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Internal Assessment Test 3 – July 2021

Sub:	Wireless Cellular and LTE 4G Broadband					Sub Code:	17EC81	Branch:	ECE/TCE
Date:	17.07.2021	Duration:	90 min's	Max Marks:	50	Sem / Sec:	VIII ECE - A, B, C, D & TCE		OBE

	Answer any FIVE FULL Questions	MARKS	CO	RBT
1	Describe the various phases of SI mobility with a neat diagram.	[10]	CO1	L1
2	Explain RRC states and its functions.	[10]	CO1	L1
3	Explain three basic approaches to mitigate ICI in downlink and uplink.	[10]	CO1	L2
4	Explain the functions and services of RLC and MAC layers.	[10]	CO1	L2
5	Discuss the Random-access procedures in LTE in detail.	[10]	CO1	L1
6	Explain Channel Quality Indicator (CQI) feedback with the help of CQI estimation and reporting modes.	[10]	CO1	L2
7	Explain the different logical channels supported in LTE.	[10]	CO2	L1
8	Explain briefly layer mapping and precoding in modulation mapping.	[10]	CO2	L2
9	Explain the main services and functions of PDCP sublayer for the user plane.	[10]	CO2	L2

Signature of CI

Signature of CCI

Scheme Of Evaluation
Internal Assessment Test 3 – July 2021

Sub:	Wireless Cellular and LTE 4G Broadband							**Code:**	17EC81
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Note: Answer Any Five Questions

Question #	Description	Marks Distribution	Max Marks
1	**Describe the various phases of S1 mobility with a neat diagram.** Diagram Explanation of the Components	 4 M 6 M	10 M
2	**Explain RRC states and its functions.** Explanation of RRC Idle state Explanation of RRC Connected state	 5 M 5 M	10 M
3	**Explain three basic approaches to mitigate ICI in downlink and Uplink.** Explanation of approaches related to downlink Explanation of approaches related to uplink	 5 M 5 M	10 M
4	**Explain the functions and services of RLC and MAC layers.** Explanation of functions and services of RLC Explanation of functions and services of MAC	 5 M 5 M	10 M
5	**Discuss the Random-access procedures in LTE in detail.** Diagram Explanation	 3 M 7 M	10 M
6	**Explain Channel Quality Indicator (CQI) feedback with the help of CQI estimation and reporting modes.** CQI Estimation Explanation of 2 types of CQI Feedback	 2 M 8 M	10 M
7	**Explain the different logical channels supported in LTE.** Explanation of Control channels		10 M

	Explanation of Traffic channels	6 M 4 M	
8	**Explain briefly layer mapping and precoding in modulation mapping.** Explanation of Layer Mapping Explanation of Precoding	5 M 5 M	10 M
9	**Explain the main services and functions of PDCP sublayer for the user plane.** Explanation of PDCP User Plane Explanation of PDCP Control Plane	5 M 5 M	10 M

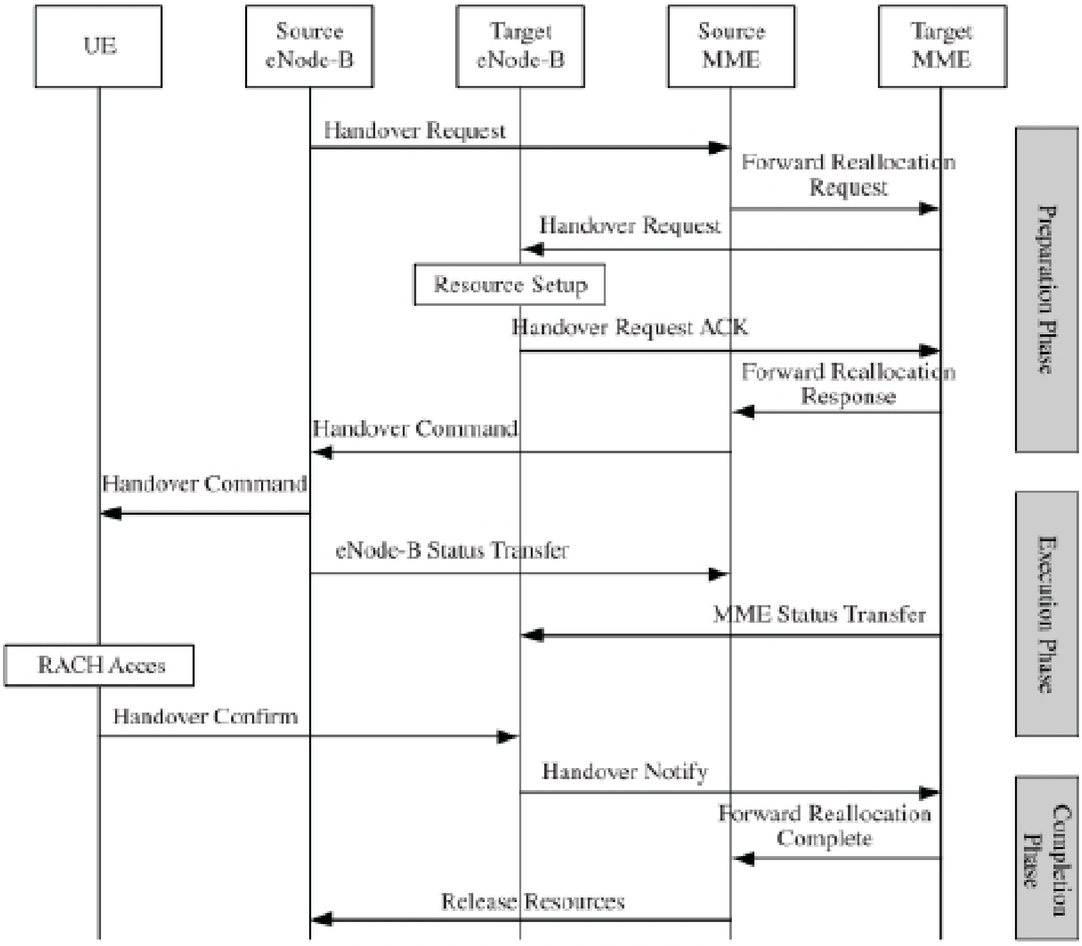
CMR Institute of Technology
Department of ECE
Solution for 3rd Internals-July 2021
17EC81- Wireless Cellular and LTE 4G Broadband

1. **Describe the various phases of S1 mobility with a neat diagram.**

- Similar to the UMTS Serving Radio Network Subsystem(SRNS) relocation Procedure and has 3 phases:
- Preparation Phase
- Execution Phase
- Completion Phase

(1) Preparation Phase

- Once a handover decision is made, and identifying Target MME, eNode-B, the network needs to allocate resources on the target side for handover to happen
- MME sends a handover request to the target eNode-B and request for resource allocation to the UE
- After resource allocation at the target eNode-B , it sends a handover request ACK to the MME
- After receiving the handover request ACK by the MME, it sends a handover command to the UE via the source eNode-B



(2) Execution Phase

- Once the UE receives the handover command, it access the target eNode-B using the Random Access Channel (RACH)
- Source eNode-B initiates the status transfer where the PDCP content of the UE is transferred to the target eNode-B
- Source eNode-B forwards the data stored in the PDCP buffer to the target eNode-B
- Now 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

(3) Completion Phase

- When the target eNode-B receives the handover confirm message, it sends a handover notify message to the MME
- Now, MME informs the source eNode-B to release the resources, originally used by the UE

2. Explain RRC states and its functions.

10.4 RRC Overview: *RRC is responsible for:*

- *RRC connection Management*
- *Radio bearer control*
- *Mobility functions*
- *UE measurement reporting and control*
- *Broadcasting system information and paging.*

10.4.1 RRC States: Two states of RRC as shown in figure

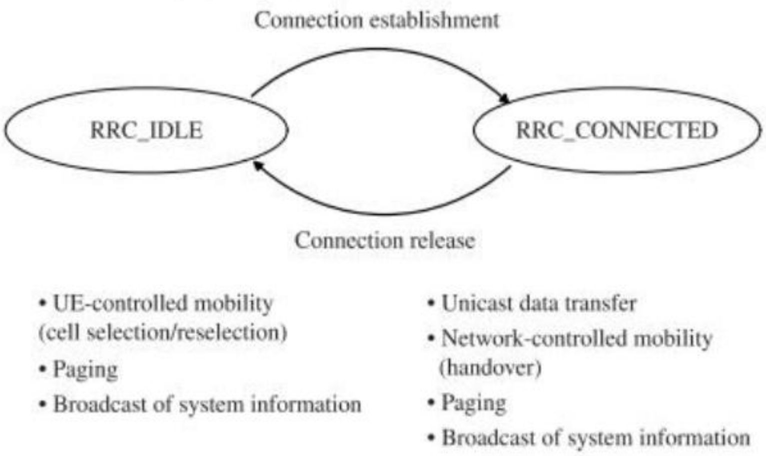


Figure 10.13 RRC states in LTE.

- ***RRC-IDLE STATE:***

  1. *UE receives broadcasts of system information*
  2. *Paging information.*
  3. *Mobility control is handled by UE (performs neighboring cell measurements and cell selection/reselection.*

4. *UE monitors paging channel for incoming calls.*
5. *UE specifies the paging DRX cycle.*

- ***RRC states: RRC-CONNECTED:***

1. *UE transmits/receive data from the network (eNode-B).*
2. *UE monitors control channels (PDCCH) associated with the shared data channel for data.*
3. *UE reports channel quality information and feedback information to the network (eNode-B) to assist the data transmission.*
4. *UEs provide neighboring cell measurement information.*
5. *The n/w controls mobility/handover of the UE.*

10.4.2 RRC Functions:

- Signaling Radio Bearers SRBs are the radio bearers and used only for the transmission of RRC and NAS messages.
  - ***SRB 0****: It is FOR RRC messages using the CCCH logical channel.*
  - ***SRB 1****: It is for RRC messages and NAS messages.*
  - ***SIB 2****: It is for NAS messages using DCCH logical channel.*
- All SIBs other than Type 1 carries system information messages.
- Following are the main functions of the RRC protocol.

1. ***Broadcast of system information:***

- It is divided in to Master Information Block (MIB) and a number of System Information Blocks (SIBs)
- **MIB:** contains most essential and most frequently transmitted parameters which are needed to acquire other information from the cell.
- **SIB Type 1**: contains parameters to determine the cell selection, information of time- domain scheduling of other SIBs.
- **All SIBs** other than Type 1 carries system information messages.

2. ***RRC connection control*:** It includes

- RRC connection establishment, modification and release.
- Paging and Initial security activation
- Establishment of SRBs
- Radio bearers carrying user data
- Radio configuration control
- QoS control
- Recovery from radio link failure.

3. ***Measurement configuration and reporting***: It includes
   - Measurement establishment, modification and release.
   - Configuration and deactivation of measurement gaps
   - Measurement reporting for intra-freq. and inter-freq.
   - Inter RAT mobility
4. ***Other functions***: It include
   - Transfer of dedicated NAS information
   - Non-3GPP dedicated information
   - Transfer of UE radio access capability information.
   - Support for self-configuration and self-optimization

3. Explain three basic approaches to mitigate ICI in downlink and uplink.

- LTE uses universal frequency reuse to meet the spectrum efficiency (i.e., same spectrum is used in each cell) which leads to higher ICI.
- ICI minimization can be achieved through BS coordination or networked MIMO.
- ICI minimization techniques used for both uplink and downlink.

10.6.1 Downlink ICI Minimization: There are 3 approaches.

1. ***ICI randomization***: Scramble the codeword after channel coding with PR sequence. Scrambling is Cell specific.
2. ***ICI Cancellation***: UE decodes the interfering signals (from neighboring cells) and subtract them from the desired signal. *Disadvantage* is UE can't decode the PDCCH from neighboring cells and does not know the transmission format of neighbor cells. *Practical solution is to use* linear spatial interference cancellation with statistical knowledge of interference channels. ICI minimization in downlink is limited by the capability and no. of antennas at UEs.
3. ***ICI Coordination/Avoidance:*** It is based on scheduler implementation at eNode-Bs. Restrictions to the downlink resource management in a coordinated between neighboring cells. The restrictions can be on time/frequency resources or Transmit power at eNode-B. It needs additional inter eNode-B communication and UE measurements and report. The *ICI Coordination/Avoidance technique can be static or semi static.*
   - ***Static ICI Coordination/Avoidance***: This is done during cell planning and doesn't need frequent reconfiguration. It doesn't consider cell load and user distribution.
   - ***Semi-Static ICI Coordination/Avoidance***: It needs reconfigurations on a time-scale (seconds or longer). The information (transmit power, traffic load) exchange between neighboring eNode-Bs is over X2 interface.

- LTE system defines eNode-B power restriction signaling in the downlink using Relative Narrowband Transmission Power (RNTP) indicator exchanged between eNode-Bs over X2 interface. Each bit of RNTP indicator corresponds to one PRB, it indicates maximum transmitter power on that PRB. Based on the RNTP indicators from neighboring cells, each eNode-B improve the performance of UEs in its own cell by scheduling and power allocation. Figure 10.6 shows a simple example of power patterns in three neighboring cells

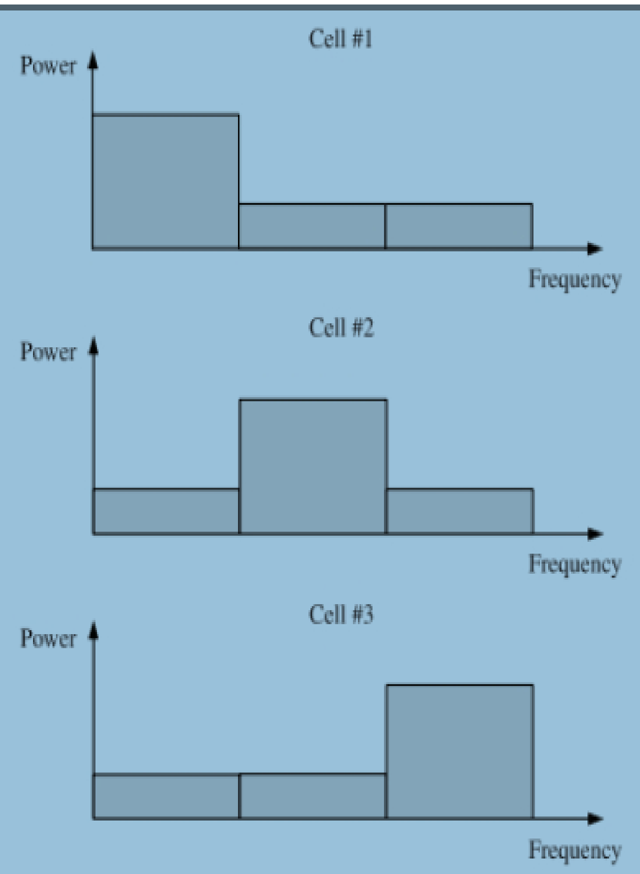


Figure 10.16 Possible downlink power levels of three neighboring cells. Edge users in each cell would be allocated to the higher power levels.

10.6.2 Uplink ICI minimization:

- ICI randomization: Scramble the encoded symbols prior to modulation.
- UE specific scrambling is used.
- *ICI cancellation*: It is more applicable in the uplink than downlink as the eNode-B has higher computational capability and more antennas.
- Uplink Power Control: LTE uses FPC to suppress ICI in the uplink.
- ICI Coordination/avoidance: Similar to downlink.

- ***Coordinated Multi-Point (CoMP) Reception***:
  - It is developed for uplink in LTE-Advanced.
  - There is a coordinated reception at multiple eNode-Bs of transmitted signals from geographically separated UEs in different cells.
  - As Uplink scheduling is performed at the eNode-B, coordinated inter-cell scheduling is applied to control ICI.
  - Uplink CoMP reception has limited impact on the radio-interface specifications.

4. **Explain the functions and services of RLC and MAC layers.**

- **Functions of MAC layer:**

➢ Performs multiplexing and demultiplexing of logical channels on to the transport channel

- At eNode-B,it performs multiplexing and prioritizing various UEs serving by the eNode-B
- At UE, it performs multiplexing and prioritizing various radio bearers associated with the UE
- It provides services to the RLC layer through Logical channels
- It takes service from PHY layer through transport channels

- **Functions of RLC layer:**

- Performs Segmentation and Concatenation on PDCP PDUs based on size mentioned by the MAC layer
- Reorders RLC PDUs if they receive out of order due to H-ARQ process in the MAC layer
- RLC supports ARQ mechanism

- **Data Transfer modes of RLC:**

- RLC entity can be operated in 3 different modes

(i) Transparent Mode(TM)
(ii) Unacknowledged Mode(UM)
(iii) Acknowledged Mode(AM)

Transparent Mode(TM)

- Simplest mode
- Not used for user plane data transmission
- RLC entity doesn't add any RLC header to the PDU
- No data Segmentation or concatenation
- No retransmissions
- Order of delivery is not guaranteed.
- Example- RRC broadcast messages, paging messages uses TM

The Unacknowledged Mode (UM)

- Order of delivery is guaranteed
- DTCH logical channels operate in this mode
- UM RLC entity performs data segmentation or concatenation of RLC SDUs
- No retransmissions of the lost PDU
- Examples- delay- sensitive, error-tolerant real time applications like VoIP
- Relevant RLC headers are included in the UM data PDU
- At the Rx, UM RLC entity performs duplicate detection and reordering

The Acknowledged Mode(AM)

- Most complex one, which requests retransmission of missing PDUs in addition to the UM mode functionalities
- 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
- When the AM RLC entity needs to retransmit a portion of an AMD PDU, which results from the ARQ process and segmentation, the transmitted PDU is called the AMD PDU segment
- 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:

- Transfer/receive PDUs from Upper Layers
- Error detection using ARQ(only in AM mode)
- Concatenation, Segmentation and reassembly of RLC SDUs (only in UM and AM data transfer)
- In-sequence delivery of upper layer PDUs (only in UM and AM data transfer)
- Duplication Detection (only in UM and AM data transfer)
- RLC SDU discard (only in UM and AM data transfer)
- RLC re-establishment

Services and functions of MAC sublayer

- Mapping between logical channels and transport channels
- Multiplexing/demultiplexing of MAC SDUs belonging to one or more logical channels from the same transport block
- Scheduling for uplink and downlink transmission
- Error correction through H-ARQ
- Priority handling between logical channels of one UE or between UEs by means of dynamic scheduling
- Transport Format Selection (i.e.) selection of MCS for link adaptation
- Padding if the MAC PDU is not fully filled with data

5. Discuss the Random-access procedures in LTE in detail.

- In order to be synchronized with the network, RACH procedure is used by UE.
- Suppose a UE wants to access the network, so first it will try to attach or synchronize with the network. In LTE a separate channel PRACH (Physical Random Access Channel) is provided for initial access to the network.

- The UEs also obtain uplink timing information from the initial handshake.
- In LTE, there are two random access mechanisms:
  1. Non-synchronized random access: *Non-synchronized random access is used ohm the UE uplink has not been time synchronized, or when the UE uplink loses synchronization. Its main purpose is to obtain synchronization of the uplink, notify the eNode-B that the UE has data to transmit, or transmit a small amount of control information and data packets.*
  2. Synchronized random access: *Synchronized random access is used when uplink synchronization is present. Its main purpose is to request resources for uplink data transmission from the eNode-B scheduler.*

- ***Non-synchronized random access procedure:***
  - Prior to initiation of the non-synchronized random access procedure, each UE obtains the following information broadcast from eNode-B:
    - Random access channel parameters
    - Including POACH configuration
    - Frequency position and preamble forma
    - Parameters for determining the root sequences and their cyclic shifts in the preamble sequence set for the cell.
  - The non-synchronized random access procedure consists of following steps is depicted in the figure 9.5 and described as follows

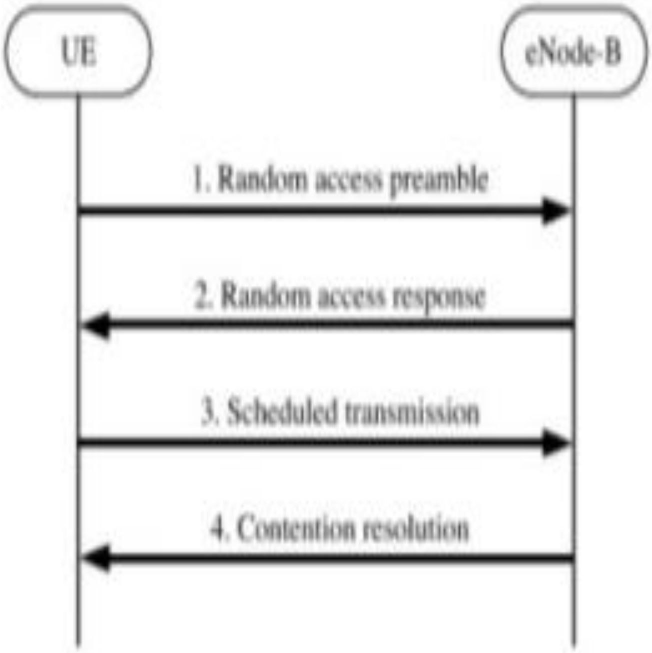


Figure 9.5 The non-synchronized random access procedure.

1. Multiple UEs transmit randomly selected random access code.
2. eNode - B conducts a multiuser detection process and allocates resources to the detected UEs.
3. Each UE transmits detailed information losing allocated resources.
4. The eNode-B transmits the contention-resolution message on the DL-SCH. When the previous steps are finished successfully. eNode-B and each UE initiate data communication.

Step 1: Random Access Preamble Transmission:

- The UE randomly selects a random access preamble transmitted by eNodeB, and transmits on the PRACH physical channel.
- Open-loop power control is used to determine the initial transmit power level.
- Multiple UEs may transmit their random access preambles simultaneously through the same channel, and the eNode-B monitors the random access channel and conducts multiuser detection identifying each RACH transmission.
- The RACH signals from the different UEs are based on the Zadoff-Chu sequence with different cyclic shift resulting in a zero cross-correlation between them.
- The eNode-B also calculates the timing correction for the uplink transmission for each UE.

Step 2: Random Access Response:

- eNode-B transmits the corresponding random access response on the DL-SCH, which contains the identity of the detected preamble, the timing correction for uplink transmission, a temporary identity for transmission in following steps, and an initial uplink resource grant.
- The random access response message can also include a backoff indicator to instruct the UE to back off for a period of time before retrying another random access attempt.
- The uplink scheduling grant for the following uplink transmission contains 20 bits, and the content is illustrated in Table 9.20.

Table 9.20 The Content of Random Access Response Grant

Information Type	Number of Bits	Purpose
Hopping flat	1	Indicates whether PUSCH frequency hopping is applied in the following step.
Fixed-size resource block assignment	10	Indicates the assigned radio resource for the following transmission.
Truncated modulation and coding scheme	4	Determines the modulation and coding scheme.
TPC command for scheduled PUSCH	3	Adjusts the transit power of PUSCH.
UL delay	1	Adjusts the uplink transmission timing.
CQI request	1	Used in non-contention-based random access procedure to determine whether an aperiodic CQI report is included in the corresponding PUSCH transmission.

- Once the random access preamble is transmitted, it will monitor the PDCCH for random access response identified by the Random Access Radio Network Temporary Identifier (RA-RNTI), as the time-frequency slot carrying the preamble is associated with an RA-RNTI.
- If the received random access response matches the transmitted preaanble, the UE may stop monitoring.

Step 3: Scheduled Transmission:

- After step 2, the UE is uplink synchronized and can transmit additional messages on scheduled UL-SCH.
- This step is to assist contention resolution.
- If the UEs that perform random access attempts in the same time-frequency resource use different preambles.
- Different UEs can be identified by the eNode-B and there is no collision. However. it is possible that multiple UEs select the same preamble, which causes a collision.
- To resolve the contention for access, the UE that detects a random access preamble transmits a message containing a terminal identity.
- If the UE is connected to a cell, Cell Radio Network Temporary Identifier (C-RNTI) will be tool, which is a unique UE ID at the cell level; otherwise, a core network identifier is used. In step 1 the H-ARQ protocol is supported to improve the transmission reliability.

Step 4: Contention Resolution:

- In this step, the eNode-B transmits the contention-resolution message on the DL-SCH, which contains the identity of the winning UE.
- The UE that observes a match between this identity and the identity transmitted in step 3 declares a success and completes its random access procedure.
- If this UE has not been assigned a C-RNTI, the temporary identity is then set as its C-RNTI.
- The H-ARQ protocol is supported in this step and the UE with successful access will transmit an H-ARQ acknowledgment.

6. Explain Channel Quality Indicator (CQI) feedback with the help of CQI estimation and reporting modes.

9.3 Channel Quality Indicator (CQI) Feedback: It includes

1. *Introduction*
2. *CQI estimation*
3. *CQI feedback modes*

9.3.1 Introduction: *CQI is an indicator carrying the information on how good/bad the communication channel quality is. The CQI basically includes CQI, PMI (Precoding Matrix Indicators), RI (Rank Indicator) components. The requirement for each of these components depend on transmission mode. All transmission modes need UE to provide CQI feedback.*

- *CQI reporting contains information sent from a UE to the eNode-B to indicate a suitable downlink transmission data rate, i.e.*, a Modulation and Coding Scheme (MCS) value.
- CQI is a 4-bit integer and is based on the observed signal to-interference-plus-noise ratio (SNIR) at the UE.
- The CQI estimation process takes into account the UE capability such as the number of antennas and the type of receiver used for detection.
- The CQI reported value are used by the eNode-B for downlink scheduling and link adaptation, which are important features of LTE.
- LTE supports wideband and subband CQI reporting.
  1. A wideband CQI reporting:
     - *The wideband report provides one CQI value for the entire downlink system bandwidth.*
     - *It is a value of single 4-bit integer that represent an effective SINR as observed by the UE.*
     - *It is most efficient in terms of uplink bandwidth consumption since it requires only a single 4-bit feedback.*
     - *With wideband CQI, the variation in the SINR across the channel due to frequency selective nature of the channel is masked out.*
     - *It is not suitable for frequency selective scheduling.*
     - *It is the preferred mode to use for high speeds where the channel changes rapidly since frequent subband reporting would exhaust a large portion of the uplink bandwidth.*
     - *Wideband CQI is also the preferred mode for services such as VoIP where a large number of simultaneous UEs are supported and latency is more critical than the overall throughput since VoIP is typically a low data rate application with very strict latency requirement.*
  2. A subband CQI reporting:
     - *To support frequency selective scheduling, each UE needs to report the CQI with a fine frequency granularity, which is possible with subband CQI reporting.*

- *A subband CQI report consists of a vector of CQI value, where each CQI value is representative tithe SINR observed by the UE over a sub-band.*
- *A subband is a collection of n adjacent Physical Resource Blocks (PRBs) where the value tint can be 2, 3, 4, 6, or 8 depending on the channel bandwidth and the CQI feedback mode.*
- *It requires more uplink bandwidth but is more efficient since it allows for a frequency selective scheduling, which maximizes the multiuser diversity gain.*

- Note:

  (1). *One of the critical aspects of designing the CQI feedback mechanism for LTE is the optimization between the downlink system performance and the uplink bandwidth consumed by the feedback mechanism.*

  (2). *The LTE standard does not specify how to select between wideband and subband CQI reporting depending on the UE speed or the QoS requirements of the application. It is left up to the equipment manufacturer to develop their proprietary algorithms in order to accomplish this.*

9.3.2 A Primer on CQI Estimation

- Downlink cell-specific *Reference Signals (RS)* are used by each UE to estimate the MIMO LTE channel from the eNode-B.
- The estimated MIMO channel along with the known reference signal is then used to calculate the other-cell interference level.
- The important thing is to understand that reference signals are sent in both UL and DL while the CQI is sent in UL only (either on PUCCH or PUSCH) but it reports the DL signal strength based on the channel estimation.
- The UE uses the estimated channel and interference plus noise variance to compute the SINR on the physical resource element (PRE) carrying the reference signal.
- The UE computes SINR samples over multiple OFDM symbols and subcarriers, which are then used to calculate an effective SINR. The effective SINR is given as:

$$\mathrm{SINR}_{\mathrm{eff}} = \alpha_1 I^{-1}\left(\frac{1}{N}\sum_{k=1}^{N} I\left(\frac{\mathrm{SINR}_k}{\alpha_2}\right)\right)$$

  Where N is the number of samples. α_1 *and* α_2 adapt to different modulation and coding schemes.

- Exponential Effective SINR Mapping (EESM) and the mutual information-based methods are preferred since they have been shown to give a more accurate estimate of the channel quality.

- In the case of wideband CQI feedback, the UE measures the SINR from the reference signal over all the PRBs, and then computes its CQI based on the effective SINR across the entire channel bandwidth.
- In subband CQI the UE measures the SINR over the PRBs contained in the given subband, and then computes the CQI.
- If a UE reports a CQI value for a particular subband, it is called *subband feedback*.
- If a UE reports a single CQI value for whole system bandwidth, it is called *wideband feedback*.
- Based on the estimated effective SINR, the UE picks the CQI index that indicate the highest MCS level (modulation and code rate) that can be supported with a 10% BLER on the first H-ARQ transmission.
- The CQI feedback is used by the eNode-B to select an optimum PDSCH transport block with a combination of modulation scheme and transport block size corresponding to the CQI index that could be received with target block error probability after the first H-ARQ transmission.
- The target block error probability is left open as an implementation choice, typical values are in the range of 10-25%.

- The supported CQI indices and their interpretations are given in Table 9.3. In total, there are 16 CQI values, which require a 4-bit CQI feedback. In Table 9.3, the efficiency for a given CQI index is calculated as: efficiency = $Q_m \times$ code rate,

  Where Q_m is the number of bits in the modulation constellation. Taking CQI index 4 as an example, as $Q_m = 2$ for QPSK. We have efficiency = $2 \times \frac{308}{1024} \approx 0.6016\ bits/symbol$.

9.3.3 CQI Feedback Modes

- There are two reporting CQI feedback modes in the time domain
  1. Periodic reporting: *The UE reports CQI, PMI, and RI with reporting periods configured by the higher layer. PUCCH is used for this report.*
  2. Aperiodic reporting: *It can be used to provide large and more detail reporting in a single reporting instance via PUSCH. Report Timing is triggered by DCI*
- Note: *In cases where both periodic reporting on the PUCCH and the aperiodic reporting PUSCH happen to be on the same subframe, the UE will only transmit the aperiodic report over the PUSCH and ignore the periodic PUCCH report.*
- Both periodic and aperiodic reporting modes support wideband and subband CQI reporting.
- In LTE there are two distinct reporting mechanisms for subband CQI feedback when the aperiodic reporting mode is used:
  1. *Higher Layer Configured Subband Report*: In this case, the UE reports the subband CQI for each band in a single feedback report. The size of a band is specified by a higher layer message and is contingent on the system bandwidth.
  2. *UE Selected Subband Report*: In this case, the UE reports the subband CQI for the 'M' bands with the highest CQI values. The CQI for the rest of the bands is not reported.
- The average per sector downlink throughput for various wideband and subband CQI feedback modes as shown Figure 9.2. These result are typical of a 10MHz FDD system in a multicell.

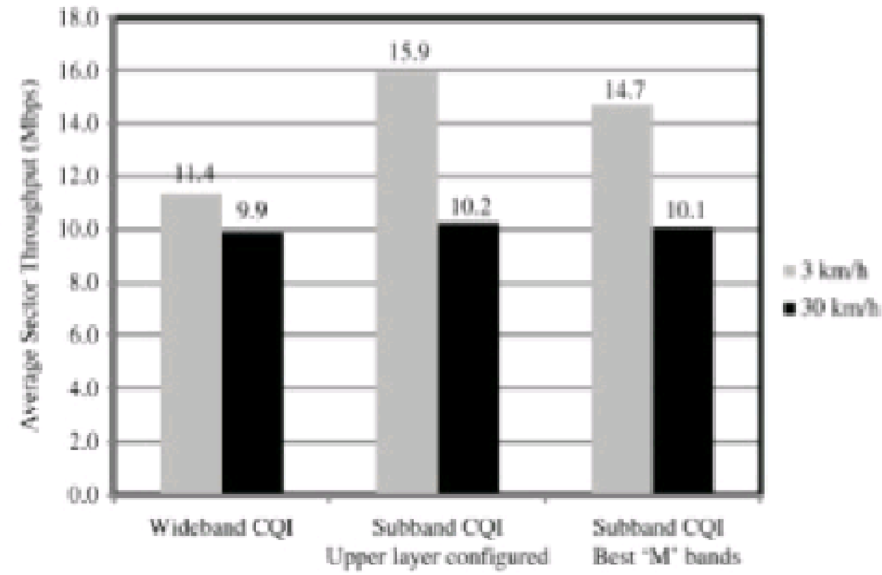


Figure 9.1: The average downlink throughput per sector for various CQI feedback

- Each reporting class supports a number of different reporting modes. Where each reporting mode is characterized by a specific CQI feedback type and a PMI feedback type. Which are listed in Table 9.4 and Table 9.5 for periodic reporting and aperioclic reporting respectively.

- **Periodic CQI Reporting:** UE is semi-statically configured by higher layers. UE periodically feedback CQI on the PUCCH in one of the reporting mode given in Table 9.4. Note that
- Mode 1-0 and 2-0 do not report PMI and they are used for OL MIMO modes and single-antenna port transmission.
- Mode 1-1 and mode 2-1 report a single PMI for CL NIIMO modes, i.e., only the wideband PMI is reported.
- The periodic CQI feedback is useful for scheduling and adaptive modulation and coding, and can also be used to check or change semi-static parameters such as the MIMO mode or transmission mode. Considering the reporting for CQI/PMI and RI, there are four different reporting types supported for each of these reporting modes as given in Table 9.7:
  1. Type 1: report supports CQI feedback for the UE selected subbands.
  2. Type 2: report supports wideband CQI and Phil feedback.
  3. Type 3: report supports RI feedback.
  4. Type 4: report supports wideband CQI.

- **Aperiodic CQI Reporting**
  - The UE shall perform aperiodic CQI, PMI and RI reporting using the PUSCH channel in subframe n + k. The value of it is specified as follows:
    a. For FDD, k = 4.
    b. For TDD UL/DL configuration 1-6, k, is given in Table 9.10.
    c. For TDD UL/DL configuration 0:

Table 9.10 The Values of k for TDD Configuration 0–6

TDD UL/DL Configuration	DL Subframe Number n									
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	4	6				4	6			
1		6			4		6			4
2				4					4	
3	4								4	4
4									4	4
5									4	
6	7	7				7	7			5

  - As shown in Table 9.5, there are three different aperioclic CQI feedback types:
    1. Wide-band feedback
    2. Higher layer-configured subband feedback,
    3. UE-selected subband feedback.
    4. Five reporting modes.
    5. Modes 2-0 arid 3-0 are for single-antenna-port transmission and OL MIMO modes, while Mode 3-1 with single PMI and Modes 1-2 and 2-2 with multiple P511 are for CL MEMO modes.

7. **Explain the different logical channels supported in LTE.**

- **Logical Channels:**
  - Used by the MAC to provide services to the RLC
  - Defined based on the information it carries
  - Two types depending on the service:
    - (1) Logical Control Channels
    - (2) Logical Traffic Channels

Logical Control Channels:

- Transfer control Plane information

(1) Broadcast Control Channel(BCCH)

- Downlink common channel used to broadcast system control information to the mobile terminals in the cell
- Gives information such as downlink system BW, antenna configuration, and reference signal power
- Mapped to two different transport channels BCH and DL-SCH

(2) Multicast Control Channel(MCCH)

- Point-to-multipoint downlink channel
- Transmits control information to UEs in the cell
- Only used by UEs that receive multicast/ broadcast services

(3) Paging Control Channel (PCCH)

- Downlink channel that transfers paging information to registered UEs in the cell

(4) Common Control Channel(CCCH)

- Bi-directional channel for transmitting control information between the network and UEs with no RRC connection(UE is in the idle state)
- Used during the Random access procedure

(5) Dedicated Control Channel(DCCH)

- Point-to-Point, bi-directional channel that transmits dedicated control information between a UE and the network
- Used when RRC connection is available(UE attached to the network)

Logical Traffic Channels:

- Used to transfer user plane information

(1) Dedicated Traffic Channel (DTCH)

- Point-to-point, bi-directional channel used between a given UE and the network
- Exist in both Uplink and Downlink

(2) Multicast Traffic Channel(MTCH)

- Unidirectional, point-to-multipoint data channel that transmits that transmits traffic data from the network to UEs

8. Explain briefly layer mapping and precoding in modulation mapping.

- Mapping and precoding are associated with MIMO

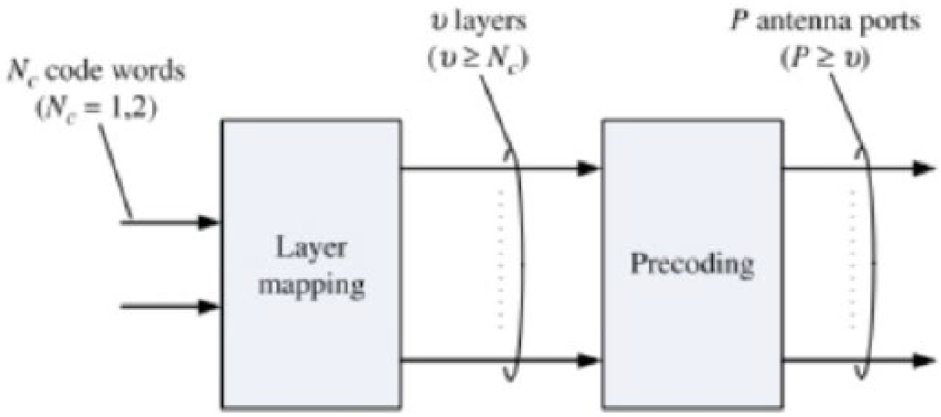


Figure- Layer mapping and Precoding

Layer Mapping

- This is the process where each codeword is mapped to one or multiple layers
- A codeword is defined as the output of each channel coding associated with a single transport block coming from the MAC layer
- For MIMO transmission with multiple codewords on different spatial channels, efficient detectors with successive interference cancellation can be used.
- In LTE up to four transmit/receive antennas are supported, the no.of codewords is limited to two

- A Layer corresponds to a data stream of the spatial multiplexing channel
- Each codeword is mapped into one or multiple layers
- The number of layers(transmission rank) is at least as many as the number of codewords $v \geq N_c$

Precoding

- This is the process where the layer data are allocated to multiple antenna ports
- An antenna port is defined by its associated reference signal

- The number of transmit antenna ports at the eNode-B is sent to UEs through the PBCH channel, which can be 1,2, or 4 in LTE
- Antenna ports are divided into three groups:

(1) Antenna ports 0-3: these ports are cell-specific, and used for downlink MIMO transmission

(2) Antenna port 4: It is MBSFN specific and is used for MBSFN transmission

(3) Antenna port 5: It is UE specific and is used for beamforming to a single UE using all physical antennas

- Cell specific ports and the UE specific ports cannot be simultaneously used
- Layer mapping is different for different MIMO modes described as follows:

(1) Single antenna port: one codeword is mapped to a single layer

(2) Transmit Diversity: one codeword is mapped to two or four layers

(3) Spatial Multiplexing: $N_c$codewords are mapped to v layers and the detailed mapping is hown in table below:

Number of Layers	Codeword 0	Codeword 1
1	Layer 0	
2	Layer 0	Layer 1
2	Layer 0, 1	
3	Layer 0	Layer 1,2
4	Layer 0,1	Layer 2,3

Figure-Codeword to Layer mapping for Spatial Multiplexing

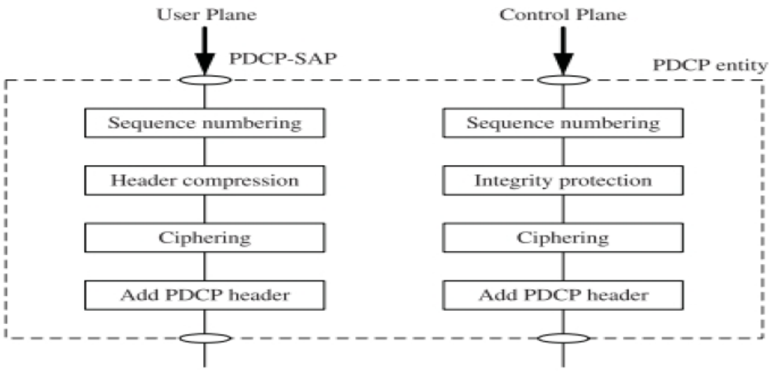
- Single codeword mapped to two layers occurs only when the initial transmission contains two codewords and a codeword mapped onto two layers needs to be retransmitted
- Both Open Loop(OL) and Closed Loop(CL) spatial multiplexing modes are supported in LTE
- The precoder is either fixed or selected from a predefined codebook based on the feedback from UEs.
- General form for precoding is

$y(i) = W(i) * x(i)$ where $W(i)$ is the precoding matrix of size $P \times v$

9. Explain the main services and functions of PDCP sublayer for the user plane.

- A PDCP entity is associated either with the control plane or user plane depends on which radio bearer it is carrying data for.
- Each radio bearer is associated with one PDCP entity.
- 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 DCCH and DTCH types of logical channels.

- The main services and functions of the PDCP sublayer for the user plane and control plane as shown in Figure 10.5 are as follows.



- ***Functions of 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

- ***Functions of 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

- The PDCP PDUs can be divided into two categories:

1. ***The PDCP data PDU:*** *It 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 /uncompressed IP packet or control plane data containing one RRC message and a Message Authentication Code for Integrity (MAC-I) field for integrity protection.*
2. ***The PDCP control PDU:*** *It is used only within the user plane to convey a PDCP status report during handover and feedback information for header compression. It carries peer-to-peer signaling b/w the PDCP entities at two ends. It doesn't carry higher layer SDU.*

- The constructions of the PDCP data PDU formats from the PDCP SDU for the user plane and the control plane are shown in Figure 10.6.

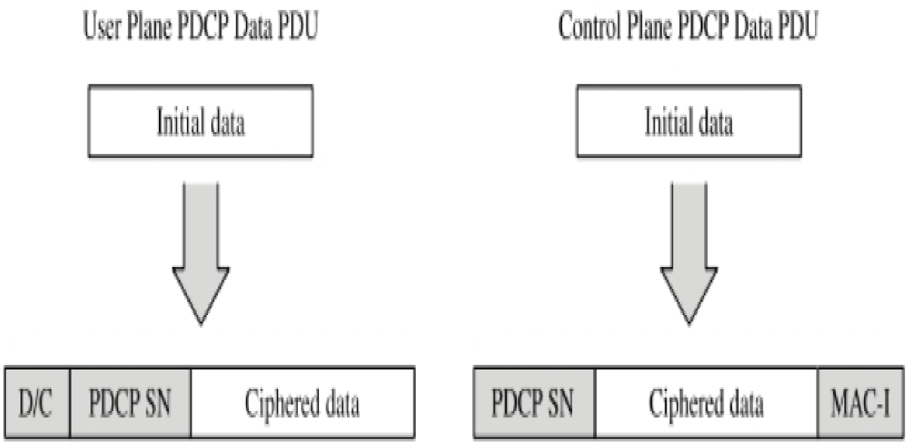


Figure 10.6 PDCP data PDU formats for the user plane and the control plane.

- The various types of PDCP PDU carried on the user and control plane are shown in Table 10.2. There are three different types of PDCP data PDUs, distinguished by the length of the Sequence Number (SN).

Table 10.2 PDCP Data Units

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

- 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 to distinguish data and control PDUs.
- This is required since the PDCP data PDU can carry both user plane and control plane data.