4G to 5G networks and standard releases

ITU PITA Workshop on
Mobile network planning and security

Sami TABBANE

23-25 October 2019 – Nadi, Fiji Islands

Objectives

Provide an overview of various technologies and standards of 4G and future 5G

Agenda

I. 4G and LTE networks

II. LTE Release 10 to 14

III. 5G

I. 4G and LTE networks

1. 4G motivations

Introduction

- Geneva, 18 January 2012 – Specifications for *IMT-Advanced* agreed at the ITU Radiocommunications Assembly in Geneva.
- ITU determined that "LTE-Advanced" and "WirelessMAN-Advanced" should be accorded the official designation of *IMT-Advanced*:
  - 3GPP LTE Advanced: LTE Release 10, supporting both paired Frequency Division Duplex (FDD) and unpaired Time Division Duplex (TDD) spectrum;
  - Wireless MAN-Advanced: Mobile WiMax 2, or IEEE 802. 16m.

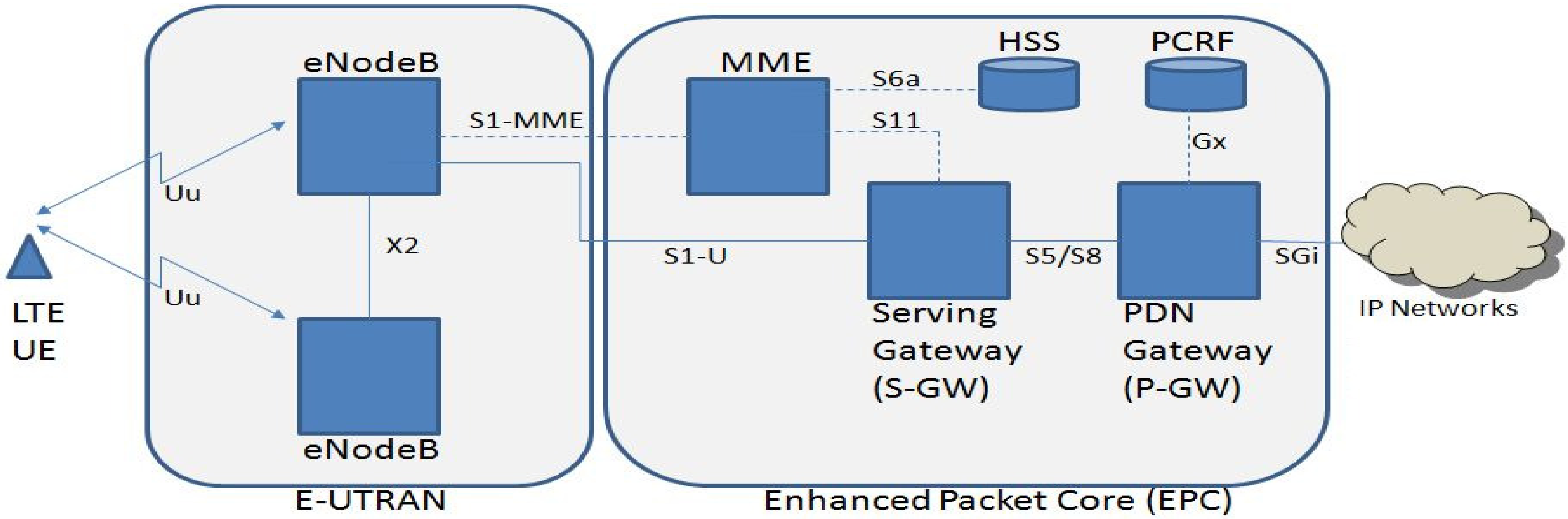
Needs for IMT-Advanced systems

- Need for **higher data rates** and greater spectral efficiency
- Need for a **Packet Switched only** optimized system
- Use of **licensed frequencies** to guarantee quality of services
- **Always-on experience** (reduce control plane latency significantly and reduce round trip delay)
- Need for **cheaper infrastructure**
- **Simplify architecture** of all network elements

Impact and requirements on LTE characteristics

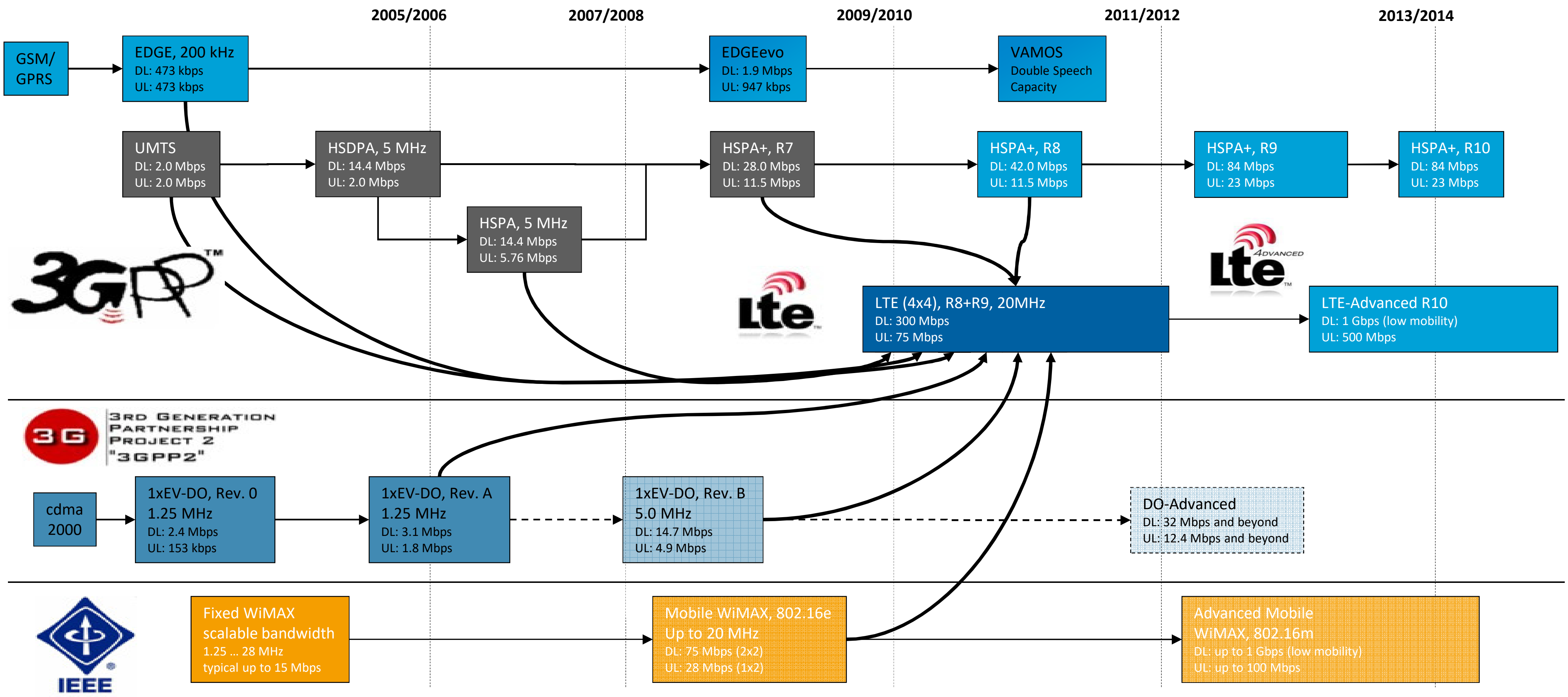
- Architecture (flat)
- Frequencies (flexibility)
- Bitrates (higher)
- Latencies (lower)
- Cooperation with other technologies (all 3GPP and non-3GPP)
- Network sharing (part or full)
- Full-IP (QoS issues, protocols integration, lower costs)
- OFDMA
- Broadcast services
- Intelligent radio schemes

LTE Architecture



2. Evolution 3G-4G

Wireless technology evolution path



3GPP Releases – main features from 3G to 4G

- **Release '99**
  - –The basis for early 3G deployment
- **Release 4**
  - –First steps towards IP-based operation
  - –Also defines the low chip rate TDD mode (TD-SCDMA)
- **Release 5**
  - –IMS - IP-based Multimedia Services
  - –HSDPA - High Speed Downlink Packet Access
- **Release 6**
  - –2nd phase of IMS
  - –High Speed Uplink
- **Release 7**
  - –Enhanced uplink
  - –Other spectrum
  - –Multiple input multiple output antennas (MIMO)
- **Release 8**
  - –Long Term Evolution (LTE) and System Architecture Evolution (SAE)
- **Release 9**
  - –Enhancement of Release 8 features
  - –Refinement of LTE
  - –Preliminary studies into LTE Advanced
- **Release 10**
  - –LTE Advanced

Main wireless broadband systems

	HSPA	3GPP LTE	IEEE 802.16e[1]
Standardization body	3GPP	3GPP	IEEE
Deployment frequencies (GHz)	All 3G bands	All 3G bands, 2.6GHz	2.5, 3.5, 5.8 GHz
Bandwidth (MHz)	5	1.25, 2.5, 5, 10, 15, 20	5, 10, 20
Uplink scheme	CDMA	SC-FDMA	OFDMA
Downlink scheme	CDMA	OFDMA	OFDMA
Preferred duplex scheme	FDD	FDD	TDD, FDD

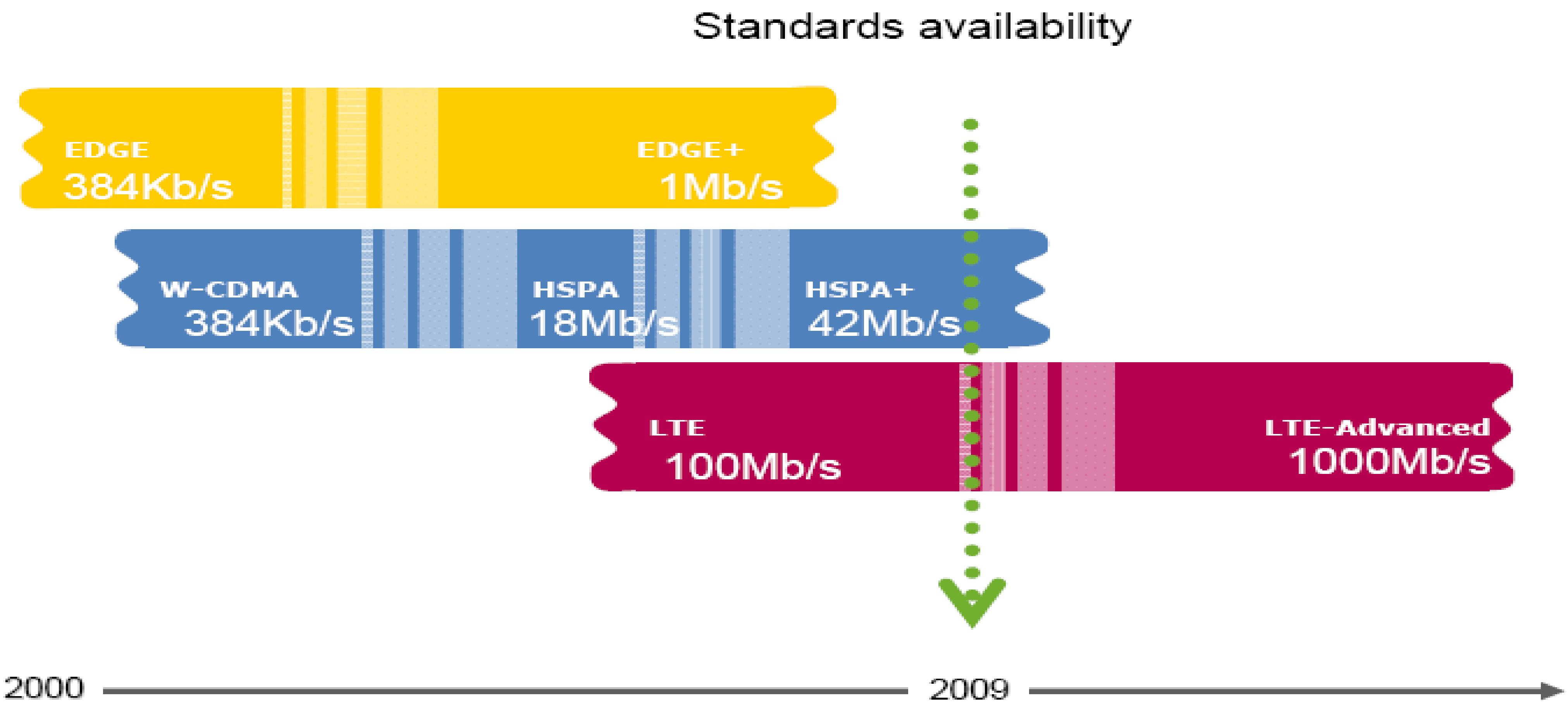
3. Evolution R9 – R10

3GPP history and members

- Founded in December 1998

- 3GPP is a collaborative standardization activity between ETSI (Europe) and:
  - ARIB (Japan-radio)
  - TTC (Japan-network)
  - TTA (Republic of Korea)
  - CCSA (Peoples’ Republic of China)
  - ATIS (North America)

3GPP family standards evolution



4. Performance Objectives

Needs at the access level for LTE (Release 8)

- Radio interface bitrates: 100 Mbit/s DL and 50 Mbit/s UL.
- Data transmission delay: less than 5 ms between UE and the Access Gateway (AGW)
- Mobility: speeds between 120 and 350 km/h (or even up to 500 km/h depending on the frequency band)
- Co-existence and Interworking with 3G: HO between E-UTRAN and UTRAN should be achieved with less than 300 ms for real-time services and 500 ms for NRT services.
- Multicast support for multimedia applications.

Latency definitions

- *Latency* = time a message takes to traverse a system.
- In a computer network =time for a data packet data to get from one point to another.
- Depends on:
- Speed of the transmission medium (e.g., copper wire, optical fiber or radio waves)
- Delays in the transmission by devices (e.g., routers and modems).
- Latency and bandwidth determine the network connection speed.
- A **low latency** = **high network efficiency**.
- Low enough latency ➔ no need for **local storage or computing** in a wireless device.
- ***Latency increase = grow of local processing.***

Web: 1 sec.

Voice: 150 ms

Traffic safety: 100 ms

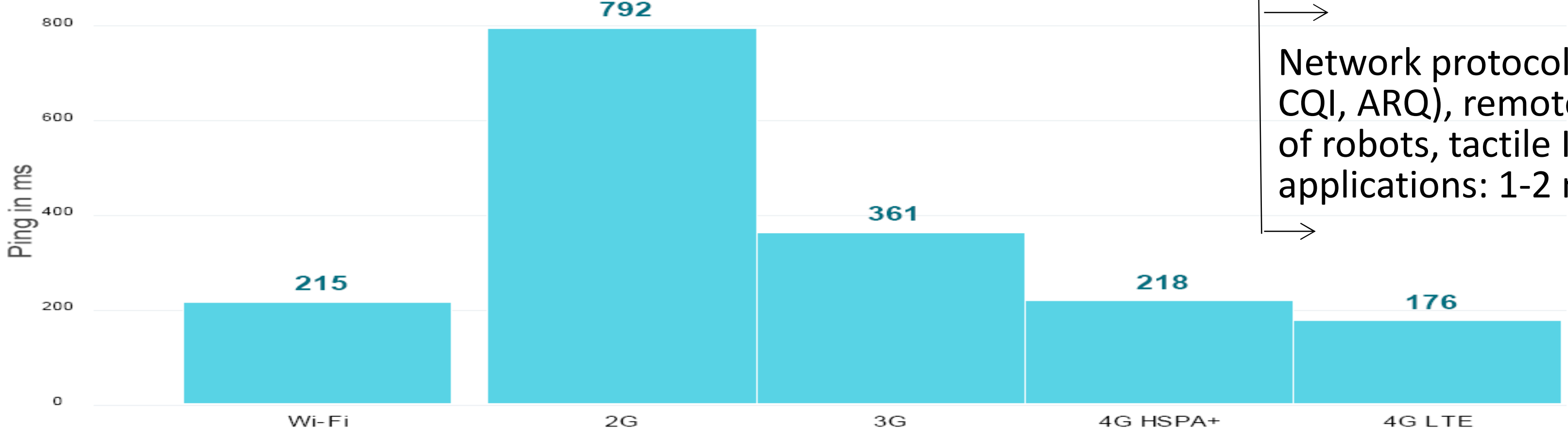
Online gaming: 50 ms

Cloud computing: 5 ms

Security (airplanes, …): < 5 ms

Health devices, safety or control mechanisms, electrical-distribution grid, financial trading: 2-5 ms

Network protocols (e.g., CQI, ARQ), remote control of robots, tactile Internet applications: 1-2 ms



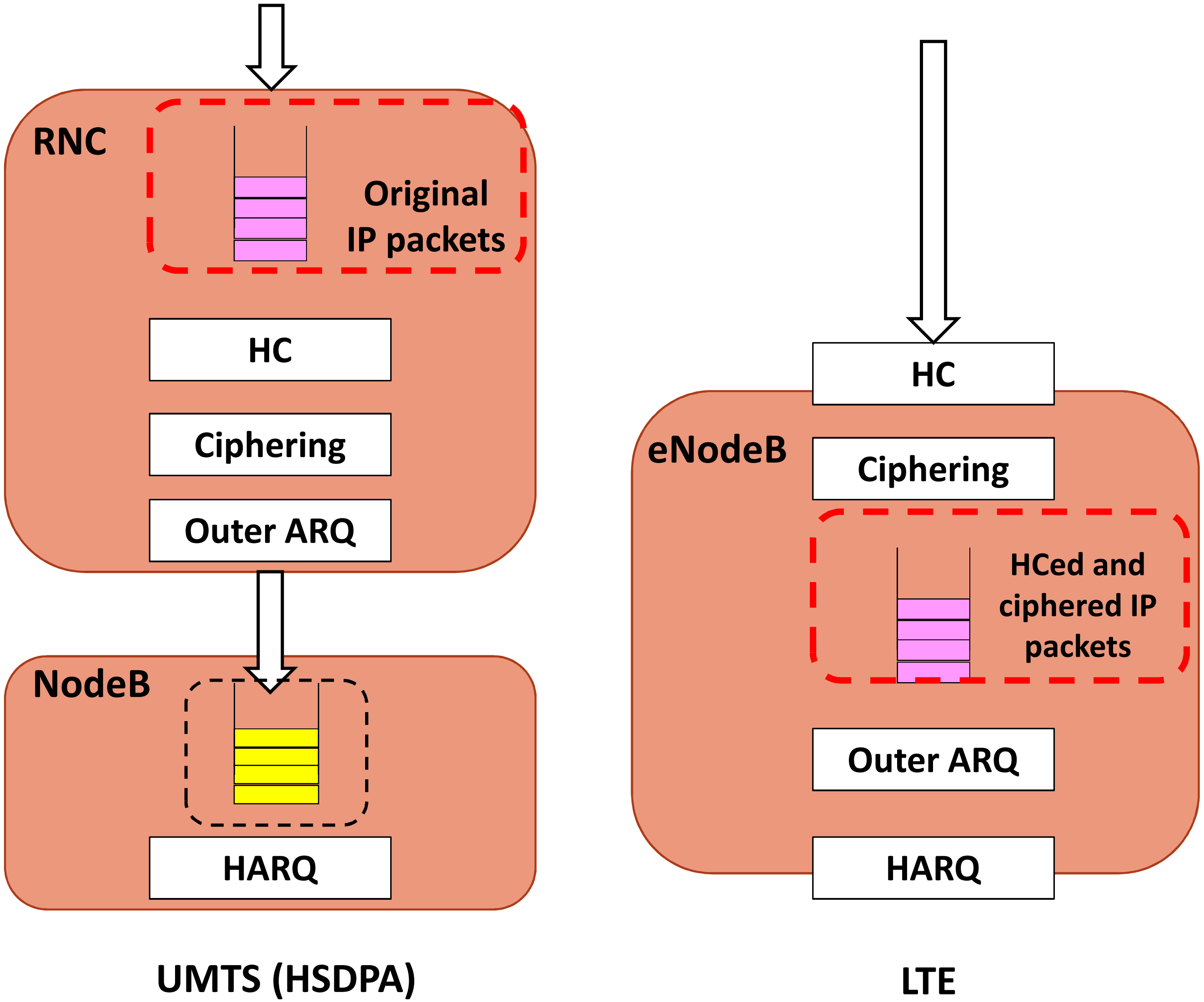
Peak data rates DL and UL

Modulation coding		1.4 MHz	3.0 MHz	5.0 MHz	10 MHz	15 MHz	20 MHz
QPSK 1/2	Single stream	0.7	2.1	3.5	7.0	10.6	14.1
16QAM 1/2	Single stream	1.4	4.1	7.0	14.1	21.2	28.3
16QAM 3/4	Single stream	2.2	6.2	10.5	21.1	31.8	42.4
64QAM 3/4	Single stream	3.3	9.3	15.7	31.7	47.7	63.6
64QAM 4/4	Single stream	4.3	12.4	21.0	42.3	63.6	84.9
64QAM 3/4	2x2 MIMO	6.6	18.9	31.9	64.3	96.7	129.1
64QAM 1/1	2x2 MIMO	8.8	25.3	42.5	85.7	128.9	172.1
64QAM 1/1	4x4 MIMO	16.6	47.7	80.3	161.9	243.5	325.1

Modulation coding		1.4 MHz	3.0 MHz	5.0 MHz	10 MHz	15 MHz	20 MHz
QPSK 1/2	Single stream	0.7	2.0	3.5	7.1	10.8	14.3
16QAM 1/2	Single stream	1.4	4.0	6.9	14.1	21.6	28.5
16QAM 3/4	Single stream	2.2	6.0	10.4	21.2	32.4	42.8
16QAM 1/1	Single stream	2.9	8.1	13.8	28.2	43.2	57.0
64QAM 3/4	Single stream	3.2	9.1	15.6	31.8	48.6	64.2
64QAM 1/1	Single stream	4.3	12.1	20.7	42.3	64.8	85.5
64QAM 1/1	V-MIMO (cell)	8.6	24.2	41.5	84.7	129.6	171.1

5. Key features of LTE and LTE Advanced

Differences between HSPA and LTE



Key Features

Key Features of LTE (1)

- Multiple access scheme
  - Downlink: **OFDMA**
  - Uplink: **Single Carrier FDMA** (SC-FDMA)
- *Adaptive modulation and coding*
  - DL modulations: QPSK, 16QAM, and 64QAM
  - UL modulations: QPSK and 16QAM
  - Rel-6 Turbo code: Coding rate of 1/3, two 8-state constituent encoders, and a contention- free internal interleaver.
- **Bandwidth scalability** for efficient operation in differently sized allocated spectrum bands
- ***Single frequency network*** (SFN) operation to support MBMS

Key Features

Key Features of LTE (2)

- **MIMO** technology for enhanced data rate and performance.
- **ARQ** at the RLC sublayer and **Hybrid ARQ** at the MAC sublayer.
- **Power control** and **link adaptation**
- **Interference coordination** between eNBs
- Support for both FDD and TDD
- **Channel dependent scheduling**
- **Reduced radio-access-network nodes** to reduce cost, protocol-related processing time & call set-up time

Key Features

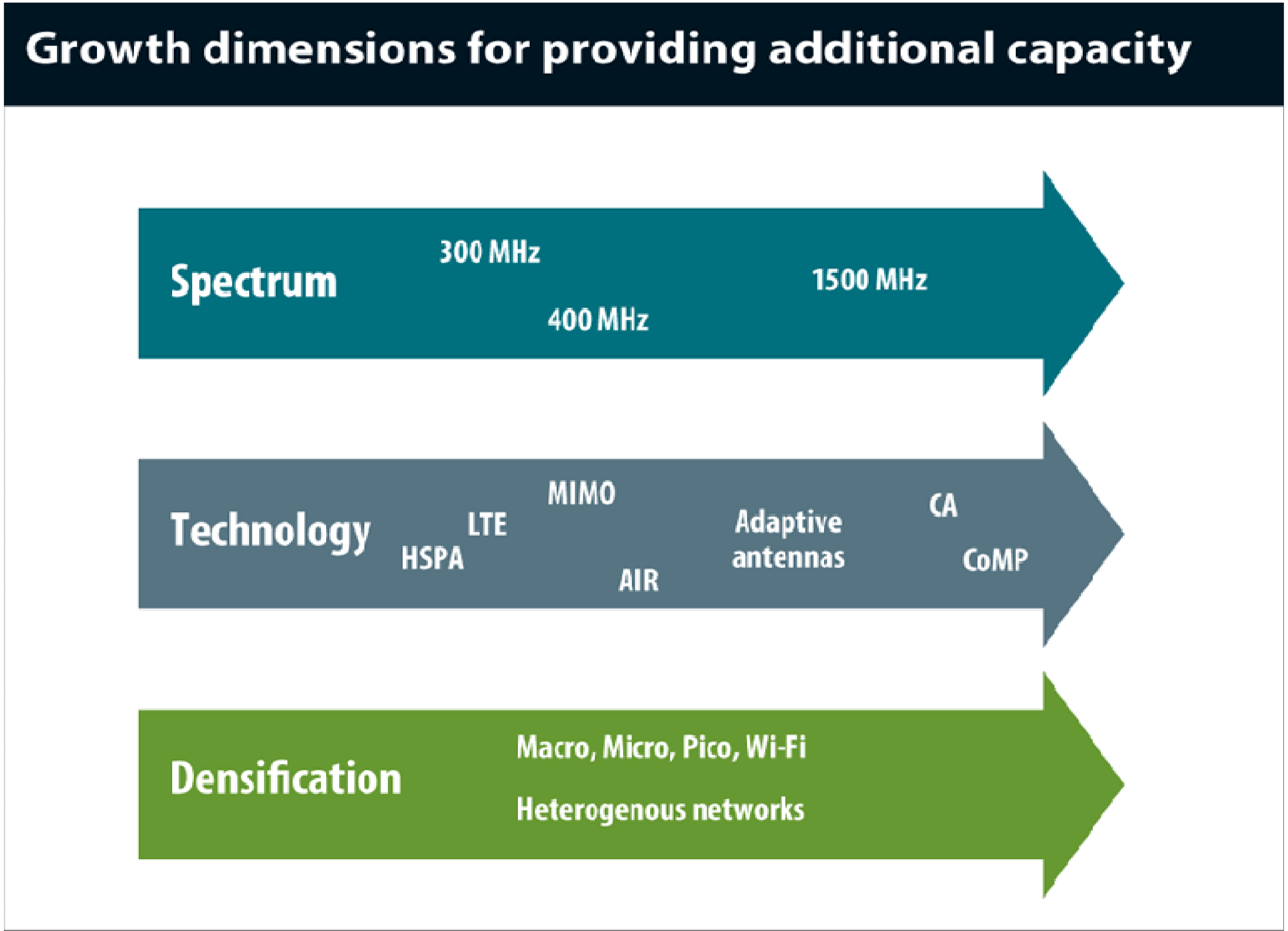
Key Features of LTE (3)

- **Always-on** connectivity to reduce sessions establishment sand releases signaling overhead and connection setup time.

Internet Mobile

Date	Heure	Volume(en Ko)
07/04/14	15:07:39	5 240,000
07/04/14	15:19:14	150,000
07/04/14	15:23:17	630,000
07/04/14	16:37:16	100,000
07/04/14	16:48:52	10,000
07/04/14	16:55:30	360,000
07/04/14	17:22:20	0,000
07/04/14	18:50:37	10,000
07/04/14	18:51:09	60,000
07/04/14	19:23:56	0,000
08/04/14	08:07:07	170,000
08/04/14	08:16:57	10,000
08/04/14	10:21:18	3 150,000
08/04/14	11:10:02	20,000
08/04/14	11:12:13	360,000
08/04/14	11:24:30	30,000
08/04/14	13:13:19	100,000
08/04/14	13:20:36	150,000
08/04/14	13:22:07	150,000
08/04/14	13:53:48	0,000
08/04/14	13:53:58	20,000
08/04/14	13:56:07	40,000

Key techniques for enhancing network capacity



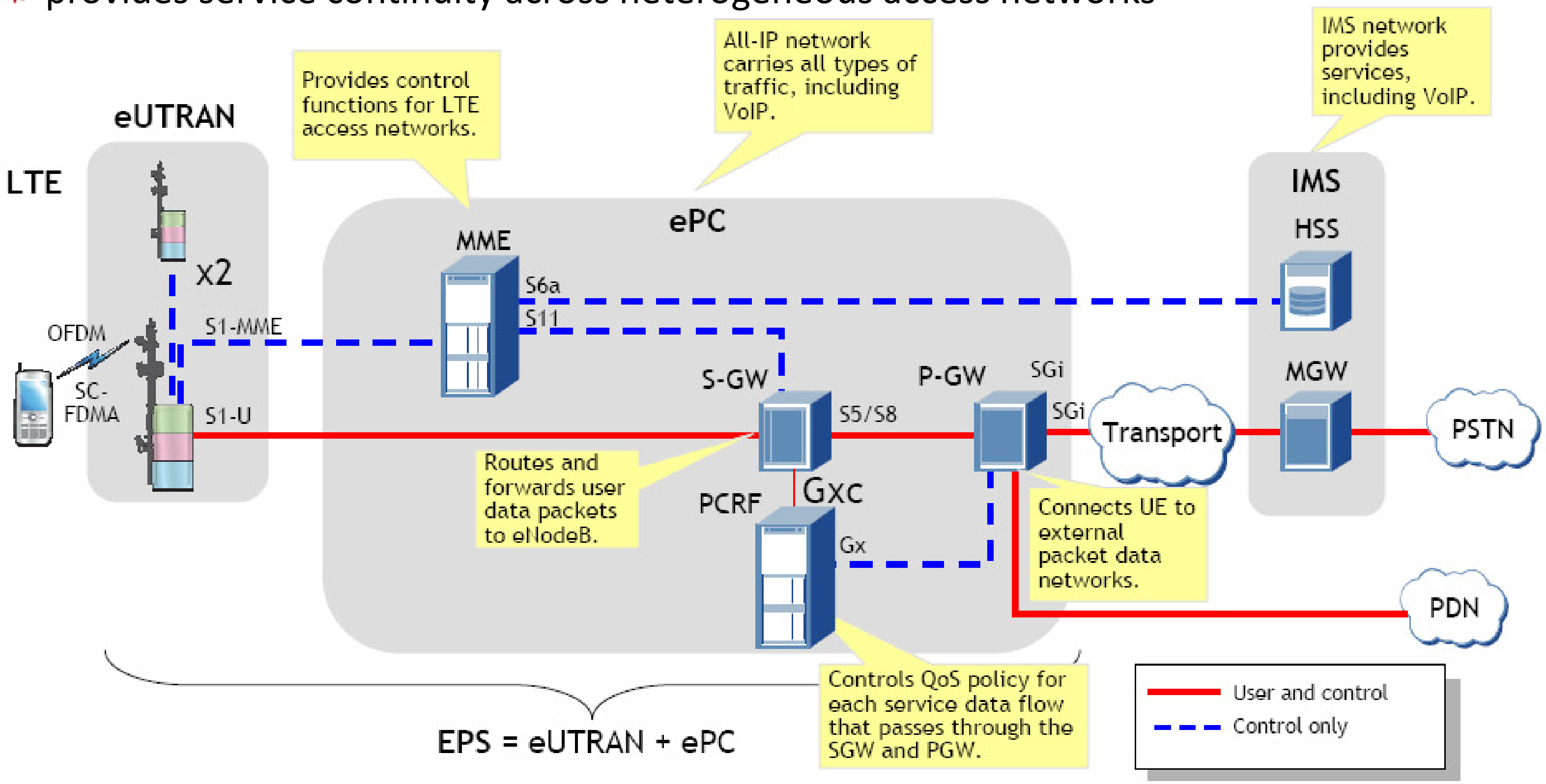
3GPP LTE objectives

- Scalable bandwidth: 1.25, 2.5, 5, 10, (15), 20MHz
- Peak data rate (scaling linearly with the spectrum allocation)
  - DL (2 Rx @ UE): 100Mb/s for 20MHz spectrum allocation
  - UL (1 Tx @ UE): 50Mb/s for 20MHz spectrum allocation
- Spectrum efficiency
  - DL: 3-4 times HSDPA for MIMO (2,2)
  - UL: 2-3 times HSUPA for MIMO(1,2)
- > Reference Antenna configurations (typical achievable targets)
  - DL: 2Tx and 2 Rx
  - UL: 1 Tx and 2 Rx
- Latency
  - C-plane: < 50-100ms to establish U-plane
  - U-plane: << 10ms from UE to AGW
- Capacity
  - 200 users for 5MHz, 400 users in larger spectrum allocations (active state)
- Mobility
  - LTE is optimized for speeds 0-15km/h up to 350km/h

Architecture

LTE architecture

- System Architecture Evolution (SAE) goal: develop a framework for the evolution and migration of current systems to a system which supports the following:
  - high data rates
  - low latency
  - packet-optimized (all IP network)
  - provides service continuity across heterogeneous access networks



Evolved UTRAN Architecture

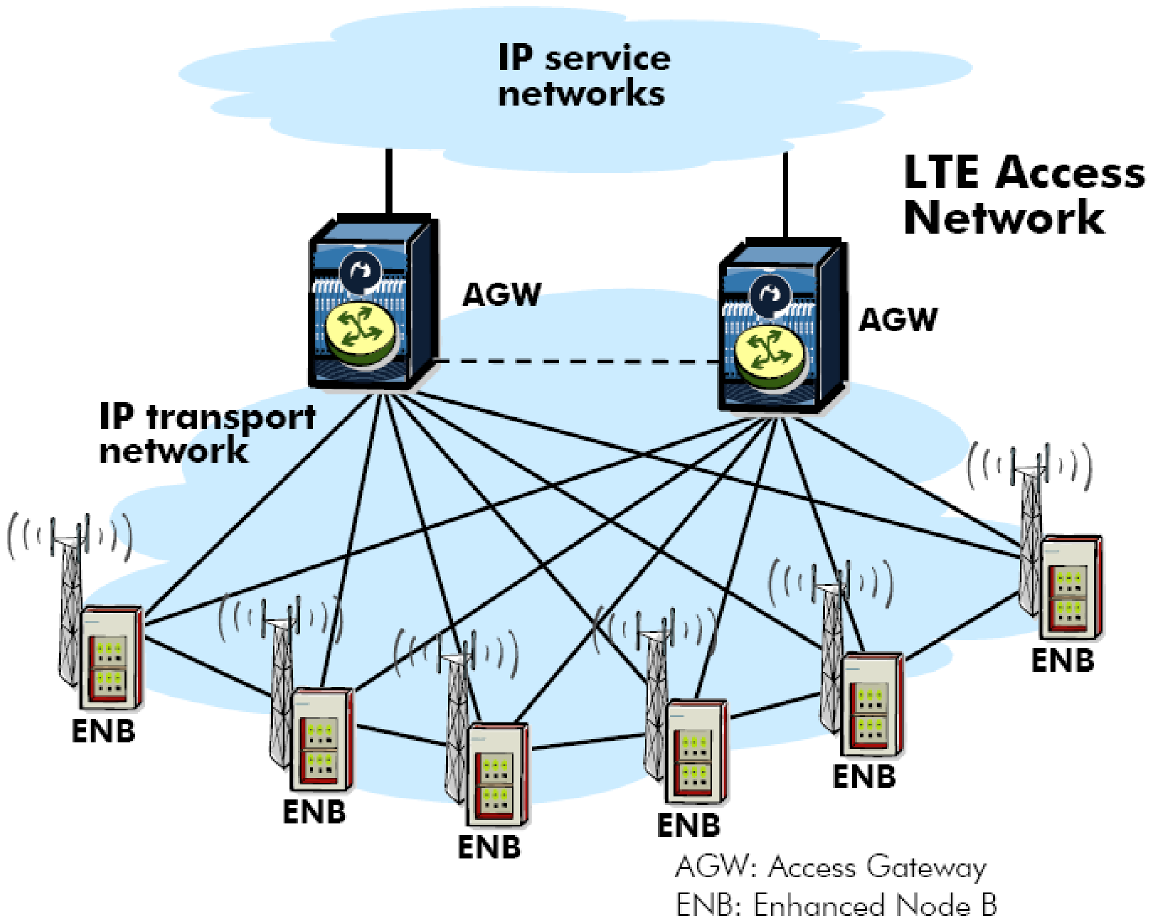
- **EPC - Evolved Packet Core**
  - MME: Mobility Management Entity
  - S-GW: Serving Gateway
  - P-GW: Gateway for the Packet Data Network
- **E-UTRAN - Evolved UTRAN, known as LTE**
  - eNB - enhanced NodeB, base stations
- **Architecture simpler than UTRAN Release 6**
  - EPC/LTE – 2 user-plane nodes: eNB, S/P-GW
  - UTRAN R6 – 4 user-plane nodes: NodeB, RNC, SGSN, GGSN
  - ➢ Consequences
    - **Ciphering** and **header compression** performed at eNBs
    - **Handovers between eNBs** handled through X2 interface rather than by the RNC

- **Flat architecture =**
  - Signaling messages reduction (up to 30% saving)
  - Network performance increase (up to 40%)
  - Integration of the features in a single equipment

  ➔ OPEX and CAPEX reduction (up to 25% for the MME/SGSN and up to 35% for a SGW/PGW/GGSN)
  - Time and cost of maintenance reduced

User plane Overview

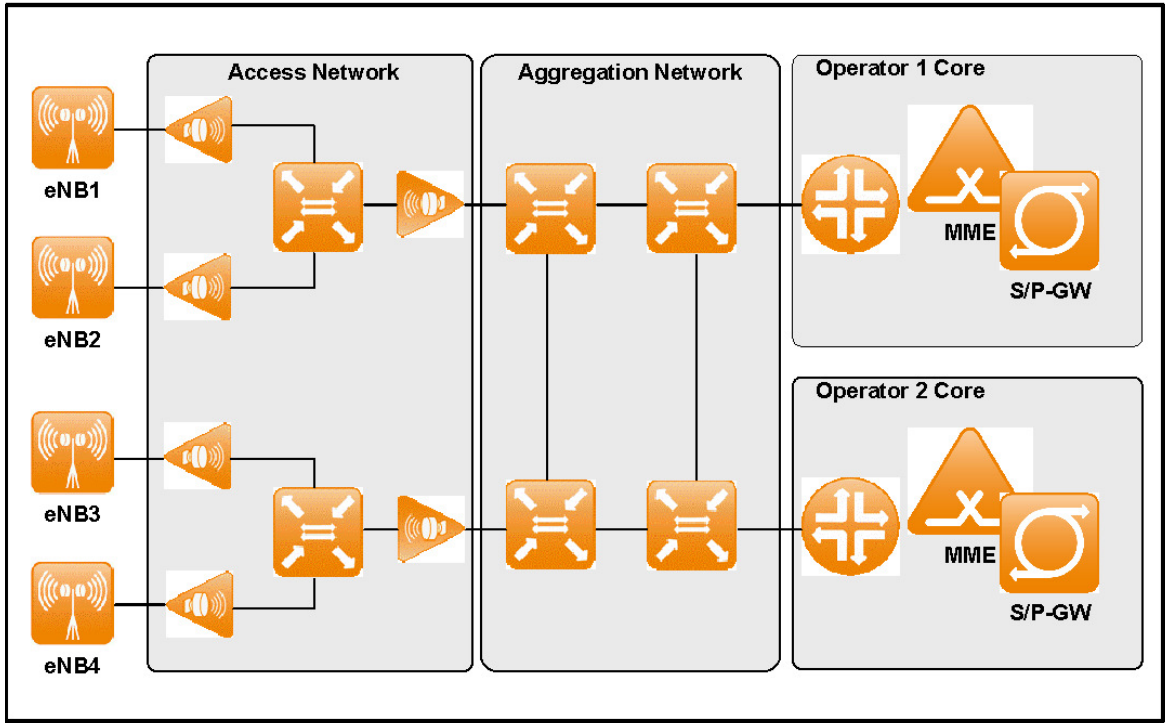
- User plane Traffic Architecture:
  - Cost efficient 2 types of nodes architecture
  - Fully meshed approach with tunneling mechanism over IP transport network
  - **Access Gateway** (AGW)
  - **Enhanced Node B** (ENB)



S1-flex Mechanism

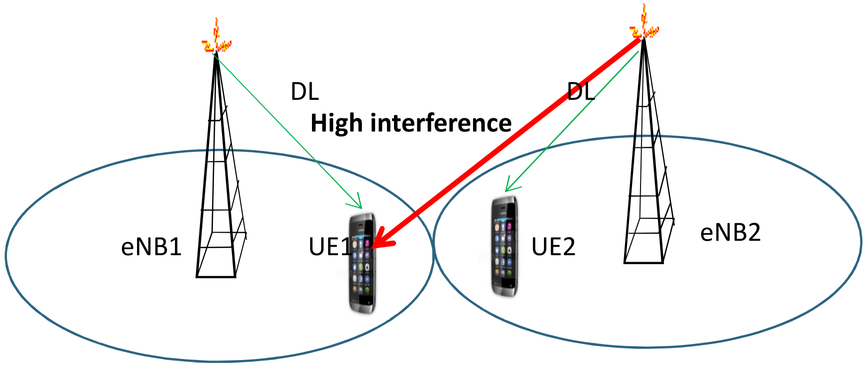
- Allows:
  - Network redundancy,
  - Load sharing of traffic across network elements in the CN, the MME and the SGW,
- Creates **pools** of MMEs and SGWs,
- Each eNB connected to multiple MMEs and SGWs in a pool.

Multiple Operator Core Network



- **MOCN** → service providers can have **separate core networks** (MME, SGW, PDN GW) and **E-UTRAN (eNBs) jointly shared**.
- Enabled by the S1-flex mechanism (each eNB can be connected to multiple core networks entities).

Introduction to ICIC



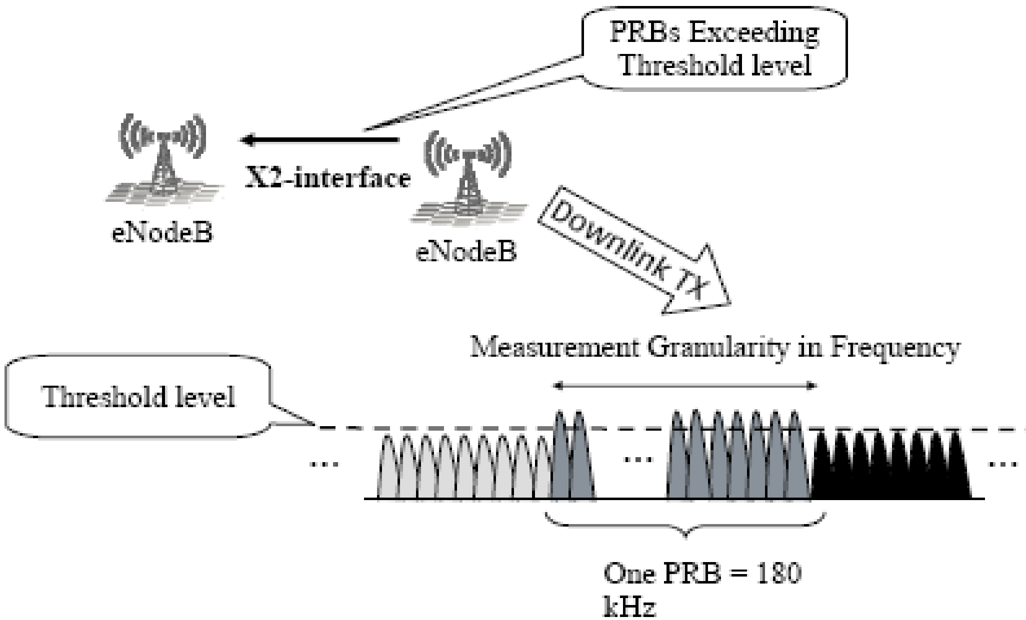
Motivations: **Interference issues**

ICIC

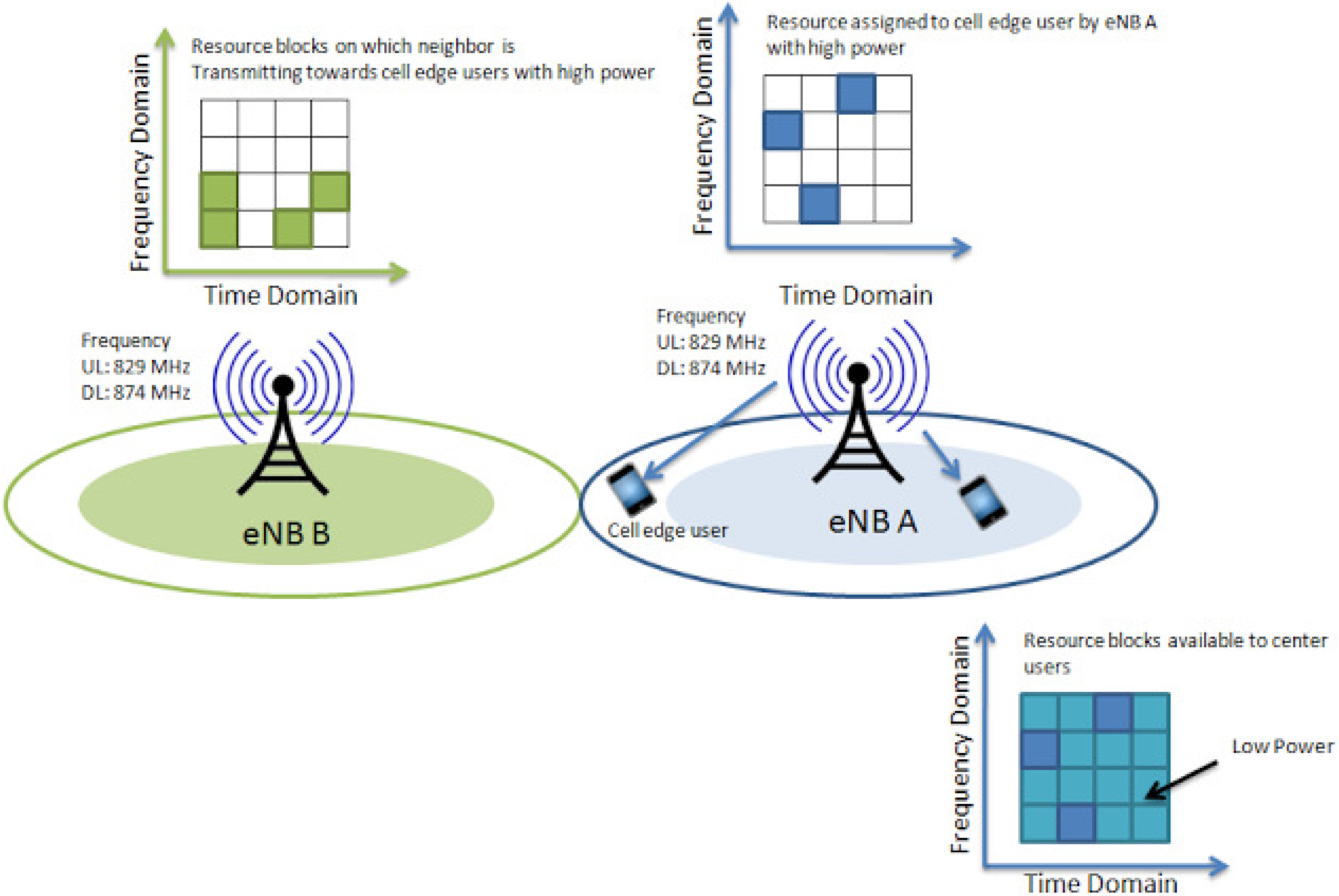
❖**Prevents** from using the **same** PRB

❖Or use the same PRB but with

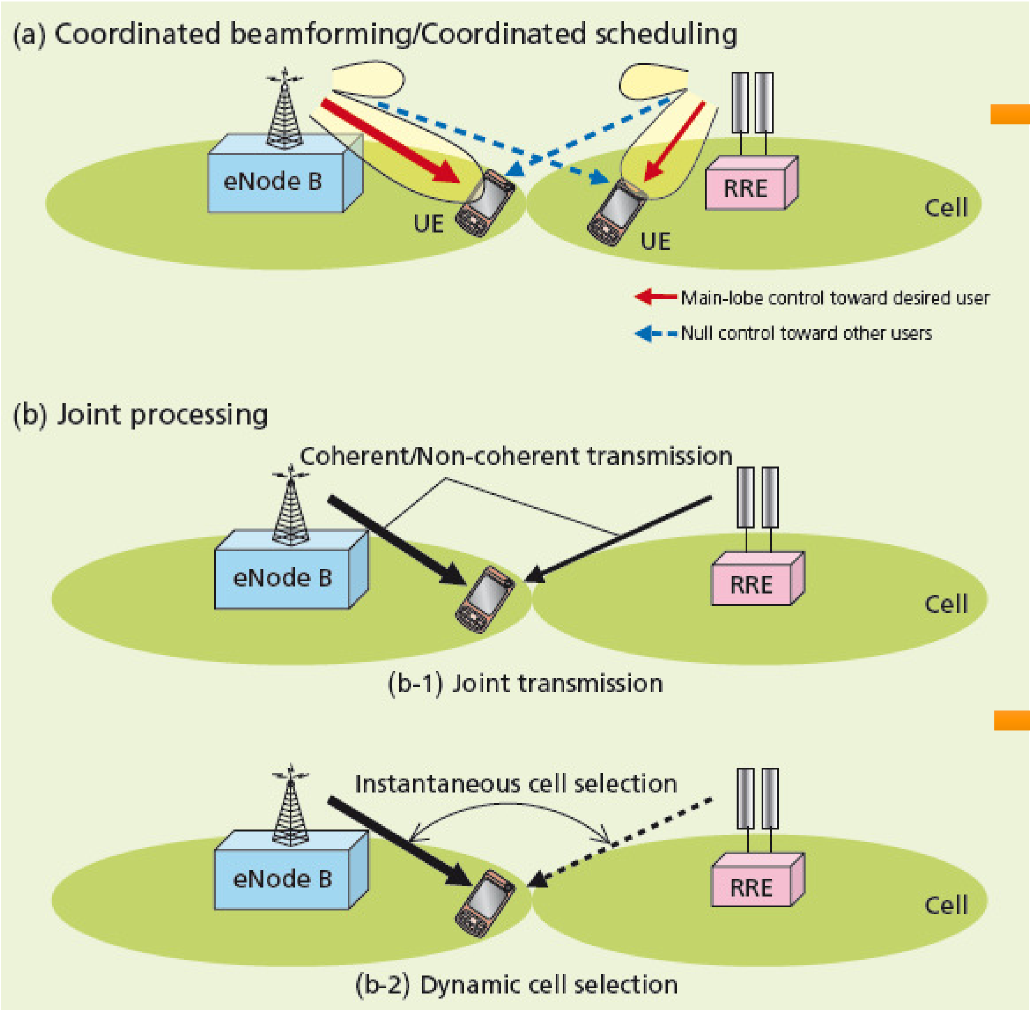
reduced interference



Introduction to ICIC



CoMP in Downlink



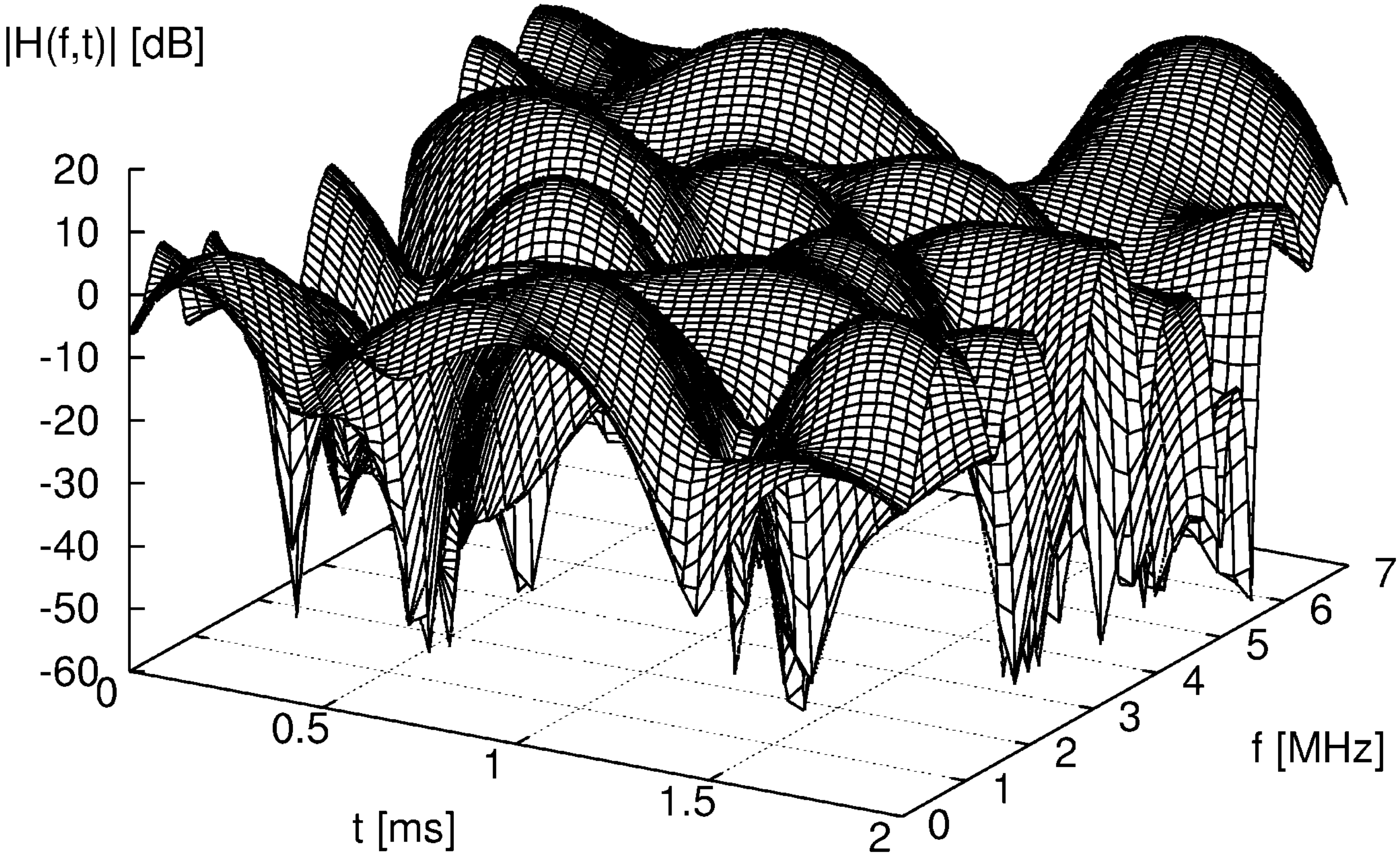
Coordinated scheduling / beamforming: the UE receives the data from a unique eNB. Coding and scheduling coordinated between several eNB to minimize the interference and increase the throughput.

Joint processing: coordination between several eNB transmitting or receiving simultaneously.

Downlink physical layer

1. Radio interface

Radio channel characteristics

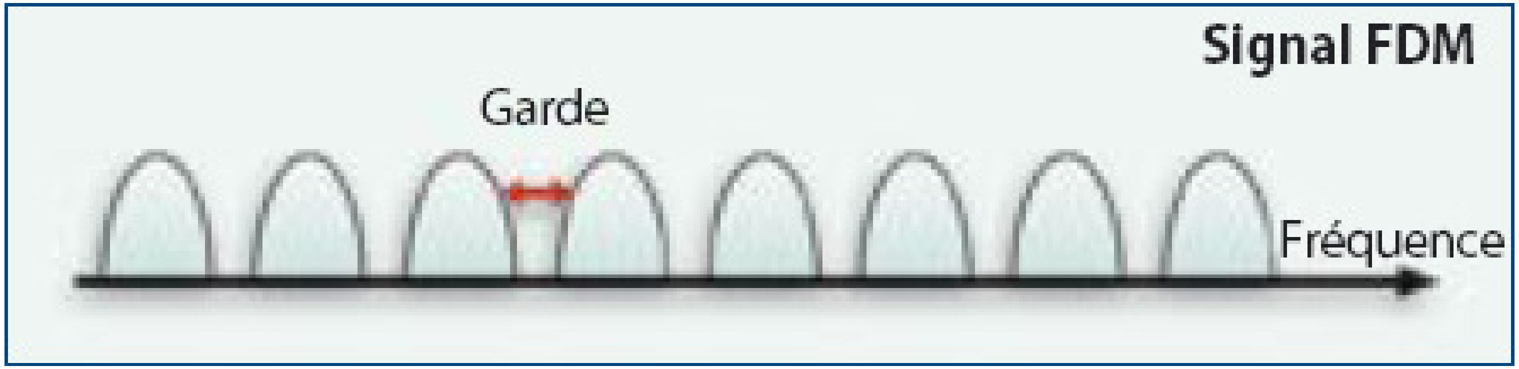


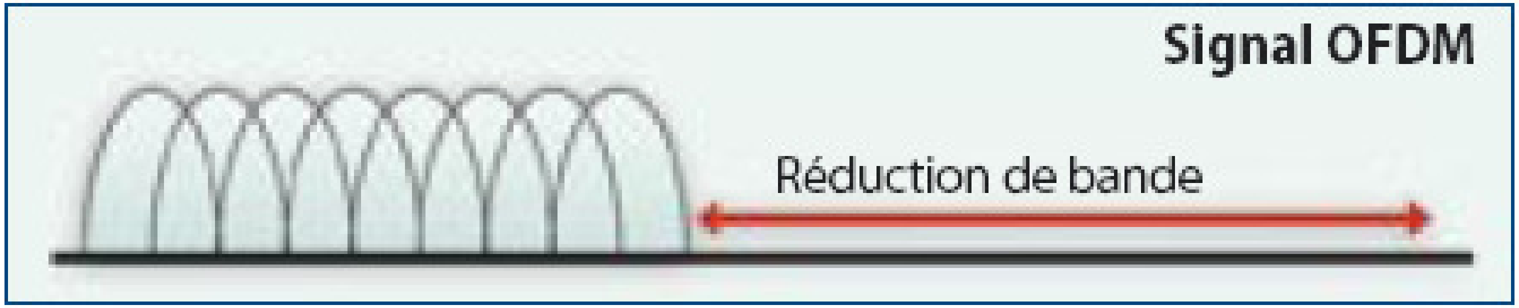
Basics

- ***Characteristics***
    - System based on FFT
    - Modulation and mapping
    - Orthogonality
    - Guard interval and cyclic extension

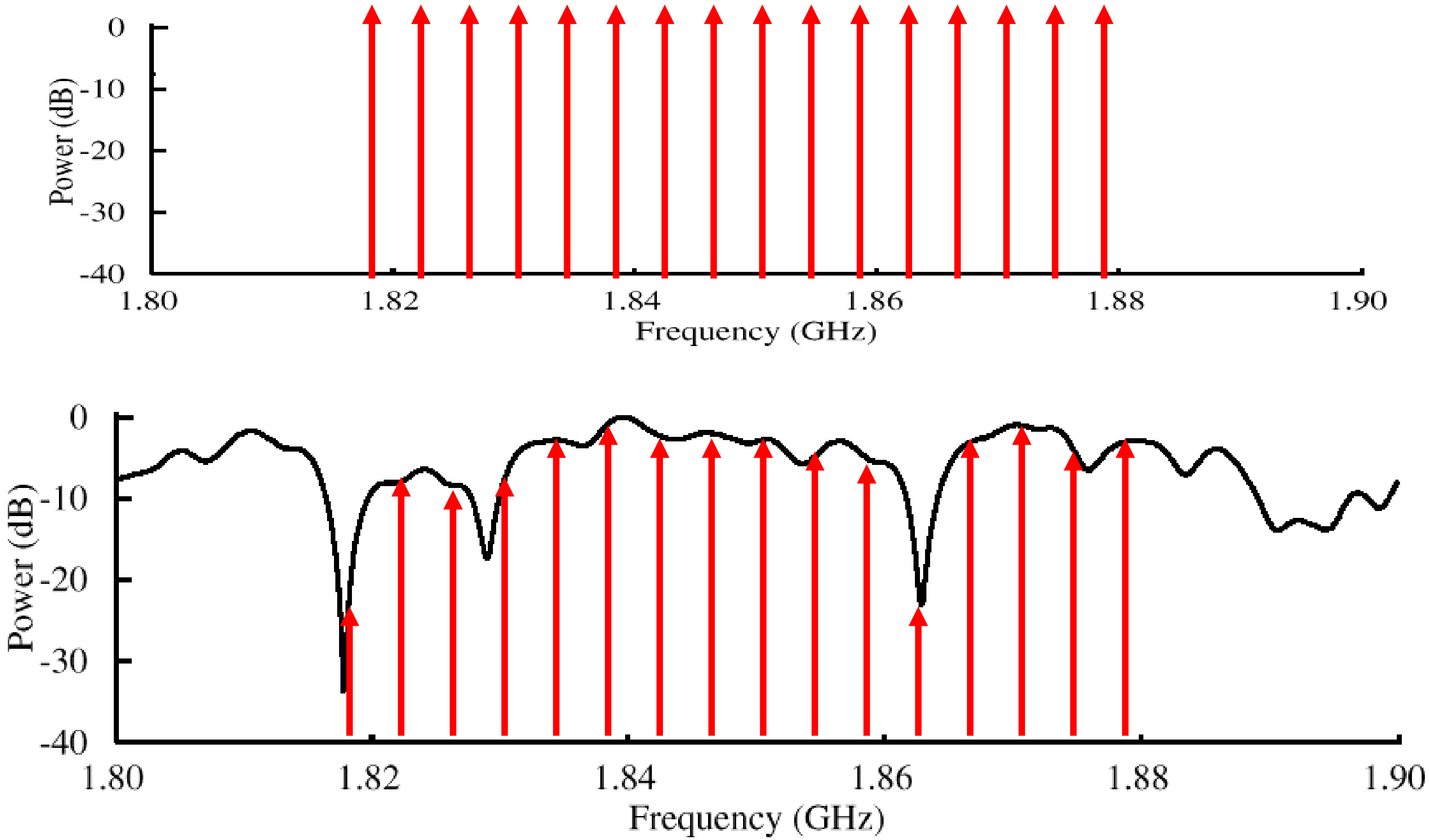
- ***Principle***
  - ***Multi-carrier modulation*** = division of the binary stream into multiple streams and transmitted over different sub-carriers.
  - Bit rate on each of the N subcarriers (R_N) < total bitrate (R).
    - With $R_N \approx R/N$.
  - Number of subcarriers such that each subcarrier has a bandwidth (BN) less than its coherence bandwidth ($B_c = B/N$).
  - Elimination of the ISI by introducing a cyclic prefix.

Basics



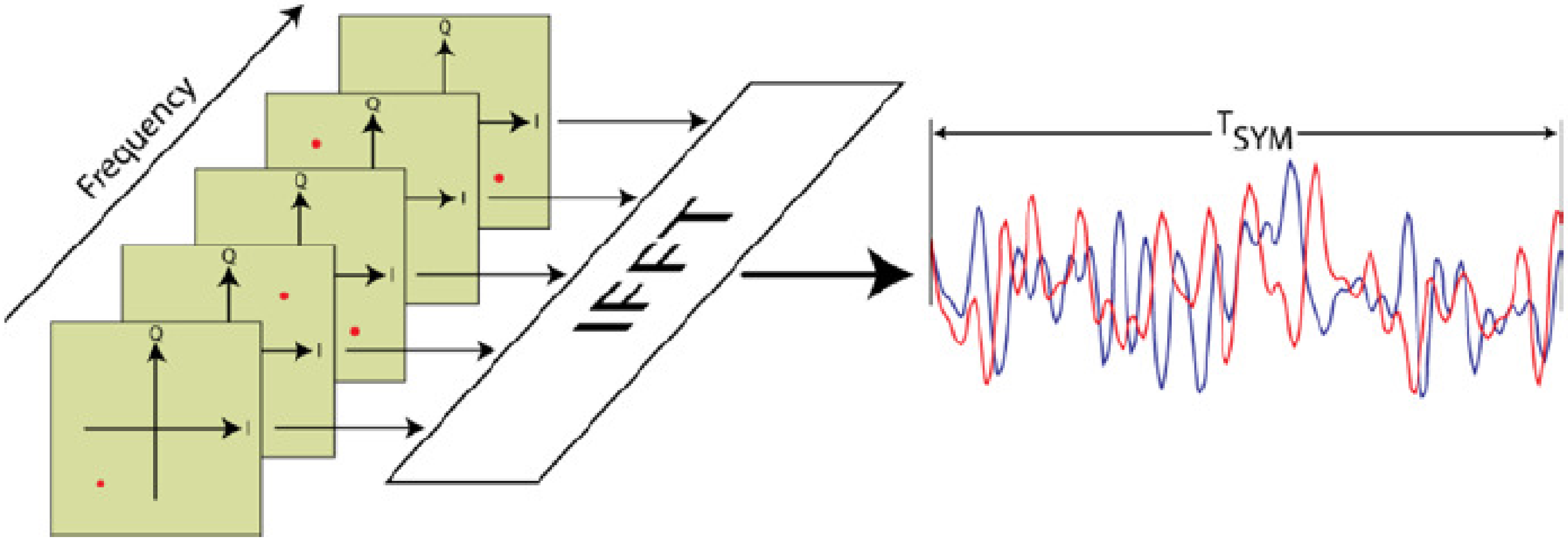


OFDM Transmission – Robustness against fast fading



Radio channel effects

The IFFT converts input signals into parallel output sine wave modulated



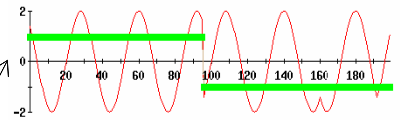
OFDM operation

Input data flow: **1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, -1, …**

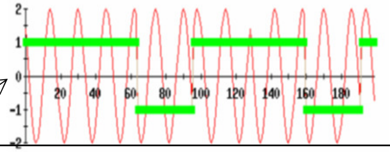
Serial to parallel

C1	1	1	1	-1
C2	1	1	-1	1
C3	-1	1	-1	-1
C4	-1	-1	-1	1

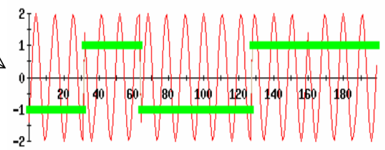
Mapping



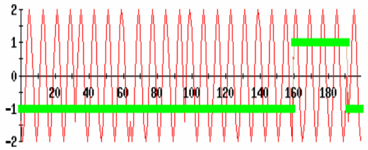
BPSK modulated signal for C1



BPSK modulated signal for C2



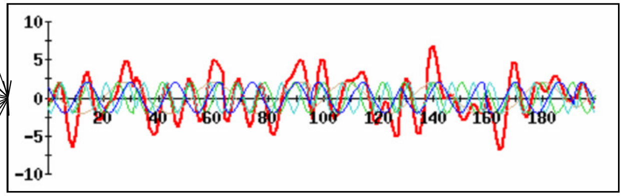
BPSK modulated signal for C3



BPSK modulated signal for C4

IFFT

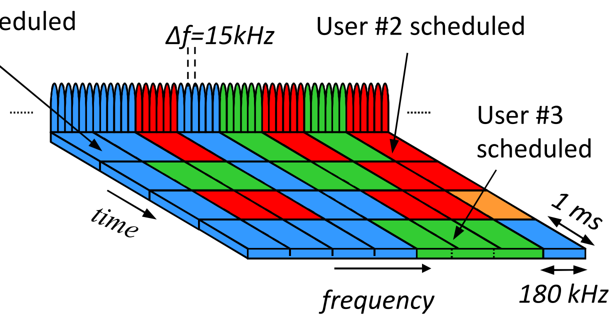
Final OFDM Signal = Sum of all signals



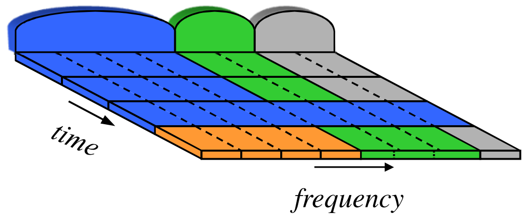
$$V(t) = \sum_{n=0}^{N-1} I_n(t)\sin(2\pi n t)$$

LTE physical layer

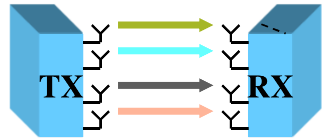
- DL: adaptive OFDM
  - Scheduling channel and link adaptation dependent in the time and frequency domain

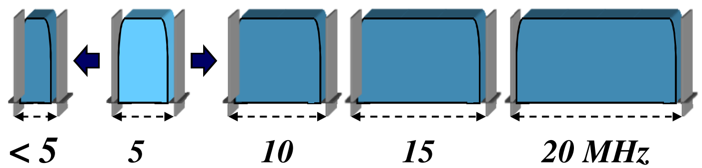


- UL: SC-FDMA with a dynamic bandwidth (pre-coded OFDM)
  - PAPR ➡ Better spectrum efficiency
  - Reduced UL interference (allows intra-cell orthogonality)

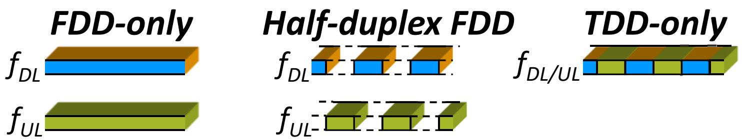


- Flexible bandwidth (with resolution of 180 kHz)
  - Possibility to deploy in bandwidth of <5 MHz to 20 MHz
- Multiple antennas, RBS and terminal
  - MIMO, antennas lobes, TX- and RX diversity, interference rejection
  - High bitrates and higher capacity

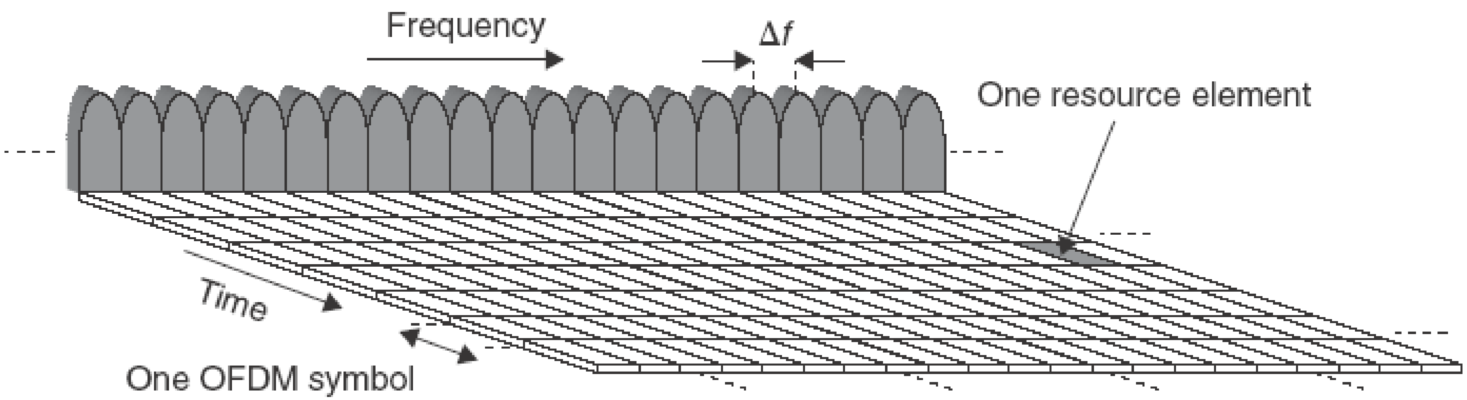




- Harmonised FDD and TDD concept
  - FDD and TDD maximum spectrum sharing
- Maximum UE capacity: BW = 20 MHz

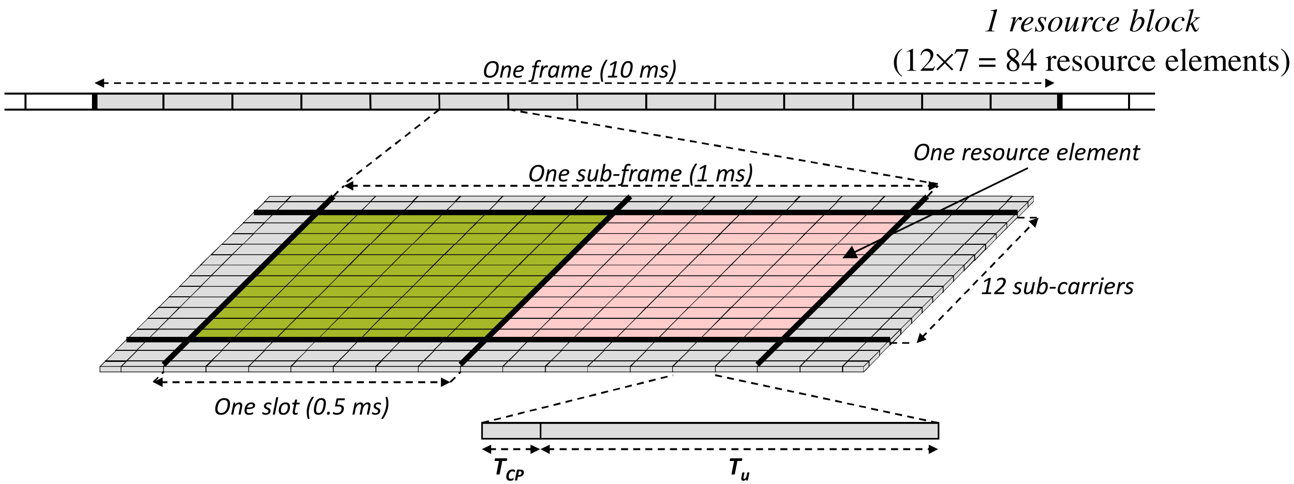


Downlink physical resources



Downlink Physical resource

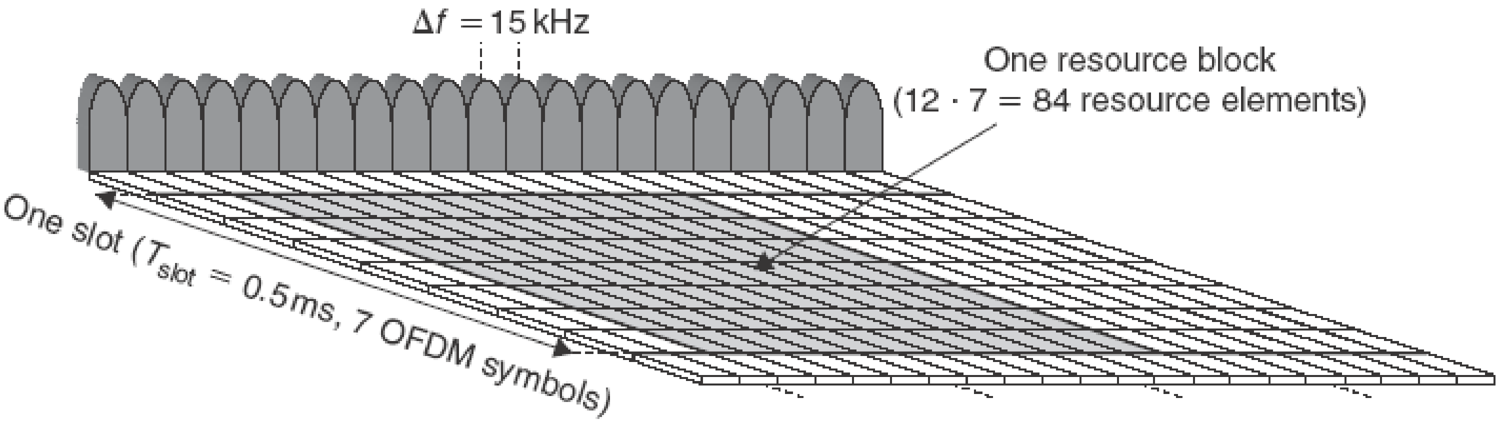
DL physical resource



- Temporal structure:
  - 10 ms **frame** = 10 **sub-frames** of 1 ms
  - 1 sub-frame = 2 **slots** of 0.5 ms
  - 1 slot = 7 **symbols OFDM** (6 symbols if extended CP)
- *Resource blocks:*
  - 12 sub-carriers during 1 slot
  - Allocation by pair of 2 consecutive *resource blocks*
- DC carrier not used

Downlink physical resources

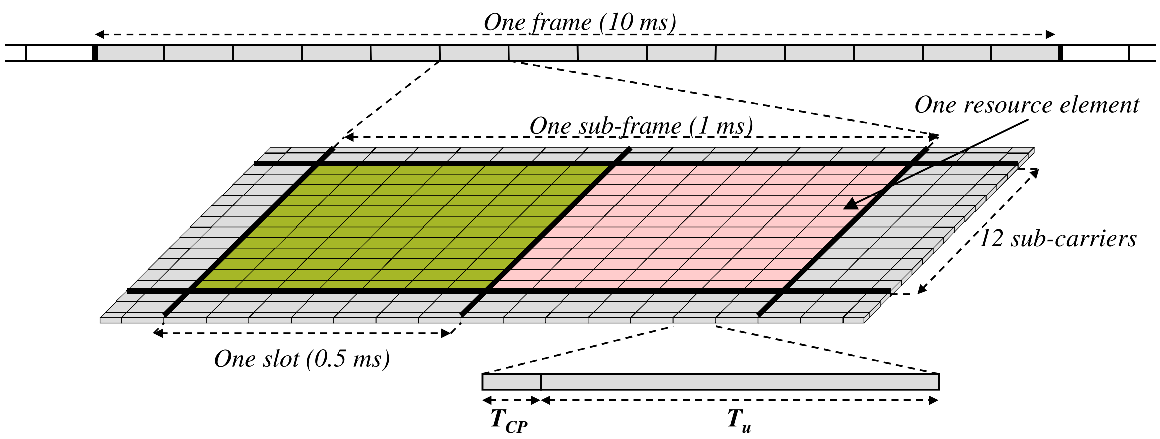
- Cyclic prefixes of different lengths can be used in different subframes
- Each Resource Block is composed of 12 subcarriers in a slot of 0.5 ms ⇨ Each Resource Block is composed of:
- 12 * 7 = 84 Resource Elements for normal cyclic prefix
- 12 * 6 = 72 Resource Elements for extended cyclic prefix



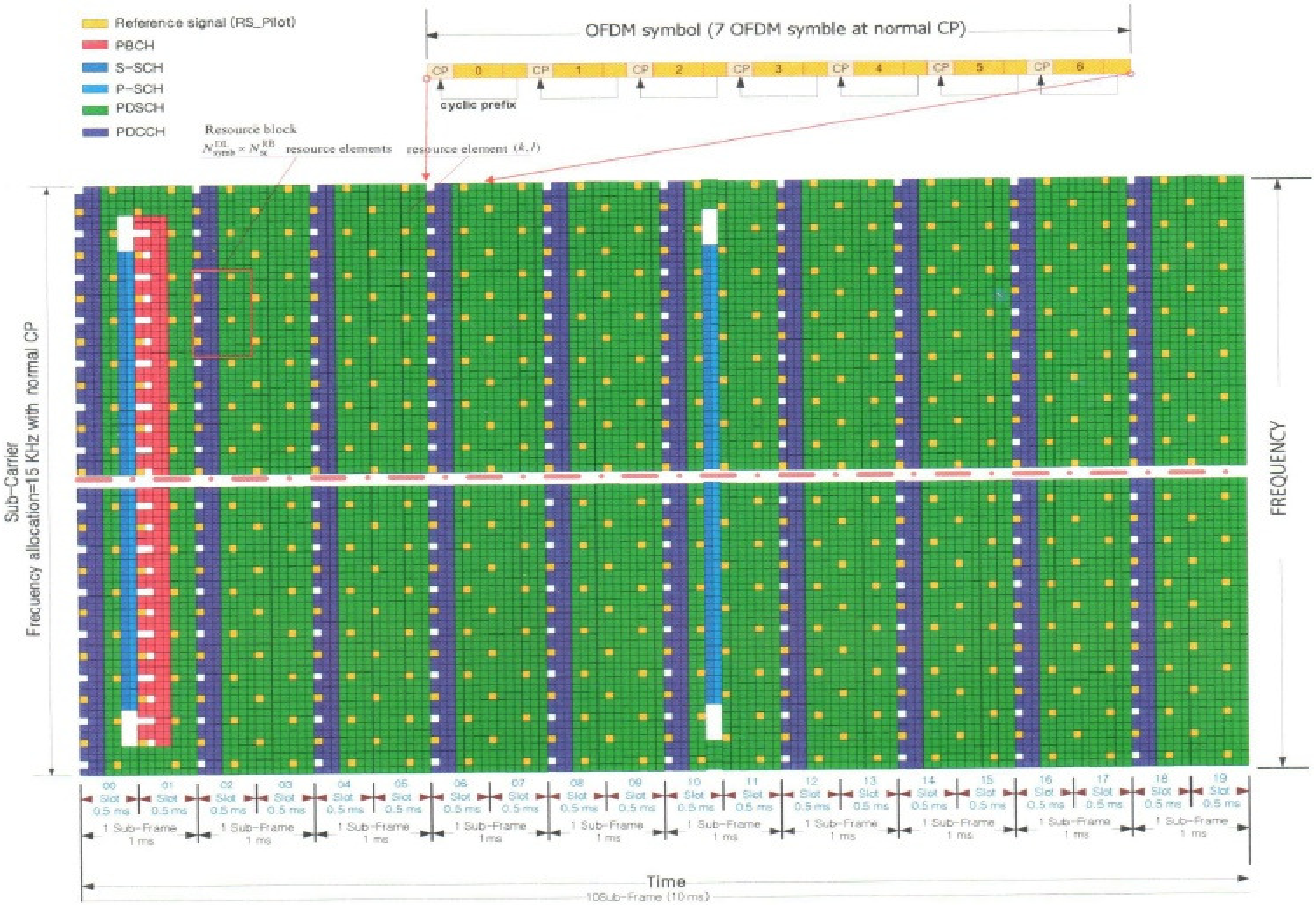
Resource Block for a Normal Cyclic Prefix

Signaling

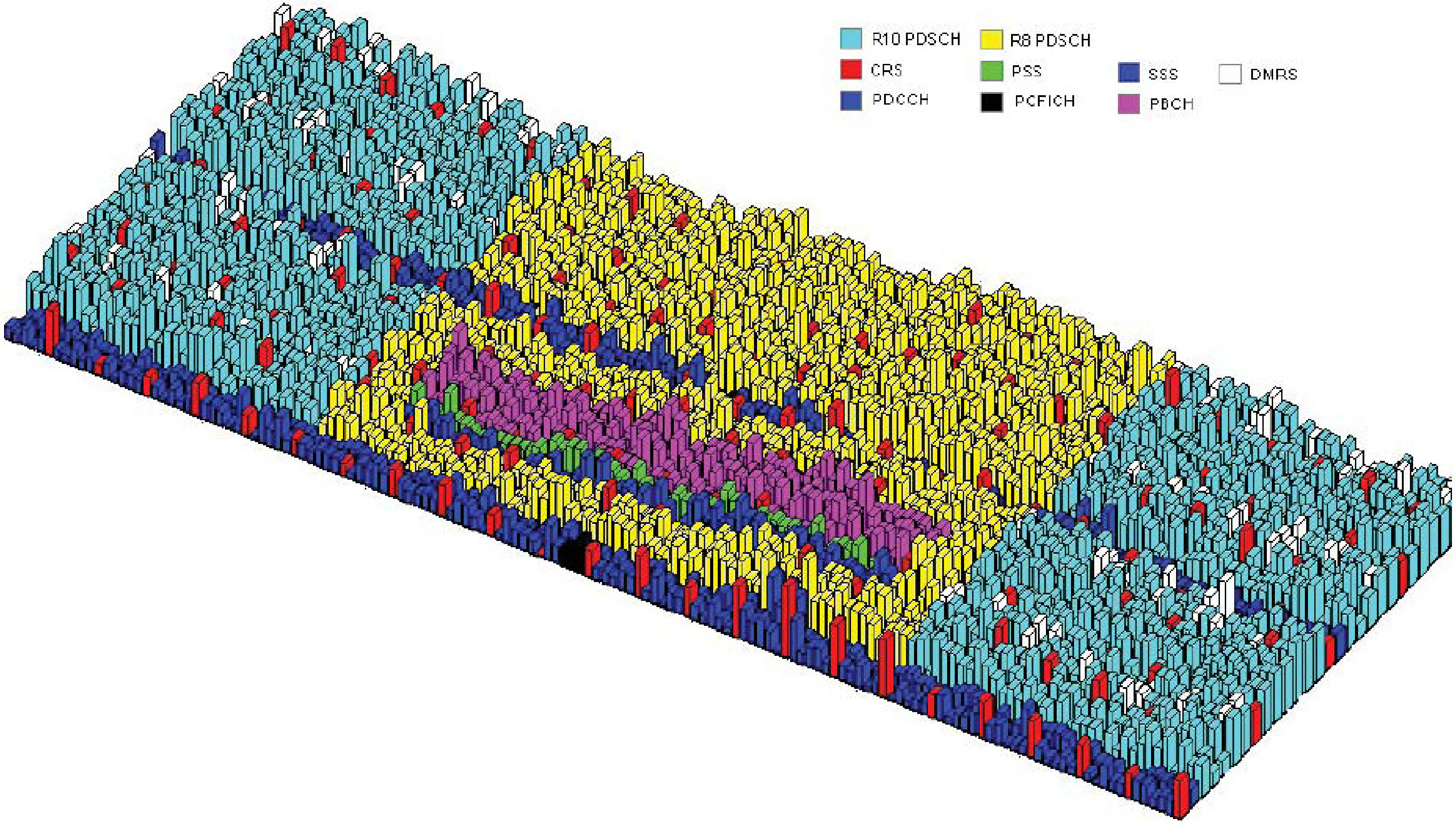
- A DL resource contains signaling bits:
  - Specific ***reference signals*** (RS) of the Cell (*channel estimation* and *CQI* measurements)
  - L1/L2 signaling (for DL HARQ and scheduling info, UL scheduling, power commands)
  - Primary and secondary synchronization signals (Cell selection)
  - Broadcast and paging channel



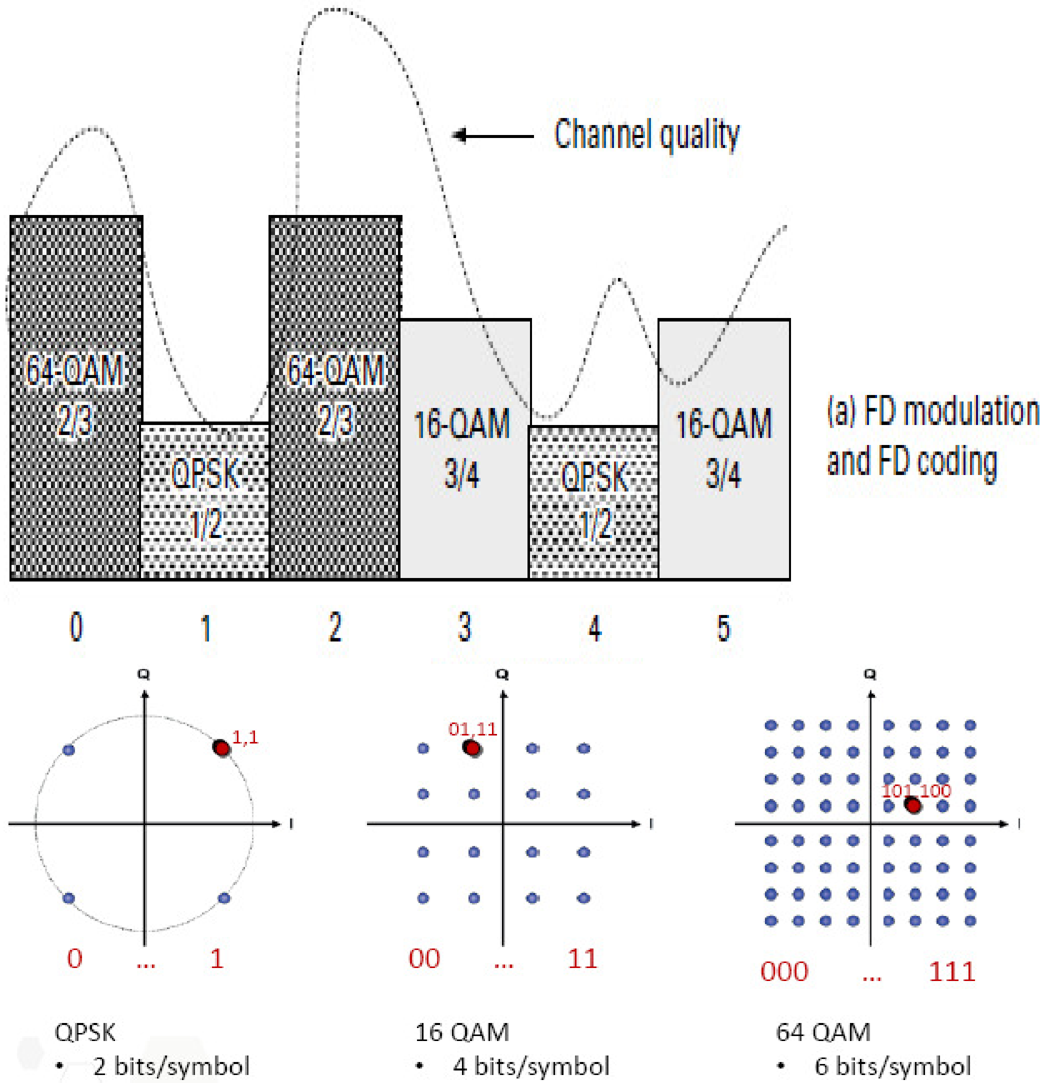
LTE downlink frame



Example of resource block allocation in LTE-Advanced



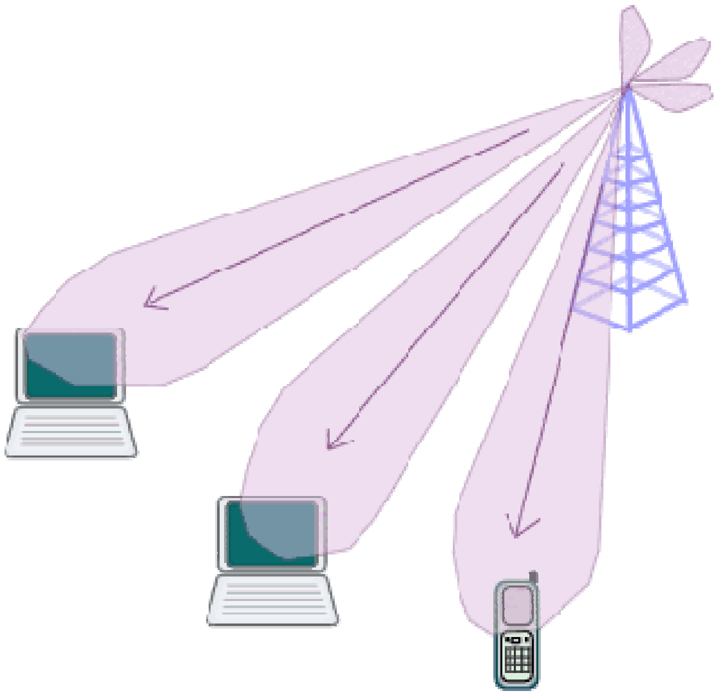
Link adaptation

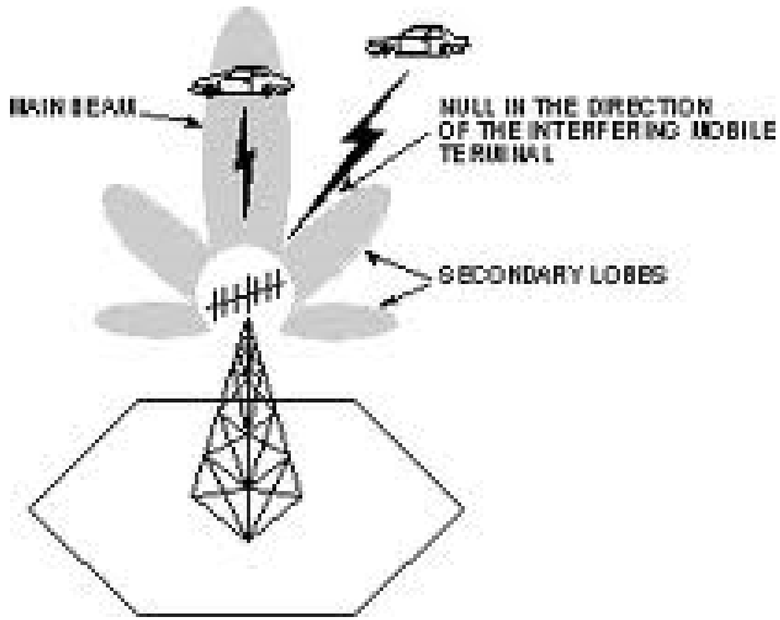


CQI index	modulation	code rate x 1024
0	out of	range
1	QPSK	78
2	QPSK	120
3	QPSK	193
4	QPSK	308
5	QPSK	449
6	QPSK	602
7	16QAM	378
8	16QAM	490
9	16QAM	616
10	64QAM	466
11	64QAM	567
12	64QAM	666
13	64QAM	772
14	64QAM	873
15	64QAM	948

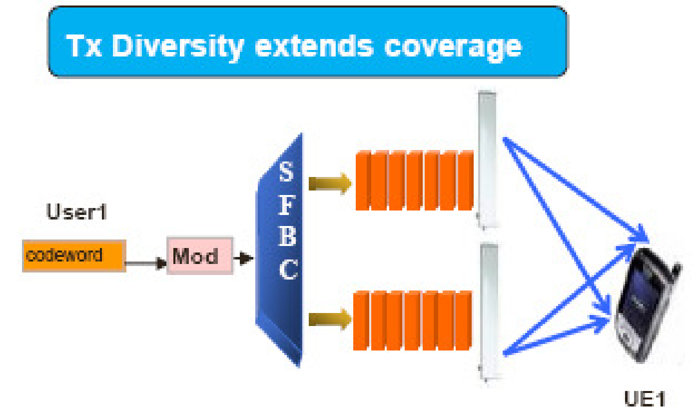
Multiple Antennas in Reception

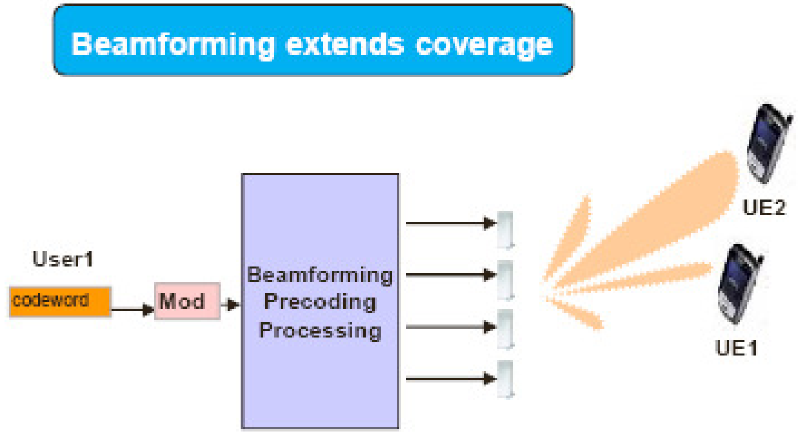
- Removing intra-cell interference (SDMA: *Space Division Multiple Access*) ⇨ Multiple terminals transmit simultaneously using the same frequency resource

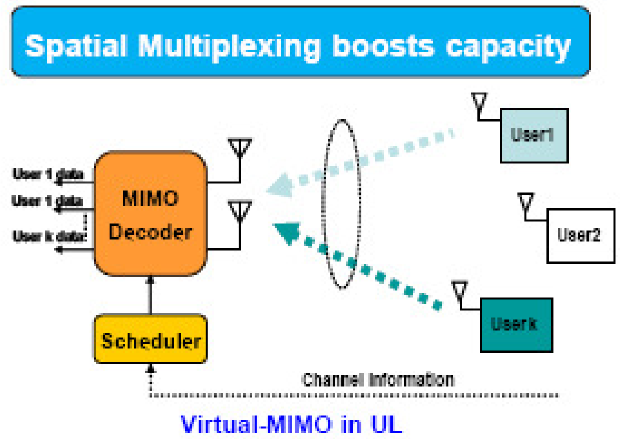


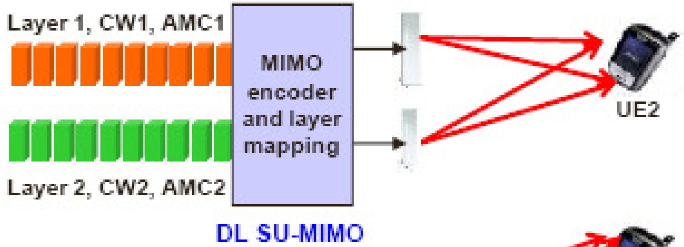


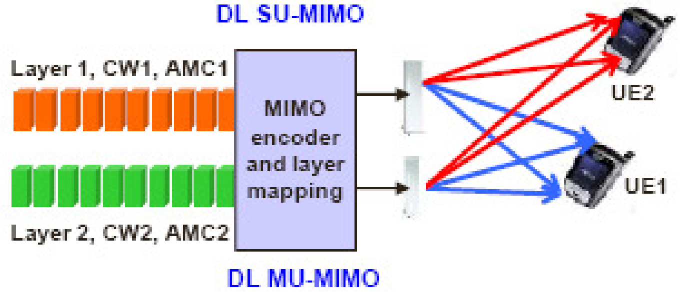
MIMO and Beamforming



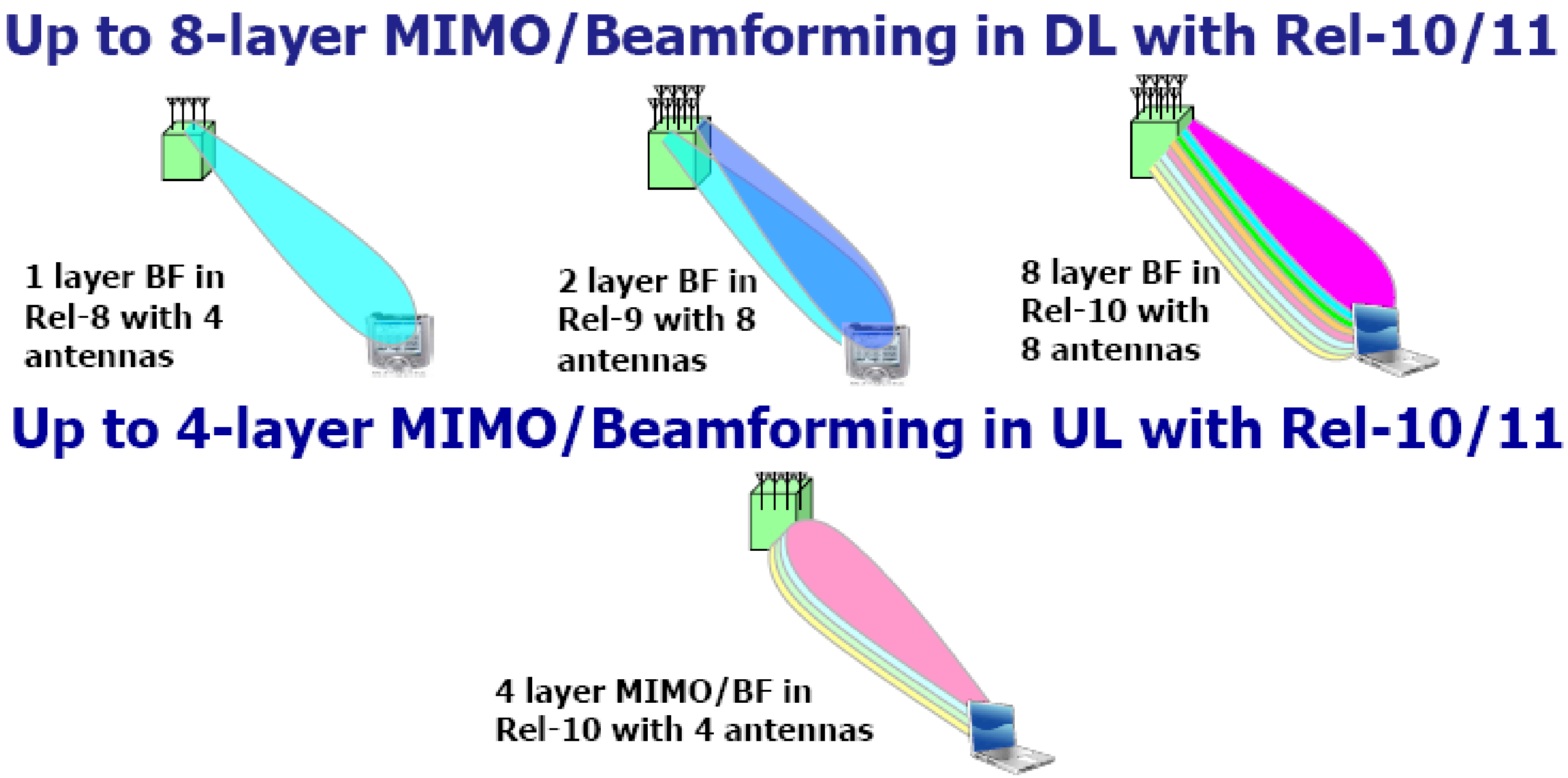








MIMO and Beamforming in Rel-10-11

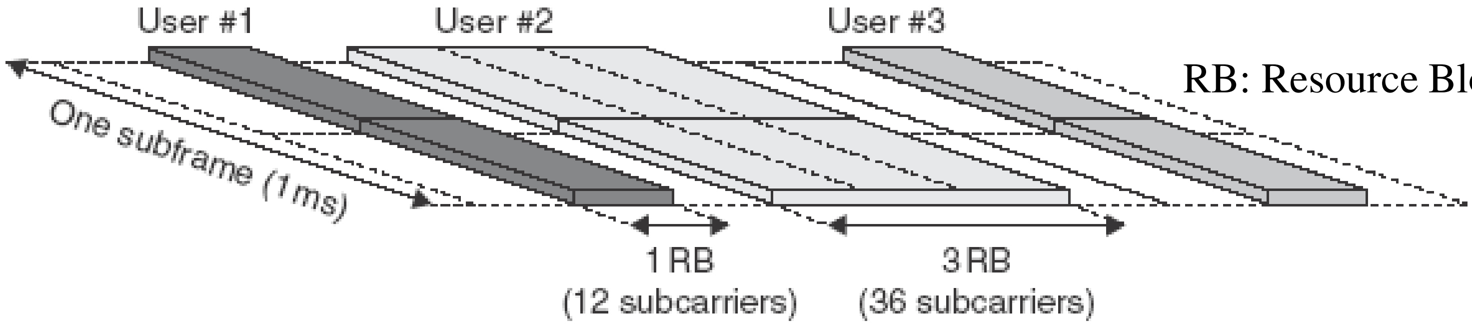


Uplink physical layer

Uplink physical resources

Uplink physical resources

- Unlike the uplink, the resource blocks assigned to the terminal in the uplink must be consecutive in the frequency domain
- Same as in the downlink, a resource block in the uplink is composed of 12 DFTS-OFDM subcarriers in a slot of 0.5 ms

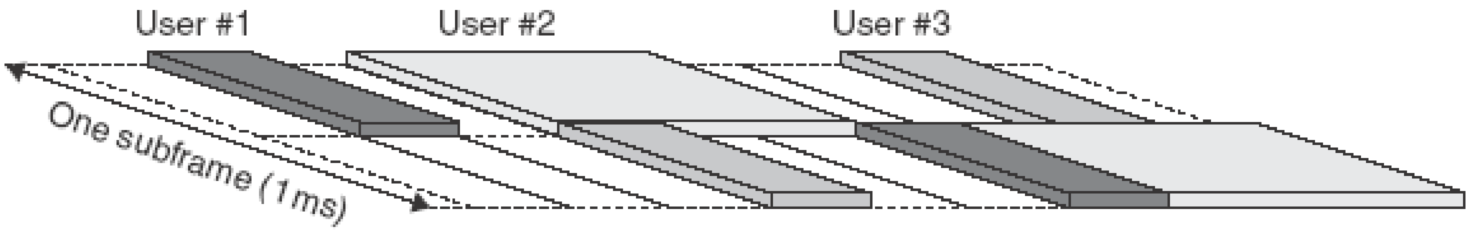


RB: Resource Block

Resource allocation in the uplink

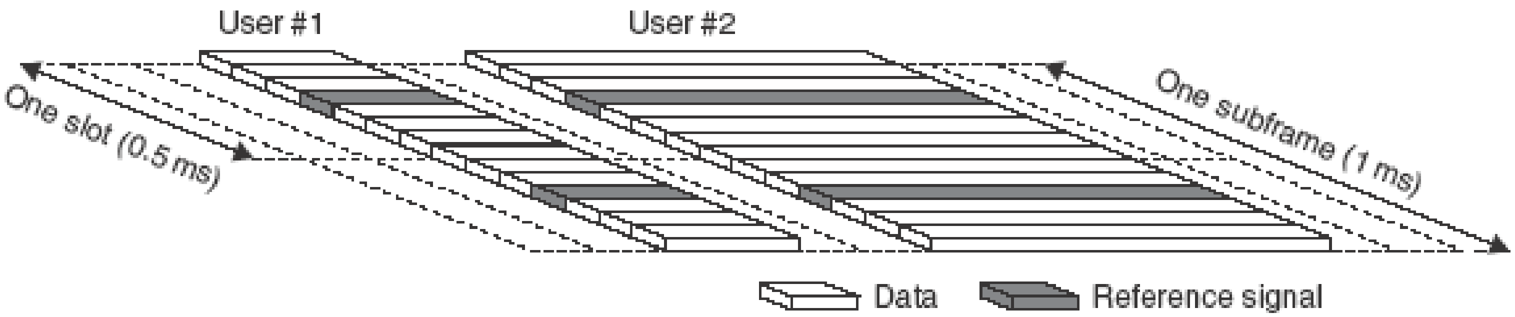
Uplink physical resources

- Inter-slot frequency hopping can be used in the uplink ⇨Physical resources used on the 2 slots do not occupy the same subcarriers
- RF transmission band completely covers the spectrum in the uplink ⇨ The frequency hopping changes the DFT-IFFT mapping
- Frequency hopping two benefits: Diversity and frequency diversity interference



Frequency hopping in the uplink

Uplink reference signal

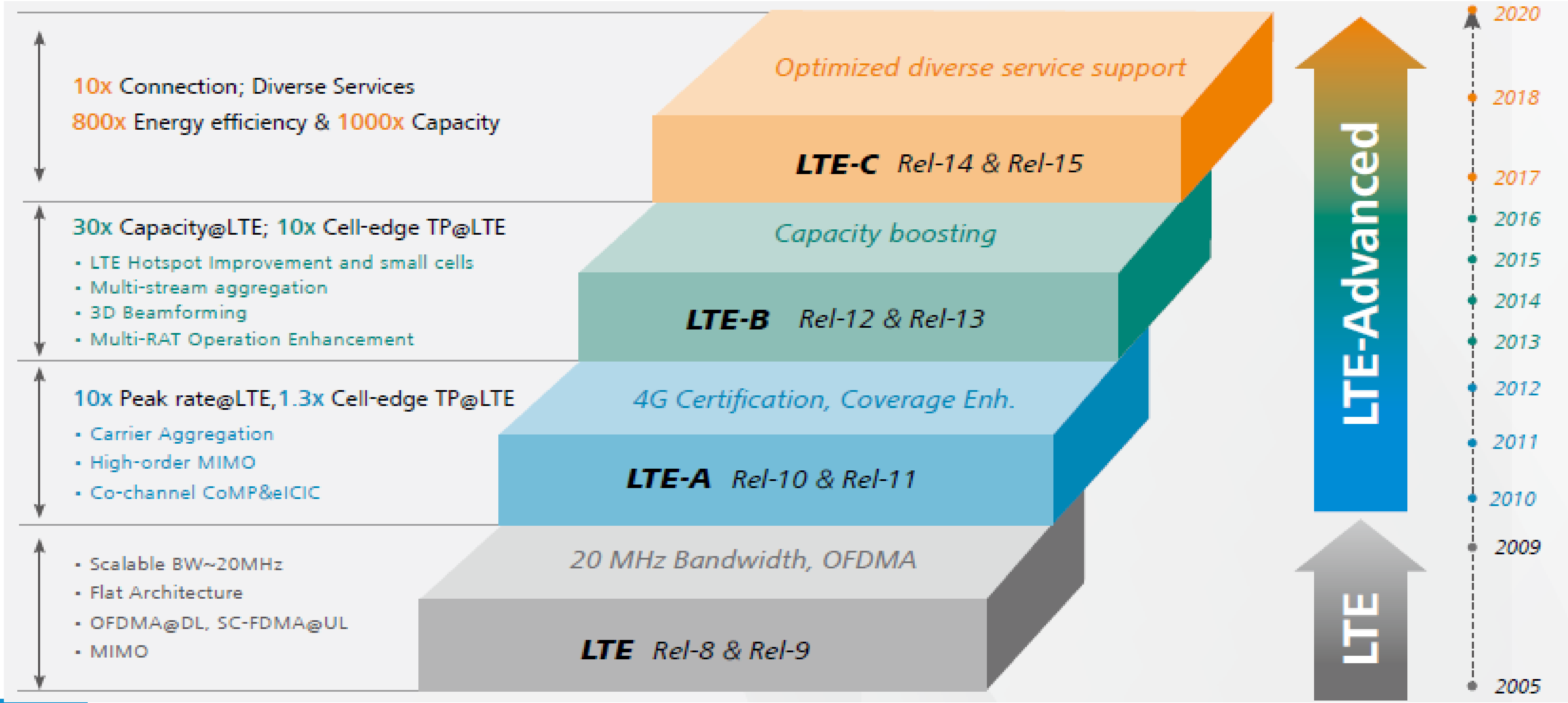


Uplink reference signal Inserted in the 4th block of each slot
(NormaCyclic Prefix l)

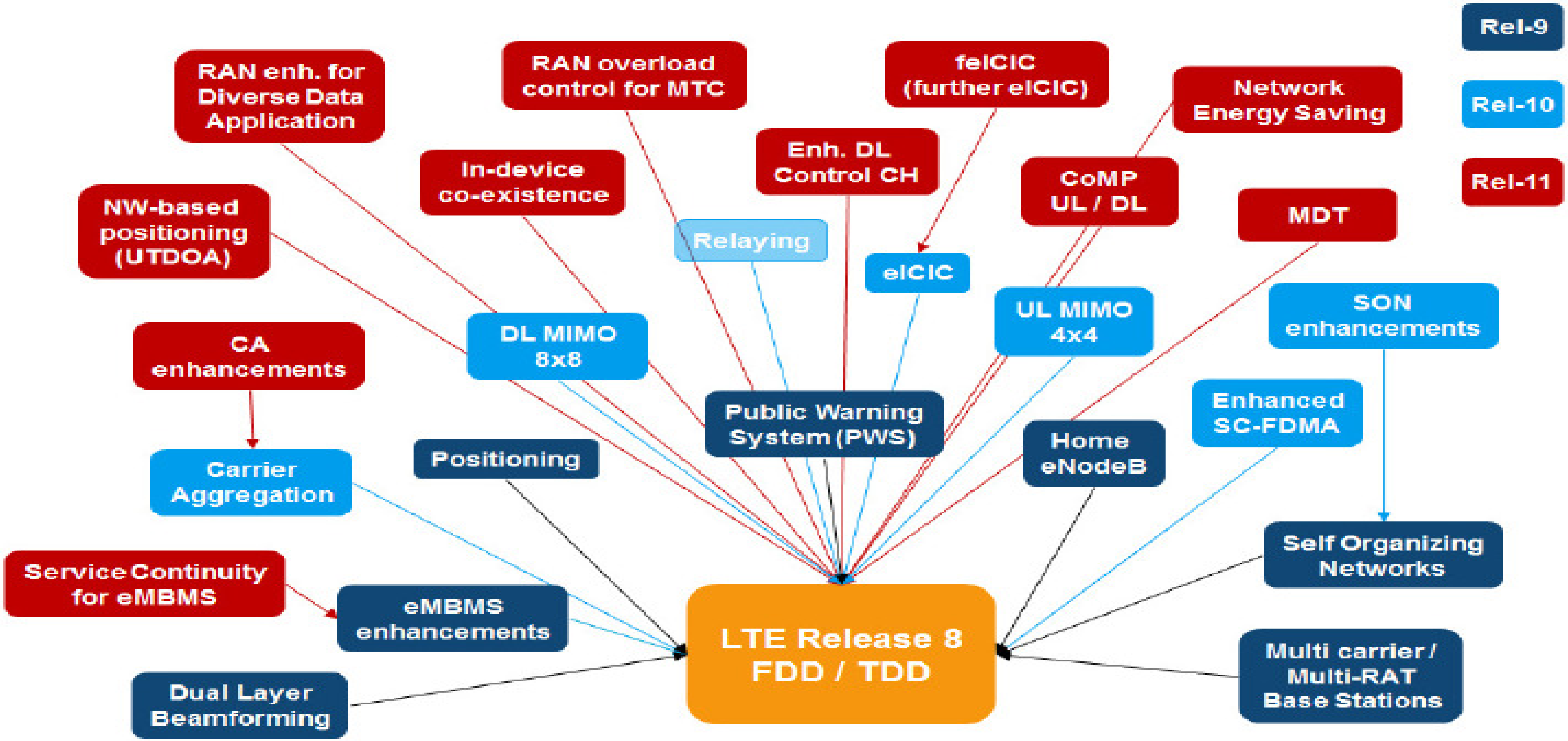
- Frequency hopping can be applied ⇨ Transmission of two slots on frequencies remote ⇨ interpolation between two reference symbols blocks.

II. Releases 10 to 13 main features

LTE Evolutions



LTE releases evolutions



LTE to LTE-M

3GPP Releases	8 (Cat.4)	8 (Cat. 1)	12 (Cat.0) LTE-M	13 (Cat. 1,4 MHz) LTE-M
Downlink peak rate (Mbps)	150	10	**1**	**1**
Uplink peak rate (Mbps)	50	5	**1**	**1**
Number of antennas (MIMO)	2	2	**1**	**1**
Duplex Mode	Full	Full	**Half**	**Half**
UE receive bandwidth (MHz)	**20**	**20**	**20**	**1.4**
UE Transmit power (dBm)	**23**	**23**	**23**	**20**

Release 12

- New category of UE ("Cat-0"): **lower complexity** and low cost devices
- **Half duplex FDD** operation allowed
- **Single receiver**
- Lower data rate requirement (Max: 1 Mbps)

Release 13

- Reduced receive bandwidth to 1.4 MHz
- **Lower device power** class of 20 dBm
- 15dB additional link budget: **better coverage**
- More **energy efficient** because of its extended discontinuous repetition cycle (eDRX)

Release 12 new network features

eMTC

Objectives

- Long battery life: ~***10 years*** of operation with 5 Watt Hour battery
- Low device cost: comparable to that of GPRS/GSM devices
- Extended coverage: ***>155.7 dB*** maximum coupling loss (MCL)
- Variable rates: ~***10 kbps to 1 Mbps*** depending on coverage needs

Deployment

- Can be deployed in any ***LTE spectrum***
- Coexist with other LTE services within ***the same bandwidth***
- Support ***FDD, TDD*** and ***half duplex (HD) modes***
- Reuse ***existing LTE base stations*** with ***software update***

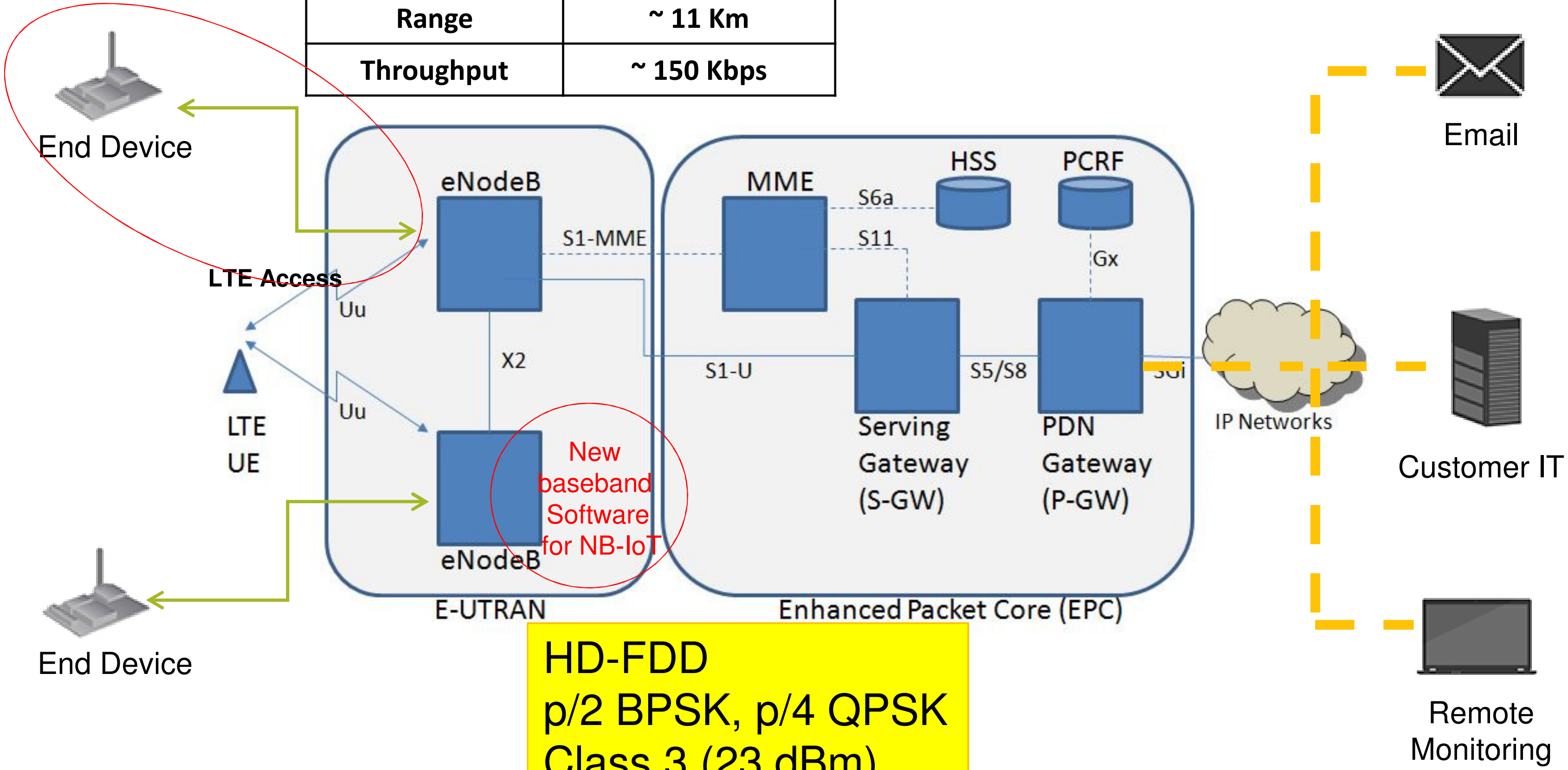
Main PHY/RF features

- Narrowband operation with ***1.08 MHz bandwidth***
- ***Frequency hopping***
- ***TTI bundling/repetition*** to achieve large coverage enhancements
- ***New UE power class of 20 dBm.***

Release 13 new radio features

NB-IoT Architecture

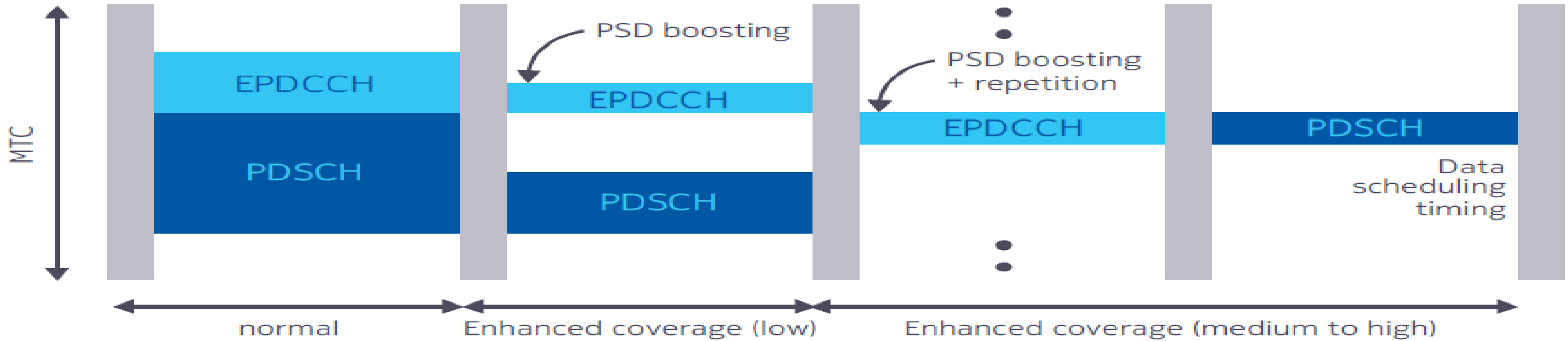
Frequency Band	Ultra Narrow Band
Range	~ 11 Km
Throughput	~ 150 Kbps



HD-FDD
p/2 BPSK, p/4 QPSK
Class 3 (23 dBm)
Class 5 (20 dBm)

Full coverage for IoT

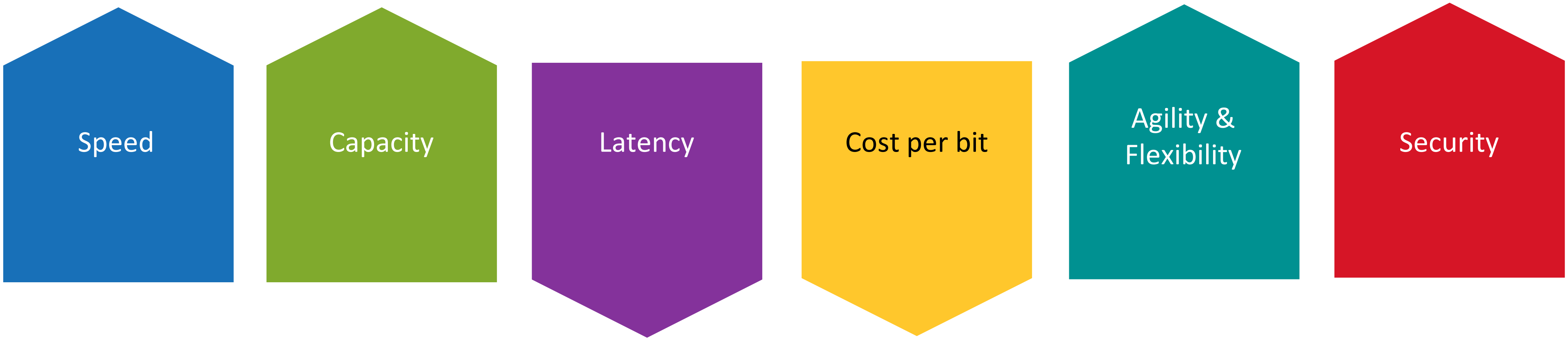
- In LTE-M 1.4 MHz and NB LTE-M 200 kHz: basic LTE design is used with modifications for support of coverage enhancements: **Elimination of LTE DL control channels** including PDCCH, PCFICH and PHICH. Only the EPDCCH is supported.
- In enhanced coverage mode, **PSD** (*Power Spectral Density*) **boosting** and **repetition** are used to reach devices in poor coverage.
- Coverage increased by operating in 200 kHz or 1.4 MHz (/20 MHz): 20 dB and 11.5 dB improvement.
- LTE-M allows output power reduction by 3 dB for lower implementation cost.
- Control and data signals can be repeated to reach the required coverage enhancements



III. 5G

5G Objectives

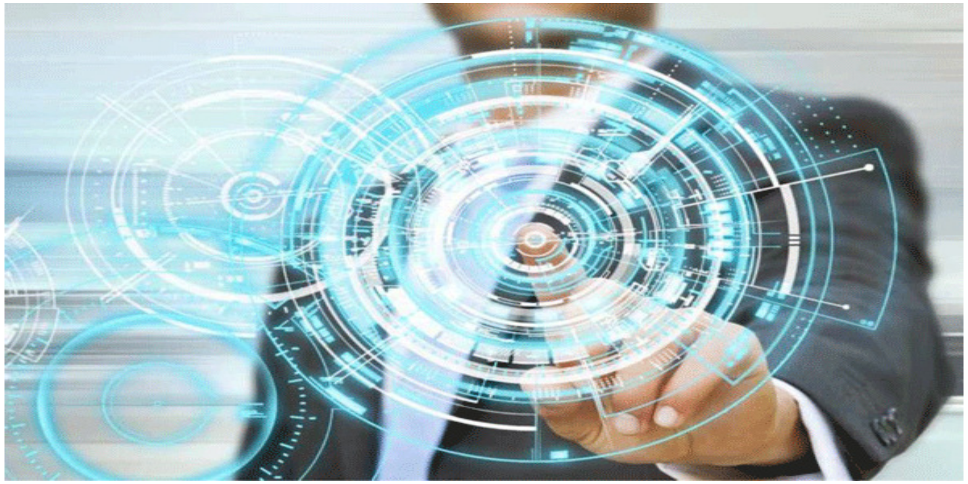
Context: the evolving demands on the network



"Maybe along with the three legs that 5G stands on (**massive Machine Type Communication** (MTC), **enhanced Mobile Broadband** (eMBB), and **Ultra Reliable Communication** (URC)) we need to add a fourth leg of **ultra low cost broadband** (ULCBB)."

Alan Gatherer, Editor in Chief, ComSoc Technology News

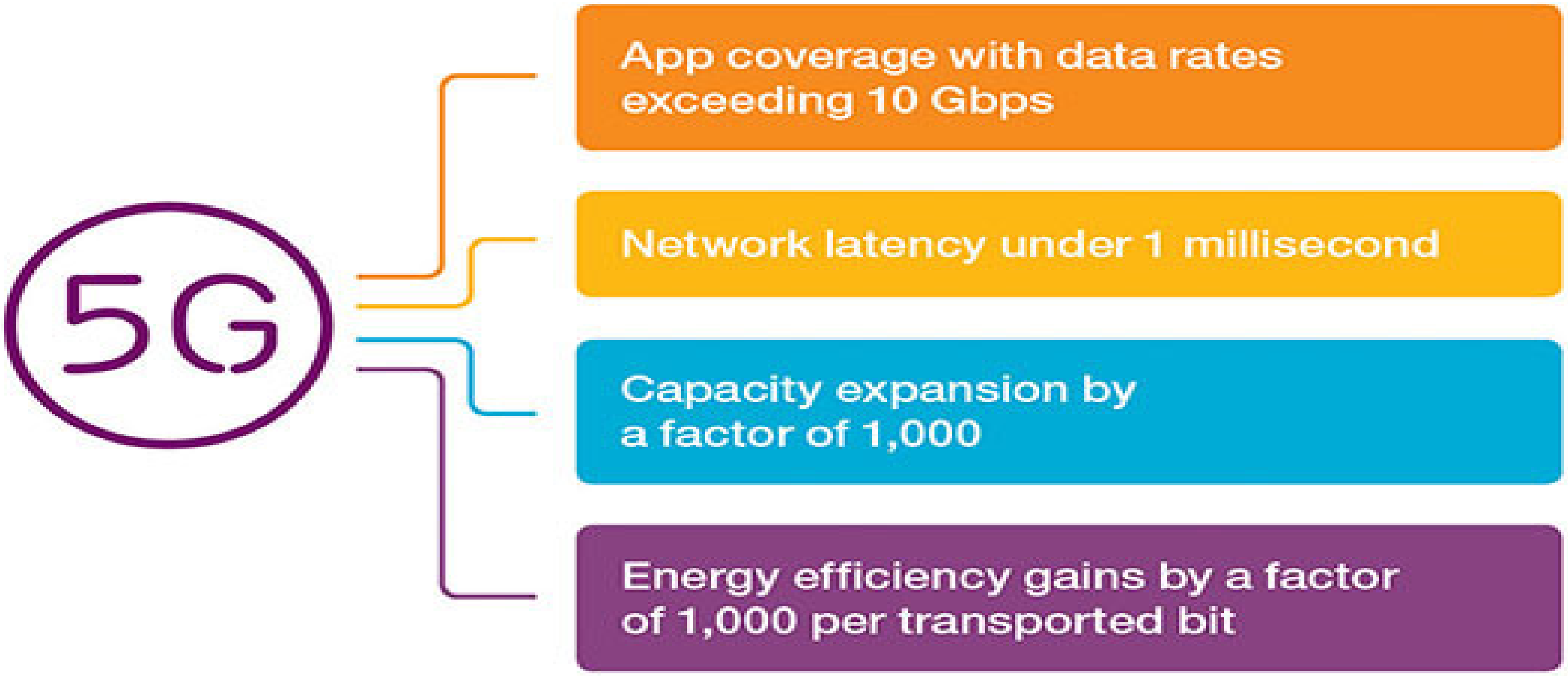
1 ms latency and tactile internet



- IEEE defines the **tactile internet** as dealing with processes or objects in perceived real time.
- Allows ***catch a falling object remotely***, ***control a connected car*** at an intersection.

- Automation, education, entertainment, gaming, farming, health care, industrial transportation, …
- Enables humans to control robots remotely in real time.

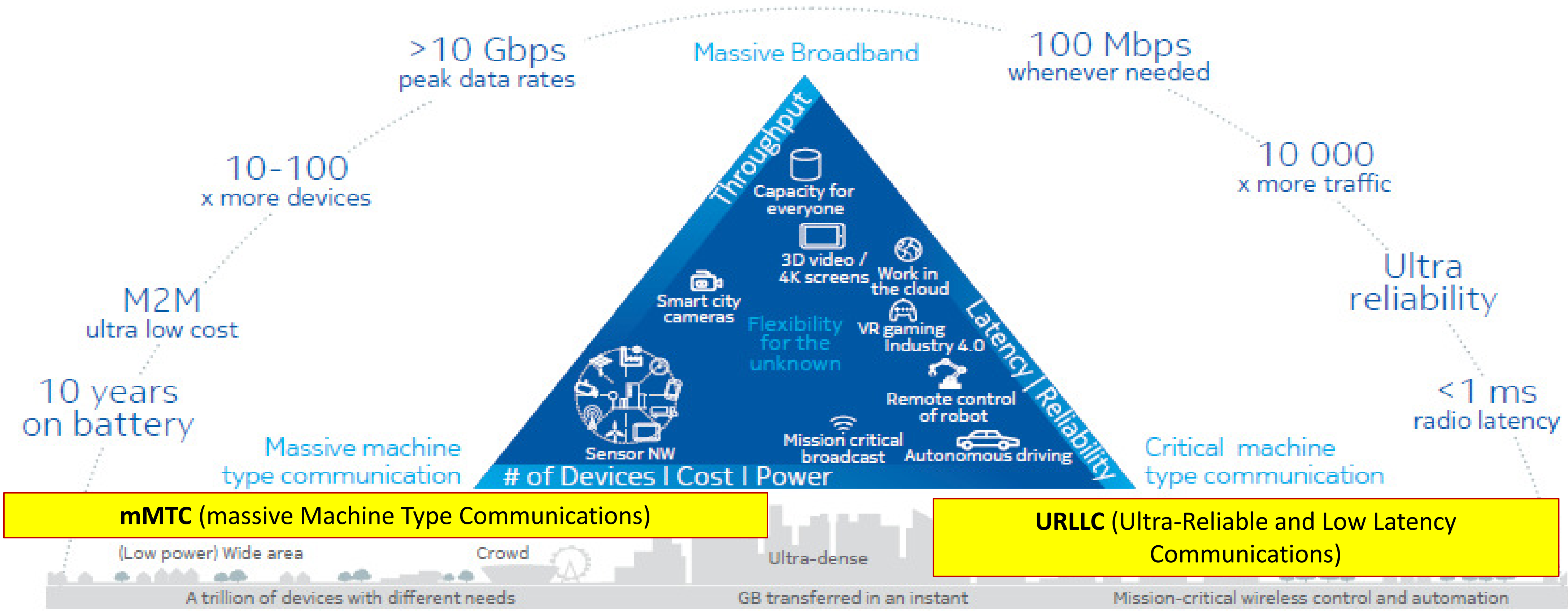
5G Main Objectives



Optimize the $\text{bit/s/Hz/m}^{2}\text{/Joule/\$}$

5G three pillars

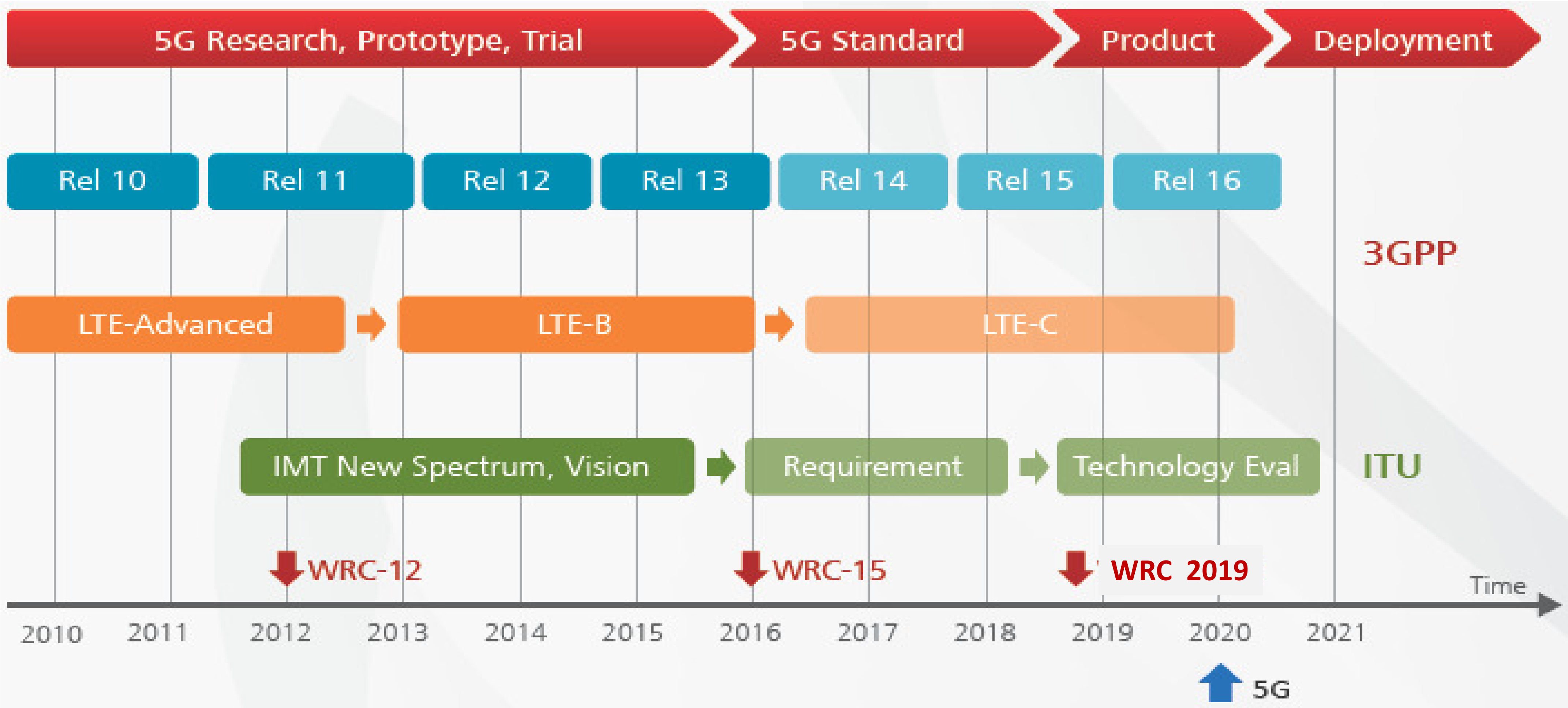
eMBB (enhanced Mobile BroadBand)



mMTC (massive Machine Type Communications)

URLLC (Ultra-Reliable and Low Latency Communications)

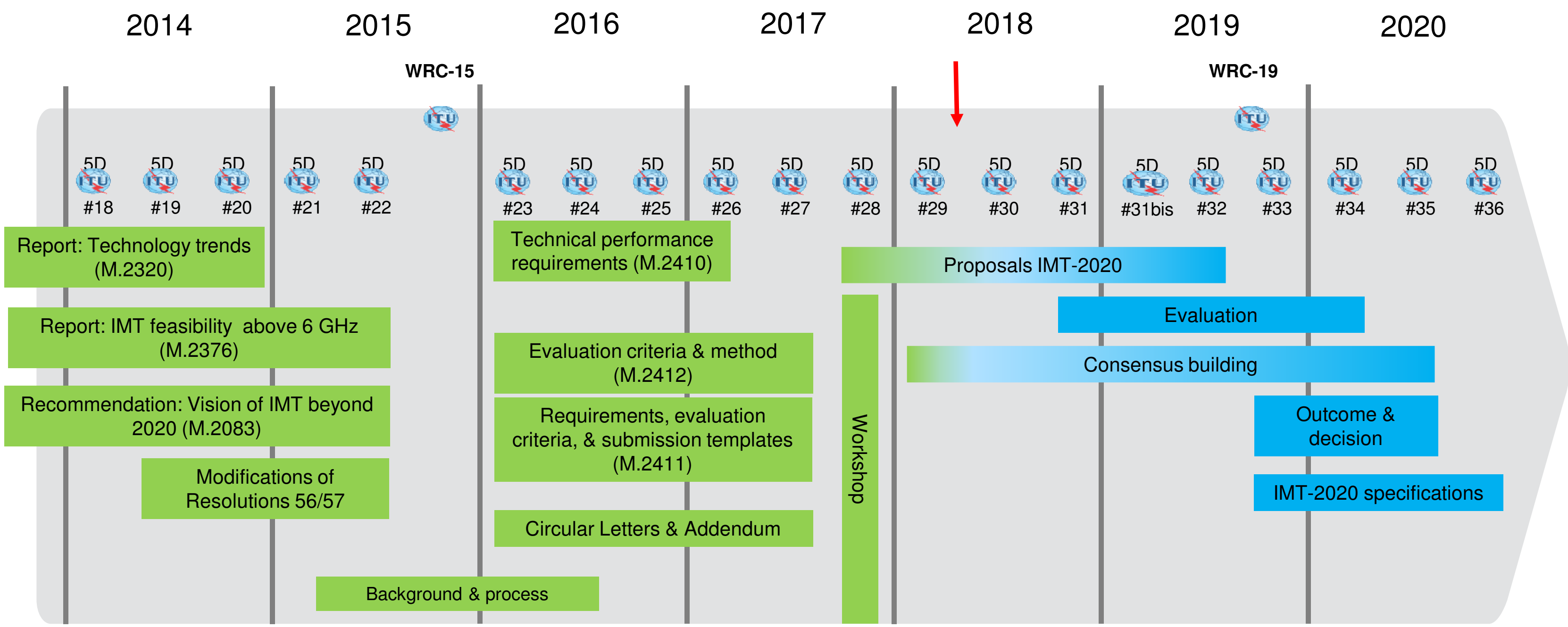
5G Roadmap



5G Research, Prototype, Trial
5G Standard
Product
Deployment
Rel 10
Rel 11
Rel 12
Rel 13
Rel 14
Rel 15
Rel 16
3GPP
LTE-Advanced
LTE-B
LTE-C
IMT New Spectrum, Vision
Requirement
Technology Eval
ITU
WRC-12
WRC-15
WRC 2019
Time
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
5G

ITU-R WP5D

ITU-R WP 5D timeline for IMT-2020
Detailed specifications for the terrestrial radio interfaces



- Initial technology submission: Meeting 32 (**June 2019**)
- Detailed specification submission: Meeting 36 (**October 2020**)

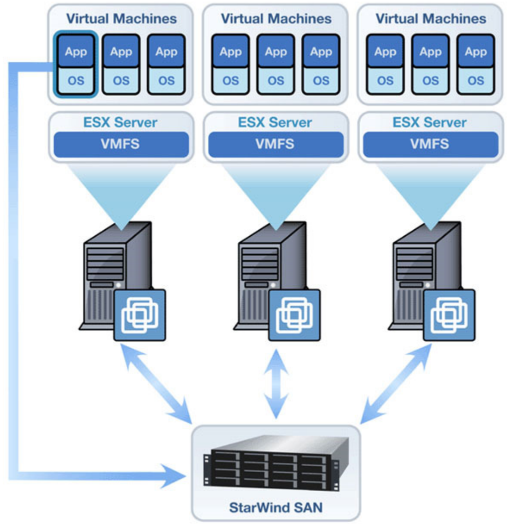
Operators' challenges:

- Reduce CAPEX and OPEX,
- Quickly introduce new standards in the networks,
- Allow flexible operation to cope with users' needs and handsets constraints,

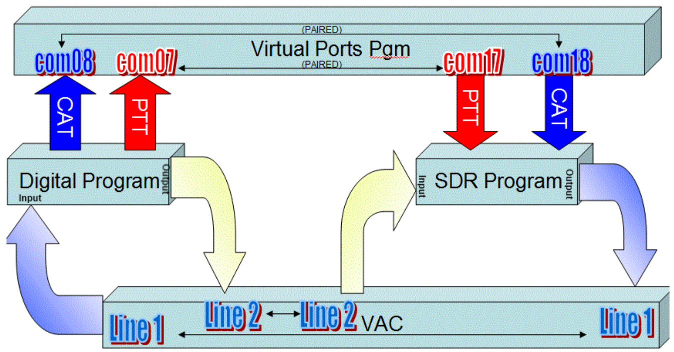
↳ Require **flexible**/**scalable**/**dynamic**/… systems and networks

Last decade main evolutions in ICT and Radio technologies

- Virtualization,
- Clouding,
- Software radios,
- Big data,
- …

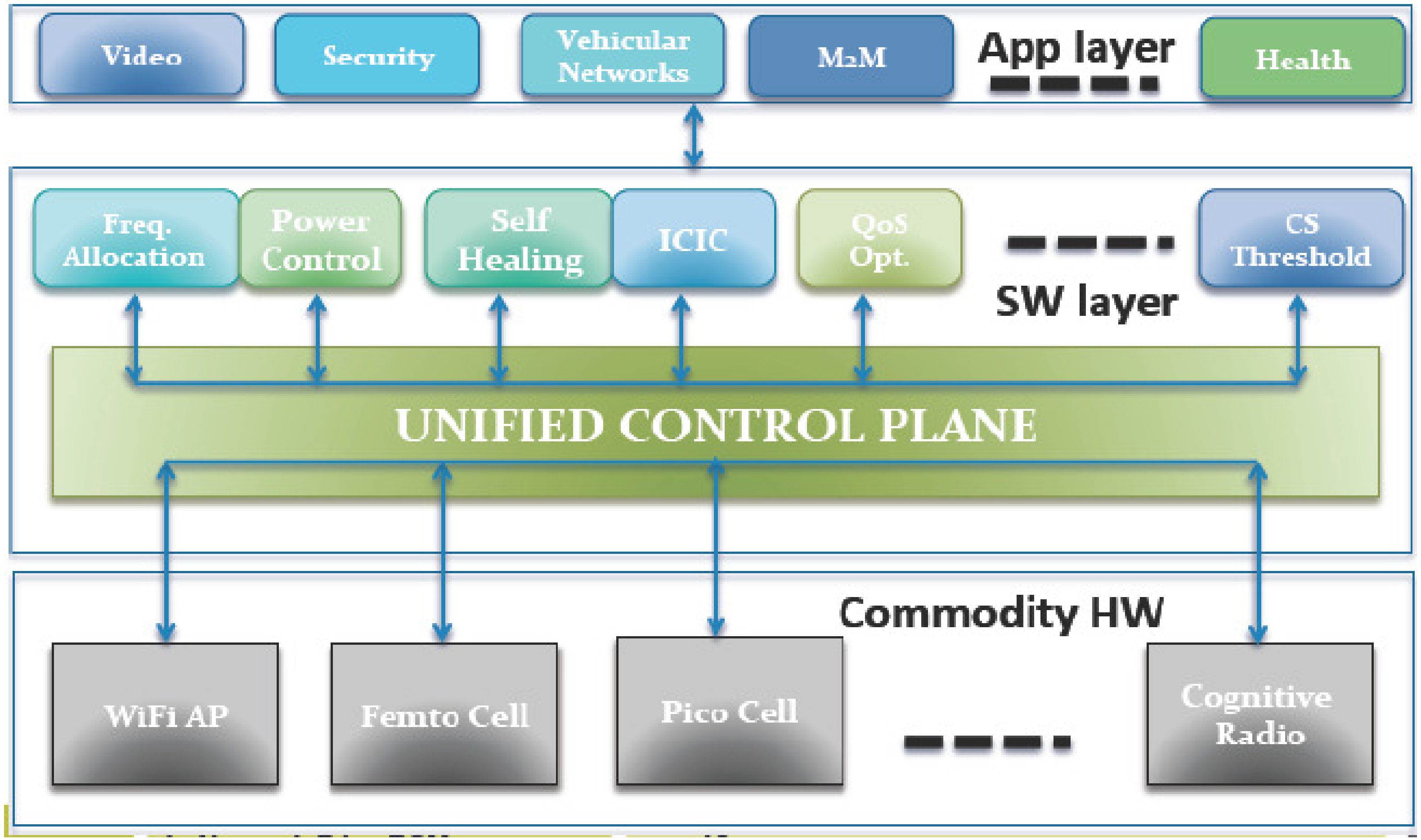


Digital Data and SDR

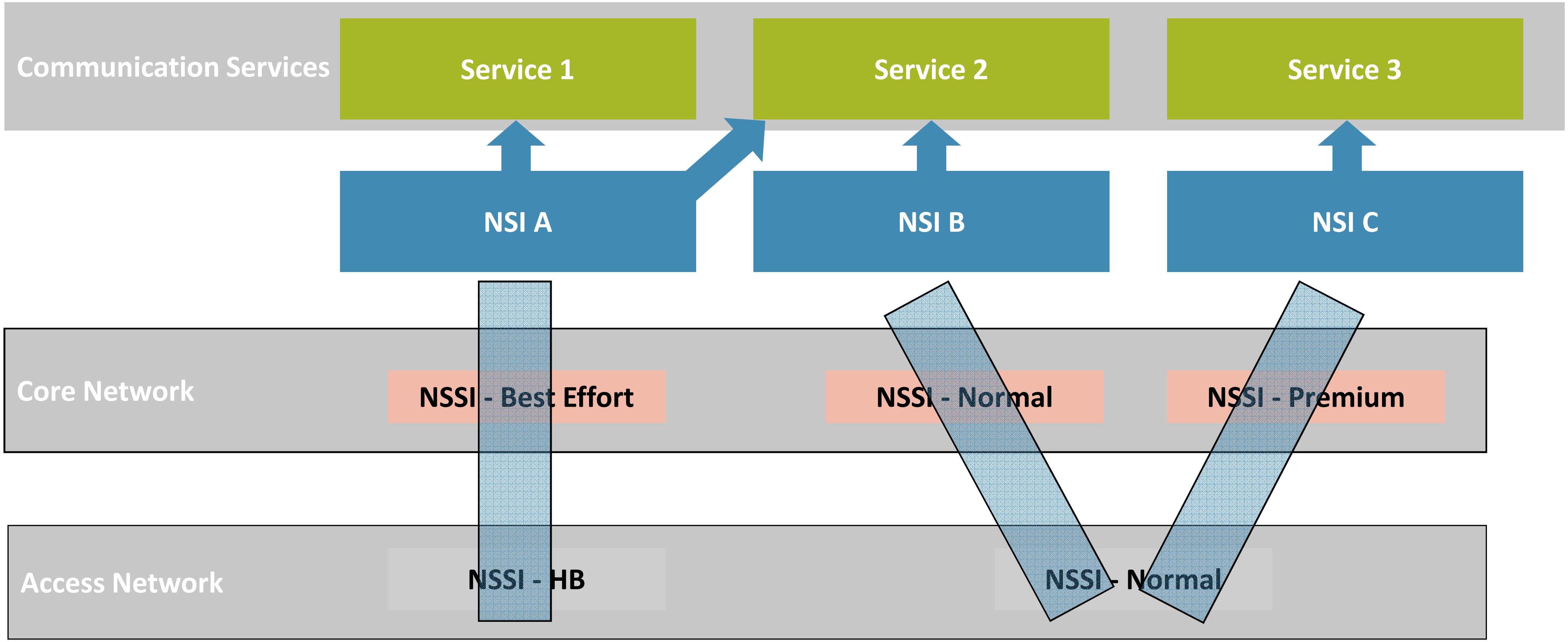


SDN and NFV

SDN and **NFV** will enable mobile operators to dynamically and automatically adapt capacity and signaling in lock-step with the rise and fall of customer demands on the network.

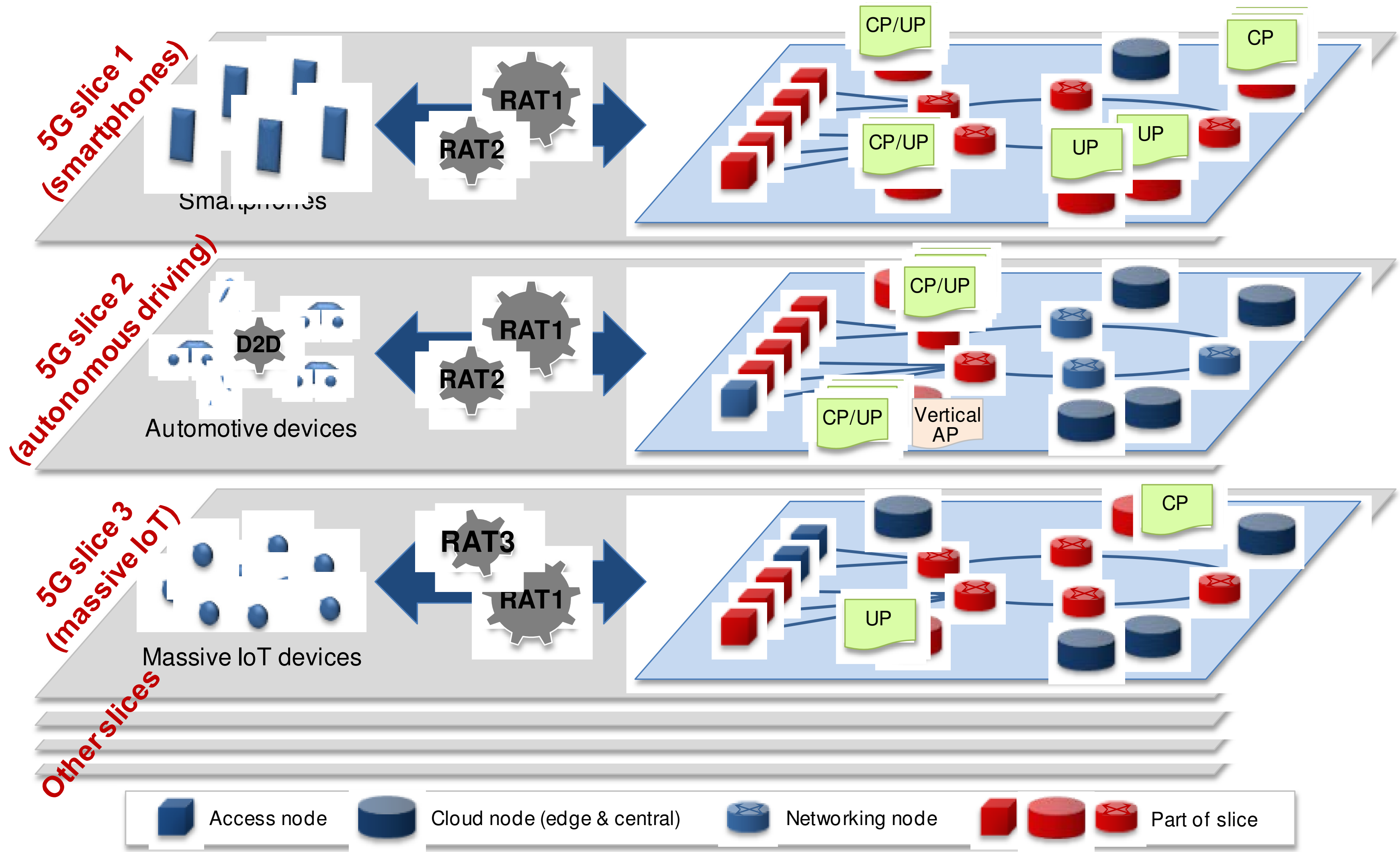


Slicing in 5G



Slicing architecture

5G Network Slicing example



Thank You