(COMPUTER NETWORKS & COMMUNICATION PROTOCOLS)

The Downlink Transmission (OFDMA) and Uplink Transmission (SC-FDMA) of 3GPP Long Term Evolution LTE – Physical Layer

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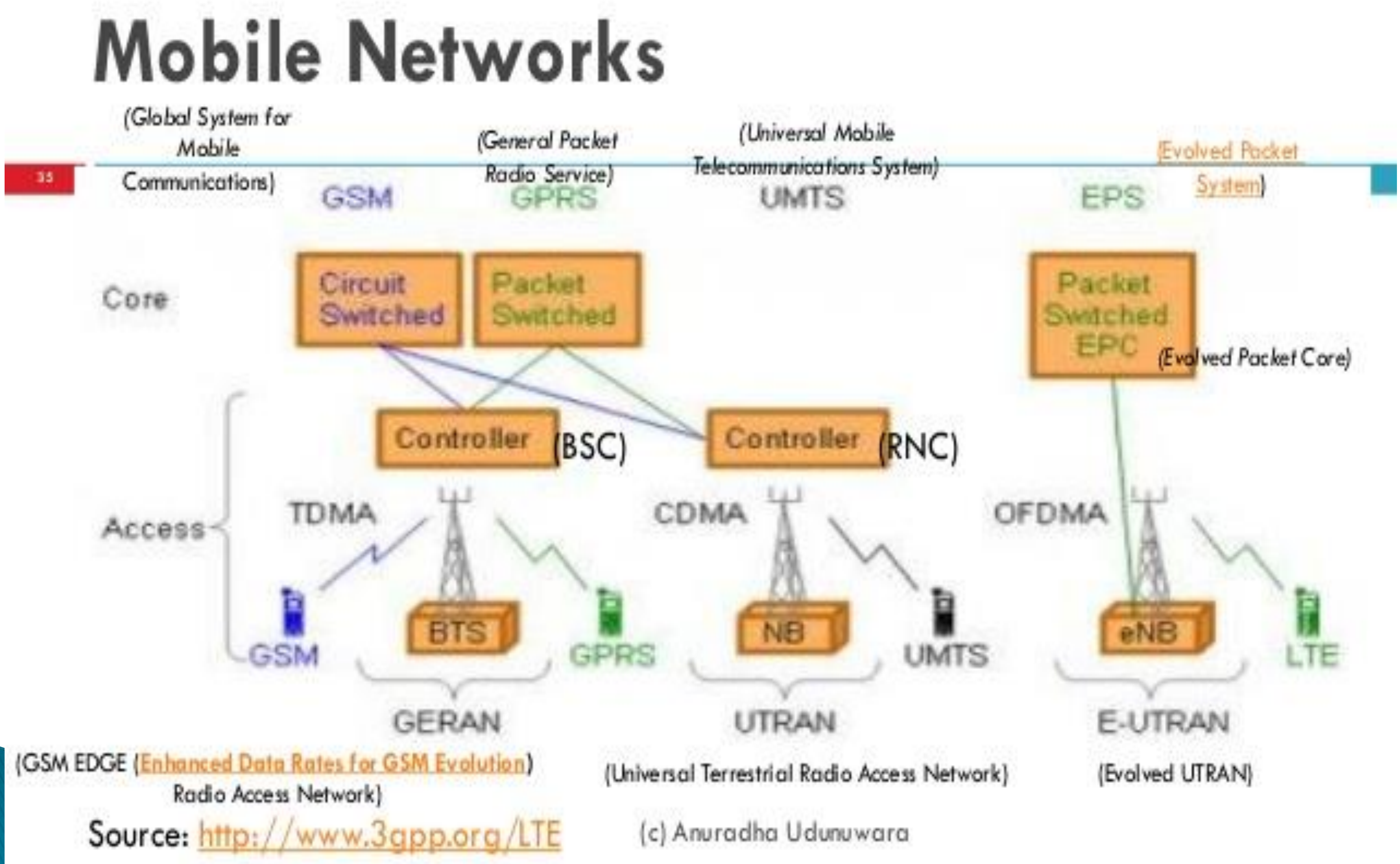
Project Background and Stimulus

- Downlink transmission is based on Orthogonal Frequency Division Multiple Access (OFDMA) which converts the wide-band frequency selective channel into a set of many flat fading sub channels.

- Uplink multiple access is based on the Single Carrier Frequency Division Multiple Access (SC-FDMA).

- The LTE physical layer is based on Orthogonal Frequency Division Multiplexing scheme OFDM to meet the targets of high data rate and improved spectral efficiency, MIMO options with 2 or 4 Antennas is supported. The modulation schemes supported in the downlink and uplink are QPSK, 16QAM and64QAM.

Part One



Mobile Networks
(Global System for Mobile Communications)
(General Packet Radio Service)
(Universal Mobile Telecommunications System)
(Evolved Packet System)
35
GSM
GPRS
UMTS
EPS
Core
Circuit Switched
Packet Switched
Packet Switched EPC
(Evolved Packet Core)
Controller
(BSC)
Controller
(RNC)
Access
TDMA
CDMA
OFDMA
GSM
BTS
GPRS
NB
UMTS
eNB
LTE
GERAN
UTRAN
E-UTRAN
(GSM EDGE (Enhanced Data Rates for GSM Evolution) Radio Access Network)
(Universal Terrestrial Radio Access Network)
(Evolved UTRAN)
Source: http://www.3gpp.org/LTE
(c) Anuradha Udunuwara

System model and Description

SC-FDMA was found to have a better PAPR reduction than OFDMA and has become modulation choice for uplink communication in Long Term Evolution (LTE).

SC-FDMA system, baseband modulated data is passed through S/P converter which generates a complex vector of size M that can be written as X = [Xo, X1, X2, ….., XM-1]^T. Then *DFT* precoding is applied to this complex vector: Eq. (1).

$$x_n = \frac{1}{\sqrt{M}} \sum_{l=0}^{M-1} X_l . e^{-j2\pi \frac{n}{M} l} \quad , n = 0, 1, 2, M\text{-}1$$

System model and Description

This *DFT* precoded signal is then mapped on to the N subcarriers:

$$\text{get}\ \hat{Y}_k = \left[\hat{Y}_0, \hat{Y}_1, \hat{Y}_2, \ldots\ldots, \hat{Y}_{N-1}\right]^T$$

The *IDFT* precoded signal with N subcarriers: Eq. (2).

$$\hat{x}_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \hat{Y}_k . e^{j2\pi \frac{n}{N} k} \qquad , n = 0, 1, 2, N\text{-}1$$

ˆ Y_k we get after subcarrier mapping. Using Eqs. (1) and (2) we get complex baseband SC-FDMA signal with N subcarrier: Eq.(3).

$$\hat{x}_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \left(\frac{1}{\sqrt{M}} \sum_{l=0}^{M-1} X_l . e^{-j2\pi \frac{n}{M} l} \right) . e^{j2\pi \frac{n}{N} k}$$

System model and Description

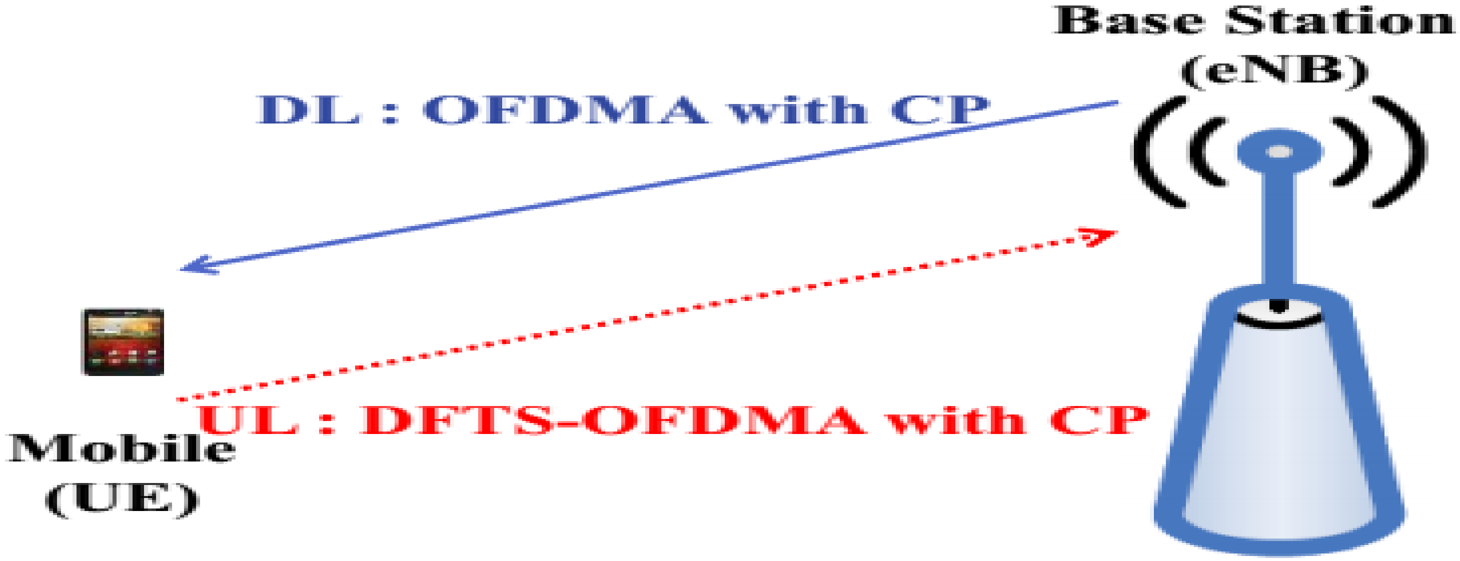
$$x(t) = e^{j\omega_c t} \sum_{n=0}^{N-1} \hat{x}_n . r(t - n\breve{T})$$

The complex passband signal of localized SC-FDMA (LFDMA) after RRC pulse shaping: Eq. (4).

where ωc is carrier frequency, r(t) is baseband pulse:

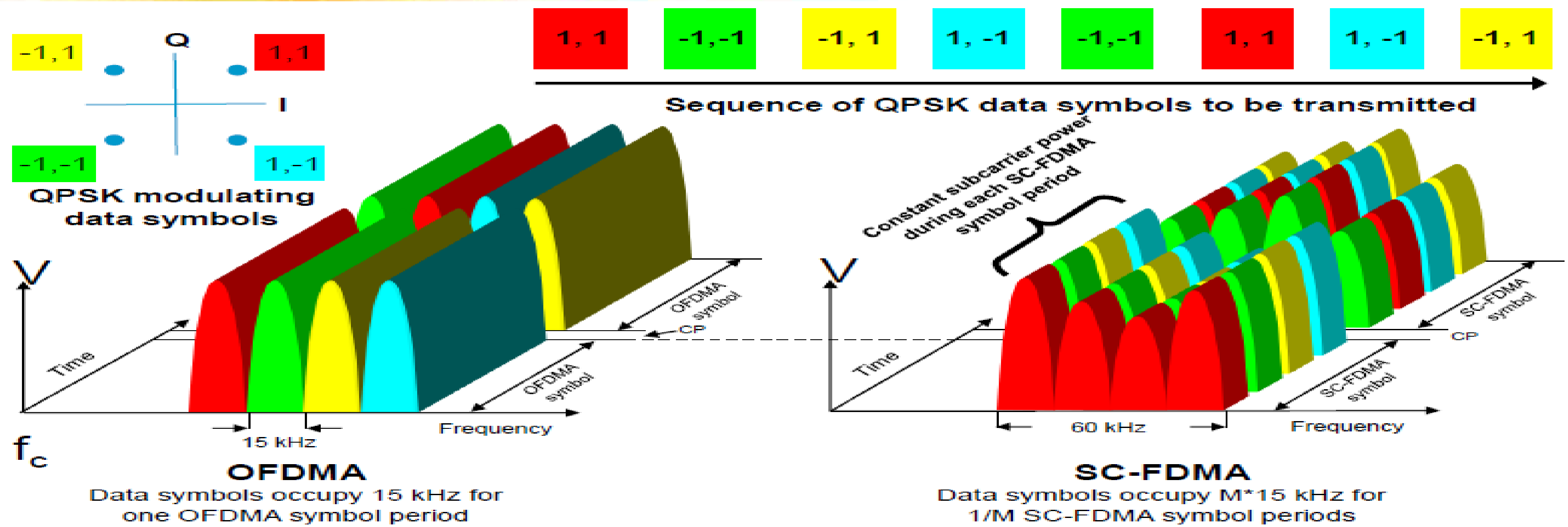
$$\breve{T} = (M / N)T$$

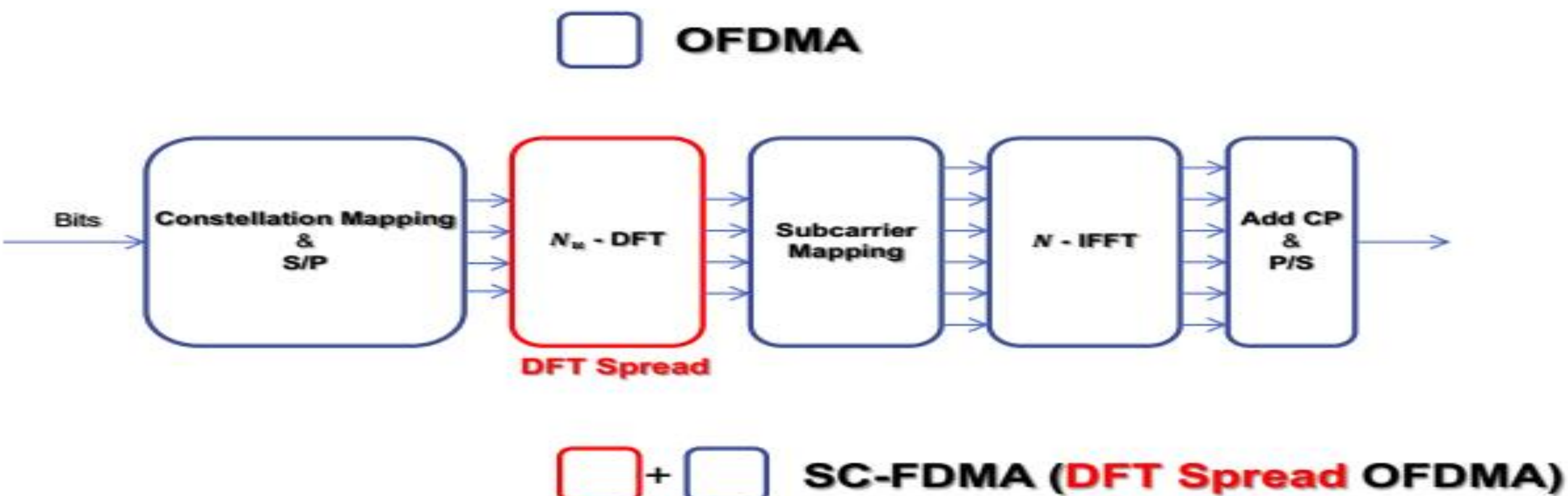
is compressed symbol duration after *IFFT* and T is symbol duration in seconds.



System model and Description

Fig. (1) OFDMA & SC-FDMA System.





Analysis and Techniques

Peak to average power ratio (PAPR)

The PAPR of signals in Eq. (4) with pulse shaping: Eq. (5).

$$PAPR = \frac{\max_{0 \le t \le N\tilde{T}} |x(t)|^2}{\frac{1}{N\tilde{T}} \int_0^{N\tilde{T}} |x(t)|^2 dt}$$

Complementary cumulative distribution function (CCDF) of the signals for the MC/SC systems. Eq. (6).

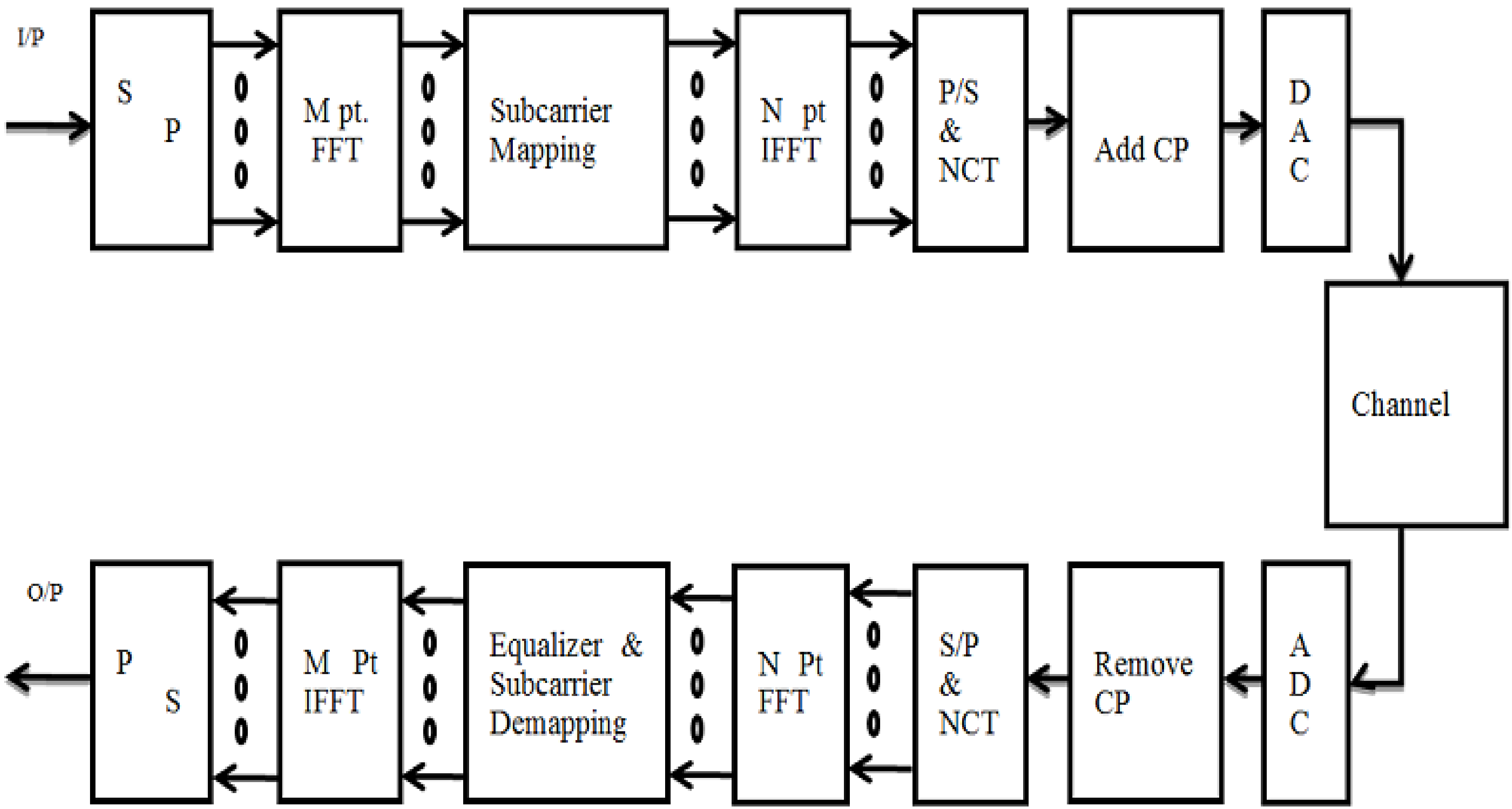
$$P(PAPR > PAPR_0) = 1 - \left(1 - e^{PAPR_0}\right)^N$$

where PAPR0 is the clipping level and this equation can be interpreted as the probability that the PAPR of a symbol block exceeds some clip level PAPR0.

In general $\text{PAPR} = \frac{\text{Peak power}}{\text{Average power}}$

Analysis and Techniques

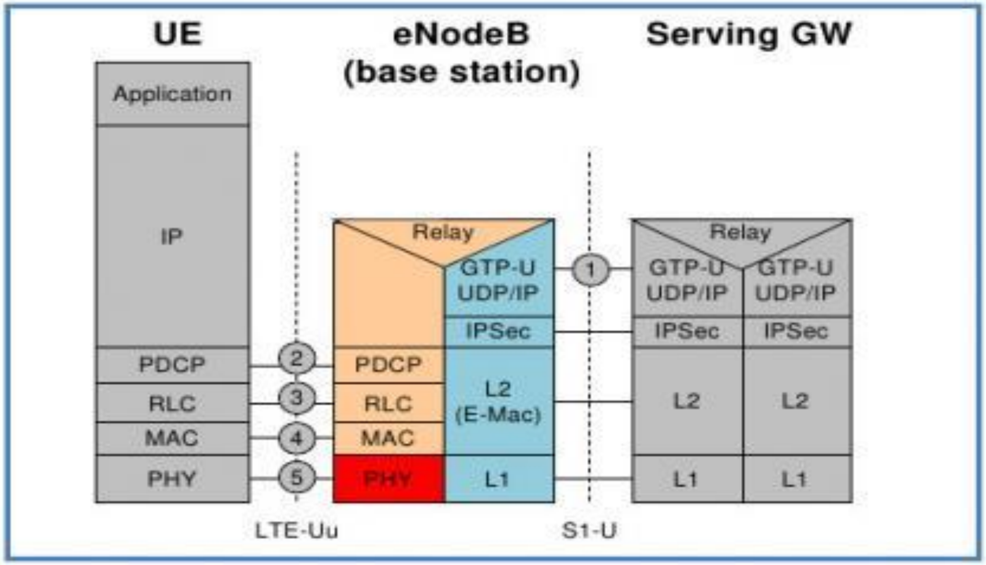
Transceiver structure of SCFDMA with NCT



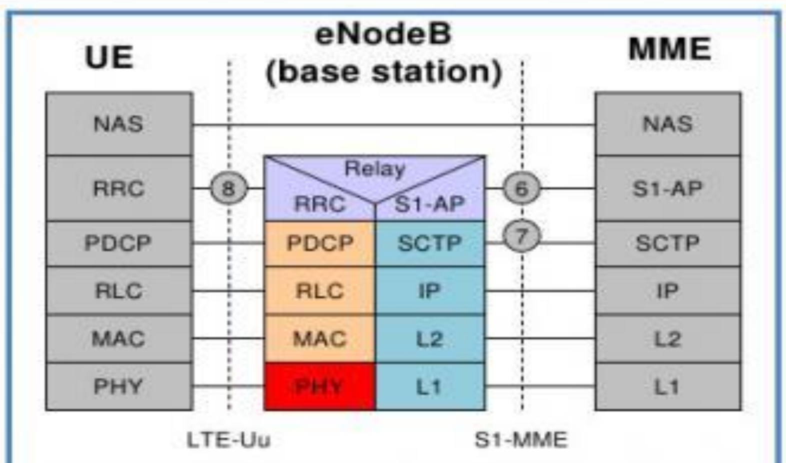
Part Two

Wireless LTE protocol stack reference

- User Plane (data plane)



- Control Plane



Wireless PHY

Transport

Layer 2

Layer 3

Source: 3GPP TS 23.401 V8.3.0 (2008-09)

1. 3GPP 36.414
2. 3GPP 36.323
3. 3GPP 36.322
4. 3GPP 36.321
5. 3GPP 36.21x
6. 3GPP 36.413
7. 3GPP 36.412 IETF RFC 4960
8. 3GPP 36.331

LTE Stack

- **RLC and M**AC sublayers (terminated in eNB on the network side) perform the same functions as for the user plane
- The various functions performed by RRC (terminated in eNB on the network side) are
- - Broadcast
- - Paging
- - RRC connection management
- - Mobility functions
- - UE measurement reporting and control.
- **PDCP** sublayer performs
- - Integrity Protection
- Ciphering.

NAS (terminated in aGW on the network side) performs

- - SAE bearer management
- - Authentication
- - Idle mode mobility handling
- - Paging origination

LTE Layer 2

- **MAC (media access control) protocol**

- handles uplink and downlink scheduling and HARQ signaling.
- Performs mapping between logical and transport channels.

- **RLC (radio link control) protocol**

- focuses on lossless transmission of data.
- n-sequence delivery of data.
- Provides 3 different reliability modes for data transport.

- **PDCP (packet data convergence protocol)**

- handles the header compression and security functions of the radio interface.

- **RRC (radio resource control) protocol**

- handles radio bearer setup
- active mode mobility management
- Broadcasts of system information, while the NAS protocols deal with idle mode mobility management and service setup

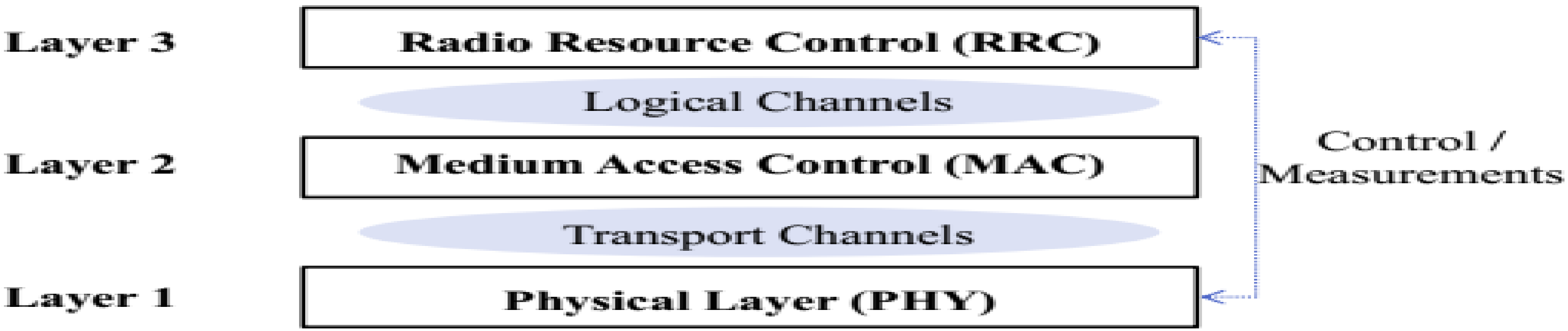
LTE Layer 1(Physical)

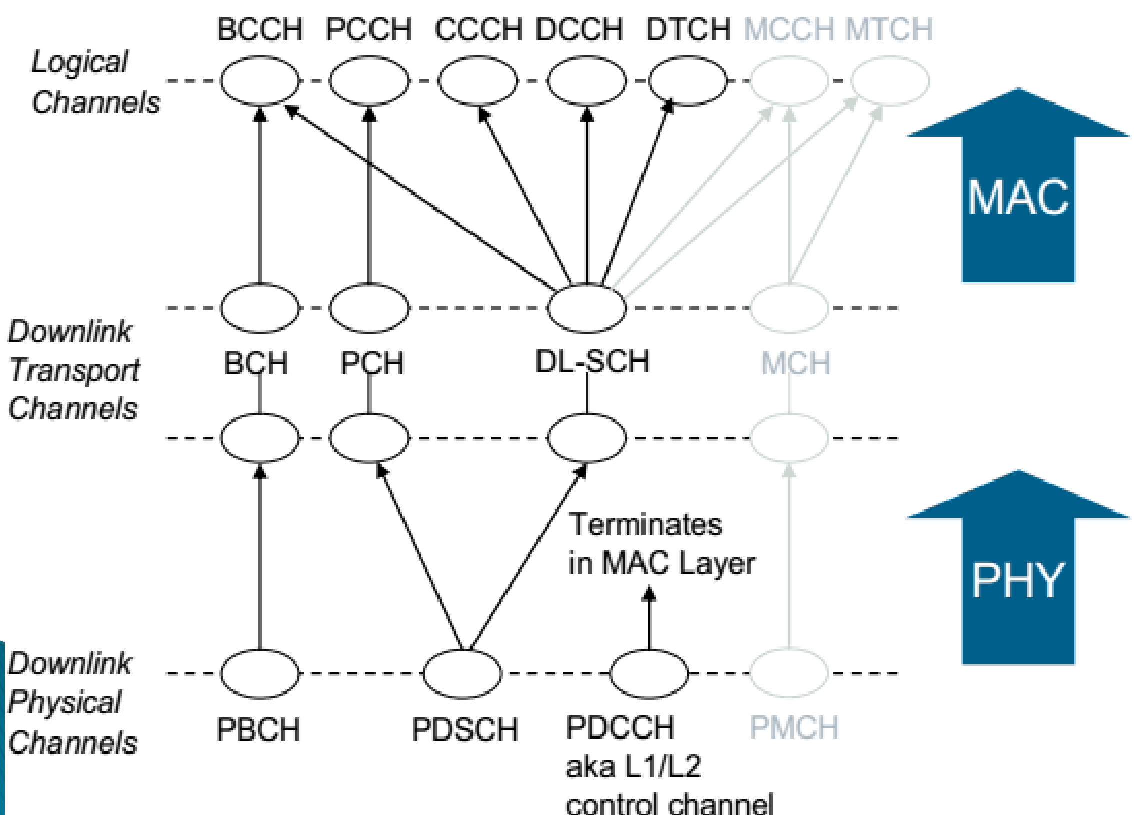
- The physical layer is defined taking bandwidth into consideration, allowing the physical layer to adapt to various spectrum allocations.

- The modulation schemes supported in the downlink are QPSK, 16QAM and 64QAM, and in the uplink QPSK, 16QAM.The Broadcast channel uses only QPSK.

- The channel coding scheme for transport blocks in LTE is Turbo Coding with a coding rate of R=1/3, two 8-state constituent encoders and a contention-free quadratic permutation polynomial (QPP) turbo code internal interleaver.

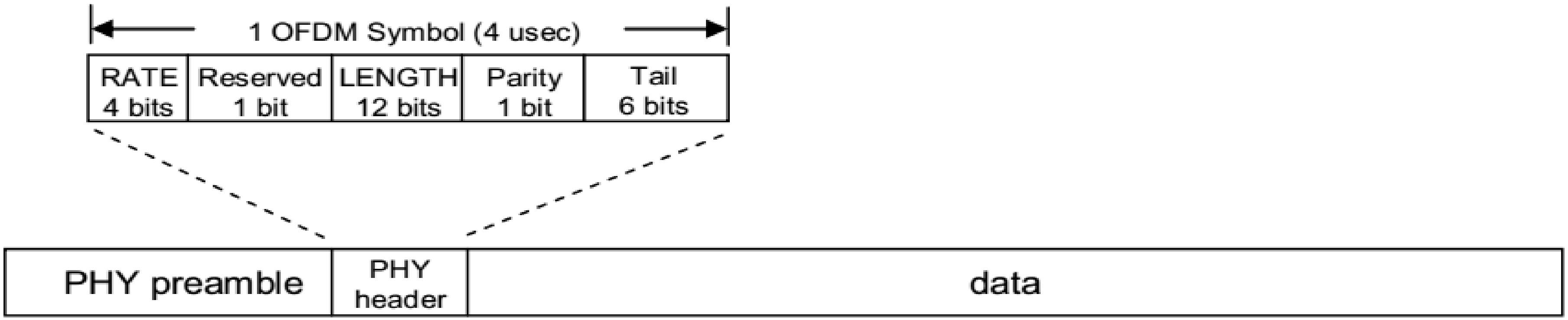
LTE Protocol Architecture around PHY



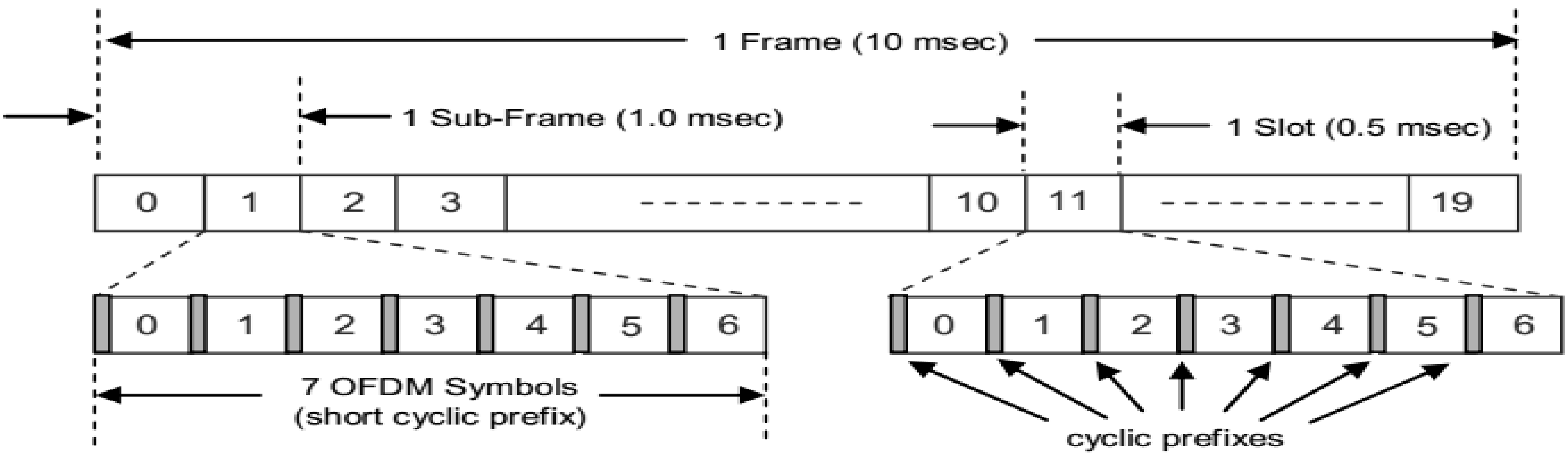


- **Logical Channels**
  - PCCH: Paging Control Channel
  - BCCH: Broadcast Control Channel
  - CCCH: Common Control Channel
  - DCCH: Dedicated Control Channel
  - DTCH: Dedicated Traffic Channel
  - MCCH: Multicast Control Channel
  - MTCH: Multicast Traffic Channel
- **Transport Channels**
  - PCH: Paging Channel
  - BCH: Broadcast Channel
  - DL-SCH: Downlink Shared Channel
  - MCH: Multicast Channel

OFDMA PHY Layer Preamble , Header & Frame Structure

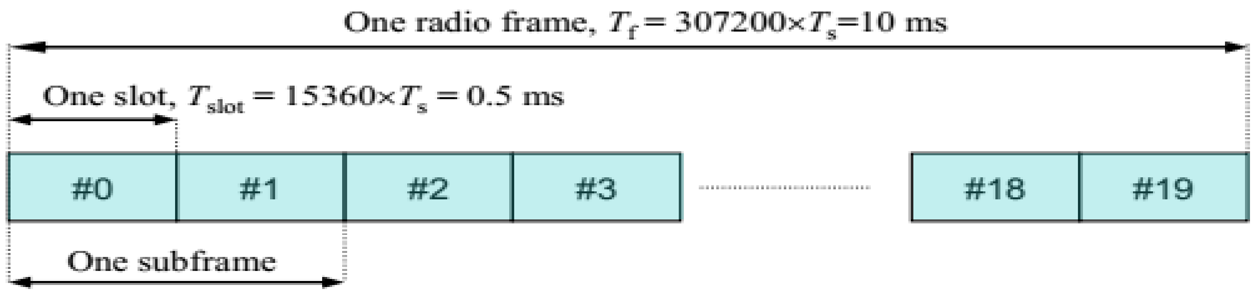


In OFDMA, users are allocated a specific number of subcarriers for a predetermined amount of time. These are referred to as physical resource blocks (PRBs) in the LTE specifications. PRBs thus have both a time and frequency dimension. Allocation of PRBs is handled by a scheduling function at the 3GPP base station (eNodeB).



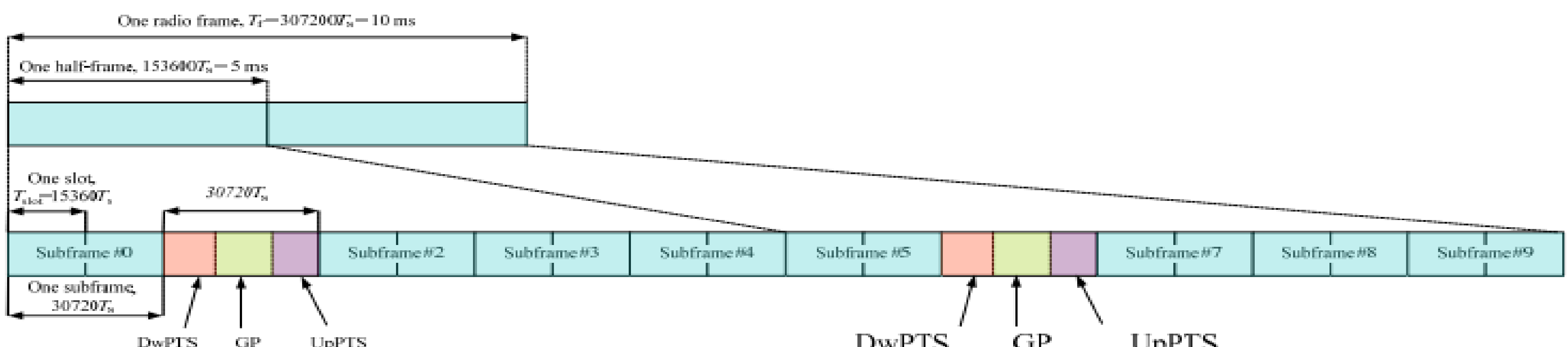
Frame structure type 1

- Applicable to FDD and half duplex FDD
- Each radio frame is $T_f = 307200 \times T_s = 10$ ms long and consists of 20 slots of length $T_{slot} = 15360 \times T_s = 0.5$ ms, numbered from 0 to 19($T_s = 1/(15000 \times 2048)$ seconds)



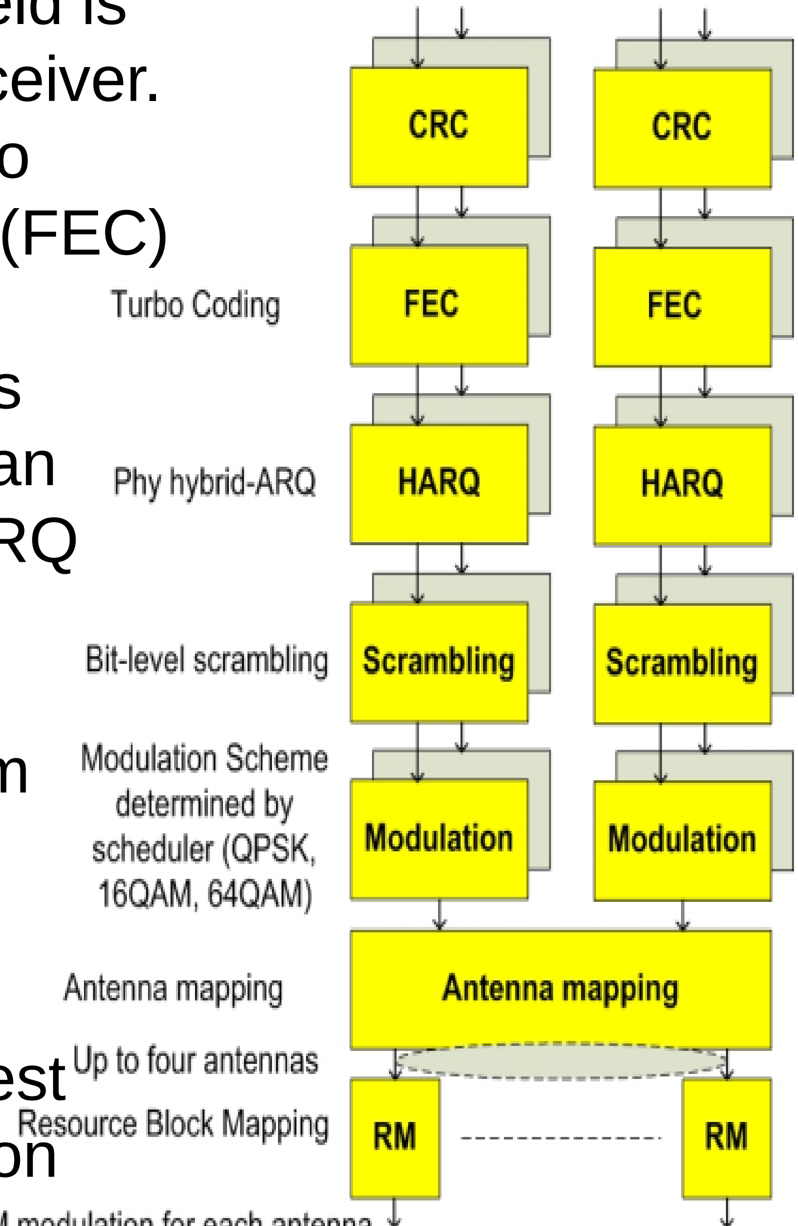
Frame structure type 2

- Applicable to only TDD
- Each radio frame consists of two half frame length $T_f = 153600 \times T_s = 5$ ms each and each half frame consists of 8 slots of length $T_{slot} = 15360 T_s = 0.5$ ms and
- Three special fields, DwPTS, GP, and UpPTS in subframe #1 and #6
- Subframes 0 and 5 and DwPTS are always reserved for downlink transmission
- The lengths of DwPTS and UpPTS is given below subject to the total length of DwPTS, GP and UpPTS being equal to $30720 T_s = 1$ ms
- Supported configurations of uplink-downlink subframe allocation are specified

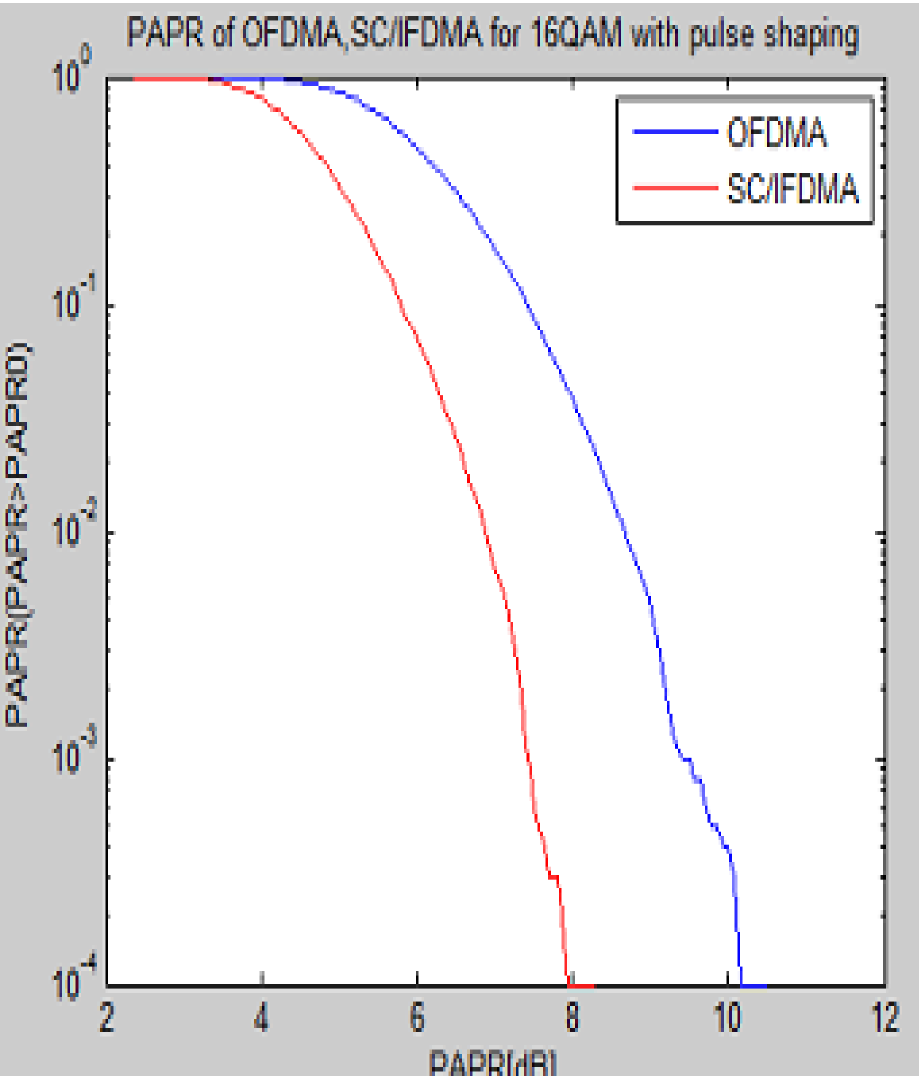


LTE downlink signal generation chain

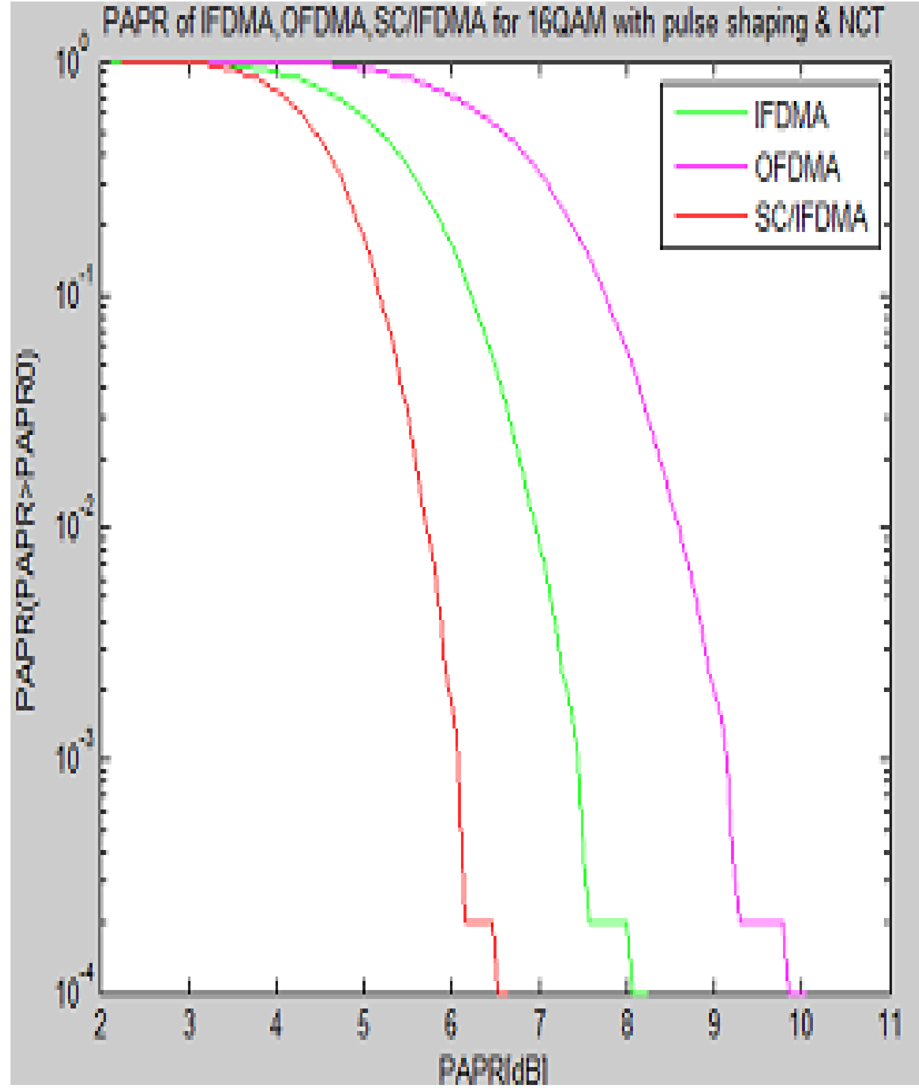
CRC (Cyclic Redundancy Check) field is introduced to detect errors in the receiver. After the CRC module comes a turbo encoder as forward error correction (FEC) channel coder.
The LTE downlink turbo encoder has $R = 1/3$ as basic code rate and is (can be) with puncturing. There is an HARQ module following the turbo encoder. HARQ stands for Hybrid Automatic Repeat Request and is a mechanism based on stop and wait ARQ which transmits the packets again in case of errors detected by the CRC.
The Hybrid Automatic Repeat-reQuest (HARQ) process, done in combination between the MAC and the PHY.



Simulation Results



CCDF plots of PAPR for the OFDMA, SC/IFDMA.



CCDF plots of PAPR for the OFDMA, SC/IFDMA and IFDMA with NCT.

Project Summary

- The **SC-FDMA** is used to optimize the range and power consumption in the uplink while the **OFDMA** is used in the downlink direction to minimize receiver complexity, especially with large bandwidths.
- The results show that the proposed technique has **better PAPR reduction** compared to **OFDMA and SC-FDMA** signals with overall and also **improve BER performance**.
- **Hybrid ARQ**
  The Hybrid Automatic Repeat-reQuest (HARQ) process, done in combination between the MAC and the PHY.
- **TDD Batter than FDD**, It enables dynamic allocation of DL and UL resources to efficiently support asymmetric DL/UL traffic (adaptation of DL:UL ratio to DL/UL traffic) and Transceiver designs for TDD implementations are less complex and therefore less expensive.

References

[1] H. G. Myung, J. Lim, and D. J. Goodman (Sept 2009), PAPR of Single Carrier FDMA Signals with Pulse Shaping, The 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC '06), Helsinki, Finland.Yong Wan.

[2] Czylwik, A., 'Comparison between adaptive OFDM and single carrier modulation with frequency domain equalisation', IEEE Vehicular Technology Conference 1997, VTC-97, Phoenix, USA, pp. 863–869.

[3] V. Vijayarangan, Dr. (Mrs) R. Sukanesh , "An Overview Of Techniques For Reducing Peak to Average Power Ratio And Its Selection Criteria For Orthogonal Frequency Division multiplexing Radio Systems" Journal Of Theoretical And Applied Information Technology, Year 2009 ,Vol-5, No-5, E-Issn- 1817-3195/Issn-1992-8645.

[4] 3rd Generation Partnership Project (3GPP); Technical Specification Group Radio Access Network; Physical Layer Aspects for Evolved UTRA, http://www.3gpp.org/ftp/Specs/html-info/25814.htm, date of site access 24/08/2013.

[5] Myung, H.G., Goodman, D.J., 'Single Carrier FDMA: A New Air Interface forLong Term Evolution',Wiley,2008.

ÖNEMLİ

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