Institut
Mines-Télécom

Evolution to 5G

Philippe Martins

martins@telecom-paristech.fr

Outline

- Introduction: invariant functions of a cellular system
- 3GPP standardization evolution
- EPS architecture

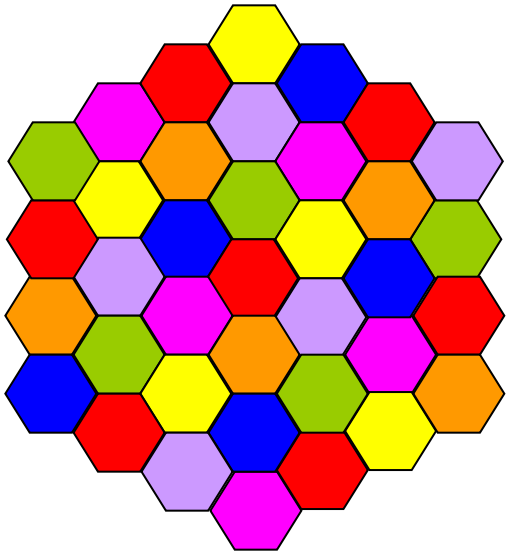
Introduction: invariant functions of a cellular system

- Cellular concept
- Multiple access
- Duplexing
- Terminal states
- Beacon
- Mobility management
- Paging and Random access
- Continuity of communications procedures
- Security functions

Cellular concept

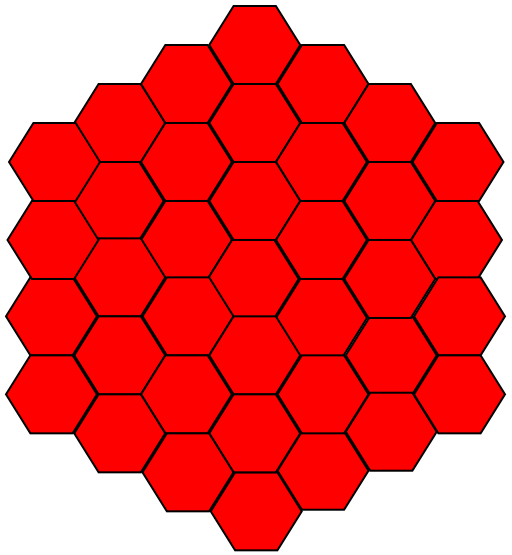
- **Principle**
  - Division of a covered area in several cells
  - Each cell is served by a base station
  - A network is formed by a set of cells
- **Advantages**
  - Cellular network can cover wide geographical areas
  - Lower transmitted powers
- **Problem: How to separate different cells**
  - Separation in frequency (Neighbor cells use different carrier frequencies): 2G systems, in some situations 4G also.
  - Separation in codes (Neighbor cells use different scrambling codes): 3G systems

Cellular concept



GSM

- K ≠ 1
- Example : K = 18 for TCH channels



UMTS

- K = 1 **BUT**
- Planning on primary scrambling codes necessary to separate cells

Multiple access

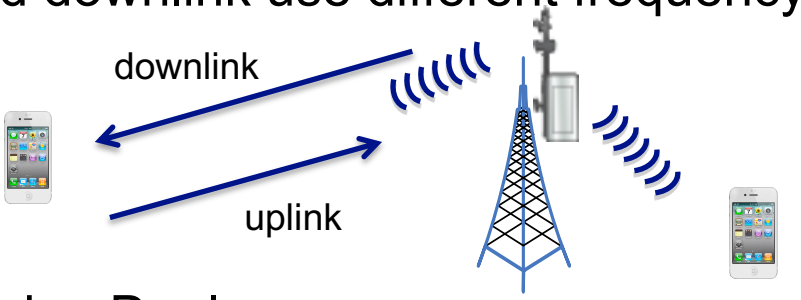
- **FDMA**
  - Frequency Division Multiple Access
  - Allocation of a dedicated frequency channel
  - 1G
- **TDMA**
  - Time Division Multiple Access
  - Time sharing approach: allocation of a dedicated timeslot
  - Several users can be time multiplexed on a frequency channel
  - 2G
- **CDMA**
  - Code Division Multiple Access
  - Allocation of orthogonal codes
  - Terminals can transmit simultaneously on the same band
  - 3G

Multiple access

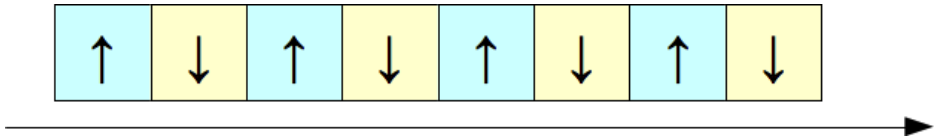
- **OFDMA**
  - Orthogonal Frequency Division Multiplex Access
  - Time and frequency multiplexing.
  - LTE (Long Term Evolution) and LTE-Advanced in the downlink

Duplexing

- **How to handle bidirectional communications: duplexing**
- **FDD**
  - Frequency Division Duplex
  - Uplink and downlink use different frequency bands



- **TDD**
  - Time Division Duplex
  - Uplink and Downlink use different timeslots



Terminal states

- **Idle mode**
  - No active communication
  - User may be « contacted » at any time by the network (via the paging procedure)
  - **Reselection** and **location update** procedures may be activated

- **Dedicated Mode**
  - Ensures communication continuity with user mobility (particularly when switching of cell)
  - **Handover** (or **handoff**) procedures may be activated

Mobility Management

- **Cells are grouped in logical sets called:**
  - **Location areas** for switched circuit based services in 2G and 3G
  - **Routing areas** for packet based services in 2G and 3G
  - **Tracking areas** in LTE and LTE-Advanced systems
- **In Idle mode, location of terminal is know only at location/routing/tracking area level.**
- **Terminal decides alone to switch of cell: autonomous reselection procedure**

Beacon

- **Beacon (or Broadcast Channel)**
  - Broadcast system information to terminals
    - Provides cell and network identities, location area.
    - Radio and network parameters.
  - Periodical transmission on the air interface
  - Fixed Transmission Power

Paging and random access

- **Paging**
  - Used to contact and locate a terminal in idle mode (for example when the network wants to setup an incoming call or wants to transmit a short message to a terminal).

- **Random Access**
  - First message sent by terminal to contact network
  - Sent on a contention resource (a shared channel where collisions may occur)

Continuity of communications procedures

- **MAHO (Mobile Assisted Handoff or Handover)**
  - The terminal performs measurement reports while in communication
  - It sends the report to the network (base station controller)
  - Based on that report the network decides whether it is necessary to trigger a handover for the terminal (change of cell)
- **Measurement reports**
  - Contain different radio link measurements (Received Power, Signal to Interference Ratio (SINR), …)

Continuity of communications procedures

- **Power Control**
  - Based on measurement performed by base station, the network controls the terminal transmission level.
  - Historically the network adapts the terminal transmission power
  - Reduce interference
  - Minimize Terminal power consumption

Security functions

- **Authentication of users**
  - 2G: user authentication
  - 3G, 4G: mutual authentication (user and network authentication)
- **Ciphering of communications**
  - 2G: on air interface for GSM, and on access network for GPRS (between terminal and SGSN)
  - 3G: on access network (between terminal and RNC)
  - 4G: two levels of ciphering:
    - Air interface (between terminal and e-nodeb)
    - Access network (between terminal and MME)
- **Integrity of information**
  - 3G and 4G systems

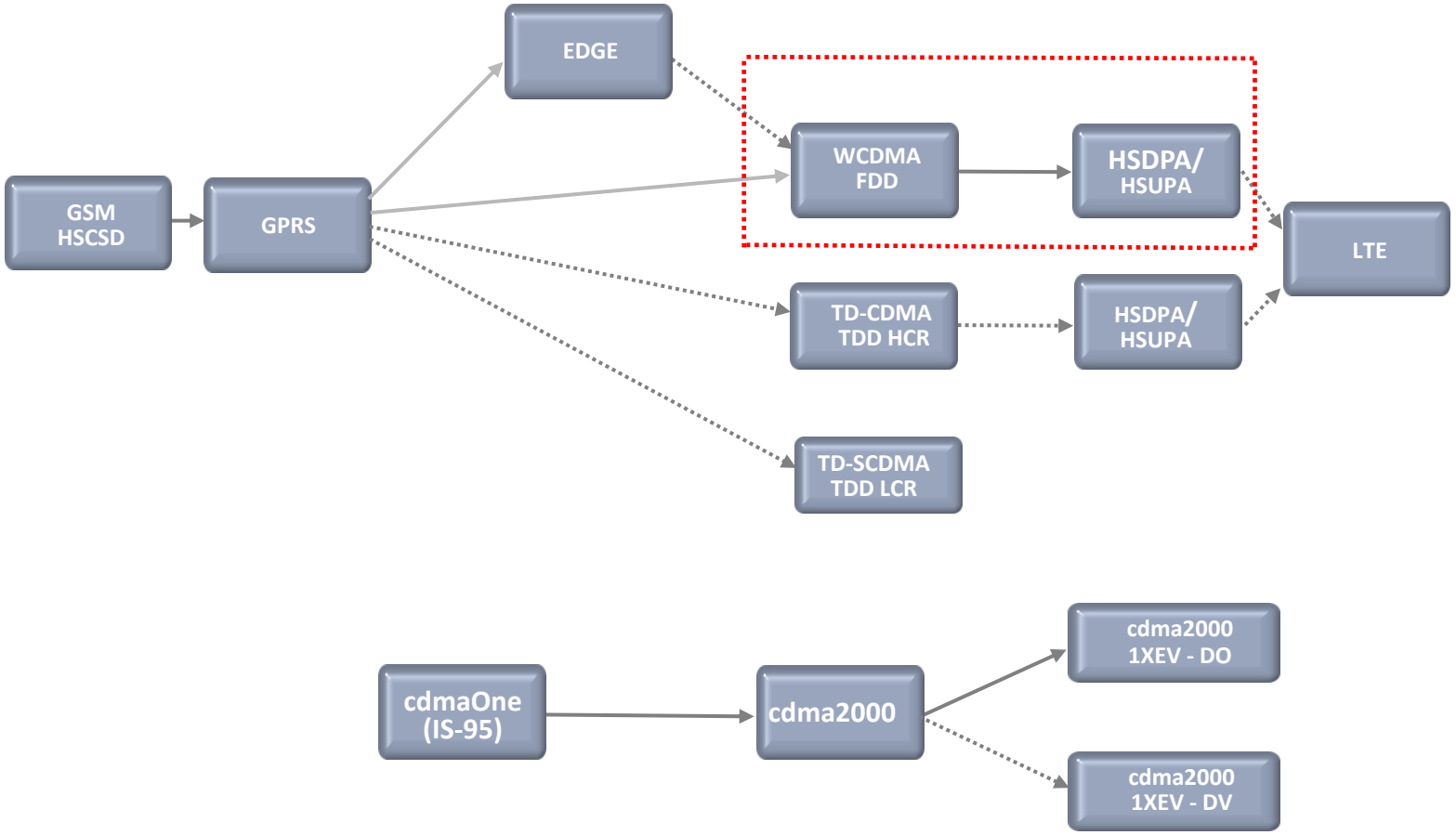
3GPP standards evolution

- Cellular systems evolution
- Cellular standards evolution outline
- Second generation outline
- Third generation outline
- Evolution of third generation: HSPA
- 3GPP systems architecture evolution

Cellular systems evolution

- **1G: analog systems, voice**
  - AMPS (Advanced Mobile Phone System - Bell Labs)
  - NMT (Nordic Mobile Telephone – SFR)
  - Radiocom 2000 (France Telecom)
- **2G: digital, voice and low data rate services (9–384 kbps)**
  - GSM (Global System for Mobile Communications)
  - GPRS (General Packet Radio Services)
  - EDGE (Enhanced Data rates for GSM Evolution)
- **3G: digital, voice and data services (1,9–42 Mbps)**
  - UMTS (Universal Mobile Telecommunications System)
  - HSPA (High Speed Packet Access)
  - HSPA+, DC-HSPA (Dual Cell)
- **4G : digital, voice over IP, high data rate services (150Mbps–1Gbps)**
  - LTE (Long Term Evolution)
  - LTE Advanced
- **5G (10Gbps)**

Cellular standards evolution



Second generation outline

- **Frequency bands**
  - 900 MHz
  - 1800 MHz (DCS 1800)
  - 1900 MHz (PCS 1900)
- **Digital transmission on FDMA/TDMA channel with a FDD duplex mode**
- **Terminal transmission Power**
  - 2W for GSM 900
  - 1W for DCS 1800
- **Raw data rate at physical layer: 271 kbps per carrier (TRX)**

Second generation outline

- **Frequency bands**
  - 900 MHz
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  - 1900 MHz (PCS 1900)
- **Digital transmission on FDMA/TDMA channel with a FDD duplex mode**
- **Terminal transmission Power**
  - 2W pour GSM 900
  - 1W pour DCS 1800
- **Access packet mode on the air interface: Use of TBF concept (Temporary Block Flow)**

Second generation outline

- **New PCU (Packet Controller Unit) function in charge scheduling of radio blocks between different users in a cell.**
- **New IP core network to connect terminals to Internet :**
  - SGSN (access router handling user attachment to the network, user mobility management, routing of IP packets between terminals and core network.).
  - GGSN (Access point to Internet)

Third generation outline

- **UMTS is a third generation system:**
  - UMTS defines a new air interface based on W-CDMA multiple access technic.
- **UMTS relies on a new access network (UTRAN):**
  - Based on ATM technology R99 behind base stations (non ATM on the air interface)
  - Possibly based on IP in the following releases (R4, R5, …)
- **Evolution of the UMTS core network is more progressive:**
  - First UMTS Release 99 (R99) uses the same technologies as in second generation systems.
  - The following releases (R4 et R5, R6, …) introduce significant changes: « *NGN Next Generation Networks* ».

Evolution of third generation: HSPA

HSDPA

# de codes	Modulation	Max data rate
5 codes	QPSK	1.8 Mbps
5 codes	16-QAM	3.6 Mbps
10 codes	16-QAM	7.2 Mbps
15 codes	16-QAM	10.1 Mbps
15 codes	16-QAM	14.4 Mbps

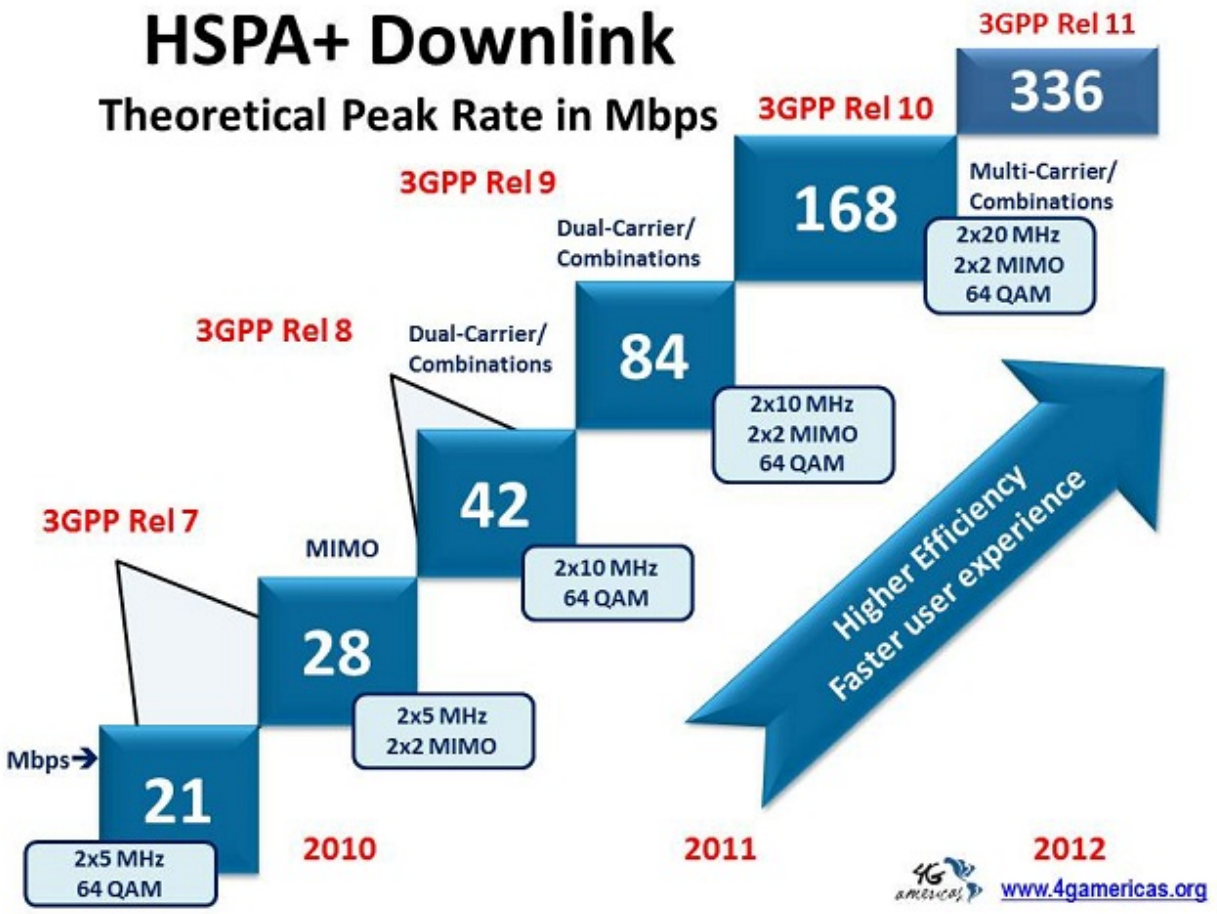
HSUPA

# de codes	TTI	Max data rate
2 x SF4	2 ms 10 ms	1.46 Mbps
2 x SF2	10 ms	2.0 Mbps
2 x SF2	2 ms	2.9 Mbps
2 x SF2 + 2 x SF4	2 ms	5.76 Mbps

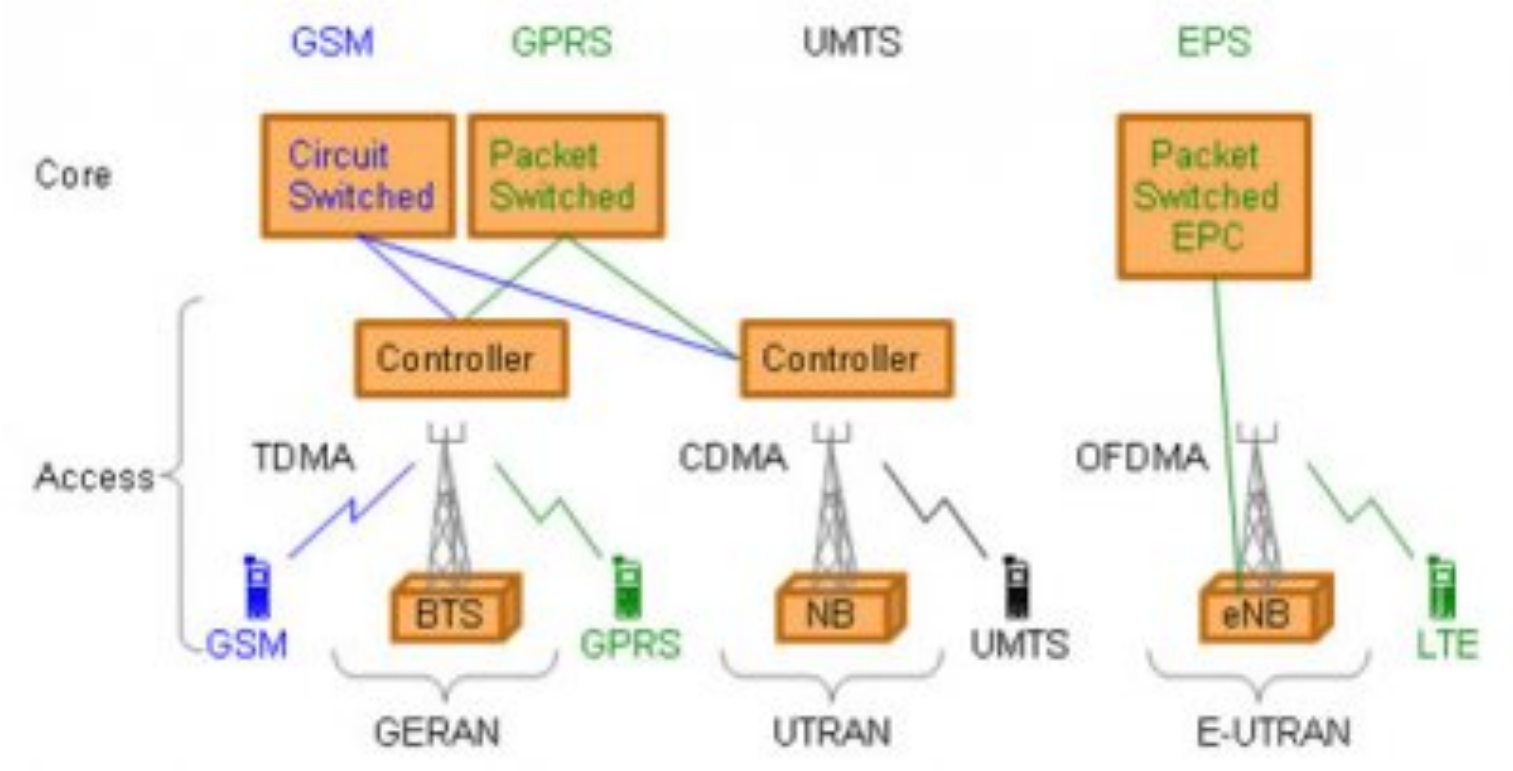
Evolution of third generation: HSPA

- Rel-7: 64QAM or 2X2 MIMO => 21 or 28 Mbps
- Rel-8: DC + 64QAM or 2X2 MIMO + 64QAM => 42 Mbps
- Rel-9: DC + 2X2 MIMO + 64QAM => 84 Mbps
- Rel-10: 4C + 2X2 MIMO + 64QAM => 168 Mbps
- Rel-11: (8C or 4X4 MIMO) + 64QAM => 336 Mbps

Evolution of third generation: HSPA



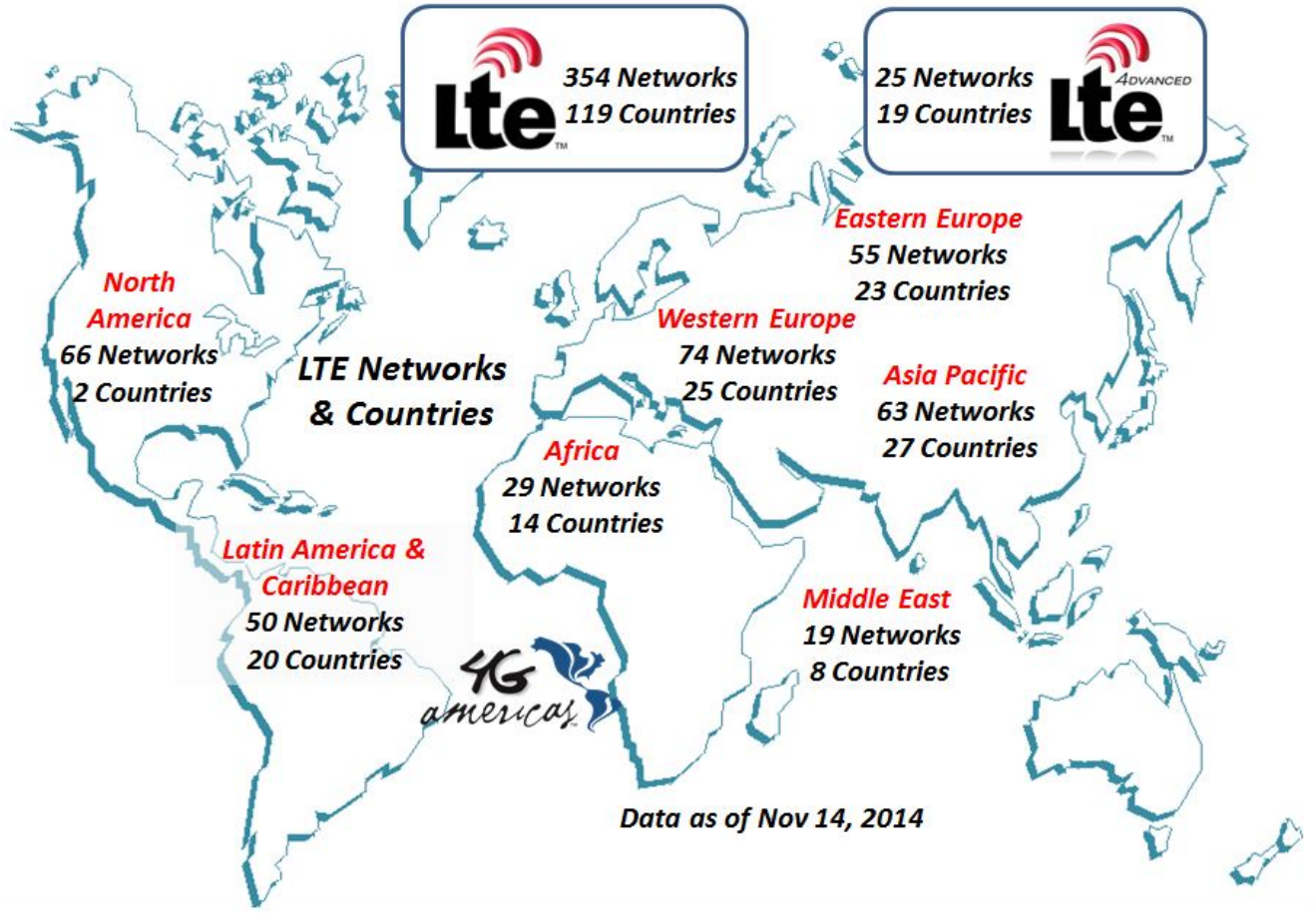
3GPP systems architecture evolution



From 2G to LTE (Source: http://www.3gpp.org/technologies/keywords-acronyms/98-lte)

LTE worldwide deployment

Source: http://www.4gamericas.org/index.cfm?fuseaction=page&pageid=939



6,6 billion mobile subscribers (november 2014)

EPS architecture

- Introduction
- E-nodeb functions
- EPC functional entities
- EPS functional interfaces

Introduction

- **3GPP has defined a new mobile network for 4G named EPS (Evolved Packet System)**
- **It is subdivided into two parts:**
  - E-UTRAN (Evolved Terrestrial Access Network)
  - EPC (Evolved Packet Core Network-

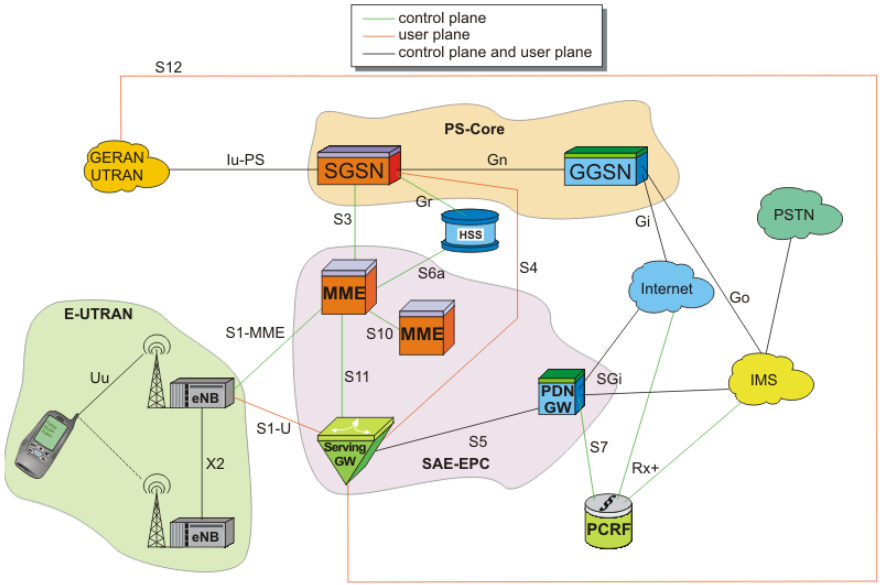


Figure: EPS Architecture (source: http://www.telecom-cloud.net/lte-nuggets/basics-of-lte-dimensioning/)

Introduction

- **E-UTRAN is also called LTE (Long Term Evolution).**
  - One single type of device: enodeB.
  - Concentration of base station and base station controller in the same device:.
  - eNodeB are connected to core network through S1 interface
  - eNodeB are interconnected through X2 interface
  - Air interface: OFDMA in downlink and SCFDMA in uplink.

Introduction

- **All IP system**
  - No circuit switched available.

- **Interworking with legacy cellular networks**
  - GERAN (name of 2G access network).
  - UTRAN (name of 3G access network).
  - Non 3GPP systems: WLAN, M2M (Machine to Machine communications), …

E-nodeb functions

- **e-nodeb is the base station controller for LTE**
- **It has the following functions:**
  - Radio admission Control
  - Radio Resource Allocation (Data and signaling radio bearers)
  - Handover triggering and execution
  - Mobility Anchor when inter enodeb handover is triggered
  - Broadcast system information to terminals on broadcast channels (beacon)
  - Transmission/reception of packets to/from air interface (modulation, coding, ARQ, Hybrid ARQ, header compression operations).

E-nodeb functions

- Measurement configuration and provision (informs terminals how to perform and transfer measurement reports)
- Scheduling of radio resources between different terminals in the cell

EPC Functional entities

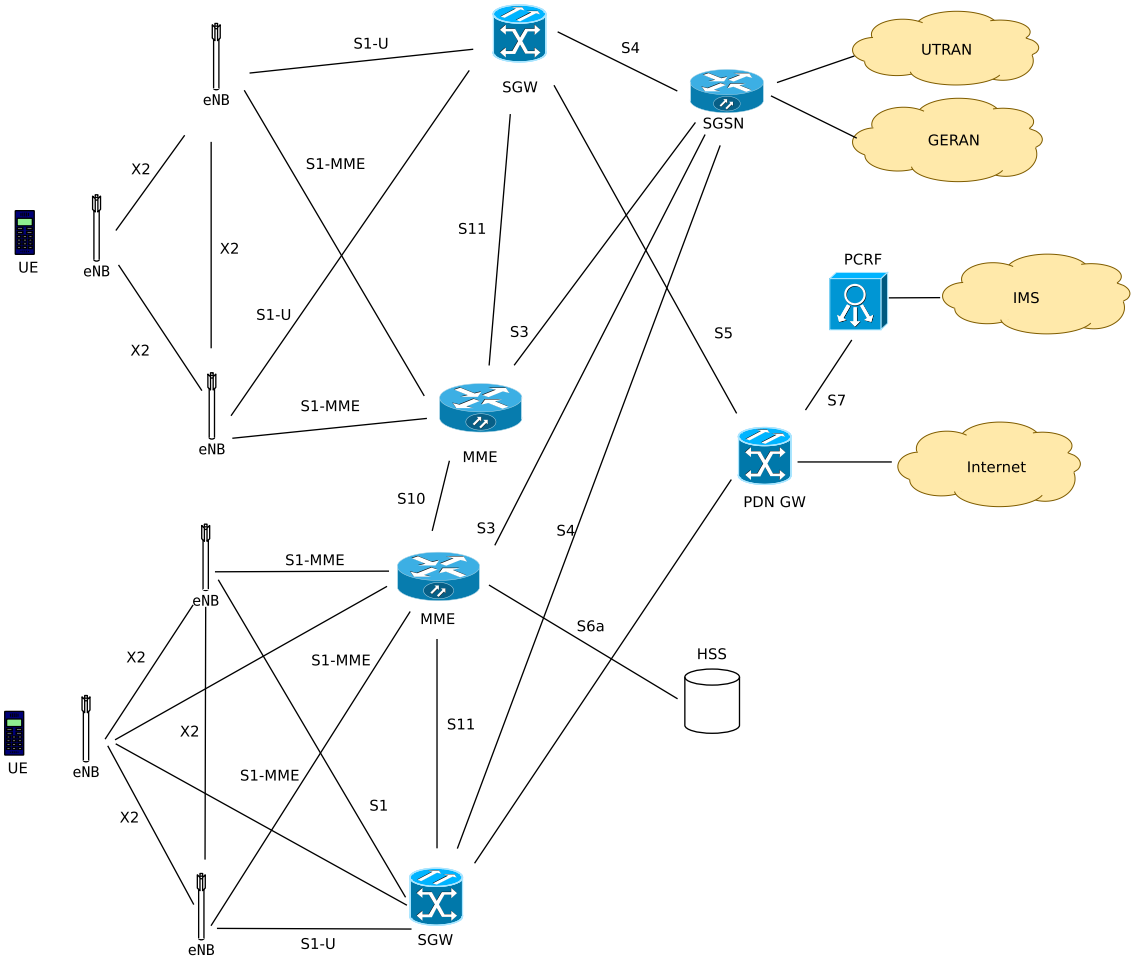
- **PCRF (Policy and Charging Rules Function)**
  - Call Admission Control for QoS
  - Billing and charging per flow
  - Transmits QoS rules to P-GW (PDN Gateway)

- **HSS (Home Subscriber Server)**
  - Subscriber data
  - Security data (authentication, ciphering, integrity)
- **PDN Gateway (P-GW)**
  - Allocates an IP address to each terminal (IPv6 or IPv4)
  - Routing of packets to terminals according to QoS constraints
  - PCEF (Policy Control Enforcement Function): enforces QoS for GBR (Granted Bit Rate).
  - Filtering

EPC Functional entities

- **S-GW (Serving Gateway)**
  - Routes packets from or to terminals.
  - Mobility Anchor for data bearers during handoff procedure between two e-nodeb
  - Buffers data from core network during handoff procedure
- **MME (Mobility Management Entity)**
  - Receives NAS messages from or to terminals
  - Admission Control for Bearers between terminal and network.
  - NAS security procedures
  - Idle state mobility handling (tracking area location update procedures)

EPS Functional interfaces



EPS Functional interfaces

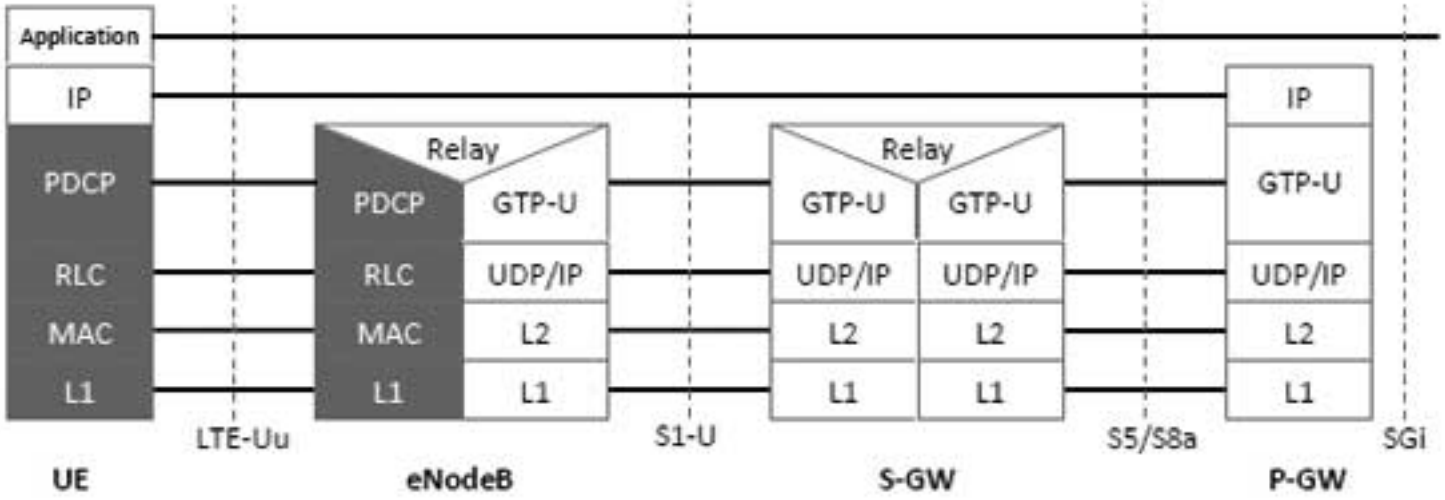


Figure: user plane protocol stack http://www.tutorialspoint.com/lte/lte_radio_protocol_architecture.htm

EPS functional interfaces

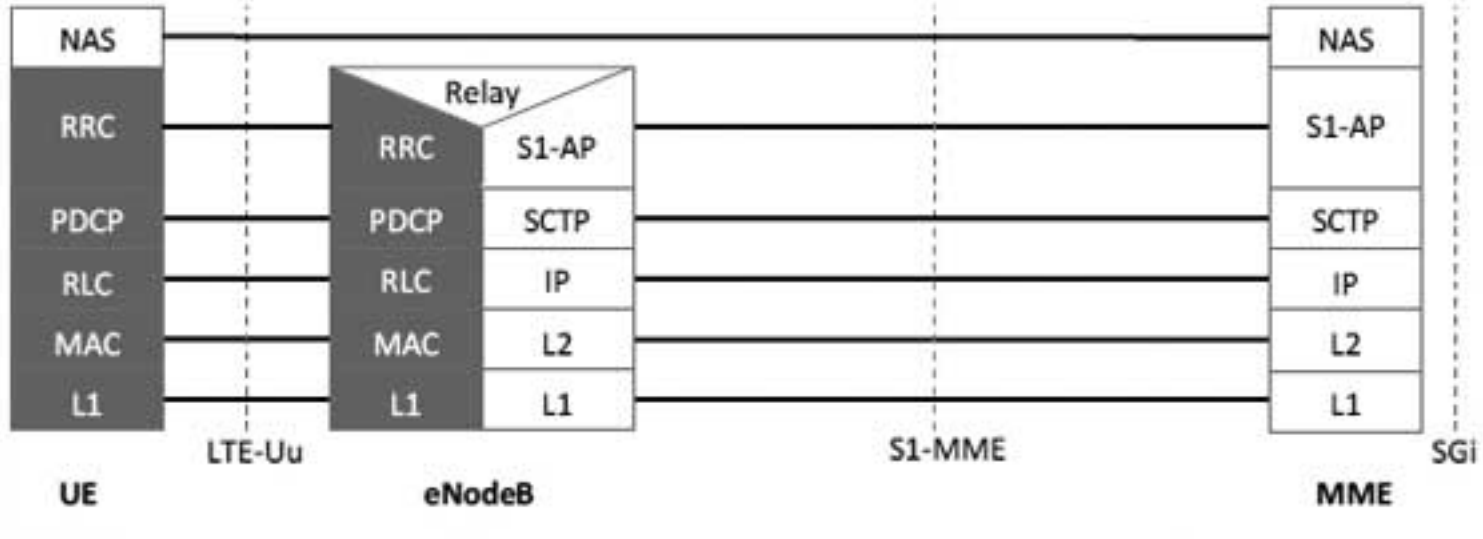
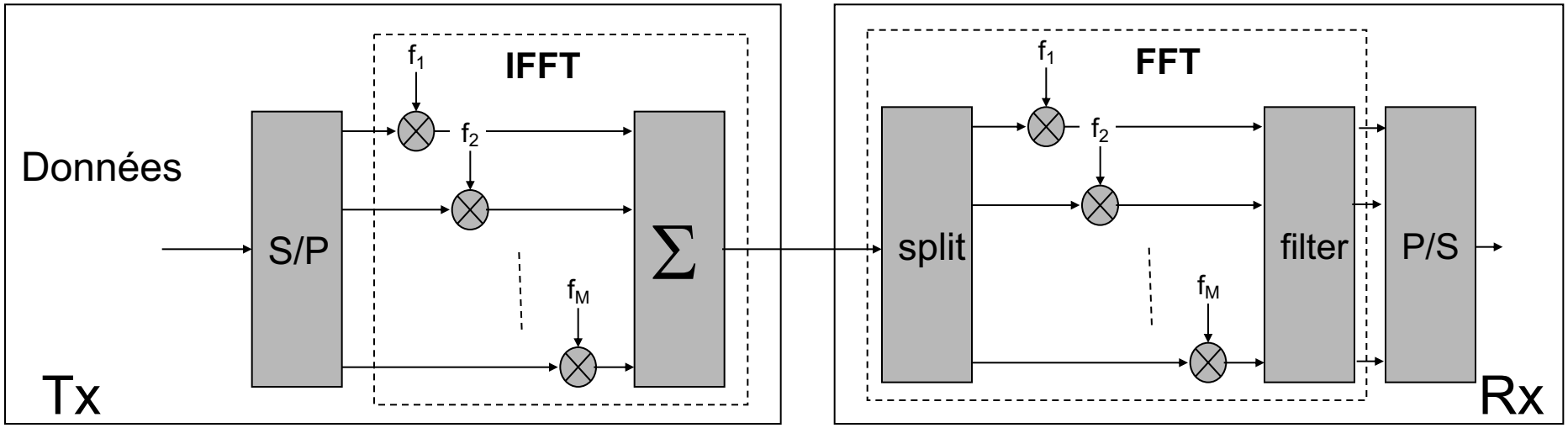
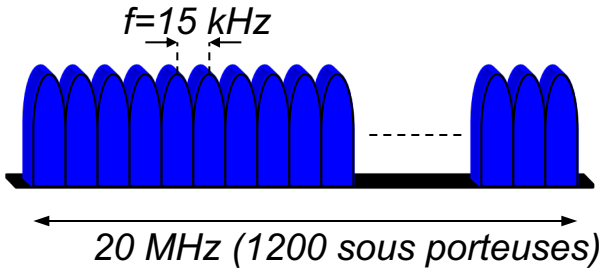


Figure: control pane protocol stack (source http://www.tutorialspoint.com/lte/lte_radio_protocol_architecture.htm)

OFDM signal generation

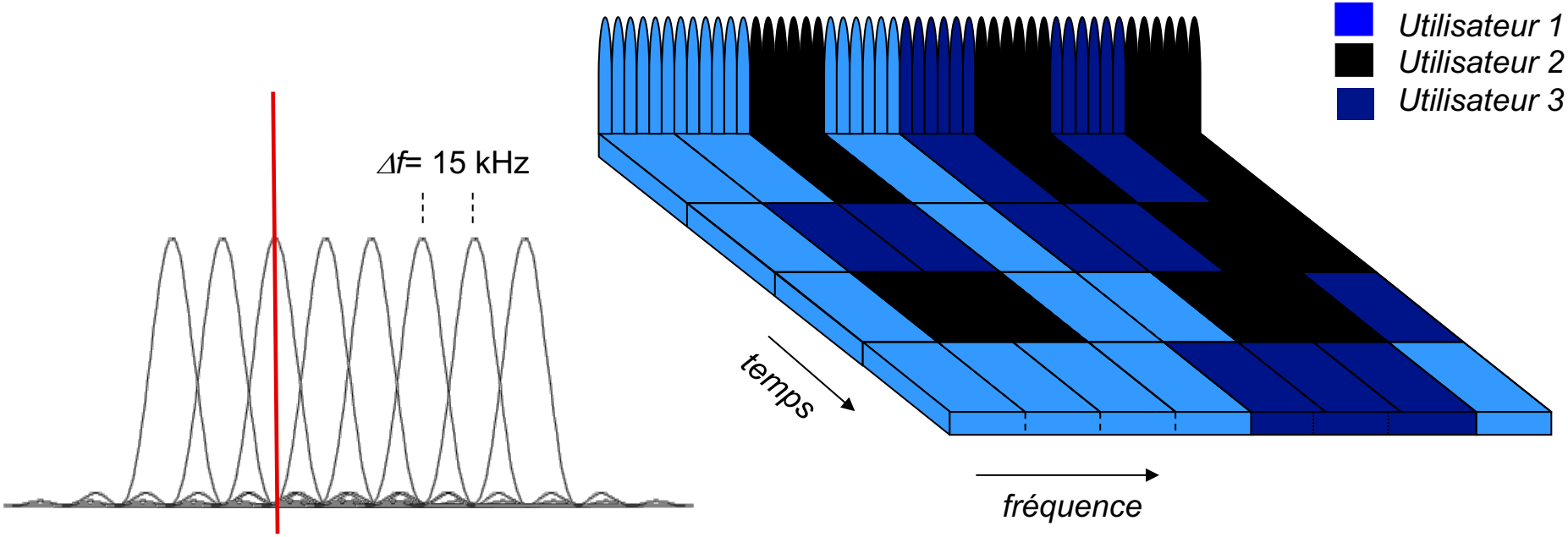




Source: LTE Fundementals, Sven Anders Sturesson

LTE Downlink OFDMA - Orthogonal Frequency Division Multiplexing Access

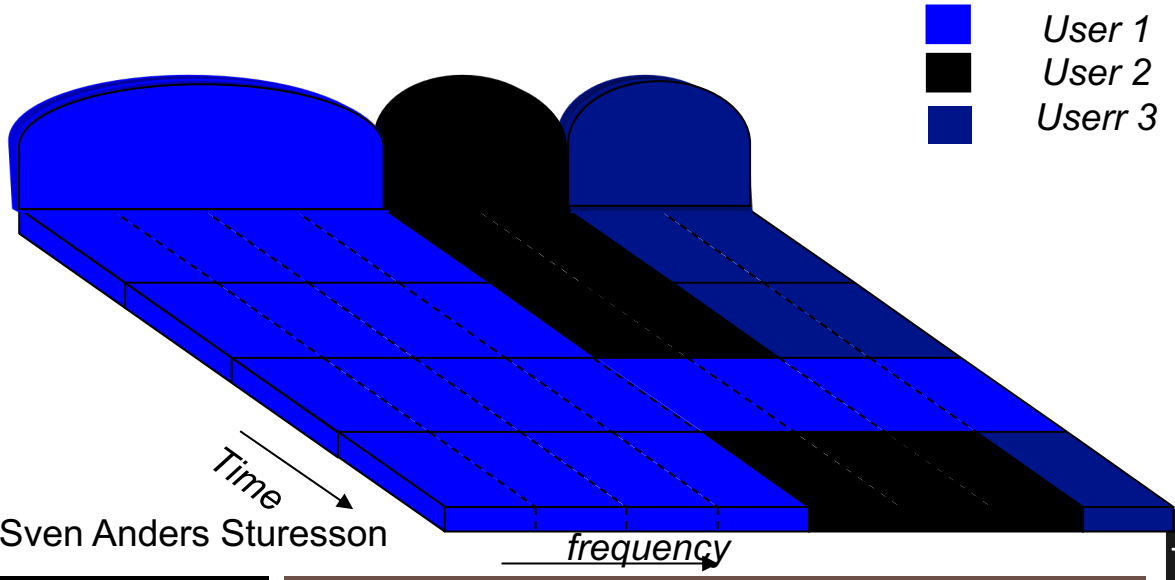
- Grand nombre de sous-porteuses de 15 kHz
- Sous porteuses orthogonales



Source: LTE Fundementals, Sven Anders Sturesson

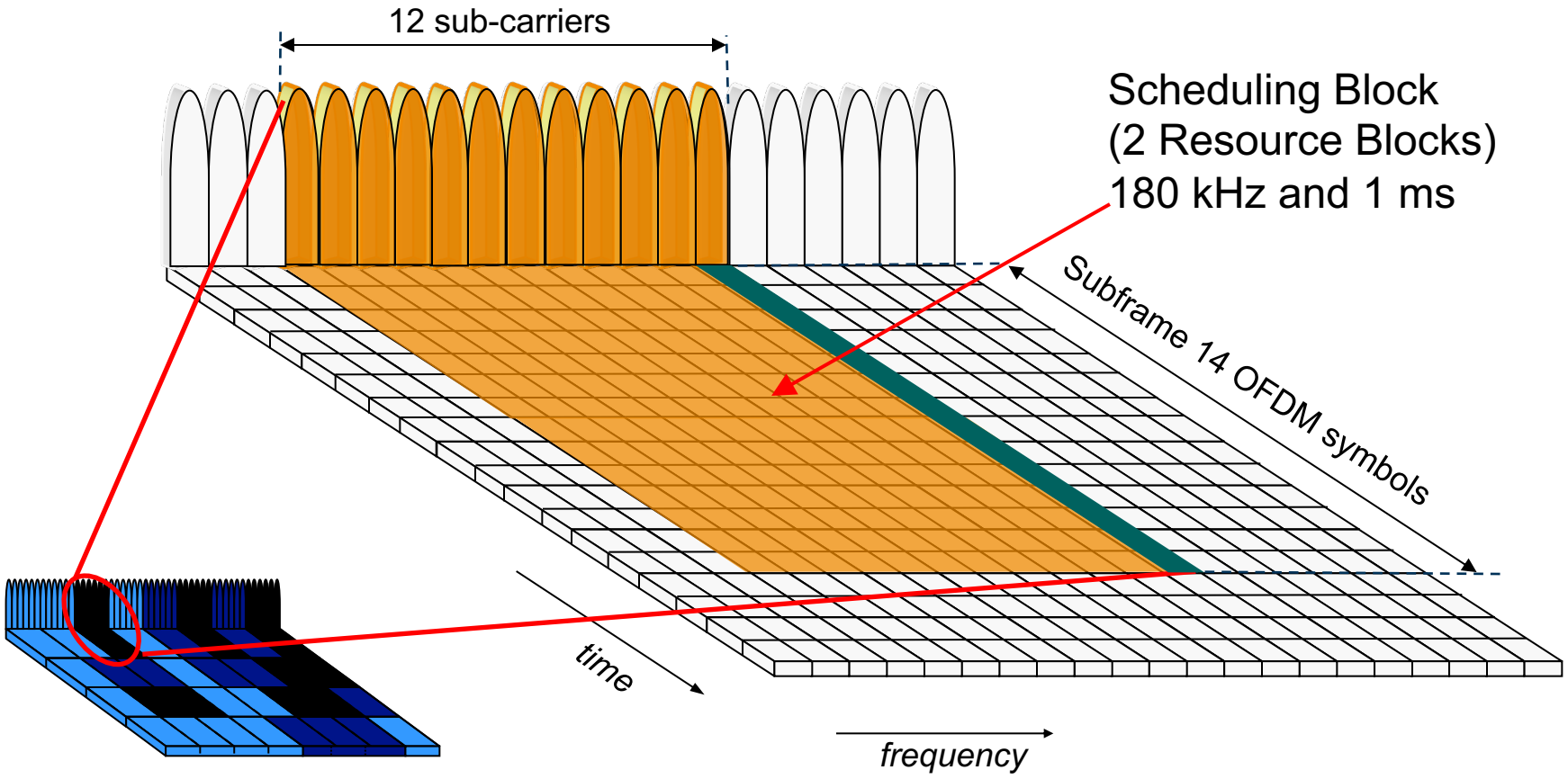
Uplink
SC-FDMA – Single Carrier FDMA

- **Simimlar to OFDMA**
  - 15 kHz subcarriers
  - Same time/frequency structure
- **Better PAPR (Peak To Average Power Ratio)**



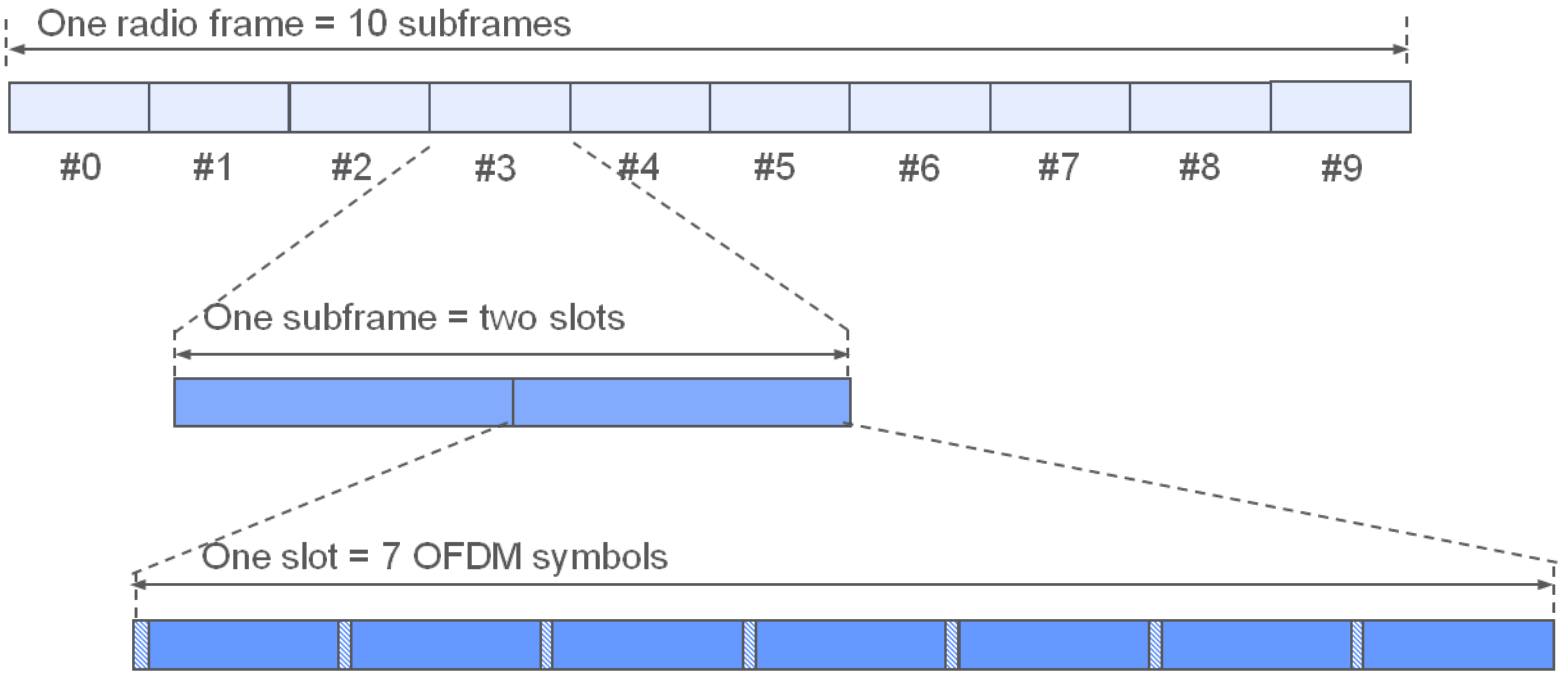
Source: LTE Fundementals, Sven Anders Sturesson

Radio resource allocation



Source: LTE Fundementals, Sven Anders Sturesson

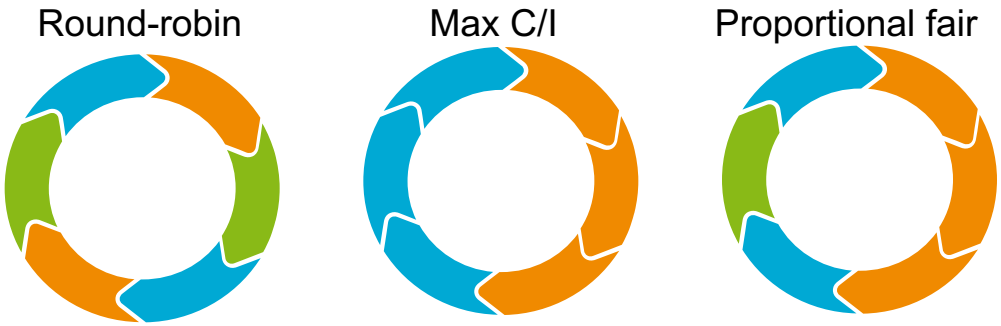
LTE air interface numerology



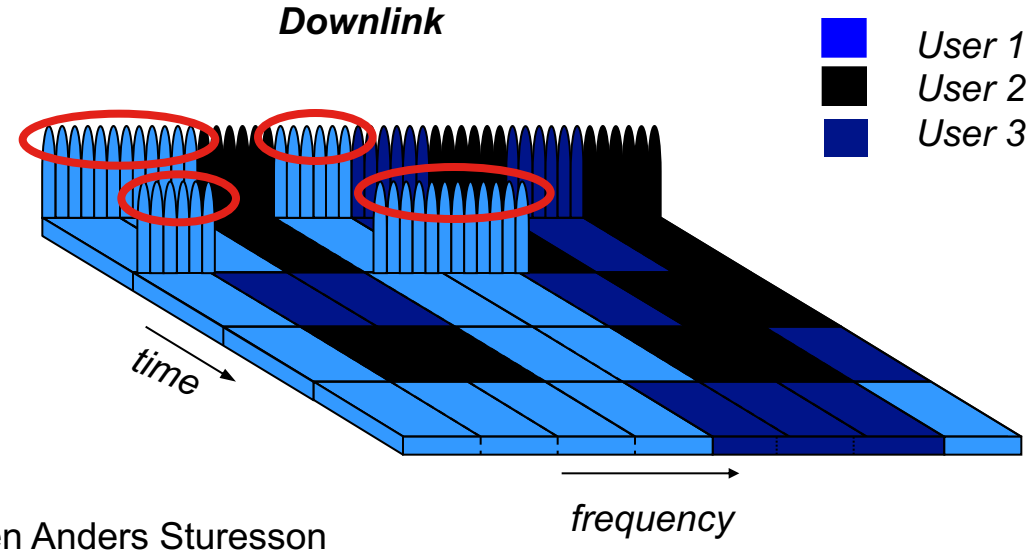
Source: LTE Fundementals, Sven Anders Sturesson

Scheduling

- **Time domain**
  - Round-robin
  - Max C/I
  - Proportional fair



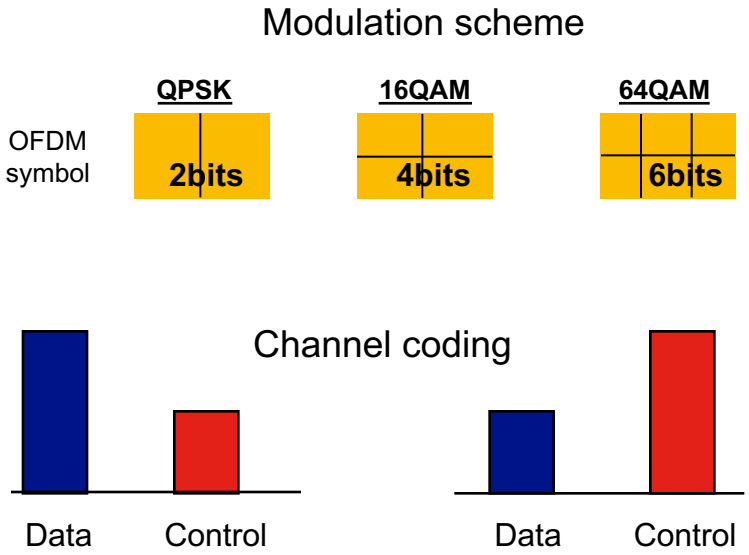
- **Frequency domain**
  - Contiguous
  - Random
  - Measure based



Source: LTE Fundementals, Sven Anders Sturesson

Link adaptation

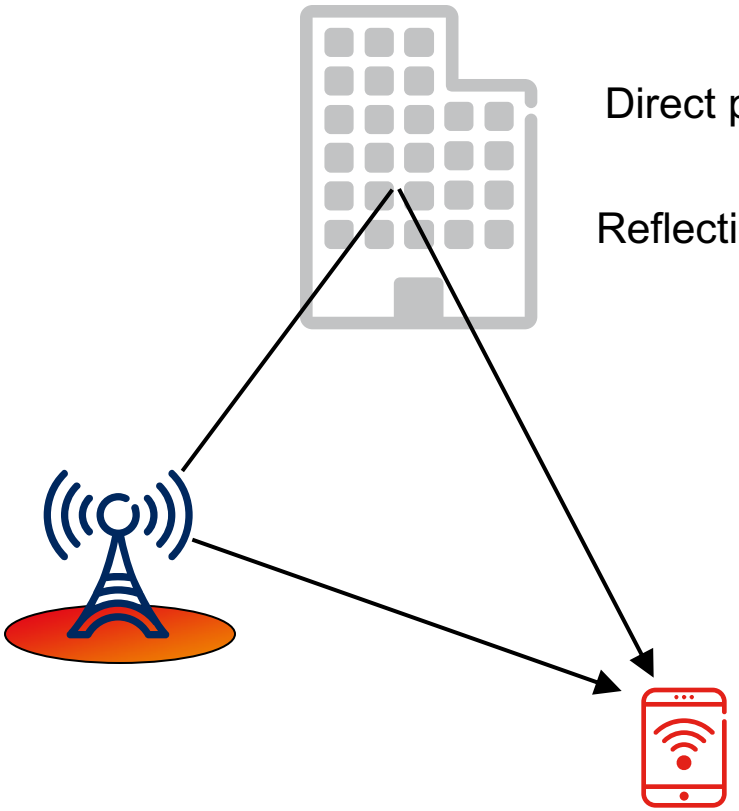
- **Time domain (/user)**
  - Modulation
  - Channel coding

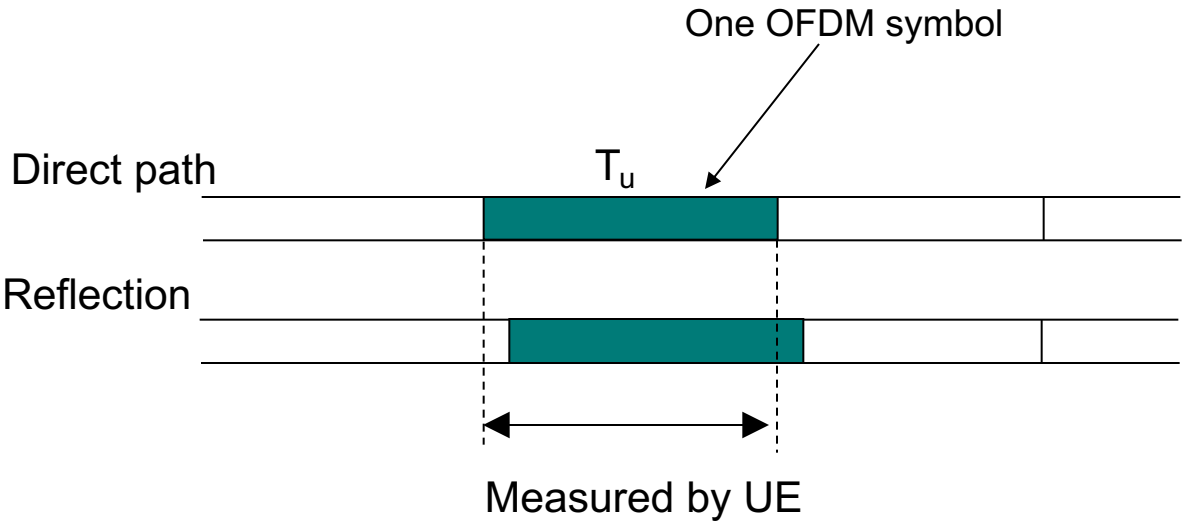


- **Frequency domain (/Scheduling Block)**
  - *unused*

Source: LTE Fundementals, Sven Anders Sturesson

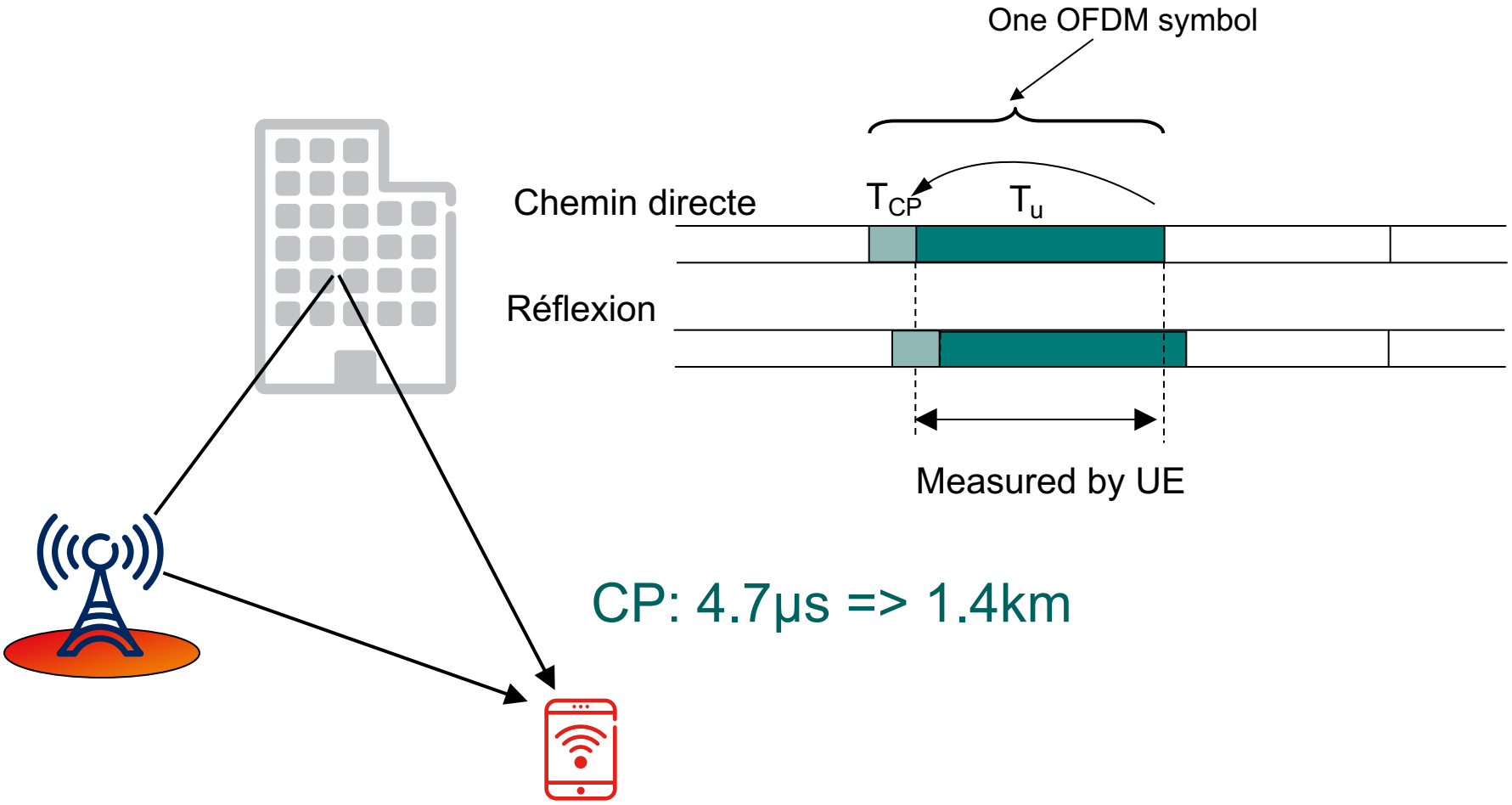
Delay spread





Source: LTE Fundementals, Sven Anders Sturesson

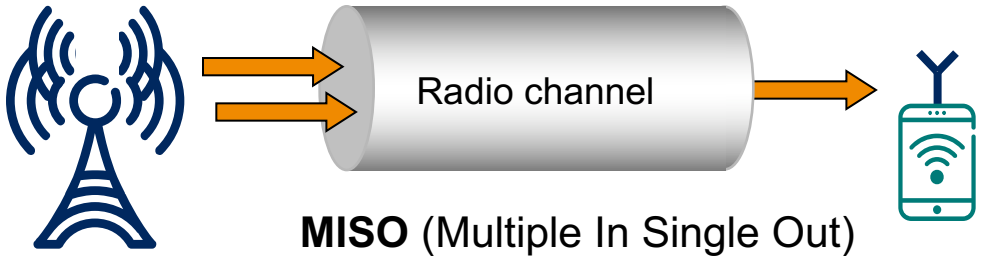
Cyclic prefix insertion



CP: 4.7µs => 1.4km

Source: LTE Fundementals, Sven Anders Sturesson

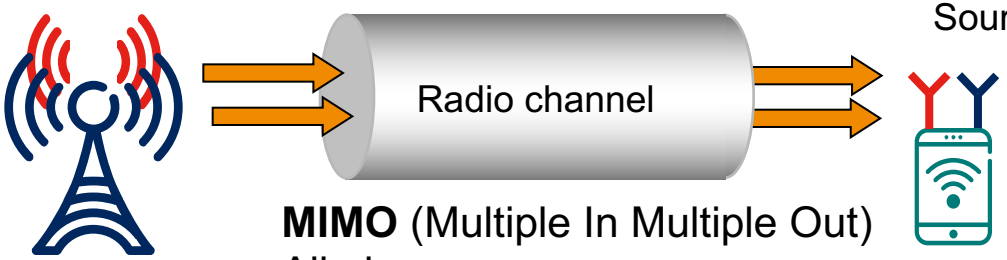
MIMO schemes (examples)



MISO (Multiple In Single Out)
Beam forming
Transmit diversity

SIMO (Single In Multiple Out)
Receive diversity

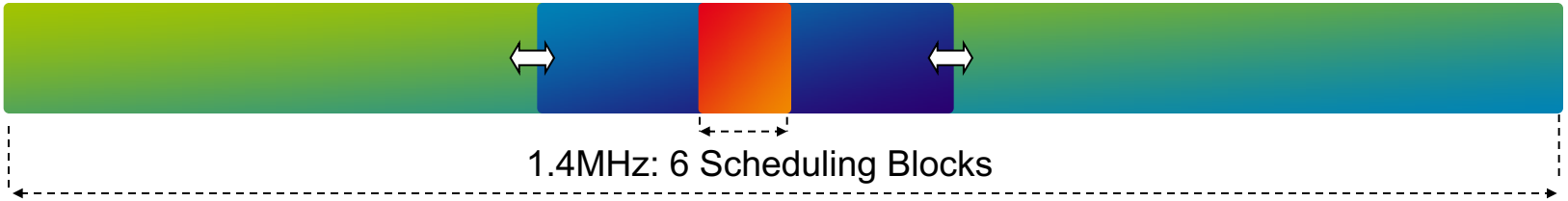
Source: LTE Fundementals, Sven Anders Sturesson



MIMO (Multiple In Multiple Out)
All above +
Spatial multiplexing (MIMO)

Spectrum Flexibility

- New and existing bands
- FDD and TDD
- Plusieurs largeurs de bandes



LTE Channel bandwidths [MHz]	1.4	3	5	10	15	20

Source: LTE Fundementals, Sven Anders Sturesson

LTE DL peak rate
20 MHz and 4x4 MIMO et 64 QAM

14 OFDM symbols per 1.0 ms subframe

64QAM = 6 bits per symbol

6 x 14 = 84 bits per 1.0 ms subframe

84bits/1.0ms = 84kbps per subcarrier

12 x 84kbps = 1.008Mbps per Scheduling Block

100 Scheduling Blocks in 20MHz

100 x 1.008Mbps = 100.8Mbps per antenna

4 x 4 MIMO: 403.2Mbps !

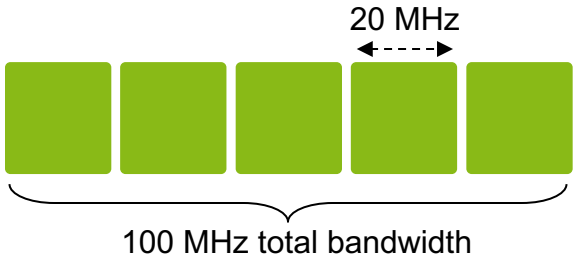
BUT in reality approx. 300Mbps

…and UL
no MIMO
75Mbps

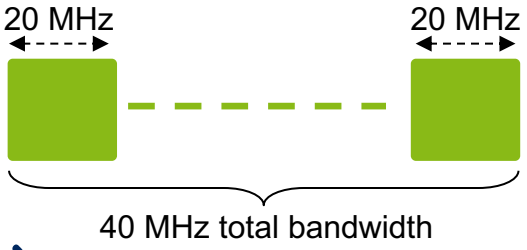
Source: LTE Fundementals, Sven Anders Sturesson

LTE 3GPP Rel 10 Higher peak rates

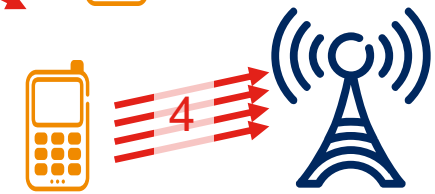
- **Carrier aggregation**



- **Spectrum aggregation**



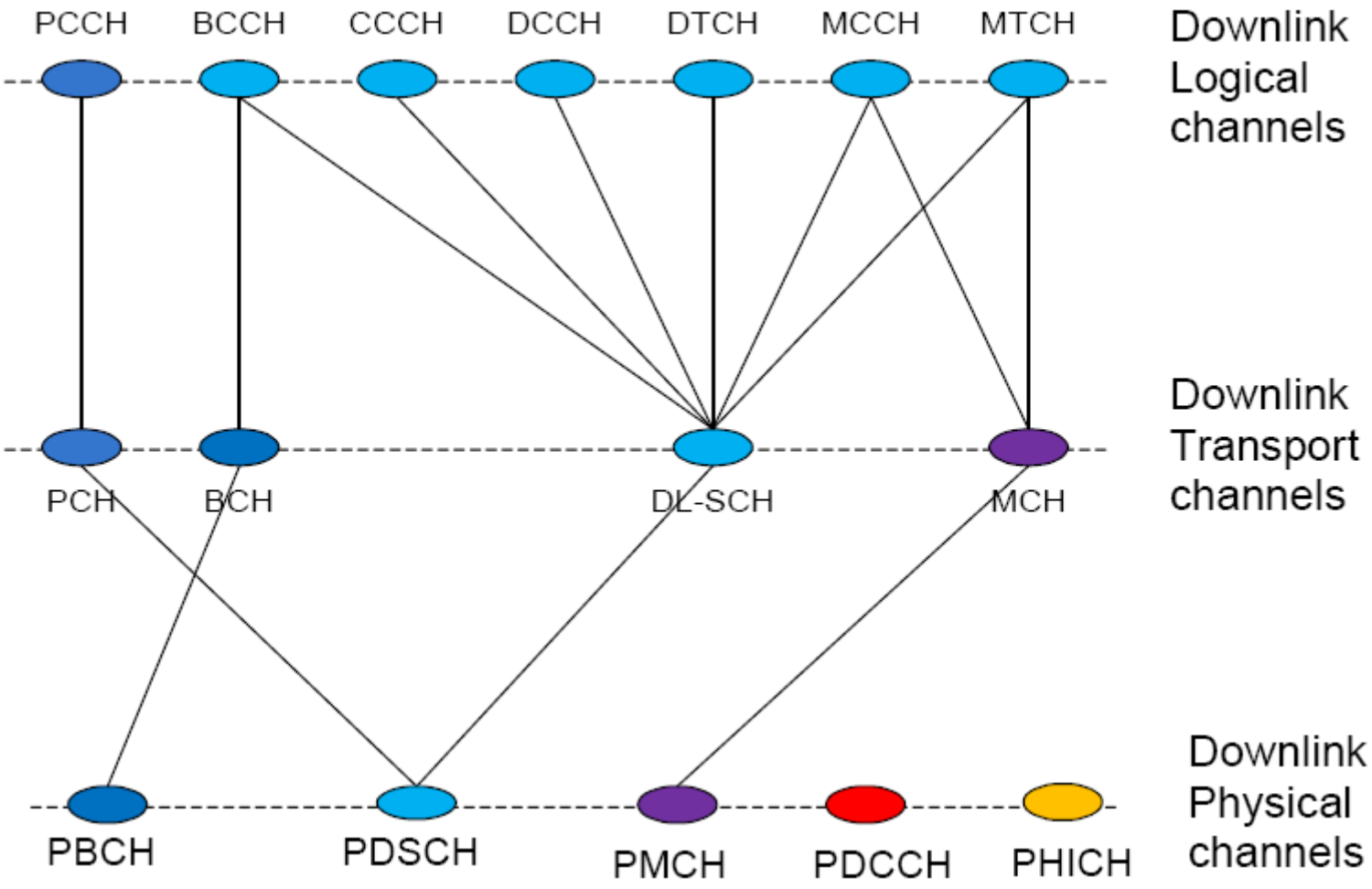
- **DL/UL Multi-Antenna transmission**



Source: LTE Fundementals, Sven Anders Sturesson

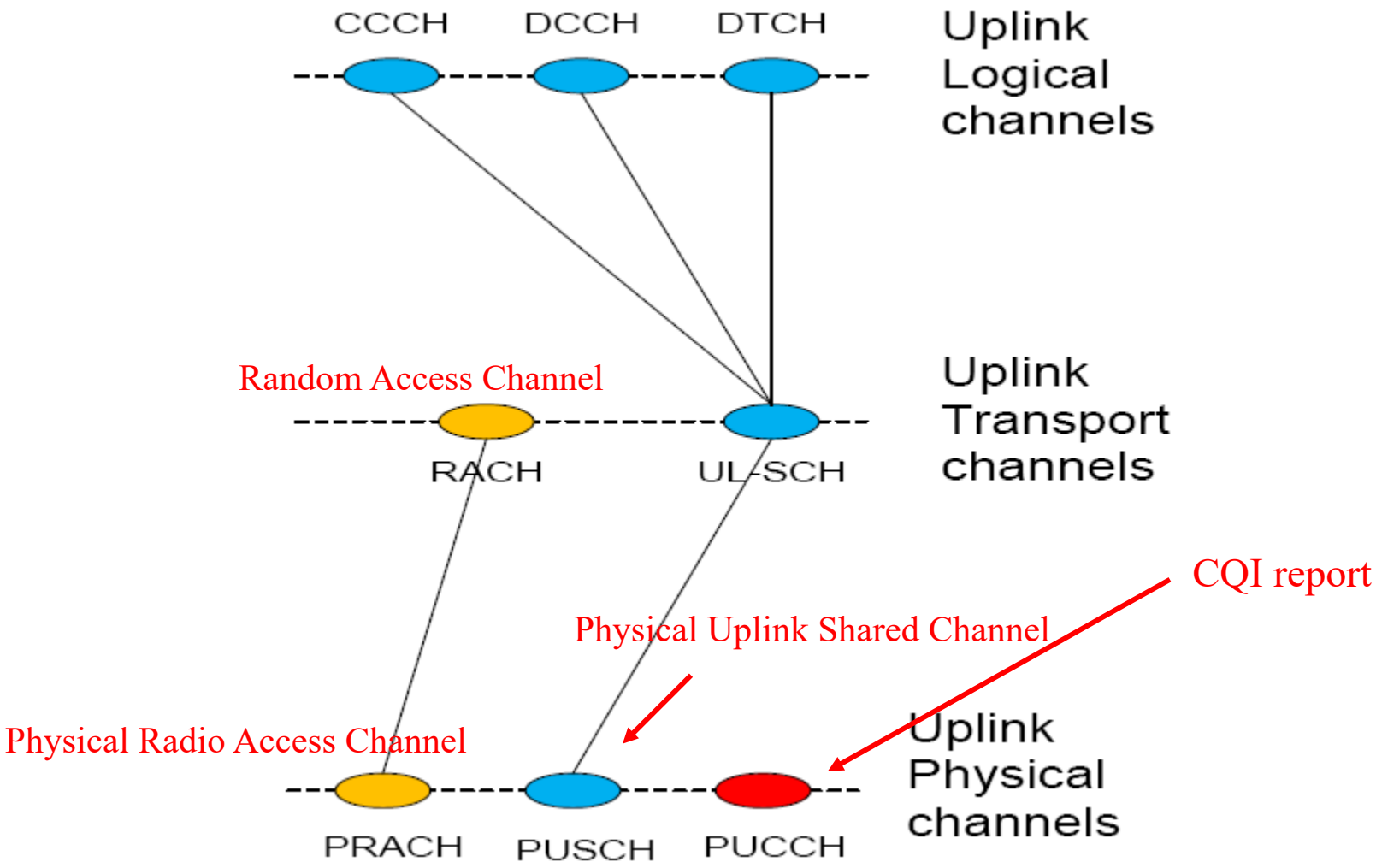
downlink

Source: LTE Fundementals, Sven Anders Sturesson



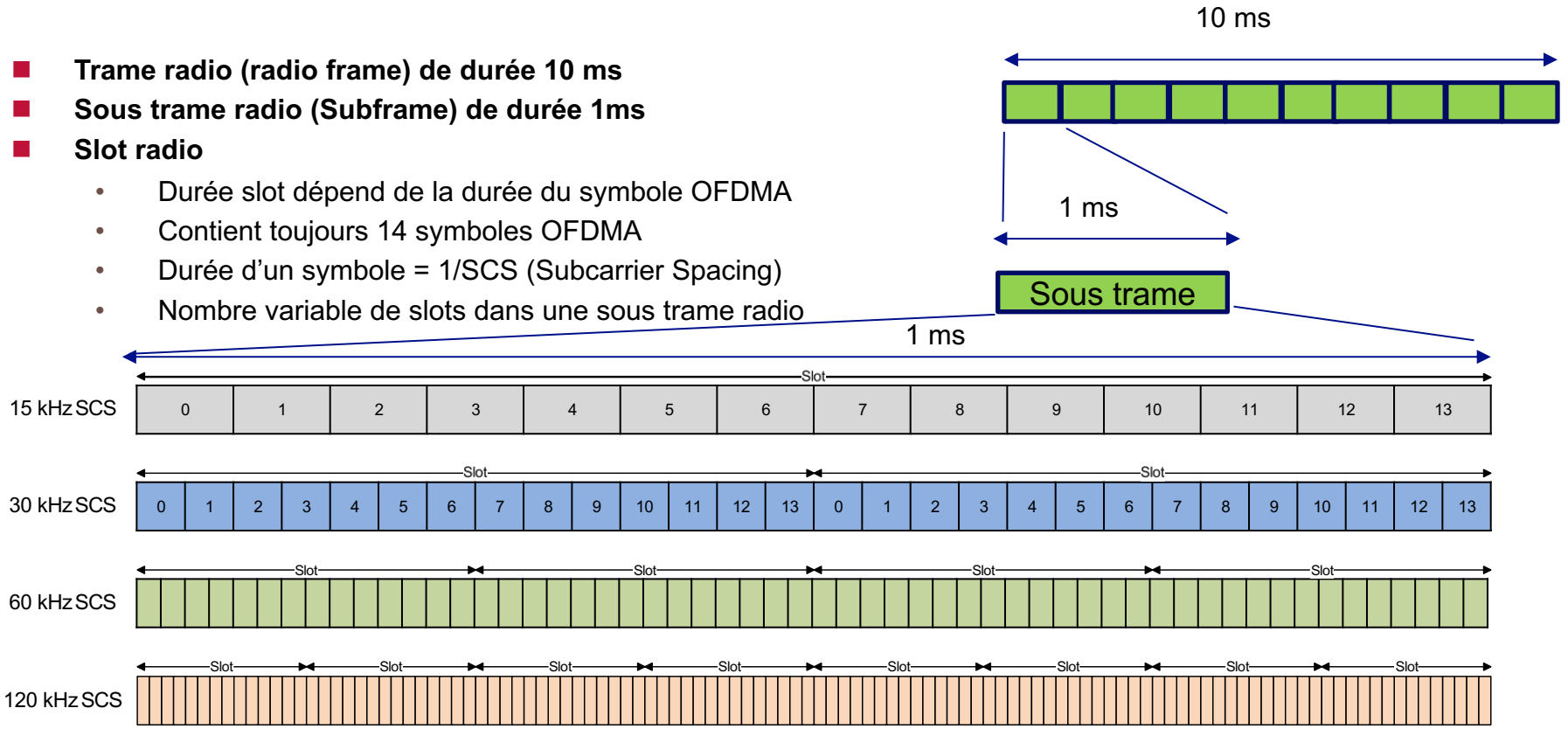
uplink

Source: LTE Fundementals, Sven Anders Sturesson



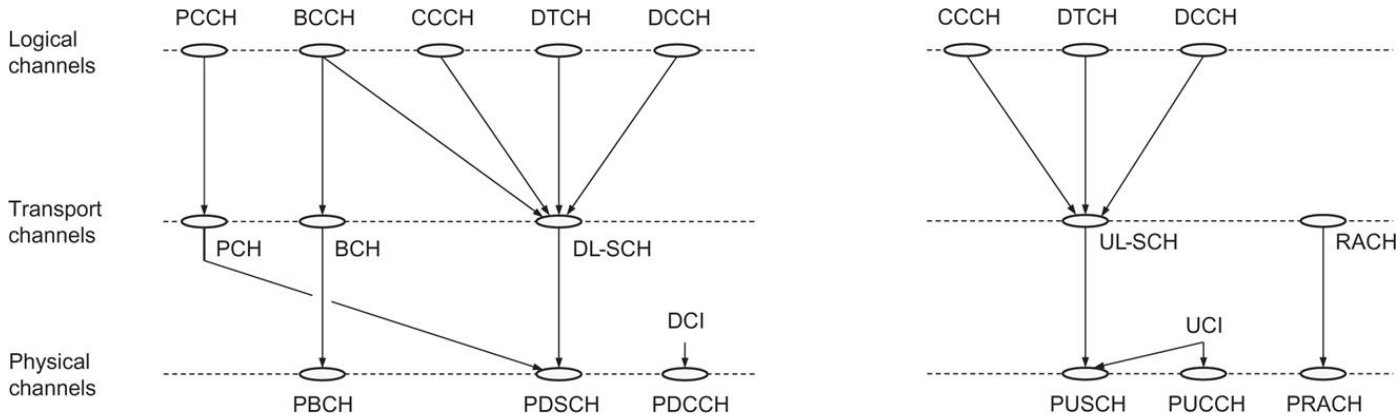
Numérologie de l'interface radio 5G

- **Trame radio (radio frame) de durée 10 ms**
- **Sous trame radio (Subframe) de durée 1ms**
- **Slot radio**
  - Durée slot dépend de la durée du symbole OFDMA
  - Contient toujours 14 symboles OFDMA
  - Durée d'un symbole = 1/SCS (Subcarrier Spacing)
  - Nombre variable de slots dans une sous trame radio

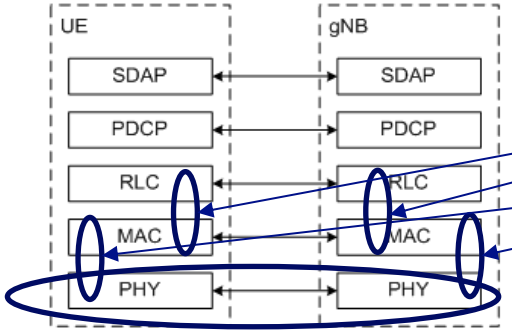


Source: présentation de Amitabha Ghosh, 5G New Radio (NR) : Physical Layer Overview and Performance, IEEE Communication Theory Workshop – 2018, 15 Mai 2018

Canaux downlink et uplink



Downlink **Uplink**



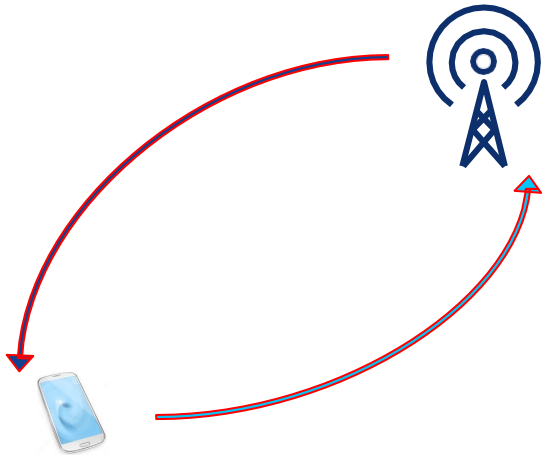
Canaux logiques

Canaux de transport

Canaux physiques

Canaux physiques et signaux de références

- PBCH (Physical Broadcast channel)
- PDSCH (Downlink shared channel)
- PDCCH (Physical Downlink control) channel



- PRACH Random access channel
- PUSCH Uplink shared channel
- PUCCH Uplink control channel

Signaux de référence voie descedante

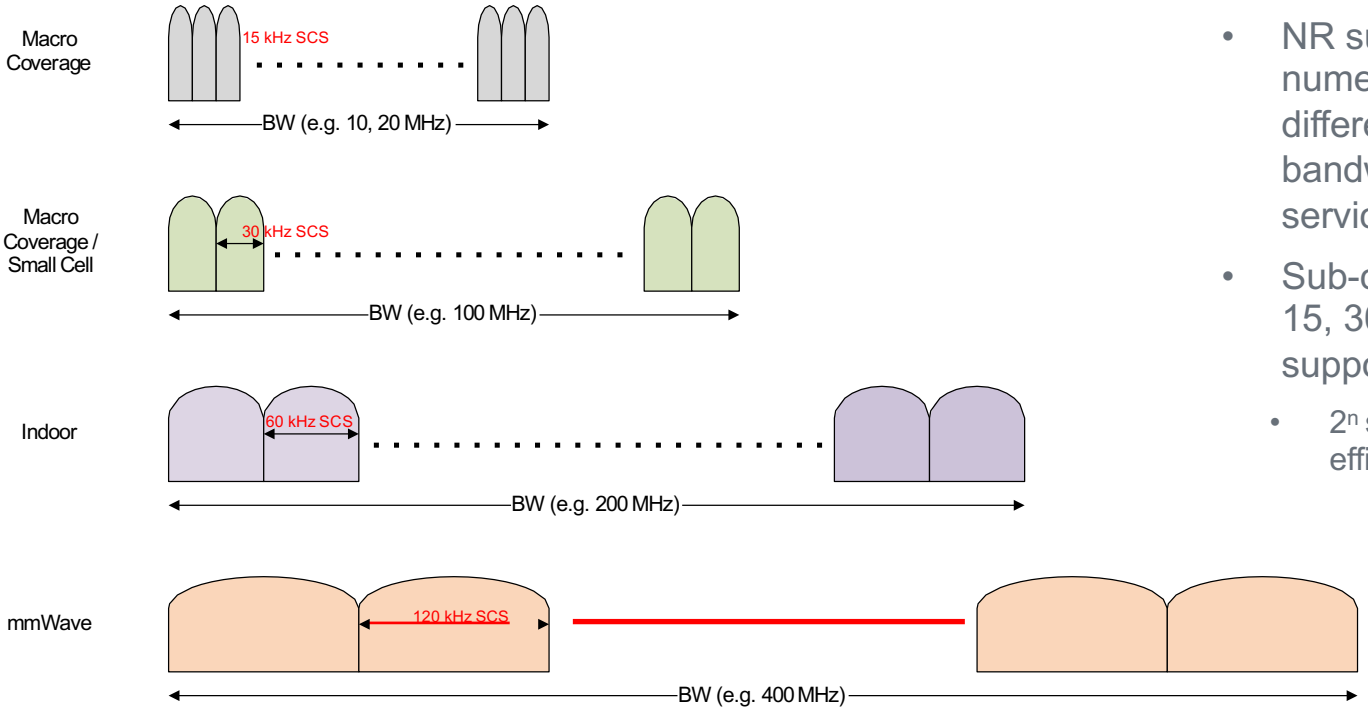
- Demodulation Reference signal (DMRS)
- Phase-tracking Reference signal (PT-RS)
- Channel State Information Reference signal (CSI-RS) Primary Synchronization (PSS)
- Secondary Synchronization (SSS)

Signaux de référence voie montante

- Demodulation Reference signal (DMRS)
- Phase-tracking Reference signal (PTRS)
- Sounding Reference signal (SRS)

Source: présentation de Amitabha Ghosh, 5G New Radio (NR) : Physical Layer Overview and Performance, IEEE Communication Theory Workshop – 2018, 15 Mai 2018

Différentes configurations SCS



- NR supports scalable numerology to address different spectrum, bandwidth, deployment and services
- Sub-carrier spacing (SCS) of 15, 30, 60, 120 kHz is supported for data channels
  - 2^n scaling of SCS allows for efficient FFT processing

Source: présentation de Amitabha Ghosh, 5G New Radio (NR) : Physical Layer Overview and Performance, IEEE Communication Theory Workshop – 2018, 15 Mai 2018