LTE:

A feature based introduction

LTE Core Features

LTE Radio Primer

Irfan Ali

info@ikiteknoloji.com

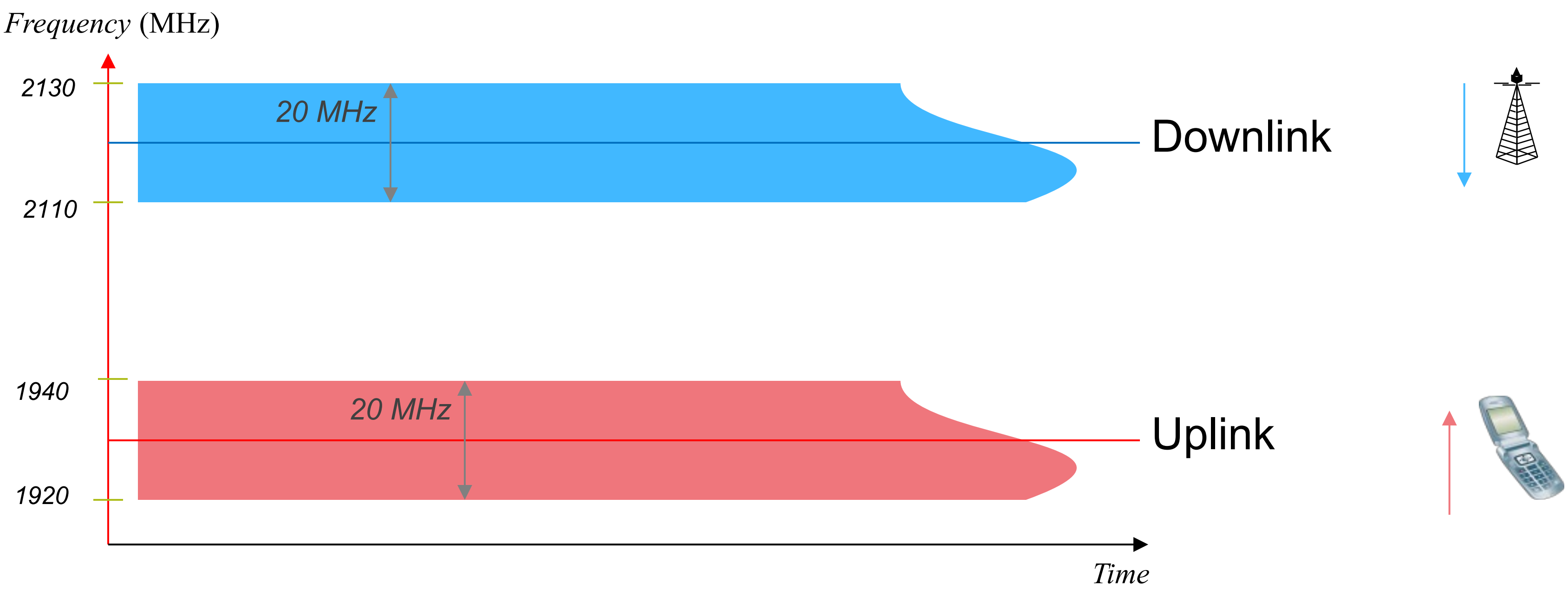
Overview

- **Downlink**: How are control and data information sent to multiple mobiles?
  - OFDM
  - Downlink Radio Frame Structure
  - In a sub-frame, how does a mobile know where to look for data.
  - Logical Channels and Physical Channels
  - Radio Protocol stack
  - Channel signal strength measurement

- **Uplink:** How is control and data information received from multiple mobiles?
  - SC-FDMA
  - Uplink Radio Frame Structure
  - Radio Frame Synchronization (Timing Advance)
  - Physical Channels and Logical Channels
  - Uplink Reference Signal Transmission

When does the base-station talk and when do the mobiles talk?

- The question is when and “where” in the time-frequency domain.
- LTE supports two duplexing modes:
  - Frequency Division Duplexing (FDD)
  - Time Division Duplexing (TDD)



Frequency Division Duplexing

What if OFDM

- OFDM = Orthogonal Frequency Division Multiplexing
- What are orthogonal functions?
  - Two functions $h_1(t)$ and h_2(t) are orthogonal over an interval $[0,T]$, if

$$\boxed{\langle h_1, h_2 \rangle = \int_0^T h_1(t) h_2(t) dt = 0}$$

  - Set of functions $\{h_1(t)$, $h_2(t)$,…, $h_n(t)$ } are mutually orthogonal, if

$$\langle h_i, h_k \rangle = 0, \text{if } i \neq k, \text{ and } \langle h_i, h_i \rangle = m_i$$

  - If $g(t) = \alpha_1 h_1(t) + \alpha_2 h_2(t) + \ldots + \alpha_n h_n(t)$, for $[0,T]$, then

$$\boxed{\langle g, h_i \rangle = \langle \alpha_i h_i, h_i \rangle = \alpha_i \ m_i, \quad \text{for } i = 1..n}$$

Orthogonal cosine functions

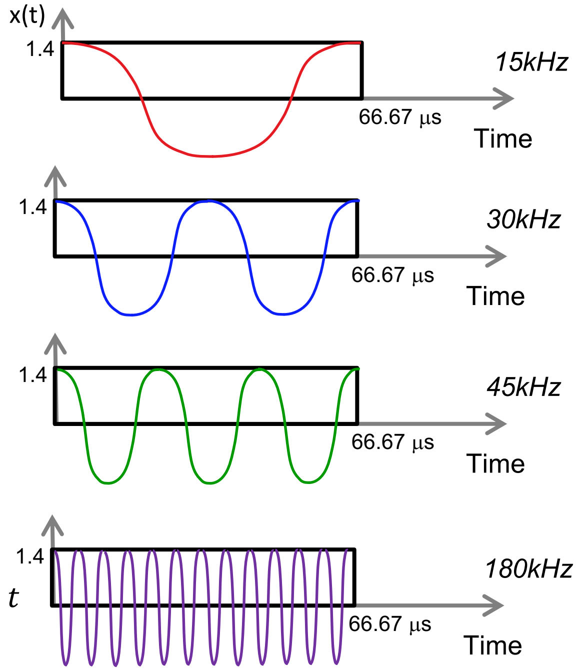
- Harmonics (multiples) of cosine functions of frequency f_0, are
- Let f_0 = 15 kHz , T = 66.67 µs

$h_1 = \sqrt{2}\cos 2\pi f_0 t$

$h_2 = \sqrt{2}\cos 2\pi .2 f_0\, t$

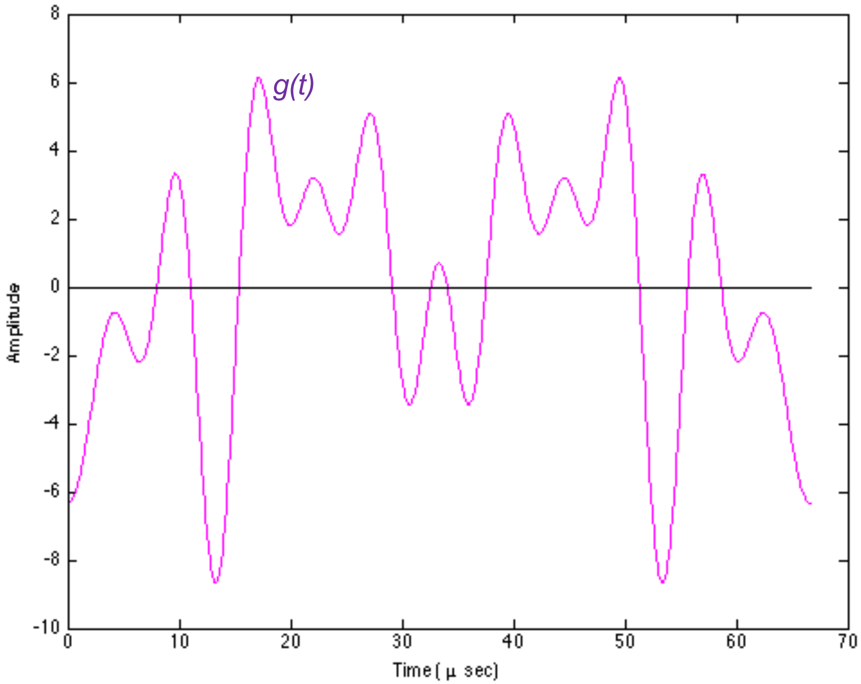
$h_3 = \sqrt{2}\cos 2\pi .3 f_0\, t$

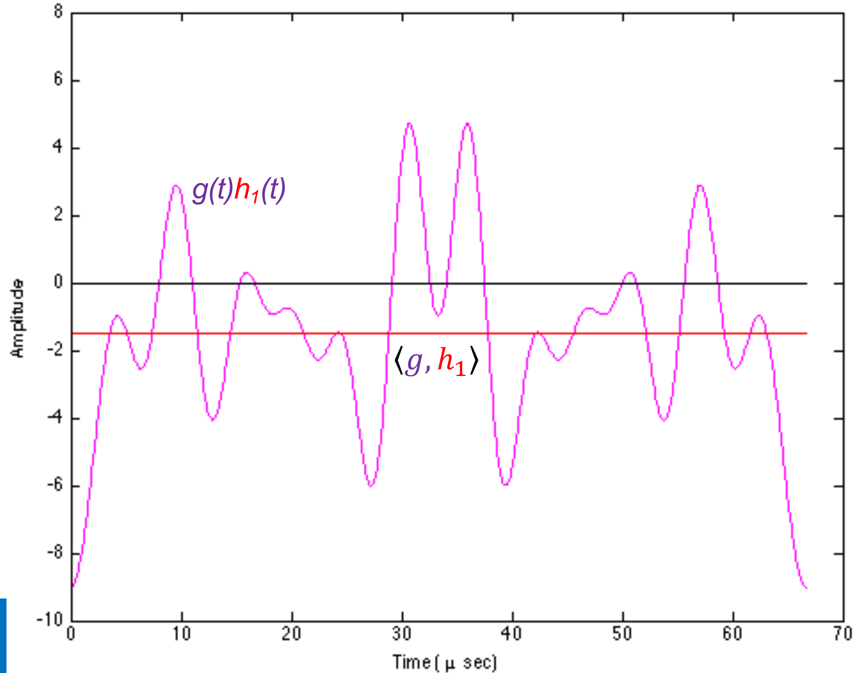
$h_{12} = \sqrt{2}\cos 2\pi .12 f_0\, t$



$g = -1.5\, h_1 + rand(1,-1)h_2 + \cdots + rand(1,-1)h_{12}$

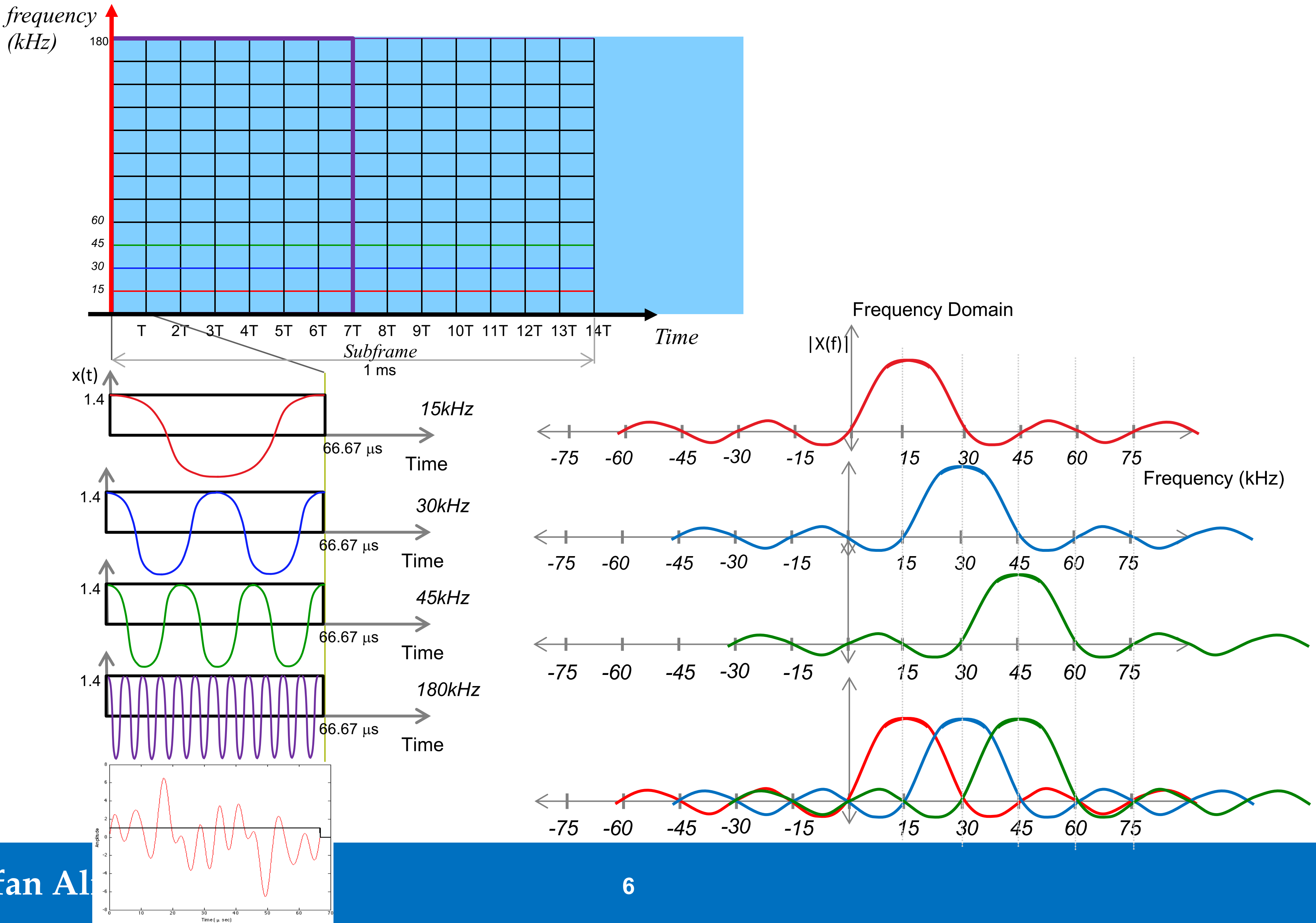
$\langle g, h_1 \rangle$



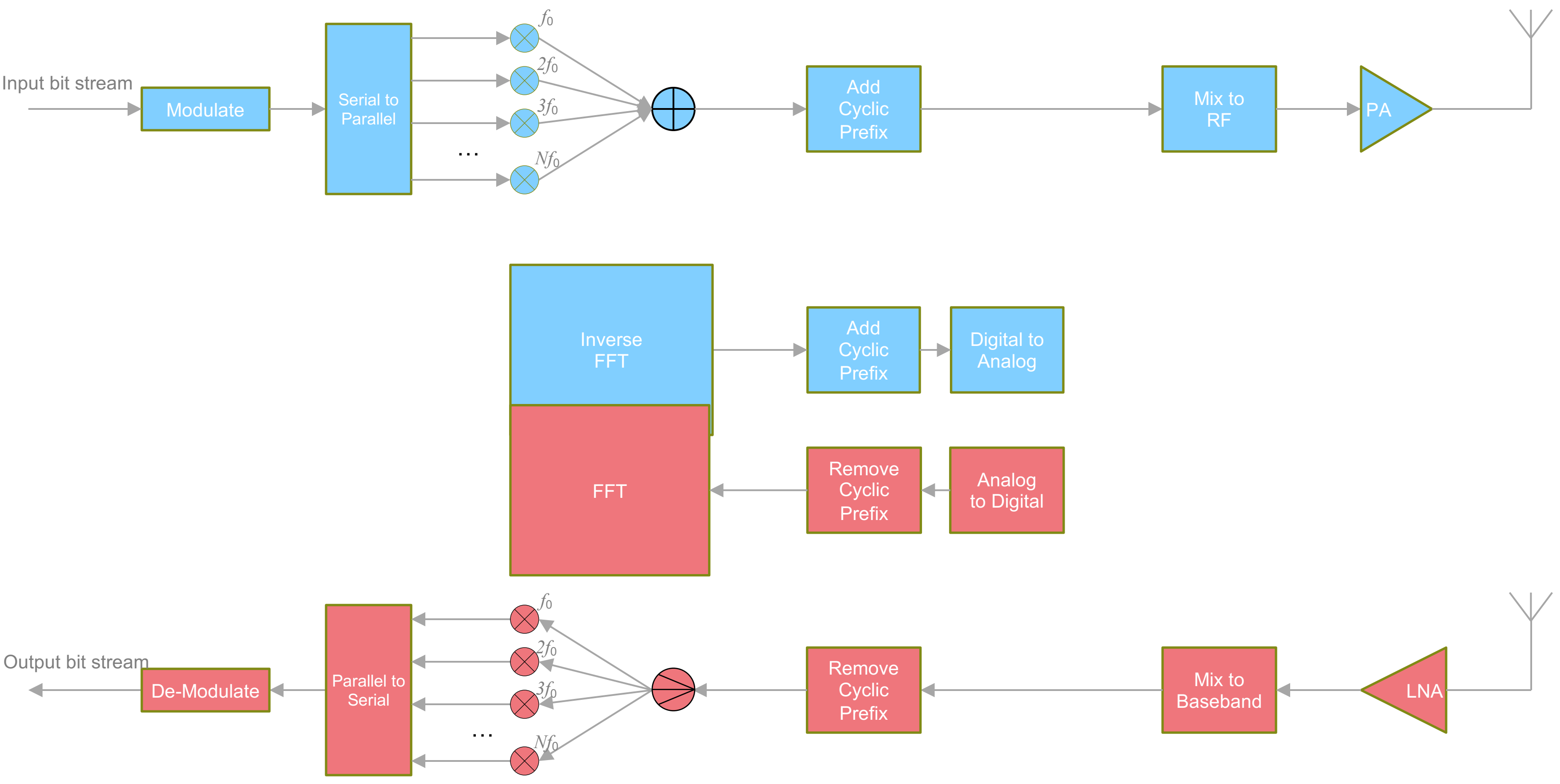


What is OFDM

- Orthogonal Frequency Division Multiplexing



How is OFDM signal generated?



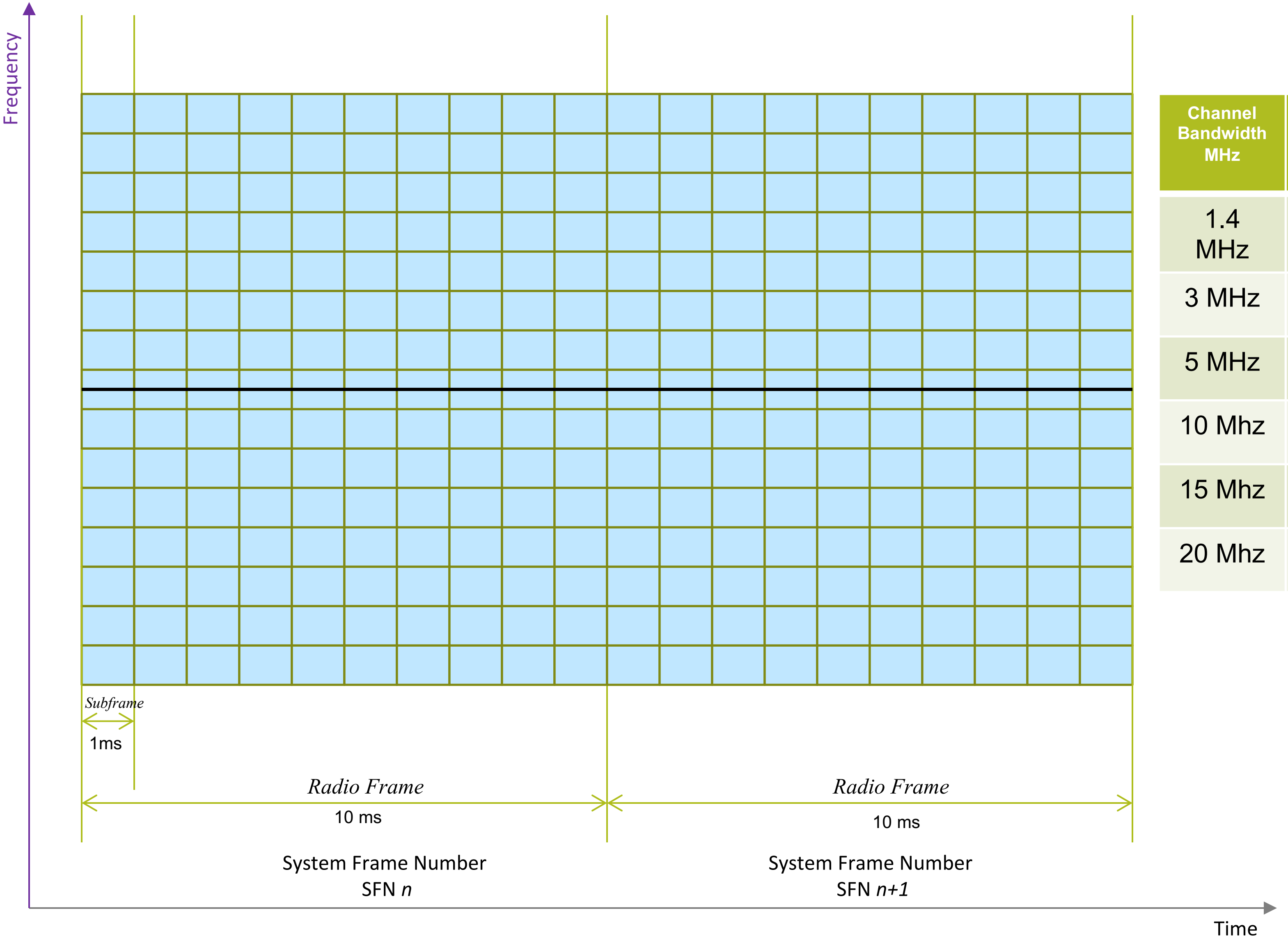
Why OFDM?

- The OFDM symbols duration is relatively long (66.67 μs), which allows one to add time-gap (preamble) to handle relatively long delay-spread of the channel (5 μs ~ 1.5 km) without loosing much capacity.
    - Reduced inter-symbol interference

- Multiple sub-carriers (rather than a single carrier) over large bandwidths (20 MHz) enable to handle channel-fades over these large bandwidths.

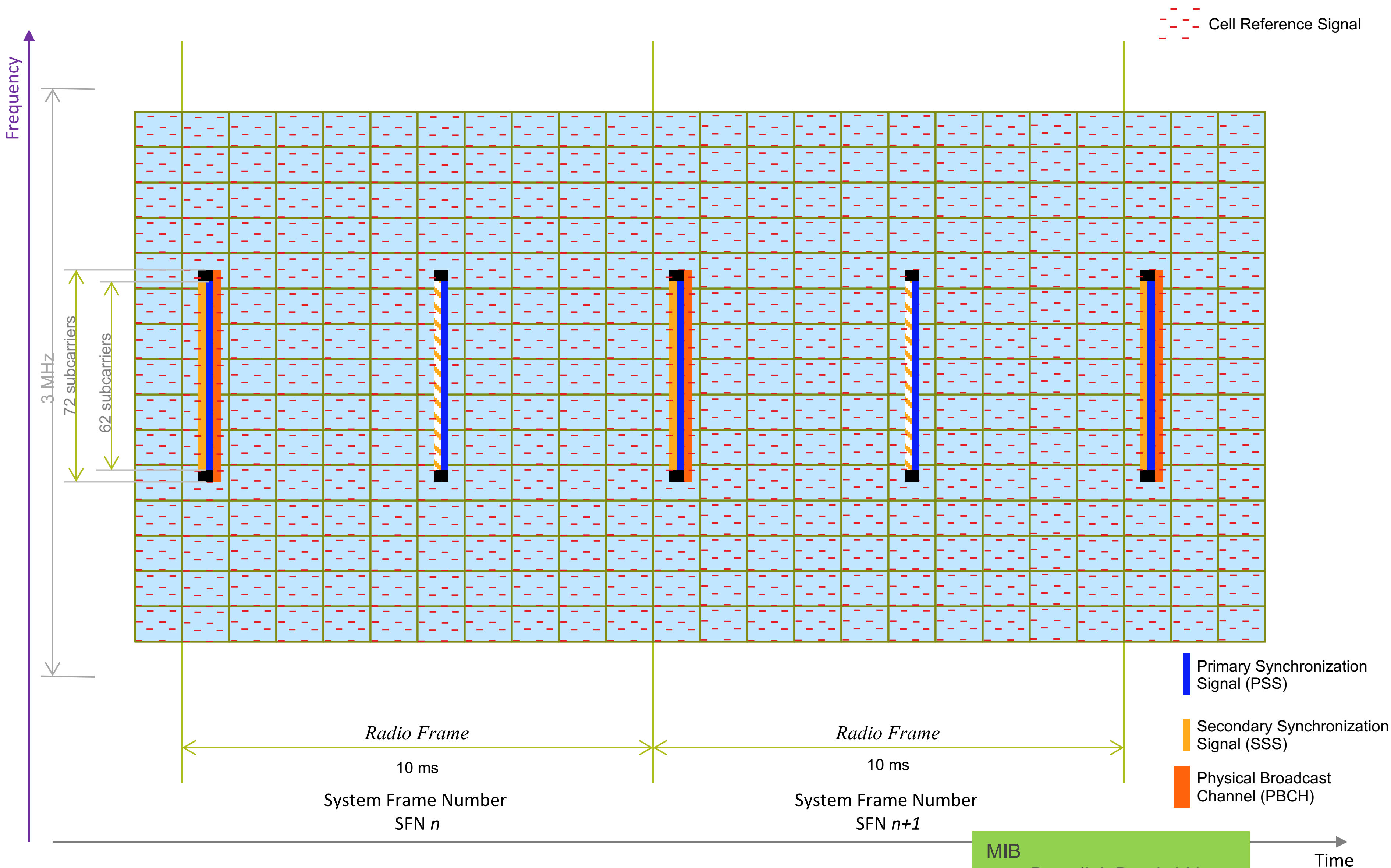
- Increased processing capability.

LTE Downlink Frame Structure



Channel Bandwidth MHz	# Resource Blocks in Frequency Domain	Total Subcarrier Bandwidth MHz
1.4 MHz	6	1.095
3 MHz	15	2.715
5 MHz	25	4.515
10 Mhz	50	9.015
15 Mhz	75	13.515
20 Mhz	100	18.015

Synchronizing to DL Radio Frame



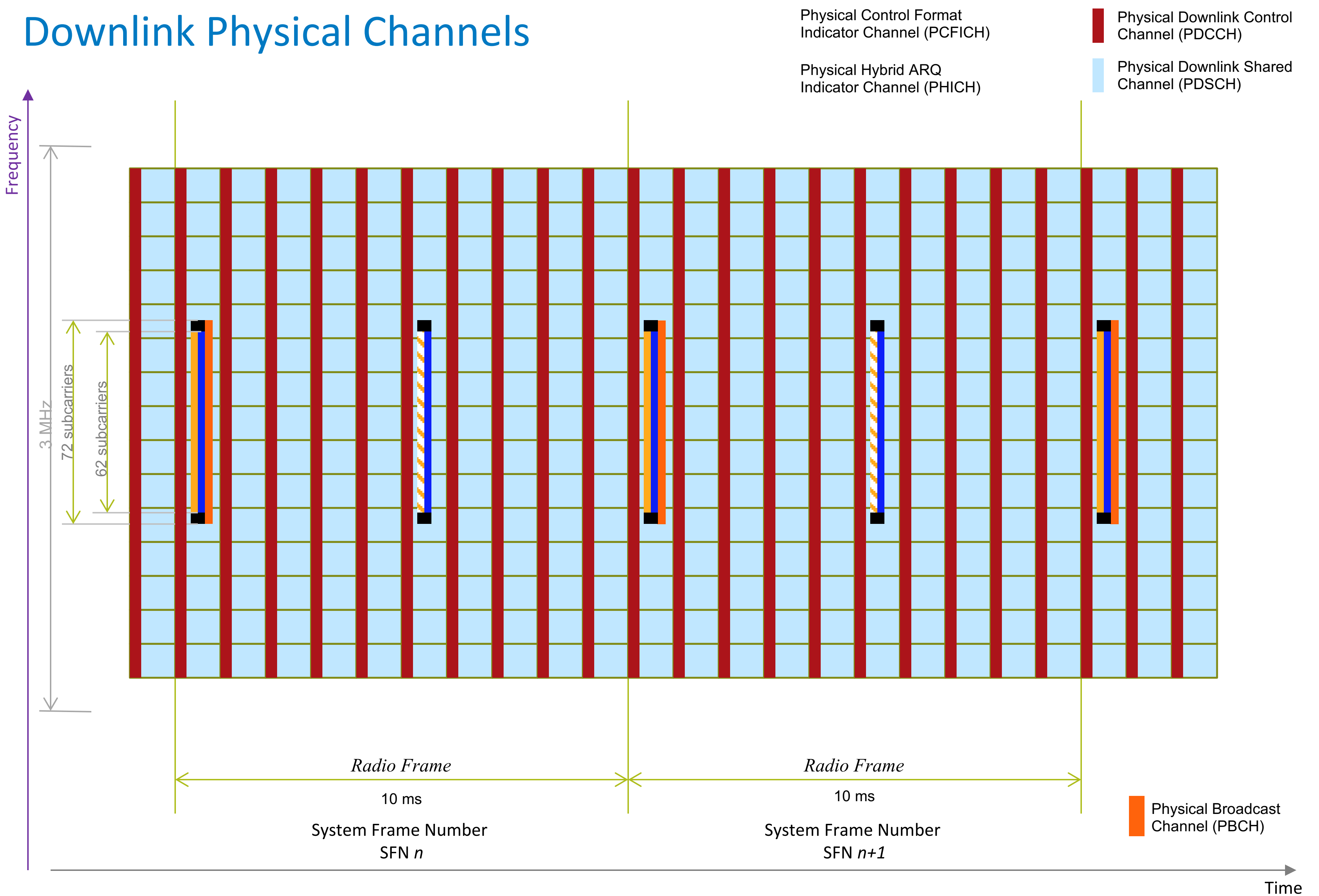
MIB
- Downlink Bandwidth
- System Frame Number
- PHICH Configuration

PHICH Physical Hybrid ARQ Indicator Channel

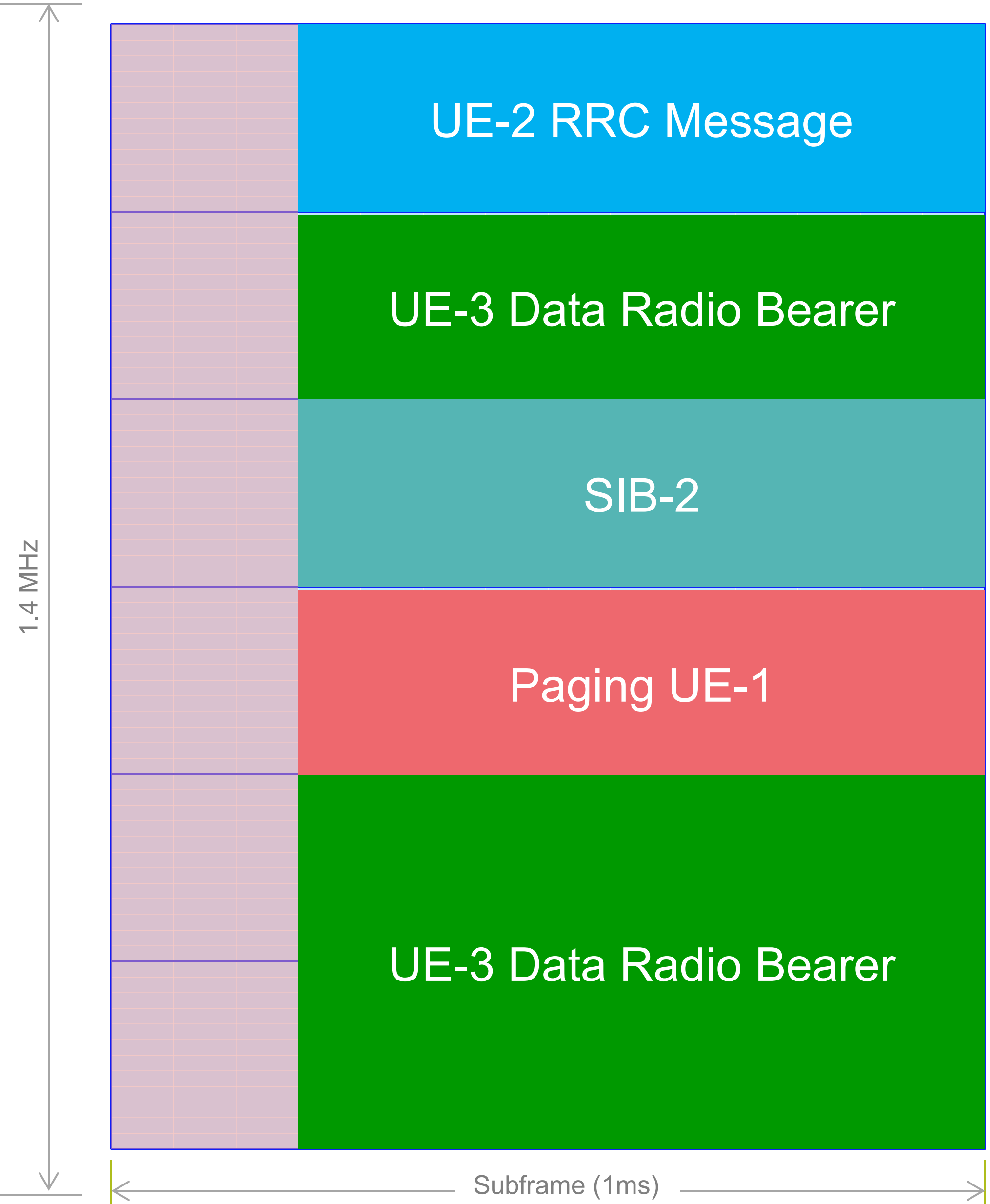
Synchronization Signals

- The Primary Synchronization Signal is allocated to the central 62 subcarriers in the 1^{st} and 6^{th} subframe of every Radio Frame. It's in the 7^{th} symbol in the subframe. Both transmissions are identical.
- The Primary Synchronization Signal is used to:
  - Achieve symbol, slot and subframe synchronization
  - Determine the first part of Physical Layer Cell Identity (PCI): 3 values.
- The Secondary Synchronization Signal is allocated to the central 62 subcarriers in the 1^{st} and 6^{th} subframe of every Radio Frame. It's in the 6^{th} symbol in the subframe.
- The 2 SSS transmissions within each radio frame use different sequences to allow the UE to differentiate between the 1^{st} and 2^{nd} transmission, i.e. allowing the UE to achieve frame synchronization.
- The Secondary Synchronization Signal is used to:
  - Achieve frame synchronization
  - Determine the second part of Physical Layer Cell Identity: 168 different values. This way the UE determines the PCI of the cell, which is 1 of 504 different values

Downlink Physical Channels

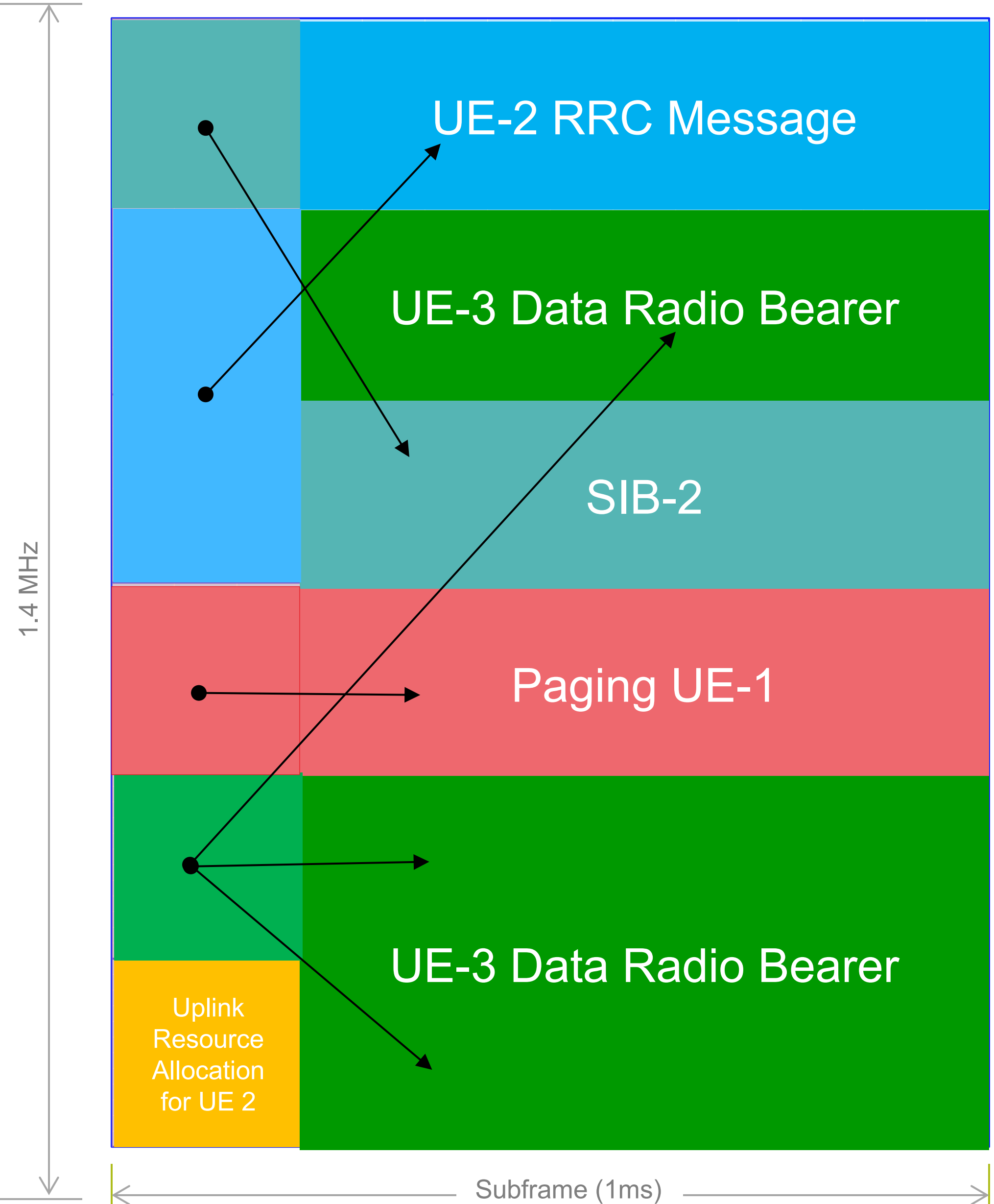


Physical Downlink Shared Channel (PDSCH)



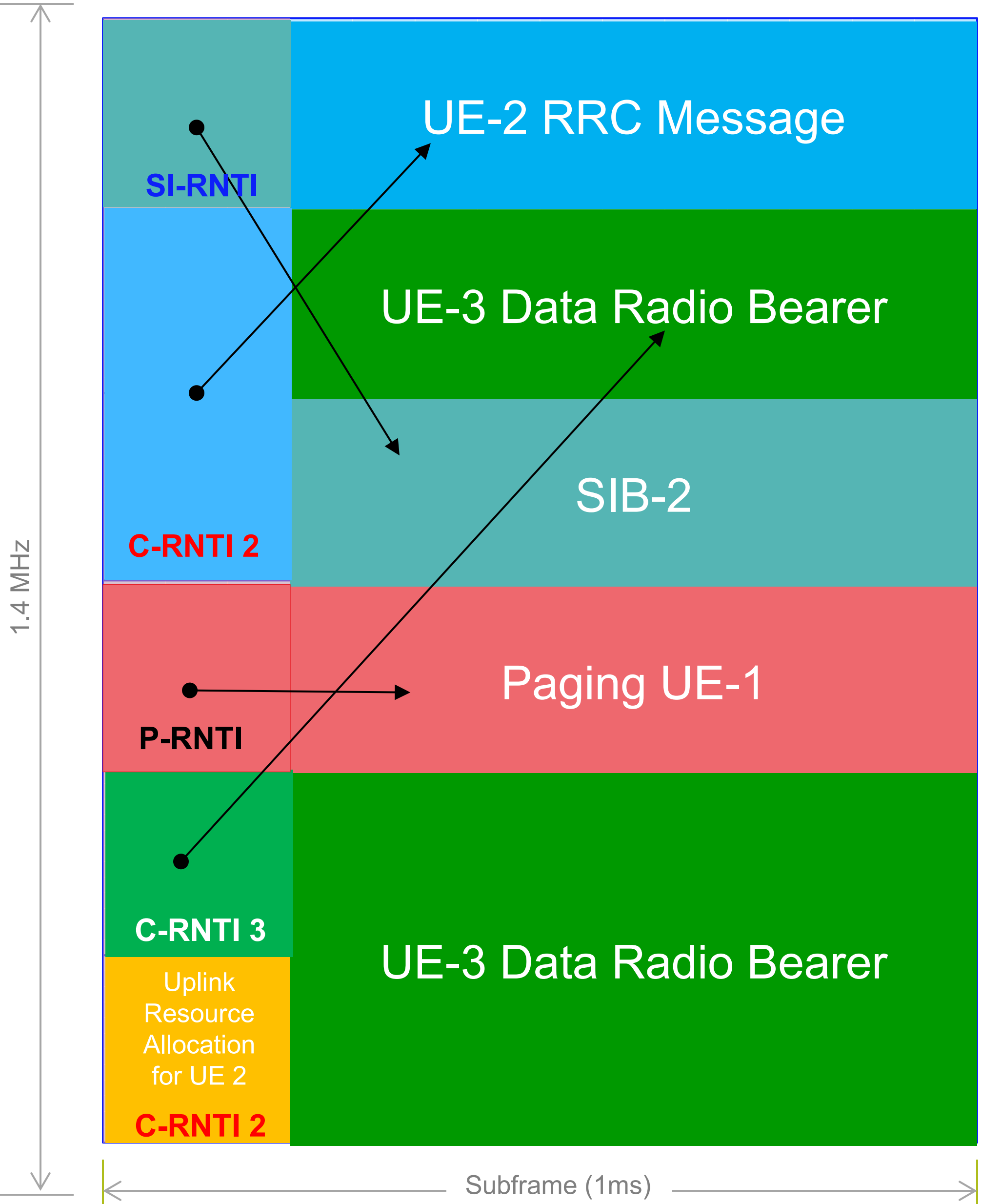
- In the remaining 11 symbols of the subframe
- Transfers :
  - System Information Blocks (SIBs).
  - Paging RRC message
  - Other RRC messages
  - Application data.
- QPSK (2 bits/RE), 16 QAM (4 bits/RE) or 64 QAM (6 bits/RE) modulation is used.

Physical Downlink Control Channel (PDCCH)



- In the first 1-to-3 (configurable) symbols of every subframe (1 ms)
- Transfers **Downlink Control Information (DCI)**.
- DCI messages consists of multiples (i=1,2,3,4) of 36 resource elements.
- Three goals:
  - Downlink resource allocation for same subframe.
    - Allocated as Resource Block Group
      - RBG Size = 1, for 1.4 MHz,
      - RBG Size = 4, for 20 MHz
    - Bitmap used to indicate which RBG is allocated to UE
  - Uplink resource allocation
  - Transmit Power Control
- QPSK modulation is used (2 bits/RE)
- DCI has a 16 bit CRC

How does a mobile know if there is a message for it in a subframe?



- There are four identities that a mobile searches for in the Downlink Control Information (DCI) in the PDCCH:
  - UE's unique cell-radio network temporary identity (C-RNTI)
  - Paging-RNTI, P-RNTI (0xFFFE) and
  - System Information-RNTI, SI-RNTI (0xFFFF).
  - P-RNTI and SI-RNTI are the same for all mobiles.
  - The check for P-RNTI and SI-RNTI are not performed in every subframe, but on selected/ "paging-occasion" subframes, (once every DRX cycle).
  - During Random access
    1. Random Access-RNTI (RA-RNTI): For Random access response message.
    2. Temporary C-RNTI: For RRC Connection Setup message
- In the PDSCH, the MAC header tells the mobile, if the message is an RRC message or a data packet
  - Logical Channel ID = 0..2 -> SRB 0..2
  - Logical Channel ID = 3..10 -> DRBs

How does the mobile find out what information is being sent to it?

- If Logical Channel ID == 0 (SRB0) Common Control Channel (CCCH)

  DL-CCCH-MessageType ::= CHOICE {

  rrcConnectionReestablishment
  rrcConnectionReestablishmentReject
  rrcConnectionReject
  rrcConnectionSetup }

  Sent before RRC Channel is setup

- If Logical Channel ID == 1, 2 (SRB1 and SRB2) Dedicated Control Channel (DCCH)

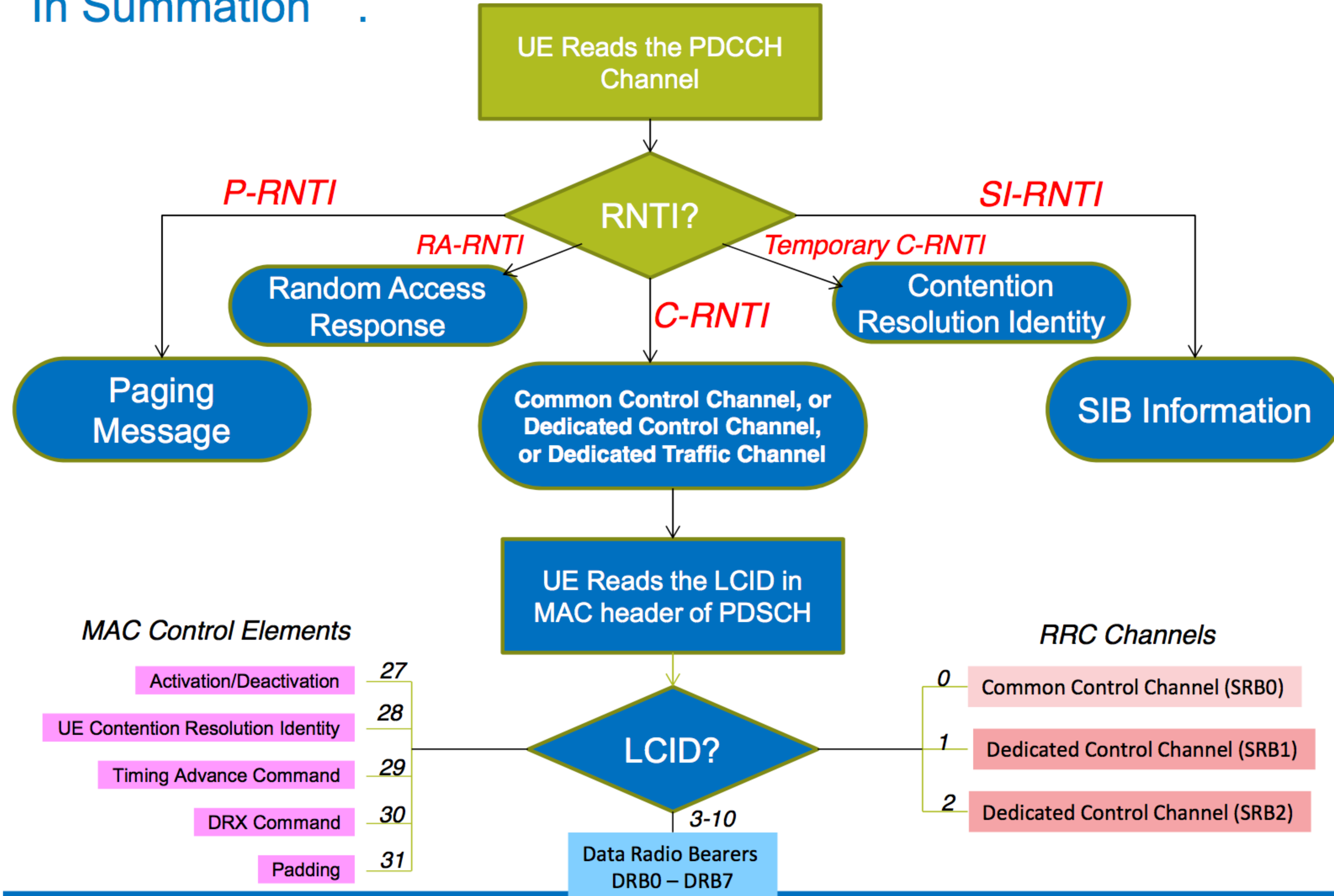
  DL-DCCH-MessageType ::= CHOICE {

  csfbParametersResponseCDMA2000
  dlInformationTransfer
  handoverFromEUTRAPreparationRequest
  mobilityFromEUTRACommand
  rrcConnectionReconfiguration
  rrcConnectionRelease
  securityModeCommand
  ueCapabilityEnquiry
  counterCheck
  ueInformationRequest-r9
  spare6 NULL, spare5 NULL, spare4 NULL,
  spare3 NULL, spare2 NULL, spare1 NULL }

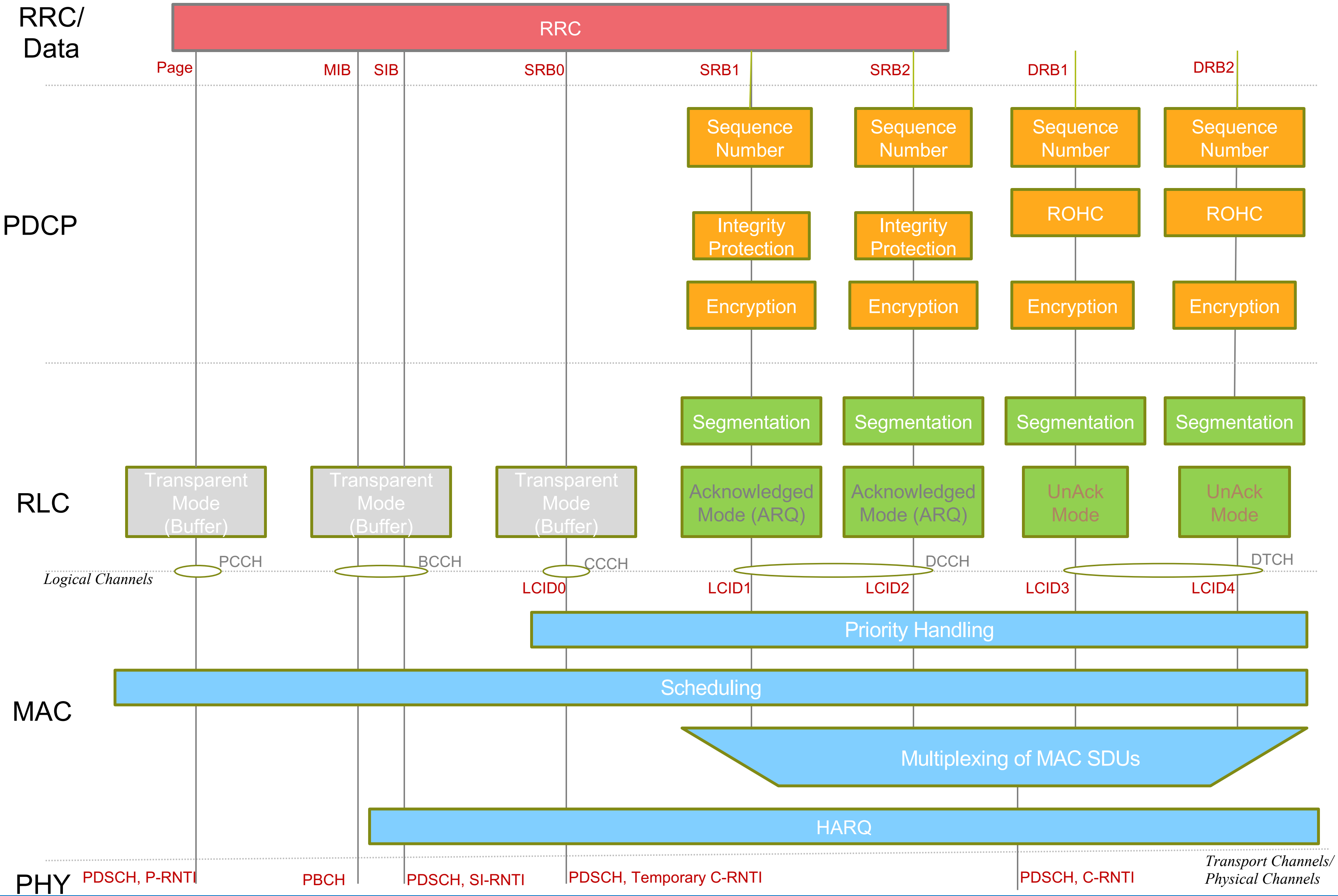
  Sent after RRC Channel is setup

- If Logical Channel ID == 3-10 (DRBs): Dedicated Traffic Chanel (DTCH). Data traffic

In Summation .

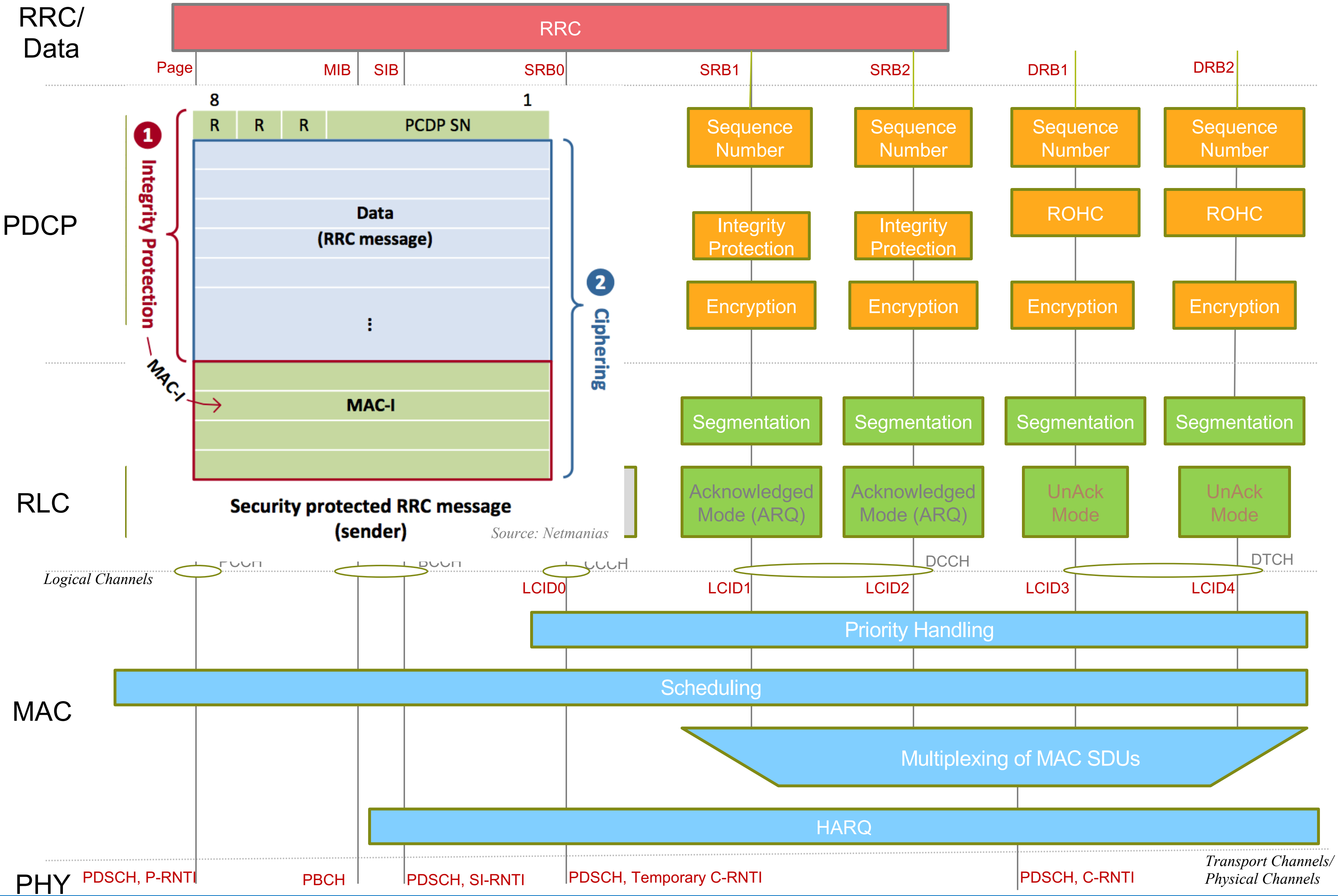


Downlink Protocol Layers and Channel Mapping in eNB



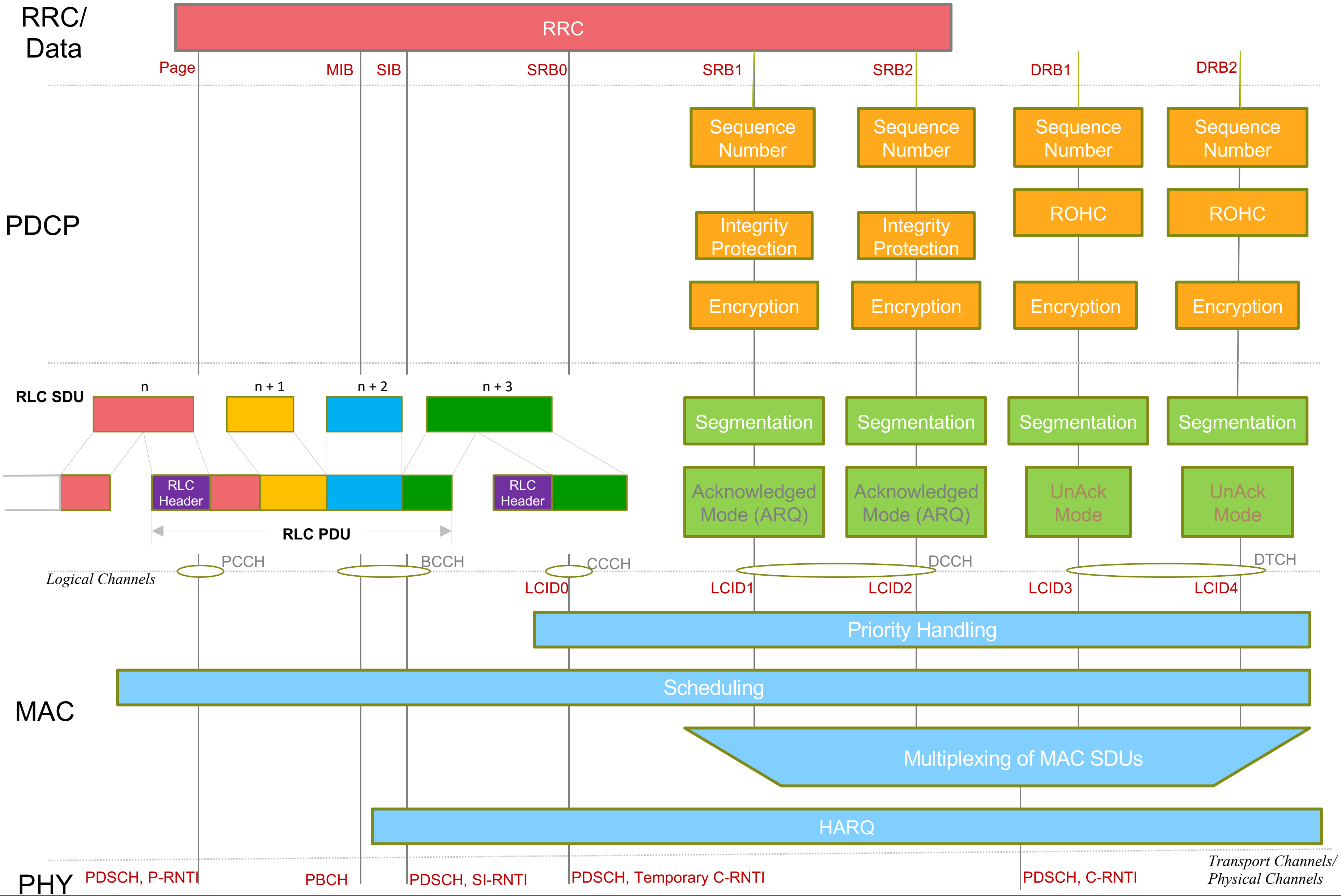
RRC Radio Resource Control
PDCP Packet Data Convergence Protocol
RLC Radio Link Control
MAC Medium Access Control

Downlink Protocol Layers and Channel Mapping in eNB



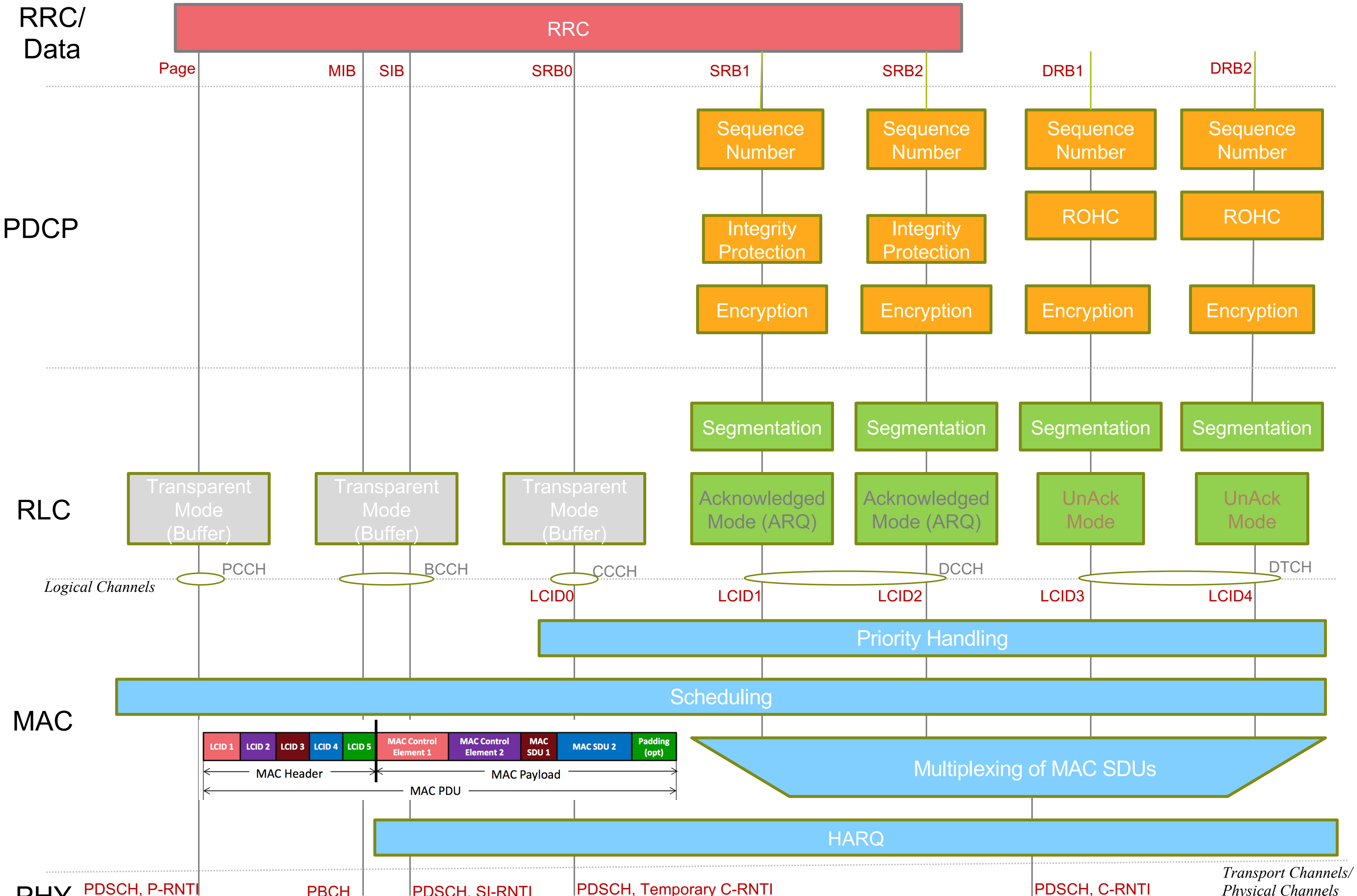
RRC Radio Resource Control
PDCP Packet Data Convergence Protocol
RLC Radio Link Control
MAC Medium Access Control

Downlink Protocol Layers and Channel Mapping in eNB



RRC	Radio Resource Control
PDCP	Packet Data Convergence Protocol
RLC	Radio Link Control
MAC	Medium Access Control

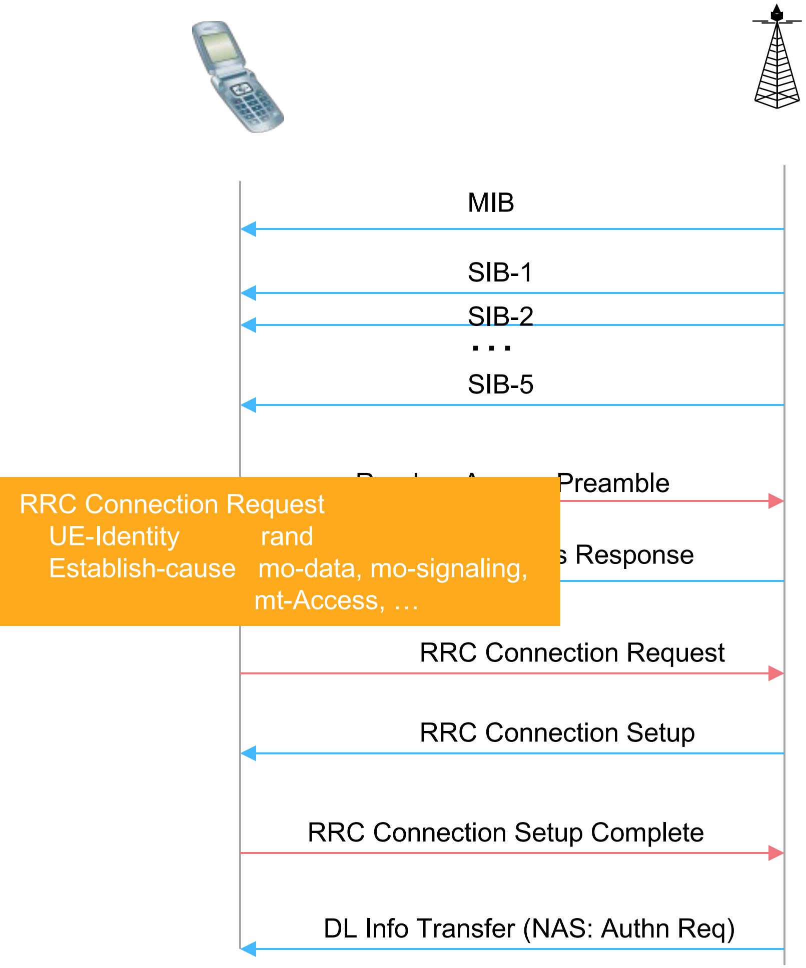
Downlink Protocol Layers and Channel Mapping in eNB

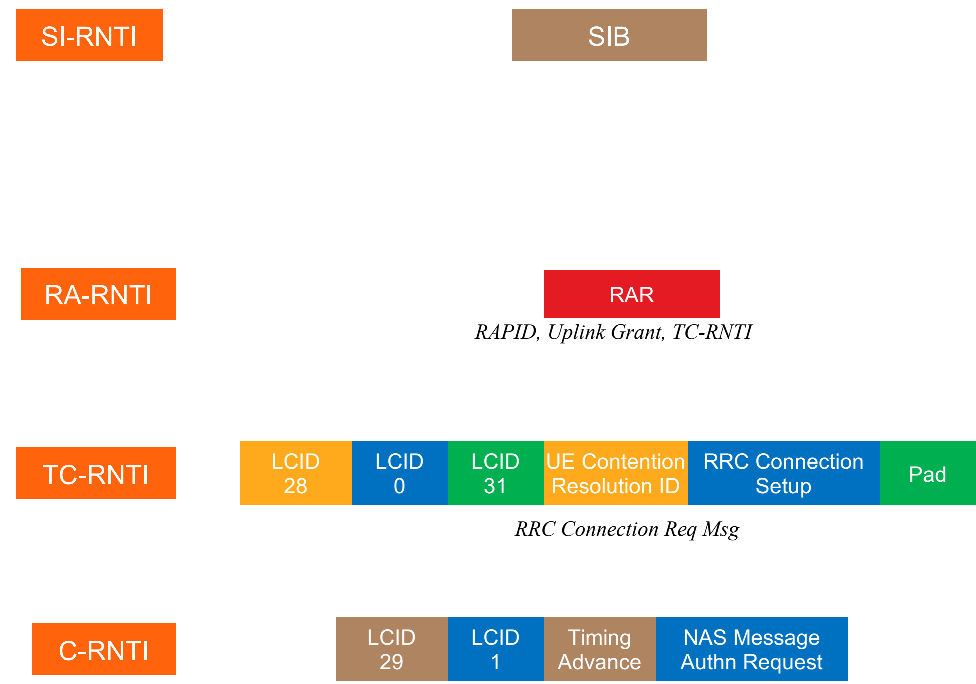


RRC Radio Resource Control
PDCP Packet Data Convergence Protocol
RLC Radio Link Control
MAC Medium Access Control

Example of IDs in the PDCCH and message in PDSCH

Info	Content
MIB	Downlink Channel Bandwidth, PHICH Configuration, SFN
SIB 1	PLMN ID, Tracking Area Code, Cell Selection Parameters, Frequency band, cell barring, Scheduling info for other SIBs
SIB2	Access Class Barring, Channel (RACH, BCCH, ..) parameters, UE timers, UL Carrier Frequency
SIB3	Cell Selection Parameters
SIB4	Inter Frequency neighbour cell info
SIB5	Intra Frequency neighbour cell info

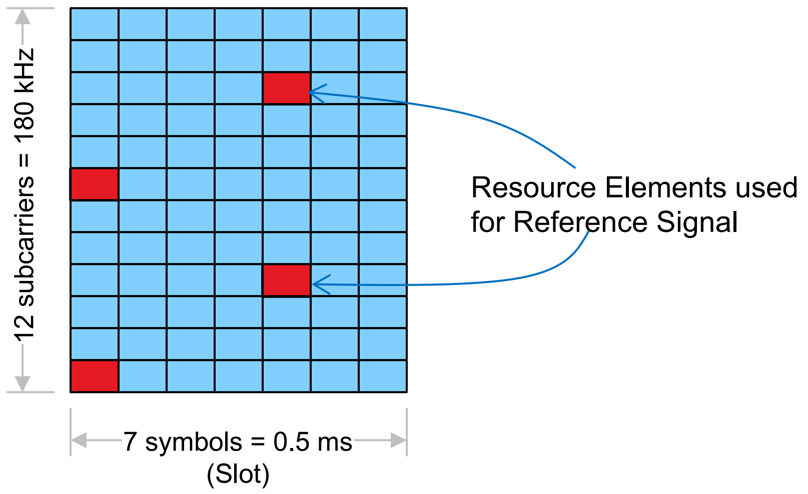




Cell Reference Signals (CRS)

- Cell Reference Signals
  - Known reference signals are inserted at regular intervals within the OFDM time-frequency grid.
  - There are four resource elements per resource block that are dedicated to Reference Signal.

- The location of Reference Signals depends on the Physical layer cell identity of the cell.
- The Primary and Secondary Synchronization Signals the Physical Layer Cell Identity

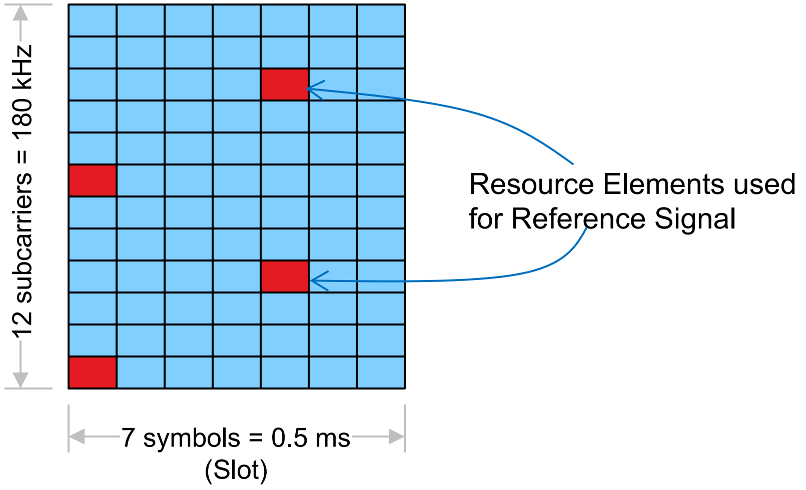


Reference Signal Received Power (RSRP)

- The RSRP is the average power (in watts) received from a single Reference Signal (RS) resource element
- RSRP measures only the RS power and excludes all noise and interference power.
- Knowledge of absolute RSRP enables mobile to calculate downlink path-loss.
- The maximum RSRP is based on maximum input power to UE of -25dBm (0.0032 mWatts). In 1.4 MHz BW with 6 RBs (72 Resource Elements), max RSRP is -44 dBm.
- The minimum value is -140 dBm (has 6 dBm of margin from minimum possible received power at UE).

$$\boxed{RSRP = \frac{1}{K}\sum_{k=1}^{K} P_{rs,k}}$$

where, $P_{rs,k}$ is the estimated received power (in Watts) of the kth Reference Signal Resource element

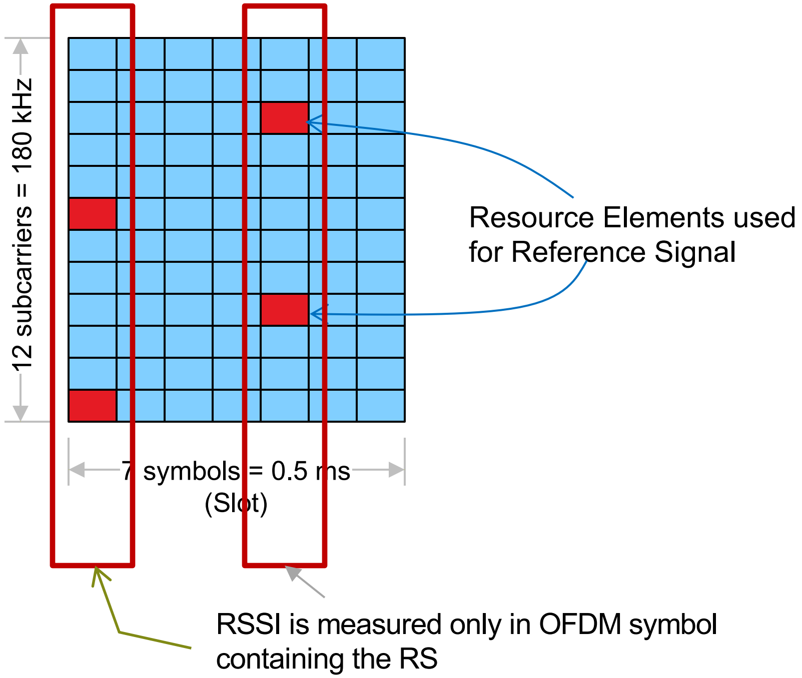


Measurement 2: Reference Signal Received Quality (RSRQ)

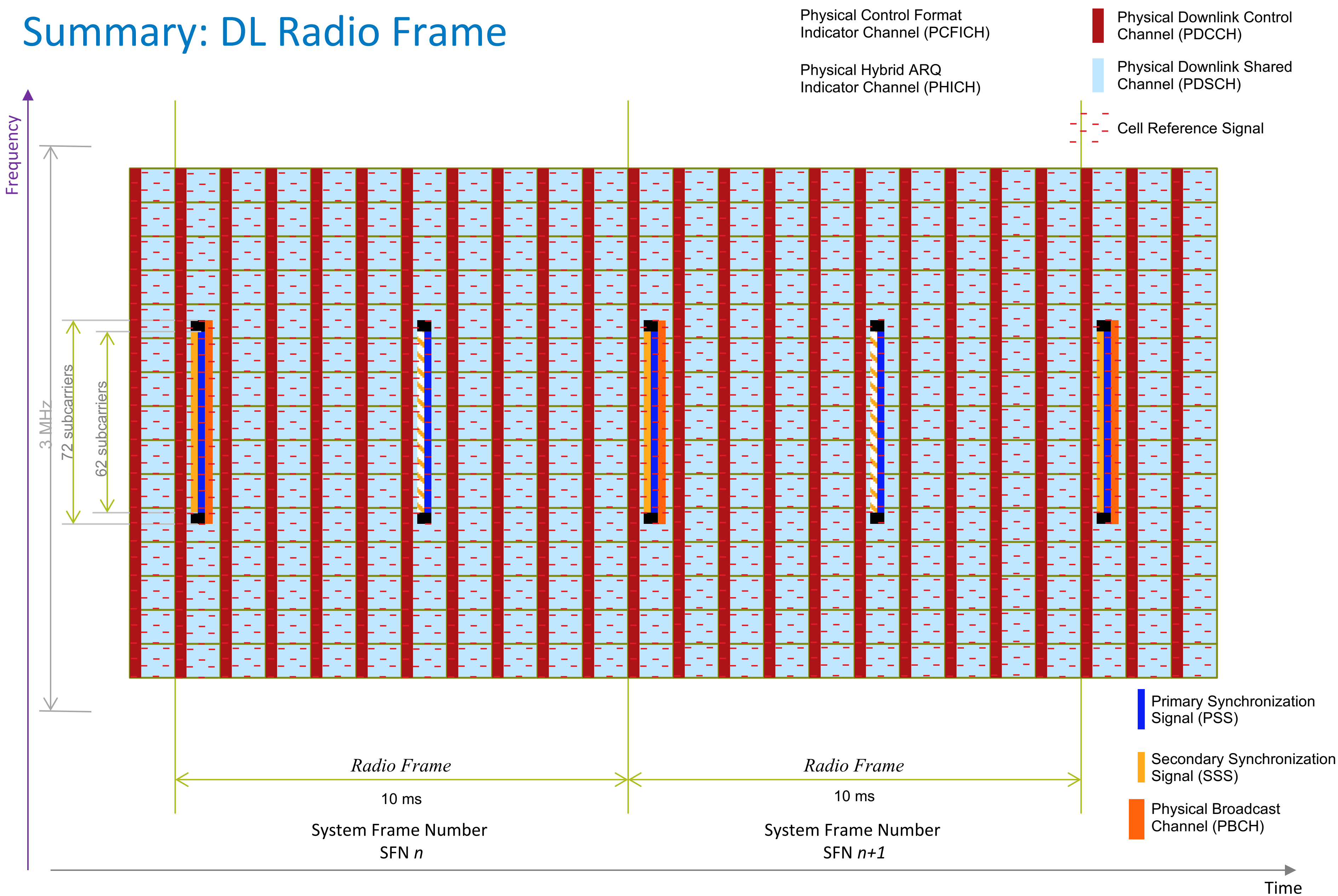
- RSRP does not give an indication of signal quality, i.e. the strength of the reference signal compared to overall energy in the channel (aka received signal strength indicator (RSSI))
- The RSSI parameter represents the entire received power including the wanted power from the serving cell as well as all co-channel power and other sources of noise.
- Measuring RSRQ becomes particularly important near the cell edge when decisions need to be made, regardless of absolute RSRP, to perform a handover to the next cell.
- The maximum value of RSRQ is -3 dB. (One reference signal has 50% energy in the RB)
- The minimum value of reported RSRQ is -19.5 dB. (One reference signal RE has only 1% of energy in RB)

$$RSRQ = \frac{RSRP}{(RSSI / N_{RB})}$$

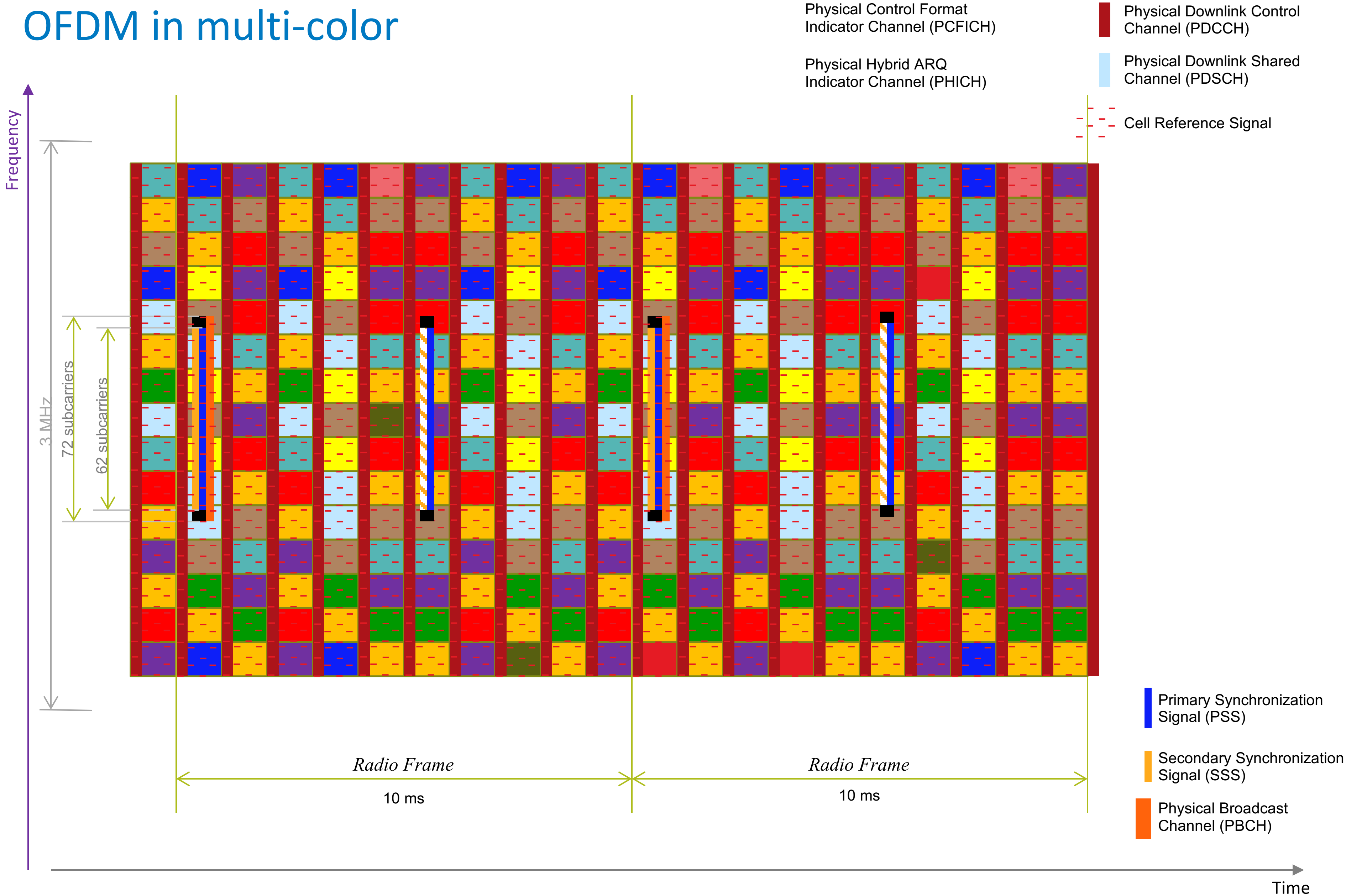
where N_{RB} is the number of Resource blocks
(N_{RB}= 6 for 1.4MHz Bandwidth)



Summary: DL Radio Frame



OFDM in multi-color



References

- Specifications:
  - TS 36.300: RAN Architecture
  - TS 36.331: RRC
  - TS 36.323: PDCP
  - TS 36.322: RLC
  - TS 36.321: MAC
- Other References:
  - LTE in Bullets
  - www.sharetechnote.com
  - www.youtube.com/lte4g