# OVERVIEW AND CHANNEL STRUCTURE OF LTE

## MODULE – 3

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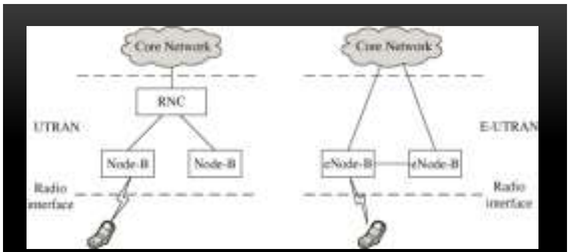
- **Overview and Channel Structure of LTE:** Introduction to LTE, Channel Structure of LTE, Downlink OFDMA Radio Resource, Uplink SC-FDMA Radio Resource(Sec 6.1 – 6.4 of Text).
- **Downlink Transport Channel Processing:** Overview, Downlink shared channels, Downlink Control Channels, Broadcast channels, Multicast channels, Downlink physical channels, H-ARQ on Downlink (Sec 7.1 – 7.7 of Text).
- L1, L2.

## OVERVIEW AND CHANNEL STRUCTURE OF LTE

- The radio interface of a wireless network is the interface between the mobile terminal and the base station.
- In the case of LTE it is located between the RAN–E-UTRAN and the user equipment (UE, the name for the mobile terminal in 3GPP).
- The E-UTRAN network architecture is simpler and flatter
  - Compared to the UMTS Terrestrial Radio Access Network (UTRAN) for 3G systems, which has two logical entities—the Node-B (the radio base station) and the radio network controller (RNC)
- It is composed of only one logical node

  —the evolved Node-B (eNode-B).



- Compared to the traditional Node-B, the eNode-B supports additional features, such as radio resource control, admission control, and mobility management, which were originally contained in the RNC.
- This simpler structure simplifies the network operation and allows for higher throughput and lower latency over the radio interface.

- The LTE radio interface aims for a *long-term evolution*
- so it is designed with a clean slate approach as opposed to High-Speed Packet Access (HSPA)
- which was designed as an add-on to UMTS in order to increase throughput of packet switched services.
- The clean slate approach allows for a completely different air interface, which means that advanced techniques, including *Orthogonal Frequency Division Multiplexing (OFDM)* and *multiantenna transmission and reception (MIMO)*, could be included from the start of the standardization of LTE.

- For multiple access, it moves away from Code Division Multiple Access (CDMA)
  - instead uses Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink
  - Single-Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink.

## INTRODUCTION TO LTE
## - DESIGN PRINCIPLES

- The LTE standard was designed as a completely new standard, with new numbering and new documentation, and it is not built on the previous versions of 3GPP standards.
- Earlier elements were brought in only if there was a compelling reason for them to exist in the new standard.

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## - DESIGN PRINCIPLES

- The basic design principles that were agreed upon and followed in 3GPP while designing the LTE specifications include:

1. **Network Architecture**
2. **Data Rate and Latency**
3. **Performance Requirements**
    - ➢ ***Spectrum Efficiency***
    - ➢ ***Mobility***
    - ➢ ***Coverage***
    - ➢ ***MBMS Service***
4. **Radio Resource Management**
5. **Deployment Scenario and Co-existence with 3G**
6. **Flexibility of Spectrum and Deployment**
7. **Interoperability with 3G and 2G Networks**

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**- DESIGN PRINCIPLES**

## 1. NETWORK ARCHITECTURE

- Unlike 3G networks, LTE was designed to support packet-switched traffic with support for various QoS classes of services.
- LTE is different in the sense that it is a clean slate design and supports packet switching for high data rate services from the start.
- The LTE radio access network, E-UTRAN, was designed to have the minimum number of interfaces
    - ✓ while still being able to provide efficient packet-switched transport for traffic belonging to all the QoS classes such as conversational, streaming, real-time, non-real-time, and background classes.

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**- DESIGN PRINCIPLES**

## 2. DATA RATE AND LATENCY

- The design target for downlink and uplink peak data rates for LTE are 100 Mbps and 50 Mbps
    - ➢ when operating at the 20MHz frequency division duplex (FDD) channel size.
- The user-plane latency: time taken to transmit a small IP packet from the UE to the edge node of the radio access network or vice versa measured on the IP layer.
- The target for one-way latency in the user plane is ***5 ms*** in an unloaded network, that is, if only a single UE is present in the cell.
- For the control-plane latency,
    - the transition time from a camped state to an active state is less than 100 ms
    - while the transition time between a dormant state and an active state should be less than 50 ms.

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**- DESIGN PRINCIPLES**

## 3. PERFORMANCE REQUIREMENTS

- The target performance requirements for LTE are specified in terms of spectrum efficiency, mobility, and coverage, and they are in general expressed relative to the 3GPP Release 6 HSPA.
- **– Spectrum Efficiency** The average downlink user data rate and spectrum efficiency target is ***three to four times that of the baseline HSDPA*** network.
- Similarly, in the uplink the average user data rate and spectrum efficiency target is two to three times that of the baseline HSUPA network.
- The cell edge throughput should be two to three times that of the baseline HSDPA and HSUPA.

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**- DESIGN PRINCIPLES**

## 3. PERFORMANCE REQUIREMENTS…

- **– Mobility** The mobility requirement for LTE is to be able to support hand-off/mobility at different terminal speeds.
- Maximum performance is expected for the lower terminal speeds of 0 to 15 km/hr, with minor degradation in performance at higher mobile speeds up to 120 km/hr.
- LTE is also expected to be able to sustain a connection for terminal speeds up to 350 km/hr but with significant degradation in the system performance.

## 3. PERFORMANCE REQUIREMENTS…

- **– Coverage** For the cell coverage, the above performance targets should be met up to 5 km.
- For cell ranges up to 30 km, a slight degradation of the user throughput is tolerated and a more significant degradation for spectrum efficiency is acceptable, but the mobility requirements should be met.
- Cell ranges up to 100 km should not be precluded by the specifications.

- **– MBMS Service** LTE should also provide enhanced support for the Multimedia Broadcast and Multicast Service (MBMS) compared to UTRA operation.

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## 4. RADIO RESOURCE MANAGEMENT

- The radio resource management requirements cover various aspects such as
  - ➢Enhanced support for end-to-end QoS
  - ➢Efficient support for transmission of higher layers
  - ➢Support for load sharing/balancing and
  - ➢Policy management/enforcement across different radio access technologies.

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## 5. DEPLOYMENT SCENARIO AND CO-EXISTENCE WITH 3G:

- At a high level, LTE shall support the following two deployment scenarios:

**– Standalone deployment scenario**

where the operator deploys LTE either with

- ➢ no previous network deployed in the area or with
- ➢ no requirement for interworking with the existing UTRAN/GERAN (GSM EDGE radio access network) networks.

**– Integrating with existing UTRAN and/or GERAN deployment scenario**,

where the operator already has either

- ➢ a UTRAN and/or a GERAN network deployed with full or
- ➢ partial coverage in the same geographical area.

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## 6. FLEXIBILITY OF SPECTRUM AND DEPLOYMENT

- In order to become a truly global standard, LTE was designed to be operable under a wide variety of spectrum scenarios, including its ***ability to coexist and share spectrum with existing 3G technologies***.
- Service providers in different geographical regions often have different spectrums in terms of the carrier frequency and total available bandwidth, which is why LTE was designed to have a scalable bandwidth from 1.4MHz to 20MHz.
- In order to accommodate flexible duplexing options, LTE was ***designed to operate*** in ***both*** frequency division duplex (***FDD***) and time division duplex (***TDD***) modes.

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## 7. INTEROPERABILITY WITH 3G AND 2G NETWORKS

- Multimode LTE terminals, which support UTRAN and/or GERAN operation, should be able to support ***measurement of***, and ***handover*** from and to, both 3GPP UTRAN and 3GPP GERAN systems with acceptable terminal complexity and network performance.

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## NETWORK ARCHITECTURE

- The entire network is composed of the radio access network (E-UTRAN) and the core network (EPC), both of which have been defined as new components of the end-to-end network in Release 8 of the 3GPP specifications.

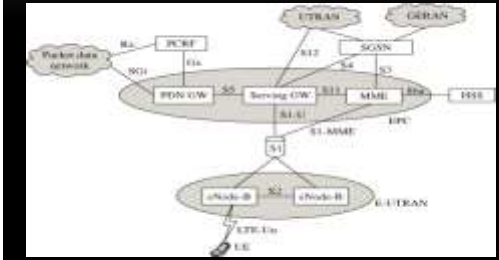

**Fig: LTE end-to-end network architecture**

- • **UE:** The mobile terminal.
- • **eNode-B:** The eNode-B (also called the base station) terminates the air interface protocol and is the first point of contact for the UE.
- eNode-B is the only logical node in the E-UTRAN, so it includes some functions previously defined in the RNC of the UTRAN, such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

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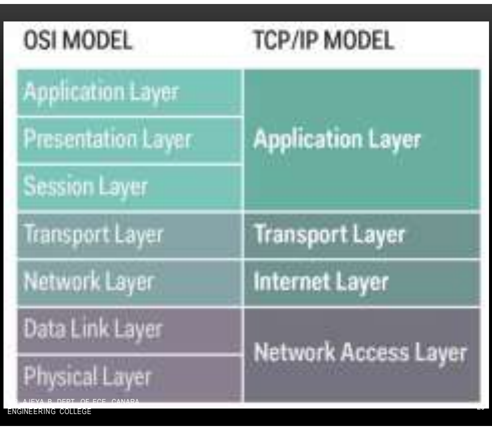

| OSI MODEL | TCP/IP MODEL |
|---|---|
| Application Layer | Application Layer |
| Presentation Layer | |
| Session Layer | |
| Transport Layer | Transport Layer |
| Network Layer | Internet Layer |
| Data Link Layer | Network Access Layer |
| Physical Layer | |

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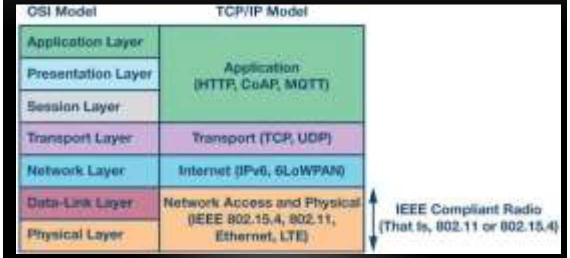
## WHERE DOES THE LTE STANDARD WORK IN THE PROTOCOL STACK?



| OSI Model | TCP/IP Model |
|---|---|
| Application Layer | Application (HTTP, CoAP, MQTT) |
| Presentation Layer | |
| Session Layer | |
| Transport Layer | Transport (TCP, UDP) |
| Network Layer | Internet (IPv6, 6LoWPAN) |
| Data-Link Layer | Network Access and Physical (IEEE 802.15.4, 802.11, Ethernet, LTE) |
| Physical Layer | |

IEEE Compliant Radio (That is, 802.11 or 802.15.4)

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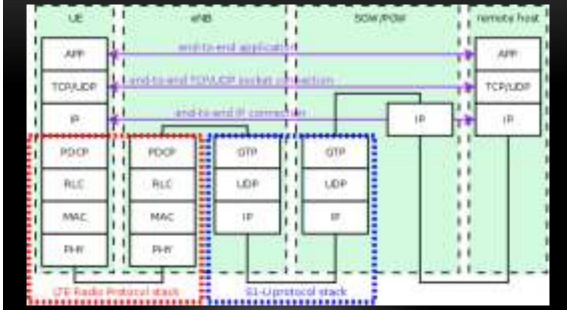

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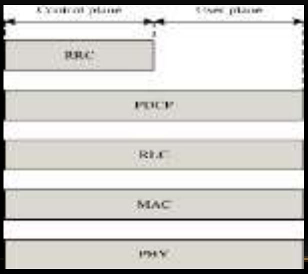
## RADIO INTERFACE PROTOCOLS

- LTE radio interface is designed based on a layered protocol stack, which can be divided into control plane and user plane protocol stacks



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## RADIO INTERFACE PROTOCOLS....

**1. Radio Resource Control (RRC):** performs the control plane functions including

- Paging, maintenance and release of an RRC connection-security handling-mobility management, and QoS management.

**2. Packet Data Convergence Protocol (PDCP):**

- IP packet header compression and decompression based on the RObust Header Compression (ROHC) protocol, ciphering of data and signaling, and integrity protection for signaling.
- There is only one PDCP entity at the eNode-B and the UE per bearer.

## RADIO INTERFACE PROTOCOLS….

**3. Radio Link Control (RLC):**

- Segmentation and concatenation of data units, error correction through the Automatic Repeat reQuest (ARQ) protocol, and in-sequence delivery of packets to the higher layers.
- It operates in three modes:
  1. – **The Transparent Mode (TM):** simplest one, without RLC header addition, data segmentation, or concatenation, and it is used for specific purposes such as random access.
  2. – **The Unacknowledged Mode (UM):** allows the detection of packet loss and provides packet reordering and reassembly, but does not require retransmission of the missing protocol data units (PDUs).
  3. – **The Acknowledged Mode (AM):** is the most complex one, and it is configured to request retransmission of the missing PDUs in addition to the features supported by the UM mode.

There is only one RLC entity at the eNode-B and the UE per bearer.

## RADIO INTERFACE PROTOCOLS….

**4. Medium Access Control (MAC):**

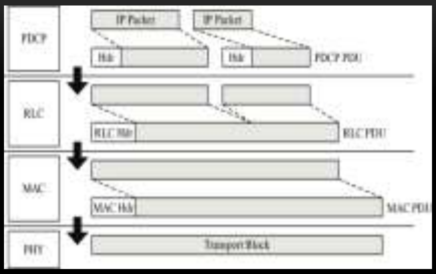
- Error correction through the hybrid-arq (H-ARQ) mechanism
- Mapping between logical channels and transport channels
- Multiplexing/demultiplexing of RLC PDUs on to transport blocks
- Priority handling between logical channels of one UE and
- Priority handling between UEs by means of dynamic scheduling.
- The mac sublayer is also responsible for transport format selection of scheduled UEs, which includes selection of modulation format, code rate, mimo rank, and power level.
- There is only one MAC entity at the eNode-B and one MAC entity at the UE.

## RADIO INTERFACE PROTOCOLS….

**5. Physical Layer (PHY):**

- The main function of PHY is the actual transmission and reception of data in forms of transport blocks.
- The PHY is also responsible for various control mechanisms such as signaling of H-ARQ feedback, signaling of scheduled allocations, and channel measurements.

## RADIO INTERFACE PROTOCOLS….



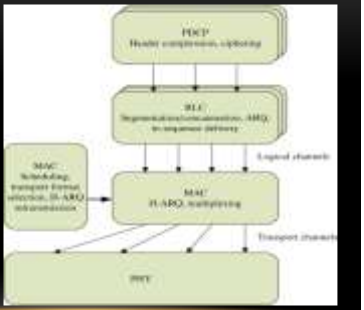
The packet flow in the user plane

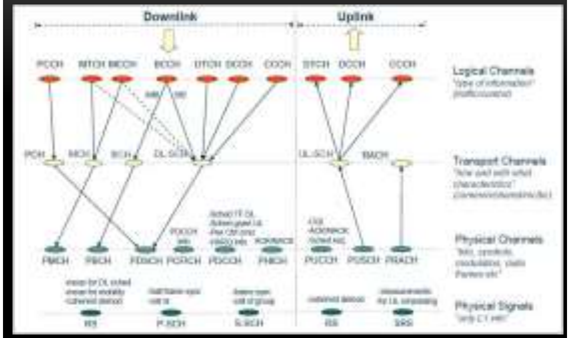
## HIERARCHICAL CHANNEL STRUCTURE OF LTE

- To efficiently support various QoS classes of services, LTE adopts a hierarchical channel structure.
- There are three different channel types defined in LTE:
  1. *Logical channels*
  2. *Transport channels*
  3. *Physical channels*
- Each associated with a service access point (SAP) between different layers.
- These channels are used by the lower layers of the protocol stack to provide services to the higher layers.

## HIERARCHICAL CHANNEL STRUCTURE OF LTE…

- The radio interface protocol architecture and the SAPs between different layers.
- SAP-Service Access Point





## HIERARCHICAL CHANNEL STRUCTURE OF LTE…

- Unlike UTRA/HSPA, LTE is based entirely on shared and broadcast channels and contains no dedicated channels carrying data to specific UEs.
- This improves the efficiency of the radio interface and can support dynamic resource allocation between different UEs depending on their traffic/QoS requirements and their respective channel conditions.

## LOGICAL CHANNELS: WHAT TO TRANSMIT?

- Logical channels are used by the MAC to provide services to the RLC.
- Each logical channel is defined based on the type of information it carries.
- In LTE, there are two categories of logical channels depending on the service they provide:
  1. *Logical control channels (5 types)*
  2. *Logical traffic channels* (2 types)

## 1. THE LOGICAL CONTROL CHANNELS

Are used to transfer control plane information, include the following types:

i. **BroadCast Control Channel (BCCH):**

- A downlink common channel used to broadcast system control information to the mobile terminals in the cell, including downlink system bandwidth, antenna configuration, and reference signal power.
- Due to the large amount of information carried on the BCCH, it is mapped to two different transport channels:
  - ➢ ***the Broadcast Channel (BCH) and***
  - ➢ ***the Downlink Shared Channel (DL-SCH).***

## 1. THE LOGICAL CONTROL CHANNELS…

ii. **MultiCast Control Channel (MCCH):** A point-to-multipoint downlink channel used for transmitting control information to UEs in the cell.

- It is only used by UEs that receive multicast/broadcast services.

iii. **Paging Control Channel (PCCH):** A downlink channel that transfers paging information to registered UEs in the cell, for example, in case of a mobile-terminated communication session.

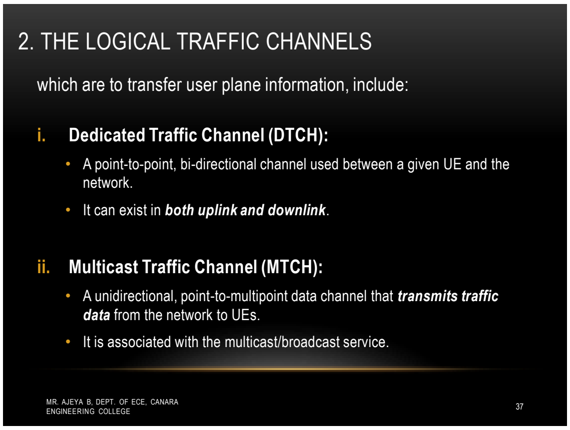
## 1. THE LOGICAL CONTROL CHANNELS…

iv. **Common Control Channel (CCCH):**

- A bi-directional channel for transmitting control information between the network and UEs when no RRC connection is available, implying the UE is not attached to the network such as in the idle state.
- Most commonly the CCCH is used during the random access procedure.

v. **Dedicated Control Channel (DCCH):**

- A point-to-point, bi-directional channel that transmits dedicated control information between a UE and the network.
- This channel is used when the RRC connection is available, that is, the UE is attached to the network.

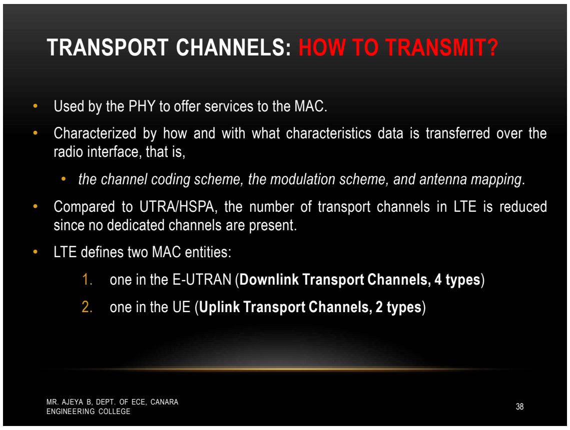


## 2. THE LOGICAL TRAFFIC CHANNELS

which are to transfer user plane information, include:

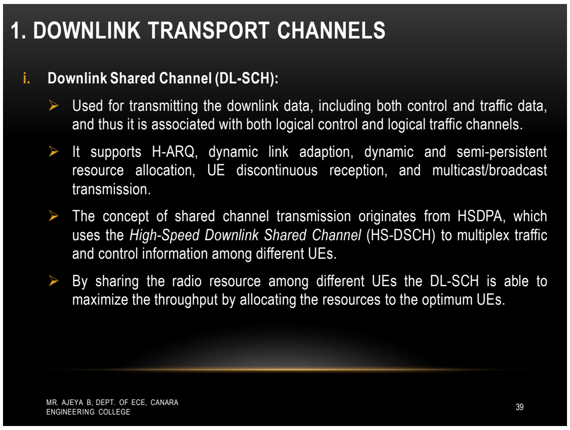
i. **Dedicated Traffic Channel (DTCH):**
  - A point-to-point, bi-directional channel used between a given UE and the network.
  - It can exist in ***both uplink and downlink***.

ii. **Multicast Traffic Channel (MTCH):**
  - A unidirectional, point-to-multipoint data channel that ***transmits traffic data*** from the network to UEs.
  - It is associated with the multicast/broadcast service.



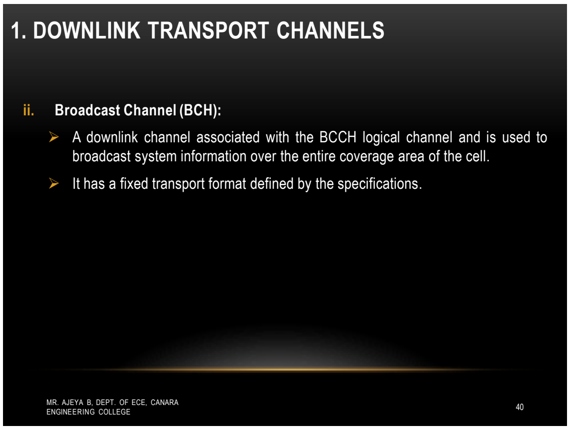
## TRANSPORT CHANNELS: HOW TO TRANSMIT?

- Used by the PHY to offer services to the MAC.
- Characterized by how and with what characteristics data is transferred over the radio interface, that is,
  - *the channel coding scheme, the modulation scheme, and antenna mapping*.
- Compared to UTRA/HSPA, the number of transport channels in LTE is reduced since no dedicated channels are present.
- LTE defines two MAC entities:
  1. one in the E-UTRAN (**Downlink Transport Channels, 4 types**)
  2. one in the UE (**Uplink Transport Channels, 2 types**)



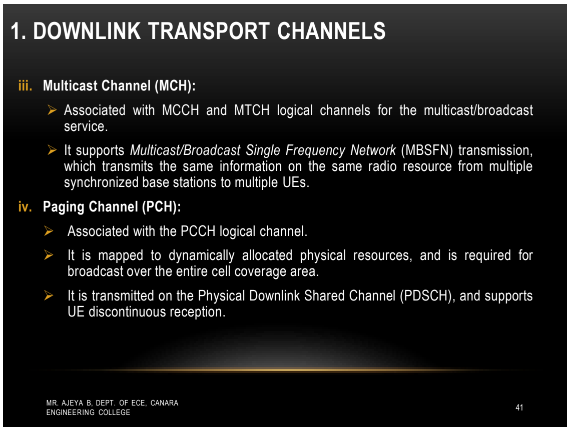
## 1. DOWNLINK TRANSPORT CHANNELS

i. **Downlink Shared Channel (DL-SCH):**
  - Used for transmitting the downlink data, including both control and traffic data, and thus it is associated with both logical control and logical traffic channels.
  - It supports H-ARQ, dynamic link adaption, dynamic and semi-persistent resource allocation, UE discontinuous reception, and multicast/broadcast transmission.
  - The concept of shared channel transmission originates from HSDPA, which uses the *High-Speed Downlink Shared Channel* (HS-DSCH) to multiplex traffic and control information among different UEs.
  - By sharing the radio resource among different UEs the DL-SCH is able to maximize the throughput by allocating the resources to the optimum UEs.



## 1. DOWNLINK TRANSPORT CHANNELS

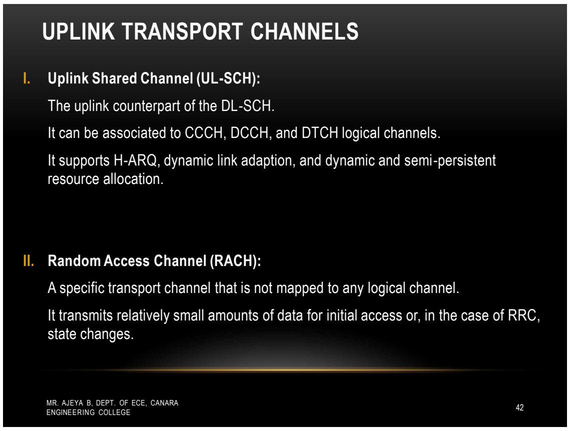
ii. **Broadcast Channel (BCH):**
  - A downlink channel associated with the BCCH logical channel and is used to broadcast system information over the entire coverage area of the cell.
  - It has a fixed transport format defined by the specifications.



## 1. DOWNLINK TRANSPORT CHANNELS

iii. **Multicast Channel (MCH):**
  - Associated with MCCH and MTCH logical channels for the multicast/broadcast service.
  - It supports *Multicast/Broadcast Single Frequency Network* (MBSFN) transmission, which transmits the same information on the same radio resource from multiple synchronized base stations to multiple UEs.

iv. **Paging Channel (PCH):**
  - Associated with the PCCH logical channel.
  - It is mapped to dynamically allocated physical resources, and is required for broadcast over the entire cell coverage area.
  - It is transmitted on the Physical Downlink Shared Channel (PDSCH), and supports UE discontinuous reception.



## UPLINK TRANSPORT CHANNELS

I. **Uplink Shared Channel (UL-SCH):**

The uplink counterpart of the DL-SCH.

It can be associated to CCCH, DCCH, and DTCH logical channels.

It supports H-ARQ, dynamic link adaption, and dynamic and semi-persistent resource allocation.

II. **Random Access Channel (RACH):**

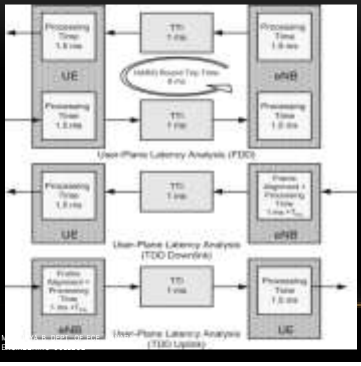
A specific transport channel that is not mapped to any logical channel.

It transmits relatively small amounts of data for initial access or, in the case of RRC, state changes.

## TRANSPORT CHANNELS….
### *TRANSPORT BLOCKS AND TTI*

- The data on each transport channel is organized into *transport blocks*,
- the transmission time of each transport block also called Transmission Time Interval (TTI), is 1 ms in LTE.
- TTI is also the minimum interval for link adaptation and scheduling decision.
- Without spatial multiplexing, at most one transport block is transmitted to a UE in each TTI
- with spatial multiplexing, up to two transport blocks can be transmitted in each TTI to a UE.

## TRANSPORT CHANNELS….
### *TRANSPORT BLOCKS AND TTI*



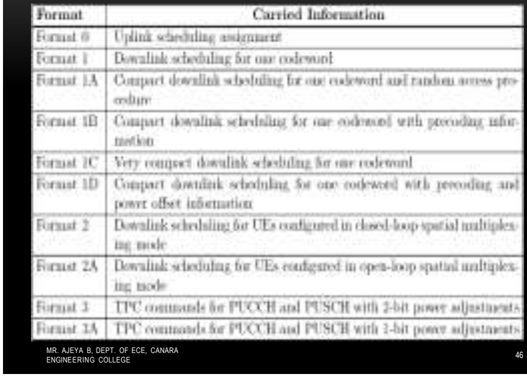
## TRANSPORT CHANNELS

The other defined control information includes

1. **Downlink Control Information (DCI):**

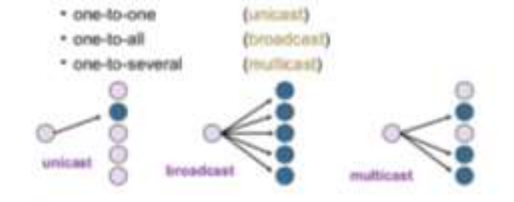
- It carries information related to downlink/uplink scheduling assignment, modulation and coding scheme, and Transmit Power Control (TPC) command, and is sent over the Physical Downlink Control Channel (PDCCH).
- The DCI supports 10 different formats
- Among them, Format 0 is for signaling uplink transmission allocation, Format 3 and 3A are for TPC, and the remaining formats are for signaling downlink transmission allocation.

## DCI FORMATS



| Format | Carried Information |
|---|---|
| Format 0 | Uplink scheduling assignment |
| Format 1 | Downlink scheduling for one codeword |
| Format 1A | Compact downlink scheduling for one codeword and random access procedure |
| Format 1B | Compact downlink scheduling for one codeword with precoding information |
| Format 1C | Very compact downlink scheduling for one codeword |
| Format 1D | Compact downlink scheduling for one codeword with precoding and power offset information |
| Format 2 | Downlink scheduling for UEs configured in closed-loop spatial multiplexing mode |
| Format 2A | Downlink scheduling for UEs configured in open-loop spatial multiplexing mode |
| Format 3 | TPC commands for PUCCH and PUSCH with 2-bit power adjustments |
| Format 3A | TPC commands for PUCCH and PUSCH with 1-bit power adjustments |

## UNICAST, MULTICAST AND BROADCAST



## TRANSPORT CHANNELS...

**2. Control Format Indicator (CFI):** It indicates how many symbols the DCI spans in that subframe.

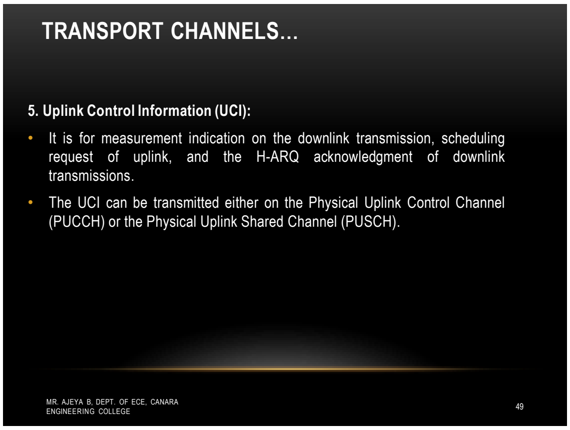
- It takes values CFI = 1, 2, or 3, and is sent over the Physical Control Format Indicator Channel (PCFICH).

**3. H-ARQ Indicator (HI):** It carries H-ARQ acknowledgment in response to uplink transmissions, and is sent over the Physical Hybrid ARQ Indicator Channel (PHICH).

- HI=1 for a positive acknowledgment (ACK) and HI = 0 for a negative acknowledgment (NAK).

**4. Uplink Control Information (UCI):** It is for measurement indication on the downlink transmission, scheduling request of uplink, and the H-ARQ acknowledgment of downlink transmissions.

- The UCI can be transmitted either on the Physical Uplink Control Channel (PUCCH) or the Physical Uplink Shared Channel (PUSCH).



## TRANSPORT CHANNELS…

**5. Uplink Control Information (UCI):**

- It is for measurement indication on the downlink transmission, scheduling request of uplink, and the H-ARQ acknowledgment of downlink transmissions.
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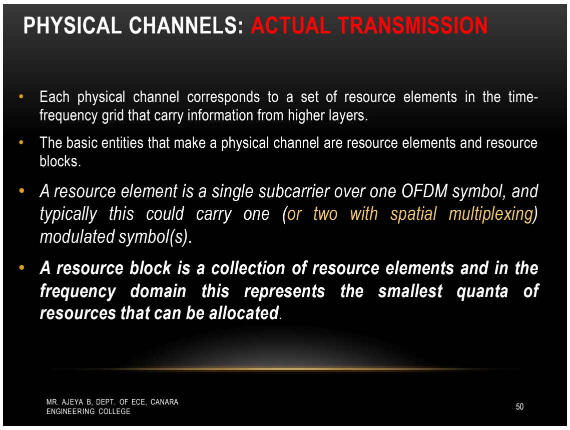
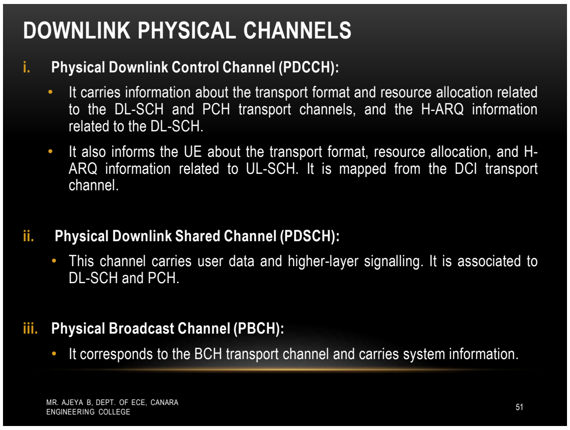


## PHYSICAL CHANNELS: ACTUAL TRANSMISSION

- Each physical channel corresponds to a set of resource elements in the time-frequency grid that carry information from higher layers.
- The basic entities that make a physical channel are resource elements and resource blocks.
- *A resource element is a single subcarrier over one OFDM symbol, and typically this could carry one (or two with spatial multiplexing) modulated symbol(s).*
- ***A resource block is a collection of resource elements and in the frequency domain this represents the smallest quanta of resources that can be allocated.***

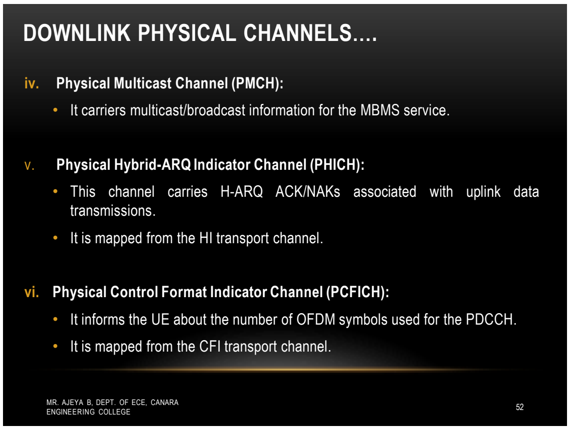


## DOWNLINK PHYSICAL CHANNELS

i. **Physical Downlink Control Channel (PDCCH):**
  - It carries information about the transport format and resource allocation related to the DL-SCH and PCH transport channels, and the H-ARQ information related to the DL-SCH.
  - It also informs the UE about the transport format, resource allocation, and H-ARQ information related to UL-SCH. It is mapped from the DCI transport channel.

ii. **Physical Downlink Shared Channel (PDSCH):**
  - This channel carries user data and higher-layer signalling. It is associated to DL-SCH and PCH.

iii. **Physical Broadcast Channel (PBCH):**
  - It corresponds to the BCH transport channel and carries system information.

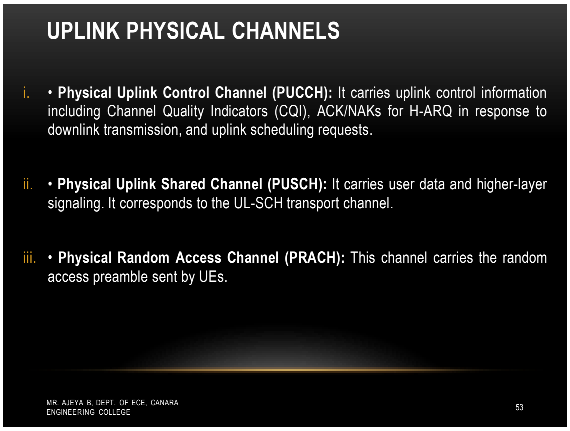


## DOWNLINK PHYSICAL CHANNELS….

iv. **Physical Multicast Channel (PMCH):**
  - It carriers multicast/broadcast information for the MBMS service.

v. **Physical Hybrid-ARQ Indicator Channel (PHICH):**
  - This channel carries H-ARQ ACK/NAKs associated with uplink data transmissions.
  - It is mapped from the HI transport channel.

vi. **Physical Control Format Indicator Channel (PCFICH):**
  - It informs the UE about the number of OFDM symbols used for the PDCCH.
  - It is mapped from the CFI transport channel.

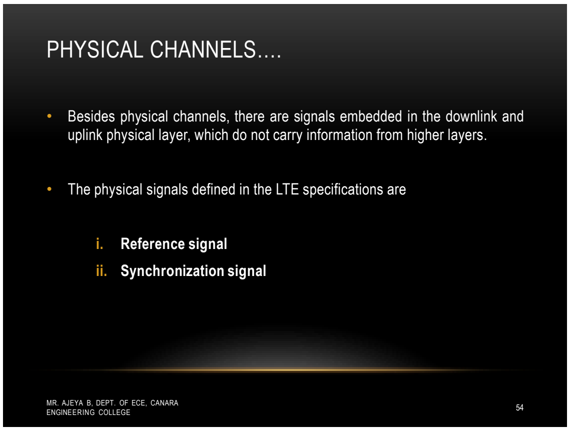


## UPLINK PHYSICAL CHANNELS

i. • **Physical Uplink Control Channel (PUCCH):** It carries uplink control information including Channel Quality Indicators (CQI), ACK/NAKs for H-ARQ in response to downlink transmission, and uplink scheduling requests.

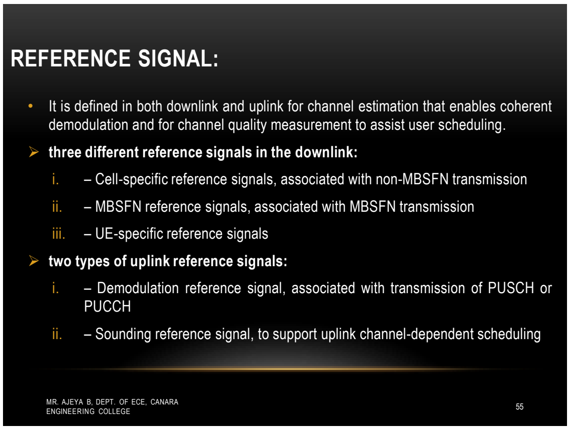
ii. • **Physical Uplink Shared Channel (PUSCH):** It carries user data and higher-layer signaling. It corresponds to the UL-SCH transport channel.

iii. • **Physical Random Access Channel (PRACH):** This channel carries the random access preamble sent by UEs.



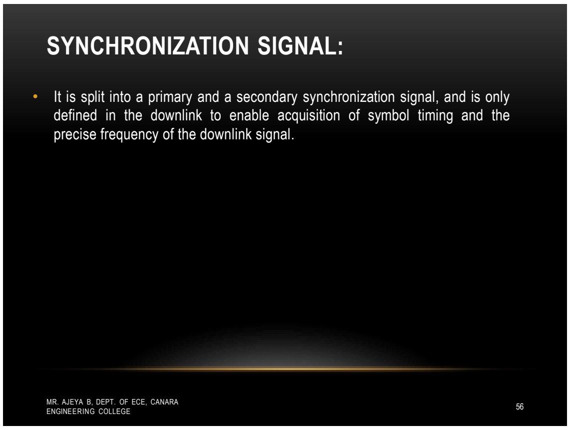
## PHYSICAL CHANNELS….

- Besides physical channels, there are signals embedded in the downlink and uplink physical layer, which do not carry information from higher layers.
- The physical signals defined in the LTE specifications are
  i. **Reference signal**
  ii. **Synchronization signal**



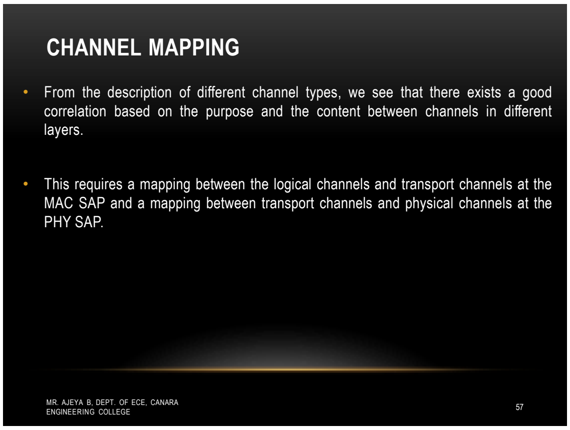
## REFERENCE SIGNAL:

- It is defined in both downlink and uplink for channel estimation that enables coherent demodulation and for channel quality measurement to assist user scheduling.
- **three different reference signals in the downlink:**
  - i. – Cell-specific reference signals, associated with non-MBSFN transmission
  - ii. – MBSFN reference signals, associated with MBSFN transmission
  - iii. – UE-specific reference signals
- **two types of uplink reference signals:**
  - i. – Demodulation reference signal, associated with transmission of PUSCH or PUCCH
  - ii. – Sounding reference signal, to support uplink channel-dependent scheduling



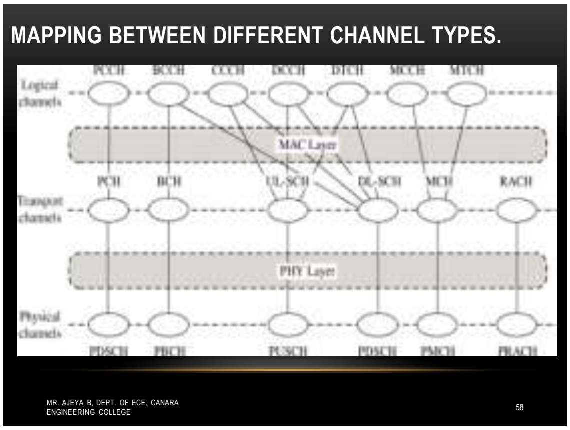
## SYNCHRONIZATION SIGNAL:

- It is split into a primary and a secondary synchronization signal, and is only defined in the downlink to enable acquisition of symbol timing and the precise frequency of the downlink signal.

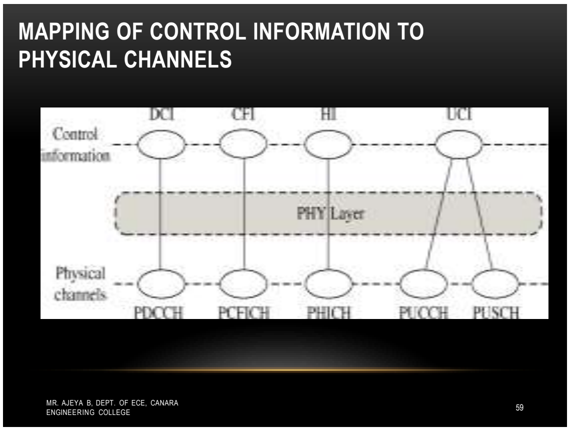


## CHANNEL MAPPING

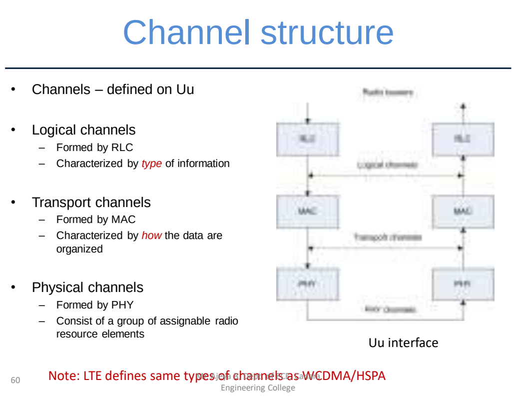
- From the description of different channel types, we see that there exists a good correlation based on the purpose and the content between channels in different layers.
- This requires a mapping between the logical channels and transport channels at the MAC SAP and a mapping between transport channels and physical channels at the PHY SAP.



## MAPPING BETWEEN DIFFERENT CHANNEL TYPES.



## MAPPING OF CONTROL INFORMATION TO PHYSICAL CHANNELS



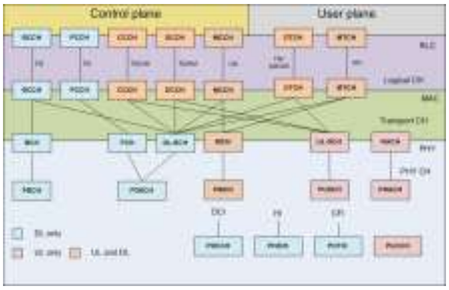
## Channel structure

- Channels – defined on Uu
- Logical channels
  - Formed by RLC
  - Characterized by *type* of information
- Transport channels
  - Formed by MAC
  - Characterized by *how* the data are organized
- Physical channels
  - Formed by PHY
  - Consist of a group of assignable radio resource elements

Uu interface

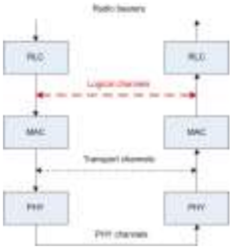
Note: LTE defines same types of channels as WCDMA/HSPA

# LTE - channel mapping



# Logical channels

- BCCH – Broadcast Control CH
  - System information sent to all UEs
- PCCH – Paging Control CH
  - Paging information when addressing UE
- CCCH – Common Control CH
  - Access information during call establishment
- DCCH – Dedicated Control CH
  - User specific signaling and control
- DTCH – Dedicated Traffic CH
  - User data
- MCCH – Multicast Control CH
  - Signaling for multi-cast
- MTCH – Multicast Traffic CH
  - Multicast data

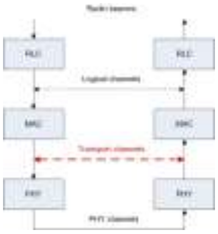


Red – common, green – shared, blue - dedicated

LTE Channels

# Transport channels

- BCH – Broadcast CH
  - Transport for BCCH
- PCH – Paging CH
  - Transport for PCH
- DL-SCH – Downlink Shared CH
  - Transport of user data and signaling. Used by many logical channels
- MCH – Multicast channel
  - Used for multicast transmission
- UL-SCH – Uplink Shared CH
  - Transport for user data and signaling
- RACH – Random Access CH
  - Used for UE's accessing the network

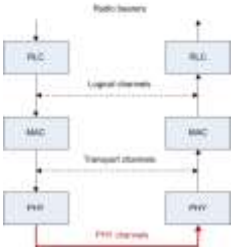


Red – common, green – shared

LTE Channels

# PHY Channels

- PDSCH – Physical DL Shared CH
  - Uni-cast transmission and paging
- PBCH – Physical Broadcast CH
  - Broadcast information necessary for accessing the network
- PMCH – Physical Multicast Channel
  - Data and signaling for multicast
- PDCCH – Physical Downlink Control CH
  - Carries mainly scheduling information
- PHICH – Physical Hybrid ARQ Indicator
  - Reports status of Hybrid ARQ
- PCIFIC – Physical Control Format Indicator
  - Information required by UE so that PDSCH can be demodulated (format of PDSCH)
- PUSCH – Physical Uplink Shared Channel
  - Uplink user data and signaling
- PUCCH – Physical Uplink Control Channel
  - Reports Hybrid ARQ acknowledgements
- PRACH – Physical Random Access Channel
  - Used for random access



LTE Channels

Red – common, green – shared

## DOWNLINK OFDMA RADIO RESOURCES

- In LTE, the downlink and uplink use different transmission schemes due to different considerations.
- In the downlink, a scalable OFDM transmission/multiaccess technique is used that allows for high spectrum efficiency by utilizing multiuser diversity in a frequency selective channel.
- The downlink transmission is based on OFDM with a cyclic prefix (CP), along with the associated multiple access.
- On the other hand, a scalable SC-FDMA transmission/multiaccess technique is used in the uplink since this reduces the peak-to-average power ratio (PAPR) of the transmitted signal.

## DOWNLINK OFDMA RADIO RESOURCES…

- OFDM is efficient in combating the frequency-selective fading channel with a simple frequency-domain equalizer
- The transceiver structure of OFDM with FFT/IFFT enables scalable bandwidth operation with a low complexity
- As each subcarrier becomes a flat fading channel, compared to single-carrier transmission OFDM makes it much easier to support multiantenna transmission, which is a key technique to enhance the spectrum efficiency.
- • OFDM enables multicast/broadcast services on a synchronized single frequency network, that is, MBSFN, as it treats signals from different base stations as propagating through a multipath channel and can efficiently combine them.

## DOWNLINK OFDMA RADIO RESOURCES…

- The multiple access in the downlink is based on OFDMA.
- In each TTI (Transmission Time Interval), a scheduling decision is made where each scheduled UE is assigned a certain amount of radio resources in the time and frequency domain.
- The radio resources allocated to different UEs are orthogonal to each other, which means there is no intra-cell interference.

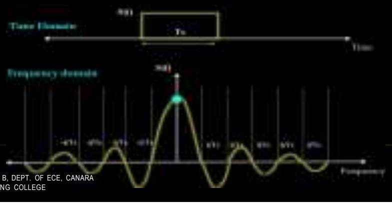
## FRAME STRUCTURE IN LTE

- The size of elements in the time domain is expressed as a number of time units

  Ts= 1/(15000 × 2048) seconds.
- The normal subcarrier spacing is defined to be

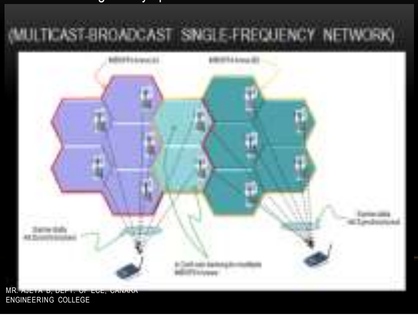
  Δf = 15kHz,

  Ts can be regarded as the sampling time of an FFT-based OFDM transmitter/receiver implementation with FFT size NFFT = 2048.



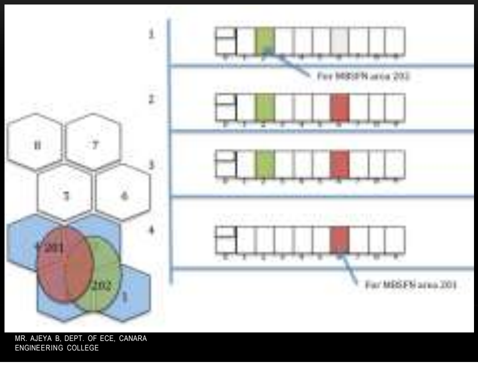
## FRAME STRUCTURE IN LTE

- In addition to the 15kHz subcarrier spacing, a *reduced subcarrier spacing* of 7.5kHz is defined for MBSFN cells, which provides a larger OFDM symbol duration that is able to combat the large delay spread associated with the MBSFN transmission.



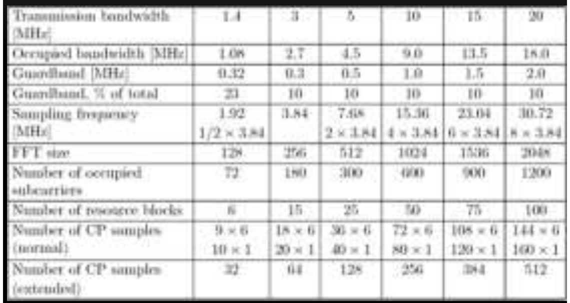
(MULTICAST-BROADCAST SINGLE-FREQUENCY NETWORK)

## (MULTICAST-BROADCAST SINGLE-FREQUENCY NETWORK)



## FRAME STRUCTURE IN LTE

### TYPICAL PARAMETERS FOR DOWNLINK TRANSMISSION



| Transmission bandwidth [MHz] | 1.4 | 3 | 5 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|
| Occupied bandwidth [MHz] | 1.08 | 2.7 | 4.5 | 9.0 | 13.5 | 18.0 |
| Guardband [MHz] | 0.32 | 0.3 | 0.5 | 1.0 | 1.5 | 2.0 |
| Guardband, % of total | 23 | 10 | 10 | 10 | 10 | 10 |
| Sampling frequency [MHz] | 1.92<br>1/2 × 3.84 | 3.84 | 7.68<br>2 × 3.84 | 15.36<br>4 × 3.84 | 23.04<br>6 × 3.84 | 30.72<br>8 × 3.84 |
| FFT size | 128 | 256 | 512 | 1024 | 1536 | 2048 |
| Number of occupied subcarriers | 72 | 180 | 300 | 600 | 900 | 1200 |
| Number of resource blocks | 6 | 15 | 25 | 50 | 75 | 100 |
| Number of CP samples (normal) | 9 × 6<br>10 × 1 | 18 × 6<br>20 × 1 | 36 × 6<br>40 × 1 | 72 × 6<br>80 × 1 | 108 × 6<br>120 × 1 | 144 × 6<br>160 × 1 |
| Number of CP samples (extended) | 32 | 64 | 128 | 256 | 384 | 512 |

## LTE BASIC TIMING UNIT TS

- In LTE, basic timing unit Ts is defined as 1/(15000 * 2048) seconds.
- The reason behind this definition is as follows:

1. Ts is sampling time for one OFDM symbol with 2048 points IFFT.
   - So the OFDM symbol duration in time domain is exactly 2048 * Ts = (1/15000) seconds
2. Ts is exactly multiple of UMTS chip rate.
   - In UMTS, the chip rate is 3.84Mcps and in 1xEV-DO, chip rate is 1.2288Mcps. This would greatly reduce the complexity of chipset.

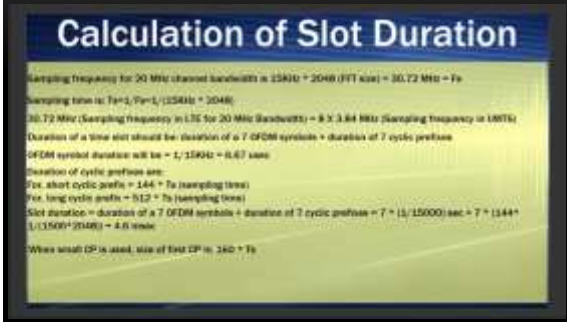
## FRAME STRUCTURE IN LTE…

- In the time domain, the downlink and uplink multiple TTIs are organized into radio frames with duration $T_f = 307200 \cdot T_s = 10$ ms.
- For flexibility, LTE supports both FDD and TDD modes.
- LTE supports two kinds of frame structures:
  1. Frame structure *Type 1* for the FDD mode and
  2. Frame structure *Type 2* for the TDD mode.

## FRAME STRUCTURE TYPE 1

### FOR THE FDD MODE

i. Time duration for one frame (One radio frame, One system frame) is 10 ms. This means that we have 100 radio frame per second.
ii. the number of samples in one frame (10 ms) is 307200 (307.200 K) samples.
iii. This means that the number of samples per second is 307200 x 100 = 30.72 M samples.
iv. Number of subframe in one frame is 10.
v. Number of slots in one subframe is 2.
vi. This means that we have 20 slots within one frame.



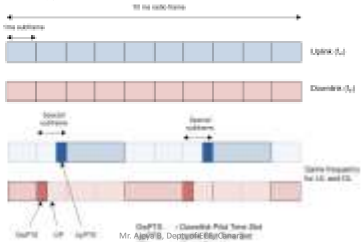
## Calculation of Slot Duration

Sampling frequency for 20 MHz channel bandwidth is 15KHz * 2048 (FFT size) = 30.72 MHz = Fs
Sampling time is: Ts=1/Fs=1/(15KHz * 2048)
30.72 MHz (Sampling frequency in LTE for 20 MHz Bandwidth) = 8 X 3.84 MHz (Sampling frequency in UMTS)
Duration of a time slot should be: duration of a 7 OFDM symbols + duration of 7 cyclic prefixes
OFDM symbol duration will be = 1/ 15KHz = 0.67 usec
Duration of cyclic prefixes are:
For. short cyclic prefix = 144 * Ts (sampling time)
For. long cyclic prefix = 512 * Ts (sampling time)
Slot duration = duration of a 7 OFDM symbols + duration of 7 cyclic prefixes = 7 * (1/15000) sec + 7 * (144* 1/(15000*2048)) = 4.6 msec

When small CP is used, size of first CP is: 160 * Ts

## Time domain structure

- Two time domain structures
  - Type 1: used for FDD transmission (may be full duplex or half duplex)
  - Type 2: used for TDD transmission
- Both Type 1 and Type 2 are based on 10ms radio frame

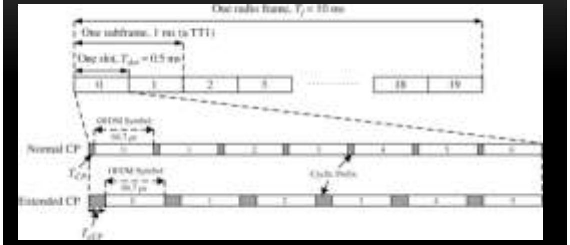


Radio frame : Type 1

Radio frame : Type 2

## FRAME STRUCTURE IN LTE…

### FRAME STRUCTURE TYPE 1



- For the normal CP, $T_{CP} = 160 \cdot T_s \approx 5.2\mu s$ for the first OFDM symbol, and
  - $T_{CP} = 144 \cdot T_s \approx 4.7\mu s$ for the remaining OFDM symbols which together fill the entire slot of 0.5 ms.
- For the extended CP, $T_{eCP} = 512 \cdot T_s \approx 16.7\mu s$.

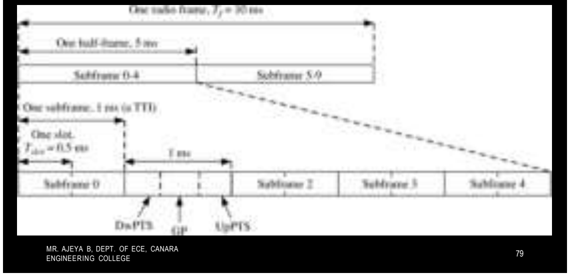
## FRAME STRUCTURE IN LTE…

### FRAME STRUCTURE TYPE 1

- For FDD, ***uplink and downlink transmissions are separated*** in the frequency domain, each with 10 subframes.
- In half-duplex FDD operation, the UE cannot transmit and receive at the same time while there are no such restrictions in full-duplex FDD.
- However, full-duplex FDD terminals need high quality and expensive RF duplex-filters to separate uplink and downlink channels, while half-duplex FDD allows hardware sharing between the uplink and downlink, which offers a cost saving at the expense of reducing data rates by half.
- Half-duplex FDD UEs are also considered a good solution if the duplex separation between the uplink and downlink transmissions is relatively small.
- In such cases, the half-duplex FDD is the preferable approach to mitigate the cross-interference between the transmit and receive chains.

## FRAME STRUCTURE TYPE 2

- Frame structure type 2 is applicable to the TDD mode.
- It is designed for coexistence with legacy systems such as the 3GPP TD-SCDMA-based standard.



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- There are special subframes, which consist of three fields: Downlink Pilot TimeSlot (DwPTS), Guard Period (GP), and Uplink Pilot TimeSlot (UpPTS).
- These fields are already defined in TD-SCDMA and are maintained in the LTE TDD mode to provide sufficiently large guard periods for the equipment to switch between transmission and reception.

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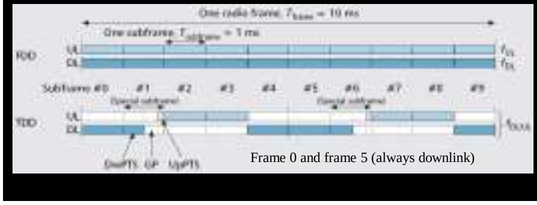
## GENERIC FRAME STRUCTURE

- Allocation of physical resource blocks (PRBs) is handled by a scheduling function at the 3GPP base station (eNodeB)



Frame 0 and frame 5 (always downlink)

---

## FRAME STRUCTURE TYPE 2

- Frame structure type 2 is applicable to the TDD mode.
- It is designed for coexistence with legacy systems such as the 3GPP TD-SCDMA-based standard.
- Each radio frame of frame structure type 2 is of length Tf = 30720 · Ts = 10 ms, which consists of two half-frames of length 5 ms each.
- Each half-frame is divided into five subframes with 1 ms duration.
- There are special subframes, which consist of three fields: Downlink Pilot TimeSlot (DwPTS), Guard Period (GP), and Uplink Pilot TimeSlot (UpPTS).
- These fields are already defined in TD-SCDMA and are maintained in the LTE TDD mode to provide sufficiently large guard periods for the equipment to switch between transmission and reception.

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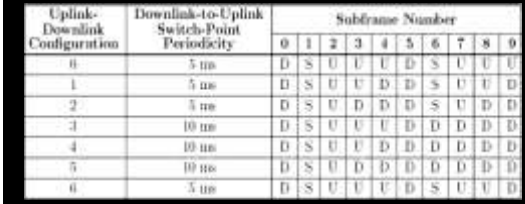
- • **The DwPTS field:** This is the downlink part of the special subframe, and can be regarded as an ordinary but shorter downlink subframe for downlink data transmission. Its length can be varied from three up to twelve OFDM symbols.
- • **The UpPTS field:** This is the uplink part of the special subframe, and has a short duration with one or two OFDM symbols. It can be used for transmission of uplink sounding reference signals and random access preambles.
- • **The GP field:** The remaining symbols in the special subframe that have not been allocated to DwPTS or UpPTS are allocated to the GP field, which is used to provide the guard period for the downlink-to-uplink and the uplink-to-downlink switch.
- The total length of these three special fields has a constraint of 1 ms. With the DwPTS and UpPTS durations mentioned above, LTE supports a guard period ranging from two to ten OFDM symbols, sufficient for cell size up to and beyond 100 km. All other subframes are defined as two slots, each with length $T_{slot}$ = 0.5 ms.

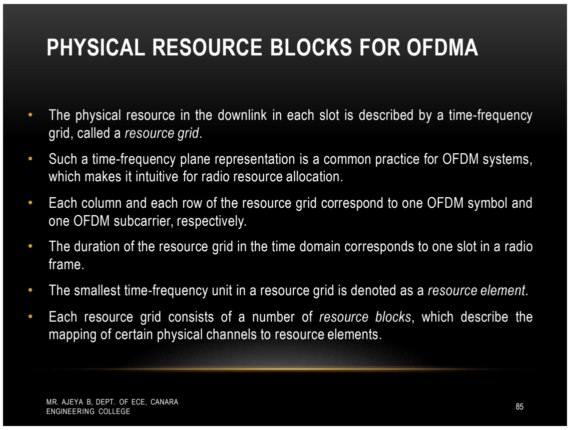
---

## UPLINK-DOWNLINK CONFIGURATIONS FOR THE LTE TDD MODE

- Seven uplink-downlink configurations with either 5 ms or 10 ms downlink-to-uplink switch-point periodicity are supported
- where "D" and "U" denote subframes reserved for downlink and uplink, respectively, and "S" denotes the special subframe.

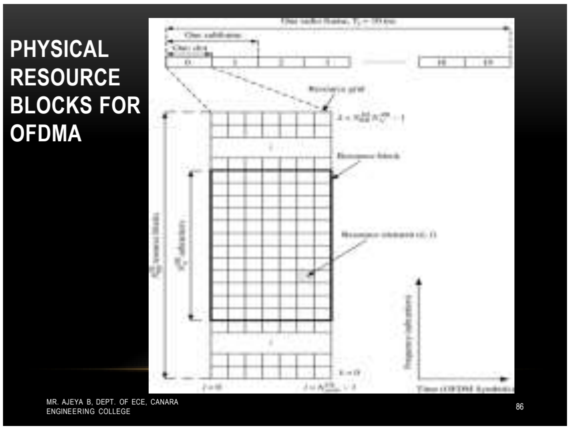


| Uplink-Downlink Configuration | Downlink-to-Uplink Switch-Point Periodicity | Subframe Number | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 0 | 5 ms | D | S | U | U | U | D | S | U | U | U |
| 1 | 5 ms | D | S | U | U | D | D | S | U | U | D |
| 2 | 5 ms | D | S | U | D | D | D | S | U | D | D |
| 3 | 10 ms | D | S | U | U | U | D | D | D | D | D |
| 4 | 10 ms | D | S | U | U | D | D | D | D | D | D |
| 5 | 10 ms | D | S | U | D | D | D | D | D | D | D |
| 6 | 5 ms | D | S | U | U | U | D | S | U | U | D |

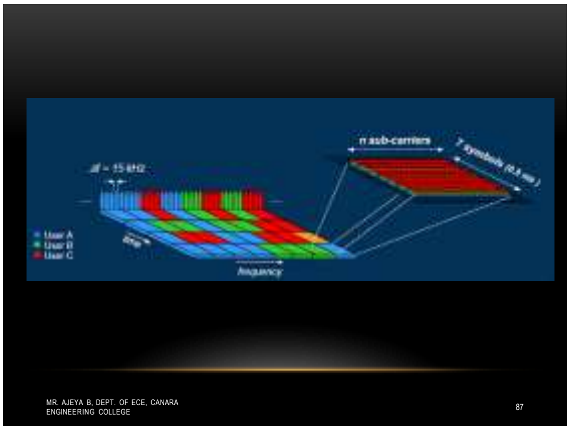


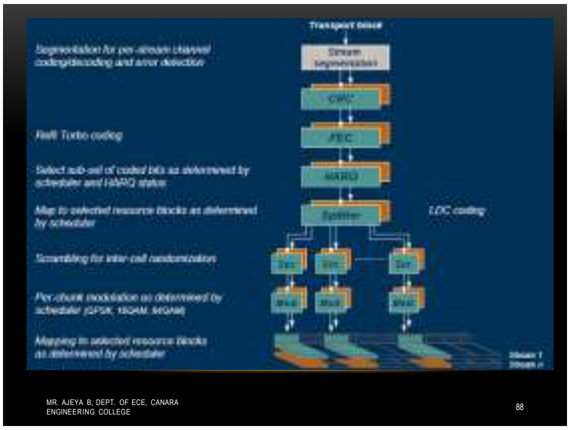
## PHYSICAL RESOURCE BLOCKS FOR OFDMA

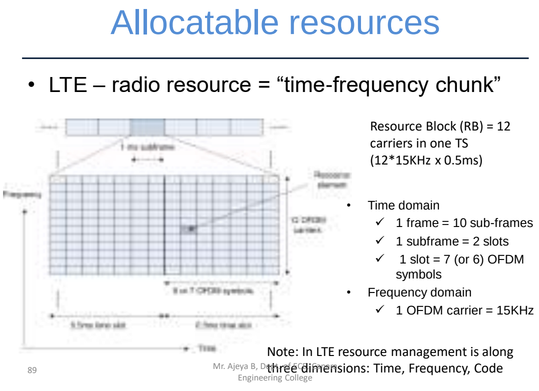
- The physical resource in the downlink in each slot is described by a time-frequency grid, called a *resource grid*.
- Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation.
- Each column and each row of the resource grid correspond to one OFDM symbol and one OFDM subcarrier, respectively.
- The duration of the resource grid in the time domain corresponds to one slot in a radio frame.
- The smallest time-frequency unit in a resource grid is denoted as a *resource element*.
- Each resource grid consists of a number of *resource blocks*, which describe the mapping of certain physical channels to resource elements.



## PHYSICAL RESOURCE BLOCKS FOR OFDMA







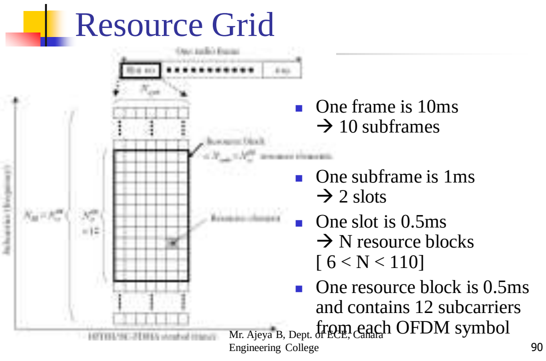
## Allocatable resources

- LTE – radio resource = "time-frequency chunk"

Resource Block (RB) = 12 carriers in one TS (12*15KHz x 0.5ms)

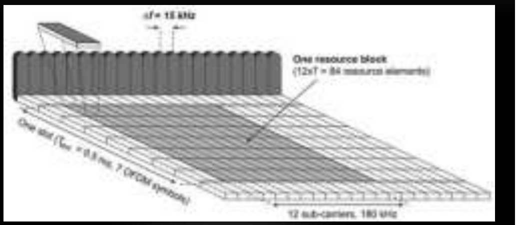
- Time domain
  - ✓ 1 frame = 10 sub-frames
  - ✓ 1 subframe = 2 slots
  - ✓ 1 slot = 7 (or 6) OFDM symbols
- Frequency domain
  - ✓ 1 OFDM carrier = 15KHz

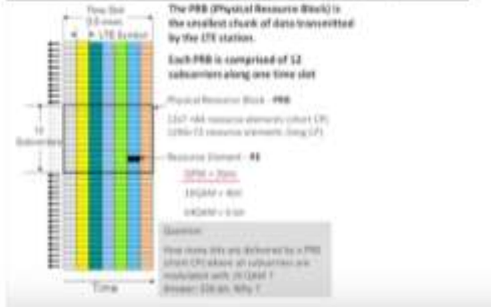
Note: In LTE resource management is along three dimensions: Time, Frequency, Code



## Resource Grid

- One frame is 10ms → 10 subframes
- One subframe is 1ms → 2 slots
- One slot is 0.5ms → N resource blocks [ 6 < N < 110]
- One resource block is 0.5ms and contains 12 subcarriers from each OFDM symbol





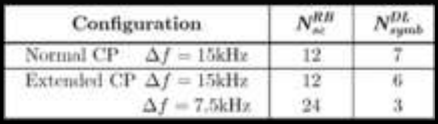
## The Physical Resources in LTE Channel

The PRB (Physical Resource Block) is the smallest chunk of data transmitted by the LTE station.

Each PRB is comprised of 12 subcarriers along one time slot

## RESOURCE GRID

- The structure of each resource grid is characterized by the following three parameters:
- •The number of downlink resource blocks $N_{RB}^{DL}$
- **The number of subcarriers in each resource block** $N_{sc}^{RB}$
- **The number of OFDM symbols in each block** $N_{symb}^{DL}$
- each downlink resource grid has $N_{RB}^{DL} \times N_{sc}^{RB} \times N_{symb}^{DL}$ resource elements



| Configuration | | $N_{sc}^{RB}$ | $N_{symb}^{DL}$ |
|---|---|---|---|
| Normal CP | $\Delta f = 15\text{kHz}$ | 12 | 7 |
| Extended CP | $\Delta f = 15\text{kHz}$ | 12 | 6 |
| | $\Delta f = 7.5\text{kHz}$ | 24 | 3 |

## RESOURCE ELEMENT

- Each resource element in the resource grid is uniquely identified by the index pair (*k*, *l*) in a slot

## THE RESOURCE BLOCK

- The resource block is the basic element for radio resource allocation.
- The minimum size of radio resource that can be allocated is the minimum TTI in the time domain, that is, one subframe of 1 ms, corresponding to two resource blocks.
- The size of each resource block is the same for all bandwidths, which is 180kHz in the frequency domain.
- There are two kinds of resource blocks defined for LTE:
  - ***physical and virtual resource blocks***
    - which are defined for different resource allocation schemes

## RESOURCE ALLOCATION

- Resource allocation's role is to dynamically assign available time-frequency resource blocks to different UEs in an efficient way to provide good system performance.
- In LTE, ***channel-dependent scheduling*** is supported, and transmission is based on the shared channel structure where the radio resource is shared among different UEs.
- *Multiuser diversity* can be exploited by assigning resource blocks to the UEs with favorable channel qualities.

## RESOURCE ALLOCATION…

- downlink resource allocation is characterized by the fact that each scheduled UE occupies a number of resource blocks while each resource block is assigned exclusively to one UE at any time.
- Physical resource blocks (PRBs) and virtual resource blocks (VRBs) are defined to support different kinds of resource allocation types.
- The VRB is introduced to support both block-wise transmission (localized) and transmission on non-consecutive subcarriers (distributed) as a means to maximize frequency diversity.

- The LTE downlink supports three resource allocation types:
  - ➢Type 0, 1, and 2.
- The downlink scheduling is performed at the eNode-B based on the channel quality information fed back from UEs, and then the downlink resource assignment information is sent to UEs on the PDCCH channel

## PHYSICAL RESOURCE BLOCK…

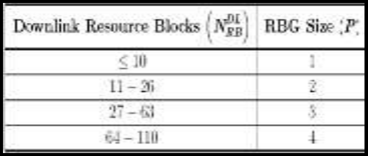
- A PRB is defined as consecutive OFDM symbols in the time domain and consecutive subcarriers in the frequency domain
- Therefore, each PRB corresponds to one slot in the time domain (0.5 ms) and 180kHz in the frequency domain.
- PRBs are numbered in the frequency domain.
- The PRB number $n_{PRB}$ of a resource element (*k, l*) in a slot is given by:

$$n_{PRB} = \left\lfloor \frac{k}{N_{sc}^{RB}} \right\rfloor$$

- The PRB is to support resource allocations of type 0 and type 1, which are defined for the DCI format 1, 2, and 2A.

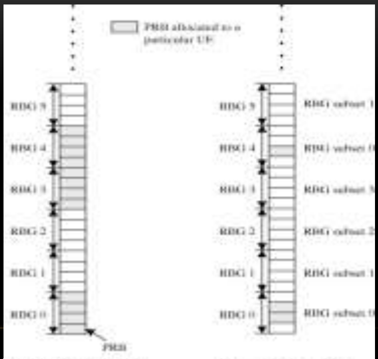
- **In type 0 resource allocations**, several consecutive PRBs constitute a resource block group (RBG), and the resource allocation is done in units of RBGs.
- Therefore, a bitmap indicating the RBG is sufficient to carry the resource assignment.
- The allocated RBGs to a certain UE do not need to be adjacent to each other, which provides frequency diversity. The RBG size *P*, that is, the number of PRBs in each RBG, depends on the bandwidth .
- An example of type 0 resource allocation, where *P* = 4 and RBGs 0, 3, 4, ..., are allocated to a particular UE.

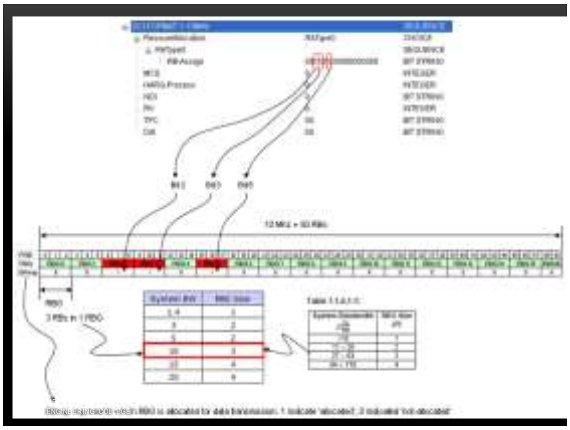
- Resource Allocation RBG Size vs. Downlink System Bandwidth

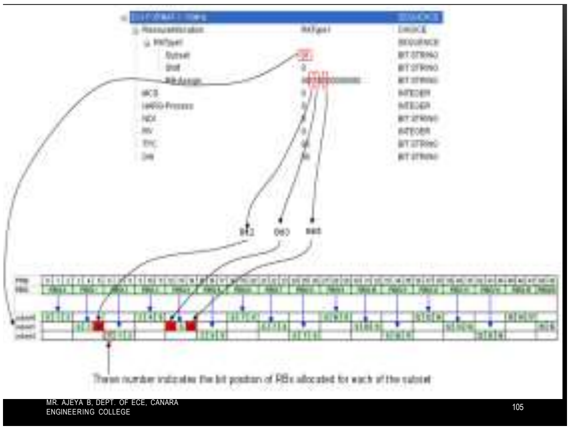


| Downlink Resource Blocks $\left(N_{RB}^{DL}\right)$ | RBG Size (*P*) |
|---|---|
| $\leq 10$ | 1 |
| 11 – 26 | 2 |
| 27 – 63 | 3 |
| 64 – 110 | 4 |

- Examples of resource allocation type 0 and type 1, where the RBG size $P = 4$.



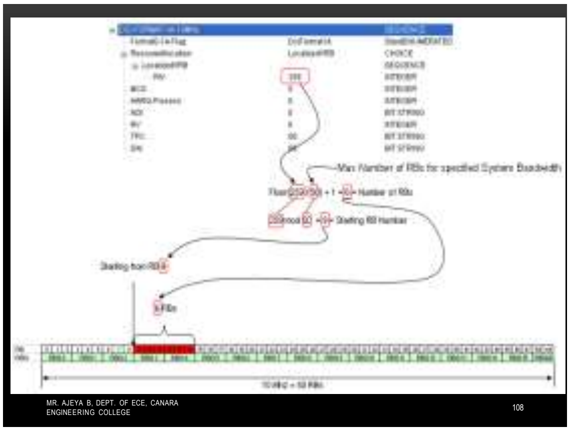




- **In type 2 resource allocations** that are defined for the DCI format 1A, 1B, 1C, and 1D, PRBs are not directly allocated.
- Instead, VRBs are allocated, which are then mapped onto PRBs.
- A VRB is of the same size as a PRB.
- There are two types of VRBs:
  - VRBs of the localized type and VRBs of the distributed type.
- For each type of VRB, a pair of VRBs over two slots in a subframe are assigned together with a single VRB number, $n_{VRB}$.
- VRBs of the localized type are mapped directly to physical resource blocks such that the VRB number $n_{VRB}$ corresponds to the PRB number $n_{PRB} = n_{VRB}$.
- For VRBs of the distributed type, the VRB numbers are mapped to PRB numbers according to the rule specified.
- For resource allocations of type 2, the resource assignment information indicates a set of contiguously allocated localized VRBs or distributed VRBs.
- A one-bit flag indicates whether localized VRBs or distributed VRBs are assigned.

- **Resource Allocation Type 2** : In this case, network allocate a set of contiguous RBs. But this contiguous RB is "Virtual" concept, not the "Physical" concept.
- It means that even though MAC layer allocate the multiple contiguous RBs, they may not be aligned contiguously when it get transmitted at PHY layer.
- This means that there should be a rule/algorithm to convert this logical(virtual) RB allocation to physical RB allocation.
- There are two type of the conversion, one is 'localized' and the other is 'distributed'. When you select 'localized', both virtuall allocation and physical allocation allocate RBs in contiguous way.
- When you select 'distributed', the virtual RB allocation is contiguous, but physical allocation is not contiguous (they are distributed over wider frequency ranges). Following is an example in RA Type 2 for 10 Mhz BW.

http://www.sharetechnote.com/html/Handbook_LTE.html



## SUPPORTED MIMO MODES

- Multiantenna transmission and reception (MIMO) is a physical layer technique that can improve both the reliability and throughput of the communications over wireless channels.
- It is considered a key component of the LTE physical layer from the start.
- The baseline antenna configuration in LTE is two transmit antennas at the cell site and two receive antennas at the UE.
- The higher-order downlink MIMO is also supported with up to four transmit and four receive antennas.

## SUPPORTED MIMO MODES…

- The downlink transmission supports both single-user MIMO (SU-MIMO) and multiuser MIMO (MU-MIMO).
- For SU-MIMO, one or multiple data streams are transmitted to a single UE through space-time processing
- for MU-MIMO, modulation data streams are transmitted to different UEs using the same time-frequency resource.

## SUPPORTED MIMO MODES…

- The supported SU-MIMO modes are listed as follows:
  i. • Transmit diversity with space frequency block codes (SFBC)
  ii. • Open-loop spatial multiplexing supporting four data streams
  iii. • Closed-loop spatial multiplexing, with closed-loop precoding as a special case when channel rank = 1
  iv. • Conventional direction of arrival (DOA)-based beamforming
- The supported MIMO mode is ***restricted by the UE capability.***

## UPLINK SC-FDMA RADIO RESOURCES

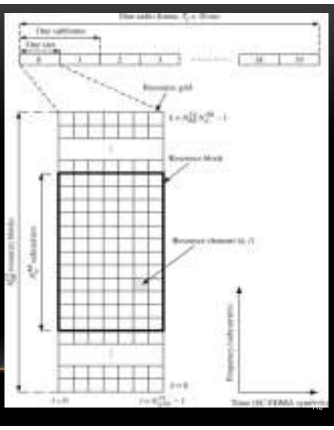
- A lower PAPR is highly desirable in the uplink as less expensive power amplifiers are needed at UEs and the coverage is improved.
- In LTE, the SC-FDMA signal is generated by the DFT-spread-OFDM.
- Compared to conventional OFDM, the SC-FDMA receiver has higher complexity, which, however, is not considered to be an issue in the uplink given the powerful computational capability at the base station.
- An SC-FDMA transceiver has a similar structure as OFDM, so the parametrization of radio resource in the uplink enjoys similarities to that in the downlink

## FRAME STRUCTURE

- The uplink frame structure is similar to that for the downlink.
- The difference is that now we talk about *SC-FDMA symbols* and *SC-FDMA subcarriers*.

## PHYSICAL RESOURCE BLOCKS FOR SC-FDMA

- As SC-FDMA can be regarded as conventional OFDM with a DFT-based precoder, the *resource grid* for the uplink is similar to the one for the downlink
- it comprises a number of resource blocks in the time-frequency plane.
- The number of resource blocks in each resource grid, $N_{RB}^{UL}$ depends on the uplink transmission bandwidth configured in the cell and should satisfy $N_{RB}^{min,UL} \leq N_{RB}^{UL} \leq N_{RB}^{max,UL}$



## RESOURCE ALLOCATION

- Similar to the downlink, shared-channel transmission and channel-dependent scheduling are supported in the uplink.
- Resource allocation in the uplink is also performed at the eNode-B.
- Based on the channel quality measured on the uplink sounding reference signals and the scheduling requests sent from UEs, the eNode-B assigns a unique time-frequency resource to a scheduled UE, which achieves orthogonal intra-cell transmission.
- Such intra-cell orthogonality in the uplink is preserved between UEs by using timing advance such that the transport blocks of different UEs are received synchronously at the eNode-B.

## RESOURCE ALLOCATION…

- This provides significant coverage and capacity gain in the uplink over UMTS, which employs non-orthogonal transmission in the uplink and the performance is limited by inter-channel interference.
- In general, SC-FDMA is able to support both localized and distributed resource allocation.
- In the current specification, only localized resource allocation is supported in the uplink, which preserves the single-carrier property and can better exploit the multiuser diversity gain in the frequency domain.
- Compared to distributed resource allocation, localized resource allocation is less sensitive to frequency offset and also requires fewer reference symbols.

## SUPPORTED MIMO MODES IN UPLINK

- For the MIMO modes supported in the uplink, the terminal complexity and cost are among the major concerns.
- MU-MIMO is supported, which allocates the same time and frequency resource to two UEs with each transmitting on a single antenna.
- This is also called Spatial Division Multiple Access (SDMA).
- The advantage is that only one transmit antenna per UE is required.
- To separate streams for different UEs, channel state information is required at the eNode-B, which is obtained through uplink reference signals that are orthogonal between UEs.

## SUPPORTED MIMO MODES IN UPLINK…

- Uplink MU-MIMO also requires power control, as the ***near-far problem*** arises when multiple UEs are multiplexed on the same radio resource.
- For UEs with two or more transmit antennas, closed-loop adaptive antenna selection transmit diversity shall be supported.
- For this scenario, each UE only needs one transmit chain and amplifier.
- The antenna that provides the best channel to the eNode-B is selected based on the feedback from the eNode-B.

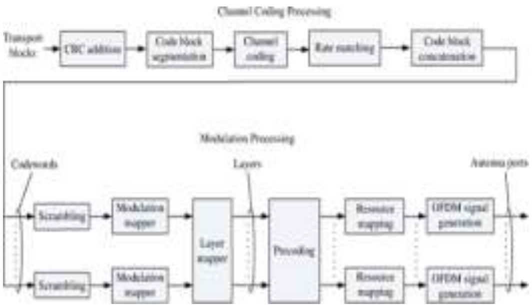
## DOWNLINK TRANSPORT CHANNEL PROCESSING

Chapter 7

## OVERVIEW

- The downlink physical layer processing mainly consists of channel coding and modulation.
- Channel coding involves mapping the incoming transport blocks from the MAC layer into different codewords.
- Modulation generates complex-valued OFDM baseband signals for each antenna port, which are then up-converted to the carrier frequency.

- **Overview of Downlink Transport Channel Processing**



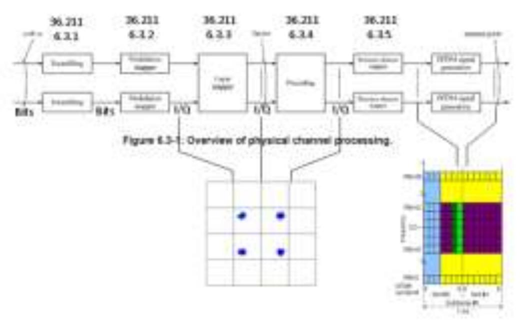


Figure 6.3-1: Overview of physical channel processing.

## CHANNEL CODING PROCESSING

- These common aspects of channel coding are applicable to both downlink and uplink transmissions.
- Channel coding for the downlink is a combination of
  - I. Error Detection
  - II. Error Correction
  - III. Rate Matching
  - IV. Interleaving
  - V. Transport Channel/Control Information mapping onto physical channels.
- Channel coding provides an error-control mechanism for data transmission using forward error correction (FEC) code and error detection based on cyclic redundancy check (CRC).

## CHANNEL CODING PROCESSING...

- For some transport channels such as the shared channel, the error-control mechanism is coupled with the retransmission mechanism using what is called the Hybrid-ARQ (H-ARQ) protocol.
- This combined ***error-control and retransmission mechanism improves the link reliability significantly*** in fading channels, as opposed to performing these two steps separately.
- In LTE, the coding rate at the channel encoder is fixed, and different effective coding rates for the whole transport block are achieved by repetition/puncturing during the rate matching procedure.

## CHANNEL CODING PROCESSING...

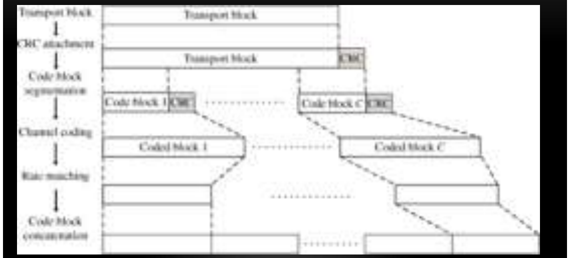


FIG: CHANNEL CODING PROCESSING

## CHANNEL CODING PROCESSING…

**CRC Addition**

- The CRC is used to provide error detection on the transport block .
- It generates parity bits by cyclic generator polynomials which are then added at the end of the transport block.
- The number of parity bits can take the value of 8, 16, or 24. The 24-bit CRC is the baseline for the downlink shared channel.

**Code Block Segmentation**

- Code block segmentation is performed when the number of bits in the sequence after CRC attachment, *B*, is larger than the maximum code block size for the turbo encoder, which is *Z* = 6144.
- It breaks the long sequence into *C* code blocks and adds an additional 24-bit CRC sequence to each block, where *C* is given by:

$$C = \begin{cases} 1 & \text{if} \quad B \le Z \\ \lceil B/(Z-L) \rceil & \text{if} \quad B > Z \end{cases}$$

-L is the number of CRC parity bits

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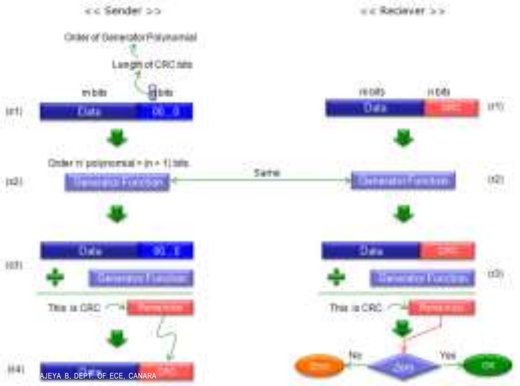

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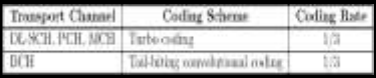
## CHANNEL CODING PROCESSING…

**Channel Coding**

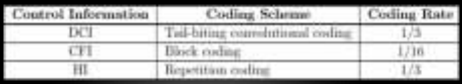
- In LTE, the channel encoders applied to transport channels include tail-biting convolutional coding and convolutional turbo coding.

➢ Channel Coding Schemes and Coding Rates for Downlink Transport Channels



| Transport Channel | Coding Scheme | Coding Rate |
|---|---|---|
| DL-SCH, PCH, MCH | Turbo coding | 1/3 |
| BCH | Tail-biting convolutional coding | 1/3 |

➢ Channel Coding Schemes and Coding Rates for Downlink Control Information



| Control Information | Coding Scheme | Coding Rate |
|---|---|---|
| DCI | Tail-biting convolutional coding | 1/3 |
| CFI | Block coding | 1/16 |
| HI | Repetition coding | 1/3 |

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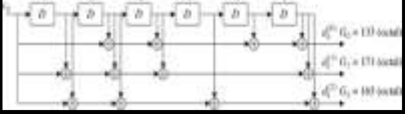
## CHANNEL CODING PROCESSING…

**Tail-Biting Convolutional Coding**

- The convolutional encoder used in LTE is a rate 1/3 encoder with a constraint length of 7 as shown in figure.



- Since the transmitted code blocks are of finite length, trellis termination must be performed at the end of each code block in order to restore the state of the encoder to the initial state for the next code block.

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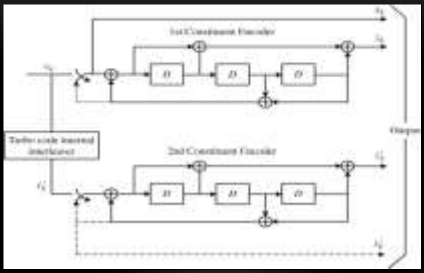
## CHANNEL CODING PROCESSING…



Structure of rate 1/3 turbo encoder (dotted lines apply for trellis termination only).

---

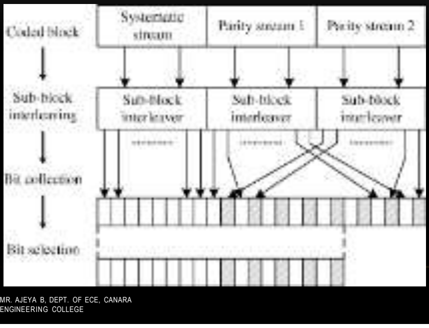
## CHANNEL CODING PROCESSING…

### Rate Matching

- The rate matching in LTE performs interleaving, as well as repetition or puncturing, in order to generate a transport block ***that fits the payload size*** determined by the modulation scheme and the number of resource blocks allocated for the transport block.
- Rate matching is defined per coded block and consists of the following stages:
  - ➢ a) interleaving, b) bit collection, and c) bit selection

## CHANNEL CODING PROCESSING…

**Rate matching for coded transport channels.**



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## CHANNEL CODING PROCESSING…

### Rate Matching…

**Interleaving**

- Interleaving is performed in order to spread out the occurrence of bursty errors across the code block, which improves the overall performance of the decoder.
- Since the interleaving is performed separately for the systematic and parity bits, a bit collection stage is required to place the systematic and parity bits in the right order as needed by the decoder.
- Finally, the bit selection stage is needed in order to repeat or puncture some of the parity bits to create the required payload.

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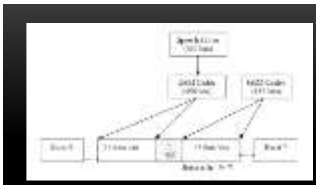

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## CHANNEL CODING PROCESSING…

### Rate Matching…

**Sub-block Interleaving**

- The interleaving is performed independently for each bit stream, done by a block interleaver with inter-column permutations.
- The inter-column permutation patterns are different for turbo coding and convolutional coding,

---

## CHANNEL CODING PROCESSING…

### Rate Matching…

**Bit Collection**

- A virtual circular buffer is formed by collecting bits from the interleaved streams.
- The systematic bits are placed at the beginning, followed by bit-by-bit interlacing of the two interleaved parity streams.
- The interlacing guarantees that an equal number of parity 1 and parity 2 bits are transmitted.

---

- The basic function of rate matching module is to match the number of bits in transport block(TB) to the number of bits that can be transmitted in the given allocation. Rate matching involves many things including sub-block interleaving, bit collection and pruning.
- The PDSCH TB is segmented into code blocks (CB) if its size is greater than 6144 bits, otherwise there will be no segmentation of the TB, but the TB and CB will be of same size
- Rate matching is performed over code blocks and is performed after the code blocks have undergone turbo encoding. The turbo encoder performs a 1/3 rate encoding, i.e for every single input bit, it gives 3 output bits in which the first bit is the original input bit called as a systematic bit and the remaining two bits are interleaved version of the input bit called parity1 and parity2 bits. These three streams of systematic, partity1 and parity2 bits are fed as input to the rate matching module,

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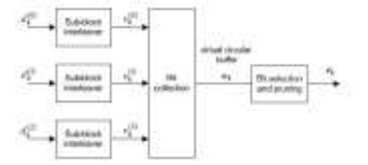

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## CHANNEL CODING PROCESSING…

### Rate Matching…

**Bit Selection**

- To select the output bit sequence, the sequence length *L* should first be determined, which depends on the number of allocated resource blocks, the modulation scheme, and the MIMO mode.
- Then *L* bits are read from the virtual circular buffer.
- The starting point of the bit selection depends on the redundancy version of the current transmission, which is different for different retransmissions associated with the H-ARQ process.
- This means that from one H-ARQ transmission to the next even though the number of bits *L* is the same, the parity bits that are punctured or repeated can be different.
- This is indicated by the redundancy version of the H-ARQ transmission.

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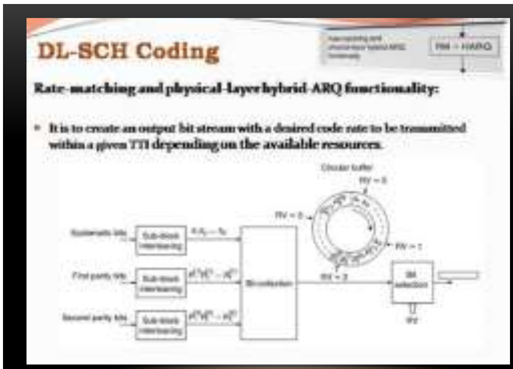


## DL-SCH Coding

**Rate-matching and physical-layer hybrid-ARQ functionality:**

- It is to create an output bit stream with a desired code rate to be transmitted within a given TTI depending on the available resources.

---

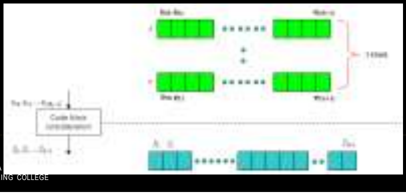
- During bit selection if the end of the buffer is reached, the reading continues by wrapping around to the beginning of the buffer.
- In this way, puncturing or repetition is achieved using a unified method.
- In the example in Figure 7.5, puncturing is achieved. With *K* input bits to the channel encoder, the effective coding rate is *K/L*, which can achieve any continuum of coding rates.

---

## CHANNEL CODING PROCESSING…

**Code Block Concatenation**

- The code block concatenation consists of sequentially concatenating the rate matching outputs for different code blocks, forming the codeword input to the modulation processing.
- It is needed only for turbo coding when the number of code blocks is larger than one.



## TRANSPORT BLOCKS TO CODEWORDS

- What does PHY do with a transport block? First, it converts the transport block into a codeword. There are a number of steps involved in this process, depending on the length of the transport block:
- Append a 24 bit checksum (CRC) to the transport block. This CRC is used to determine whether the transmission was successful or not, and triggers Hybrid ARQ to send an ACK or NACK, as appropriate
- Segment the transport block into code blocks. A code block must be between 40 and 6144 bits long. If the transport block is too small, it is padded up to 40 bits; if the TB is too big, it is divided into smaller pieces, each of which gets an additional 24 bit CRC.
- Process each code block with a 1/3 turbo coder
- Reassemble the resulting code blocks into a single codeword
- A codeword, then, is essentially a transport block with error protection.

## MODULATION PROCESSING

- Modulation takes in one or two codewords, depending on whether spatial multiplexing is used, and converts them to complex-valued OFDM baseband signals for each antenna port.
- The modulation processing consists of
  - I. Scrambling
  - II. Modulation Mapping
  - III. MIMO-related Multiantenna Processing
  - IV. Resource Mapping
  - V. OFDM signal generation.

## MODULATION PROCESSING….

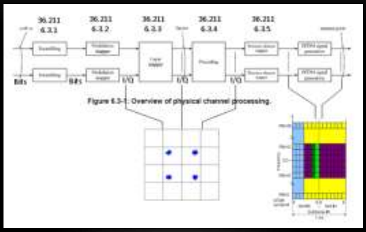


Figure 6.3-1: Overview of physical channel processing.

- The scrambling stage mixes each codeword with a pseudo-random sequence that depends on the physical cell ID and the target RNTI, to reduce the interference between transmissions from nearby cells.
- The modulation mapper takes the resulting bits in groups of two, four or six and maps them onto the in-phase and quadrature
- Components using QPSK, 16-QAM or 64-QAM.

## MODULATION PROCESSING….

### Scrambling

- Before modulation, the codeword generated through channel coding processing is first scrambled by a bit-level scrambling sequence.
- The block of bits for codeword $q$ is denoted as $b^{(q)}(0), \ldots, b^{(q)}(M_{\text{bit}}^{(q)}-1)$, where $M_{\text{bit}}^{(q)}$ is the number of bits transmitted in one subframe.
- The scrambling sequence $c^{(q)}$ is a pseudo-random sequence defined by a length-31 Gold sequence.
- The scrambled bits are generated using a modulo 2 addition as:

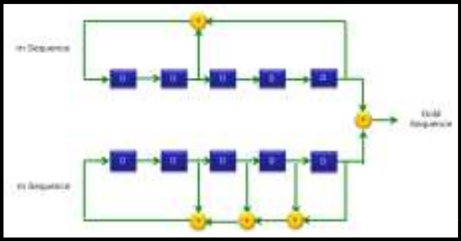
$$\tilde{b}^{(q)}(i) = \left(b^{(q)}(i) + c^{(q)}(i)\right) \bmod 2, \quad i = 0, 1, \ldots, M_{\text{bit}}^{(q)} - 1$$

- Up to two codewords can be transmitted in the same subframe, so $q = 0$ if spatial multiplexing is not used or $q$ $\{0, 1\}$ if spatial multiplexing is used.

## GOLD SEQUENCE GENERATOR

Gold Code is named after Robert Gold. It refers to a special set of binary Random (Pseudo Random) sequence in which the correlation among member sequences is very small.

Due to this property (small correlation), this is widely used for various wireless communication system as a scrambling code.



## MODULATION PROCESSING….

### Scrambling

- Except the multicast channel, for all other downlink transport channels and control information, the scrambling sequences are different for neighboring cells so that inter-cell interference is randomized, which is one of the approaches for interference mitigation.
- The same approach has already been taken in other systems such as UMTS.
- For the multicast channel, common scrambling is applied for all cells involved in a specific MBSFN transmission.

## MODULATION PROCESSING….

### Modulation Mapping

- For each codeword *q*, the block of scrambled bits [illegible] are modulated into a block of complex-valued modulation symbols [illegible]

where [illegible] is the is the number of the modulation symbols in each codeword and depends on the modulation scheme.

The relation between [illegible] and [illegible] is as follows:

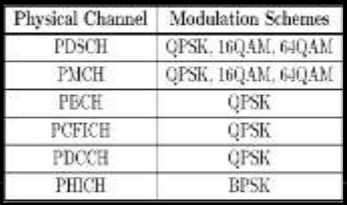
$$M_s^{(q)} = \frac{M_b^{(q)}}{Q_m}$$

where $Q_m$ is the number of bits in the modulation constellation, with $Q_m = 2$ for QPSK, $Q_m = 4$ for 16QAM, and $Q_m = 6$ for 64QAM.

## MODULATION PROCESSING….

### Modulation Mapping

- The supported data-modulation schemes in LTE include QPSK, 16QAM, and 64QAM, and BPSK is applied for the PHICH physical channel.
- Different physical channels employ different modulation schemes, listed in Table



| Physical Channel | Modulation Schemes |
|---|---|
| PDSCH | QPSK, 16QAM, 64QAM |
| PMCH | QPSK, 16QAM, 64QAM |
| PBCH | QPSK |
| PCFICH | QPSK |
| PDCCH | QPSK |
| PHICH | BPSK |

## MODULATION PROCESSING….

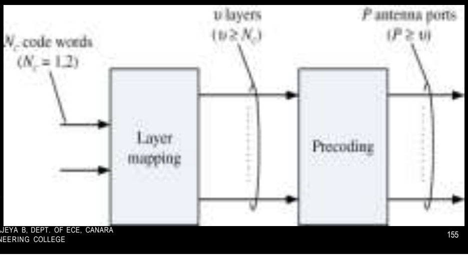
### Layer Mapping and Precoding

- Both layer mapping and precoding are associated with multiantenna transmission and reception (MIMO)
- The split between the two steps allows the inclusion of all the antenna processing schemes in a single framework.
- These two steps map the incoming codewords to up to four transmit antennas.

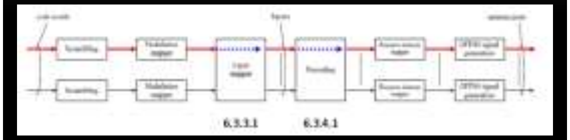
## MODULATION PROCESSING….

### Layer Mapping and Precoding…

- The layer mapper maps $N_c$ codewords to v spatial layers, while the precoder maps these v layers to *P* antenna ports

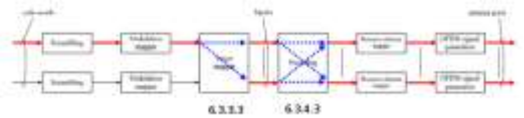


- < SISO >



- As shown below, marked in red/blue arrow, only one codeword (transport block) comes into the process and directly goes to the antenna.
- In this case, layer mapper and Precoding steps do almost nothing.

- **Tx Diversity >**
-
- As shown below, marked in red/blue arrow, only one codeword (one transport blocks) comes into the process and split into two stream (layers) by the layer mapper and finally go out through the two antenna.



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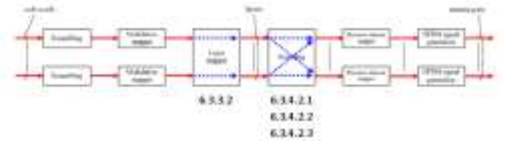
- **< 2 x 2 MIMO >**
-
- As shown below, marked in red/blue arrow, two codewords (two transport blocks) comes into the process and goes through the layer mapping without any modification and finally go out through the two antenna.
- In this case, data goes through very complicated precoding process.
- Depending on whether the 2 x 2 MIMO is Closed Loop Mode or Open Loop Mode, the different combination of the substeps are applied.



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## MODULATION PROCESSING….

- **Codeword:** A codeword is defined as the output of each channel coding/rate matching stage associated with a single transport block coming from the MAC layer.
- For MIMO transmission with multiple codewords on different spatial channels, more efficient detectors with successive interference cancellation[1] can be used.
- In LTE, although up to four transmit/receive antennas are supported, the number of codewords is limited to two.
- This is to limit the uplink feedback overhead, as a separate H-ARQ process is operated for each codeword, which requires separate signaling in the uplink control channel.

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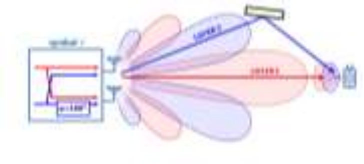
**Layer:**

- A layer corresponds to a data stream of the spatial multiplexing channel.
- Each codeword is mapped into one or multiple layers.
- Therefore, the number of layers, which is essentially the transmission rank, is at least as many as the number of codewords, that is, v ≥ $N_c$.



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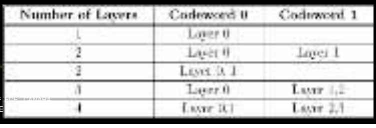
- **Antenna port:** An antenna port is defined by its associated reference signal, which is a logical entity and may not correspond to an actual physical antenna.
- The number of transmit antenna ports at the eNode-B is sent to UEs through the PBCH channel, which can be 1, 2, or 4 in LTE.
- Antenna ports are divided into three groups:
  i. – Antenna ports 0-3 are cell specific, which are used for downlink MIMO transmission.
  ii. – Antenna port 4 is MBSFN specific and is used for MBSFN transmission.
  iii. – Antenna port 5 is UE specific, which is used for beamforming to a single UE using all physical antennas.
- Cell-specific ports and the UE-specific port cannot be simultaneously used. Different reference signals are defined for different types of antenna ports

---

- • **Single antenna port:** One codeword is mapped to a single layer, which is straight-forward.
- • **Transmit diversity:** One codeword is mapped to two or four layers. It is an open-loop MIMO mode.
- • **Spatial multiplexing:** $N_c$ codewords are mapped to v layers, where $N_c$ = 1, 2, v = 1, 2, 3, 4 and v ≥ $N_c$. The detailed mapping is in Table.
- Note that the case of a 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, with rank-1 CL precoding as a special case.



| 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 |

## RESOURCE MAPPING

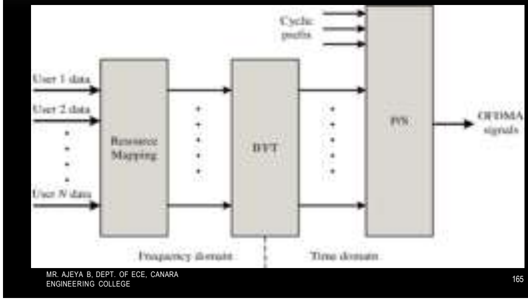
- For each of the antenna ports used for transmission of physical channels, the block of complex-valued symbols $y_p(0)$, ..., shall be mapped in sequence, starting with $y_p(0)$, to resource blocks assigned for transmission.
- The mapping to resource element ($k$, $l$) on antenna port $p$ not reserved for other purposes shall be in increasing order of first the index $k$ and then the index $l$, starting with the first slot in a subframe.

## OFDM BASEBAND SIGNAL GENERATION

- The continuous-time signal $s_l^{(p)}(t)$ on antenna port $p$ in OFDM symbol $l$ in a downlink slot is generated as:

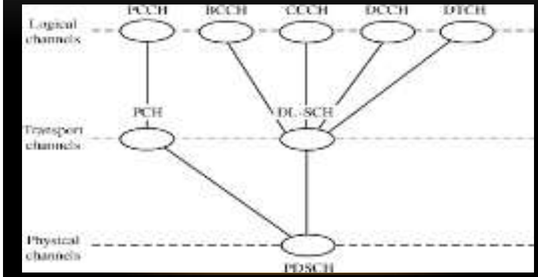
$$s_l^{(p)}(t)=\sum_{k=-\lfloor N_{RB}^{DL}N_{sc}^{RB}/2\rfloor}^{-1} a_{k^{(-)},l}^{(p)}\cdot e^{j2\pi k\Delta f(t-N_{CP,l}T_s)}+\sum_{k=1}^{\lceil N_{RB}^{DL}N_{sc}^{RB}/2\rceil} a_{k^{(+)},l}^{(p)}\cdot e^{j2\pi k\Delta f(t-N_{CP,l}T_s)}$$

**OFDMA signal generation with *N* users, where P/S denotes the parallel-to-serial converter.**



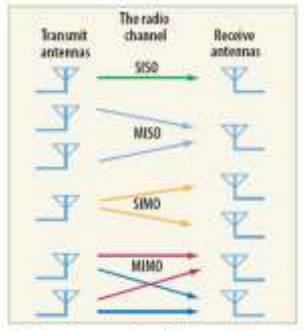
## DOWNLINK SHARED CHANNELS

- Channel mapping around the downlink shared channel.



## MULTIANTENNA TRANSMISSION

- the PDSCH supports all the MIMO modes specified in LTE, which makes this subsection an appropriate place to describe the transmission of the various MIMO modes.
- There are seven different transmission modes defined for data transmission on the PDSCH channel:
- • **Single-antenna port (port 0):** One transport block is transmitted from a single physical antenna corresponding to antenna port 0.
- • **Transmit diversity:** One transport block is transmitted from more than one physical antenna, that is, ports 0 and 1 if two physical antennas are used and ports 0, 1, 2, and 3 if four physical antennas are used.



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

- **Open-loop (OL) spatial multiplexing:** One or two transport blocks are transmitted from two or four physical antennas.
  - In this case, predefined precoder matrices are used based on the Rank Indicator (RI) feedback.
  - The precoding matrix is fixed and not adapted.
- **Closed-loop (CL) spatial multiplexing:** One or two transport blocks are transmitted from two or four physical antennas.
  - The precoding in this case is adapted based on the Precoding Matrix Indicator (PMI) feedback from the UE.

- **Multiuser MIMO:** Two UEs are multiplexed onto two or four physical antennas with one transport block to each UE.
  - The rank-1 PMI feedback from each UE is used to create the overall precoding matrix.
- **Closed-loop rank-1 precoding:** It is a special case of the CL spatial multiplexing with single-layer transmission, that is, a $P \times 1$ precoder is applied.

- **Single-antenna port (port 5):** A single transport block is transmitted from two or more physical antennas.
- The eNode-B performs beamforming to a single UE using all physical antennas.
- Unlike other modes, in this case the reference signal is also transmitted using the same beamforming vector that is used for the data symbols.
- Thus for this mode, the beamforming technique used at the eNode-B is transparent to the UE, and the UE is able to decode the transport block with the help of this UE-specific reference signal.
- Beamforming can be used to improve the received signal power and/or reduce the interference signal power, which is especially important for cell edge users.

- Transmission mode 1 can be classified as a Single-Input-Single-Output (SISO) mode that does not require any layer mapping and precoding.
- On the other hand, transmission modes 2–6 can be classified as MIMO modes, which require explicit layer mapping and precoding.
- We categorize these MIMO modes into OL and CL modes
- Cell-specific reference signals are used to assist the MIMO transmission.
- Downlink MIMO transmission, especially CL MIMO modes, requires explicit feedback from UEs, including RI and PMI contained in Uplink Control Information (UCI).

- **OL MIMO Techniques**
- The OL MIMO technique requires no or little feedback from UEs, so it is suitable for scenarios where accurate feedback is difficult to obtain or the channel changes rapidly enough, making the feedbacks obsolete, such as the high mobility scenario. OL MIMO modes include OL transmit diversity and OL spatial multiplexing.
- **OL Transmit Diversity**
- For the OL transmit diversity, the space-time block code is applied, which is different for two and four-antenna ports transmission
- For diversity transmission using two antenna ports, $p$ {0, 1}, the output $y(i) = [y_0(i) \ldots y_1(i)]^T$, $i = 0, 1, \ldots,$ of the precoding operation is determined as:

$$\begin{bmatrix} y_0(2i) & y_0(2i+1) \\ y_1(2i) & y_1(2i+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} x_0(i) & x_1(i) \\ -x_1^*(i) & x_0^*(i) \end{bmatrix}$$

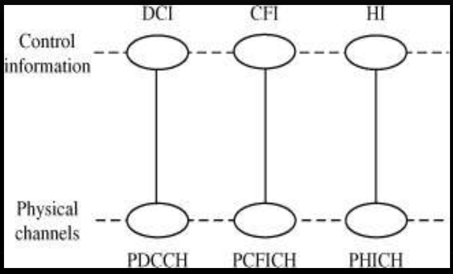
- **OL Spatial Multiplexing**
- This mode can be applied only if the channel rank is greater than 1 (RI > 1). Codebook-based precoding is used.
- For OL spatial multiplexing, the precoding is defined by:

$$\begin{bmatrix} y_0(i) \\ \vdots \\ y_{P-1}(i) \end{bmatrix} = \mathbf{W}(i)\mathbf{D}(i)\mathbf{U} \begin{bmatrix} x_0(i) \\ \vdots \\ x_{\upsilon-1}(i) \end{bmatrix}$$

## DOWNLINK CONTROL CHANNELS

- Downlink control channels are carried over the Physical Downlink Control Channel (PDCCH) and they contain control information from the MAC layer, including downlink control information (DCI), Control Format Indicator (CFI), and H-ARQ Indicator (HI).

## DOWNLINK CONTROL CHANNELS….

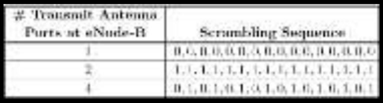


## BROADCAST CHANNELS

- Broadcast channels carry system information such as downlink system bandwidth, antenna configuration, and reference signal power.
- The UEs can get the necessary system information after the cell search (or synchronization) procedure.
- Due to the large size of the system information field, it is divided into two portions
  - I. Master Information Block (MIB) transmitted on the PBCH and
  - II. System Information Blocks (SIB) transmitted on the PDSCH.
- The PBCH contains basic system parameters necessary to demodulate the PDSCH, which contains the remaining SIB.
- The transmission of the PBCH is characterized by a fixed pre-determined transport format and resource allocation, that is, there is no higher-layer control.

## BROADCAST CHANNELS…

- Error detection is provided through a 16-bit CRC, and then the CRC parity bits are scrambled according to the eNode-B transmit antenna configuration with the scrambling sequence specified in Table:



| # Transmit Antenna Ports at eNode-B | Scrambling Sequence |
|---|---|
| 1 | 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0 |
| 2 | 1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1 |
| 4 | 0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1 |

- This implicitly tells the UE about the eNode-B antenna configuration.
- The tail-biting convolutional coding with rate 1/3 is used, and the coded bits are rate matched to 1920 bits for the normal CP and to 1728 bits for the extended CP.

## BROADCAST CHANNELS…

- The modulation scheme is QPSK. No H-ARQ is supported. For MIMO modes, PBCH supports single-antenna transmission and OL transmit diversity.
- Dynamic adaptation modulation and coding is not possible, due to the lack of channel quality feedback.

## MULTICAST CHANNELS

- *Multimedia Broadcast and Multicast Services* (MBMS), introduced in 3GPP Release 6 for the UTRA supports multicast/broadcast services in a cellular system.
- It sends the same content information to all the UEs (broadcast) or to a given set of UEs (multicast), and is envisaged for delivering services such as mobile TV.
- In principle, the MBMS transmission can originate from a single base station or multiple base stations, but multicell transmission is preferred as large gains can be achieved through soft combining of transmissions from multiple base stations.

- One major design requirement for LTE is to provide enhanced support for the MBMS transmission, which is called *Enhanced MBMS (E-MBMS )*and is achieved through the so-called Single-Frequency Network (SFN) operation.
- over-the-air combining of multicast/broadcast transmissions from multiple base stations is possible in LTE with an extended CP.

## MULTICAST CHANNELS

- The E-MBMS transmission in LTE occurs on the MCH transport channel, along with the 7.5kHz subcarrier spacing and the extended CP.

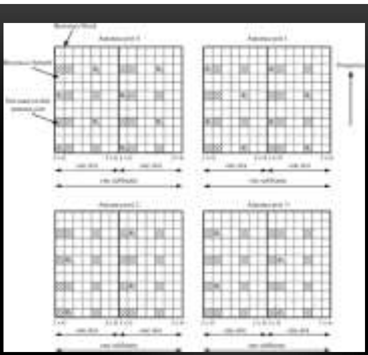
There are two types of E-MBMS transmissions:

- **Single-cell transmission (non-MBSFN operation):** The MBMS service (MTCH and MCCH) is transmitted on the MCH, and combining of MBMS transmission from multiple cells is not supported.
- • **Multicell transmission (MBSFN operation):** The MBMS service (MTCH and MCCH) is transmitted synchronously on the MCH, and combining is supported with the SFN operation.

## DOWNLINK PHYSICAL SIGNALS

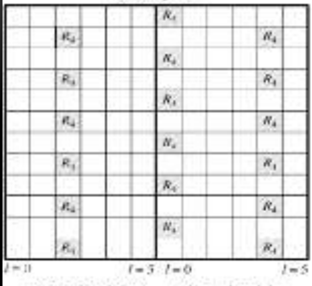
- **Downlink Reference Signals**
- Downlink reference signals consist of known reference symbols that are intended for downlink channel estimation at the UE needed to perform coherent demodulation.
- To facilitate the channel estimation process, scattered reference signals are inserted in the resource grid at pre-determined intervals.
- The time and frequency intervals are mainly determined by the characteristics of the channels, and should make a tradeoff between the estimation accuracy and the overhead.

- **Cell-Specific Reference Signals**
- Cell-specific reference signals are transmitted in all downlink subframes in a cell supporting non-MBSFN transmission.
- In the subframe used for transmission with MBSFN, only the first two OFDM symbols can be used for cell-specific reference symbols.
- Cell-specific reference signals are defined separately for antenna ports 0, 1, 2, and 3 as shown in Figure
- Therefore, in LTE a maximum of four antennas can be used while transmitting the cell specific reference signal. The cell specific reference signals are defined only for the normal subcarrier spacing of $\Delta f = 15$kHz.



**An example of mapping of downlink cell-specific reference signals, with four antenna ports and the normal CP. $R_p$ denotes the resource element used for reference signal transmission on antenna port $p$.**

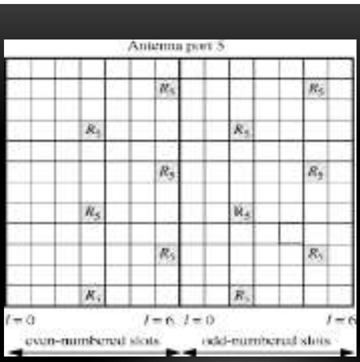
- **MBSFN Reference Signals**
- MBSFN reference signals are only transmitted in subframes allocated for MBSFN transmission, which is only defined for extended CP and transmitted on antenna port 4.
- In the time domain, for even-numbered slots, the reference symbols are inserted in the third OFDM symbol for $\Delta f = 15$kHz and in the second OFDM symbol for $\Delta f = 7.5$kHz; for odd-numbered slots, the reference symbols are inserted in the first and fifth OFDM symbols for $\Delta f = 15$kHz and in the first and third OFDM symbols for $\Delta f = 7.5$kHz.



An example of mapping of MBSFN reference signals, with the extended CP and Δ*f*= 15kHz.

## UE-SPECIFIC REFERENCE SIGNALS

- UE-specific reference signals support single-antenna-port transmission with beamforming for the PDSCH and are transmitted on antenna port 5.
- They are transmitted only on the resource blocks upon which the corresponding PDSCH is mapped.
- The UE-specific signal is not transmitted in resource elements in which one of the other physical signals or physical channels is transmitted.



An example of mapping of UE-specific signals, with the normal CP.

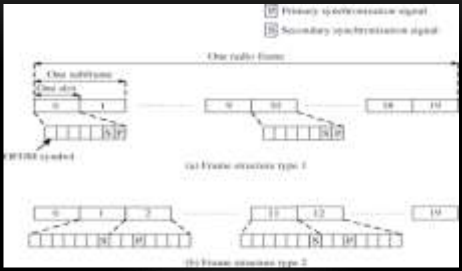
## SYNCHRONIZATION SIGNALS

- The downlink synchronization signals are sent to facilitate the cell search procedure, during which process the time and frequency synchronization between the UE and the eNode-B is achieved and the cell ID is obtained.
- There are a total of 504 unique physical-layer cell IDs, which are grouped into 168 physical-layer cell-ID groups. A physical-layer cell ID is uniquely defined as:

$$N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)};$$

- where $N_{ID}^{(1)}$ = 0, 1, ..., 167 represents the physical-layer cell-ID group and $N_{ID}^{(2)}$ = 0, 1, 2 represents the physical-layer ID within the cell-ID group.

- The difference in the location of the synchronization signal enables the UE to detect the duplex mode of the cell.



- **Figure:** The mapping of primary and secondary synchronization signals to OFDM symbols for frame structure type 1 and type 2, with the normal CP. ‘P’ and ‘S’ denote primary and secondary synchronization signals, respectively.

## H-ARQ IN THE DOWNLINK

- In a wireless network, due to the effects of channel fading and interference from neighboring cells, it is nearly impossible to guarantee error-free transmission no matter how robust the channel coding is.
- Moreover, as the coding rate decreases, the transmission becomes more robust but at the same time power efficiency is lost, that is, a significant amount of power is used to transmit a few bits of information.
- An elegant approach to solve this problem is to use the H-ARQ protocol, which combines FEC and retransmission within a single framework

## H-ARQ IN THE DOWNLINK…

- **At the receiver** turbo decoding is first applied on the received code block.
- If this is a retransmission, which is indicated in the DCI, the code block will be combined with the previously received versions for decoding.
- If there is no error detected in the output of the decoder, an ACK signal is fed back to the transmitter through the PUCCH physical channel and the decoded block is passed to the upper layer; otherwise, an NAK signal is fed back and the received code block is stored in the buffer for subsequent combining.

- **At the transmitter** for each (re)transmission, the same turbo-encoded data is transmitted with different puncturing, so each of these (re)transmissions has a different redundancy version and each is self-decodable.
- Puncturing is performed during the rate matching process