3GPP LTE/5G Networks
- PHY Layer -

Kyunghan Lee
Networked Computing Lab (NXC Lab)
Department of Electrical and Computer Engineering
Seoul National University
https://nxc.snu.ac.kr
kyunghanlee@snu.ac.kr

Adapted from Prof. Sunghyun Choi's slides

NXC LAB

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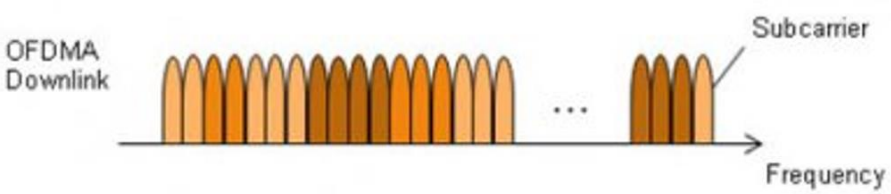
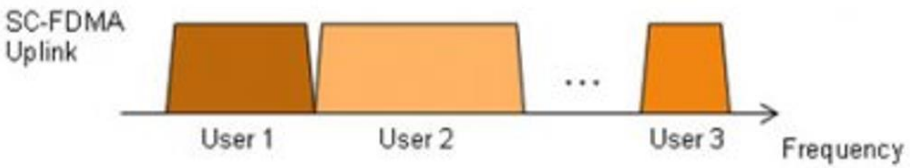
LTE Air Interface

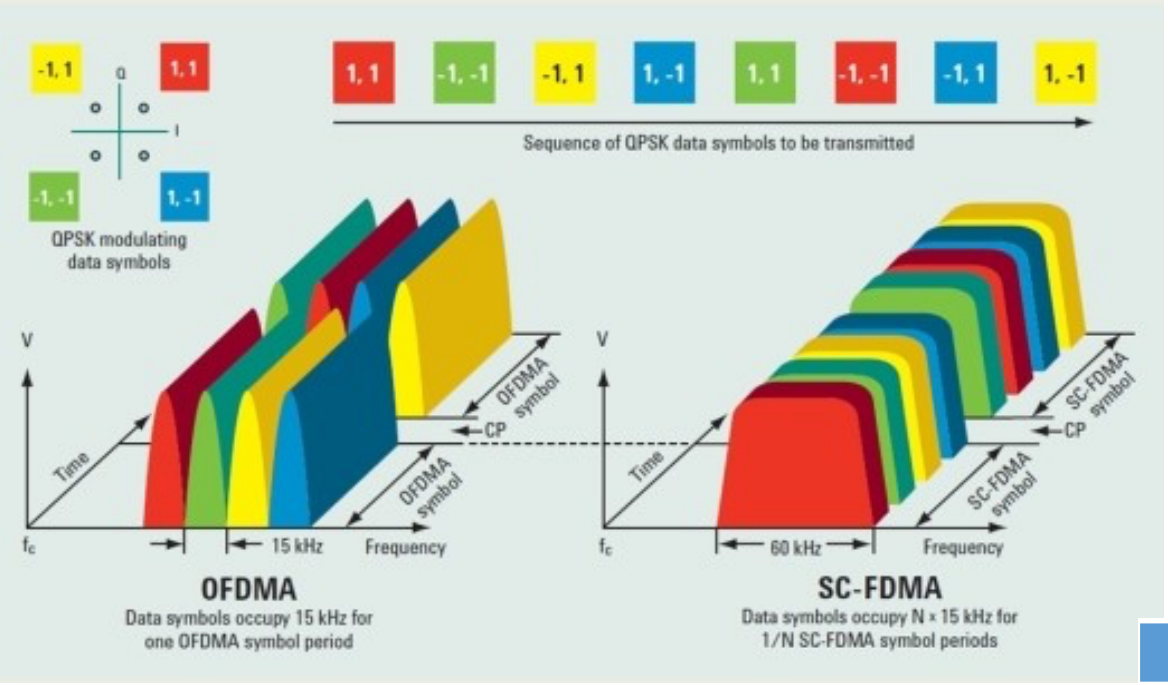
- OFDMA (Orthogonal Frequency Division Multiple Access)
  - Downlink multiplexing (in 5G, OFDMA is optional for uplink)
  - Multicarrier schemes subdivide the used channel bandwidth into a number of parallel sub-channels
  - High spectral efficiency

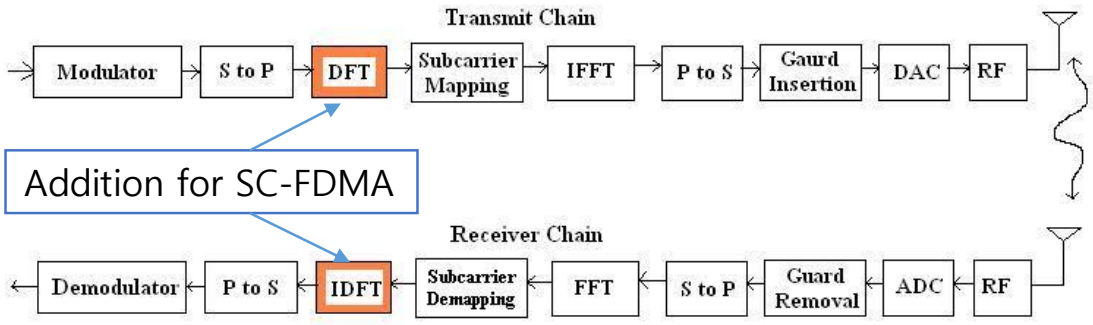


- SC-FDMA (Single Carrier FDMA)
  - Uplink multiplexing
  - Advantage over OFDMA to have lower PAPR (Peak Average Power Ratio), meaning less power consumption and lower cost amp



OFDMA vs SC-FDMA

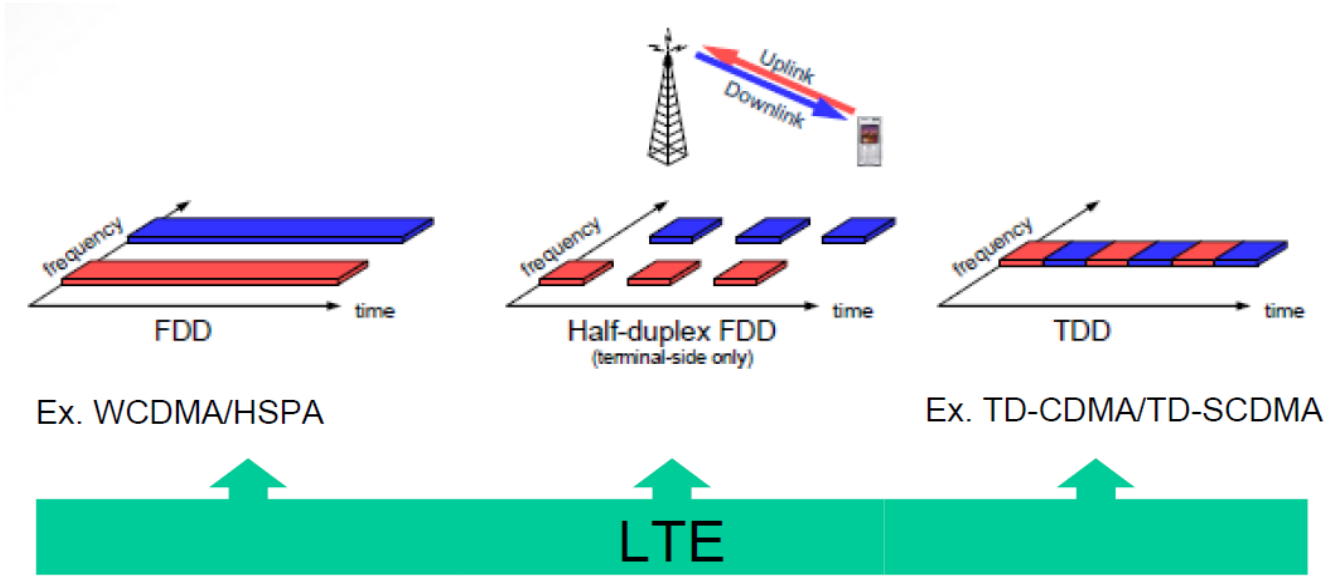




	OFDMA	SC-FDMA
Allocated Subcarrier	Non-contiguous	Contiguous
Spectral Efficiency	High	Low
Frequency Synchronization	High sensitivity	Low sensitivity
PAPR	High	Low
Carried Information over subcarrier	Each subcarrier carries only information related to one specific modulation symbol	Each subcarrier carries information about multiple modulation symbols

Duplexing Scheme

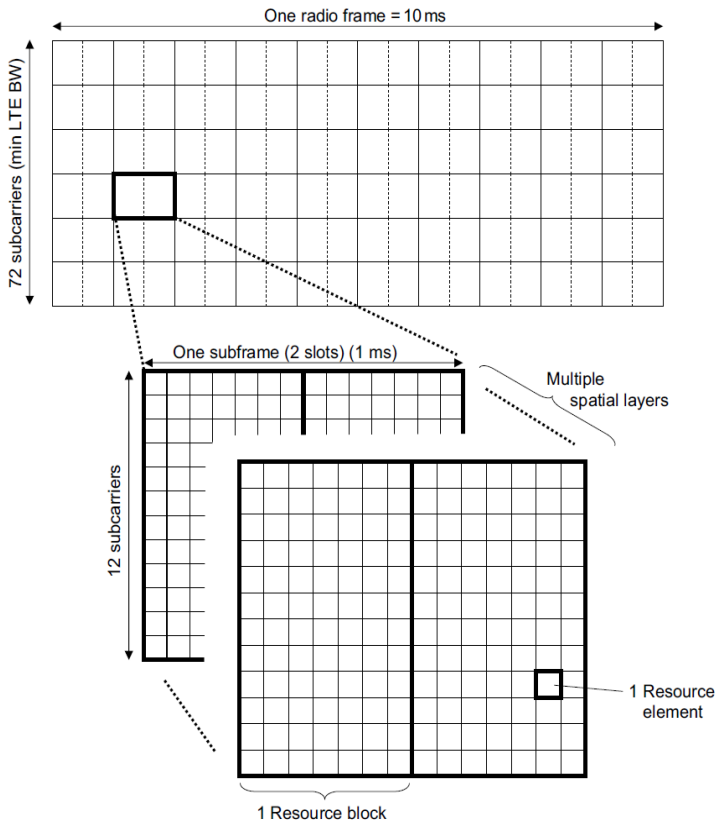
- FDD and TDD



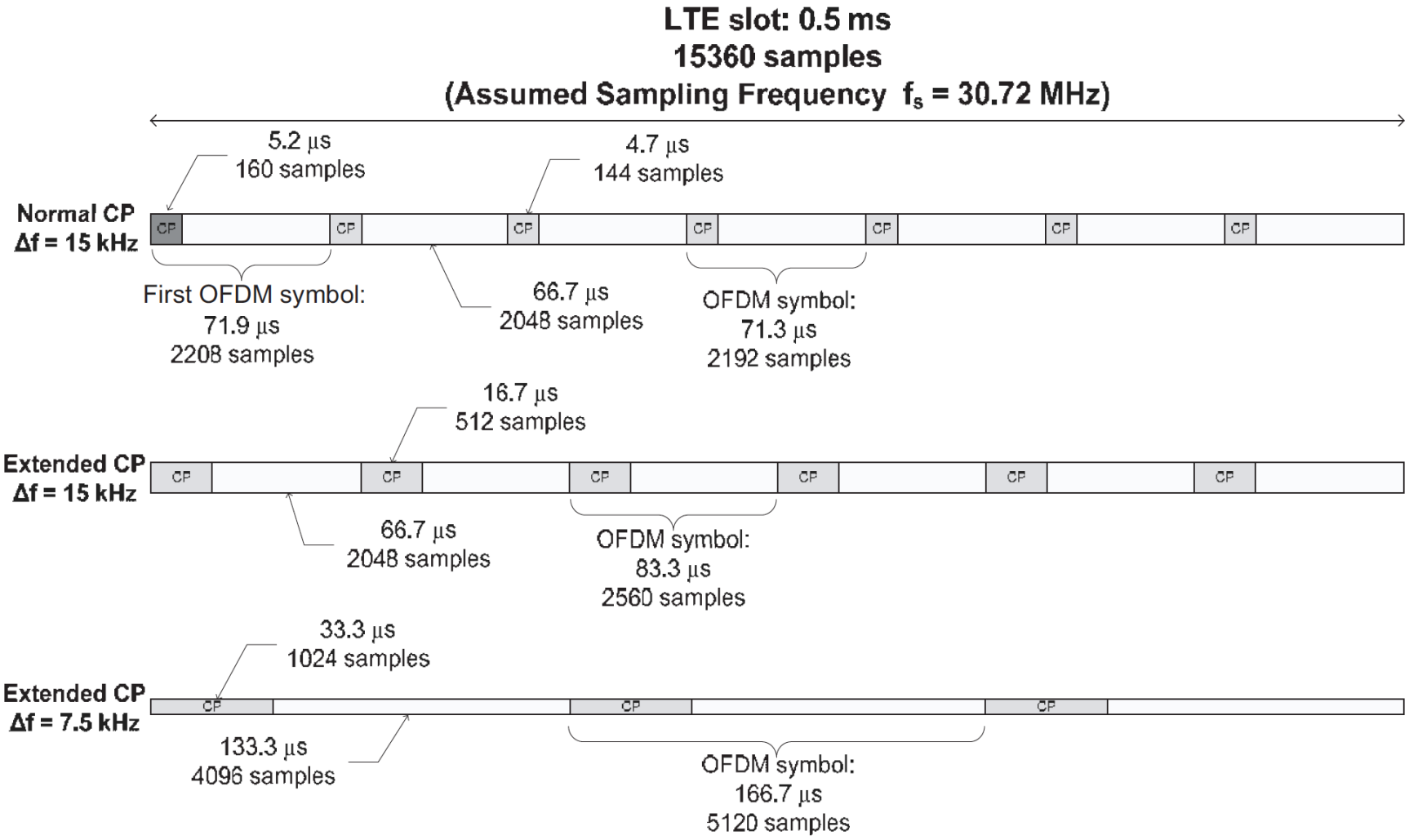
- LTE supports both FDD and TDD within a single radio-access technology

Introduction – Resource Structure

- Resource Element (RE) & Resource Block (RB)
  - 1 slot = 0.5 ms
    = 7 OFDM symbols (normal CP)
    = 6 OFDM symbols (extended CP)
  - Resource Element (RE)
    = 1 OFDM symbol x 1 subcarrier
  - Resource Block (RB)
    = 1 slot x 12 subcarriers
    = 84 or 72 REs
- Some REs are reserved for
  - Synchronization Signals
  - Reference Signals
  - Control signaling and
    critical broadcast system information

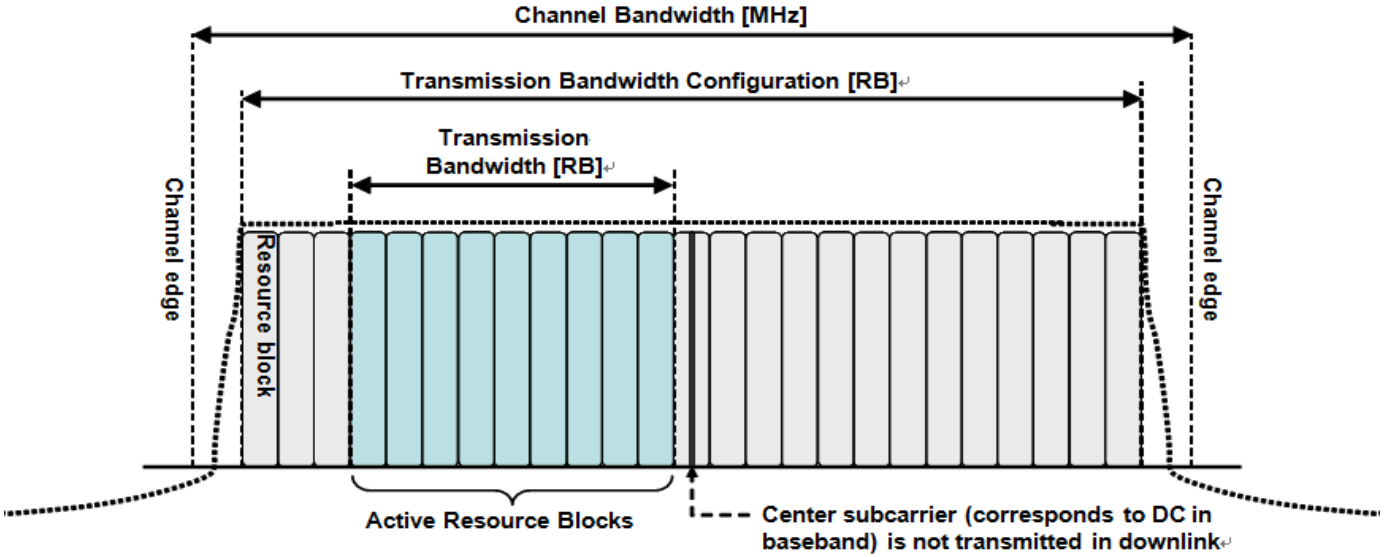


LTE OFDM Symbol and CP Lengths



Resource Structure

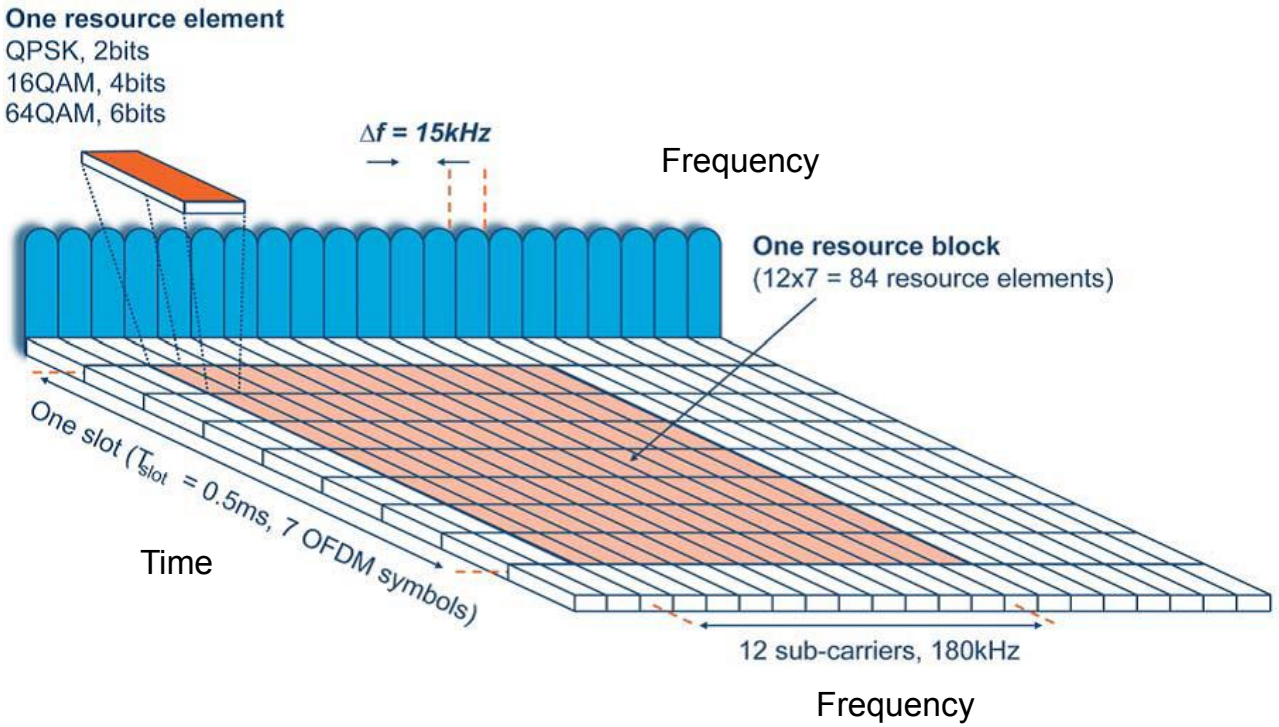
- Resource Block



Channel bandwidth [MHz]	1.4	3	5	10	15	20
Transmission bandwidth configuration N_{RB}	6	15	25	50	75	100

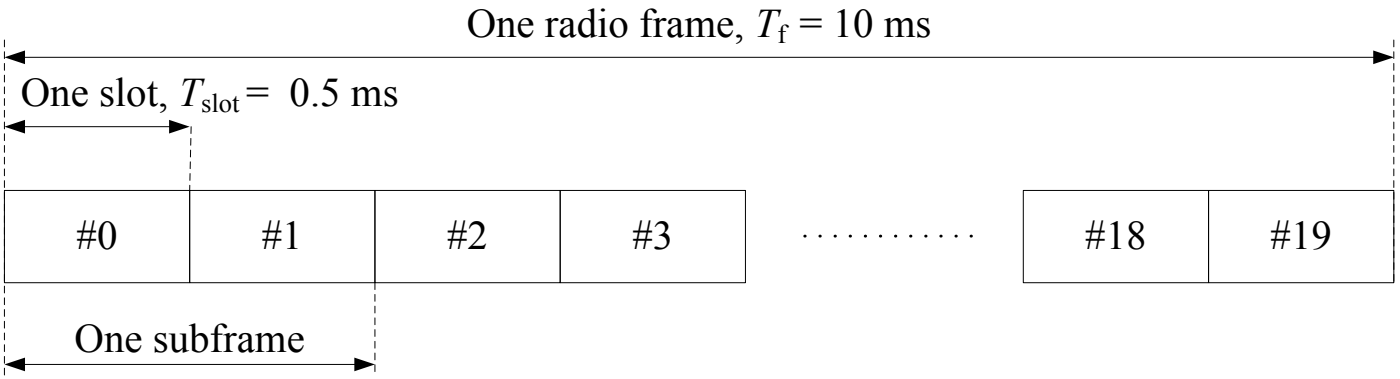
Resource Structure (Frequency)

- Resource Block
  - Subcarrier spacing =15 kHz
  - Resource Block: 180 kHz (15 kHz * 12 subcarriers)



Resource Structure (Time)

- Radio frame
  - 1 subframe = 1 msec = 1 TTI (Transmission Time Interval)
  - 1 radioframe = 10 msec = 10 subframes

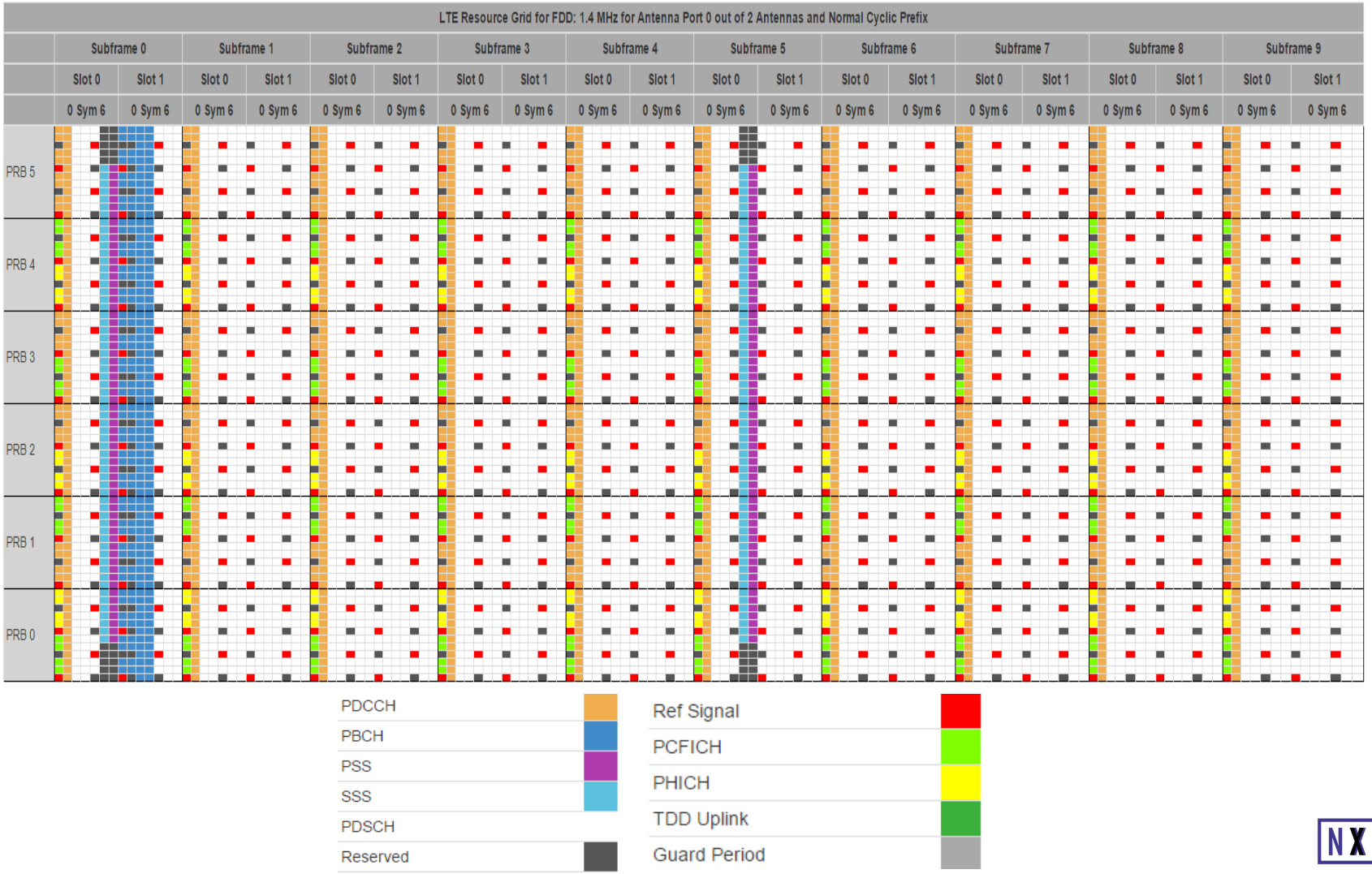


Physical Downlink Channels

- PSCH (Primary Synchronization Channel), SSCH (Secondary Synchronization Channel)
  - Primary or Secondary Synchronization Signal (PSS or SSS) is transmitted
- PBCH (Physical Broadcast Channel)
  - System information is transmitted
- PDCCH (Physical Downlink Control Channel)
  - Control information is transmitted
- PDSCH (Physical Downlink Shared Channel)
  - User data is transmitted
- PCFICH (Physical Control Format Indicator Channel)
  - Indicates the number of symbols to be used for PDCCH
- PHICH (Physical HARQ Indicator Channel)
  - HARQ acknowledgement for UL data

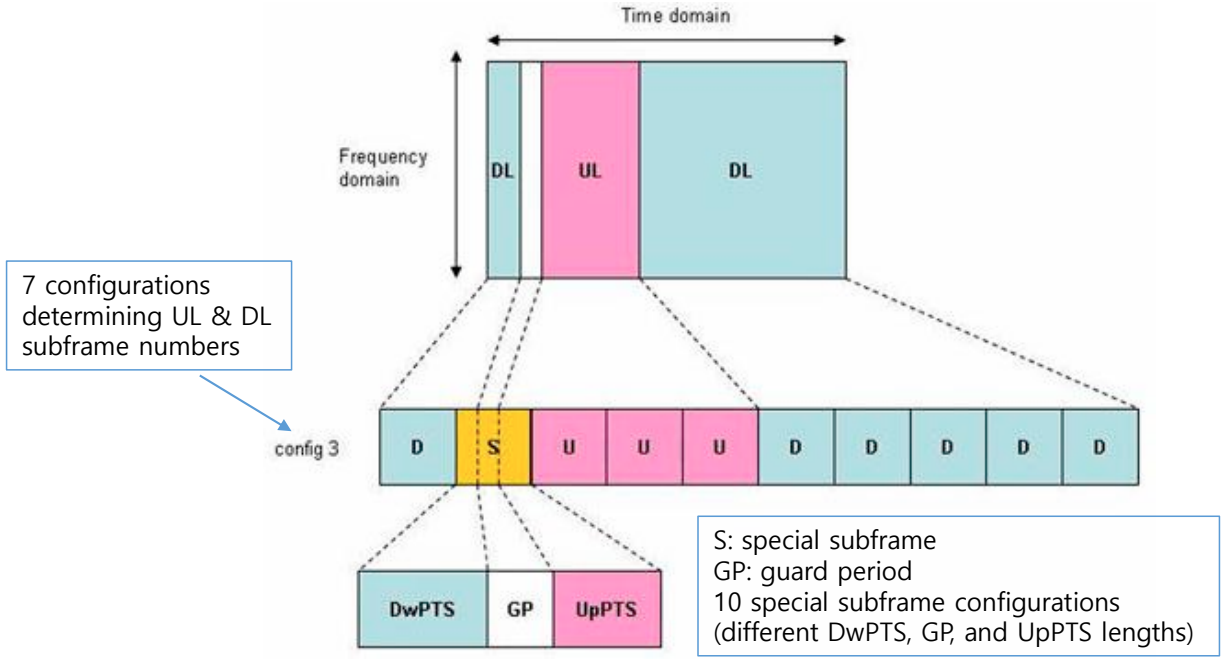
Resource Grid Example (FDD Downlink)

(Source: http://dhagle.in/LTE) 1.4 MHz BW, normal CP, 2 PDCCH symbols, 2 Tx ports



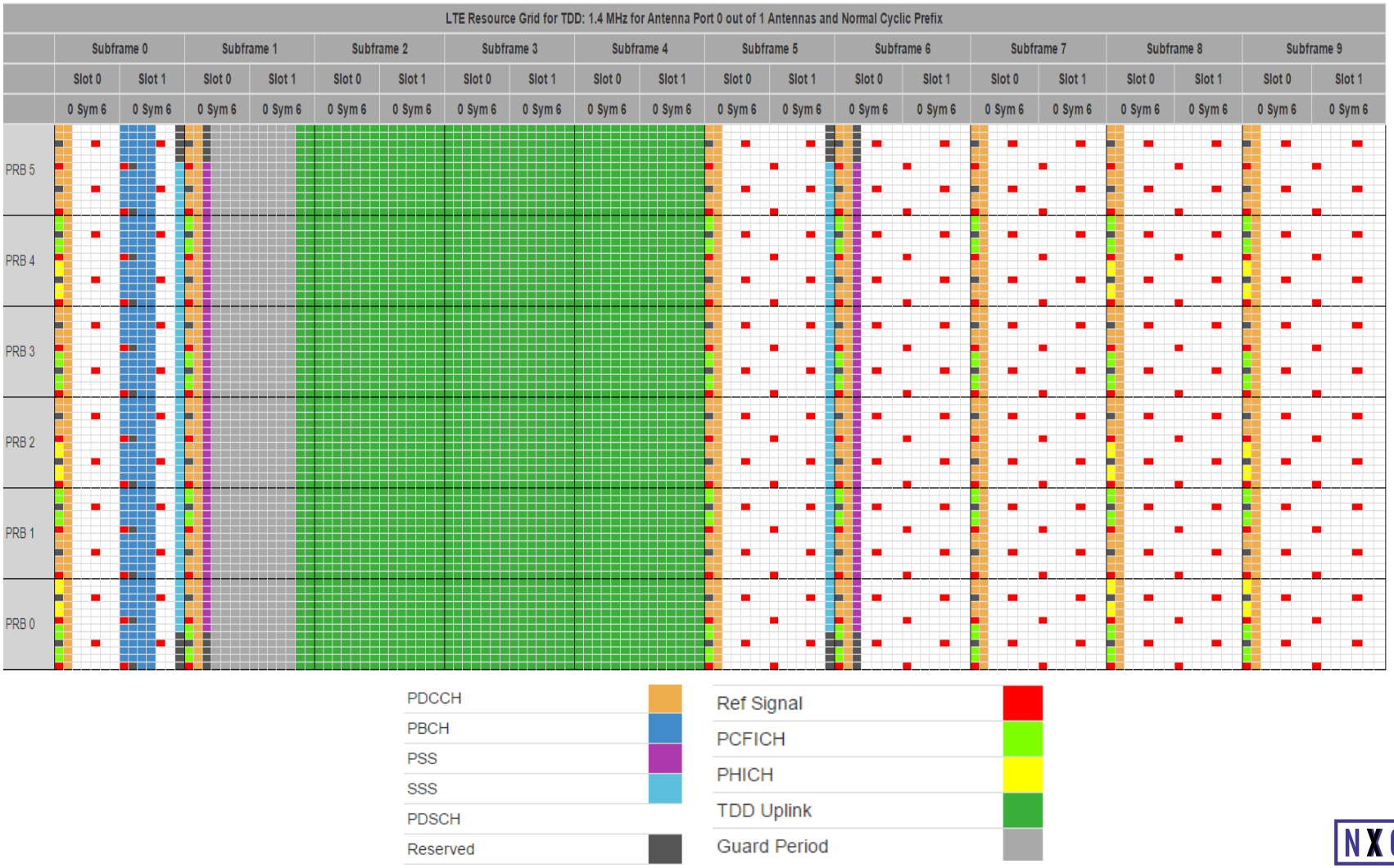
Resource Structure (TDD)

- DwPTS (Downlink Pilot Time Slot)
  - DwPTS contains PSS and PDCCH
  - PDSCH can also be transmitted during DwPTS when DwPTS is configured to be longer than a slot
- UpPTS (Uplink Pilot Time Slot)
  - UpPTS can contain PRACH and SRS, but cannot contain PUCCH or PUSCH



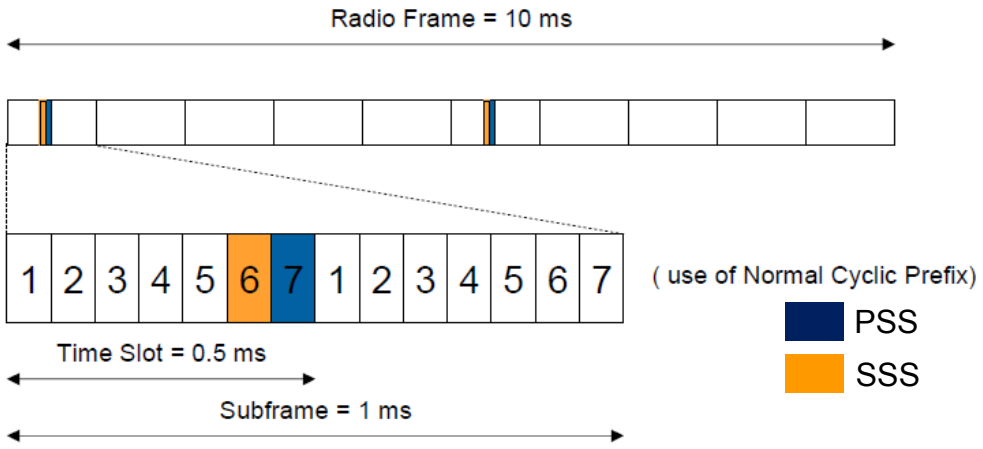
Resource Grid Example (TDD)

- (Source: http://dhagle.in/LTE) 1.4 MHz BW, normal CP, 2 PDCCH symbols, 1 Tx ports)



Synchronization Channels

- PSS (Primary Synchronization Signal)
  - Transmitted within the last symbol of the first slot of subframes 0 and 5
  - Within one cell, the two PSSs within a frame are identical
  - Enables UE to acquire the slot boundary and determine which group of contiguous 7 OFDM symbols belong to a slot
- SSS (Secondary Synchronization Signal)
  - Transmitted within the second last symbol of the same slot just prior to the PSS
  - Two SSSs within a frame are different
  - To obtain Radio frame timing



Broadcast Channels

- Physical Broadcast Channel (PBCH) carries basic system information which allows the other channels to be configured
- Two categories of system info.
  - Master Information Block (MIB) carried on PBCH: most frequently transmitted parameters such as downlink system bandwidth, PHICH size, and 8 MSBs of SFN (System Frame Number), essential for initial access to the cell
  - System Information Blocks (SIBs): multiplexed together with unicast data transmitted on the PDSCH

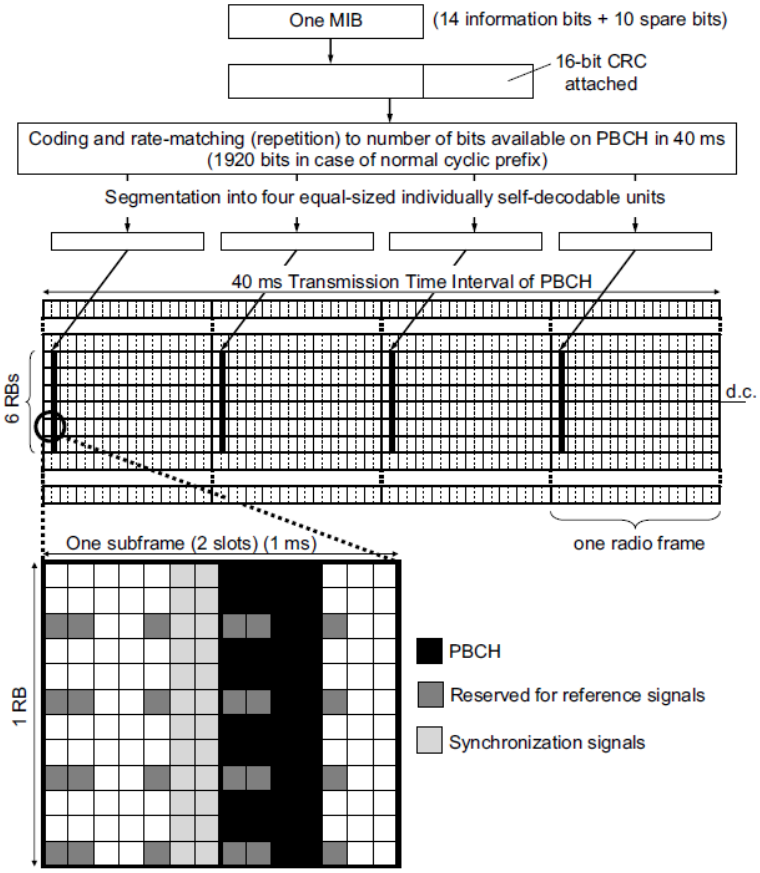
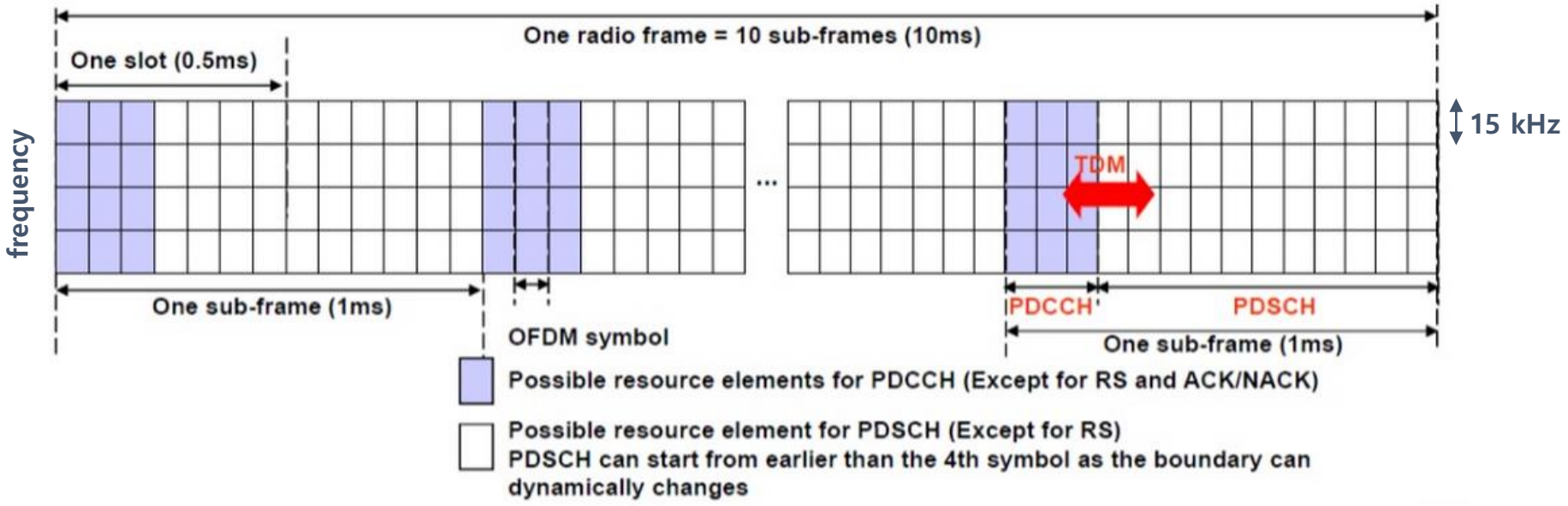


Figure 9.1 PBCH structure.

Downlink Control & Shared Channels

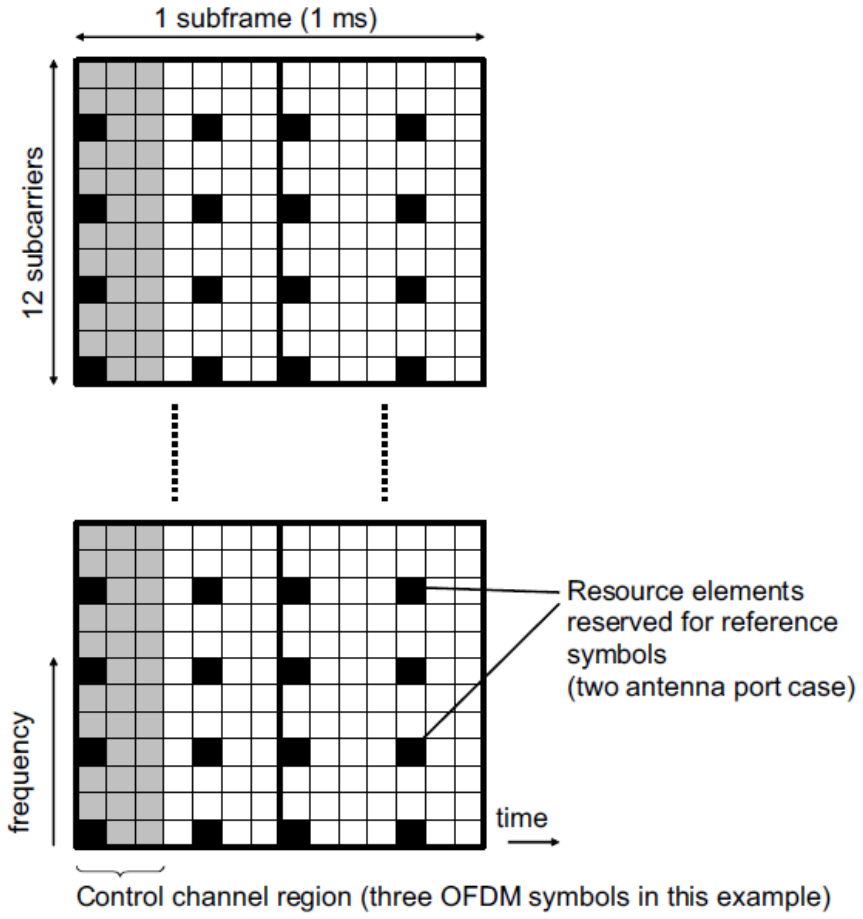
- PDCCH (Physical Downlink Control Channel)
  - Transmit scheduling assignment
- PDSCH (Physical Downlink Shared Channel)
  - Main data bearing channel which is allocated to users



Reference: Jaeho Lee, "Chap. 2. LTE Channel Structure," Aug 03, 2014 (PPT Slides).

Control Channel Structure and Contents

- Downlink control channel
  - Downlink control channels can be configured to occupy the first 1, 2 or 3 OFDM symbols in a subframe, extending over the entire system bandwidth
- Special cases
  - MBSFN (MC/BC Single Freq. Network): 0~2 symbols
  - Narrow system bandwidths: 2~4 symbols



Time-frequency region used for downlink control signaling

Physical Downlink Shared Channel (PDSCH)

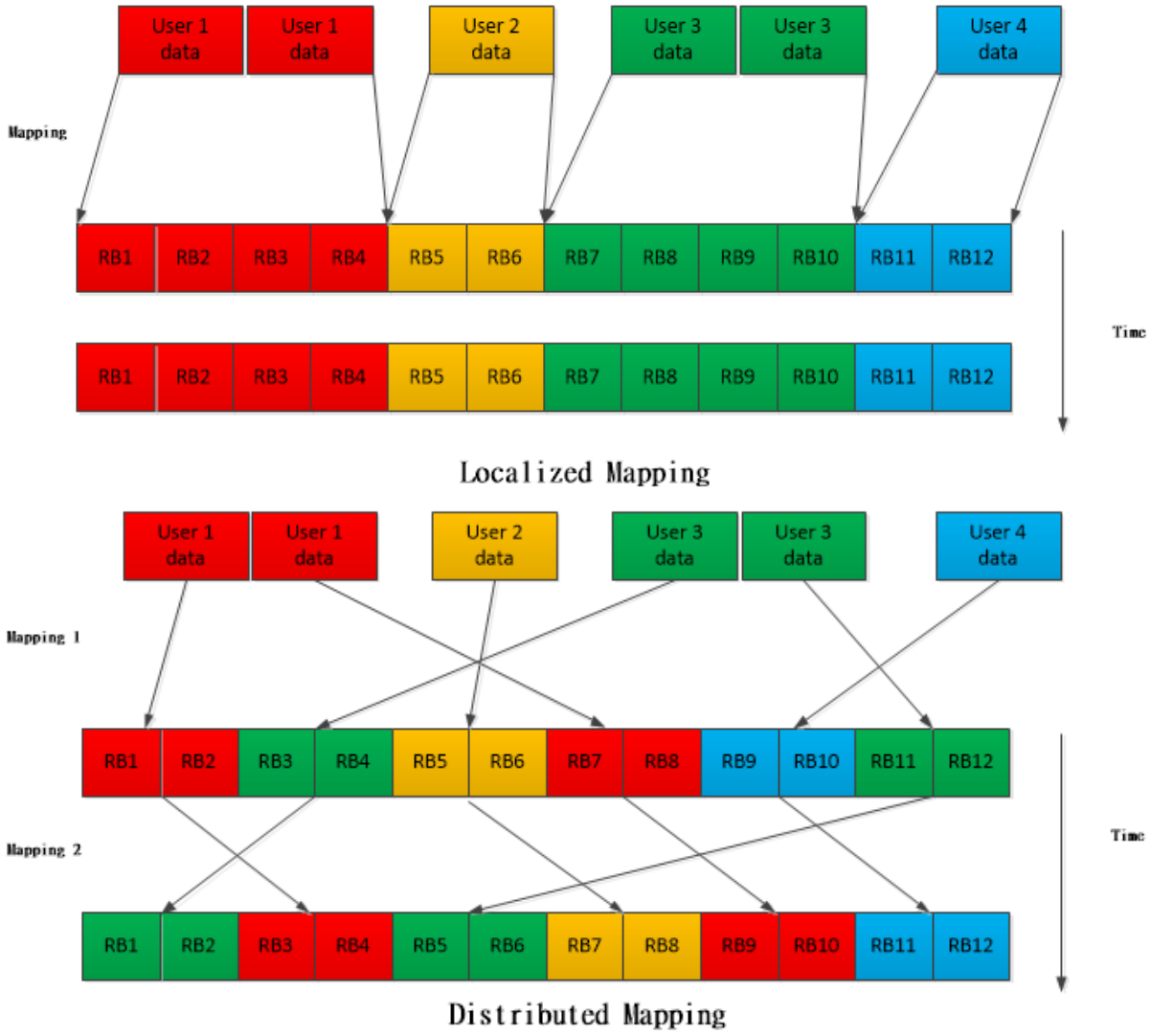
- Used for all user data, as well as for broadcast system information which is not carried on PBCH, i.e., SIBs, and for paging messages

- Various Transmission Modes
  - Transmission Mode 1: Tx from a single eNB antenna port
  - Transmission Mode 2: Transmit diversity
  - Transmission Mode 3: Open-loop spatial multiplexing
  - Transmission Mode 4: Closed-loop spatial multiplexing
  - Transmission Mode 5: Multi-user MIMO
  - Transmission Mode 6: Closed-loop rank-1 precoding
  - Transmission Mode 7: Transmission using UE-specific RSs

Physical Downlink Shared Channel (PDSCH)

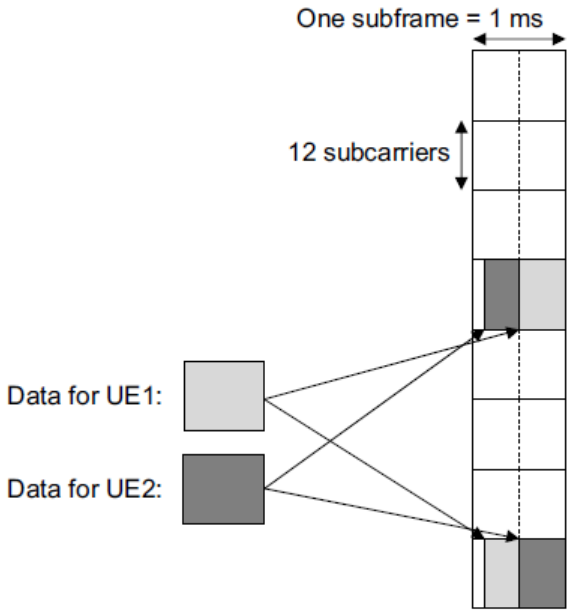
- Two types of mapping of data to physical resource blocks
  - Localized mapping: allocating all the available REs in a pair of RBs to the same UE
    - Suitable for dynamic channel-dependent scheduling according to frequency-specific channel quality information reported by the UE
  - Distributed mapping: separating in frequency the two physical RBs comprising each pair of RBs
    - Frequency diversity for small amount of data
    - An amount of data corresponding to up to two pairs of RBs may be transmitted to a UE in this way
    - Suitable for (semi-)persistent scheduling for VoIP service

Localized and Distributed Mapping



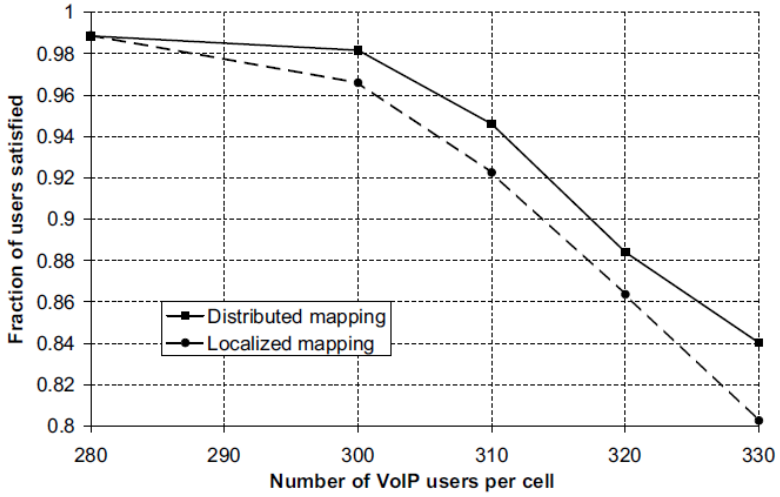
Physical Downlink Shared Channel (PDSCH)

- Potential increase in the VoIP capacity in a cell as a result of using distributed resource mapping



Frequency-distributed data mapping in LTE downlink.

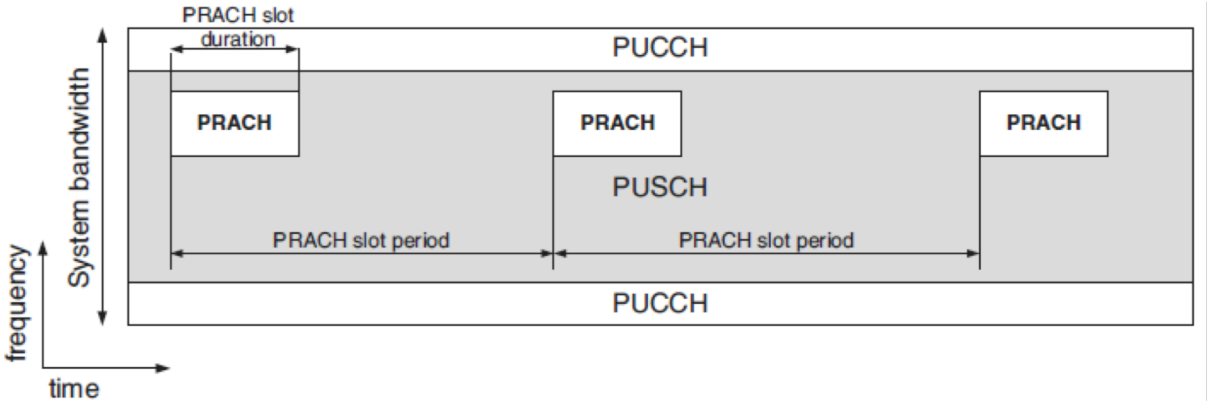
Parameter	Value
Carrier frequency	2 GHz
Bandwidth	5 MHz
Channel model	Urban micro, 3 km/h
Total eNodeB transmit power	43 dBm
VoIP model	12.2 kbps; voice activity factor 0.43
Modulation and coding scheme	Fixed: QPSK, code rate 2/3
Satisfaction criterion	98% packets within 50 ms



Example of increase in VoIP capacity arising from frequency-distributed resource mapping

Uplink Channels

- Physical Random Access Channel (PRACH)
  - Carries minimal information
  - Transmissions on the channel may be lost due to collisions
- Physical Uplink Control Channel (PUCCH)
  - Carries control information or channel status reports
  - At most one PUCCH per UE
- Physical Uplink Shared Channel (PUSCH)
  - Uplink counterpart of PDSCH



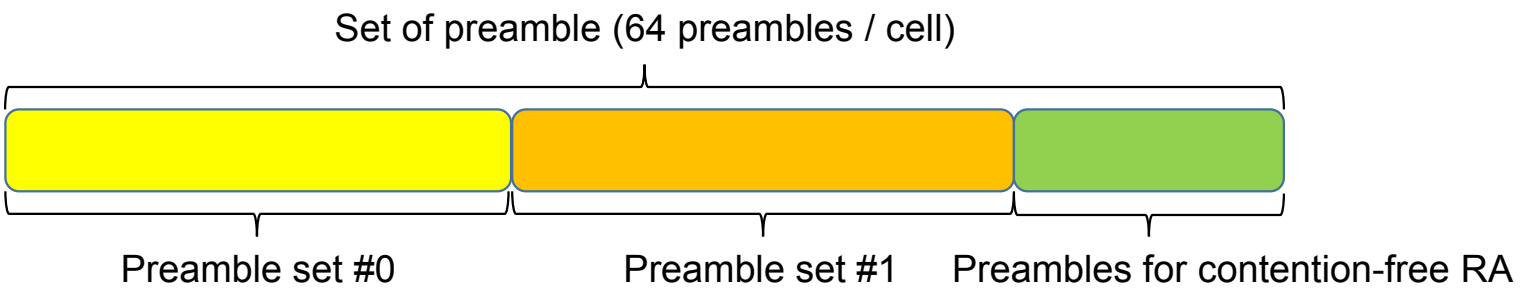
Physical Random Access Channel

- It carries random access preamble
- To achieve uplink time synchronization
  - For a UE which either has not yet acquired, or has lost, its uplink synchronization
  - No uplink synchronization → no uplink communication

- Once uplink synchronization is achieved for a UE, eNB can schedule orthogonal uplink transmission resources for it

Random Access

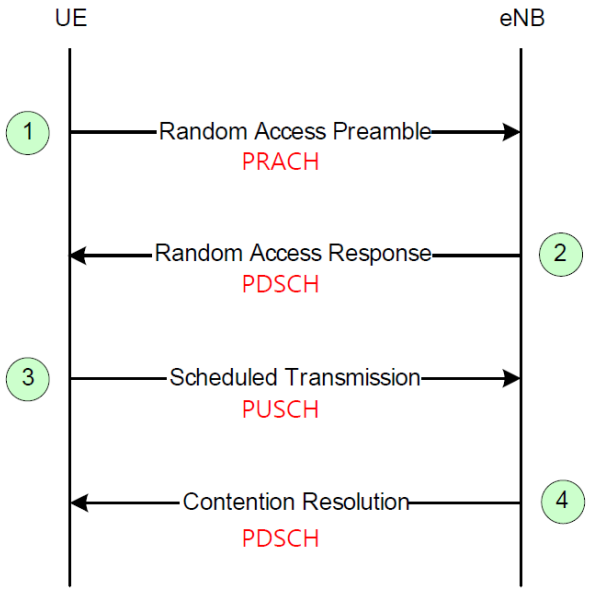
- Contention-based RA
  - Up to 64 preamble sequences
  - Contention resolution is needed
- Contention-free RA
  - eNodeB indicates what preamble to use
  - No contention → faster
  - For special purposes such as Handoff (time critical)



* Resource amount for step 3 is determined depending on preamble tx from either preamble sets #0 or #1

Random Access

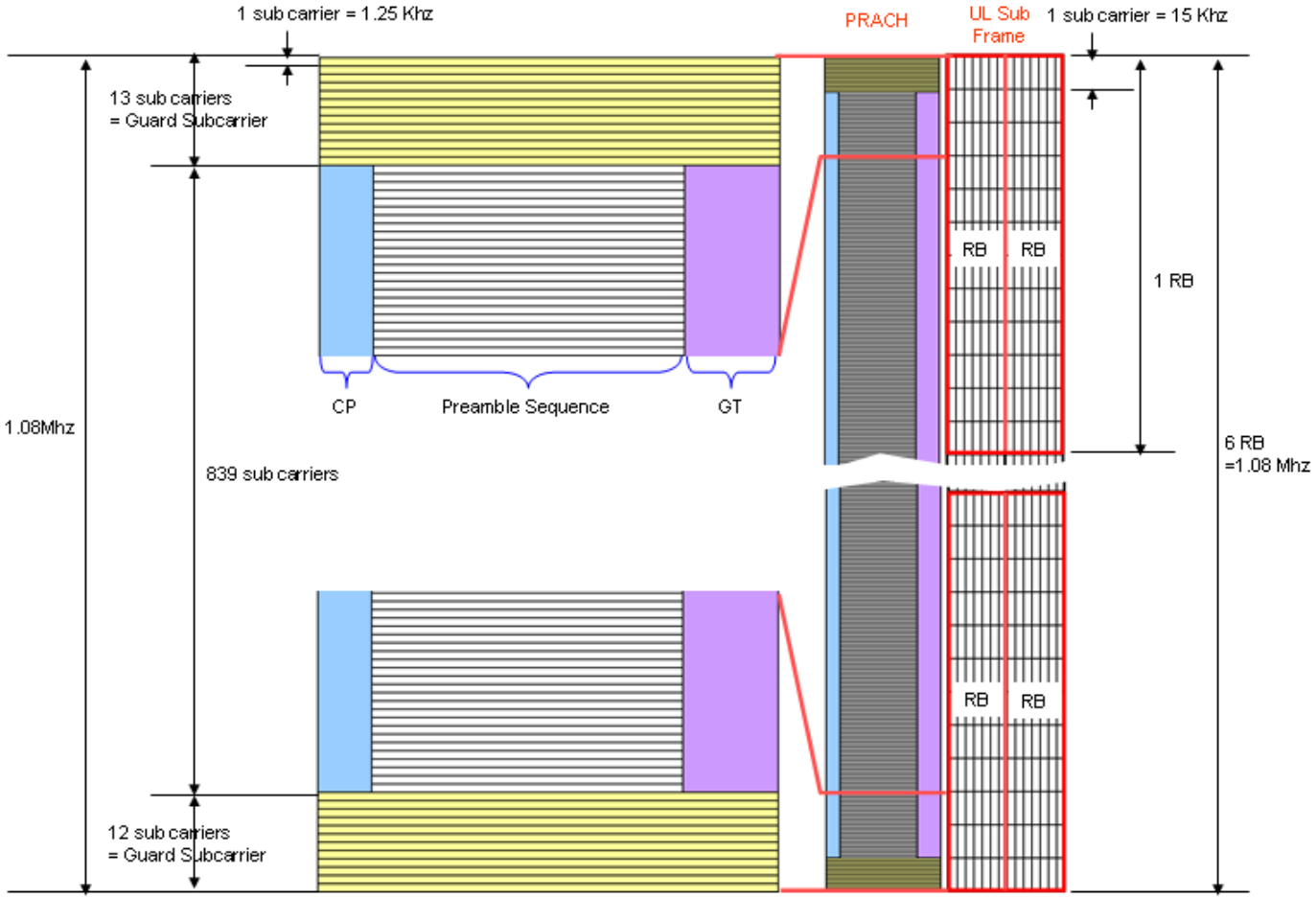
- Contention-based RA



Step 1: Preamble transmission
Step 2: Random access response (RAR)
– includes resource allocation and timing advancement information
Step 3: Layer 2 / Layer 3 message
Step 4: Contention resolution message

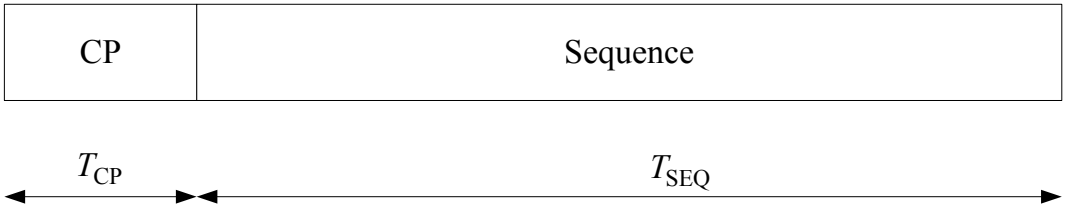
Physical Random Access Channel

- Different subcarrier spacing compared to other channels



Physical Random Access Channel

- Random access preamble used to determine timing advance
  - Zadoff-Chu sequences are used
  - Constant amplitude and zero autocorrelation



Preamble Format	T_{CP} (ms)	T_{SEQ} (ms)	Total length (ms)	# Subframes	Guard Time (ms)	Cell Radius
0	0.103	0.800	0.903	1	0.097	~14 km
1	0.684	0.800	1.484	2	0.516	~75 km
2	0.203	1.600	1.803	2	0.197	~28 km
3	0.684	1.600	2.284	3	0.716	~108 km
4	0.015	0.133	0.148			

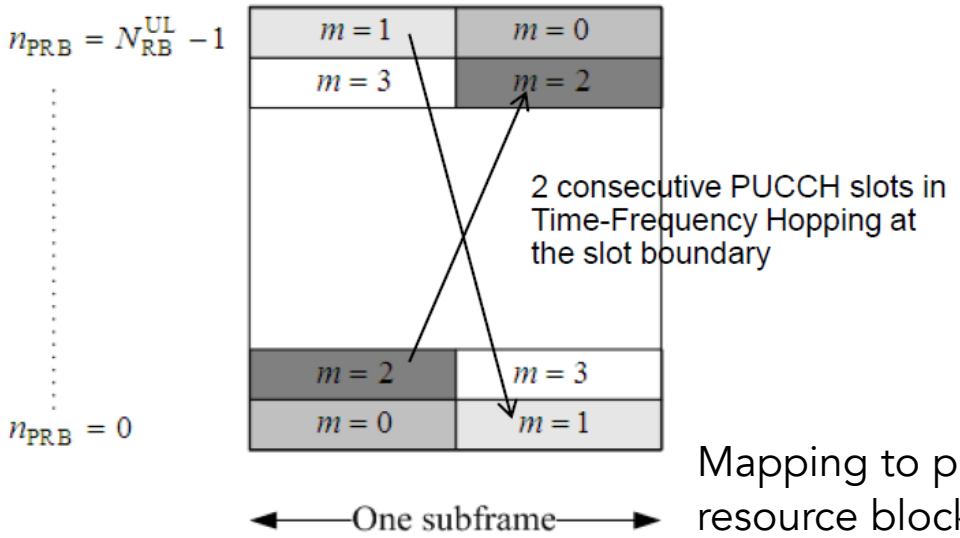
Physical Uplink Control Channel

- Uplink L1/L2 control signaling via UCI (Uplink Control Information) consists of
  - HARQ ACK/NACK for received downlink transport blocks
  - UE reports downlink channel conditions including CQI (Channel Quality Indicator), RI (Rank Indicator), PMI (Precoding Matrix Indicator)
  - Scheduling requests (SR)

- UCI transmission with either PUCCH or PUSCH
  - PUCCH is allocated to a UE as a dedicated control channel
  - UCI, multiplexed together with the uplink data, is transmitted via PUSCH if needed due to single frequency nature

Physical Uplink Control Channel

- PUCCH resources are located at the edges of the spectrum
  - To maximize frequency diversity
  - To retain single-carrier property
- PUCCH is never transmitted simultaneously with PUSCH from the same UE due to single carrier nature



Mapping to physical resource blocks for PUCCH

Physical Uplink Shared Channel

- PUSCH transmission
  - 1 bit indication in UL grant whether frequency hopping or not
  - Localized transmission w/o frequency hopping
  - Localized transmission with frequency hopping
    - - Hopping based on the hopping information in UL grant
    - - Hopping according to a predefined hopping pattern
- Inter/Intra subframe PUSCH hopping
  - Set of PRBs to be used for transmission are given by UL scheduling grant
  - A single bit signaled by higher layers indicates whether PUSCH frequency hopping is inter-subframe only or both intra and inter-subframe

Physical Uplink Shared Channel

- Example for predefined inter-subframe hopping for PUSCH with 20 RBs and M=4

Reference Signals

- An uplink physical signal is used by the physical layer without information originated from higher layers

- Two types of reference signals
  - UL demodulation reference signal (DM RS) for PUSCH, PUCCH
  - UL sounding reference signal (SRS) not associated with PUSCH, PUCCH transmission
  - Uplink reference signals in LTE are mostly based on Zadoff-Chu (ZC) sequences

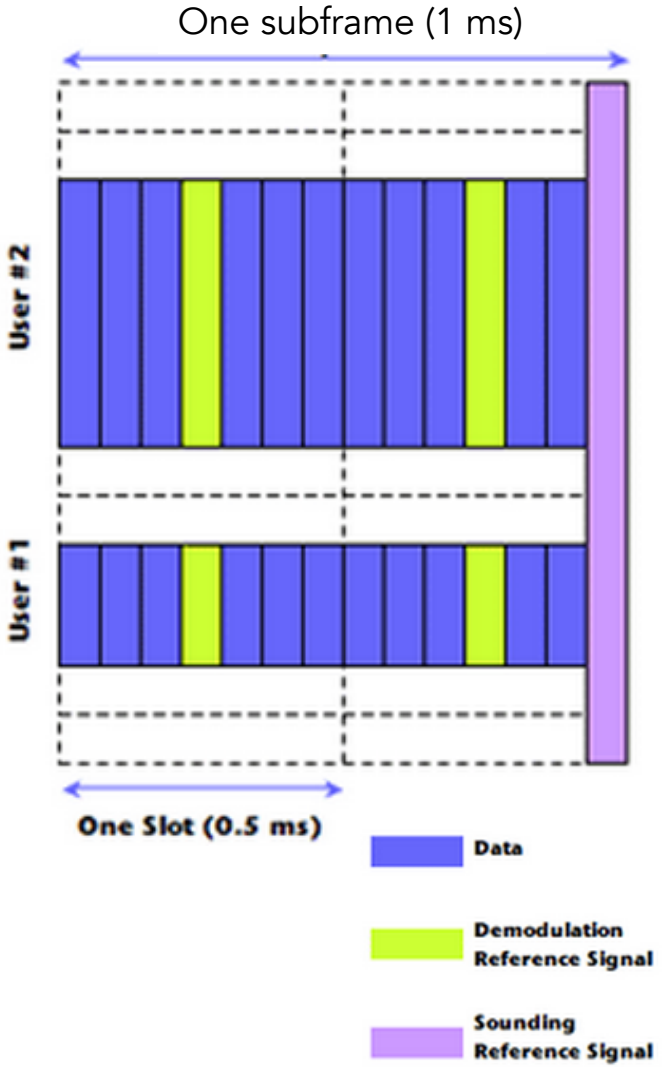
Sounding Reference Signals

- These are transmitted to allow for the network to estimate the uplink channel quality at different frequencies
  - CQ measurement for frequency/time aware scheduling
  - CQ measurement for link adaptation
  - CQ measurement for power control
  - CQ measurement for MIMO
  - Timing measurement

- Not necessarily transmitted together with any physical channel

Demodulation Reference Signal

- Demodulation Reference Signal (DMRS) is used for data reception while sounding reference signal (SRS) is used for scheduling and link adaptation.
- For each UE, DM RS for PUSCH is transmitted over bandwidths where its PUSCH is scheduled
- Different cyclic shifts can be used in different slots of a subframe
  - For extended CP, PUSCH DM RS is located at the 3rd SC- FDMA symbol
  - For normal CP, PUSCH DM RS is located at the central of one SC-FDMA symbol



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