IEE2620: System Aspects in Communications

Muhammad Mahtab Alam, Professor

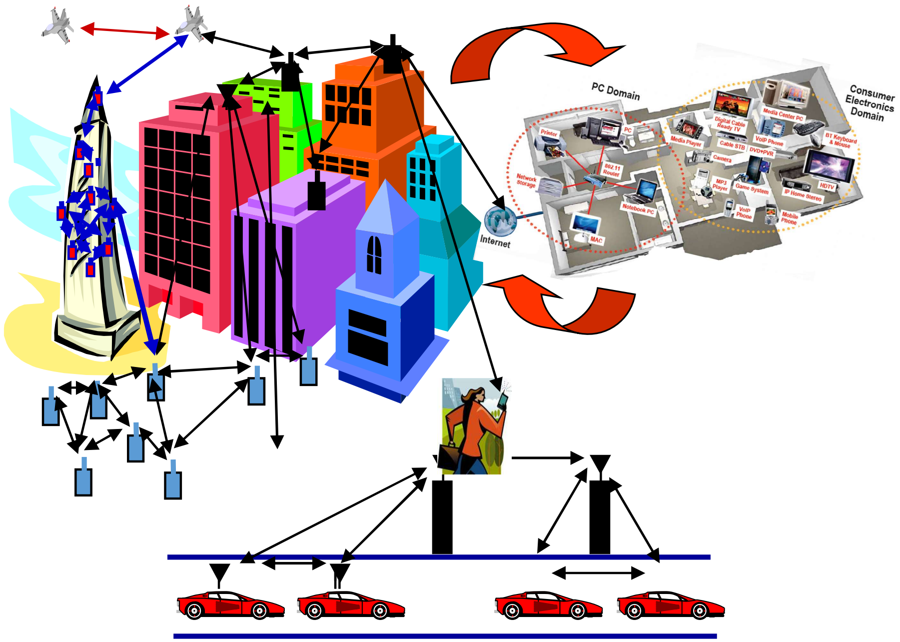
Timetable   Timetable calendar   2024/2025 Spring

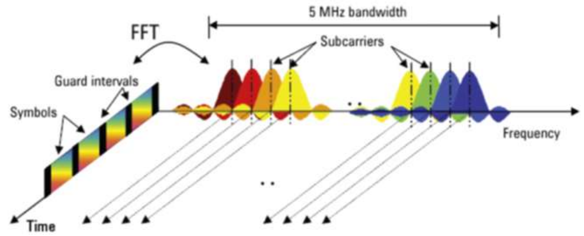
Muhammad Mahtab Alam (Study week 1-16)

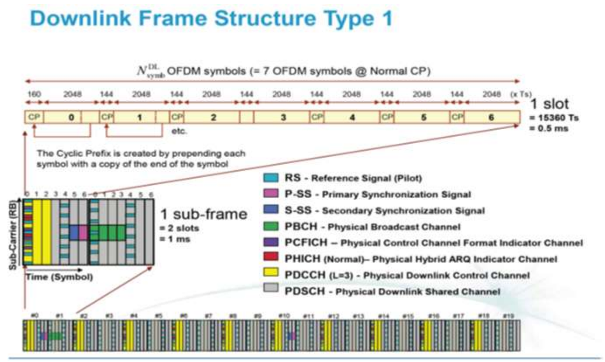
Week view   Dates view   Copy URL   Export iCalendar file

Other   Even   Odd   1 - 16   *Student group italicized* - subject is elective   Student group not italicized - subject is compulsory

Time	Course	Language	Type	Teacher	Room	Study weeks	Student groups	Syllabus	Comment
Monday									
12:00 - 13:30	IEE2620 - System Aspects in Communication	estonian	lecture	Muhammad Mahtab Alam (Tenured Full Professor)	Distance learning	1-16	*IAVM21*	View	







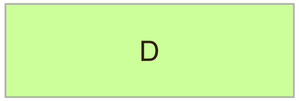
Contents

5G NR Physical Resource

Slot Format and Type

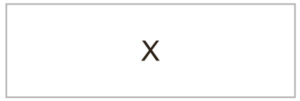
- **Slot structure (*section 4.3.2 in 3GPP TS 38.211*)**
  - Downlink, denoted as D, for downlink transmission
  - Flexible, denoted as X, for flexibly usage.
  - Uplink, denoted as U, for uplink transmission

- **Main slot types**
  - Type 1: DL-only slot

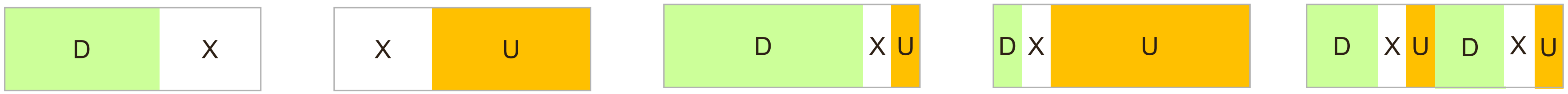


  - Type 2: UL-only slot

  - Type 3: flexible-only slot



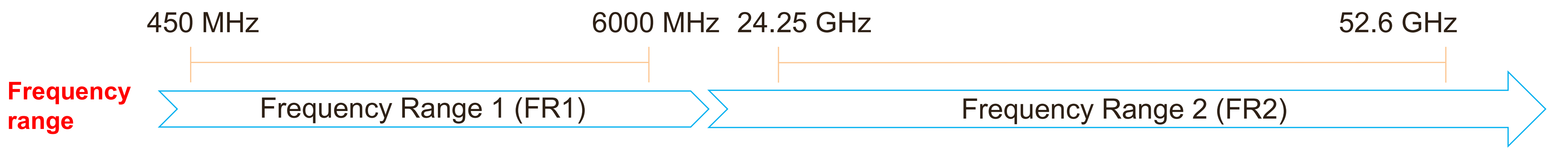
  - Type 4: mixed slot



Type4-1 Type4-2 Type4-3 Type4-4 Type4-5

- **Compared with LTE slot format, NR features:**
  - Flexibility: symbol-level uplink/downlink adaptation in NR while subframe-level in LTE
  - Diversity: More kinds of uplink/downlink configurations are supported in NR to cope with more scenarios and service types.

3GPP-defined 5G Frequency Ranges and Bands



NR Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL

NR Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD

- Frequency range (MHz)
  - 3GPP TS 38.101-2 defines 2 NR frequency ranges: FR1 and FR2. **FR1 is often called sub-6 GHz while FR2 is often referred to as millimeter wave.**
- 5G frequency band
  - 3GPP TS 38.101 mainly defines NR frequency bands.
  - NR and LTE have some frequency bands in same but the frequencies are represented in different ways.

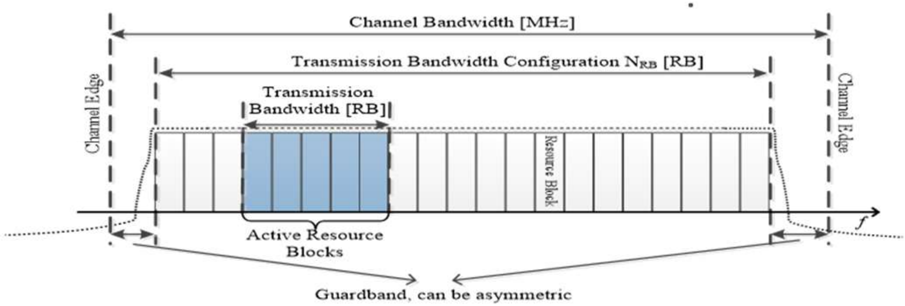
Source: 3GPP TS 38.101

Transmission Bandwidth and Spectrum Utilization

- **Transmission bandwidth varies with RG and SCS.**
  - Maximum transmission bandwidth on the gNodeB side (*Table 5.3.2-1 and 5.3.2-2 in 3GPP TS 38.104*)

SCS (kHz)	5 MHz	10 MHz	15 MHz	30 MHz	20 MHz	25 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
	N_{RB} and Spectrum Utilization (FR1: 400 MHz to 6000 MHz)												
15	25	52	79	[160]	106	133	216	270	-	-	-	-	-
	90%	93.6%	94.8%		95.4%	95.8%	97.2%	97.2%	\	\	\	\	\
30	11	24	38	[78]	51	65	106	133	162	[189]	217	[245]	273
	79.2%	86.4%	91.2%		91.8%	93.6%	95.4%	95.8%	97.2%		97.7%		98.3%
60	-	11	18	[38]	24	31	51	65	79	[93]	107	[121]	135
		79.2%	86.4%		86.4%	893%	91.8%	93.6%	94.8%		93.6%		97.2%

SCS (kHz)	50 MHz	100 MHz	200 MHz	400 MHz
	N_{RB} and Spectrum Utilization (FR2: 24 GHz to 52 GHz)			
60	66	132	264	N/A
	95%	95%	95%	\
120	32	66	132	264
	92.2%	95%	95%	95%



  - Maximum transmission bandwidth on the UE side (*3GPP TS 38.101-1 and TS 38.101-2*).
    - ✓ The number of RBs in the 30 MHz bandwidth is to be determined.
    - ✓ The 70 MHz and 90 MHz bandwidths are not supported.
    - ✓ Other values are the same as those on the gNodeB side.

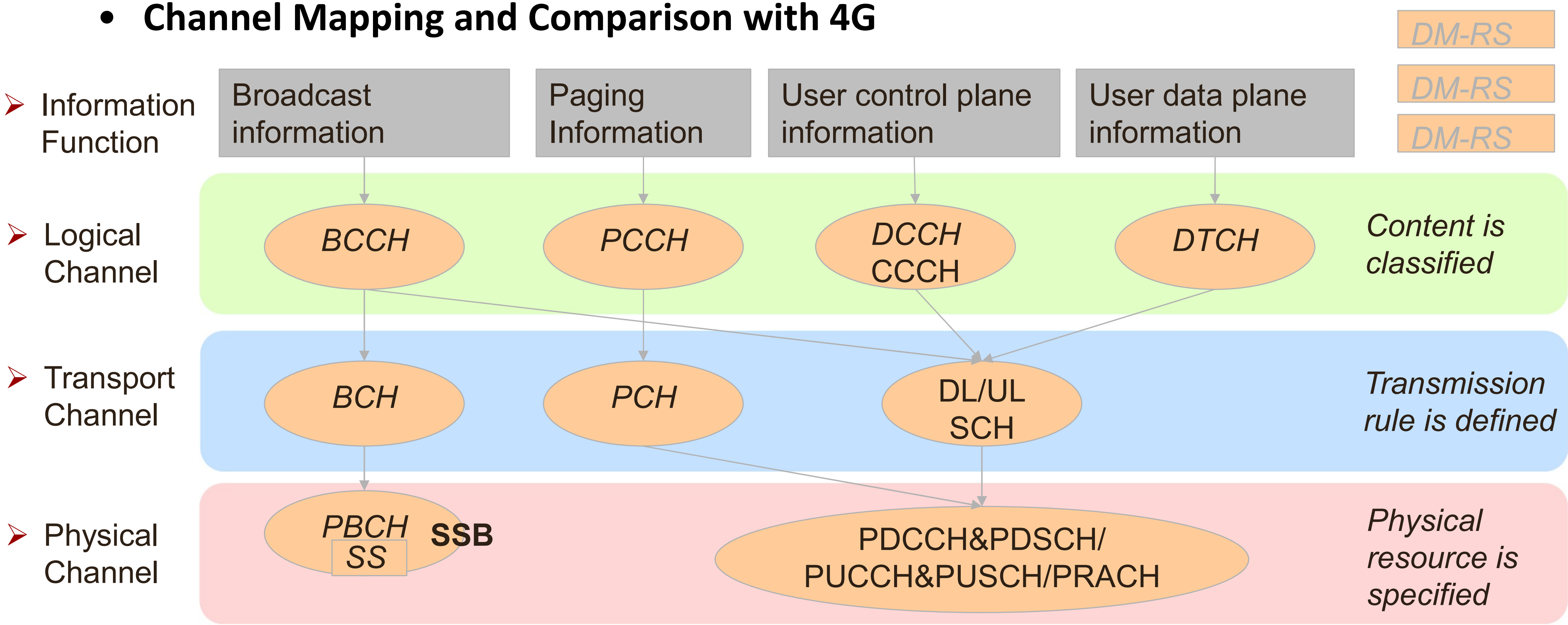
Contents

1 Overview

2 Details about 5G NR Channels and Signals

The Basic Functions of NR Air Interface

- **Channel Mapping and Comparison with 4G**

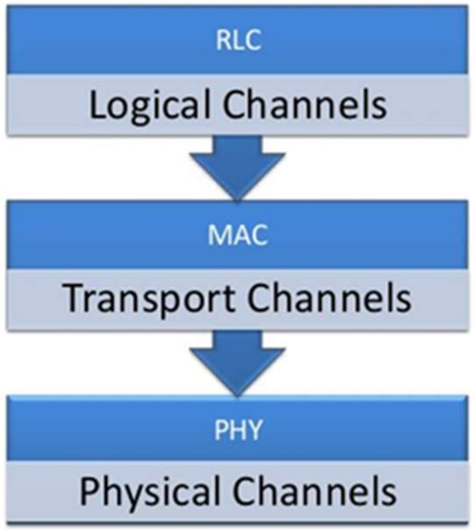


LTE Channels

LTE channel types

- There are three categories into which the various data channels may be grouped.
- ***Physical channels:*** These are transmission channels that carry user data and control messages.
- ***Transport channels:*** The physical layer transport channels offer information transfer to Medium Access Control (MAC) and higher layers.
- ***Logical channels:*** Provide services for the Medium Access Control (MAC) layer within the LTE protocol structure.

LTE Channel Architecture



1. RLC layer passes data to the MAC layer as logical channels.
2. The MAC layer formats and sends the logical channel data as transport channel.
3. The physical layer encodes the transport channel data to physical channels.

LTE system information blocks

- The system information is very essential and the same is broadcasted by LTE eNB over logical channel BCCH.
- This logical channel information is further carried over transport channel BCH or carried by DL-SCH.
- There are two parts in SIB i.e., static part and dynamic part.
  - Static part is called as MIB and is transmitted using BCH and carried by PBCH once every 40ms. MIB carries useful information which includes:
    - Channel bandwidth,
    - PHICH configuration details; transmit power, no. of antennas
    - SIB scheduling information transmitted along with other information on the DL-SCH.
  - Dynamic part refers to information that can change frequently, like cell status or neighboring cell details, which are typically transmitted more often compared to static information within the SIB, allowing for real-time network updates and adjustments as needed;
    - It is mapped on LTE Radio Resource Control (RRC) System Information (RRC SI) messages (SI-1,2,3,4,5,6,7,8,9,10,11) over DL-SCH and transmitted using PDSCH at periodic intervals.
    - SI-1 transmitted every 80ms, SI-2 every 160ms and SI-3 every 320 ms.

LTE Logical Control channels

- ***Control channels:*** these LTE control channels carry the control plane information:
  - ***Broadcast Control Channel (BCCH) :*** This control channel provides system information to all mobile terminals connected to the eNodeB.
  - ***Paging Control Channel (PCCH) :*** This control channel is used for paging information (https://ltebasics.wordpress.com/2015/06/29/what-is-paging-in-lte/) when searching a unit on a network.
  - ***Common Control Channel (CCCH) :*** This channel is used for random access information, e.g. for actions including setting up a connection.
  - ***Multicast Control Channel (MCCH) :*** This control channel is used for Information needed for multicast reception.
  - ***Dedicated Control Channel (DCCH) :*** This control channel is used for carrying user-specific control information, e.g. for controlling actions including power control, handover, etc..
- ***Traffic channels:*** These LTE traffic channels carry the user-plane data:
  - ***Dedicated Traffic Channel (DTCH) :*** This traffic channel is used for the transmission of user data.
  - ***Multicast Traffic Channel (MTCH) :*** This channel is used for the transmission of multicast data.

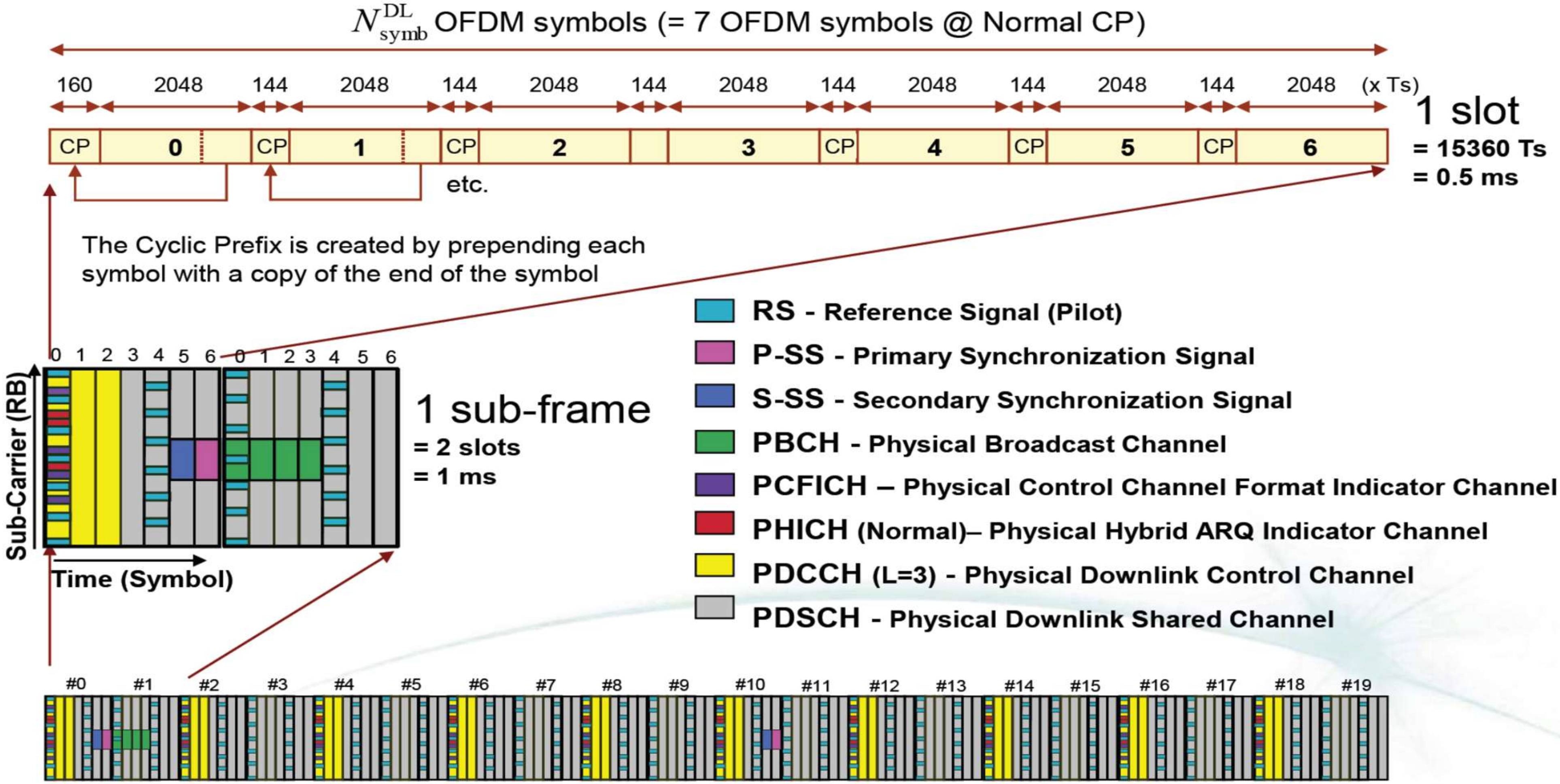
LTE transport channels

- The LTE transport channels vary between the uplink and the downlink as each has different requirements and operates in a different manner. Physical layer transport channels offer information transfer to medium access control (MAC) and higher layers.
- ***Downlink:***
  - ***<u>Broadcast Channel (BCH) :</u>*** The LTE transport channel maps to Broadcast Control Channel (BCCH)
  - ***<u>Downlink Shared Channel (DL-SCH) :</u>*** This transport channel is the main channel for downlink data transfer. It is used by many logical channels.
  - ***<u>Paging Channel (PCH) :</u>*** To convey the PCCH
  - ***<u>Multicast Channel (MCH) :</u>*** This transport channel is used to transmit MCCH information to set up multicast transmissions.
- ***Uplink:***
  - ***<u>Uplink Shared Channel (UL-SCH) :</u>*** This transport channel is the main channel for uplink data transfer. It is used by many logical channels.
  - ***<u>Random Access Channel (RACH) :</u>*** This is used for random access requirements.

Downlink Physical Signals and Channels in LTE/4G

Physical signals	Physical channels
Primary synchronization signal	Physical downlink shared channel (PDSCH)
Secondary synchronization signal	Physical broadcast channel (PBCH)
Cell-specific reference signal (CRS)	Physical downlink control channel (PDCCH)
MBSFN reference signal	Physical multicast channel (PMCH)
UE-specific reference signal	Physical control format indicator channel (PCFICH)
Positioning reference signal (PRS)	Physical hybrid automatic request (ARQ) indicator channel (PHICH)
Channel state information (CSI) reference signal (CSI-RS)	

Downlink Frame Structure Type 1



SYNCHRONIZATION SEQUENCES

A User Equipment wishing to access the LTE system follows a cell search procedure which includes a series of synchronization stages by which the UE determines time and frequency parameters that are necessary to demodulate downlink signals, to transmit with correct timing and to acquire some critical system parameters.

There are three synchronization requirements in LTE:

- symbol timing acquisition by which the correct symbol start is determined;
- carrier frequency synchronization, which mitigates the effect of frequency errors resulting from Doppler shift and errors from electronics;
- sampling clock synchronization.

There are two cell search procedures in LTE:

- One for initial synchronization
- Another for detecting neighbor cells in preparation for handover.

In both cases, the UE uses two special signals broadcast on each cell:

- Primary Synchronization Sequence (PSS)
- and Secondary Synchronization Sequence (SSS).

The detection of these signals allows the UE to complete time and frequency synchronization and to acquire useful system parameters such as cell identity, cyclic prefix length, and access mode (FDD/TDD).

At this stage, the UE can also decode the Physical Broadcast Control Channel (PBCH) and obtain important system information.

PHYSICAL Channels - Downlink (1/4)

- Two types of physical layer channels are defined:
    - physical channels, which carry information originating from higher layers
    - physical signals, which are generated at the physical layer and are used for system synchronization, cell identification, and radio channel estimation.
- The LTE physical channels vary between the uplink and the downlink as each has different requirements and operates in a different manner.
- ***Downlink:***
    - ***Physical Broadcast Channel (PBCH):*** This physical channel carries system information for UEs requiring to access the network. It only carries what is termed as Master Information Block, MIB, messages.
        - The modulation scheme is always QPSK and the information bits are coded and rate matched (https://ltebasics.wordpress.com/2013/12/24/rate-matching-in-pdsch/)
        - The bits are then scrambled using a scrambling sequence specific to the cell to prevent confusion with data from other cells.
        - The MIB message on the PBCH is mapped onto the "central 72 subcarriers or six central resource blocks" regardless of the overall system bandwidth.
        - A PBCH message is "repeated every 40 ms", i.e. one transmission time interval (TTI) of PBCH includes four radio frames.
        - The PBCH transmissions has 14 information bits, 10 spare bits, and 16 CRC bits.

PHYSICAL Channels – Downlink (2/4)

- ***Physical Control Format Indicator Channel (PCFICH) :*** As the name implies the PCFICH informs the UE about the format of the signal being received (https://ltebasics.wordpress.com/2013/08/06/what-is-pcfich/).
- It indicates the number of OFDM symbols used for the PDCCHs.
- PCFICH conveys the number of control symbols in the current subframe.
  - Since a subframe in LTE FDD can have upto 14 symbols for normal CP scenario, among the 14 OFDM symbols there can be upto 3 control symbols, depending on the amount of control data the eNodeB has to transmit. The number of controls symbols can be 1, 2 or 3. It can also be 4 incase of lower bandwidth systems such as 3MHz or less. Every subframe must have atleast one control symbol.
- Whether 1, 2, or 3. The information within the PCFICH is essential because the UE does not have prior information about the size of the control region.
- A PCFICH is transmitted on the first symbol of every sub-frame and carries a Control Format Indicator, CFI, field.
  - The CFI contains a 32 bit code word that represents 1, 2, or 3.
  - The PCFICH Encoding: Uses 32 bit,2 block coding which results in a 1/16 coding rate, and it always uses QPSK modulation to ensure robust reception.

PHYSICAL Channels – Downlink (3/4)

- ***Physical Downlink Control Channel (PDCCH) :*** The main purpose of this physical channel is to carry mainly scheduling information of different types:

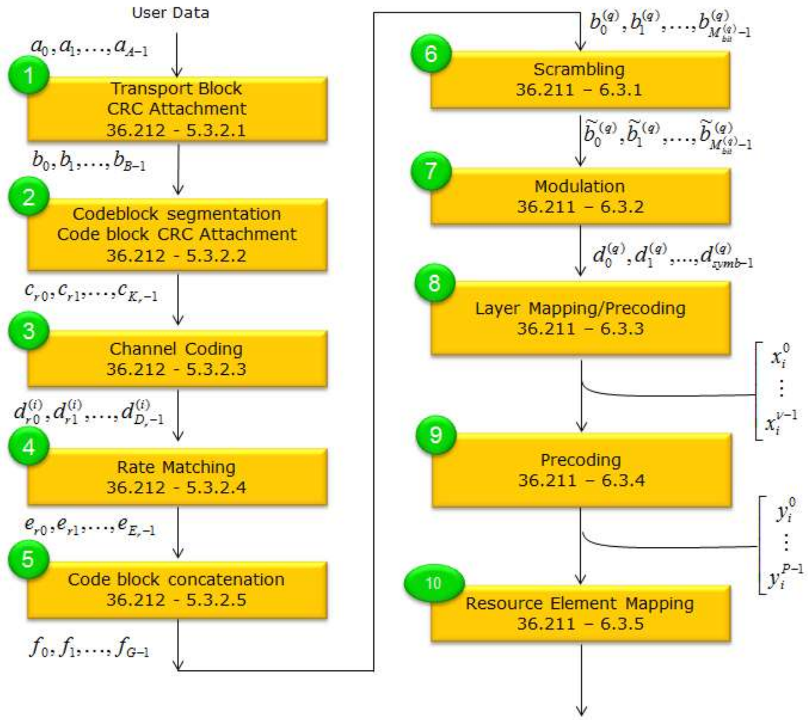
- Downlink resource scheduling
- Uplink power control instructions
- Uplink resource grant
- Indication for paging or system information
- The PDCCH contains a message known as the Downlink Control Information, DCI which carries the control information for a particular UE or group of UEs.

PHYSICAL Channels – Downlink (4/4)

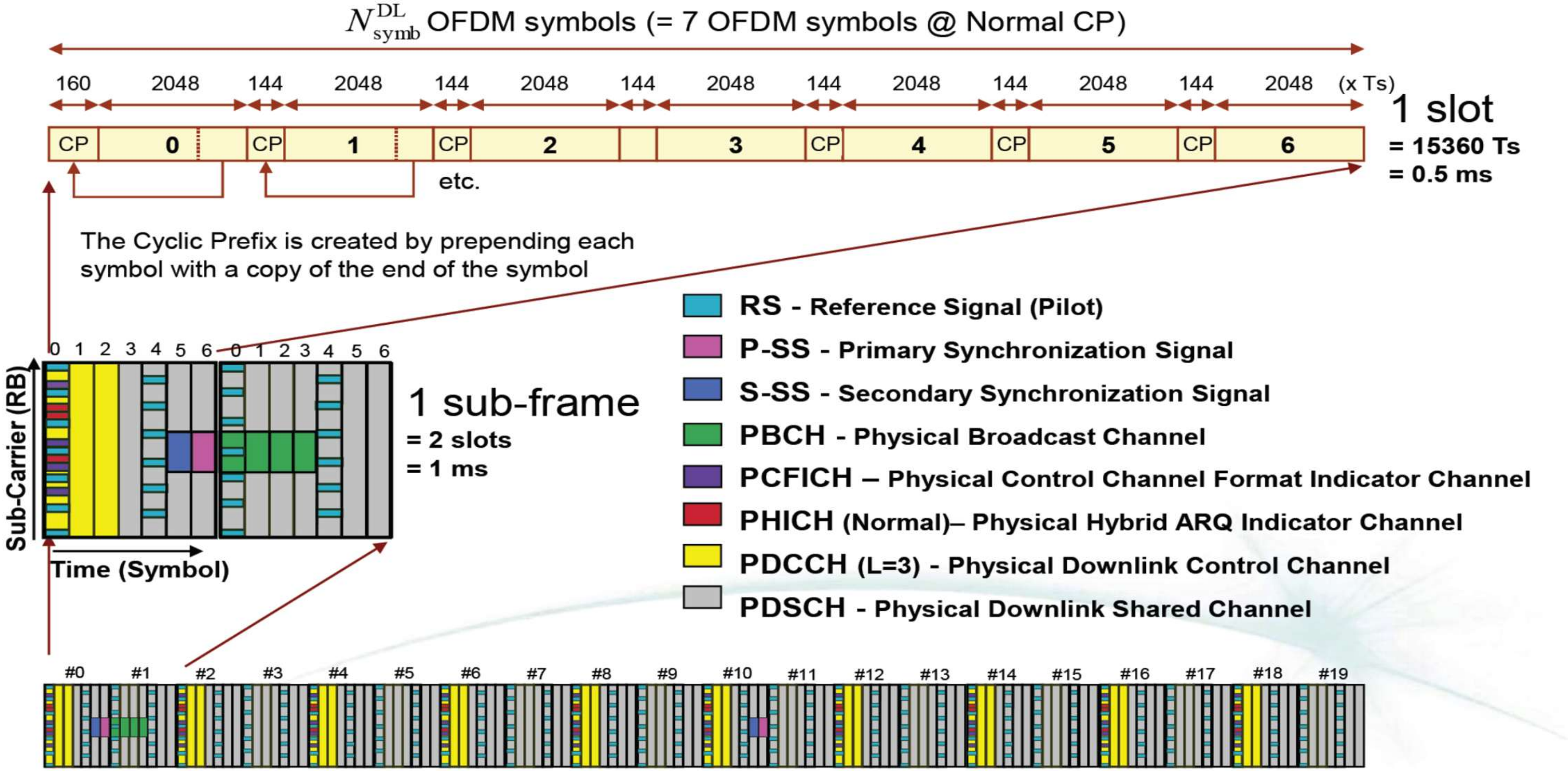
- ***<u>Physical Hybrid ARQ Indicator Channel (PHICH) :</u>*** As the name implies, this channel is used to report the Hybrid ARQ status. It carries the HARQ ACK/NACK signal indicating whether a transport block has been correctly received.
- The HARQ indicator is 1 bit long - "0" indicates ACK, and "1" indicates NACK.
- The PHICH is transmitted within the control region of the sub-frame and is typically only transmitted within the first symbol.
- If the radio link is poor, then the PHICH is extended to a number of symbols for robustness.

PDSCH (Physical Downlink Shared Channel)

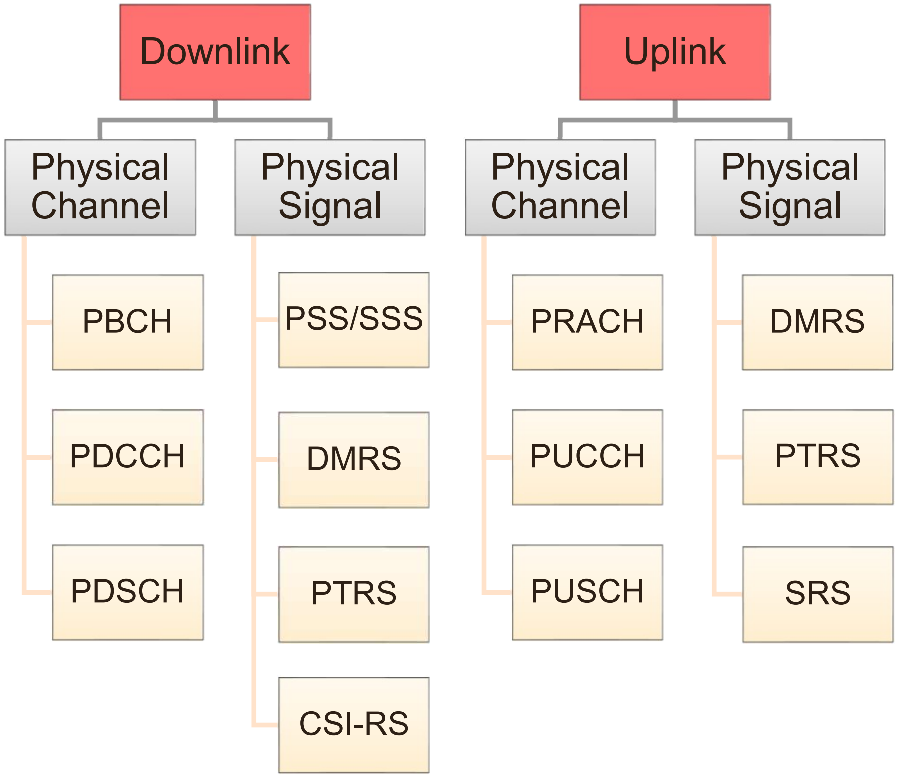
- PDSCH is a physical channel that carries user data.
  - Carries user specific data (DL Payload).
  - Carries Random Access Response Message in case of PDSCH mapped to RACH channel.
  - It can use QPSK, 16 QAM and 64 QAM. modulation scheme for each PDSCH for each user is determined by modulation and coding scheme (MCS) value in **downlink control information**.



Downlink Frame Structure Type 1



NR Physical Channels and Signals Overview



Downlink Physical Channel/Signal Functions	
SS	Used for time-frequency synchronization and cell search.
PBCH	Carries system information to be broadcast.
PDCCH	Transmits control signaling, such as signaling for uplink and downlink scheduling and power control.
PDSCH	Carries downlink user data.
DMRS	Used for downlink data demodulation and time-frequency synchronization.
PTRS	Tracks and compensates downlink phase noise.
CSI-RS	Used for downlink channel measurement, beam management, RRM/RLM measurement, and refined time-frequency tracking.

Uplink Physical Channel/Signal Function	
PRACH	Carries random access request information.
PUCCH	Transmits L1/L2 control signaling, such as signaling for HARQ feedback, CQI feedback, and scheduling request indicator.
PUSCH	Carries uplink user data.
DMRS	Used for uplink data demodulation and time-frequency synchronization.
PTRS	Tracks and compensates uplink phase noise.
SRS	Used for uplink channel measurement, time-frequency synchronization, and beam management.

Time-Frequency Domain Distribution

- **Schedulable and configurable resources through flexible physical channel and signal design.**