Mobile Communications Systems (MCS)

4th Generation Systems (LTE)

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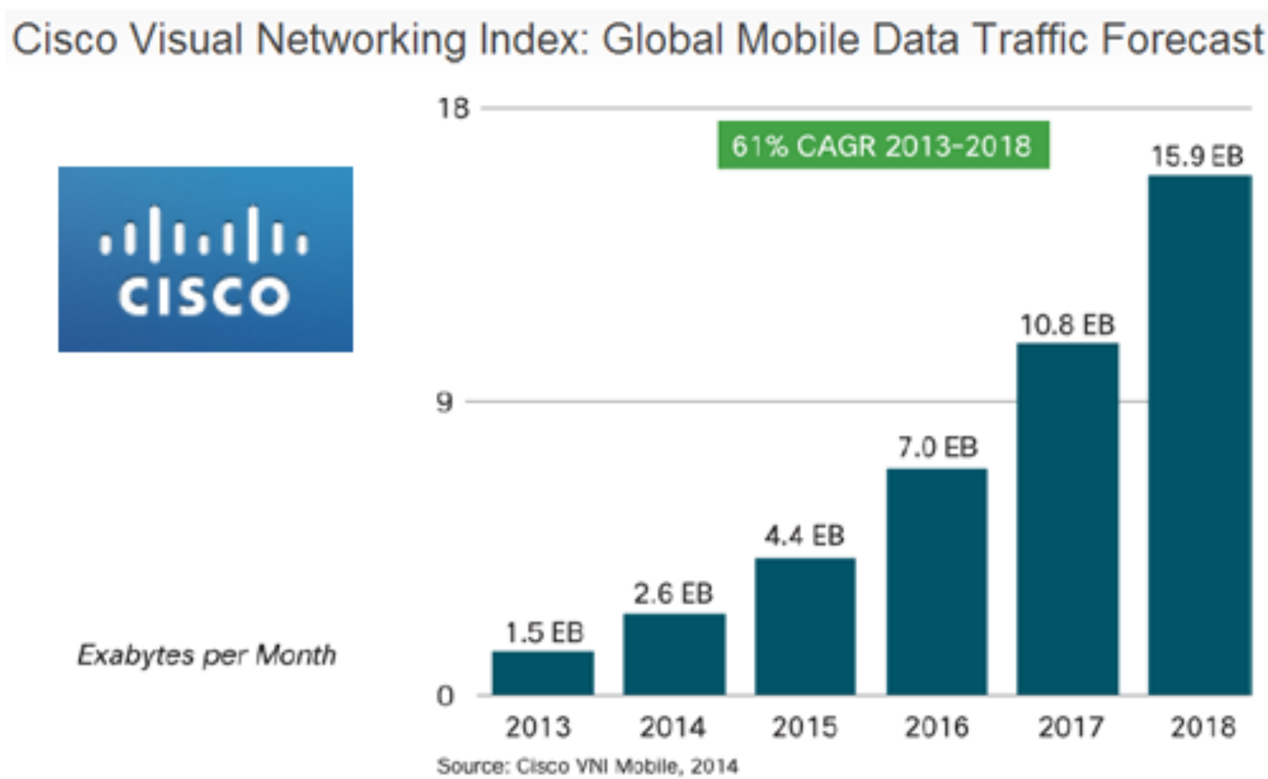
Outline

- **Part 1: Long Term Evolution**
  - Motivations for Long Term Evolution (LTE)
  - Services
  - System architecture
- **Part 2: LTE Radio Link**
  - Multiple access
  - Channel structure and mapping
  - Modulation and coding
- **Part 3: Beyond LTE**
  - Signalling protocol structure
  - Radio resources management
  - Mobility management
  - Connection management

Part 1 : Long Term Evolution

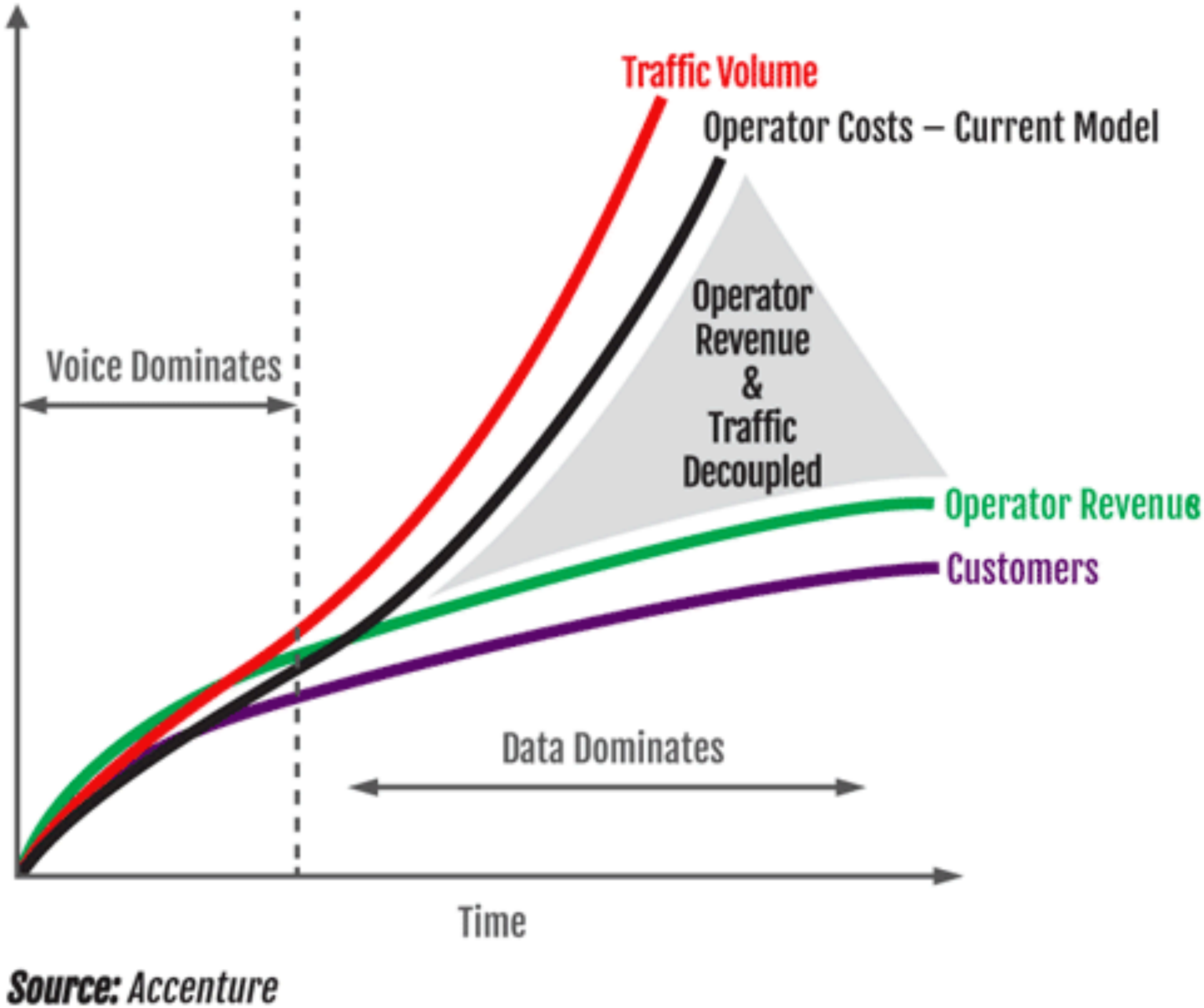
Wireless data forecast

- Cisco forecasts that CAGR for worldwide mobile data traffic from 2013 to 2018, global mobile traffic growth will be 61%, reaching close to 16 Exabytes per month by 2021.
- Global mobile traffic growth will outpace global fixed traffic growth by a factor of three.
- 1 Exabyte = 10^{18} Bytes or 1,000 Petabytes (PB) or 200 million DVDs.
- 5 Exabytes = “a transcript of all the words ever spoken”



Source : https://www.convergedigest.com/2014/02/cisco-mobile-data-traffic-growth.html

Traffic-Revenue Decoupling



Source : Lee Joon Seong/Accenture : http://www.telecomasia.net/content/big-money-big-data

Motivations for Long Term Evolution (LTE)

1. **Need to cater for higher data rates**
   - New air interface employing recent advances in spectrally efficient modulation.
   - Greater flexibility in spectrum usage.
2. **Need to cater for higher data volumes**
   - Need to evolve UMTS towards a data-centric network based on Packet Data end-to-end.
3. **Need for offer more variety and quality of services**
   - Different levels of QoS according to type of service.
   - Dramatically lower latency.
   - “Always-on” experience.
   - Improved power management in the Mobile Station (MS)
4. **Need for cheaper infrastructure**
   - Reduced number of network elements.
   - Use of more generic hardware.

3GPP introduction

- 3rd Generation Partnership Project
  - a collaboration between groups of telecommunications associations, known as the **Organizational Partners**.
  - Organisational Partners include GSMA, ETSI, CCSA.
  - Established in 1998 to define UMTS (3G)
  - Today also works on LTE and access-independent IMS
- 3GPP standardizes systems
  - Architecture, protocols
- Works by way of "releases"

A GLOBAL INITIATIVE

3GPP mode of operation

Stage 1

Requirements

"It shall be possible to..."

"It shall support…"

E.g., 22-series specs

Stage 2

Architecture

Nodes, functions

Reference points

Procedures

E.g., 23-series specs

Stage 3

Protocols

Message formats

Error cases

E.g., 29-series specs

Specification numbering example:

3GPP TS 23.401 V11.2.0

TS=Technical Specification (normative)

TR=Technical Report (info only)

Spec. number

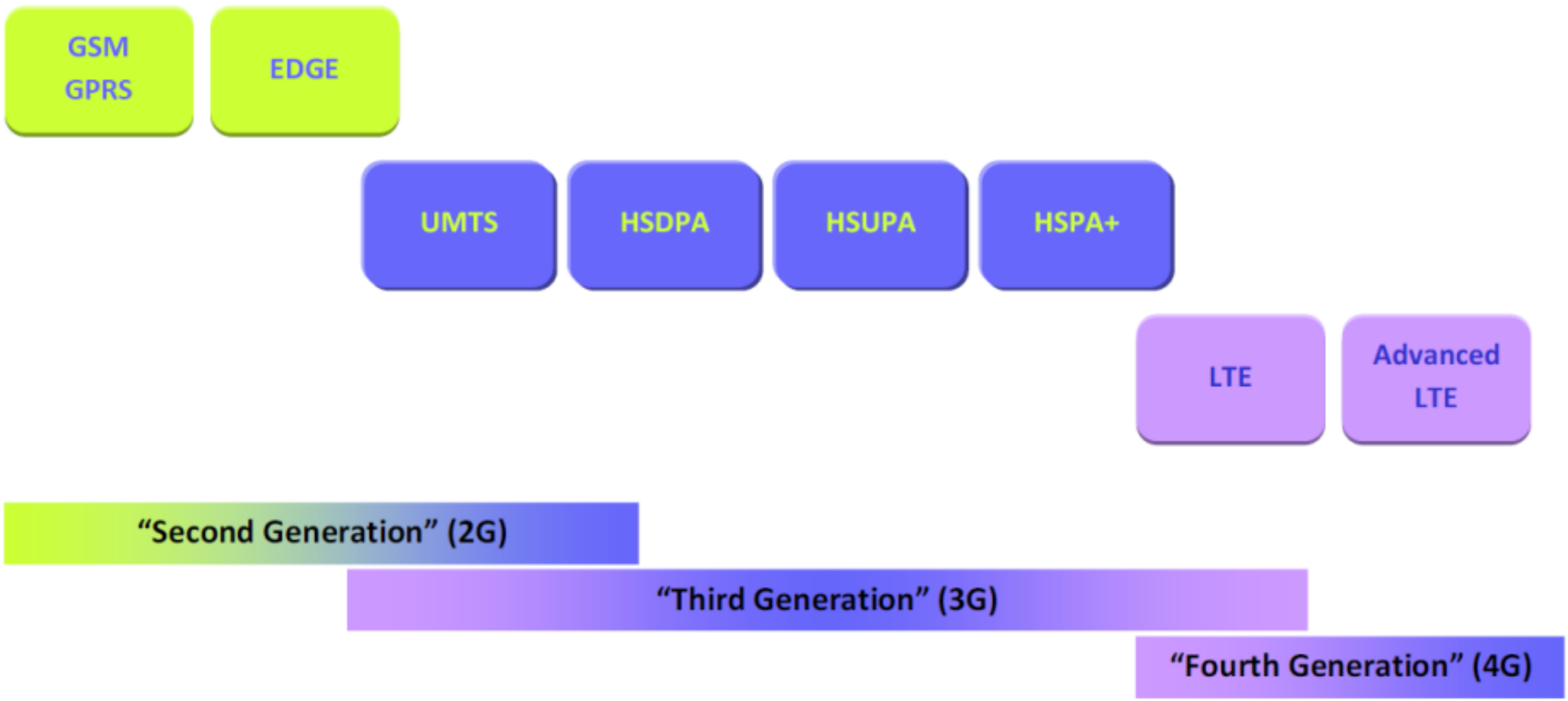
Release

- Consistent set of specs per release
- New release every 1-2 years

Updated after a meeting

http://www.3gpp.org/specification-numbering

3GPP Standards Evolution



Source : “LTE in a Nutshell : System Overview” © 2010 Telesystem Innovations Inc.

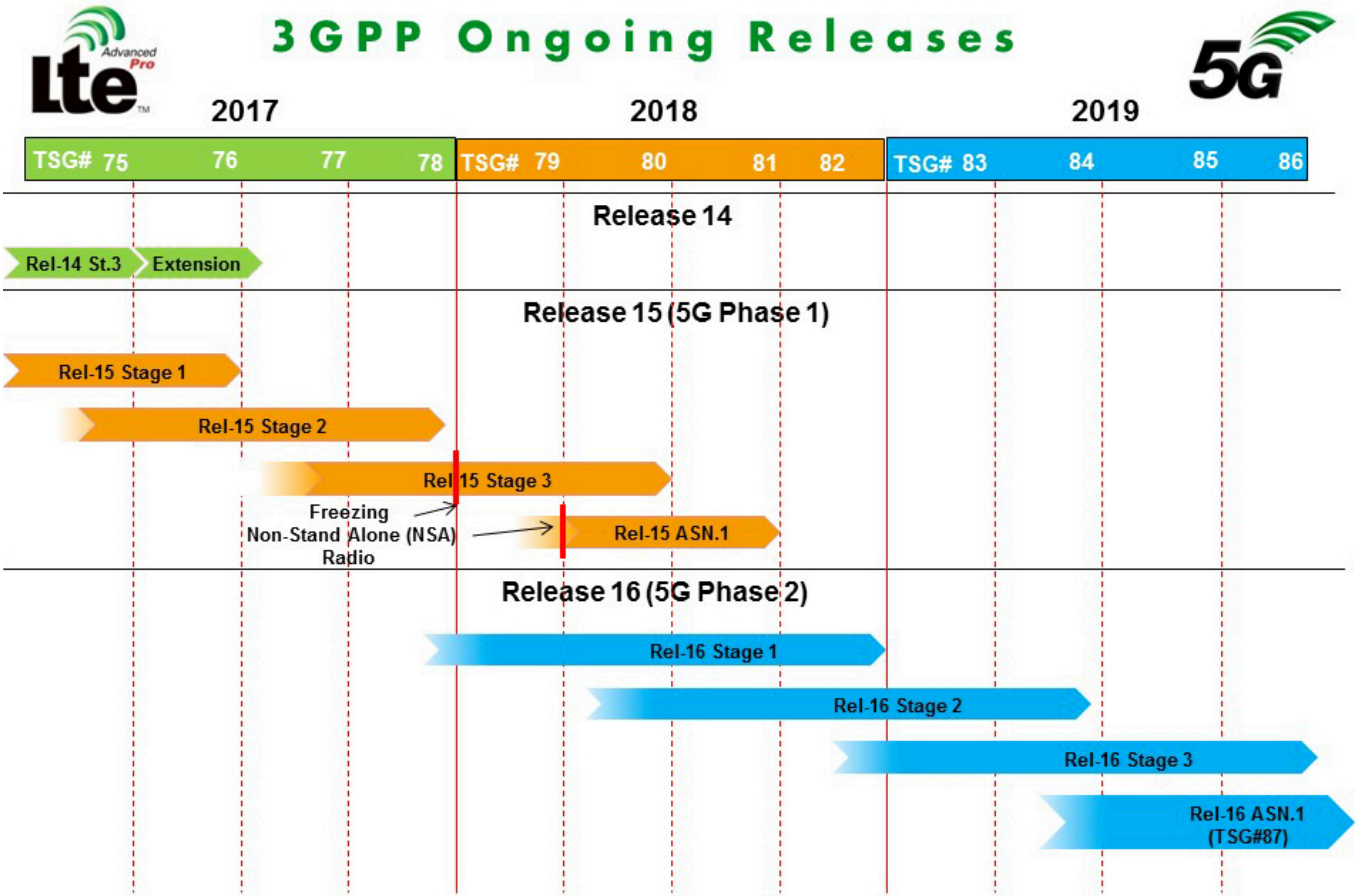
3GPP documents relating to LTE

- http://www.3gpp.org/specification-numbering
  - Pointers to the series of specifications
  - Architecture documents in 23-series
- Main LTE architecture references
  - 23.002 – Overall architecture reference
  - 23.401 – Evolved Packet Core with LTE access, GTP-based core
  - 23.060 – 2G/3G access, and integration to Evolved Packet Core
  - 23.402 – Non-3GPP access, and PMIP-based core

Key 3GPP LTE Standards Releases

Release No.	Date	Content
Release 8	2008 Q4	First LTE release. All-IP Network (SAE). New OFDMA, FDE and MIMO based radio interface, not backwards compatible with previous CDMA interfaces. Dual-Cell HSDPA.
Release 10	2011 Q1	Introduced “LTE Advanced” : Multi-Cell HSDPA (4 carriers).
Release 11	2012 Q3	Introduced Heterogeneous networks (HetNet).
Release 12	2015 Q2	Introduced Device to Device communication (D2D) and the integration of WiFi in to mobile operator's offerings.
Release 13	2016 Q2	Enhancements for operation of LTE in unlicensed spectrum, Carrier Aggregation, Machine-Type Communications (MTC), Beamforming and MIMO.
Release 15	2017 Q4	Introduces the first set of 5G standards.

3GPP LTE Standards Releases



“4G” versus “LTE”

- The 4G standard was defined by the International Telecommunications Union-Radio (ITU-R) in March 2008. According to the ITU definition of 4G, the peak download speed should be 100Mbps for high mobility devices and 1Gbps for stationary devices.
- Since that time the term “4G” has come to be used as a blanket term for all mobile data technologies that exceed typical 3G speeds.
- LTE, or “Long Term Evolution” describes a technology path, based on GSM/EDGE and UMTS/HSPA network technologies, and evolving towards the achievement of 4G speeds.
- The standards defining LTE are the responsibility of the 3GPP (3rd Generation Partnership Project) and embodied in its Release 8 document series, with minor enhancements described in Release 9.
- Most LTE networks today doesn’t achieve the 100Mbps required for 4G, but they are, nonetheless, usually referred to as “4G” or “4G LTE” by the marketing departments of mobile operators.

Key 4G/LTE Performance Requirements

- **Data Rate :**
  - Instantaneous downlink peak data rate of 100Mbit/s in a 20MHz downlink bandwidth (i.e. 5 bit/s/Hz)
  - Instantaneous uplink peak data rate of 50Mbit/s in a 20MHz uplink bandwidth (i.e. 2.5 bit/s/Hz)
- **Latency**
  - Less than 5 ms in unload condition (i.e., single user with single data stream) for small IP packet.
- **Cell range :**
  - 5 km - optimal size
  - 30km sizes with reasonable performance
  - up to 100 km cell sizes supported with acceptable performance

Latency

In packet networks, latency is defined as the amount of time it takes for a data packet to get from one designated point to another.

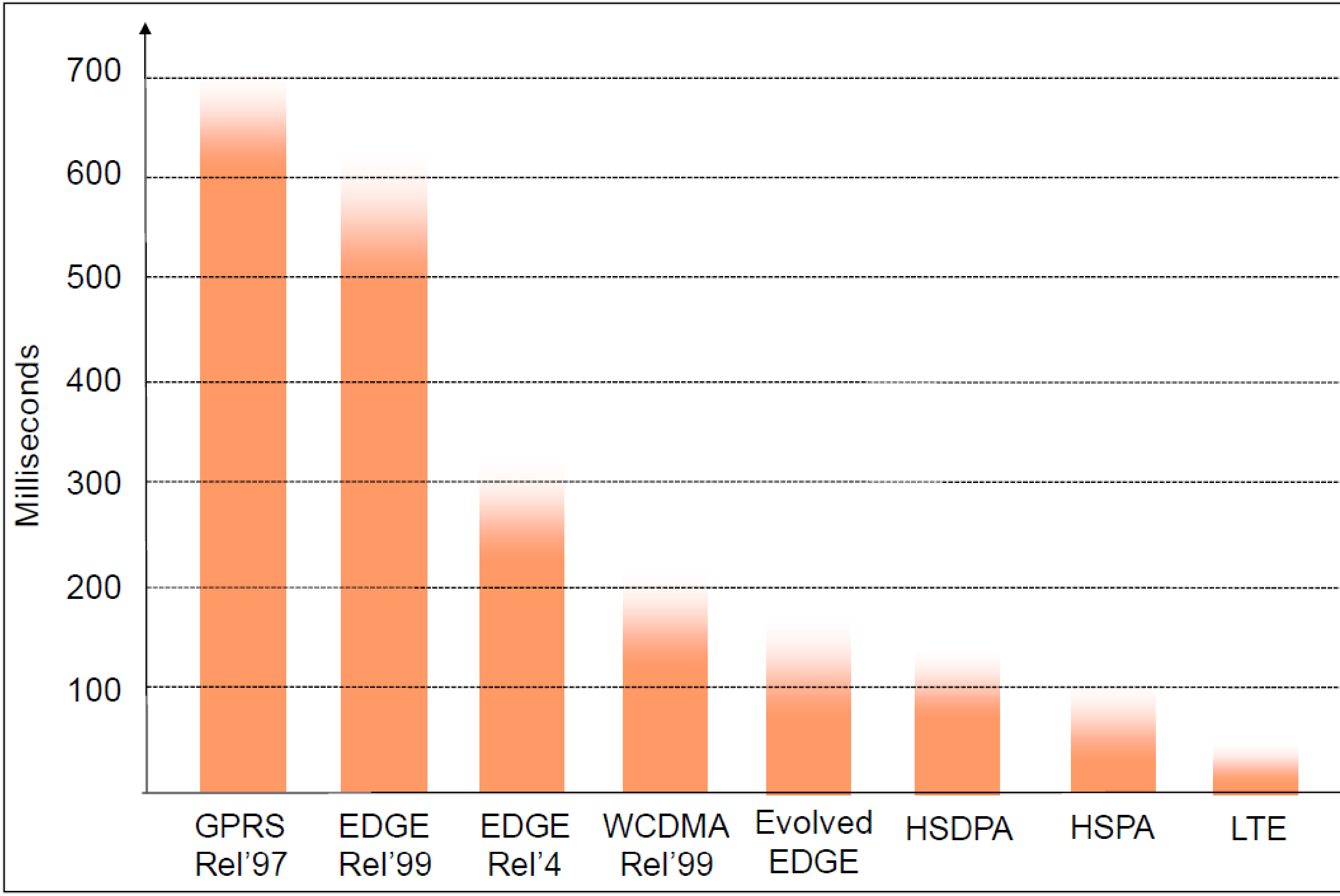
Network latency is a combination of:

1. **Propagation / Transmission delay:** The delay in traversing the medium itself from point A to point B, which depends on the type of medium (optical fiber, wireless etc.). In wireless systems the signal travels at the speed of light, so the delay will be **3.3nS per meter**. In optical fiber the speed is lower and depends on the square root of the refractive index.

2. **Router and other processing delays:** Each gateway node takes time to examine and possibly change the header in a packet. This introduces a processing delay.

3. **Buffering and storage delays:** Packets may be subject to buffering at intermediate devices such as switches and bridges, where they are stored for a short time until a following resource becomes available.

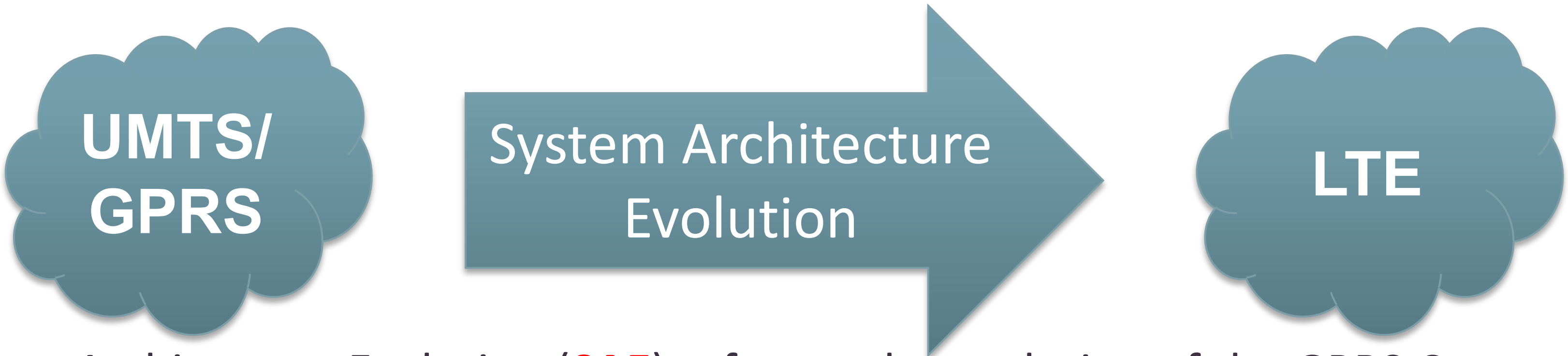
Continuous improvements in Latency



LTE - key themes

- **Technology Evolution**
  - Migration from circuit switching to packet switching for all services.
  - All IP network, end-to-end.
  - Availability of low cost computing power – generic hardware.
  - Low cost digital signal processing makes complex modulation possible – greater spectrum utilisation.
- **Network delayering**
  - Separation of application layers from the transport layers.
  - Simplified network architecture with fewer “boxes”
  - Services decoupled from underlying networks, and can be sold separately.

System Architecture Evolution (SAE)



System Architecture Evolution (**SAE**) refers to the evolution of the GPRS Core Network to accommodate LTE.

The main principles and objectives of the LTE-SAE architecture include :

- A common anchor point and gateway (**GW**) node for all access technologies.
- IP-based protocols on all interfaces.
- Simplified network architecture.
- All IP network : all services (including voice) are delivered via Packet Switched domain
- Support mobility between heterogeneous radio access technologies, including legacy systems such as GSM/GPRS, but also non-3GPP systems (say WiFi/WiMax)

Control plane and User plane

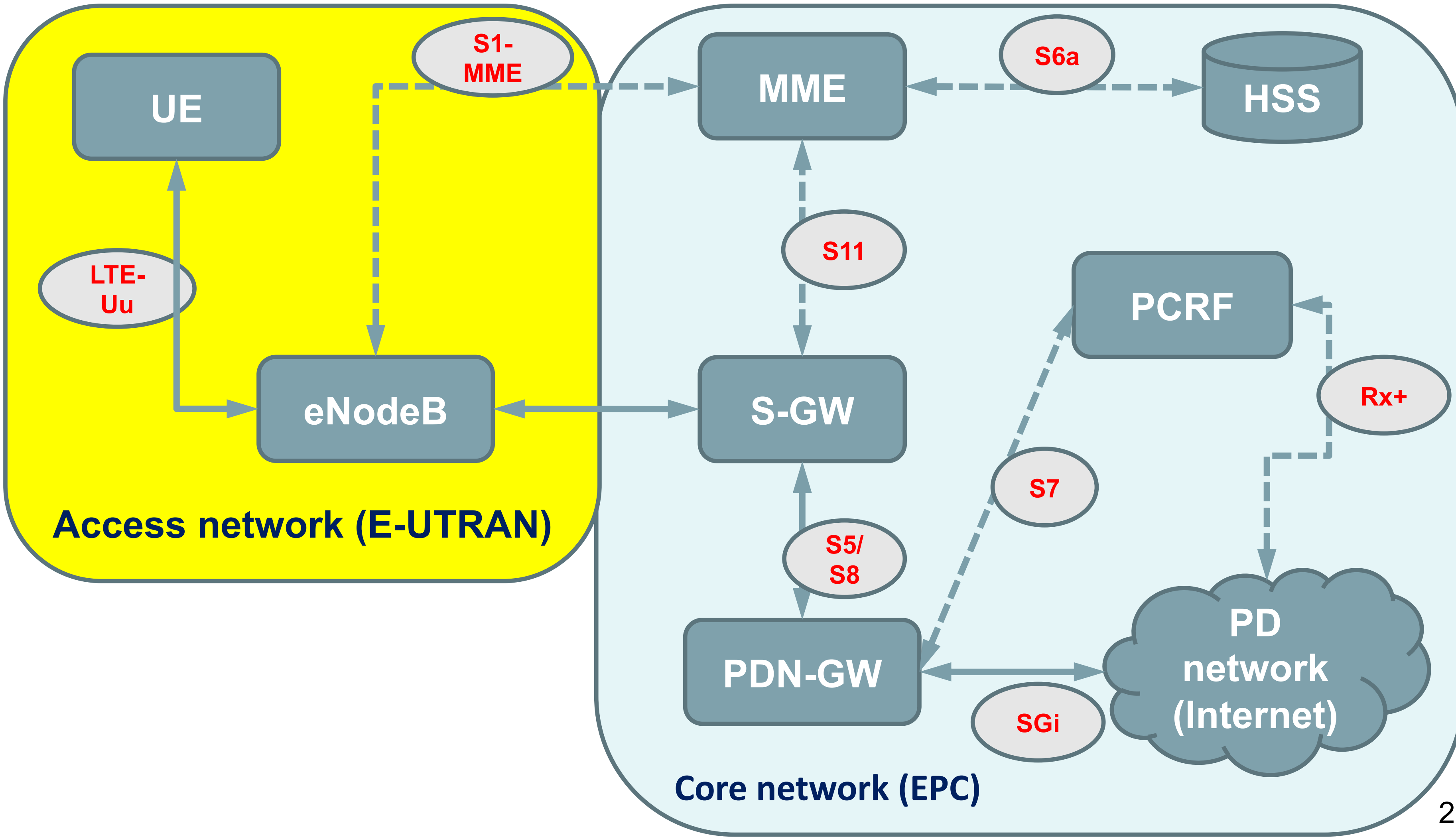
A key feature of the SAE is a flat, all-IP architecture with separation of **Control Plane** and **User Plane** traffic, as shown here. A plane is an abstraction that helps in the understanding the design and operation of an LTE network.

The user plane carries the network user traffic, whereas the control plane carries signalling traffic. Under the user plane, the application creates data packets that are processed by protocols such as TCP, UDP and IP. Under the control plane, something called the Radio Resource Control (RRC) protocol generates signalling messages that are exchanged between the base station and the mobile. In both cases, the information is processed by the Packet Data Convergence Protocol (PDCP), the Radio Link Control (RLC) protocol and the Medium Access Control (MAC) protocol, before being passed to the physical layer for transmission.

The requirements of control plane and user plane are different. The control plane requires lower throughput but higher signal integrity, whereas user plane requires higher throughput but signal integrity is less important.

LTE Network Architecture

- The LTE network consists of an Evolved Universal Terrestrial Radio Access Network (**E-UTRAN**) and an Evolved Packet Core (**EPC**).
- The various network entities are connected via specific interfaces.



LTE Access network (E-UTRAN)

- The Access Network comprises the **eNodeBs** which are interconnected through an interface called X2, and to the EPC through the S1 interface (S1-MME to the MME and S1-U to the S-GW). The protocols between the eNodeB and the UE are known as **Access Stratum (AS)** protocols. The X2 interface is used to transfer the UE context between eNodeBs to support mobility function.

- The eNodeB is responsible for radio-related functions such as **Radio Resource Management (RRM)** which include admission control, mobility control, scheduling and dynamic resource allocation to the UE in both uplink and downlink; security by encrypting user data; and other functions to ensure efficient use of the radio interface such as IP packet header compression.

- By placing all radio control functions in the eNodeB, LTE increases efficiency and reduces latency. It increases the resiliency of the network by eliminating the need for a central controller for such functions as in prior 3GPP technologies.

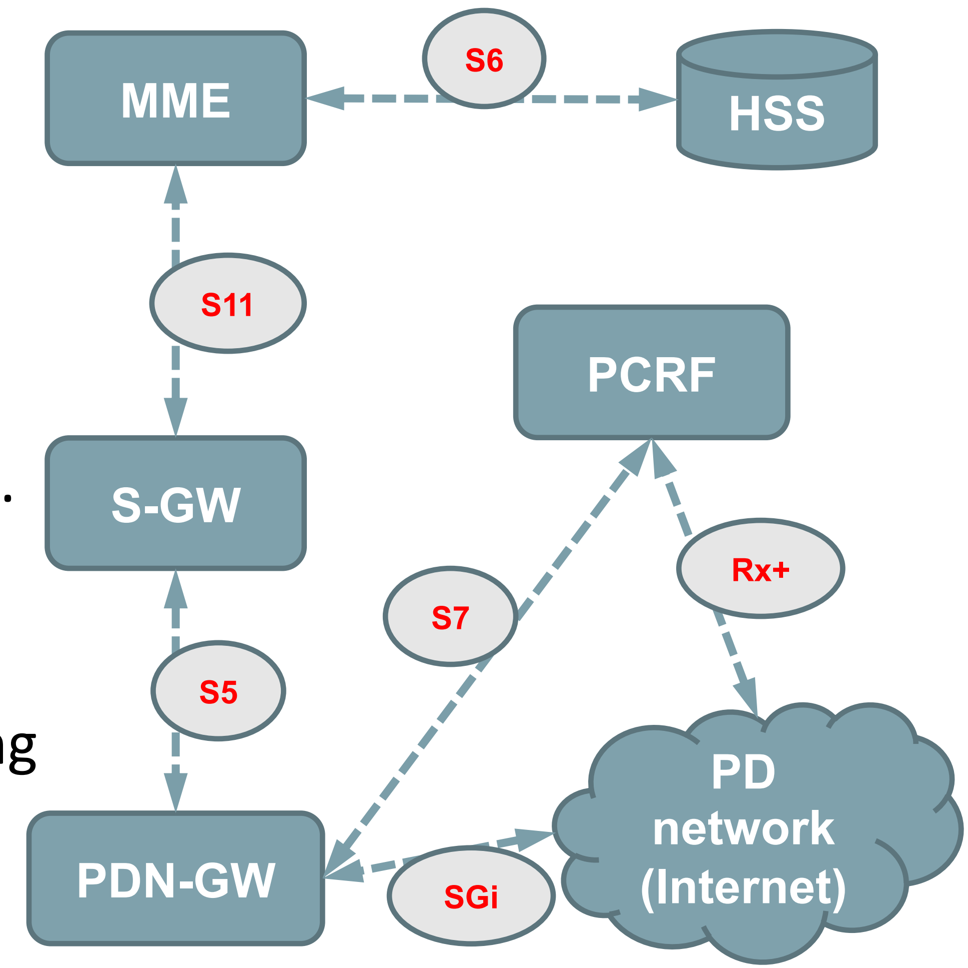
Adapted from : "LTE in a Nutshell : System Overview" © 2010 Telesystem Innovations Inc.

eNode B

- eNodeB are the wireless access points into the network.
- eNodeB support all Layer 1 and Layer 2 features associated to the E-UTRAN OFDM physical interface, and they are directly connected to network routers.
- Under LTE there is no more intermediate controlling node (i.e. BSC in 2G or RNC in 3G/ RNC) which means simplified network operation and better performance over the radio interface.
- The termination of Layer 2 protocols in eNodeB rather than in the RNC helps to decrease data-transmission latency.

The EPC (Evolved Packet Core) is composed of several functional entities:

- The **MME** (Mobility Management Entity)
- The **HSS** (Home Subscriber Server)
- The Serving Gateway (**S-GW**).
- The Packet Data Network Gateway (**PDN-GW**).
- The **PCRF** (Policy and Charging Rules Function) Server.



Serving Gateway (S-GW)

- The Serving GW is the termination point of the packet data interface towards E-UTRAN.
- When terminals move across eNodeB in E-UTRAN, the Serving GW serves as a mobility anchor for other 3GPP technologies (e.g. 2G/GSM and 3G/UMTS).
- serves as the local mobility anchor for data bearers (service flows) and retains information about the bearers when the UE is in idle mode.
- The S-GW performs some administrative functions in the visited network such as collecting charging information (e.g. volume of sent and received user data).

PDN Gateway (P-GW)

- The PDN gateway is the termination point of the packet data interface towards the Packet Data Network.
- Responsible for allocation of IP address to the UE, QoS enforcement and flow-based charging according to PCRF rules.
- The P-GW filters downlink user IP packets into different bearers depending on QoS classification.
- As an anchor point for sessions towards the external Packet Data Networks, the PDN GW also supports **Policy Enforcement features** (which apply operator-defined rules for resource allocation and usage) as well as packet filtering (like deep packet inspection for virus signature detection) and evolved charging support (like per URL charging).

Mobility Management Entity (MME)

The MME is in charge of all the Control plane functions related to subscriber and session management. From that perspective, the MME supports the following:

- **Security procedures** – this relates to end-user authentication as well as initiation and negotiation of ciphering and integrity protection algorithms.
- **Terminal-to-network session handling** – this relates to all the signalling procedures used to set up Packet Data context and negotiate associated parameters like the Quality of Service.
- **Idle terminal location management** – this relates to the tracking area update process used in order for the network to be able to join terminals in case of incoming sessions.

The MME is linked through the S6 interface to the HSS which supports the database containing all the user subscription information.

Home Subscriber Server (HSS)

The HSS (Home Subscriber Server) is the concatenation of the **HLR** and the **AuC** – two functions being already present in 2G/GSM and 3G/UMTS networks. The HLR part of the HSS is responsible for storing and updating the database containing all the user subscription information, including but not limited to :

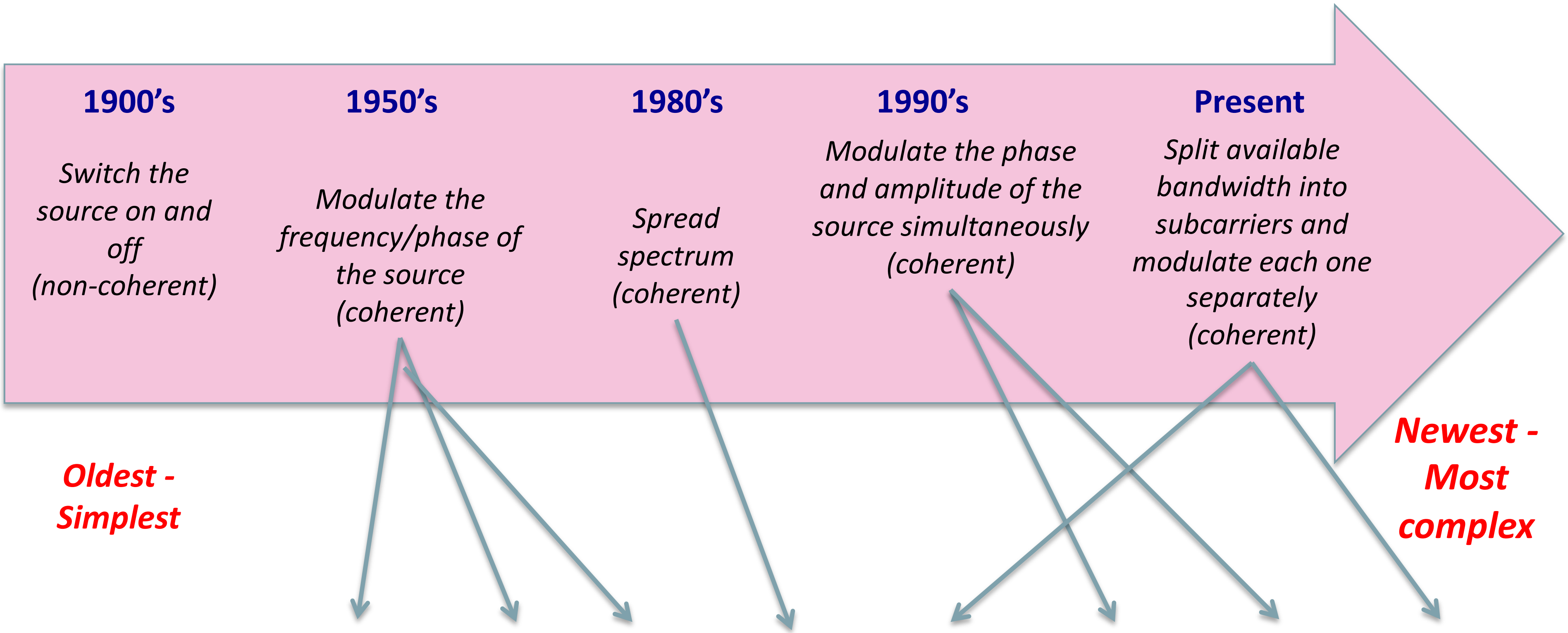
- **User identification and addressing** – this corresponds to the IMSI (International Mobile Subscriber Identity) and MSISDN (Mobile Subscriber ISDN Number) or mobile telephone number.
- **User profile information** – this includes service subscription states and user-subscribed Quality of Service information (such as maximum allowed bit rate or allowed traffic class).

The AuC part of the HSS is responsible for generating security information from user identity keys. This security information is provided to the HLR and further communicated to other entities in the network. Security information is mainly used for:

- Mutual network-terminal authentication.
- Radio path ciphering and integrity protection, to ensure data and signalling transmitted between the network and the terminal is neither eavesdropped nor altered.

Part 2 : The LTE Radio Link

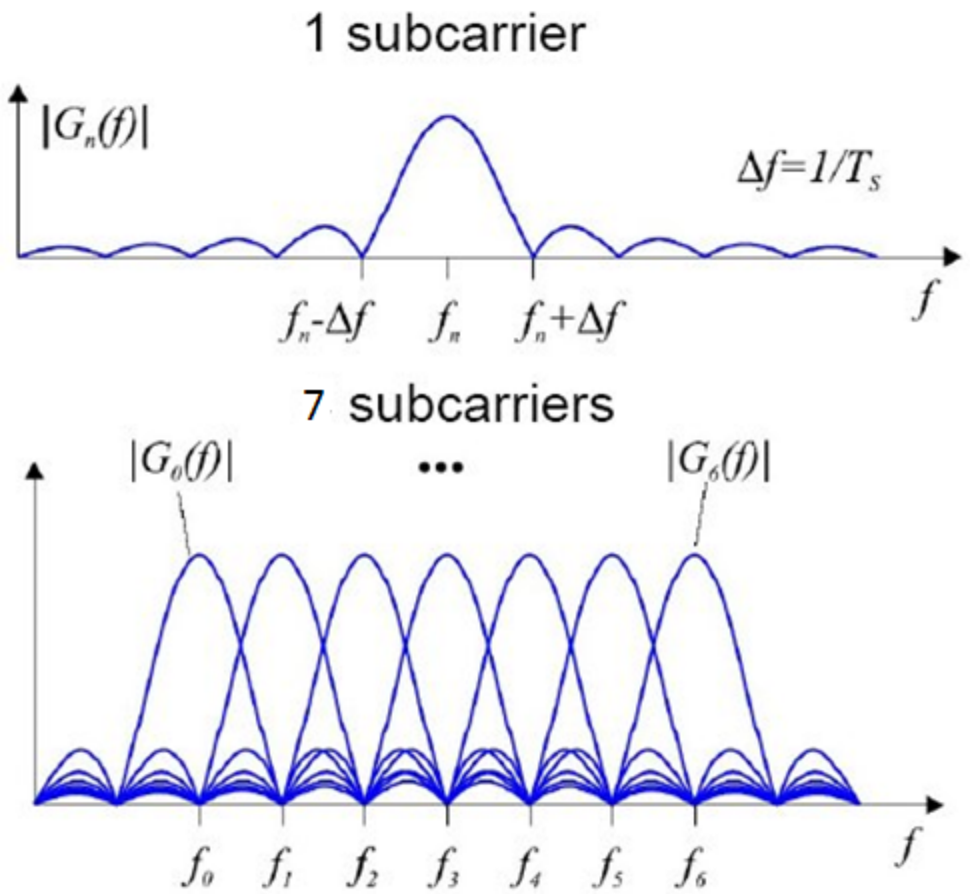
Spectral efficiency trends in the air interface



Modulation scheme	**FSK**	**GMSK**	**8-PSK**	**WCDMA**	**OFDM**	**QAM + OFDM**	**16/64 QAM**	**OFDM**
Bandwidth efficiency (BPS/Hz)	**0.45**	**0.52**	**1.35**	**2.50**	**3.00**	**7.00**	**8.00**	**16.00**
Mobile generation	1G (AMPS)	2G (GSM)	2.75G (EDGE)	3G	WiFi (802.11 a/g)	WiFi (802.11n)	3.5G (HSDPA)	4G (LTE)

LTE-Downlink air interface (OFDM)

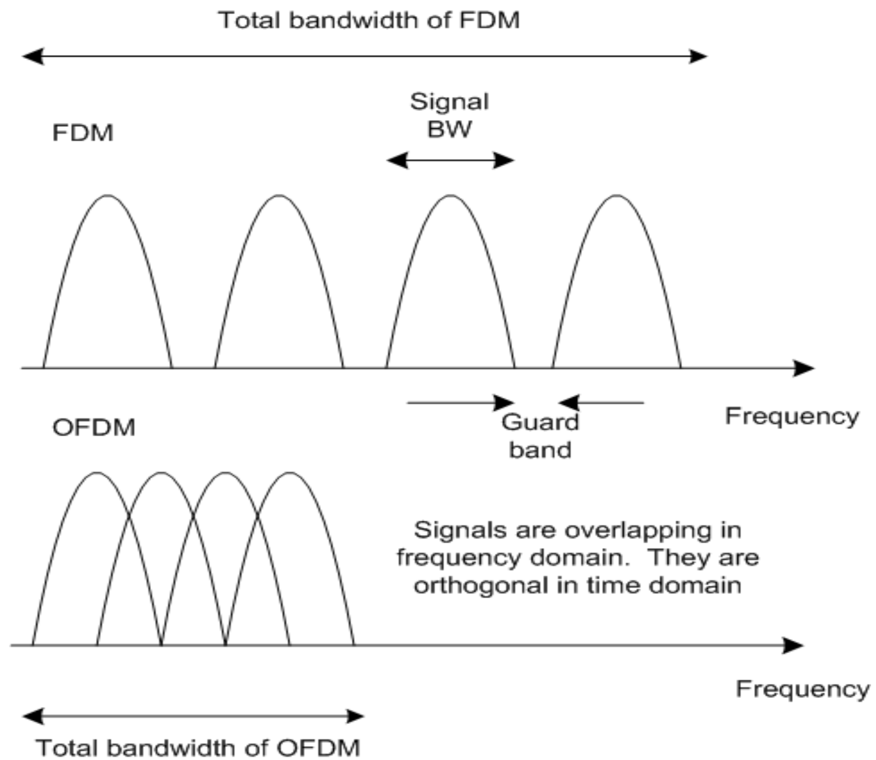
- The principle of the OFDMA is based on the use of narrow, orthogonal subcarriers
- In LTE the OFDMA sub-carrier spacing is **15KHz** regardless of the total transmission bandwidth.
- Within the LTE OFDM signal each subcarrier is modulated using one of the following formats:
  - QPSK (2 bits per symbol)
  - 16QAM (4 bits per symbol)
  - 64QAM (6 bits per symbol)

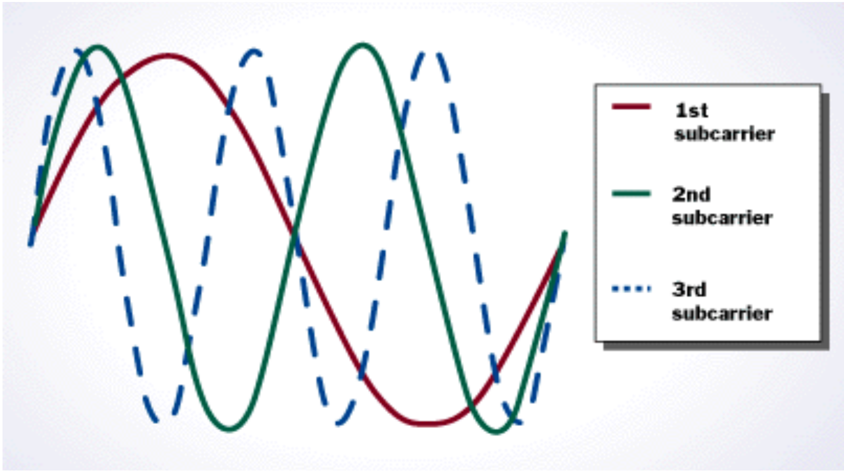


FDM versus OFDM

- OFDM minimizes separation between carriers
- In the **frequency domain**, orthogonality means that the carrier spacing is **Δf=1/T**, where T is the symbol duration.
- In the **time domain**, orthogonal means that the symbol interval is an integer number of full cycles for all carriers.
- In the LTE standard, carrier spacing is **15KHz** and the symbol duration is **66.67μs**.

Note: it is the orthogonality between carriers in time domain that allows optimum spacing in frequency domain.



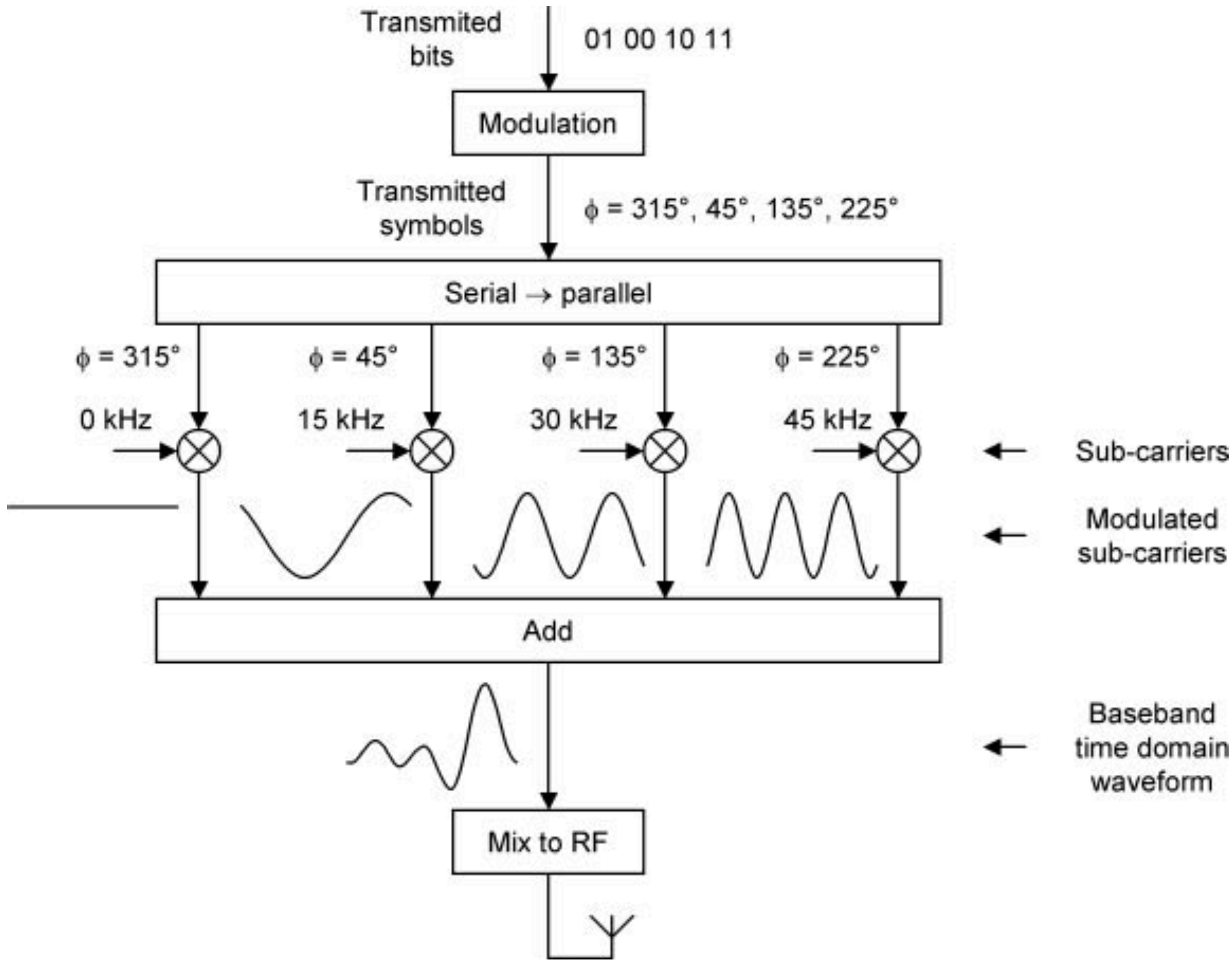


Self assessment question 6.3 :

Which one of the following signals is orthogonal to a subcarrier of frequency 15KHz?

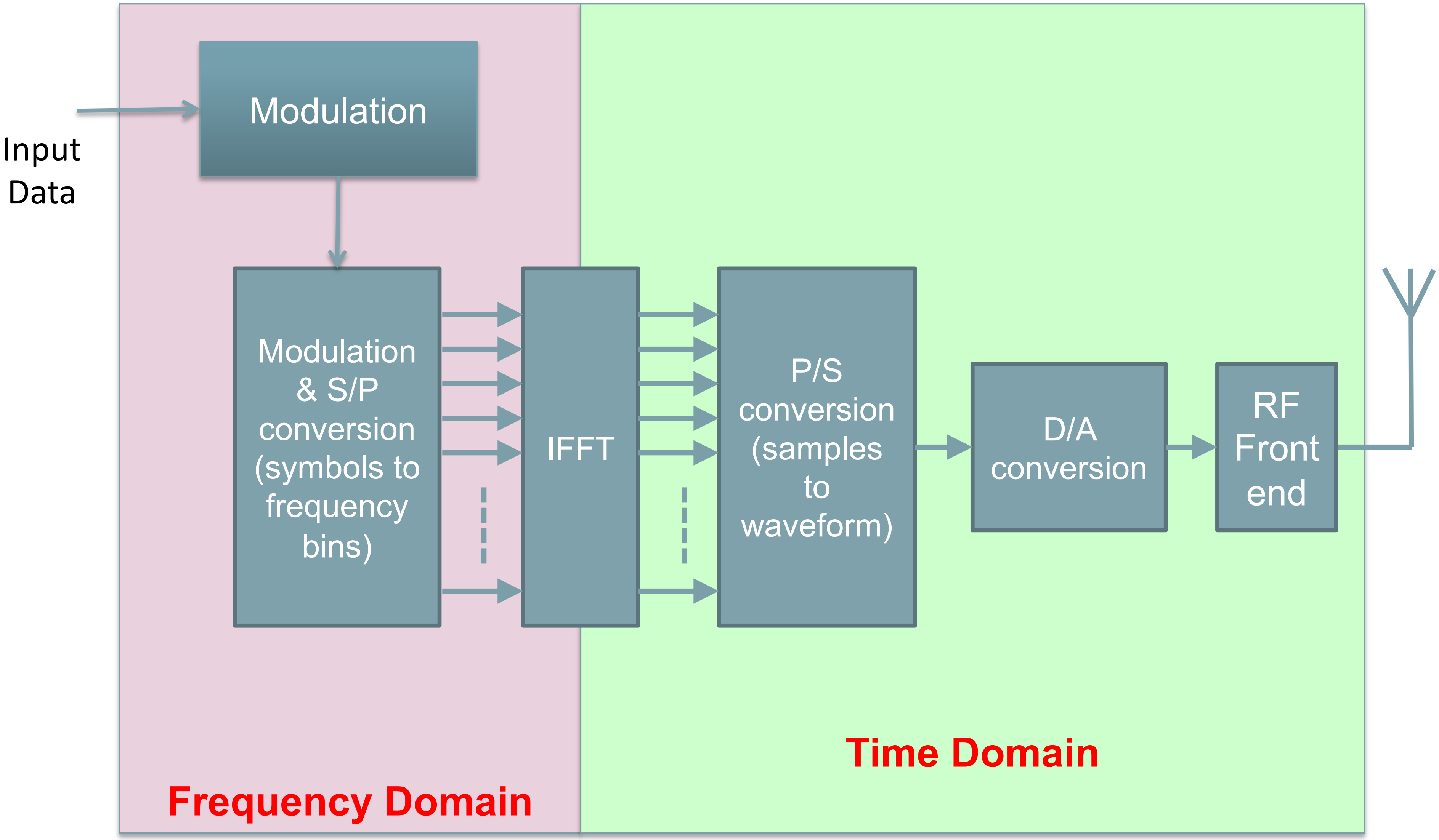
a)	20KHz
b)	200KHz
c)	300KHz
d)	100KHz

Conceptual OFDM transmitter (4 subcarriers)

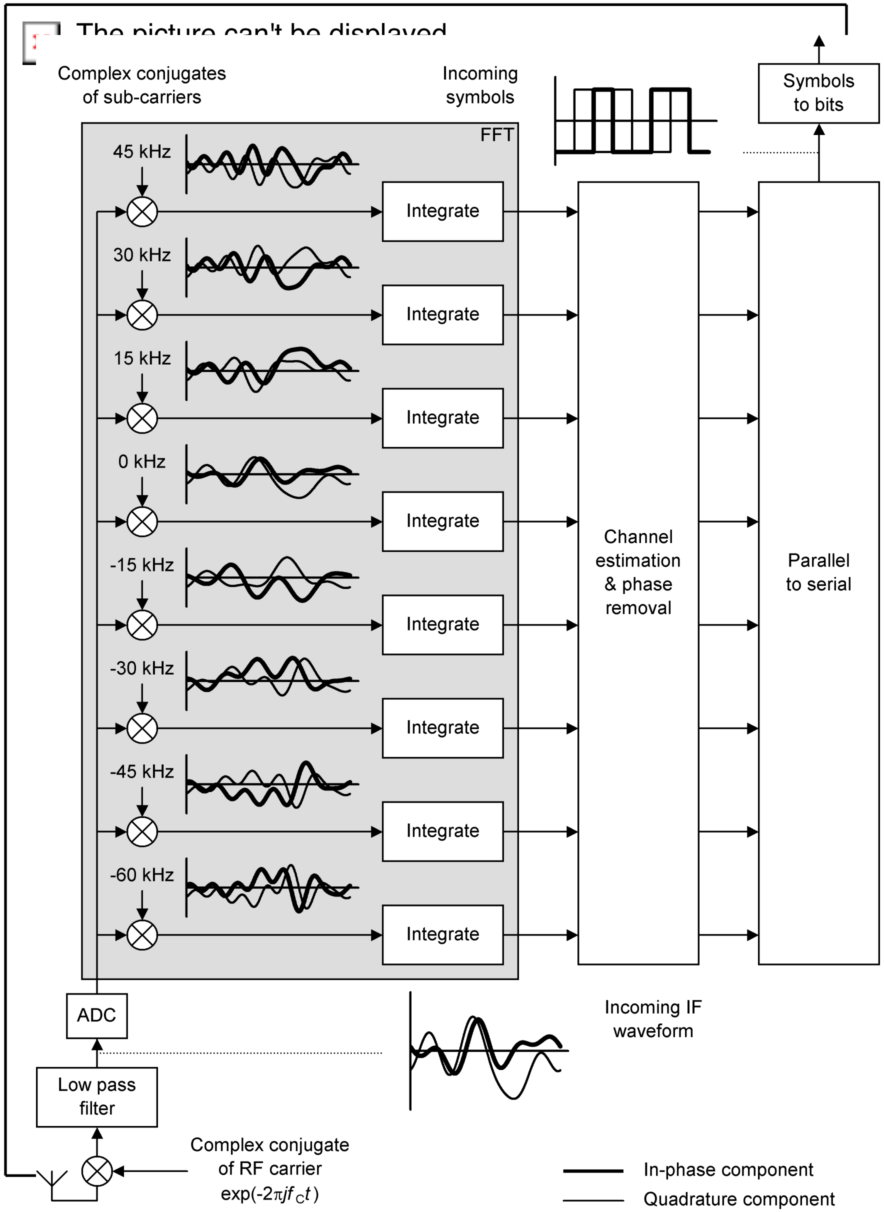


Source : *Christopher Cox "An introduction to LTE", John Wiley & Sons Ltd, 2012*

Practical OFDM Transmitter



Conceptual OFDM Receiver



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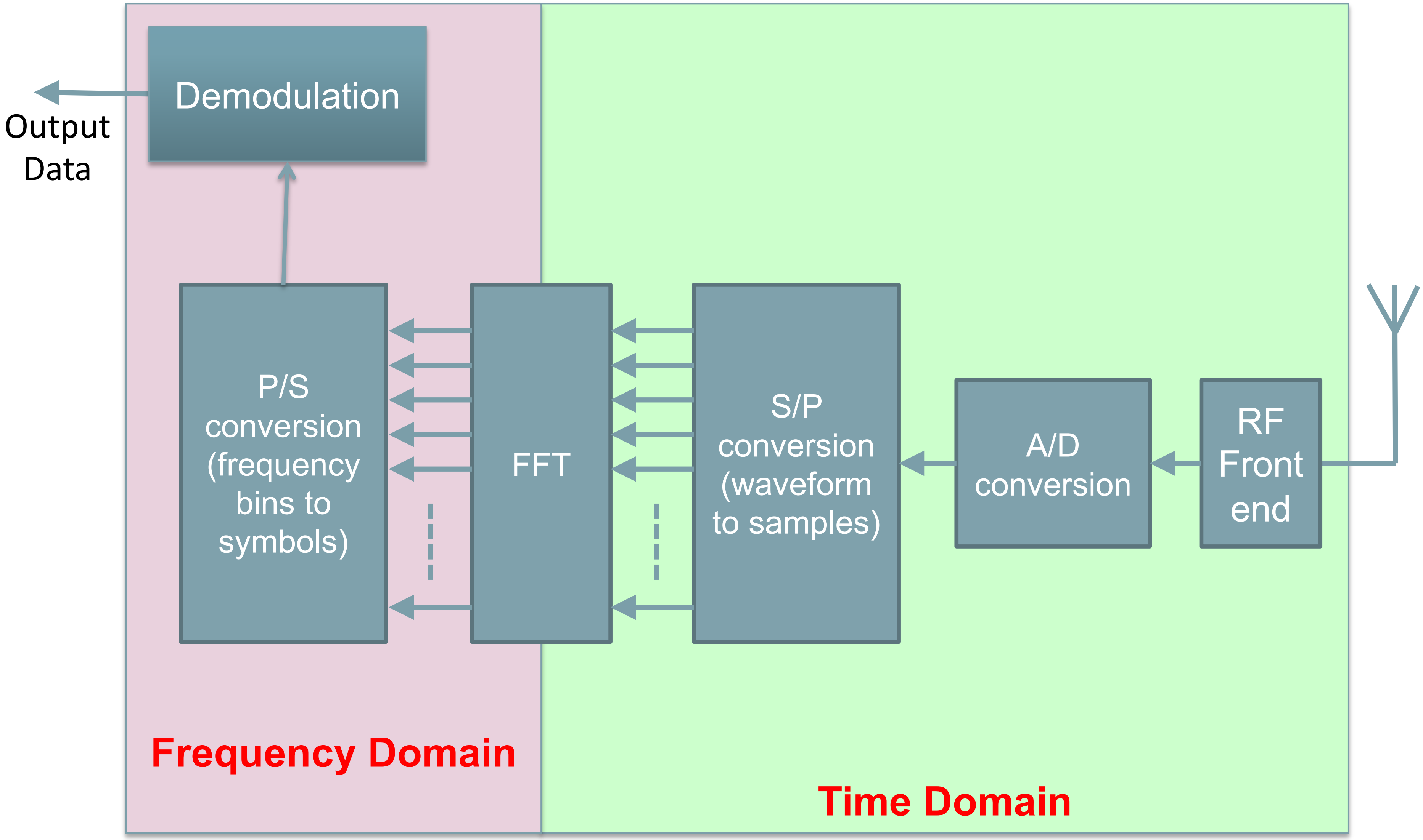
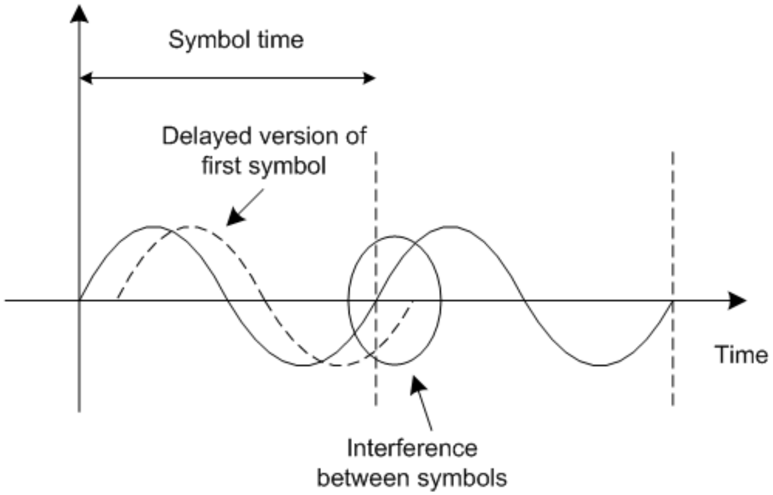
Practical OFDM Receiver

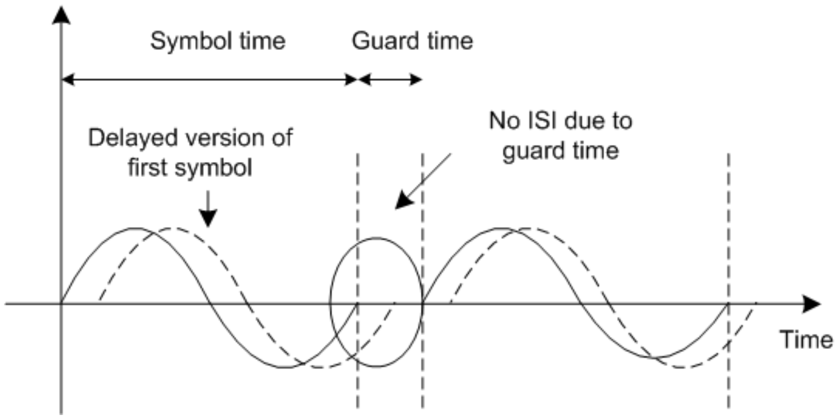


Guard interval

- The duration of the OFDM symbol is chosen to be much longer than the multi-path delay spread (typically 4 to 7μs in urban areas).
- Long symbols imply low rate on individual OFDM carriers.
- In a multipath environment long symbol minimizes the effect of channel delay spread.
- To make sure that there is no Inter Symbol Interference (ISI) between OFDM symbols a **guard interval** is inserted.



OFDM symbols without guard time



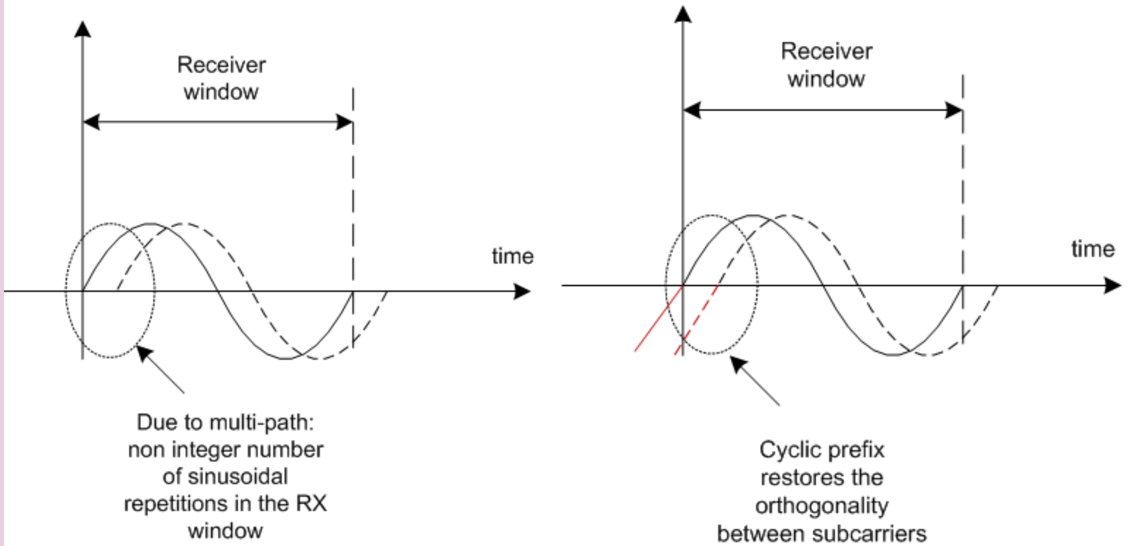
OFDM symbols with guard time

Cyclic prefix

- Inserting a guard time reduces ISI between OFDM symbols.
- Multipath propagation conditions degrade orthogonality between carriers within an OFDMS symbol.
- To regain the orthogonality between subcarriers a **cyclic prefix** (CP) is used. The duration of the cyclic prefix should be greater than the duration of the multipath delay spread.
- The cyclic prefix fills in the guard time between the OFDM symbols and is generated by copying the beginning part of the main body of the OFDMA symbol and inserting it back at the end of the symbol.
- Inserting the cyclic prefix, rather than just leaving an "empty" guard band, creates a smooth transition between the guard band and the following symbol.

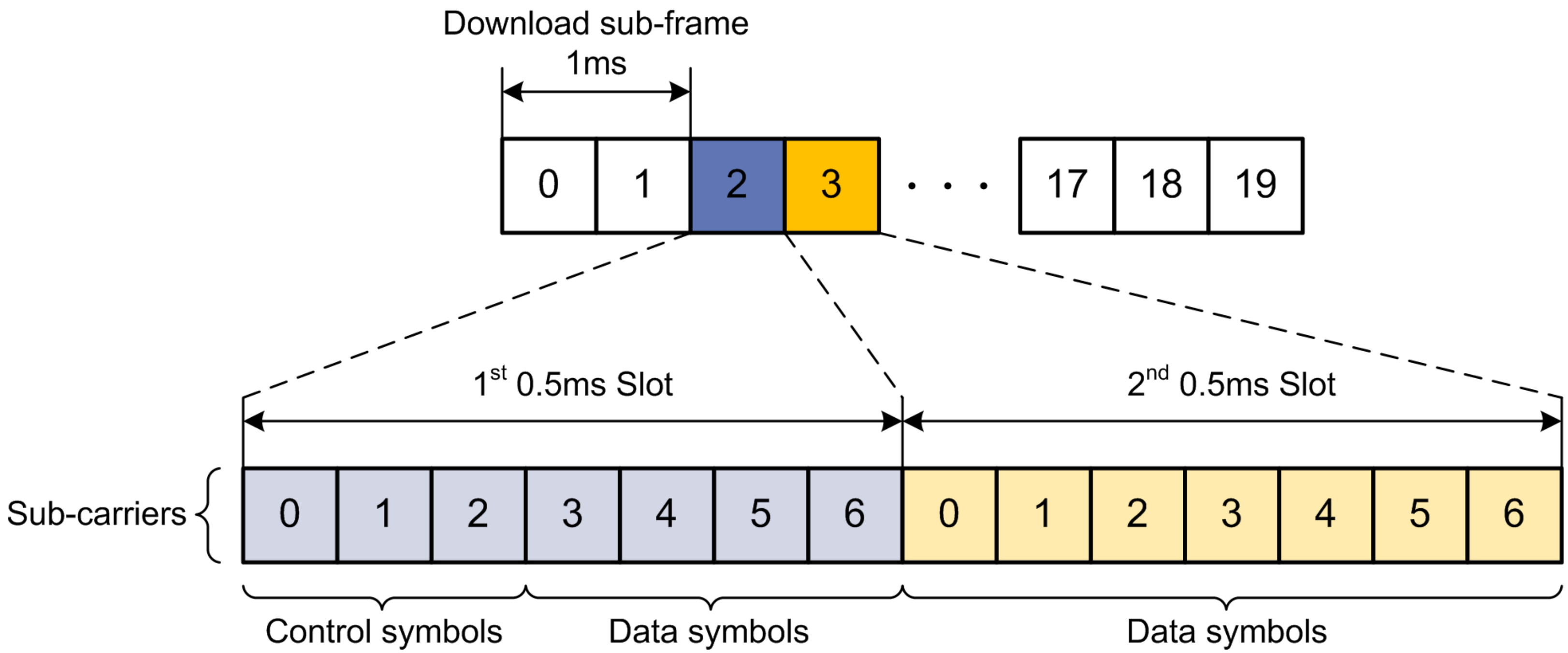
There are two choices of Cyclic prefix:

1. The standard ('short") cyclic prefix is 4.69μs. This enables the system to accommodate path variations of up to 1.4 km. This is used in urban environments.
2. A long cyclic prefix of 16.67μs is available. This enables the system to accommodate path variations of up to 5 km. This is used in rural environments.



LTE Downlink

- The duration of the LTE system frame is **10 ms,** consisting of ten 1ms sub-frames with two slots each.
- Within one slot, six or seven OFDM symbols are transmitted, depending on the cyclic prefix used (to be explained).



LTE Resource block

- Under LTE, information is organised in terms of both time and frequency, using a two dimensional **resource grid**.

- A **resource bloc** is shown here. The resource block is built from of a number of **resource elements**.

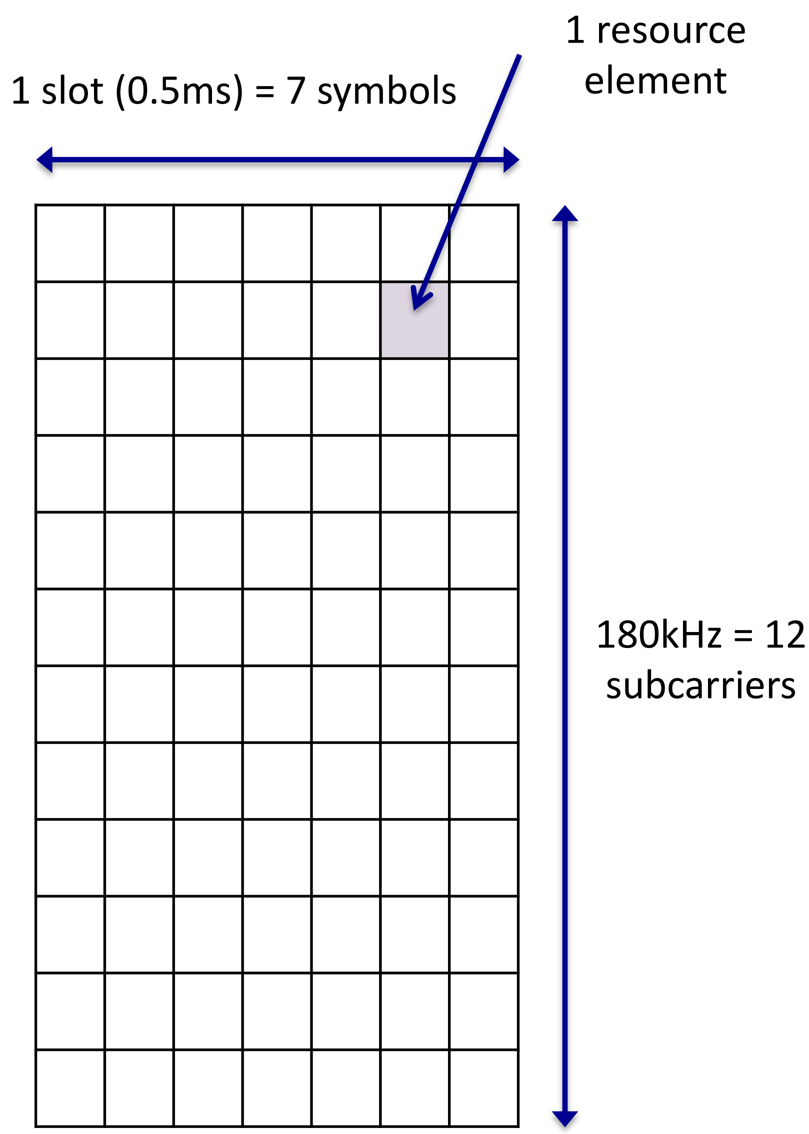
- Each resource element spans one symbol in time by one subcarrier in frequency.

- In the frequency domain one resource block occupies 12 sub carriers, i.e. 12 * 15khz = 180 KHz.

- In the time domain, the same resource block occupies one slot which is half of a subframe (0.5ms).

- For the normal cyclic prefix (shown here) there are 7 symbols per timeslot. If the extended cyclic prefix is used there are 6 symbols per timeslot.

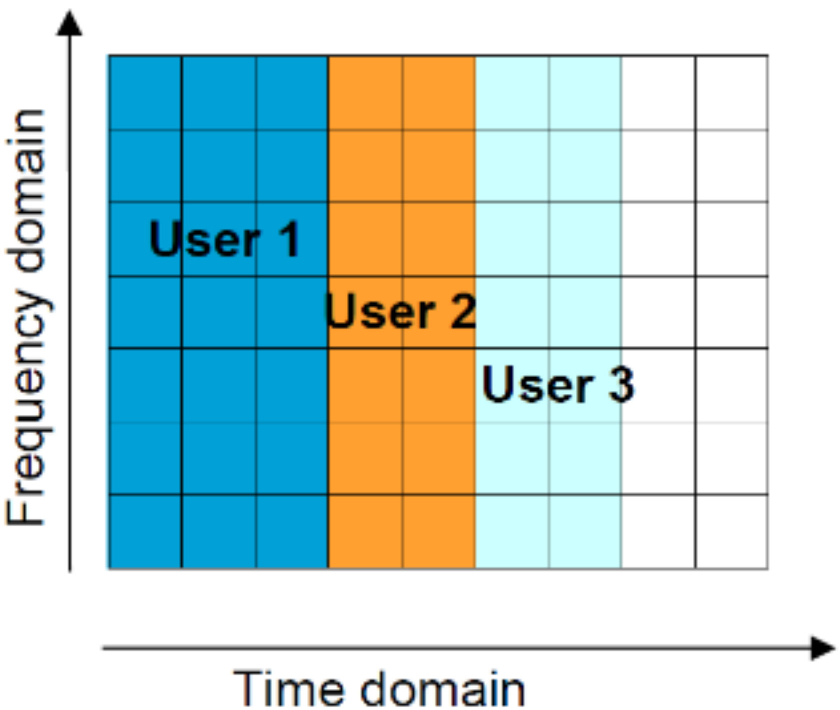
- The allocation of LTE physical resource blocks (PRBs) is handled by a scheduling function at the 3GPP base station (eNodeB).



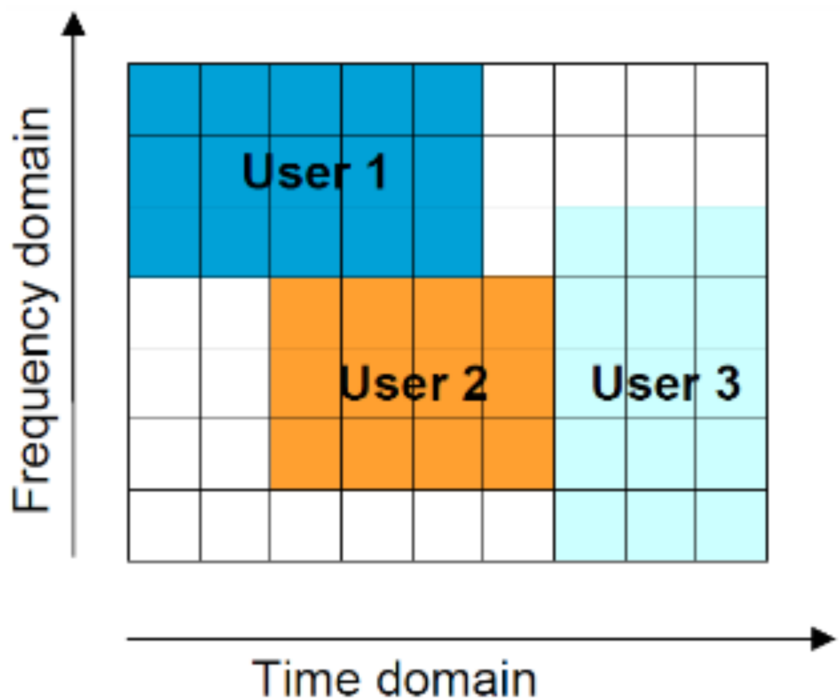
OFDM vs OFDMA

- Under classical **OFDM**, each user is able to use the full frequency range for a predetermined time.
- Under **OFDMA**, the subcarriers are dynamically allocated to multiple users at any given time.

- OFDM allocates users in time domain only

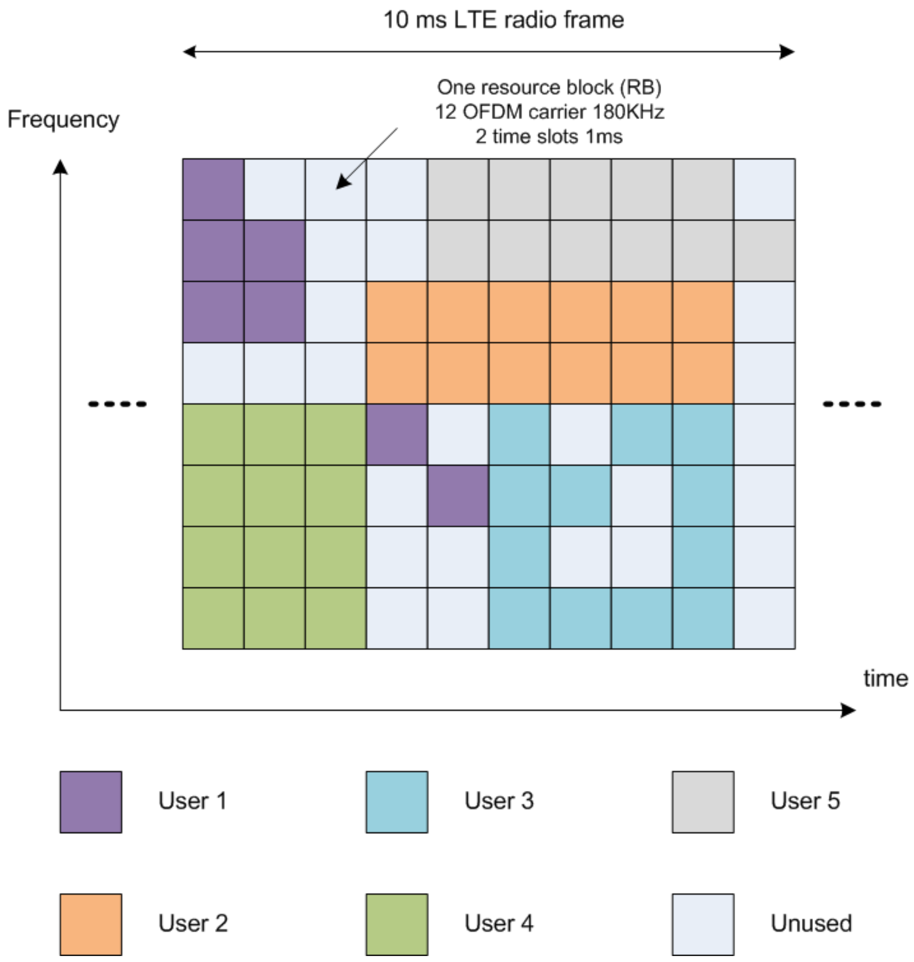


- OFDMA allocates users in time and frequency domain

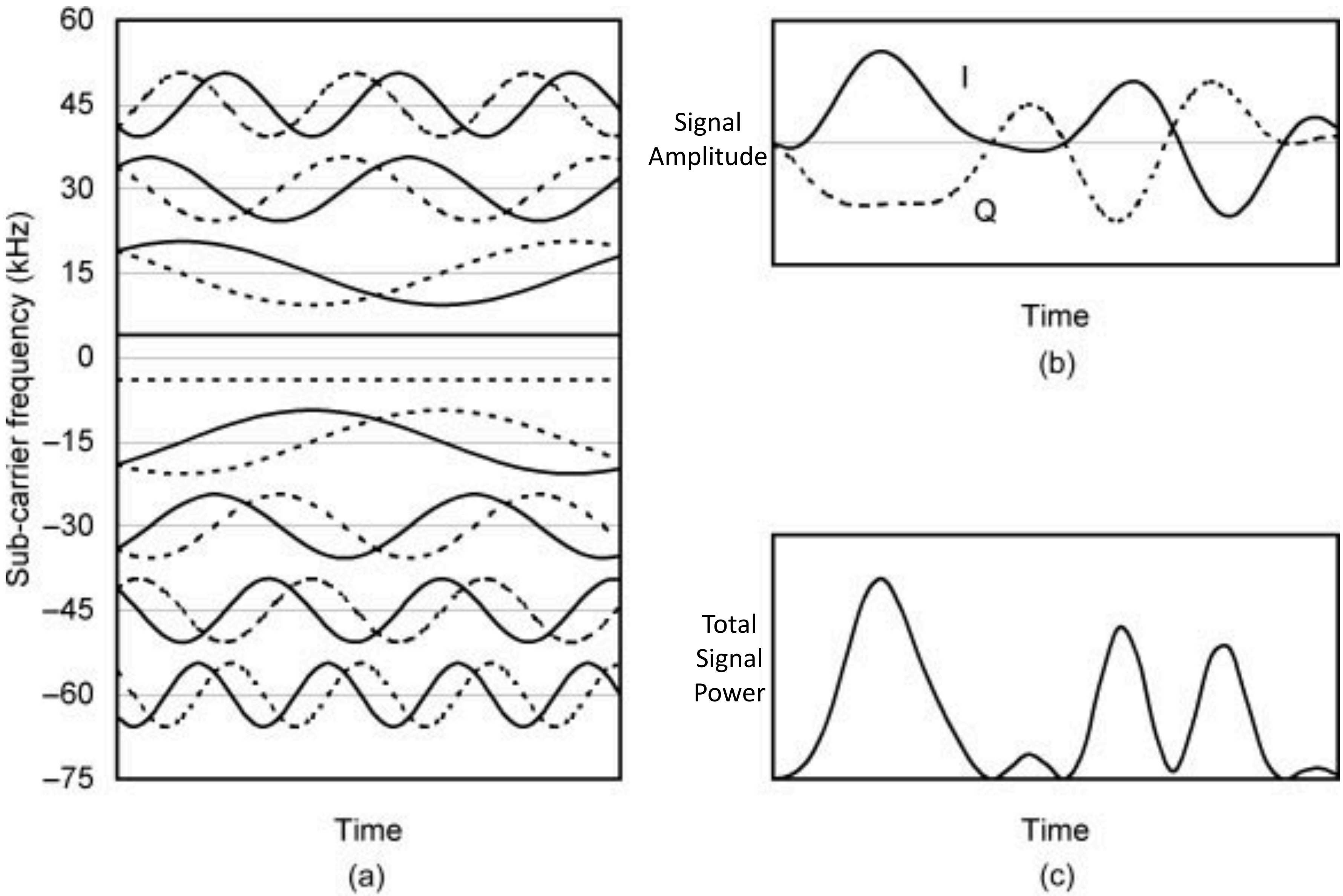


OFDMA time-frequency scheduling

- The minimum allocateable resource in LTE is **Resource Block (RB) pair**
- A resource block pair is 12 carriers wide in frequency domain and lasts for two time slots (1ms)
- Depending on the length of cyclic prefix RB pair may contain **14** or **12** OFDM symbols.
- Physical channels (PHY) consist of certain number of allocated RB pairs.
- Overhead channels typically occupy a predetermined location in time frequency domain.
- Within a RB different AMC scheme may be used.
- Allocation of the radio block is carried out by scheduler at eNode B.



Power variations with OFDM/OFDMA



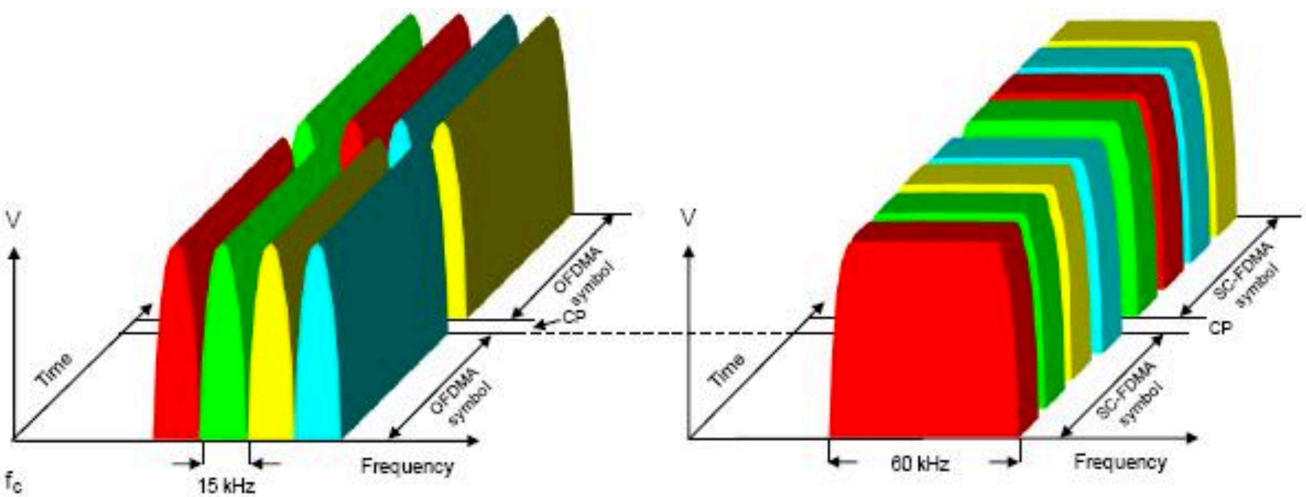
Source : *Christopher Cox, "An introduction to LTE", John Wiley & Sons Ltd, 2012*

LTE Uplink

- The uplink also uses a variant of OFDMA known as Single Carrier Frequency Division Multiple Access (SC-FDMA).
- The mobile station (MS) faces different challenges from the fixed infrastructure, most notably in terms of the limited power resource available from the battery. Hence, power efficiency of radio blocks is of far greater significance at the MS.
- The OFDM signal is characterized by a high value of **peak power to average power ratio (PAPR)**, which implies the need for a high degree of linearity in the power amplifier and a decrease in the average power of emitted signal as compared to signals for which the PAPR is insignificant.
- SC-FDMA overcomes this by "spreading" each data symbol over multiple subcarriers, SC-FDMA offers **spreading gain** or **frequency diversity gain** in a frequency selective channel. Thus, SC-FDMA can be viewed as frequency-spread OFDM or DFT-spread OFDM.

LTE Uplink (SC-FDMA)

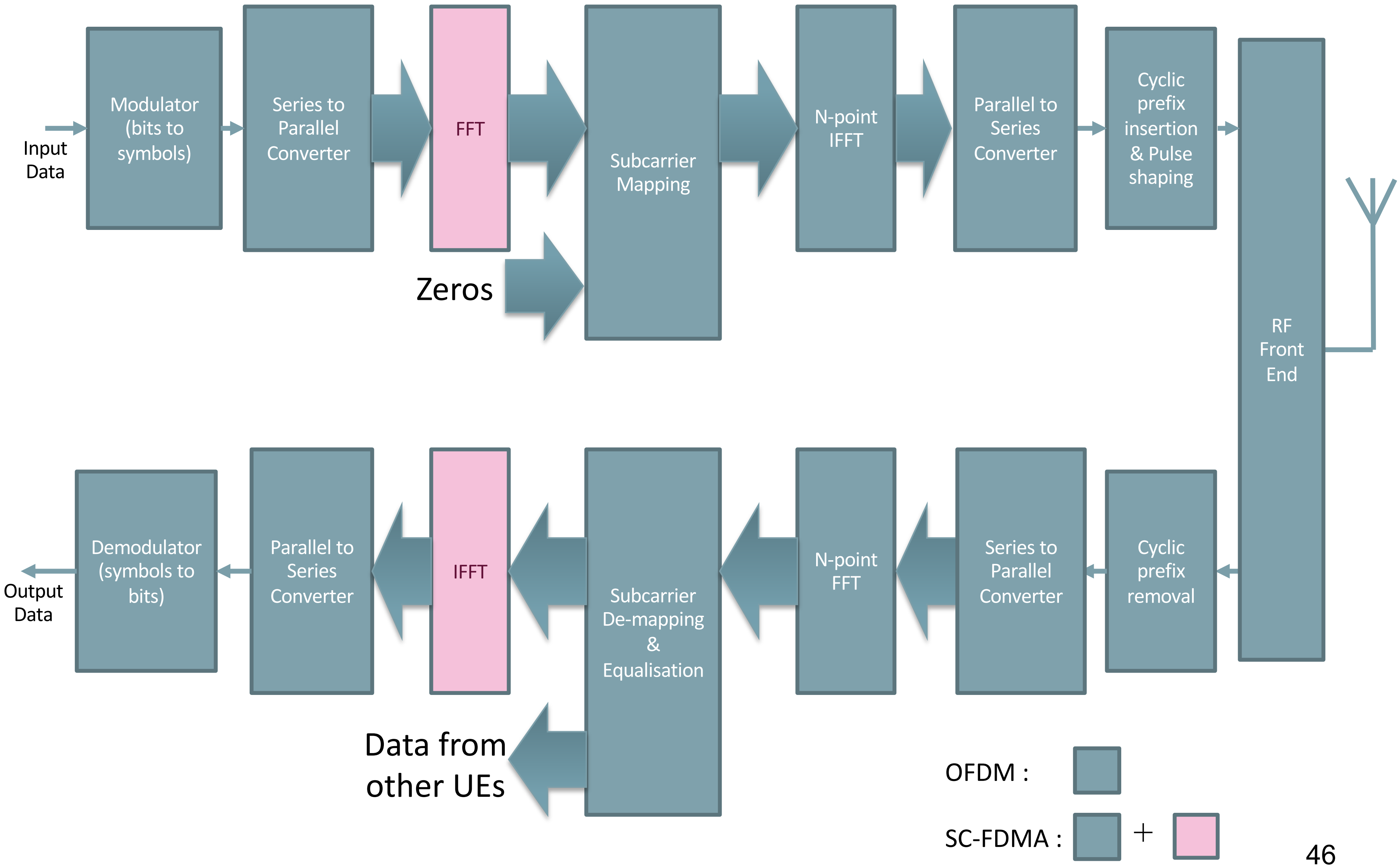
- Single Carrier FDMA (SC-FDMA) is a variation of OFDMA which facilitates reduced PAPR on the LTE uplink.
- Whereas OFDMA transmits, for example, four QPSK data symbols in parallel, one per each subcarrier, SC-FDMA transmits the four QPSK data symbols in series at four times the symbol rate, with each data symbol occupying the full N x 15 kHz bandwidth.
- Visually, the OFDMA signal is clearly multi-carrier and the SC-FDMA signal looks more like single-carrier, which explains the "SC" in its name.



Transmission scheme	OFDMA		SC-FDMA	
Analysis bandwidth	15 kHz	Signal BW (M x 15 kHz)	15 kHz	Signal BW (M x 15 kHz)
Peak to average power ratio (PAR)	Same as data symbol	High PAR (Gaussian)	< data symbol (not meaningful)	Same as data symbol
Observable IQ constellation	Same as data symbol at 66.7 µs rate	Not meaningful (Gaussian)	< data symbol (not meaningful)	Same as data symbol at M X 66.7 µs rate

The reason for using SC-FDMA rather than OFDM in the uplink is low to **Peak to Average Power Ratio** (PAPR). This leads to Improved battery life and less stringent requirements in the transceiver circuitry.

LTE Uplink transceiver implementation



Self assessment question 6.5:

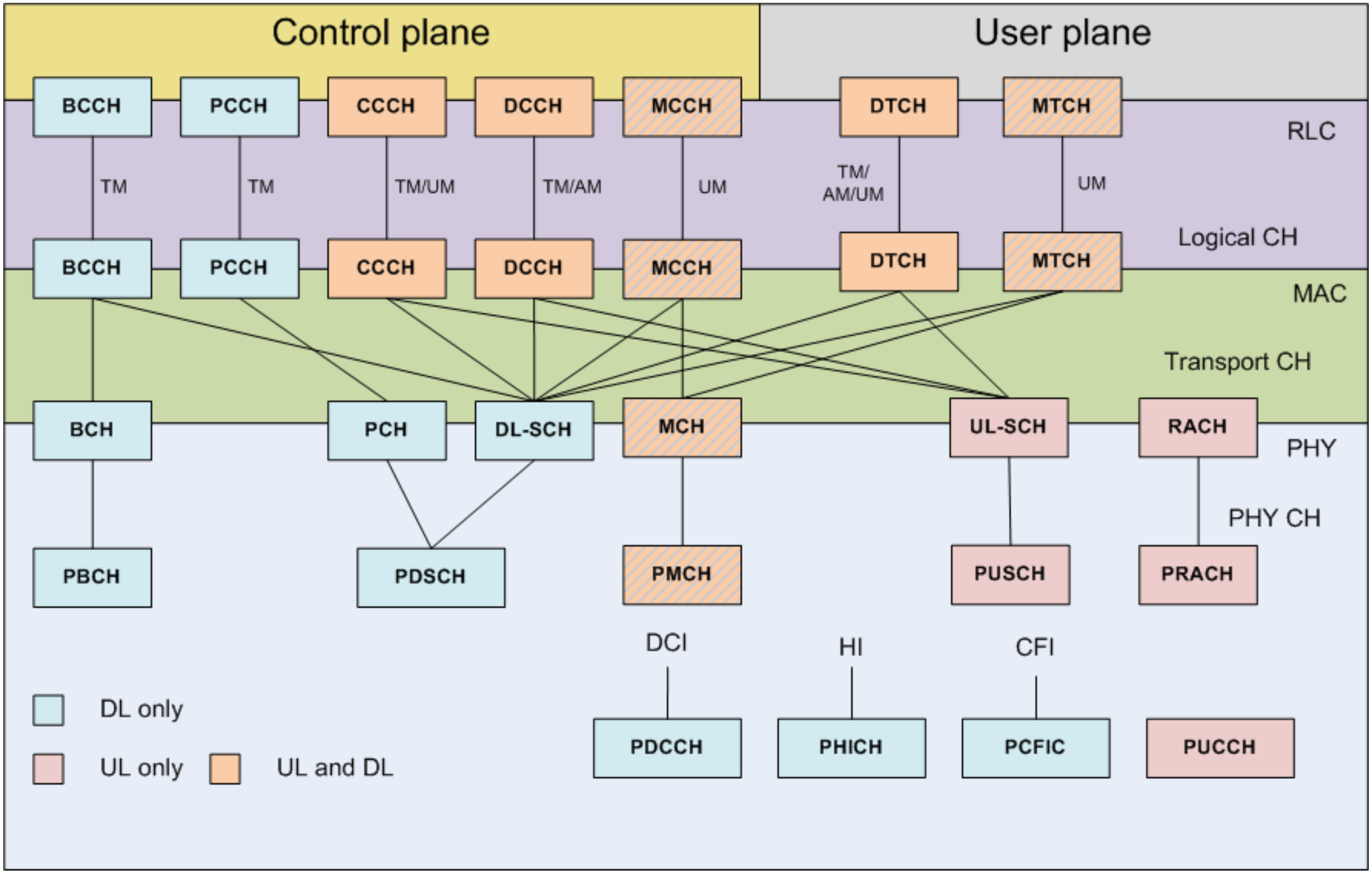
The uplink in LTE uses a modified version of OFDM, called SC-FDMA, for the following reason:

a)	To conserve battery power
b)	To reduce the PAPR thereby simplifying the design of the transmitter power amplifier.
c)	To conserve bandwidth
d)	To reduce inter-symbol interference

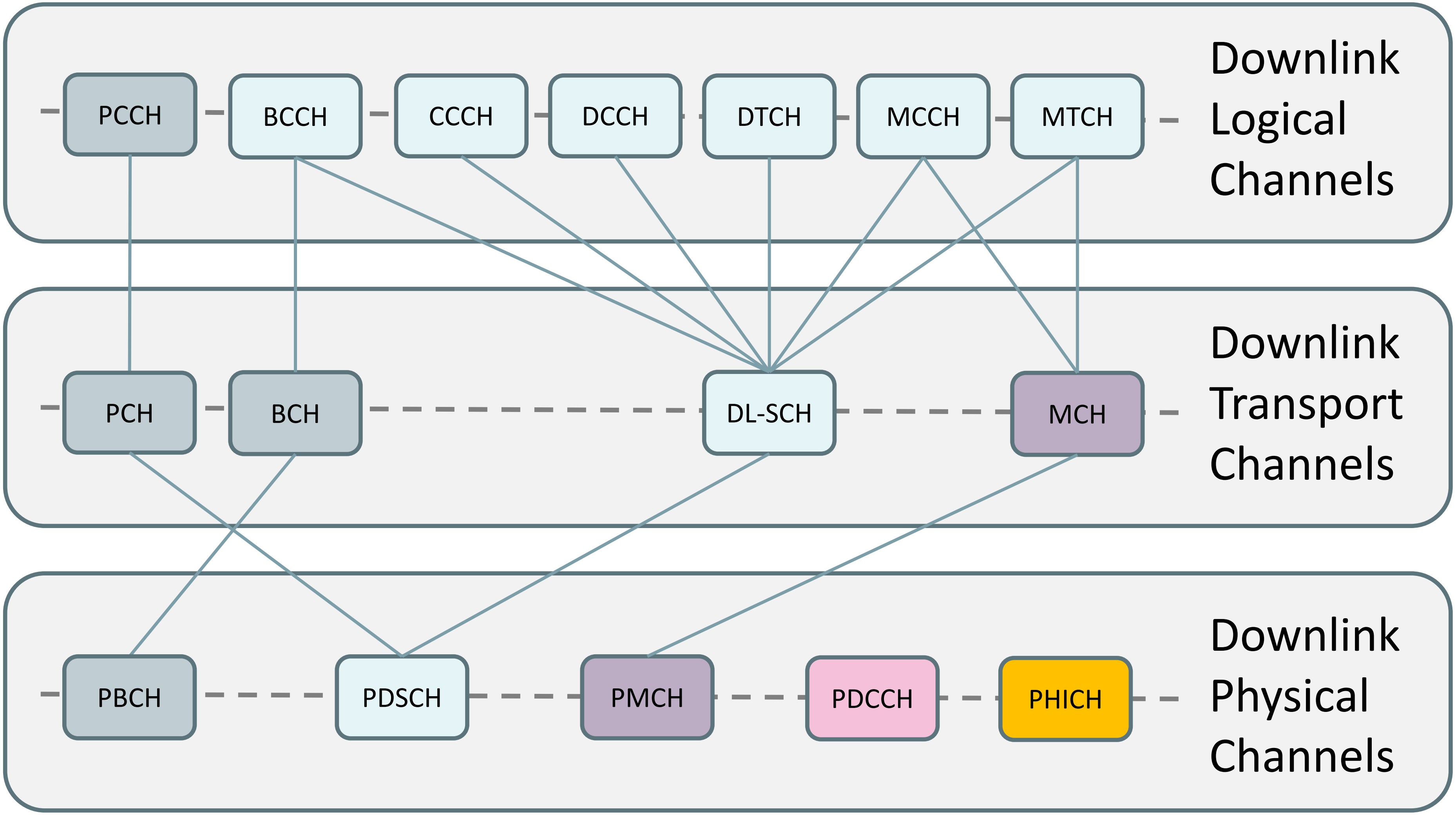
Hierarchical Channel Structure in LTE

- In order to efficiently support various QoS classes of service, LTE adopts a hierarchical channel structure. There are three different channel types, as follows:
  1. logical channels
  2. transport channels
  3. physical channels
- Each channel type is 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.
- The radio interface protocol architecture and the SAPs between different layers are shown in Figure below.
- Physical channels are the actual implementation of transport channels over the radio interface.
- Logical channels provide services at the SAP between MAC and RLC layers, while transport channels provide services at the SAP between MAC and PHY layers.

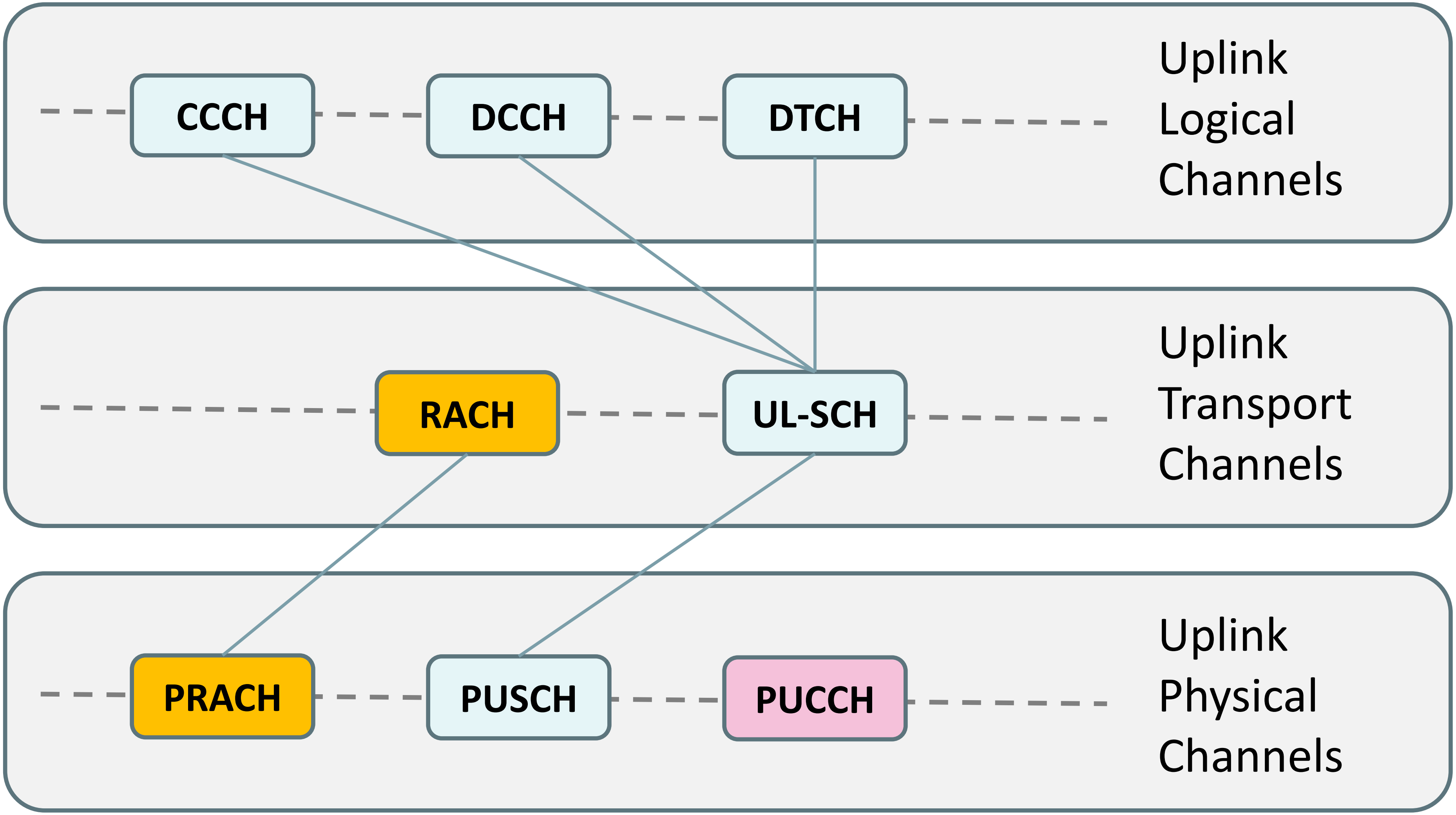
LTE Channel Architecture



LTE Downlink channels



LTE Uplink and bi-directional channels



LTE Downlink Logical Channels

Paging Control Channel (PCCH)

- A downlink channel that transfers paging information and system information change notifications.
- This channel is used for paging when the network does not know the location cell of the UE.

Broadcast Control Channel (BCCH)

- A downlink channel for broadcasting system control information.

Common Control Channel (CCCH)

- Channel for transmitting control information between UEs and network.
- This channel is used for UEs having no RRC connection with the network.

LTE Downlink Logical Channels

Dedicated Control Channel (DCCH)	• A point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. • Used by UEs having an RRC connection.
Dedicated Traffic Channel (DTCH)	• A point-to-point channel, dedicated to one UE, for the transfer of user information. • A DTCH can exist in both uplink and downlink.
Multicast Control Channel (MCCH)	• A point-to-multipoint downlink channel used for transmitting MBMS control information from the network to the UE, for one or several MTCHs. • This channel is only used by UEs that receive MBMS.
Multicast Traffic Channel (MTCH)	• A point-to-multipoint downlink channel for transmitting traffic data from the network to the UE. • This channel is only used by UEs that receive MBMS.

LTE Downlink Transport Channel

Paging Channel (PCH)

- Supports UE discontinuous reception (DRX) to enable UE power saving
- Broadcasts in the entire coverage area of the cell;
- Mapped to physical resources which can be used dynamically also for traffic/other control channels.

Broadcast Channel (BCH)

- Fixed, pre-defined transport format
- Broadcast in the entire coverage area of the cell

Multicast Channel (MCH)

- Broadcasts in the entire coverage area of the cell;
- Supports MBSFN combining of MBMS transmission on multiple cells;
- Supports semi-static resource allocation e.g. with a time frame of a long cyclic prefix.

LTE Downlink Transport Channel

Downlink Shared Channel (DL-SCH)

- Supports Hybrid ARQ
- Supports dynamic link adaptation by varying the modulation, coding and transmit power
- Optionally supports broadcast in the entire cell;
- Optionally supports beam forming
- Supports both dynamic and semi-static resource allocation
- Supports UE discontinuous reception (DRX) to enable UE power saving
- Supports MBMS transmission

LTE Downlink Physical Channels

Physical Downlink Shared Channel (PDSCH)	• Carries the DL-SCH and PCH • QPSK, 16-QAM, and 64-QAM Modulation
Physical Downlink Control Channel (PDCCH)	• Informs the UE about the resource allocation of PCH and DL-SCH, and Hybrid ARQ information related to DL-SCH • Carries the uplink scheduling grant • QPSK Modulation
Physical Hybrid ARQ Indicator Channel (PHICH)	• Carries Hybrid ARQ ACK/NAKs in response to uplink transmissions. • QPSK Modulation

Part 3 : Beyond LTE

Voice over LTE

LTE has been conceived as an IP only network. How best to transport voice traffic over such a network ?

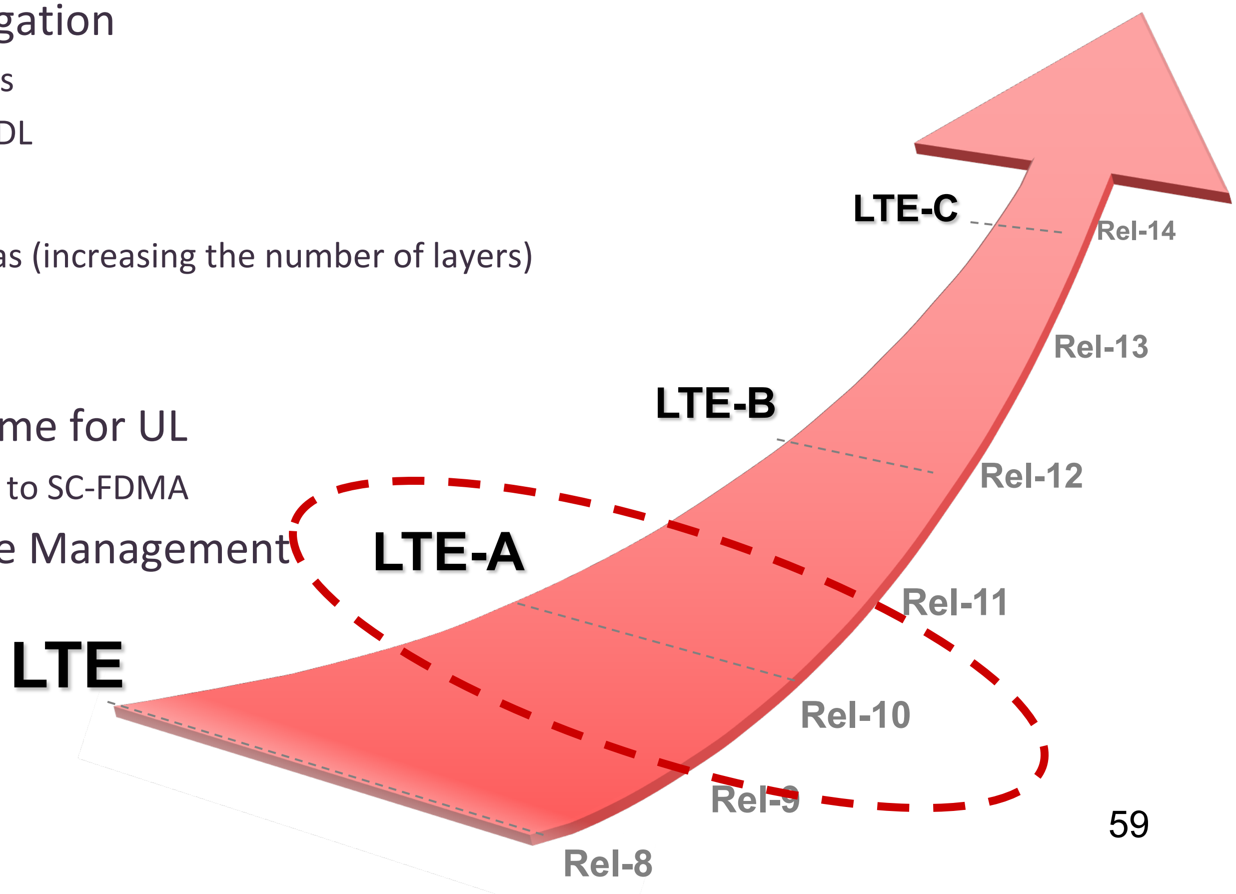
- **Voice over LTE (VoLTE)**
  - IP multimedia subsystem (IMS) with voice calls carried over packet
- **Circuit Switched Fall Back (CSFB)**
  - Calls are passed to existing MSC and carried over legacy circuits.
- **Simultaneous Voice and LTE (SVLTE)**
  - Handset works simultaneously in LTE and CS modes for data and voice respectively.
  - Relies on special handsets – power hungry.
- **Over the Top (OTT) services**
  - Skype, Vonage, etc
  - No Quality of Service, inefficient codecs

Emerging technologies for LTE-Advanced

- Multi-hop transmission (Relay)
- Multi-cell cooperation (CoMP: Cooperative Multipoint Tx/Rx)
- Interference management in heterogeneous cell overlay

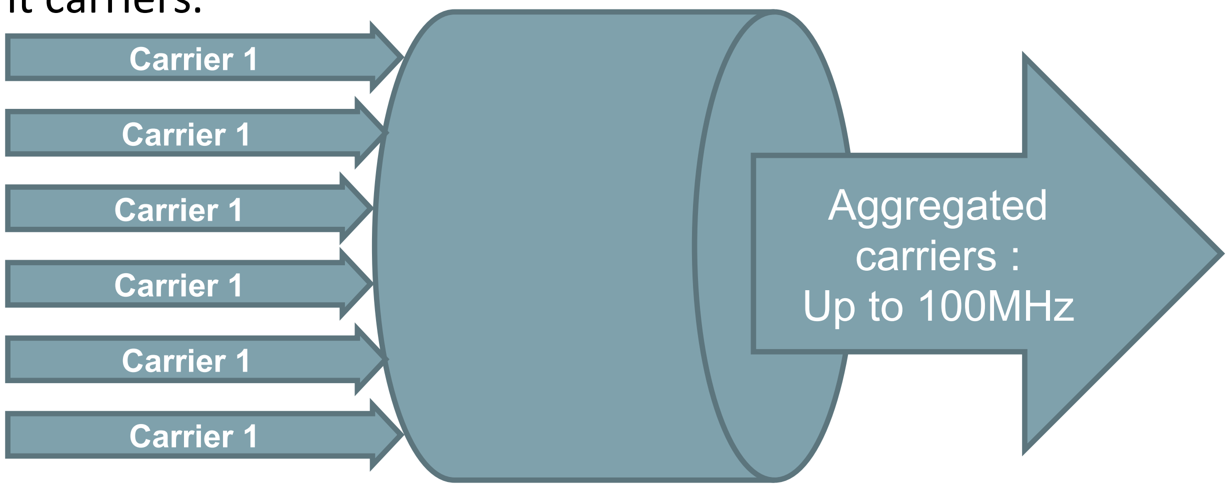
Enhancements from LTE Rel-8/9

- Bandwidth/spectrum aggregation
  - Contiguous and non-contiguous
  - Control channel design for UL/DL
- MIMO enhancement
  - Extended utilization of antennas (increasing the number of layers)
  - UL SU-MIMO
  - Enhanced UL/DL MU-MIMO
- Hybrid multiple access scheme for UL
  - Clustered SC-FDMA in addition to SC-FDMA
- DL/UL Inter-cell Interference Management



LTE Evolution – Carrier aggregation

- The obvious way to increase capacity in the LTE air interface is to add more bandwidth. Since it is important to keep backward compatibility with LTE R8 and R9 (i.e. non-LTE Advanced) mobiles, it was decided to provision the increase in bandwidth in LTE-Advanced by combining legacy R8/R9 carriers.
- The maximum bandwidth allocated for an LTE R8/R9 carrier is 20 MHz. **Carrier Aggregation (CA)** is allowed under LTE Advanced to increase the available bandwidth by combining carriers together.
- Each aggregated carrier is referred to as a component carrier. The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five component carriers can be aggregated. The maximum bandwidth available under CA is therefore100 MHz.
- The number of aggregated carriers can be different in the uplink and downlink, provided that the number of uplink component carriers is never larger than the number of downlink component carriers.



LTE Evolution – Carrier aggregation

- The easiest way to arrange carrier aggregation is to use contiguous component carriers within the same operating frequency band (as defined for LTE). This is called **Intra-Band Contiguous CA**.
- This might not always be possible depending on frequency allocation.
- For non-contiguous CA there are two categories :
- **Intra-band non-contiguous CA** : the component carriers belong to the same operating frequency band, but are separated by a frequency gap.
- **Inter-band non-contiguous CA** : the component carriers belong to different operating frequency bands.

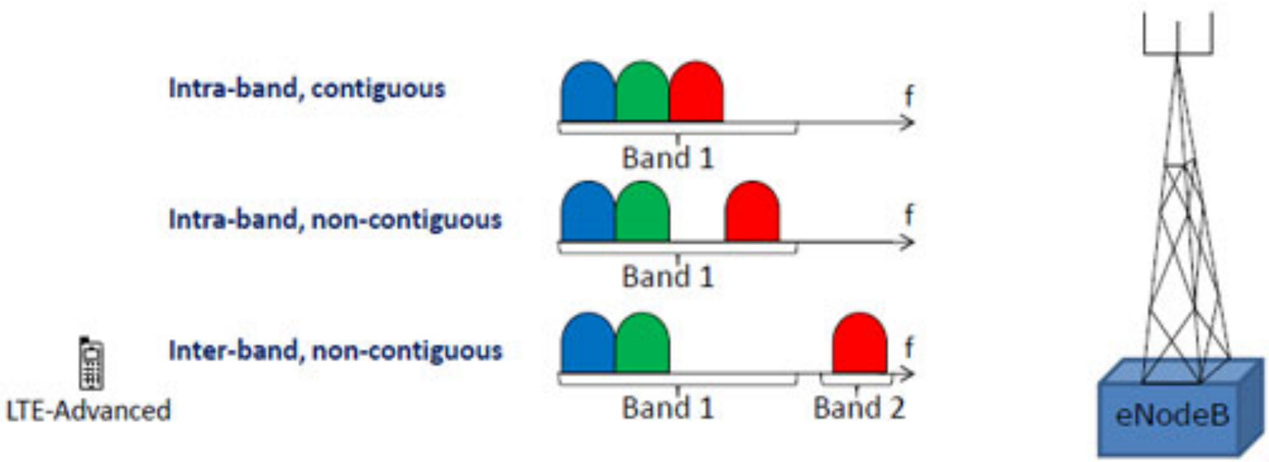
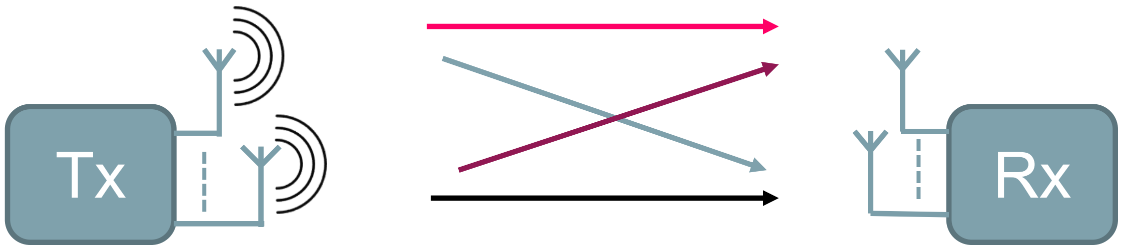
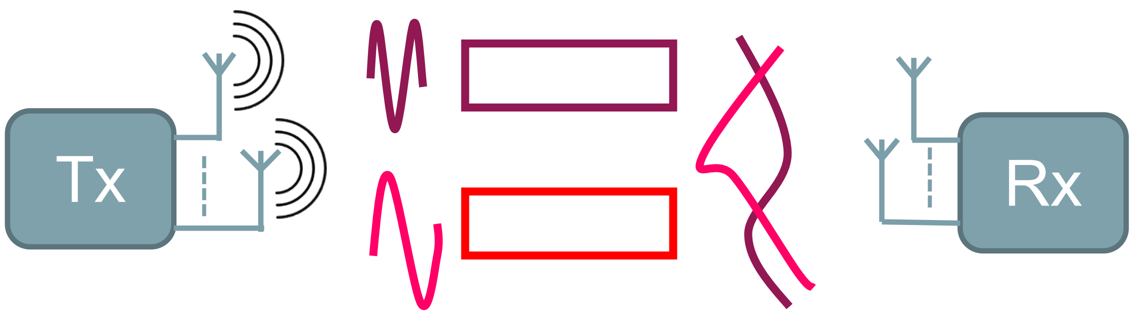


Image source : http://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced

LTE Evolution – MIMO support



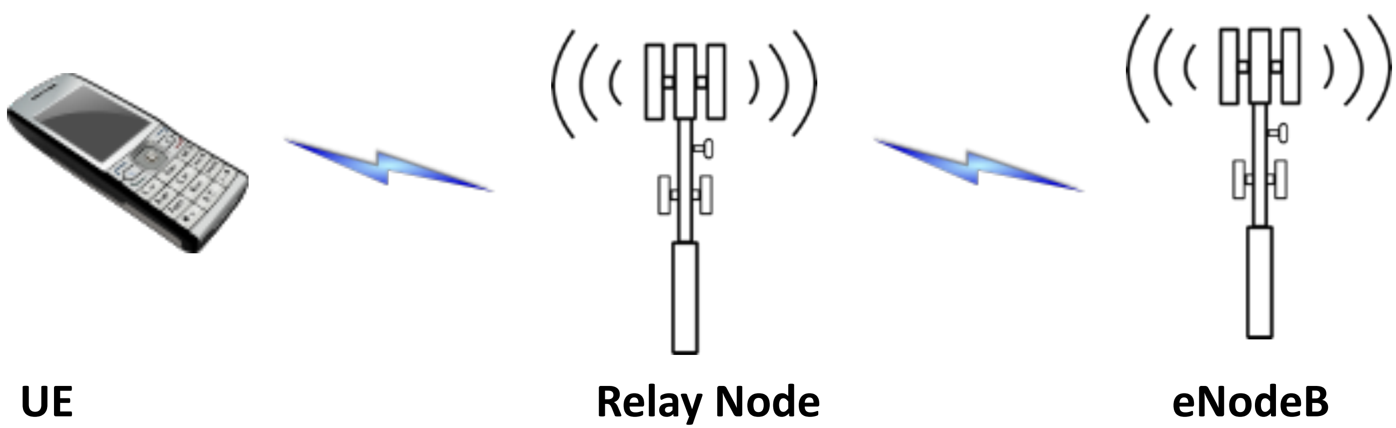
Spatial Diversity → Resistance to interference



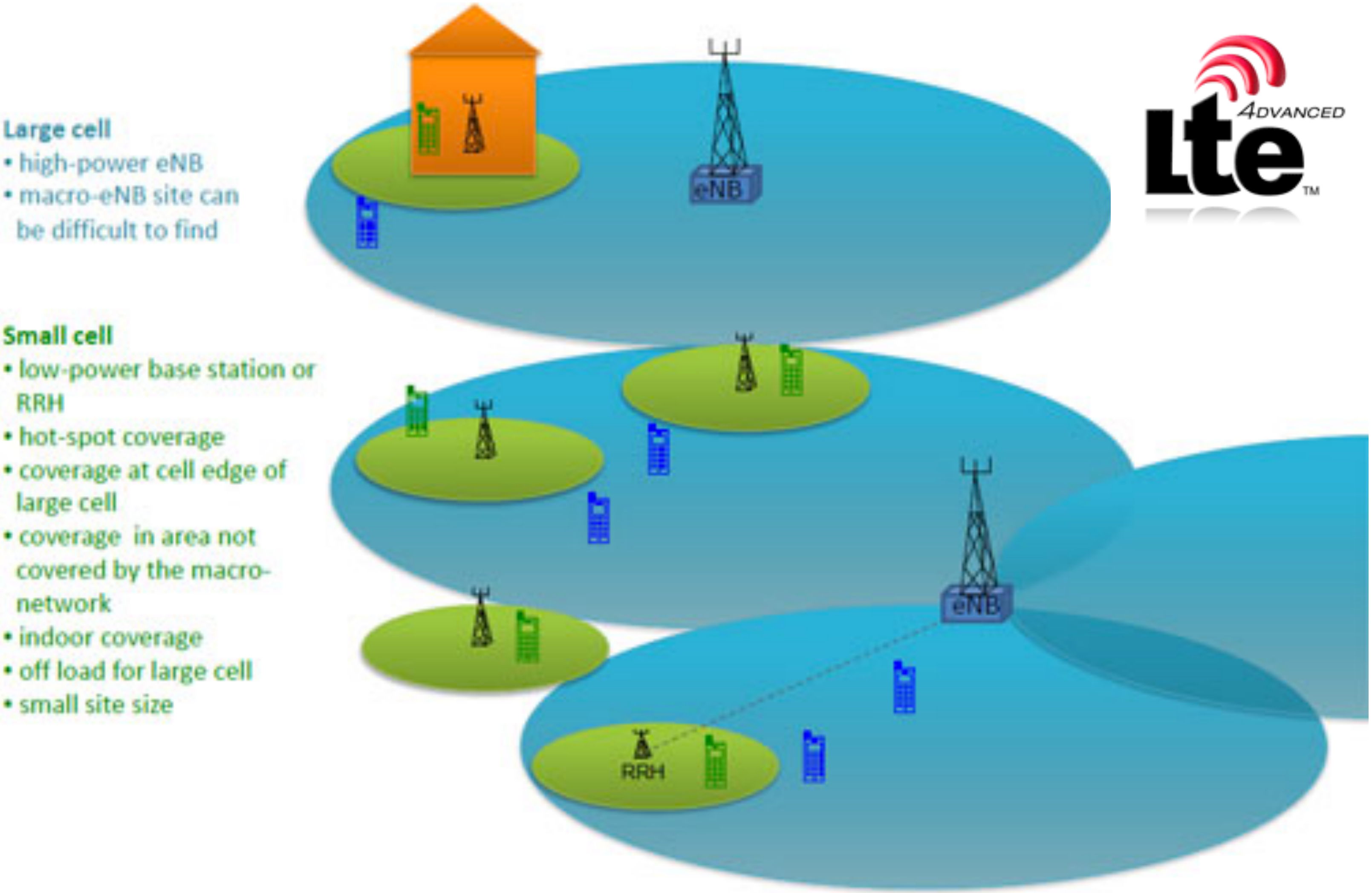
Spatial Multiplexing → Increased data rate

LTE Evolution – Relaying

- LTE-Advanced introduces the concept of **Relay Nodes (RNs)** to extend network coverage and density.
- An LTE Relay Node is a piece of fixed infrastructure that is resembles a low power base station, but without the backhaul connection. The purpose of the relays is to pick up communications between a User Equipment (UE) and the base station, thereby allowing multihop communication.
- The Relay Node is connected to the **Donor eNodeB** (DeNB) via a radio interface, Un, which is a modification of the E-UTRAN air interface Uu. Hence in the Donor cell the radio resources are shared between UEs served directly by the DeNB and the Relay Nodes.



LTE Evolution–Heterogeneous network support



Source : http://www.3gpp.org/hetnet

Summary - LTE vs. LTE-Advanced

Technology	LTE	LTE--A
Peak data rate Down Link (DL)	150 Mbps	1 Gbps
Peak data rate Up Link (UL)	75 Mbps	500 Mbps
Transmission bandwidth DL	20MHz	100 MHz
Transmission bandwidth UL	20MHz	40 MHz (requirements as defined by ITU)
Mobility	Optimized for low speeds(<15 km/hr) High Performance At speeds up to 120 km/hr Maintain Links at speeds up to 350 km/hr	Same as that in LTE
Coverage	Full performance up to 5 km	a) Same as LTE requirement b) Should be optimized or deployment in local areas/micro cell environments.
Scalable Band Widths	1.3,3, 5, 10, and 20 MHz	Up to 20–100 MHz
Capacity	200 active users per cell in 5 MHz.	3 times higher than that in LTE

Paradigm shifts in mobile technology