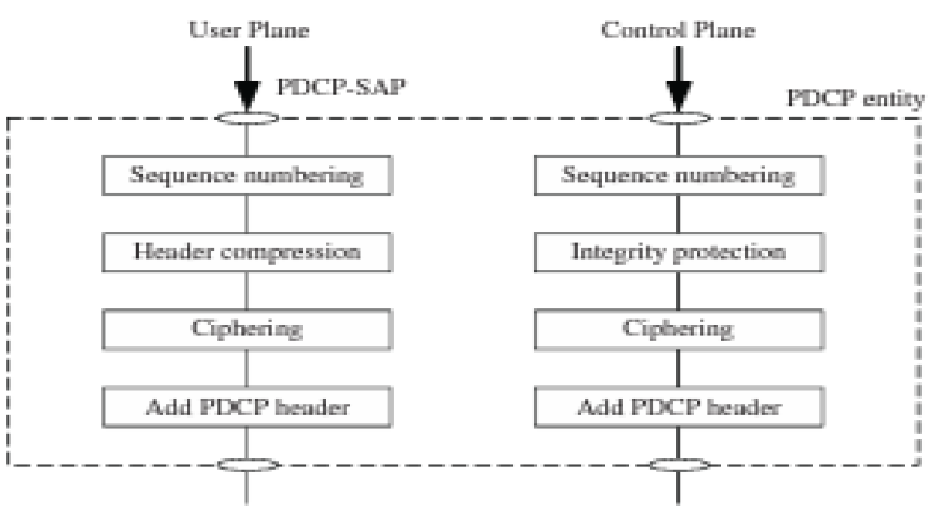

Figure 1: PDCP functions for the user plane and the control plane.

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 .

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.

The PDCP PDUs can be divided into two categories:
The PDCP data PDU is used in both the control and user plane to transport higher-layer packets. It is used to convey either user plane data containing a compressed/'un compressed IP packet or control plate data containing one RRC merge and a Message Authentication Code for Integrity (MAC-I) field for integrity protection, which will be described in detail later in this section.
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. Thus, unlike a PDCP data PDU, the PDCP control PDU does not carry any higher layer SDU but rather is used for peer-to-peer signalling between the PDCP entities at two ends.
The constructions of the PDCP data PDU formants from the PDCP SDU for the user plane and the control plane are shown in Figure . The various types of PDCP PDU carried on the user and control plane are shown in Table 1. There are three different types of PDCP data PDUs, distinguished by the length of the Sequence Number (SN).
The PDCP SN is used to provide robustness against packet loss and to guarantee sequential delivery at the receiver. The PDCP data PDU with the long SN is used for the Un acknowledge Mode (UM) and Acknowledged Mode (AM) and the PDCP data PDU with the short SN is used for the Transparent Mode (TM). Besides the SN field and the ciphered data, the PDCP data PDU for the user plane contains a "D/C' field that is

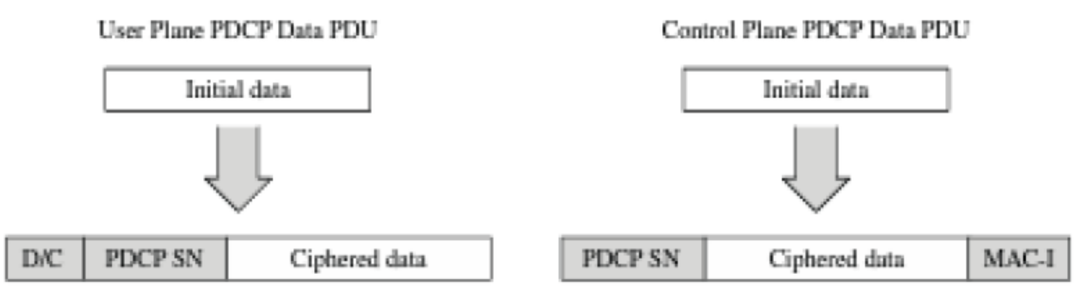

Figure 2: PDCP formats for the user plane and the control plane

PDCP PDU Type	SN Length	Applicable RLC Mode
User plane PDCP data PDU (long SN)	12 bits	AM/UM
User plane PDCP data PDU (short SN)	7 bits	UM
Control plane PDCP data PDU	5 bits	AM/UM
PDCP control PDU for ROHC feedback	N/A	AM/RM
PDCP control PDU for PDCP status report	N/A	AM

PDCP Data units

Header Compression :

The header compression protocol in LTE is based on the Robust Header Compression (ROHC) framework defined by the **Internet Engineering Task Force** (IETF) (12). 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.

However, these protocols bring 1 significant amount of header overhead at the network layer (IP), transport layer (TCP, UDP), and application layer (RTP), which contains redundant and repetitive information and necessarily consumes precious radio resources.
Therefore, an efficient header compression scheme is required, especially for VoIP services where the IP-related repetitive information in the header field is large relative to the in actual speech packets. There are multiple header compression algorithms, Galled profiles, defined for the ROHC framework. Each profile is specific to the particular network layer, transport layer, or upper-laver protocol combination, e.g-, TCP/IP and RTP/UDP/IP.

Profile ID	Usage	Reference
0x0000	No compression	RFC 4995
0x0001	RTP/UDP/IP	RFC 3095, RFC 4815
0x0002	UDP/IP	RFC 3095, RFC 4815
0x0003	ESP/IP	RFC 3095, RFC 4815
0x0004	IP	RFC 3843, RFC 4815
0x0006	TCP/IP	RFC 4996
0x0101	RTP/UDP/IP	RFC 5225
0x0102	UDP/IP	RFC 5225
0x0103	ESP/IP	RFC 5225
0x0104	IP	RFC 5225

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 11 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
The ciphering function includes both ciphering and deciphering. It is performed on both control plane data and user plane data. For the control plane, the data unit that is ciphered is the data part of the PDCP PDU and the MAC-I; for the user plane, the data unit that is ciphered is the data part of the PDCP PDU.
The ciphering is done by an XOR operation of the data unit with the ciphering stream. The ciphering stream is generated by the ciphering algorithm based on ciphering keys, the radio bearer identity, the value of COUNT, the direction of the transmission,

Figure 3: Format of COUNT

MAC/RLC Overview :
As there is close interaction between MAC and RLC sub layers 5,6, we discuss them together in this section. The RLC layer performs segmentation and/or concatenation of PDCP PDUs

the size indicated by the MAC. RIC the RLC PDUs once they are received out of order possibly due to H-ARQ processes in the MA*C* layer.
The RLC layer also supports in 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 RIO PDU has not yet been received without errors. As mentioned previously, at the transmitter and the receiver there is one RLC entity per radio bearer.
The MAC layer only performs the task of multiplexing and prioritizing the various radio bearers Associated with the UE. The MAC layer provides services to the RLC layer through logical channels, while it access the data transfer services provided by the PHY layer through transport channels.

Data Transfer Modes

Functions of the RIC layer are performed by RLC entities. Each RLC entity can be operated in three different modes: the Transparent Mode (TM), the Unacknowledged Mode (UM), and 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 is 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 us VoIP. The DTCH logical channel can be operated in the UM mode, and the RLC data PDU delivered by 10 UM RIC entity is called the UM Data (UMD) PDU.
At the transmit end, the UM RLC entity segments and/or concatenates the RIC SDU. According to the total size of RLC PDUs indicated by the MAC layer. Relevant RLC headers are also included in the 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 CITOI-Sensitive and delay-tolerant applications.
The operation of the AMRIC entity is similar to that of the UM RLC entity, except that it supports retransmission of RLC data PDUs. The receiving AM RIC 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 sub layer include
• Transferring /receiving PDUs from upper layers, i.e. from RRC for the CCCH logical channel or from PDCP for other cases
• Error correction through ARQ (only when the RLC is operated in the AM mode)
• Concatenation, segmentation, and reassembly of RLC SDUS (only for UM and AM data transfer)
• Re-segmentation of RLC data PDUs (only for AM data transfer)
• In-sequence delivery of upper-layer PDUs (only for UM and AM data transfer)

• Duplicate detection (only for UM and AM data transfer)
• Protocol error detection and recovery
• RLC SDU discard (only for UM and AM data transfer)
• RLC re-establishment

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 sub layer include

• Multiplexing/de multiplexing of NAC SDUs belonging to one or different logical channels into from the same transport block
• Error correction through H-ARQ, which has tight interaction with ARQ in the RLC layer and will be discussed later in this section.

Transport format selection, i.e., the selection of the Modulation and Coding Scheme (MOS) for link adaptation

• 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 PDU.. As discussed in the previous subsection, 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 signalling between the AM RLC entities at the two ends for ARQ procedures.

The formats of different RLC Data PDUs are shown in Figure . 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: The FI Held indicates whether a RLC SDU is Segmented at the beginning and/or at the end of the Data field.
• Length Indicator (LI) field: The LI field indicates the length in bytes of the corresponding Data field element present in the UMD or AMD PDU.
• Extension bit (E) field: The E field indicates whether a Data field follows or a set of E field and LI field follows

SN field: The SN Held 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

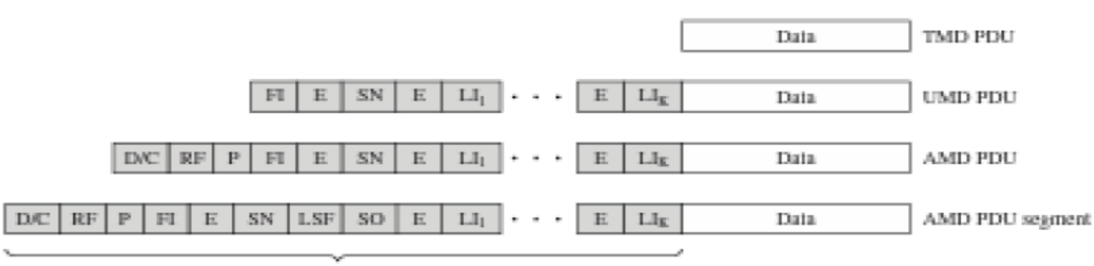

Figure 4: Formats of RLC Data PDUs

• **Data/Control (D/C) field**: The D/C field indicates whether the RLC PDU is an RLC Data PDU or an RLC Control PDU.
• **Re-segmentation Flag (RF) field**: The RF field indicates whether the RLC PDU is an AMD PDU or an AMD PDU segment.

• **Polling bit (P) field**: The P field indicates whether the transmitting side of an AM RLC entity requests a STATUS report from its per AM RLC entity. Additionally, the RLC header of an AMD PDU segment contains special fields including:

• **Segment Offset (SO) field**: The SO field indicates the position of the AMD PDU segment in bytes within the original AMD PDU.

• **Last Segment Flag (LSF) field**: The LSF Held indicates whether the last byte of the AMD PDU segment corresponds to the last byte of an AMD PDU.

The STATUS PDU is used by the receiving AM RLC entity to indicate the missing portions of AMD PDUs. The format of the STATUS PDU is shown in Figure 10.9, which Consists of the following fields:

Control PDU Type (CPT) field: The CPT field indicates the type of the RLC control PDU, and in Release the STATUS PDU is the only defined control PDU.

• **Acknowledg**ment SN (ACK SN) field: The ACK_SN field indicates the SN of the next not received RIC Data PDU, which is not reported is missing in the STATUS PDU.

• Extension bit 1 (El) field: The El field indicates whether a set of NACK_SN, El, and E2 follow us.

• Extension bit 2 (E2) field: The E2 field indicates whether a set of SO start and SO end follows.

Negative Acknowledgment SN (NACK SN) field: The NACK_SN field indicates the SN of the AMD PDU (or portions of it) that has been detected is lost at the receiving side of the AM RLC entity

• **SO start (SO start) field and SO end (SO end) field**: These two fields together indicate the portion of the AMD PDU with SN = NACK SN that has been detected is lost at the receiving side of the AM RLC entity.

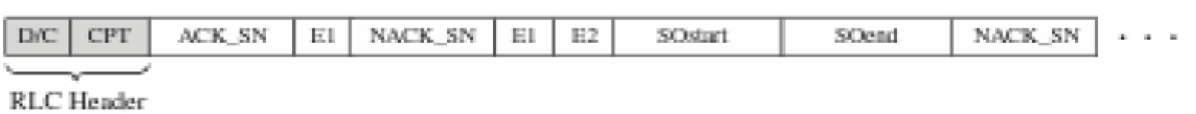

Figure 5:The format of STATUS PDU

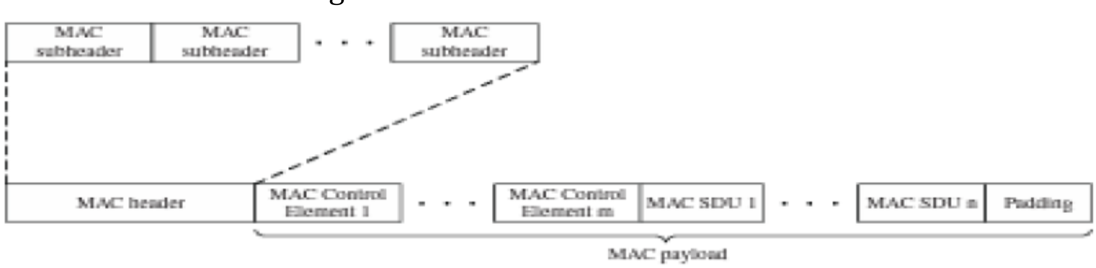

Figure 6: An example of MAC PDU consisting of MAC header

RRC Overview :

The RRC layer takes care of RRC connection management, radio bearers control, mobility functions, and UE measurement reporting and control. It is also responsible for broadcasting system information and paging. In this section, we discuss the two RRC states in LTE and the functions provided by the RRC protocol.

RRC States

Compared to UMTS, which has four RRC states, LTE has only two states RRC_IDLE und RRC.CONNECTED, is depicted in Figure 7 .This simplifies the RRC state machine handling and the radio resource management, which controls the RRC state.

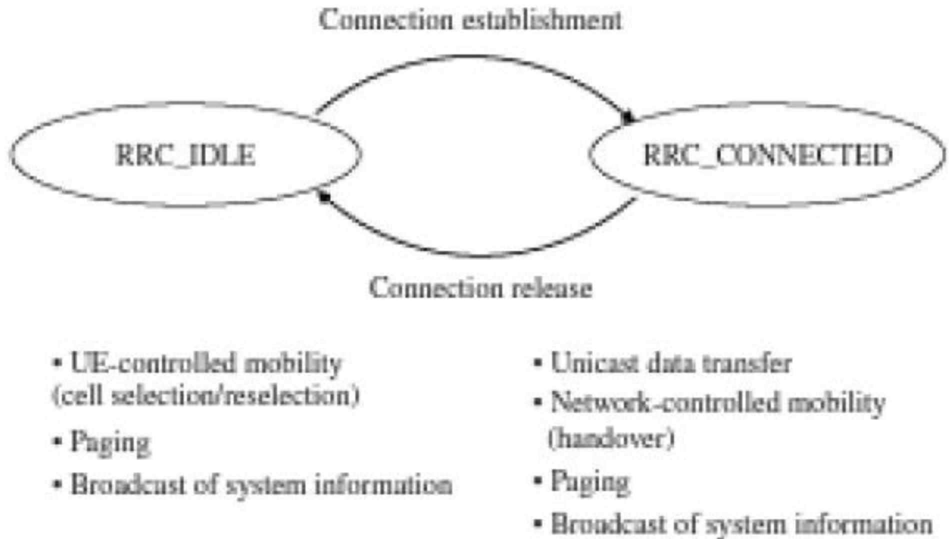

Figure 7: RRC states in LTE

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

The system information mainly contains parameters by which E-UTRAN controls the cell selection/reselection POCK, such as priorities of different frequencies. The UE shall have been allocated an ID that uniquely identifies the UE is a trucking area. The UE also monitors a paging channel to detect incoming calls, and it specifies the paging Discontinuous Reception (DRX) cycle.

In the RRC_CONNECTED state, the UE has an E-UTRAN RRC connection and 1 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) Located with the shared data channel to determine if data is scheduled for it.

In the RRC_CONNECTED state, the network controls mobility,'handover of the UE.

RRC Functions

Before going into different functions provided by the RRC protocol, we first introduce the concept of Signalling Radio Beaers (SRBs). SREs are defined as radio bearers that ne used only for the transmission of RRC and NAS message. There are three different SRBs defined in LTE .

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 1 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.

RRC connection control includes procedures related to the establishment, modification, and release of at 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 A capability information, and support of self-configuration and self-optimization.

Mobility Management

LTE mobility management functions can be categorized into two groups a) mobility within the LTE system (intra-LTE mobility) and b) mobility to other systems such as other 3GPP systems (C. UMTS) and 100-3GPP systems (inter-RAT mobility). Intra LTE mobility can happen either over the Si interface or over the X2 interface. When the UE moves from one eNode-1 to another eNode-B within the same Radio ACCESS Network (RAN) attached to the same NME, the mobility takes place over the X2 interface.

The inter-RAT mobility essentially uses the Sl-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.

Si Mobility : Si mobility is very similar to the UMTS Serving Radio Network Subsystem (SRNS) relocation procedure and consists of the following steps.

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.

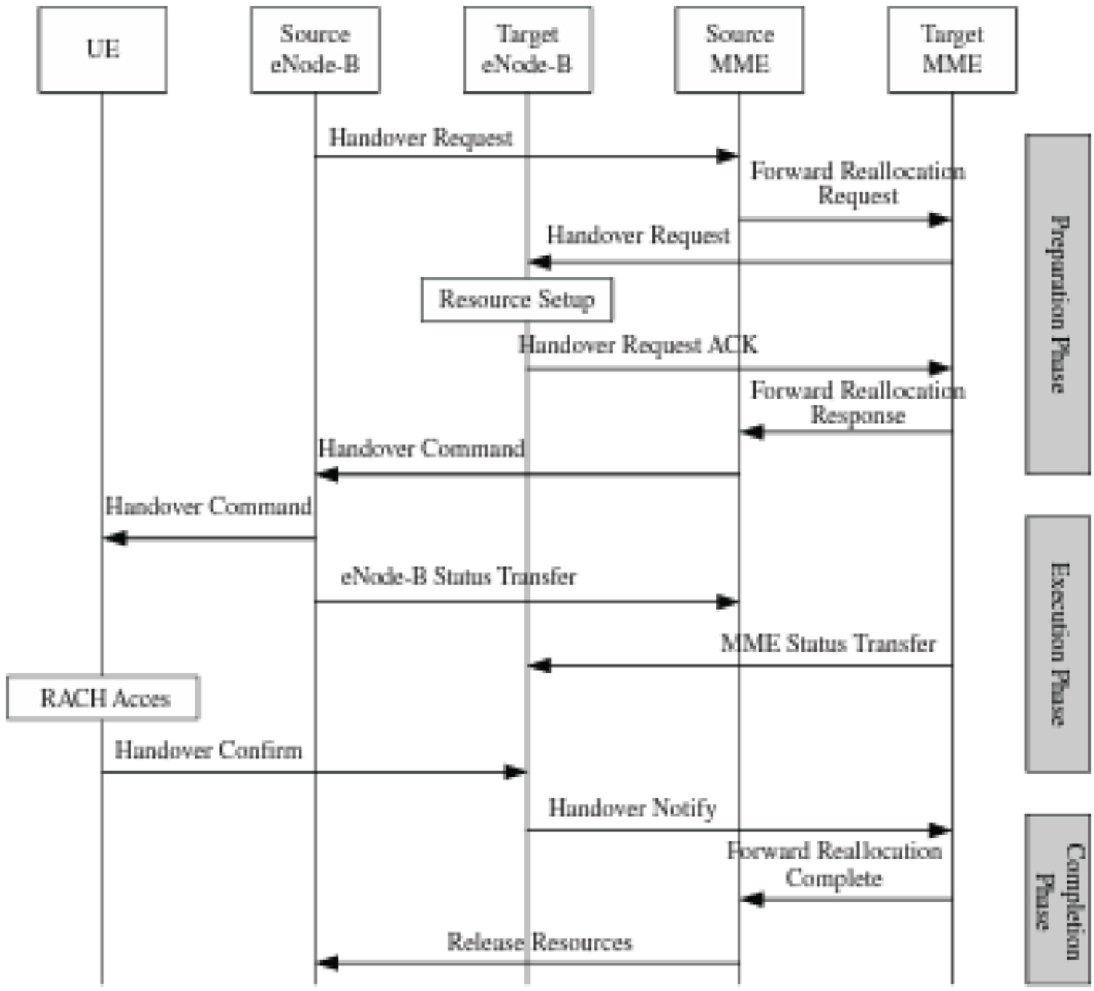

Figure 8 : Mobility Management over the SI interface

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.
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.

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-Es. When this is the arise, the mobility over Sl interface is triggered is mentioned in the previous section. Mobility over the X2 interface also consists of three steps :

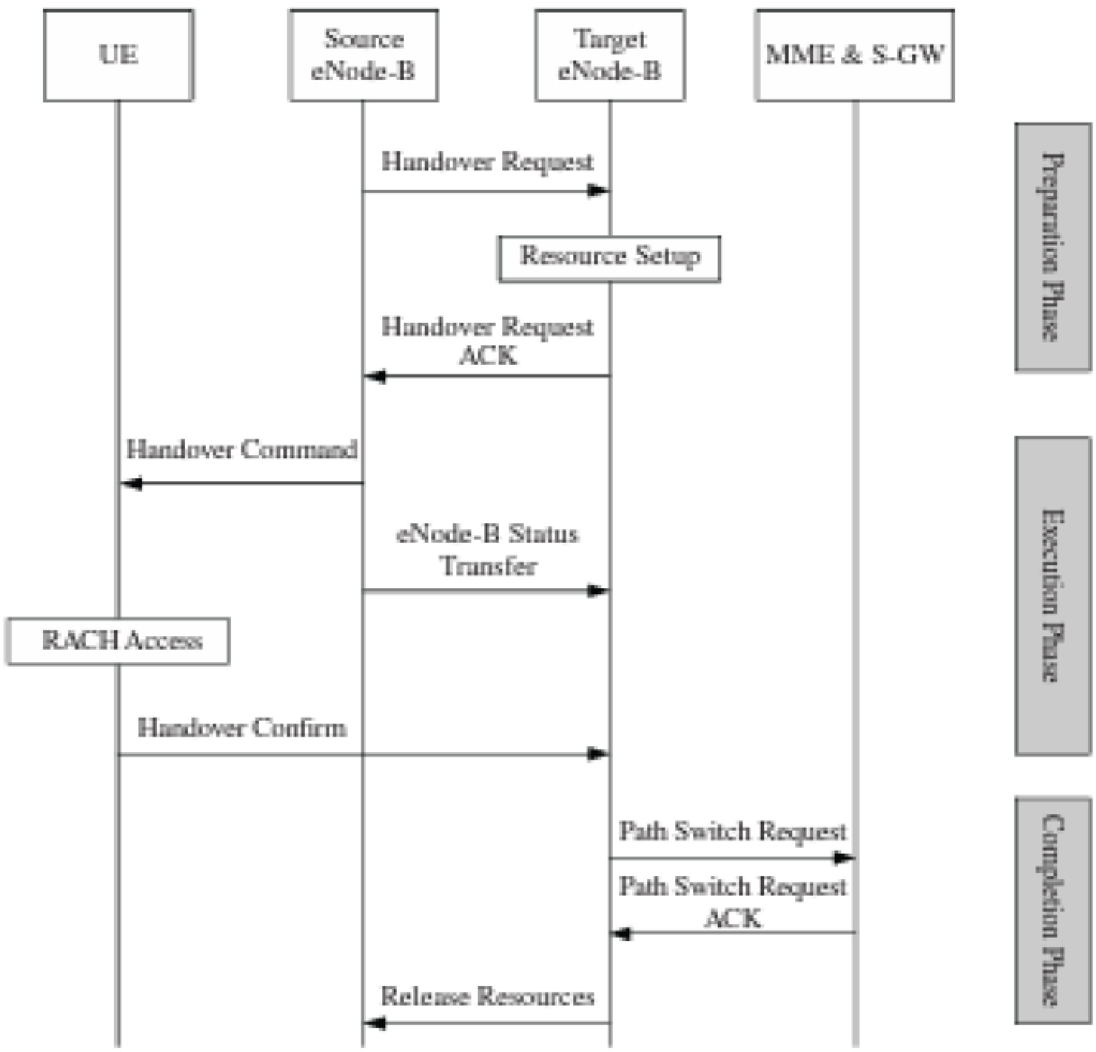

Figure 9: Mobility management over the X2 interface

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 NNE 2nd S-GW to set up the resources for the UE. In the case of mobility over X2 interface.
2. **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.
3. **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 ser plane is switched, the target eNode-B sends a message to the source eNode-B to release the resources originally used by the UE.

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. Change of system information only occurs at specific radio frames, and the concept of 1 Modification period is used. Within a modification period, system information can be transmitted a number of times with the same content.
Upon receiving a change notification contained in the Paging message, the UE knows that the current system information is valid until the next modification period boundary. After this boundary, the UE will re-acquire the required system information.
If the ETWS notification is indicated the UE that is ETWS capable will re-acquire the system information block related to ETWS immediately without waiting for the next system information modification boundary.
The paging information is carried on the PDSCH physical channel. In a certain PO, the UE is configured to decode PDCCH with CRC scrambled by the Paging-Radio Network Temporary Identifier (P-RNTI), and then decode the corresponding PDSCH for the paging information. To reduce power Consumption, the UE may use Discontinuous Reception (DRX) in the idle mode, so it needs only to monitor one PO per DRX cycle.
After receiving the Paging message, the UE can switch off its receiver to preserve battery power. The DRX cycle is configured by the E-UTRAN .

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, ie, 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 (10.11, 13, 14, 17). In this section, we discuss ICI mitigation techniques for both downlink and uplink transmissions. ICI suppression through base station coordination, or networked MIMO, has been discussed in Section 5.9.2, where the associated opportunities and challenges were highlighted.

Downlink

ICI randomization. This is achieved by scrambling the codeword after channel coding with a pseudo-random sequence, With cell specific scrambling. ICI from neighbouring cells is randomized, and then interference suppression is achieved thanks to the processing main provided by the channel code. Without scrambling, the channel decoder might be equally matched to interfering signals us to the desired signals on the same radio resource. ICI randomization has been applied in systems such as UMTS.
ICI cancellation If a UE is able to decode the interfering signals, it can IC generate and then subtract them from the desired signal. This can be achieved with a multiuser detector |16 at the UE. However, to decode the interfering signal from neighbouring cells, the UE needs to know its transmission format, which is not available us the UE cannot decode the PDCCH from neighbouring cells.
ICI coordination/avoidance This is achieved by applying restrictions to the downlink resource management in 1 coordinated way between neighbouring cells. The restrictions can be on time/frequency resources or transmit power used at each eNode-B. It requires additional inter-eNode-B communication und UE measurements and reporting.
Static ICI coordination/avoidance This is mainly done during the cell planning process and does not require frequent reconfiguration. An example is static Fractional Frequency Reuse

(FFR), Static coordination strategy requires no or little inter-eNode-B signalling, but there is performance limitation as dynamic characteristics such as cell loading or user distributions are not taken into consideration.

Semi-static ICI coordination/avoidance Semi-static coordination typically requires reconfigurations on 1 time-scale of the order of seconds or longer, and inter-eNode-B communication over the X2 interface is needed. The information exchanged between neighbouring eNode-Bs can be transmission power and/or traffic load on different resource blocks. By considering such information at neighbouring eNode-Es, ICI suppression is more efficient.

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.

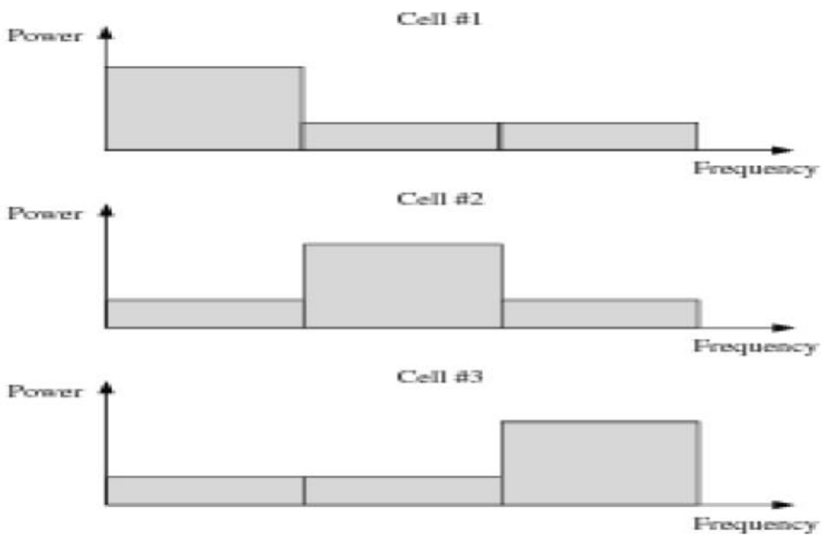

Figure 10: Possible downlink power levels of three neighbouring cells.

Uplink

• **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 neighbouring 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.

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 1pplied to control ICI, which, however, will have impact on radio-interface specifications.