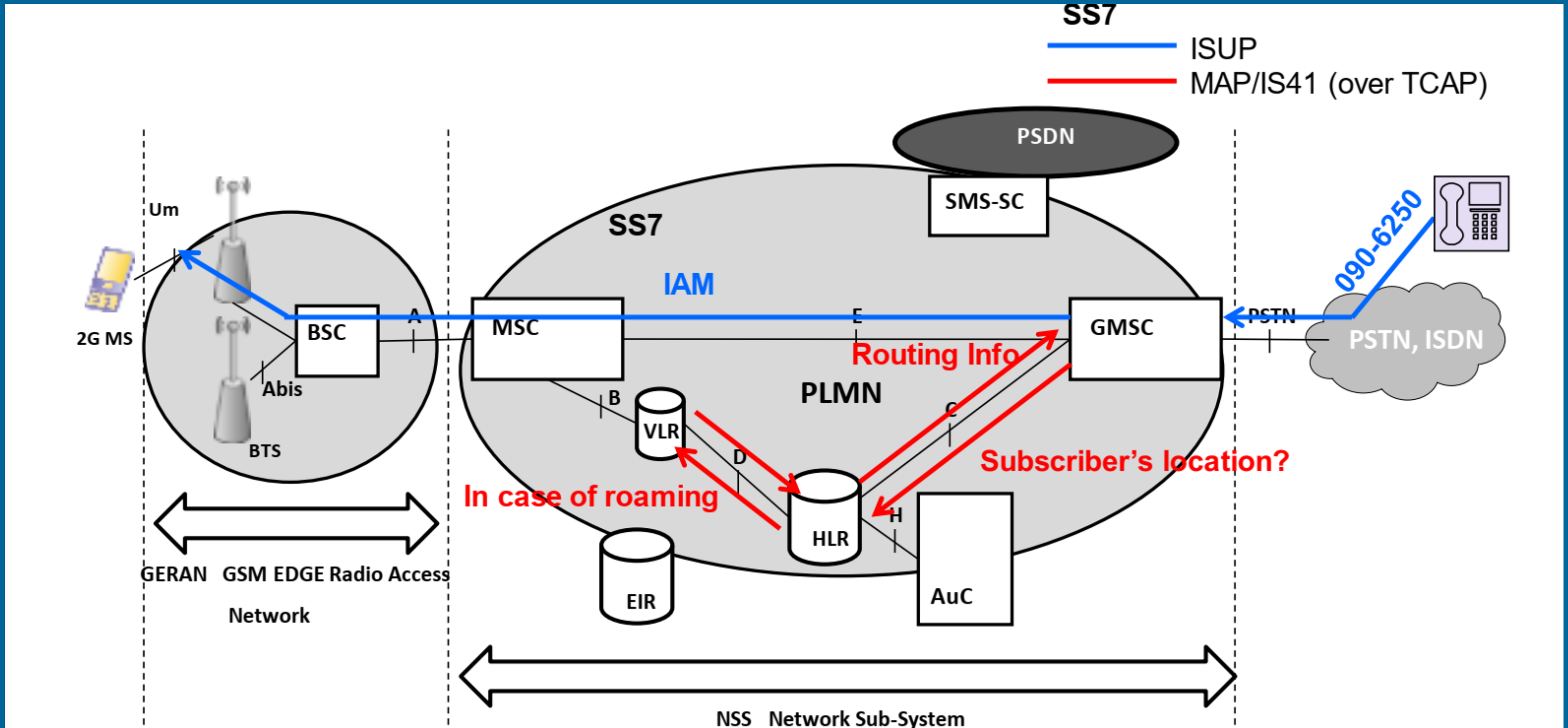
Evolution of Mobile Networks

Sharif University of Technology

Winter 1401

GSM 2G Architecture



BTS Base Transceiver Station

BSC Base Station Controller

MS Mobile Station

MSC Mobile-service Switching Controller

VLR Visitor Location Register

HLR Home Location Register

AuC Authentication Server

GMSC Gateway MSC

EIR Equipment Identity Register

PLMN	Public Land Mobile Network
PSDN	Public Switched Data Network
PSTN	Public Switched Telephone Network
PSPDN	Packet Switched Public Data Network
CSPDN	Circuit Switched Public Data Network
ISDN	Integrated Services Digital Network

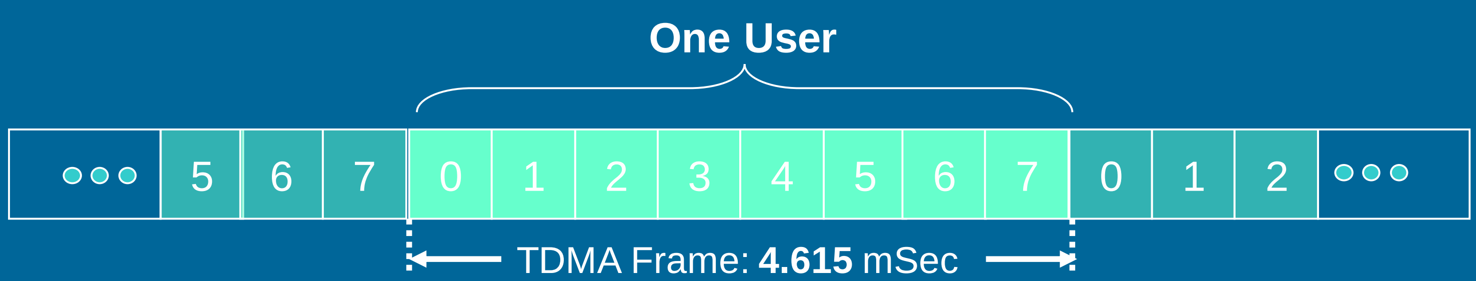
Network and Switching Subsystem

- The backbone of a GSM network is an ordinary telephone network with some added capabilities
- Mobile Switching Center (MSC)
  - An ISDN exchange with additional capabilities to support mobile communications
  - Visitor Location Register (VLR)
    - A database, part of the MSC
    - Contains the location of the active Mobile Stations
- Gateway Mobile Switching Center (GMSC)
  - Links the system to PSTN and other operators
- Home Location Register (HLR)
  - Contains subscriber information, including authentication information in Authentication Center (AuC)
- Equipment Identity Register (EIR)
  - International Mobile Station Equipment Identity (IMEI) codes for e.g. blacklisting stolen phones

2.5G GPRS: General Packet Radio Service

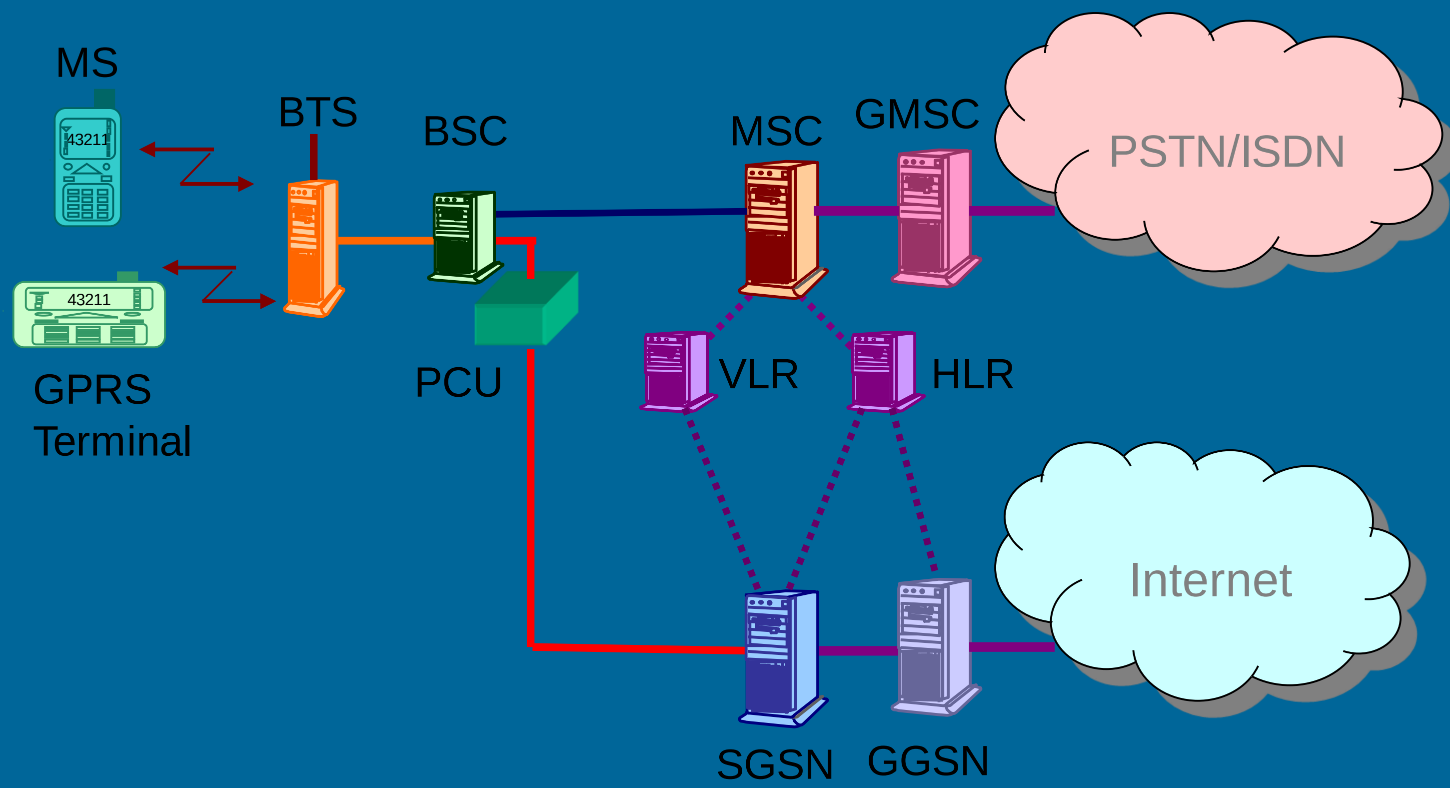
- GPRS Provides Packet-Switched Services over the GSM Radio.
- It uses the same Air Interface as GSM
- The Data Rate in GPRS is enhanced compared to GSM Due to:
  - Multi-Slot Assignment up to 8 Time Slots
  - Using Different Coding Schemes

Maximum Bit Rate = 8 x 21.4 = 171.2 kb/s



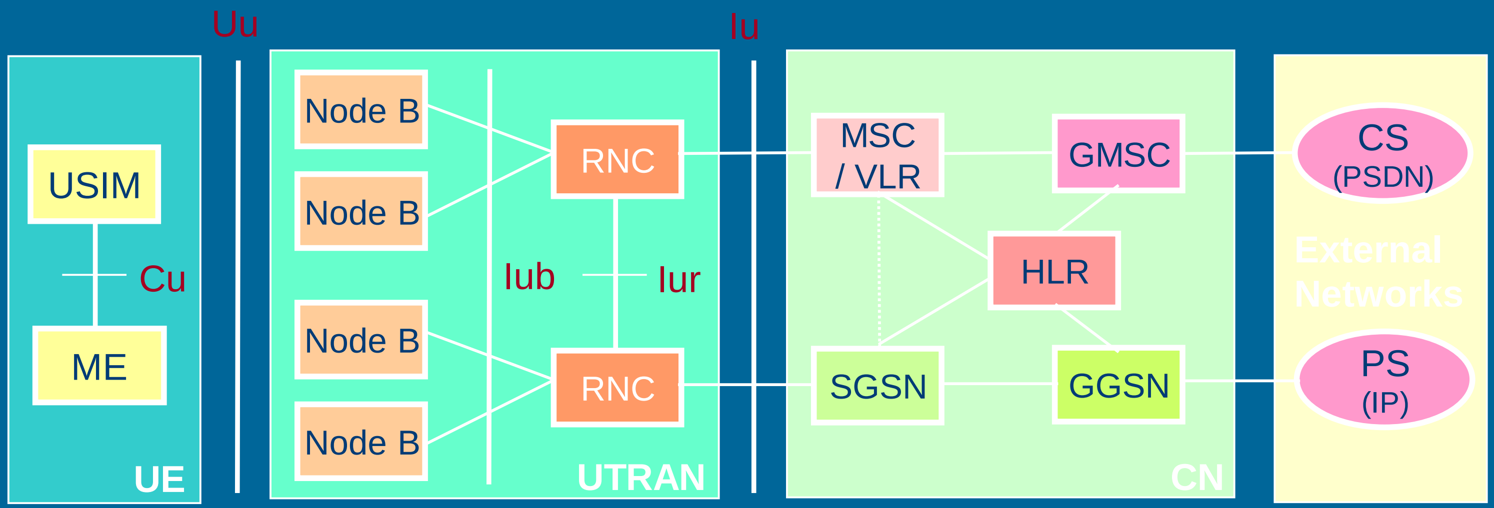
GSM TDMA Frame

GPRS Architecture



SGSN: Serving **G**PRS **S**upport **N**ode (Packete Routing, Mobility, Charging and Authentication)
GGSN: Gateway **G**PRS **S**upport **N**ode (Interface to IP World)
PCU: Packet **C**ontrol **U**nit

UMTS Network Elements



USIM: **U**MTS **S**ubscriber **I**dentity **M**odule

ME: **M**obile **E**quipment

UE: **U**ser **E**quipment

RNC: **R**adio **N**etwork **C**ontroller

UTRAN: **U**MTS **T**errestrial **R**adio **A**ccess **N**etwork

SGSN: **S**erving **G**PRS **S**upport **N**ode

GGSN: **G**ateway **G**PRS **S**upport **N**ode

CN: **C**ore **N**etwork

Basic LTE system architecture

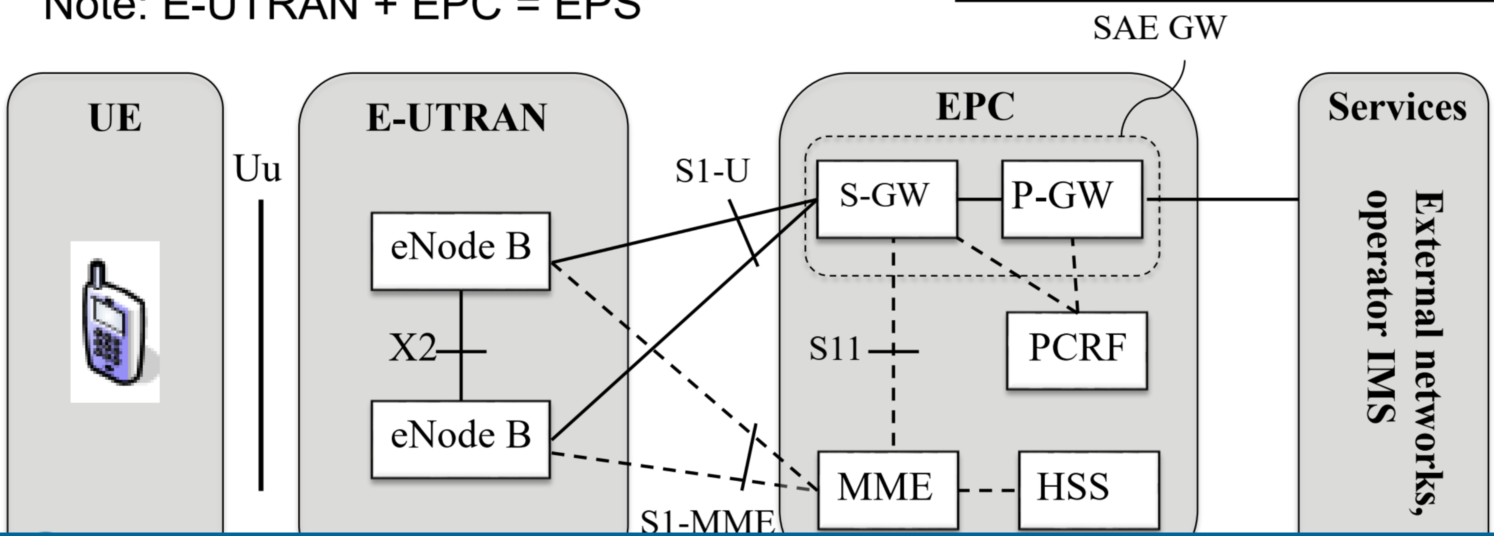
- Architecture is divided into four main domains:
  - User Equipment (UE),
  - Evolved Universal Terrestrial Radio Access (E-UTRAN),
  - Evolved Packet Core Network (EPC),
  - Services domain.
- Note: E-UTRAN + EPC = EPS

➢ ***S1-U:** User Plane interface between eNB and S-GW*

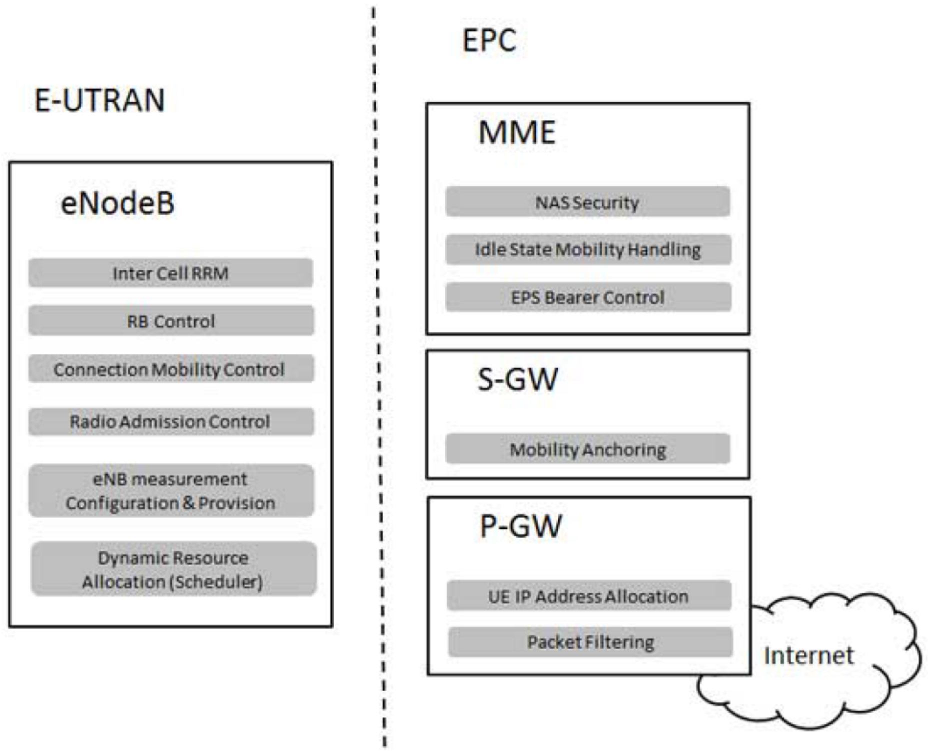
➢ ***S1-MME**: Control Plane interface between eNB and MME*

➢ ***X2:** Interface between eNBs*

➢ ***Uu**: Radio Interface between UEs and eNB*



- **PDN GW:** IP address allocation, charging and enforces QoS
- **Serving GW:** Local mobility anchor for intra-3GPP HO
- **MME:** Mobility management entity for intra-3GPP mobility, paging, authentication, bearer management, etc.
- **PCRF:** QoS and charging rule provisioning



2G/3G Versus LTE

Following table compares various important Network Elements & Signaling protocols used in 2G/3G abd LTE.

2G/3G	LTE
GERAN and UTRAN	E-UTRAN
SGSN/PDSN-FA	S-GW
GGSN/PDSN-HA	PDN-GW
HLR/AAA	HSS
VLR	MME
SS7-MAP/ANSI-41/RADIUS	Diameter
DiameterGTPc-v0 and v1	GTPc-v2
MIP	PMIP

E-UTRAN

- eNode B performs
  - Ciphering/deciphering of the User Plane data
  - Radio Resource Management (admission control, scheduling, resource usage monitoring etc.)
  - IP header compression/decompression
- eNode B is also involved with Mobility Management (MM).
  - The eNode B controls and analyses radio signal measurements carried out by the UE,
  - eNode B makes signal measurements itself
  - Based on measurement information eNode B makes decisions to handover UEs between neighbouring eNode Bs
  - Handover interactions between neighbouring eNode Bs is via X2 interface

Multiuser Scheme in LTE?

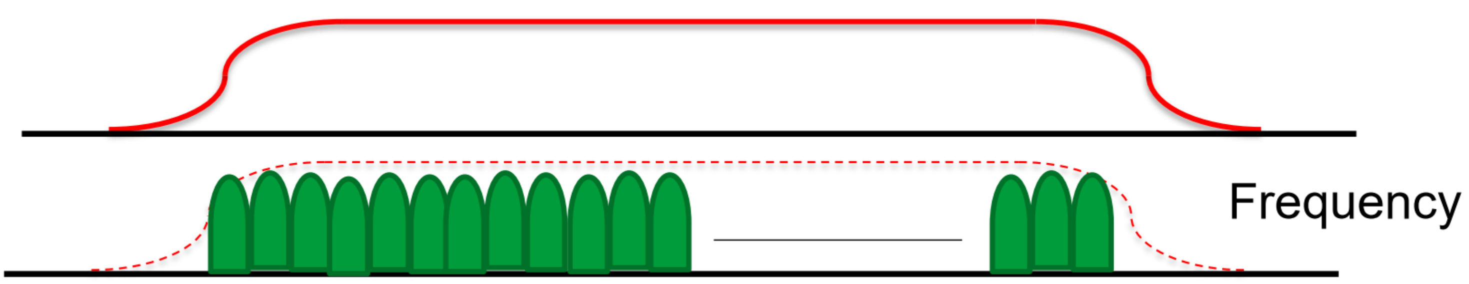
LTE: OFDMA benefits

- WCDMA/HSPA data stream sent at a very high speed over a single 5MHz carrier
- OFDMA splits the data stream into many slower data streams (longer symbol duration) that are transported over many carriers simultaneously

  => better orthogonality between users

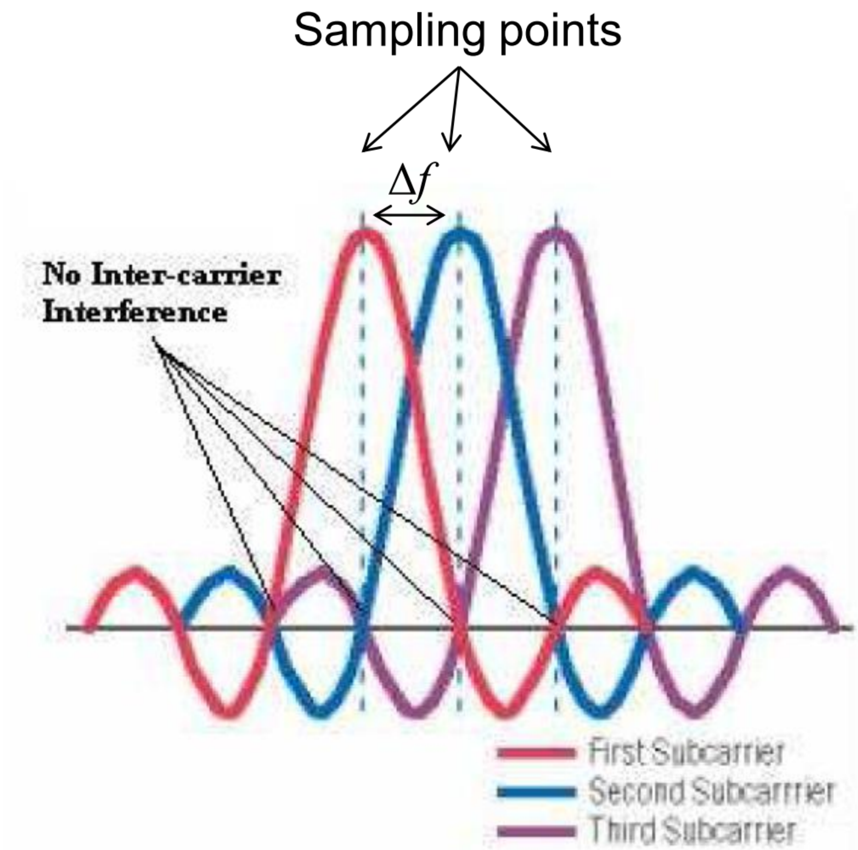
  => less interference and/or interference that can be cancelled more easily than in WCDMA/HSPA system

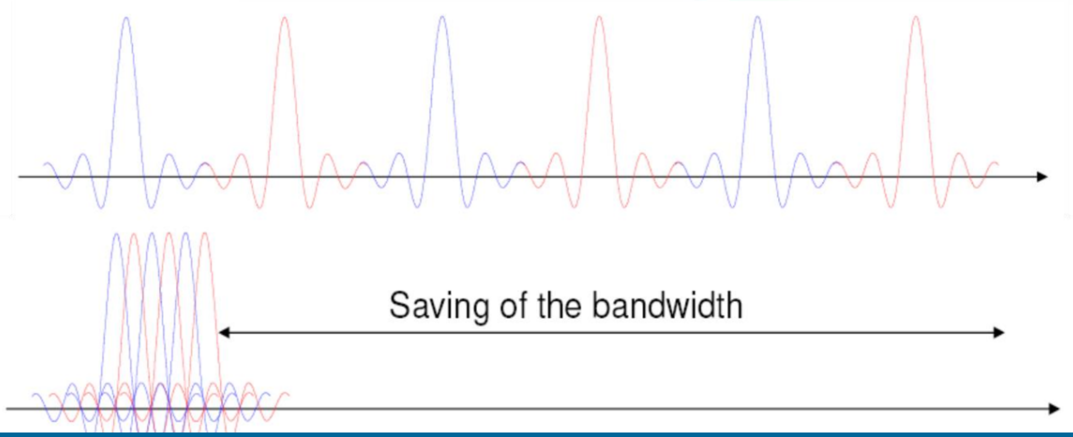
  => better network capacity can be achieved through extending carrier bandwidths to 20 MHz or wider



OFDM principle

- OFDM divides spectrum into large number of tightly packed narrow subcarriers
  - At the peak of each subcarrier, all other subcarriers have amplitude zero => avoids subcarrier interference
  - Large bandwidth savings compared to conventional multicarrier schemes
- OFDM is applied together with time division multiplexing
  - Time-shared subcarriers
- OFDMA adopted by many other wireless systems
  - WLAN, DVB-H etc.





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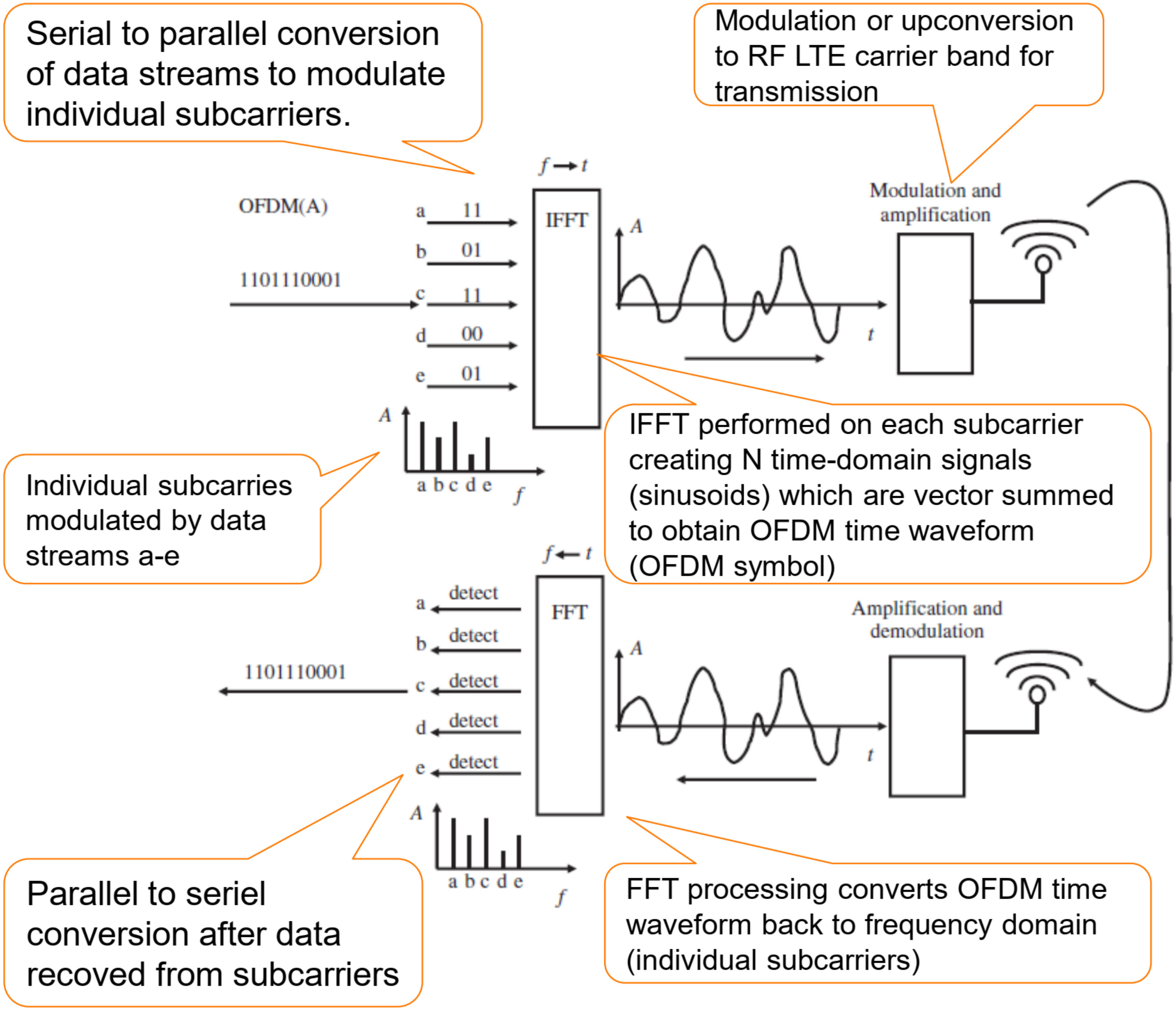
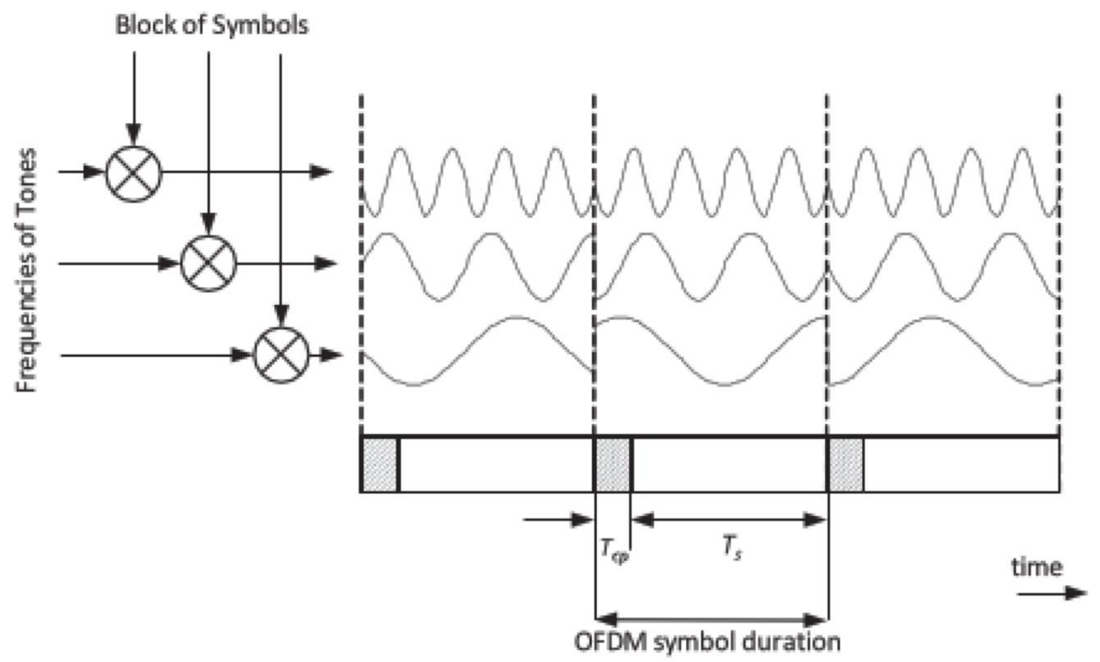
OFDMA transmission/receiption



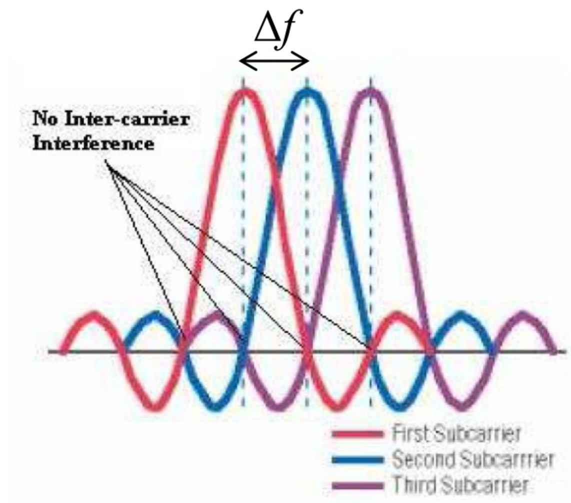
OFDM signal in time domain..



Different symbols on different subcarriers are modulated with different frequencies.

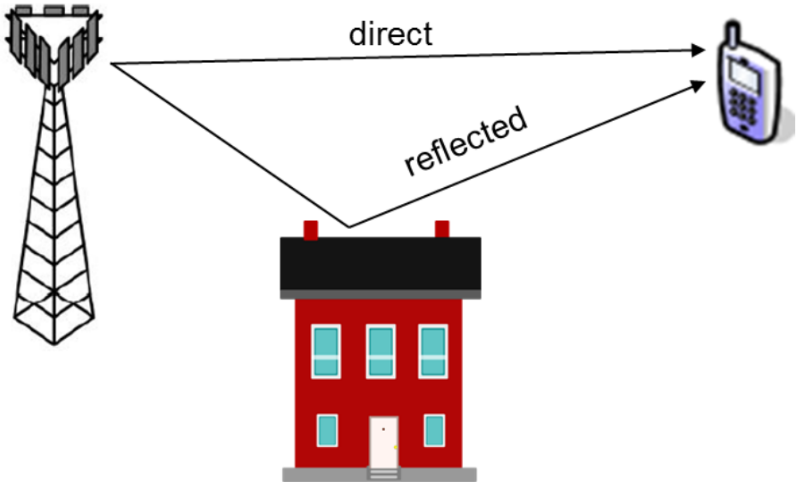
OFDM parameters for LTE

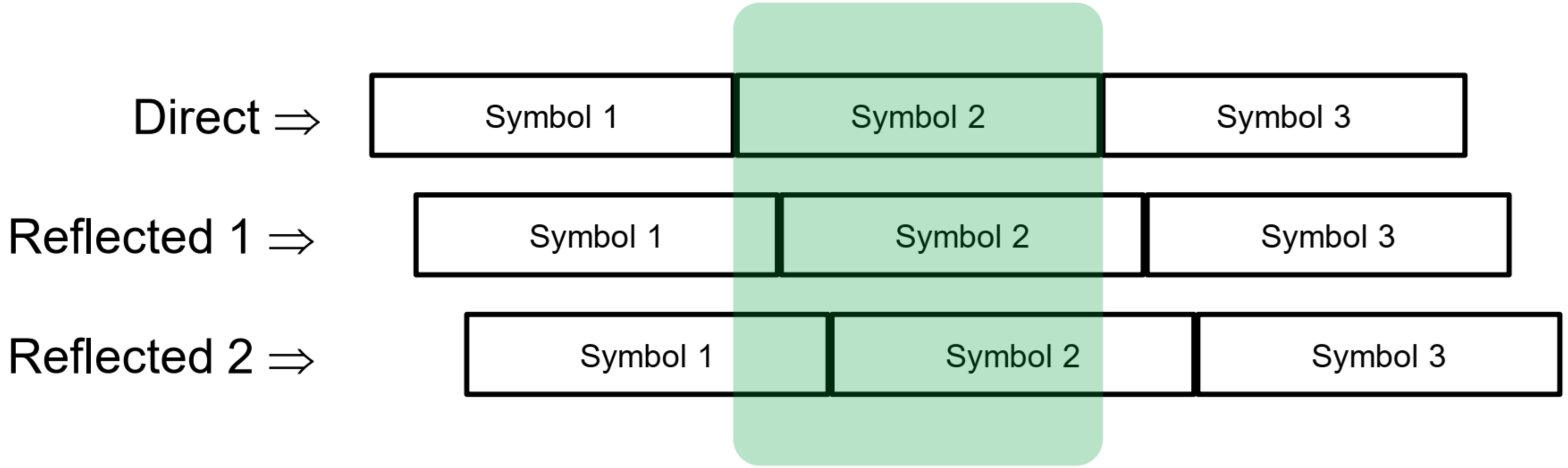
- LTE subcarrier spacing **$\Delta f = 15$kHz** represents the best found trade-off in 3GPP
  - The subcarrier spacing should be as small as possible. Then subcarrier symbol time $T_u = 1/\Delta f$ is large and less overhead (*"cyclic prefix"*) needed to combat intersymbol interference
  - However the smaller the subcarrier spacing is, the more sensitive the system is for frequency errors (intercarrier interference)



Intersymbol Interference (ISI)

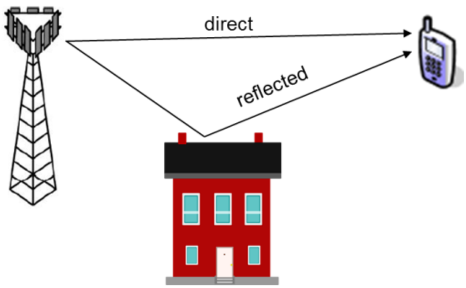
- Multipath propagation leads to ISI

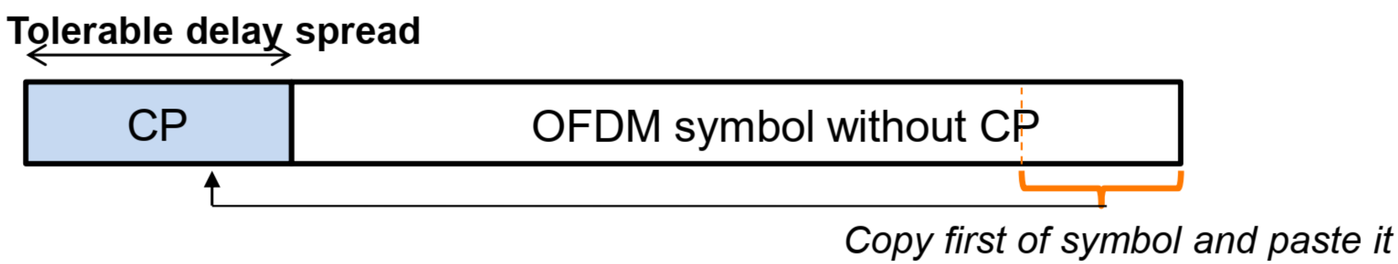




Cyclic Prefix

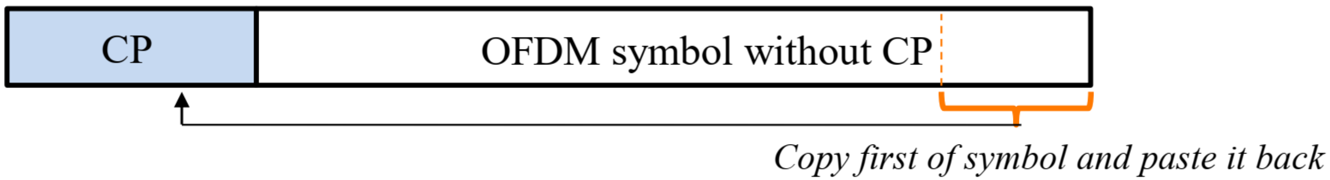
- **Delay spread = time difference between direct path and reflected path**
- The cyclic prefix (CP) length should be longer than the maximum channel delay spread
  - Longer CP robust to ISI but inefficient (too much overhead)
  - If CP is too short, it may limit cell size (more on this next slide)

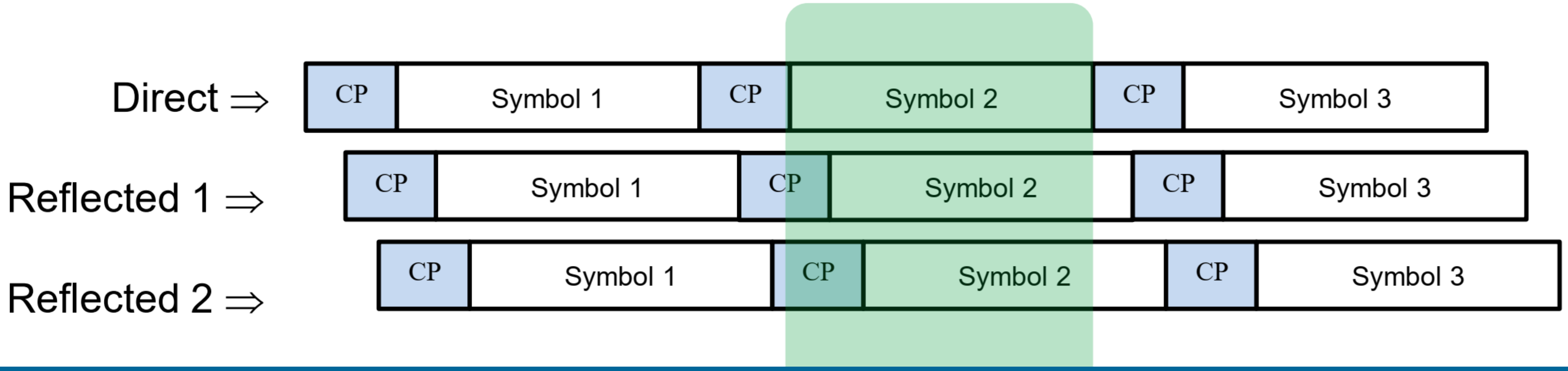




Cyclic Prefix

- A guard band added to OFDM symbol to mitigate against intersymbol interference
  - Cyclic Prefix (CP) inserted after OFDM modulation





OFDM parameters for LTE

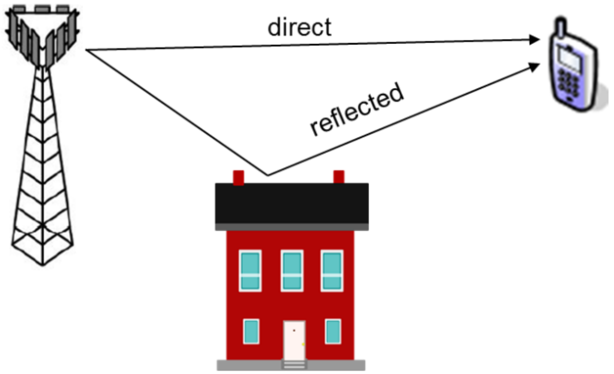
- $\Delta L = L_{reflected} - L_{direct}$ difference in travelled distance between reflected and direct signal

  $$CP\ duration = \Delta L / c$$

  where c = 3 x 10^8 m/s

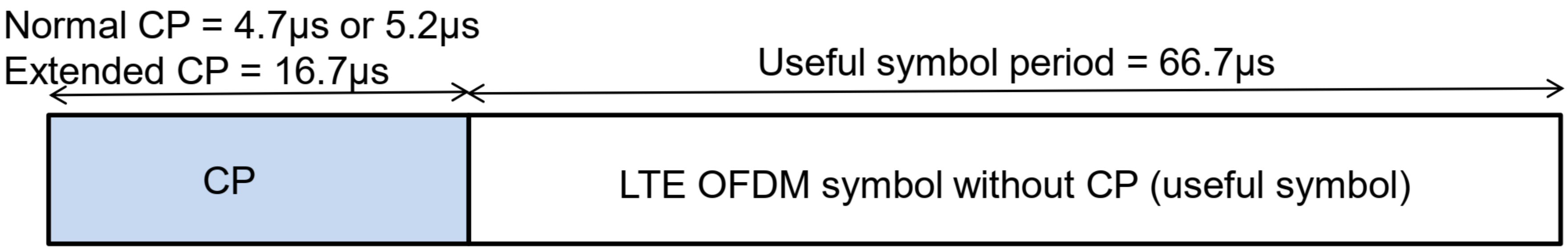
- **Normal CP = 4.7μs or 5.2μs**
  - ΔL up to 1.4 km (small/medium sized cells in urban environments)

- **Extended CP = 16.7μs**
  - ΔL up to 5 km (for large cells and/or extreme radio environments with long delay spreads)



OFDM parameters for LTE

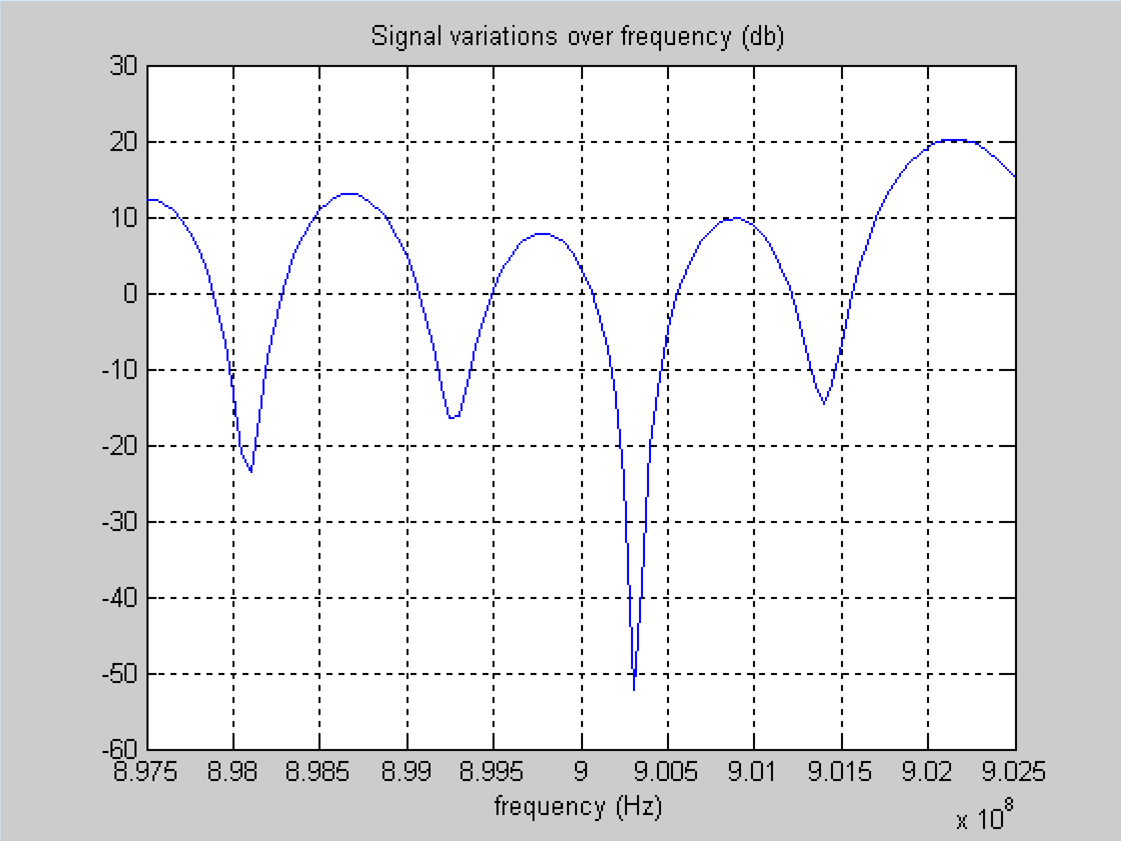
- The OFDM useful symbol time duration (without CP) is always **66.7 us**
  - We will see later, less OFDM symbols will be available for extended CP in a given slot



Effect of Channel Multipath

- Channel Coherence BW and relation to channel delay.

Channel Frequency Response and Signal BW



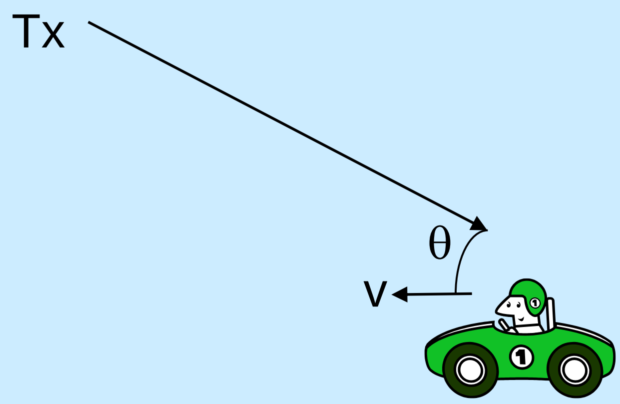
- For a narrowband signal of BW = 10KHz the above channel is close to ideal
- For a GSM signal with BW = 200KHz, channel is non-ideal, we will have ISI and equalization becomes essential
- The term "**Coherence BW**" of a channel, B_c , gives range of frequencies over which channel changes are small (for the above channel , $B_c \cong$ 40KHz)
- So, what is important is the relation between B_c and signal BW

How does small-scale changes affect the received signal?

Random Change of Carrier Frequency

- Due to motion of receiver or moving objects in the environment, the carrier frequency of received signal will also change randomly -> Doppler Effect

$f_d = v/\lambda \cos(\theta)$



- Doppler effect causes spread of bandwidth of the received signal (frequency spread)

Time variations

- Time variations in wireless channel are due to relative velocity of transmitter (or main obstacles) and the receiver
- This relative motion causes spread of carrier frequency (Doppler Spread) proportional to the velocity, $f_d = v/\lambda \cos(\theta)$:

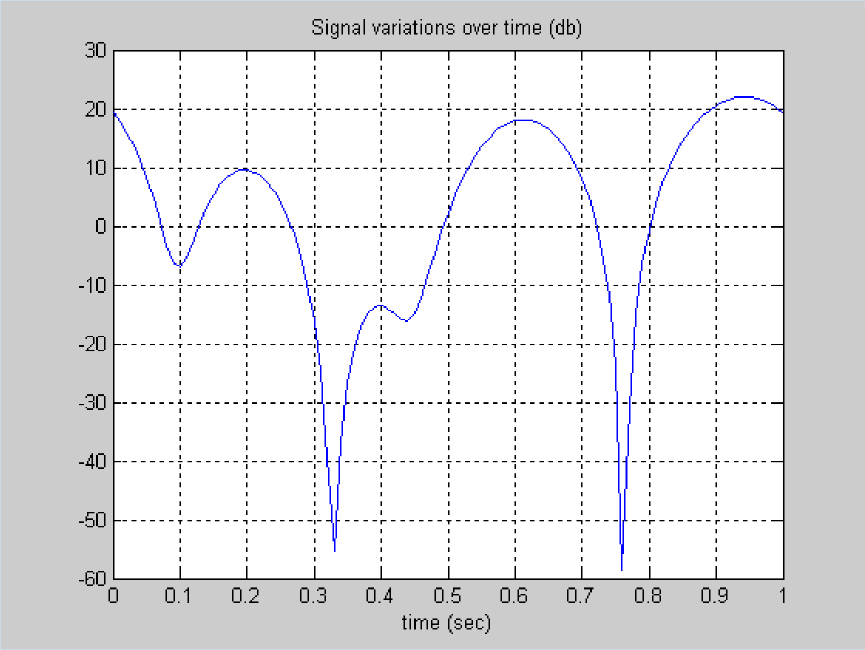
$$f_c - f_d \;\; -> \;\; f_c + f_d$$

- In addition, motion causes change in channel frequency response (fading variation) in time/space:

$v = 1m/s$

$\lambda = 30cm$

$f_d \cong 3Hz$



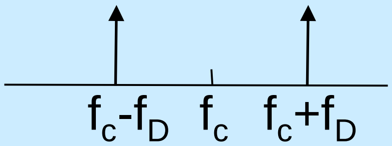
- **Coherence time of a channel (T_c)** : Time over which channel can be considered almost constant

Time variations and frequency spread

- A simple way to understand the relation between doppler shift and time variations:
- If we consider time variations as a simple form of multiplying the carrier frequency by a single tone at f_D:

In time domain: $\cos(f_c t) \cos(f_D t)$

In frequency domain:



Time/Space Variations of Signal

- **Coherence Time of a channel = $T_c \cong 1/(2f_D)$**

- For usual mobile channels:

  f_D = 100Hz -> Tc = 5msec

- For example for GSM: Burst period = .5msec

  therefore, channel almost constant during each burst.

Delay spread <-> Coherence BW

- Coherence BW of channel: Signals with frequencies apart more than B_c are affected differently by the channel
- We expect the Coherence BW of channel, B_c , be dependent on channel delay spread.
- As channel delay spread increases we expect smaller B_c and therefore faster channel variations in frequency domain

Delay spread <-> Coherence BW

- The value of B_c depends on delay spread of channel: σ_τ

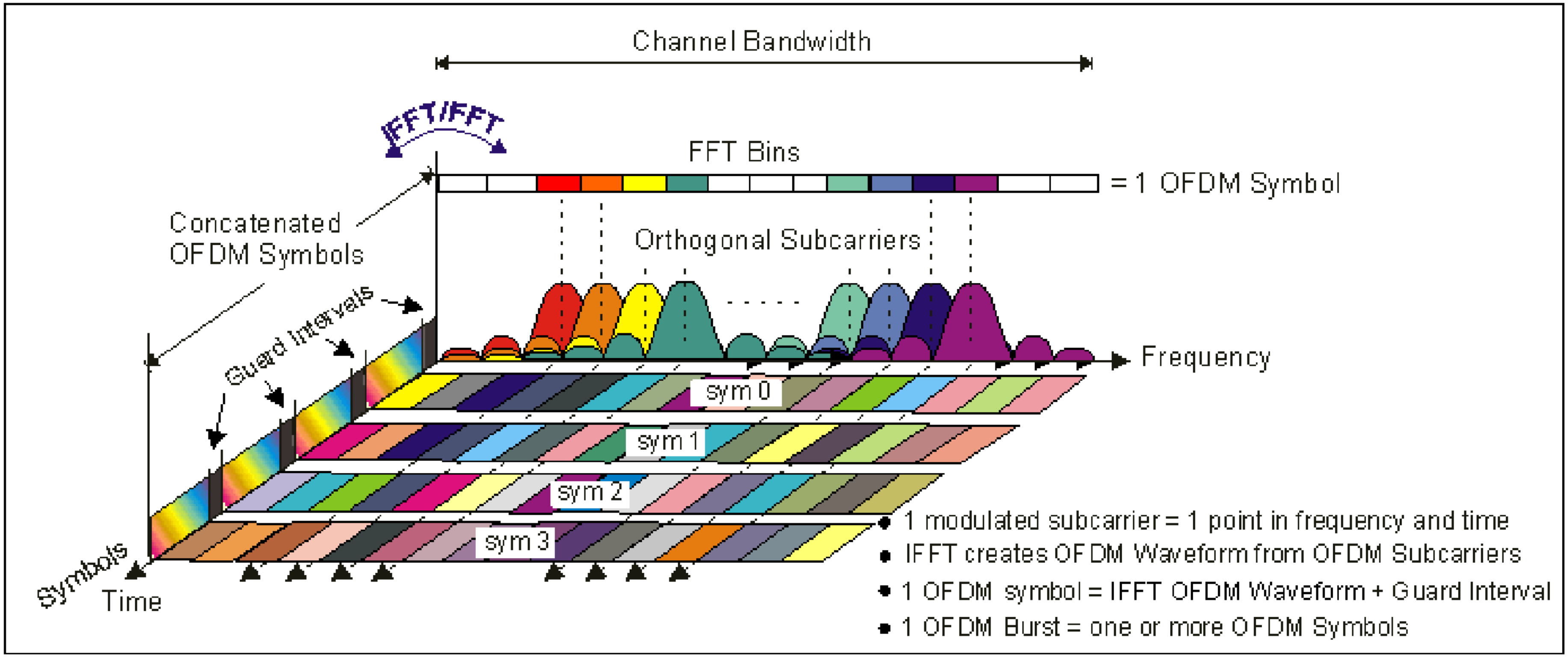
$$B_c \cong 1/(5\sigma_\tau)$$

- For example, for σ_τ = 20usec , $B_c \cong$ 10KHz

- Signal BW >> B_c $\equiv$ Ch. delay spread (σ_τ) >> Symbol duration (T_s)
  ---> ISI exists and Equalizer needed (Signal may be faded in some frequencies)

- Signal BW << B_c $\equiv$ Ch. delay spread (σ_τ) << Symbol duration (T_s)
  ---> NO ISI and No equalizer needed (But signal may be totally faded)

OFDMA transmission/receiption

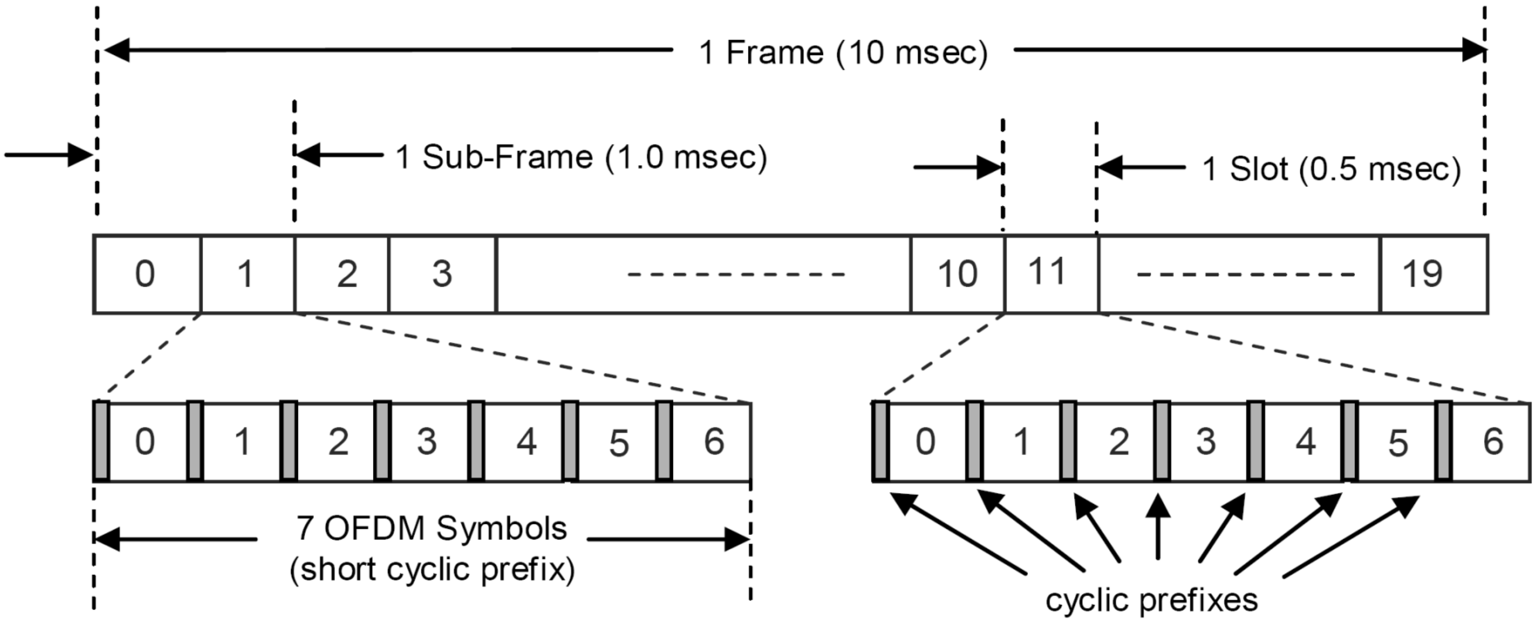


Frequency-Time Representative of an OFDM signal

Source: Keysight

LTE time frame structure

- LTE time-frame:
  - Contains 10 sub-frames of duration 1ms => Frame length is 10ms
  - Each 1 ms subframe contains 2 time slots (0.5ms)
  - Each 0.5 ms time slot contains 6-7 OFDM symbols per slot
    - 7 OFDM symbols for normal CP
    - 6 OFDM symbols for extended CP



LTE time-frequency structure

- Resources are grouped into **two dimensional Resources Blocks (RBs)**
  - RB contains the LTE time frame for each of 12 subcarriers (12 x 15 KHz = 180kHz in total)
  - User allocated resources in bundles of RBs
  - Smallest modulation structure in LTE is one symbol in time modulated on one subcarrier in frequency ⇒ **Resource Element (RE)**
  - Each RB has 84 REs (12 subcarriers x 7 symbols)

Source: Telesystems Innovations

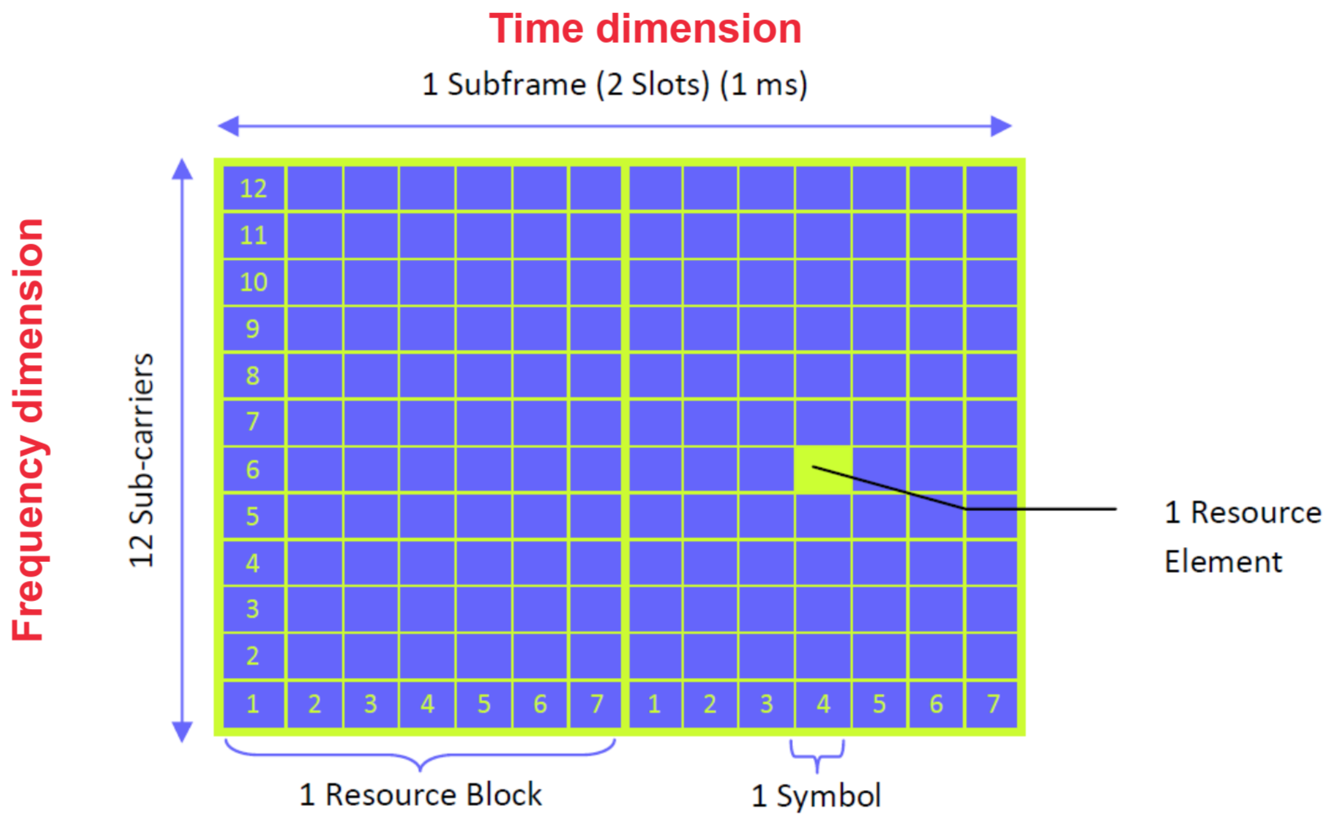
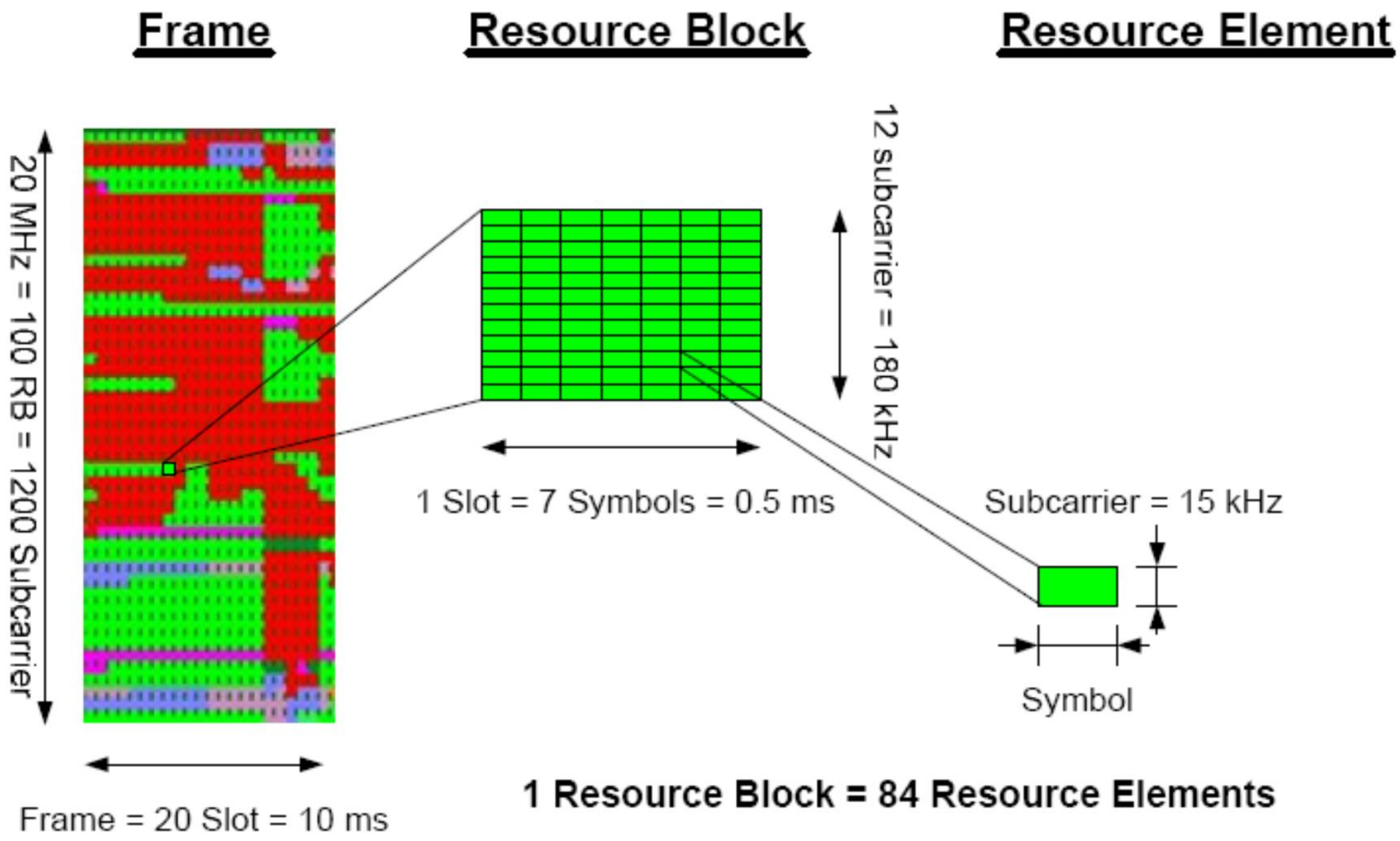


FIGURE 5 RESOURCE BLOCK AND RESOURCE ELEMENT DEFINITION (NORMAL CP MODE).

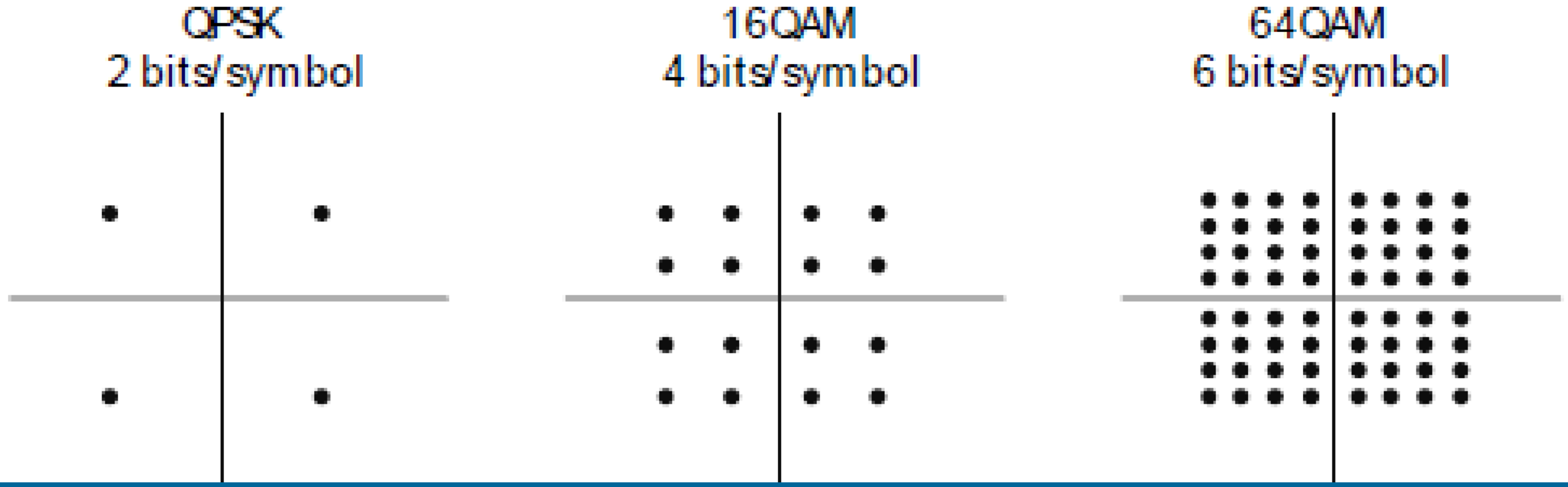
LTE time-frequency structure

- Number of RBs increases with available bandwidth (more subcarriers)
- Example below for time-frequency LTE frame structure for 20 MHz carrier bandwidth



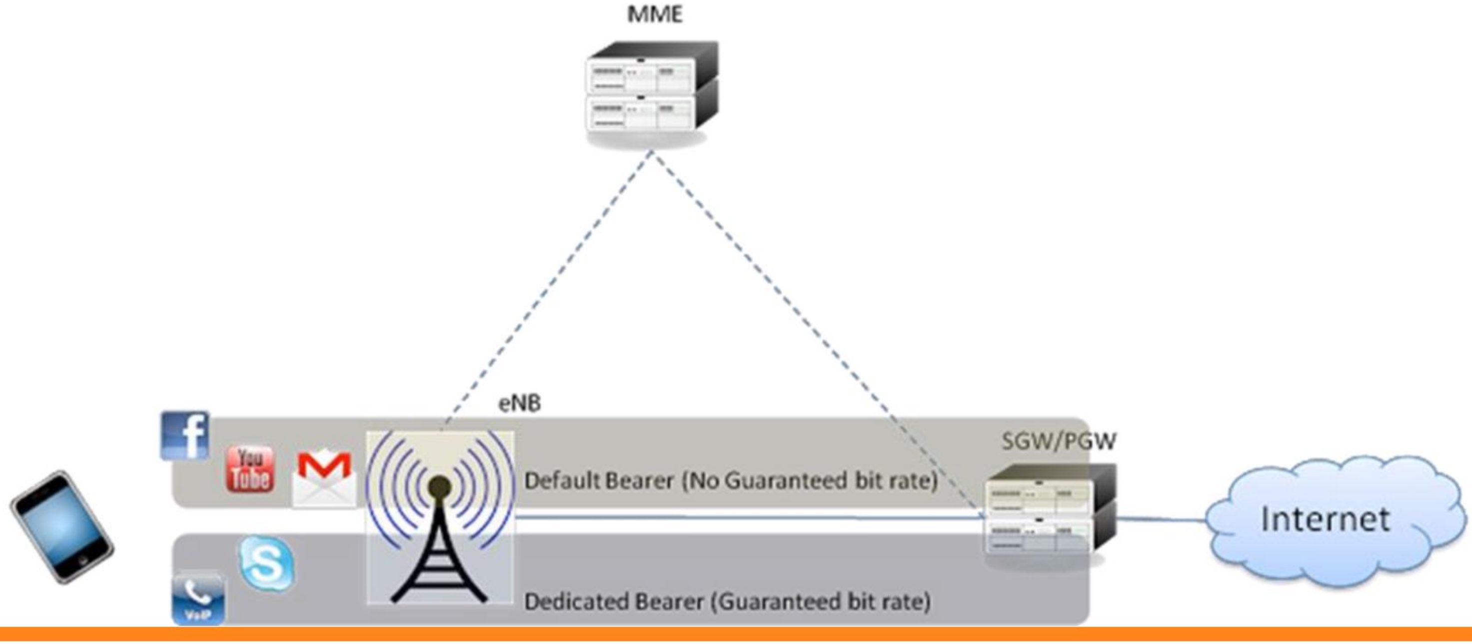
LTE Modulation (DL and UL)

- Recall 1 Resource element = 1 symbol modulated onto a 15 kHz subcarrier
- Available modulations (in LTE Rel. 8) for user data transmission are **QPSK (2 bits/symbol), 16QAM (4 bits/symbol) and 64QAM (6 bits/symbol)**
  - BPSK is used on some control channels



LTE protocol entities

- The radio interface protocols are needed to set up, reconfigure and release the **Radio Bearer services**:
  - Radio Bearer is build up in order to give for core network an illusion of a fixed communication path to UE (new bearer may be initiated by UE or core network)
  - Best effort **default bearer** (with non Guaranteed Bit Rate (non-GBR)) setup when UE attaches to the network for the first time
  - **Dedicated bearer** acts as bearer in addition to default bearer providing dedicated tunnel with non-GBR or GBR (for VoIP, streaming video etc.)

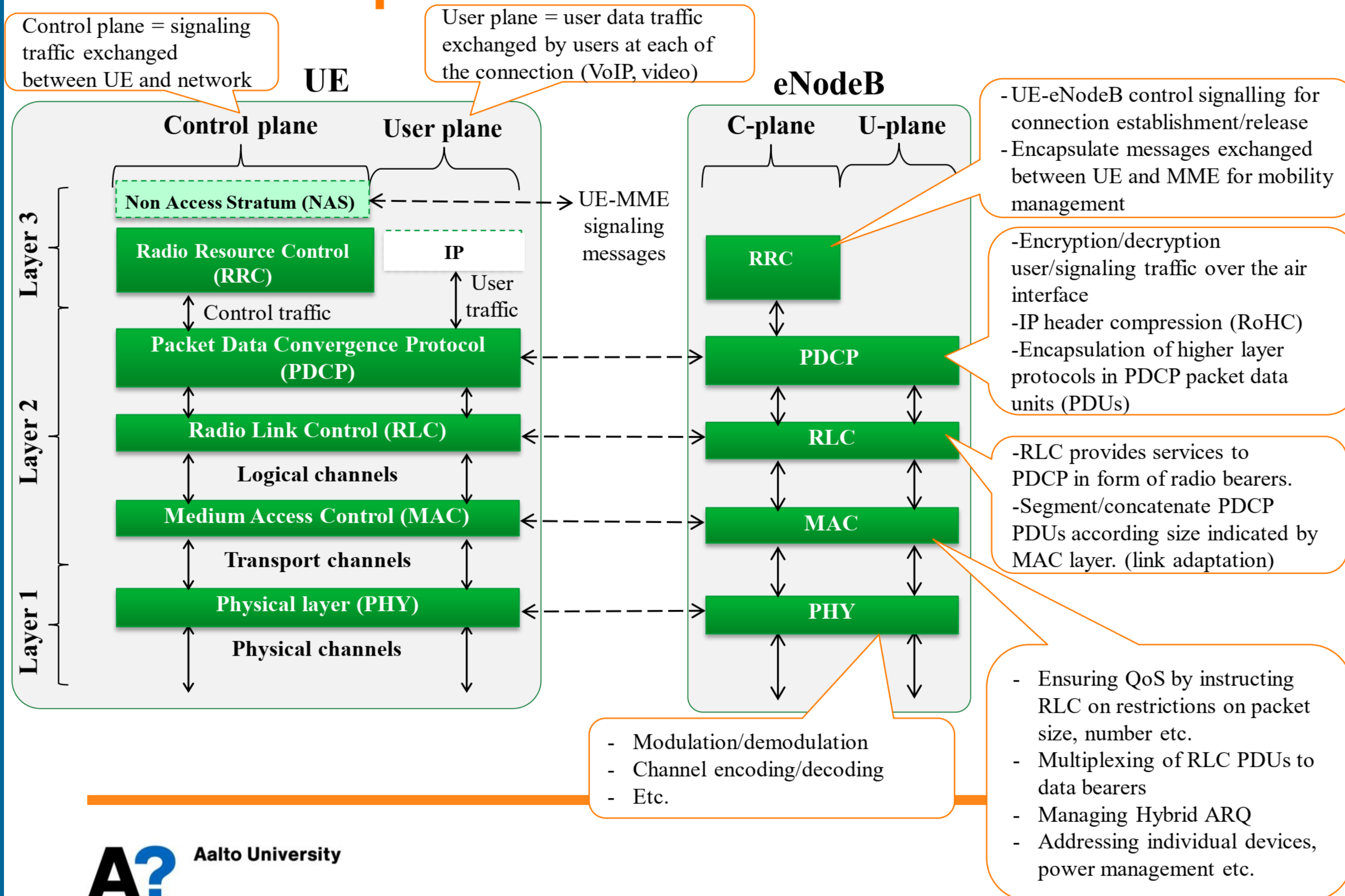


QoS Class Indentifiers (QCI)

- Within a Radio Bearer the network sets connection based on service **QoS Class Identifier (QCI)** and its related QoS parameters (packet loss, packet delay, priority etc.)
- 3GPP release 8 specifications define a mapping table for nine different QCIs and their typical services:

	QCI	Bearer Type	Priority	Packet Delay	Packet Loss	Example
Dedicated bearer	1	GBR	2	100 ms	10^{-2}	VoIP call
	2		4	150 ms	10^{-3}	Video call
	3		3	50 ms		Online Gaming (Real Time)
	4		5	300 ms	10^{-6}	Video streaming
Dedicated or default bearer	5	Non-GBR	1	100 ms		IMS Signaling
	6		6	300 ms		Video, TCP based services e.g. email, chat, ftp etc
	7		7	100 ms	10^{-3}	Voice, Video, Interactive gaming
	8		8	300 ms	10^{-6}	Video, TCP based services e.g. email, chat, ftp etc
	9		9			

LTE radio protocol stack



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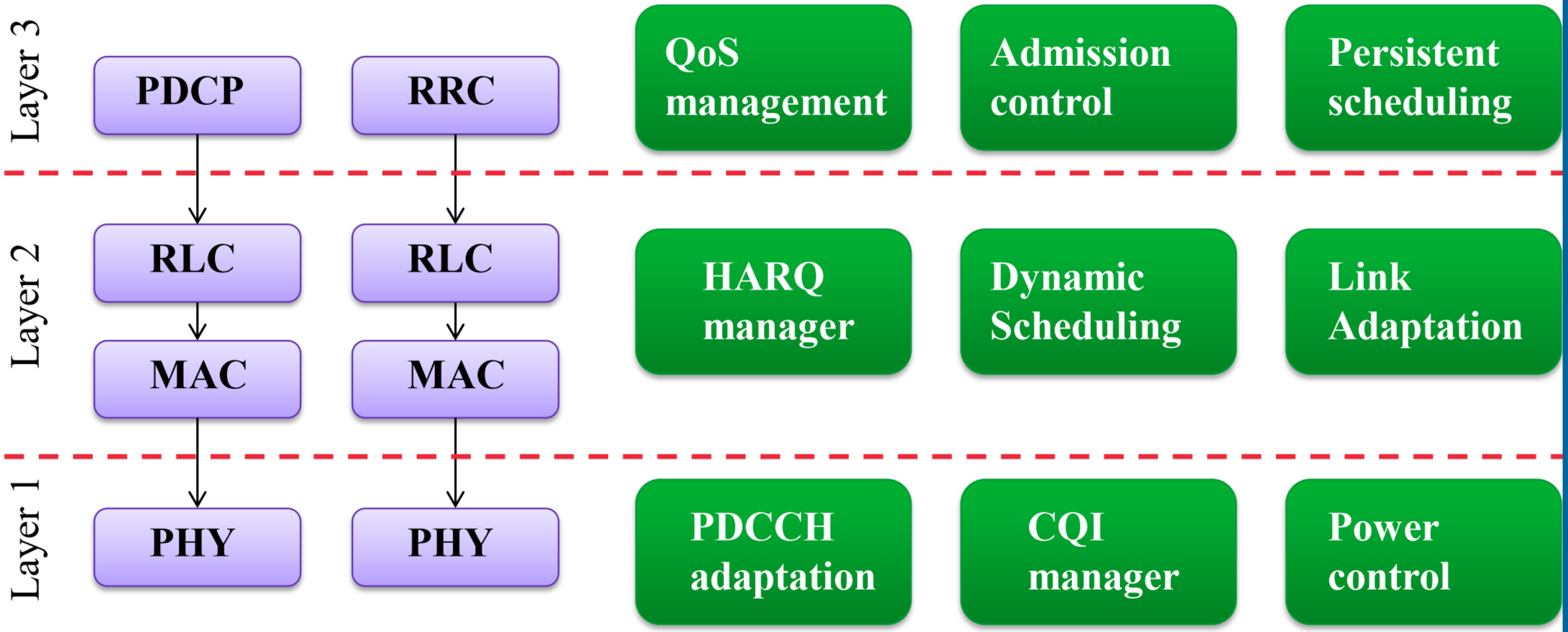
LTE Protocol Stack -> https://www.youtube.com/watch?v=PpK5MP78zL8

Radio Resource Management

- The role of **Radio Resource Management** (RRM):
  – Ensure that the radio resources are efficiently used
  – Use effectively the available (link/channel) adaptation techniques
  – Serve the users according to their configured Quality of Service (QoS) .

  - Various RRM functionalities in the different layers as shown below
    - As an example we briefly discuss **dynamic scheduling** and **link adaptation** in the next slides



Scheduling and link adaptation

- *In scheduling the controlling RRM entity is the dynamic Packet Scheduler* (PS), which performs scheduling by allocating Resource Blocks (RBs) to the users
  - Decisions performed every **Transmit Time Interval (TTI) = 1ms** (that is, every subframe)
- The overall packet scheduling goal is to maximize the cell capacity, while making sure that the minimum QoS requirements for bearers are fulfilled.
- The scheduling decisions are carried out on a per user basis even though a user has several data flows.

Scheduling and link adaptation

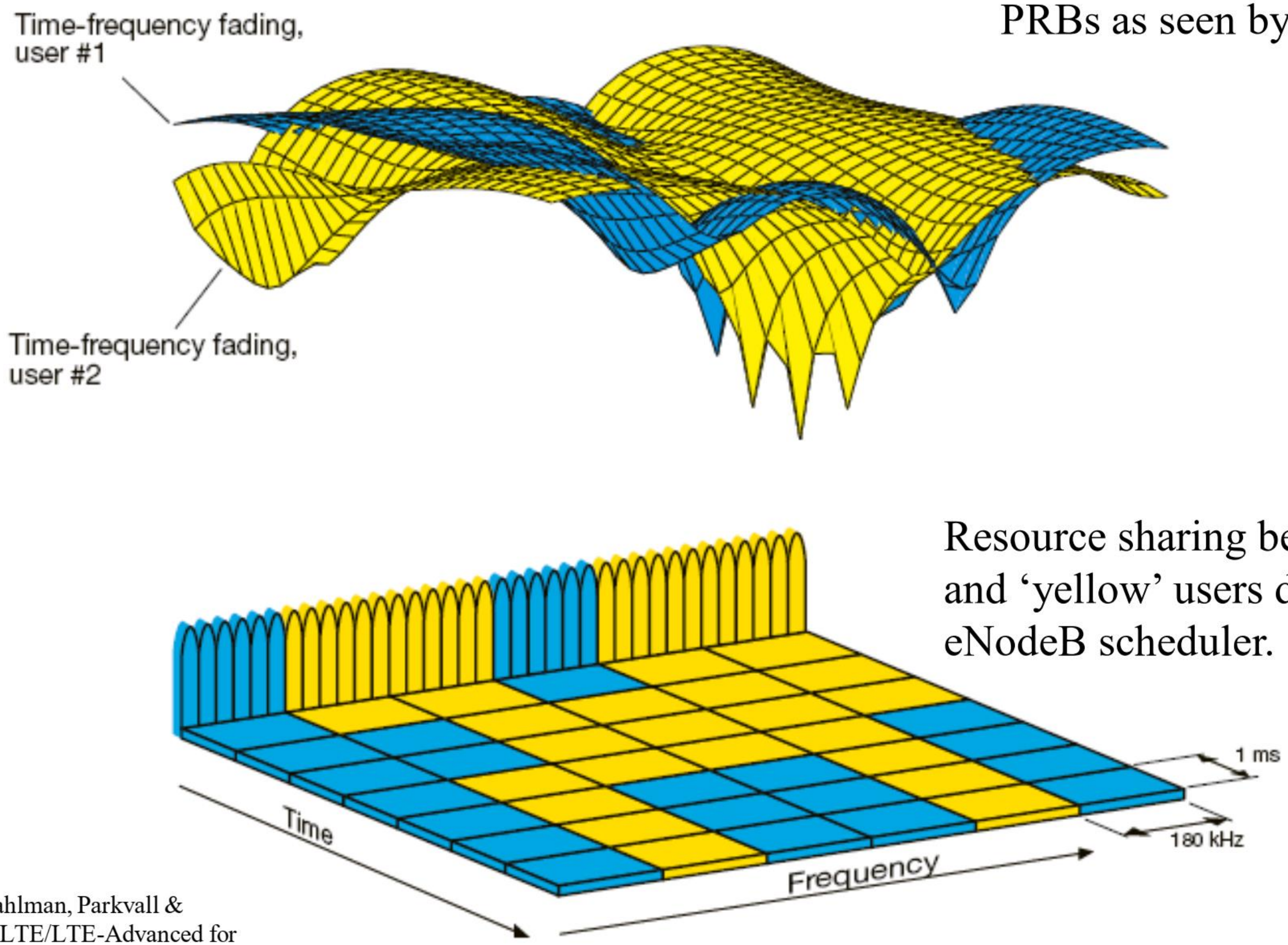
- Packet scheduling is carried out jointly with the **link adaptation** i.e. scheduling decisions include selection of the modulation and coding scheme.
  - The allocated RBs and selected modulation and coding combinations are informed to the scheduled users through physical downlink control channel (PDCCH).
  - The link adaptation unit primarily bases its decisions on **Channel Quality Indicator** (CQI) feedback from the users in the cell.

CQI index	Modulation	Coding rate × 1024	Bits per resource element
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Ref: 3GPP TS 36.213

Resource blocks in frequency-time domain

Channel time-frequency selective power response for PRBs as seen by UEs.



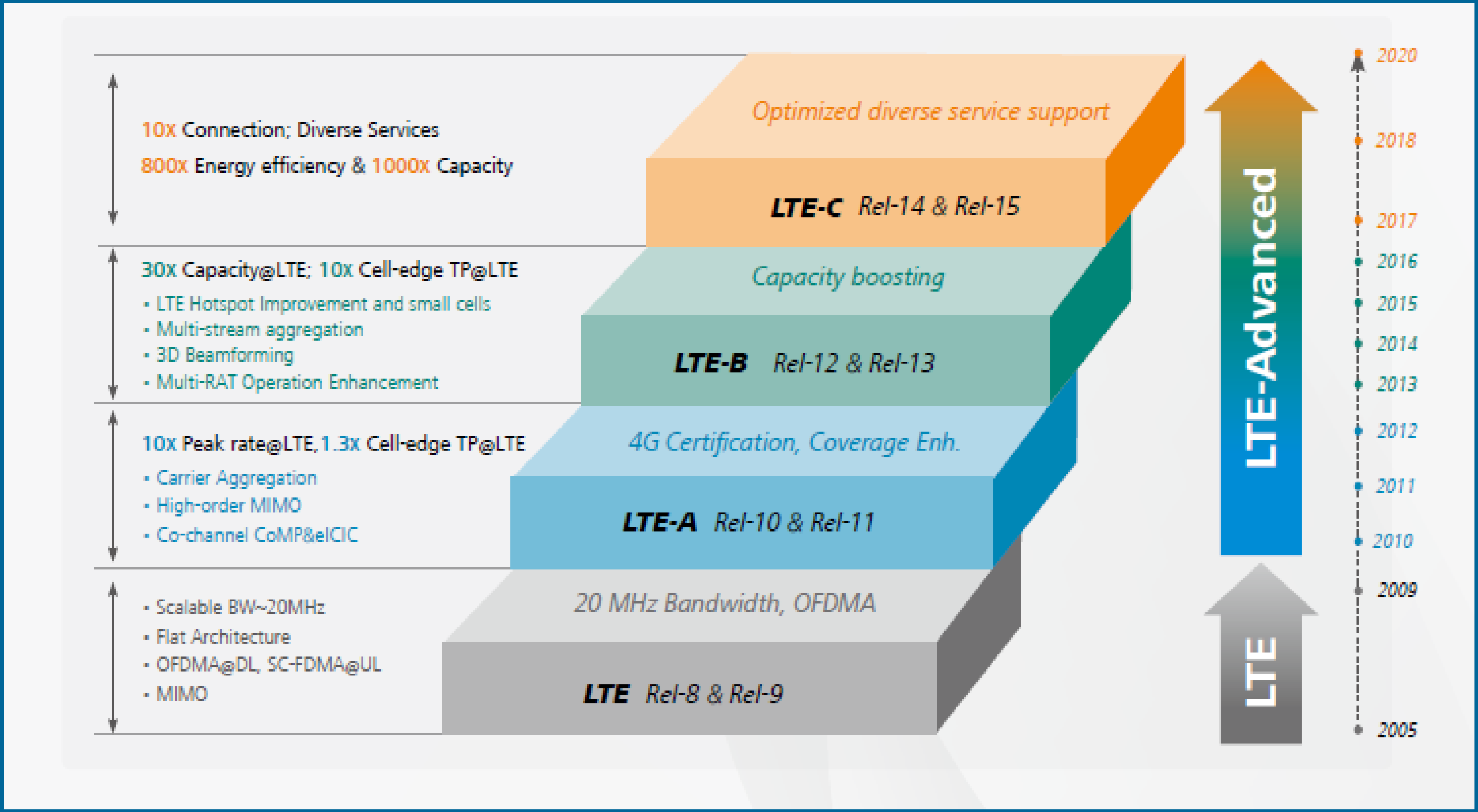
Resource sharing between 'blue' and 'yellow' users decided by eNodeB scheduler.

Source: Dahlman, Parkvall & Sköld, 4G LTE/LTE-Advanced for mobile broadband

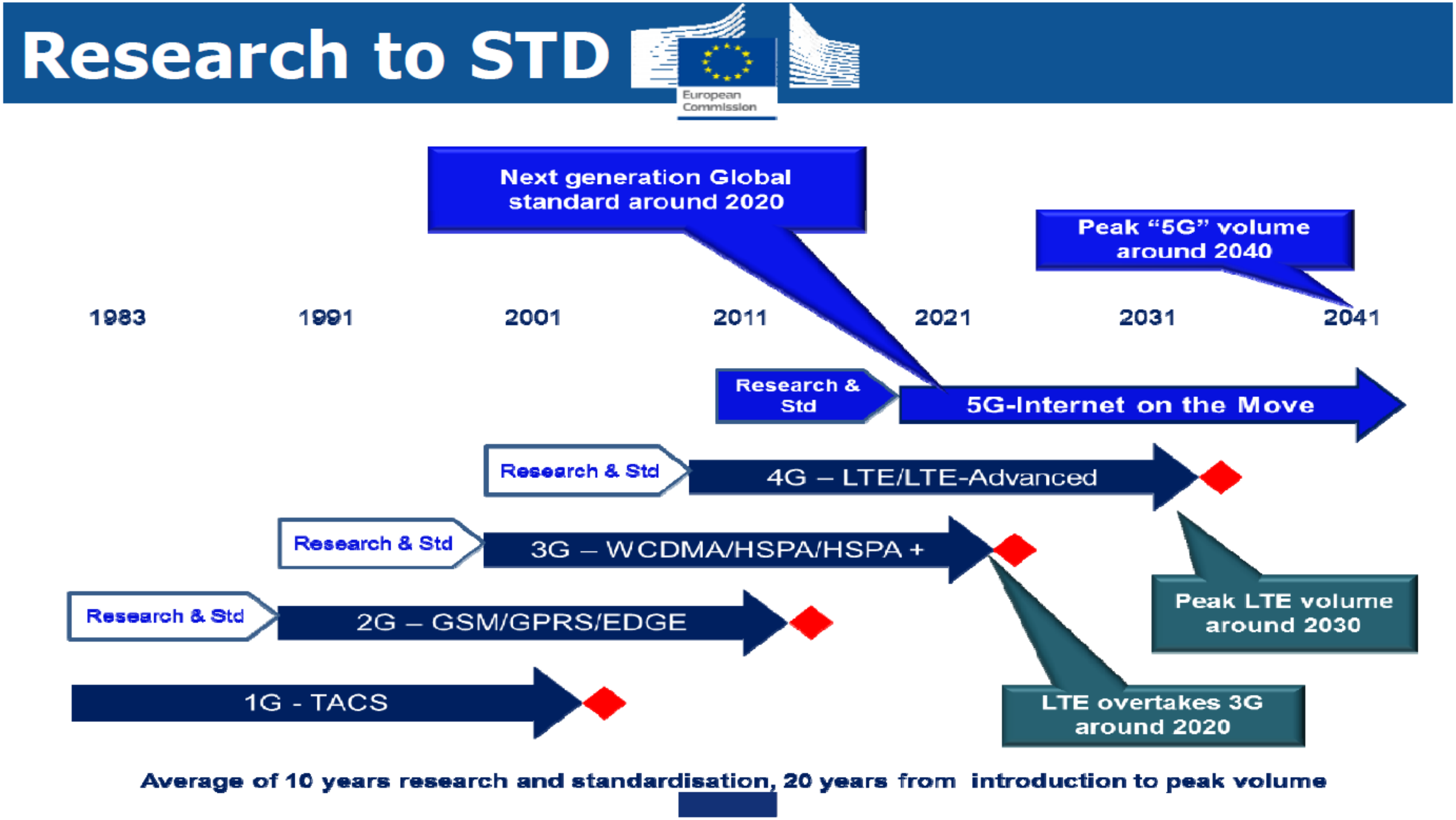
LTE Releases

- So far we covered basics of LTE in Rel 8/9.
- Next: Rel 10, also known as LTE-Advanced (LTE-A)

LTE advanced features



ETSI Meeting May 2016



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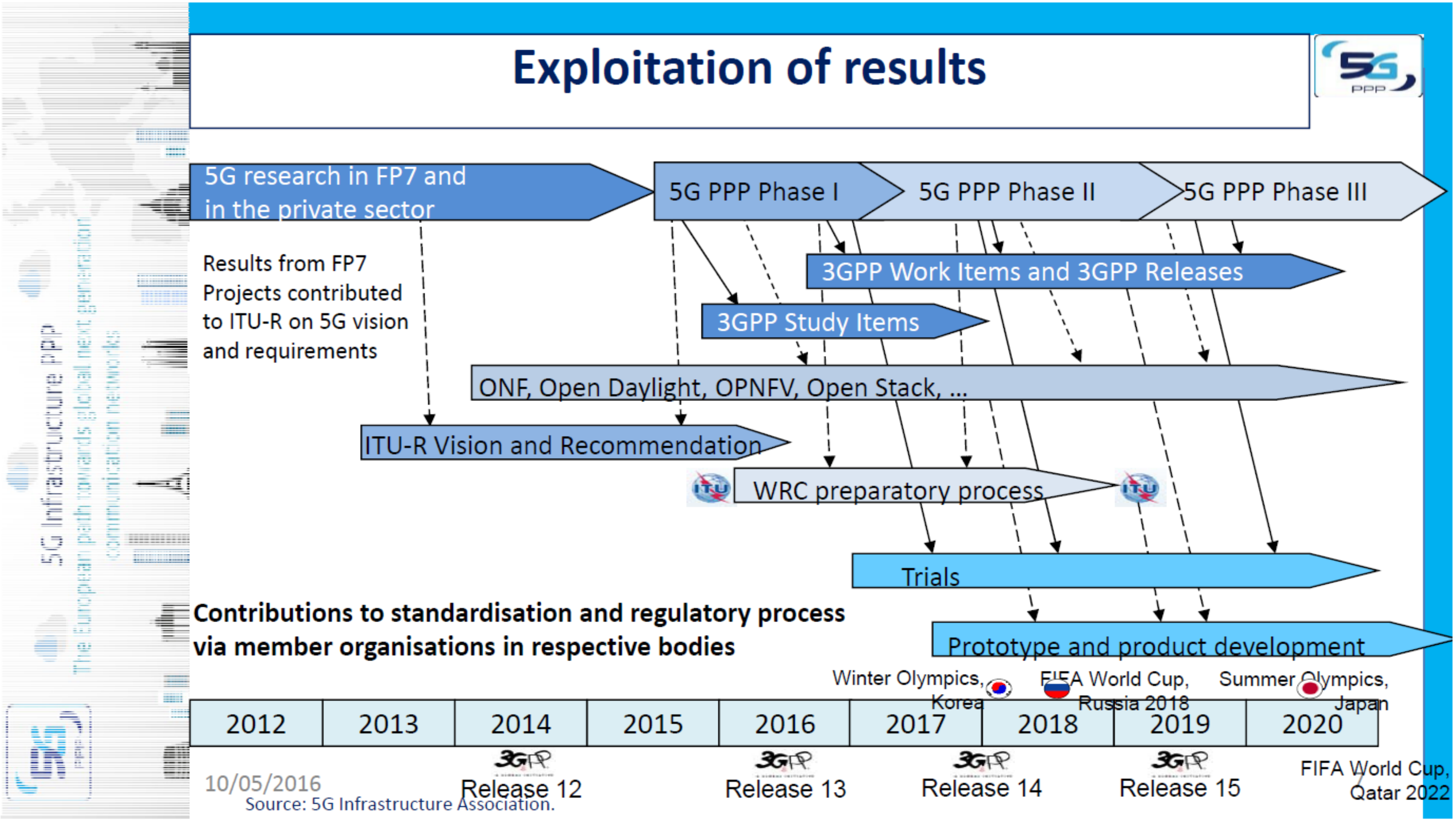
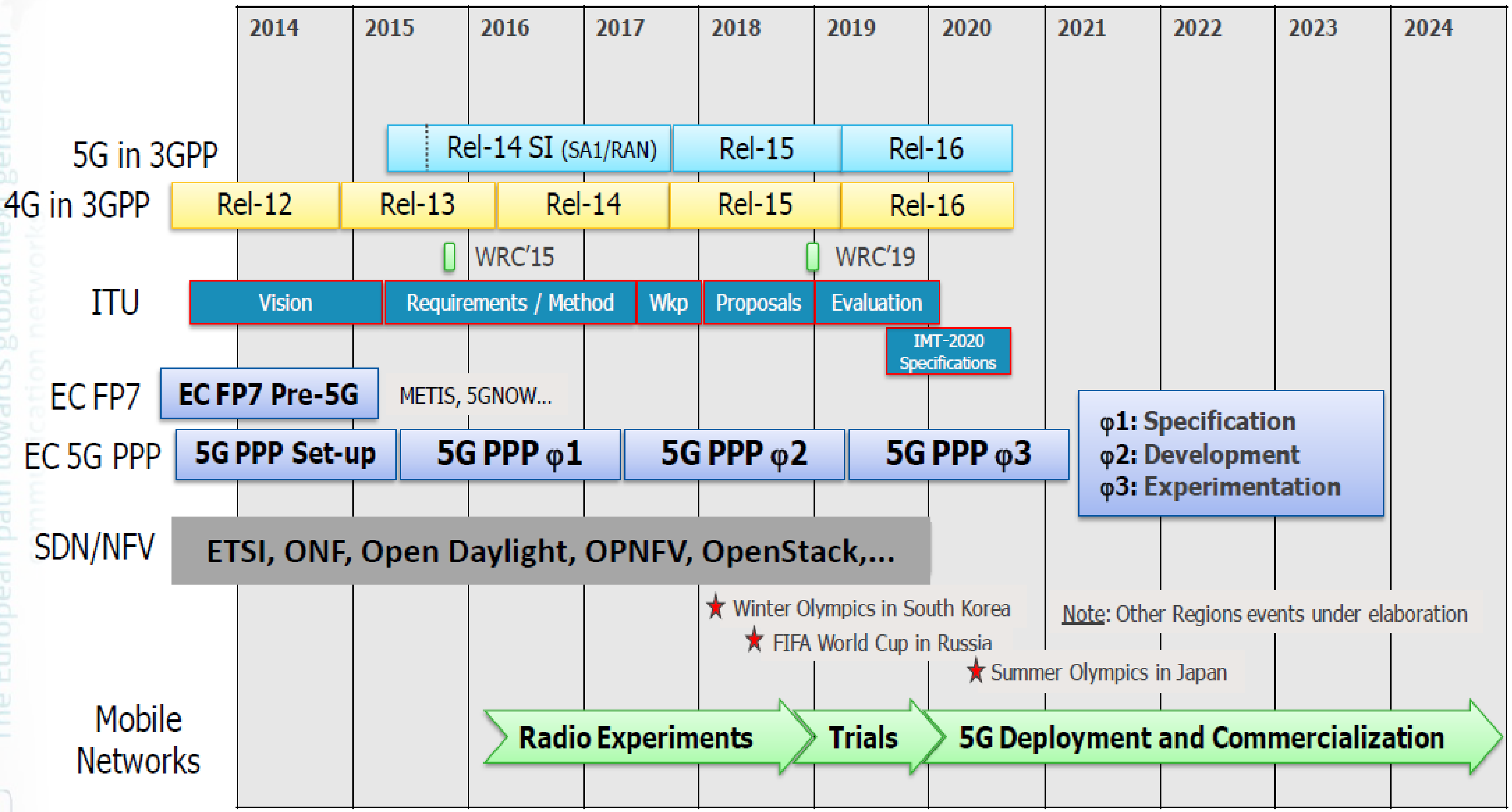


5G Time-Line
Mapping to 3GPP projected schedule

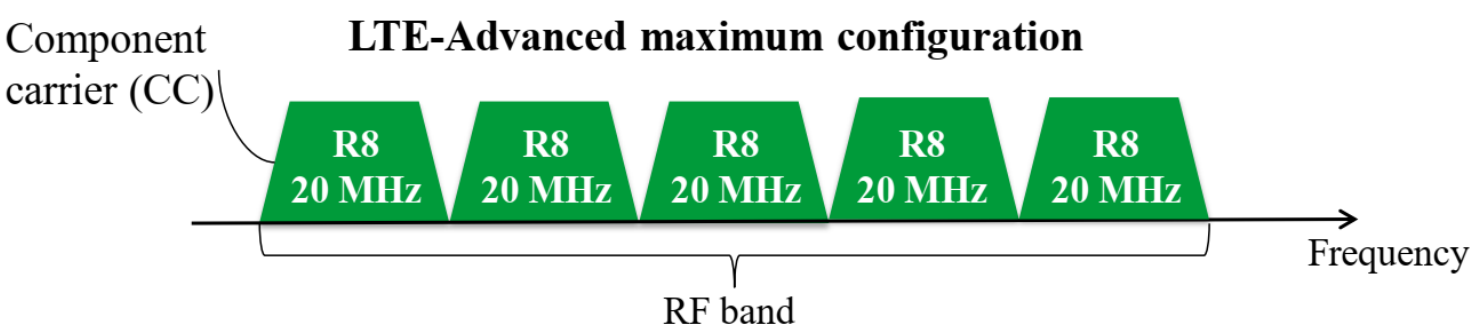


LTE-Advanced (Rel 10,11)

- Realized LTE Rel.9 peak rates:
  - In downlink 150 Mbps achieved on 20 MHz bandwidth with 2x2 MIMO. 300 Mbps achieved on 20MHz band if 4x4 MIMO is used.
  - In uplink 75 Mbps reached in LTE Rel.8 with single transmit antenna in UE.
- LTE-Advanced targets
  - 1 Gbps with 4x4 MIMO in downlink and 500 Mbps in uplink
  - How to achieve this goal?
  - One mechanism: Carrier Aggregation..

CA Principle

- The LTE-Advanced target peak data rate of 1 Gbps in downlink and 500 Mbps in uplink can be achieved with bandwidth extension from 20 MHz **up to 100 MHz**.
- In LTE-Advanced this extension is achieved through **carrier aggregation**
- By combining N LTE Release 8 **Component Carriers** (CC) together to form N x LTE bandwidth → up to 5 x 20 MHz = 100 MHz operation bandwidth could be obtained

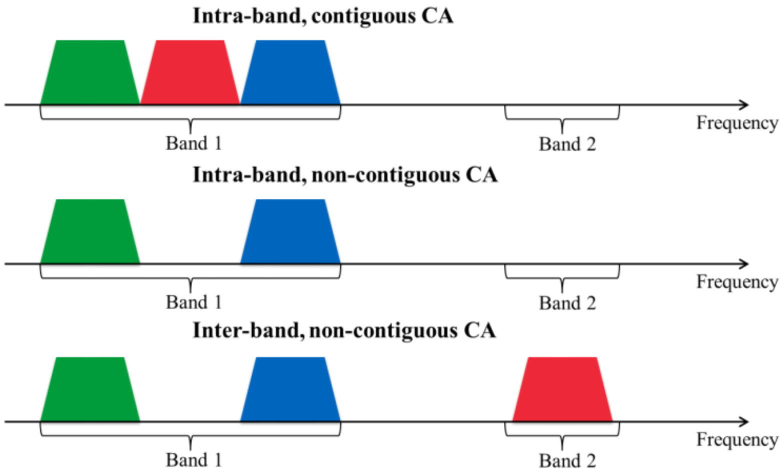


Contiguous vs non-contiguous CA

- In practice it seems that in the low frequency band (< 4 GHz) it will be difficult to allocate continuous 100 MHz bandwidth for a mobile network.
- ***The non-contiguous CA*** *technique provides a practical approach to enable mobile network operators to fully utilize their current spectrum resources*
  - Thus, to use also currently unused scattered frequency bands and those already allocated for some legacy systems, such as GSM and 3G systems.

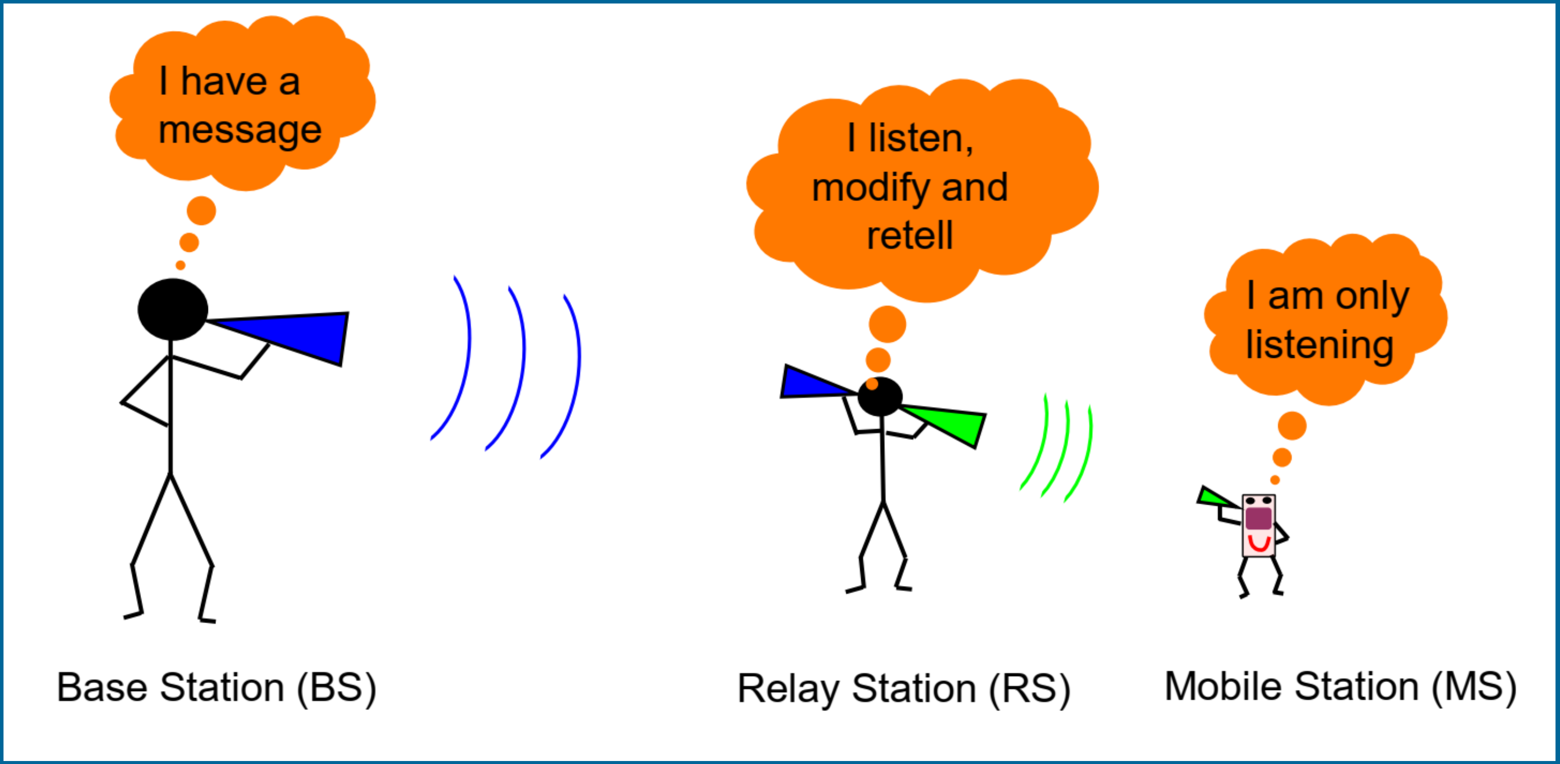
Contiguous vs non-contiguous CA

- *In terms of UE complexity, cost, capability, and power consumption, it is easier to implement contiguous CA* with minimal changes to the physical layer structure of Rel.8-9 LTE.
  - *In non-contiguous CA advanced RF components are needed in receiver in order to receive non-adjacent carriers.*
  - Compared to non-contiguous CA, *it is easier to implement resource allocation and management algorithms for contiguous CA*.



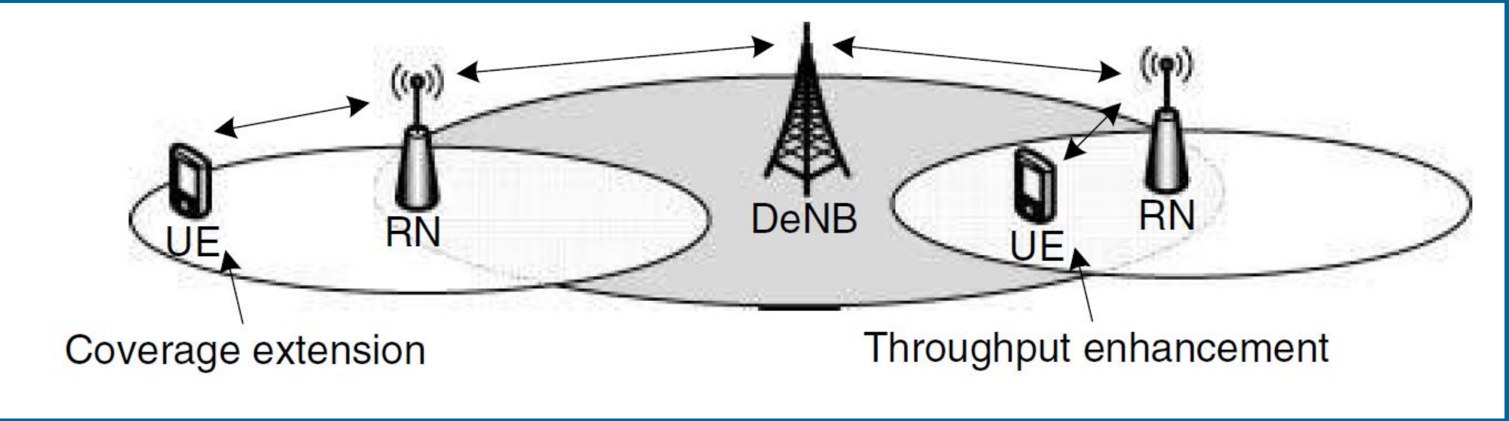
Other ideas: Relaying

- Repeaters already used in 2G/3G as "Amplify and Forward"
- In LTE, mostly digital version that "Detect and Forward"



Relay

- The Relay technique enables the extension of cell coverage by the use of an additional network node called the Relay Node (RN)
- CA and RN are the key features of LTE-Advanced
- Relaying is performed at the IP packet level
- Donor eNB (DeNB): The eNB serving the RN



Why Relays for LTE?

Some key requirements for LTE-Advanced

- 1 Gbps on the downlink and 500 Mbps on the uplink.
- Higher peak and average spectral efficiencies than in LTE Rel'8.
- More homogeneous distribution of the user experience over the coverage area.

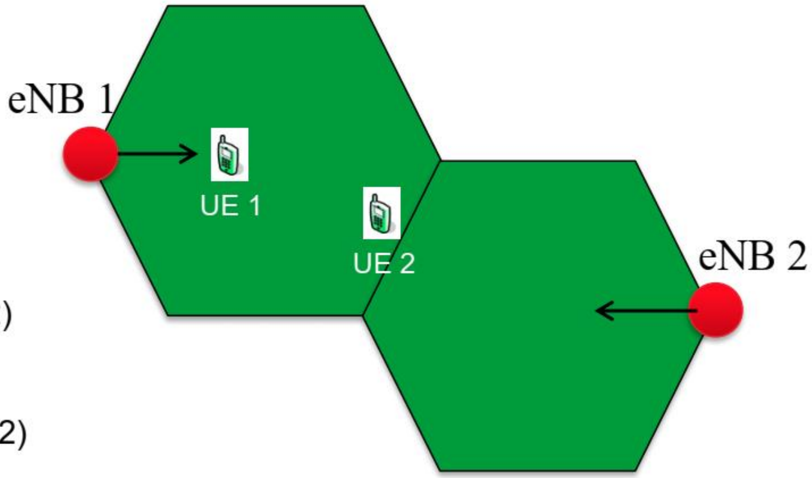
Expected properties of LTE-Advanced relays

- Enhanced capacity in hotspots.
- Enhanced cell coverage.
- Overcome extensive shadowing.
- Enable more homogenous user experience.
- Low total cost of operation (TCO).

Another Idea: CoMP

- Coordinated Multipoint Transmission and Reception

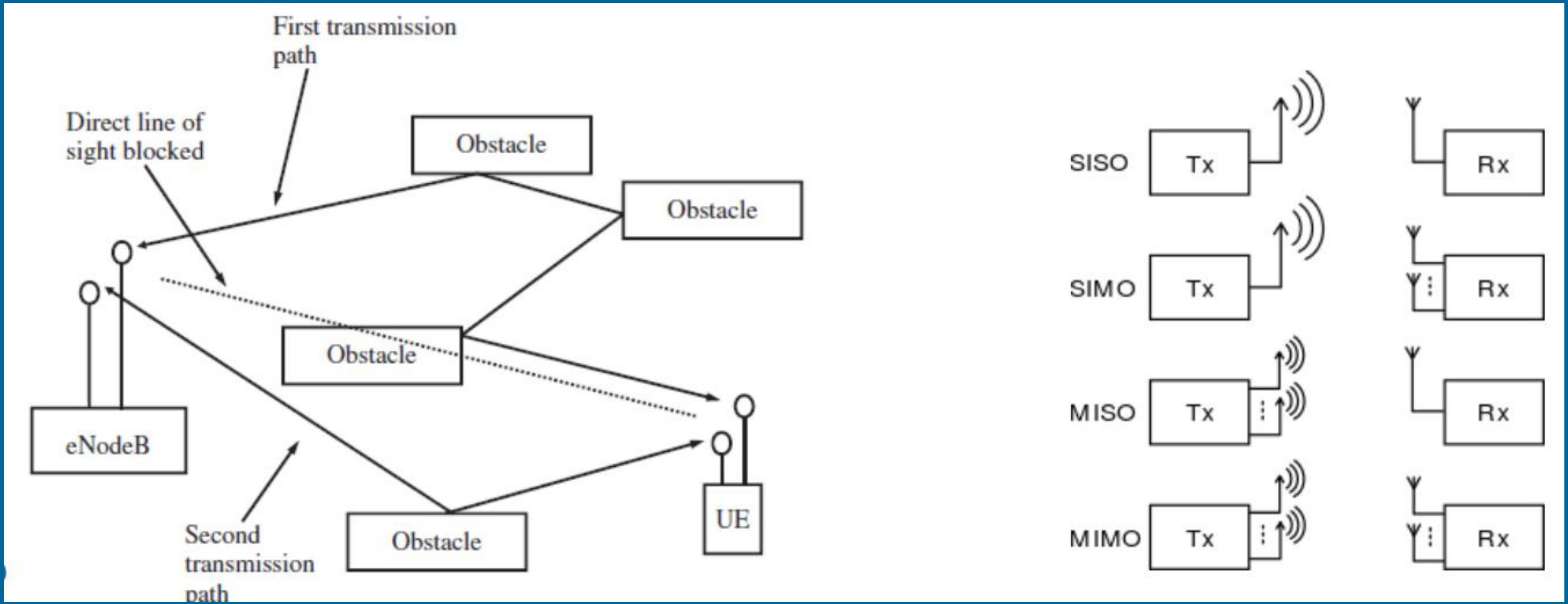
- Cell edge user typically suffer the most from inter-cell interference.
  - *Downlink*: Inter-cell interference occurs due to parallel transmissions from adjacent base stations
  - *Uplink*: Intercell interference occurs due to simultaneous transmission (on the same time-frequency resources) by users in adjacent cells.
- The goal of the CoMP is to further minimize inter-cell interference for adjacent cells that are operating on the same frequency



UE 1 in cell center
- Strong signal from serving BS (eNB1), weak interferer (eNB2)

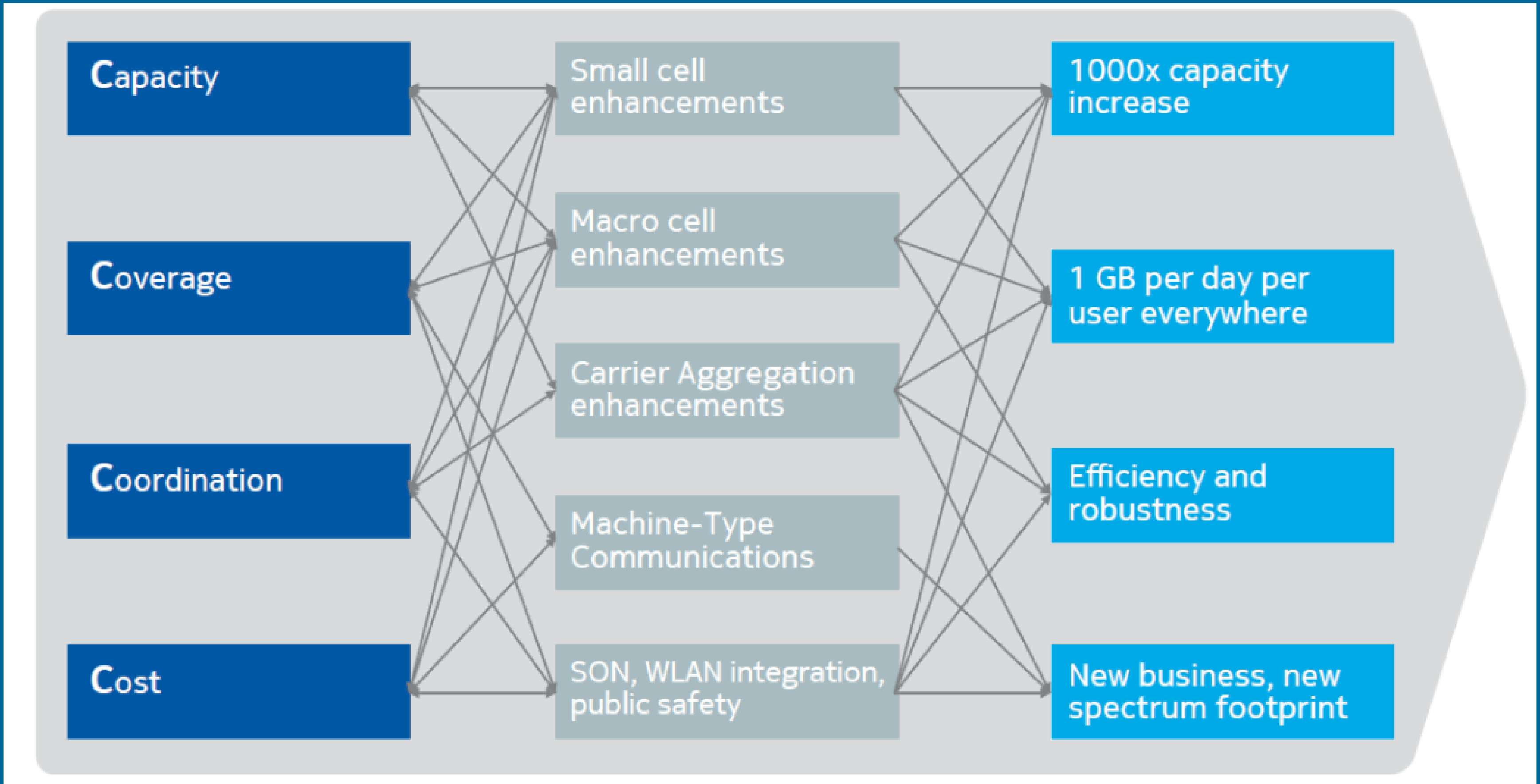
UE 2 at cell edge
- Weak signal from serving BS (eNB1), strong interferer (eNB2)

Final Idea: MIMO



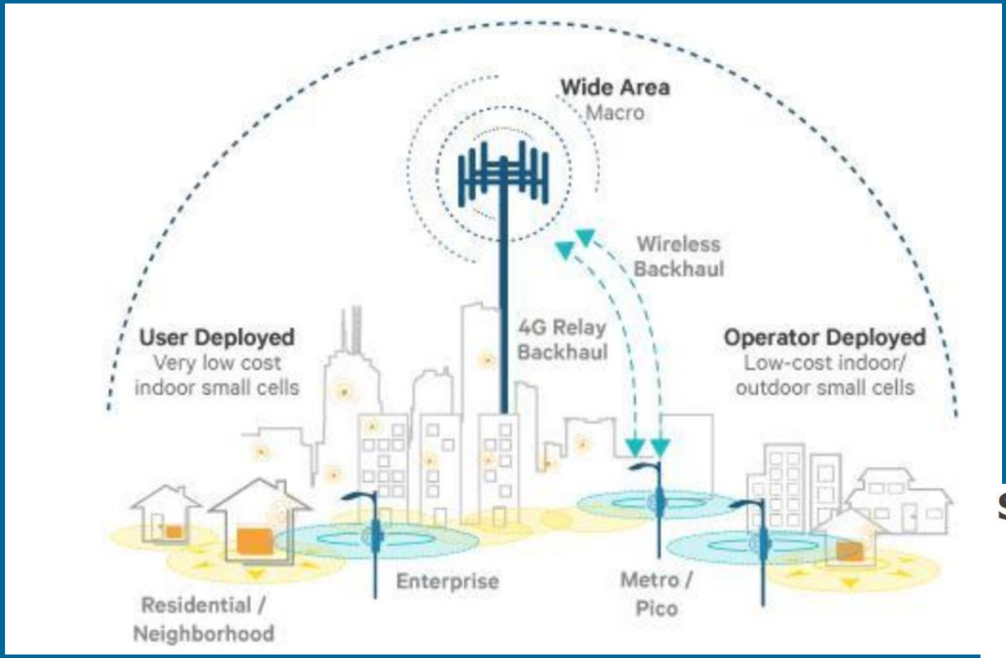
		LTE Rel.8	LTE-A target
Peak data rate	DL	300 Mbps (4x4 MIMO, 20 MHz)	1 Gbps (8x8 MIMO, 20 + 20 MHz)
Peak spectral efficiency	DL	15 bps/Hz	30 bps/Hz

Rel 12: Requirements

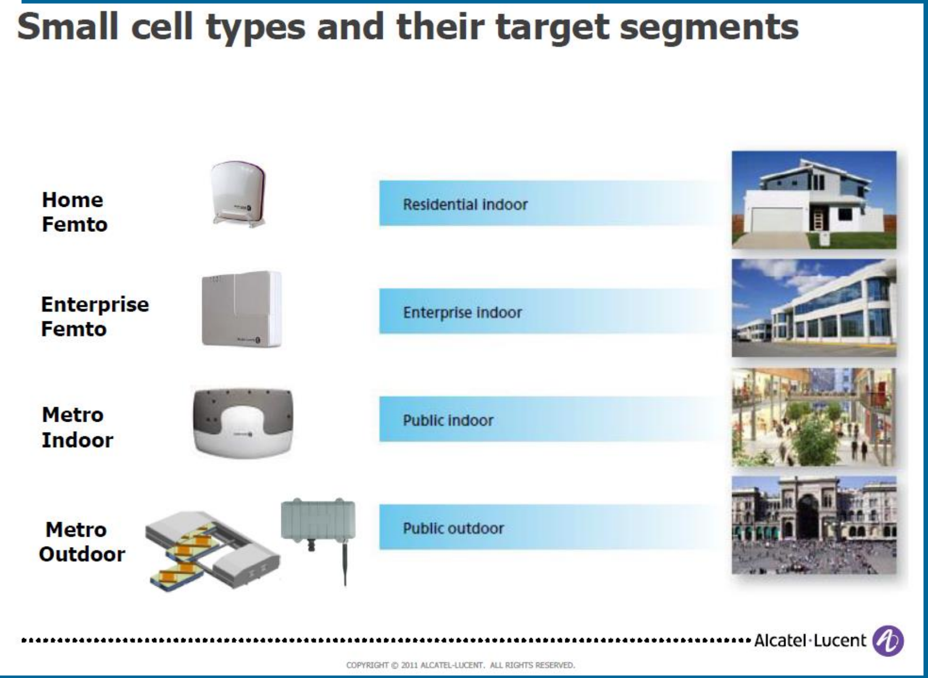


- 4 to 64 QAM in Rel 8-11
- In Rel 12, also 256QAM added for indoor small cells or outdoor LOS

Small Cells



Wide Area
Macro
Wireless
Backhaul
4G Relay
Backhaul
User Deployed
Very low cost
indoor small cells
Operator Deployed
Low-cost indoor/
outdoor small cells
Residential /
Neighborhood
Enterprise
Metro /
Pico



Small cell types and their target segments
Home
Femto
Residential indoor
Enterprise
Femto
Enterprise indoor
Metro
Indoor
Public indoor
Metro
Outdoor
Public outdoor
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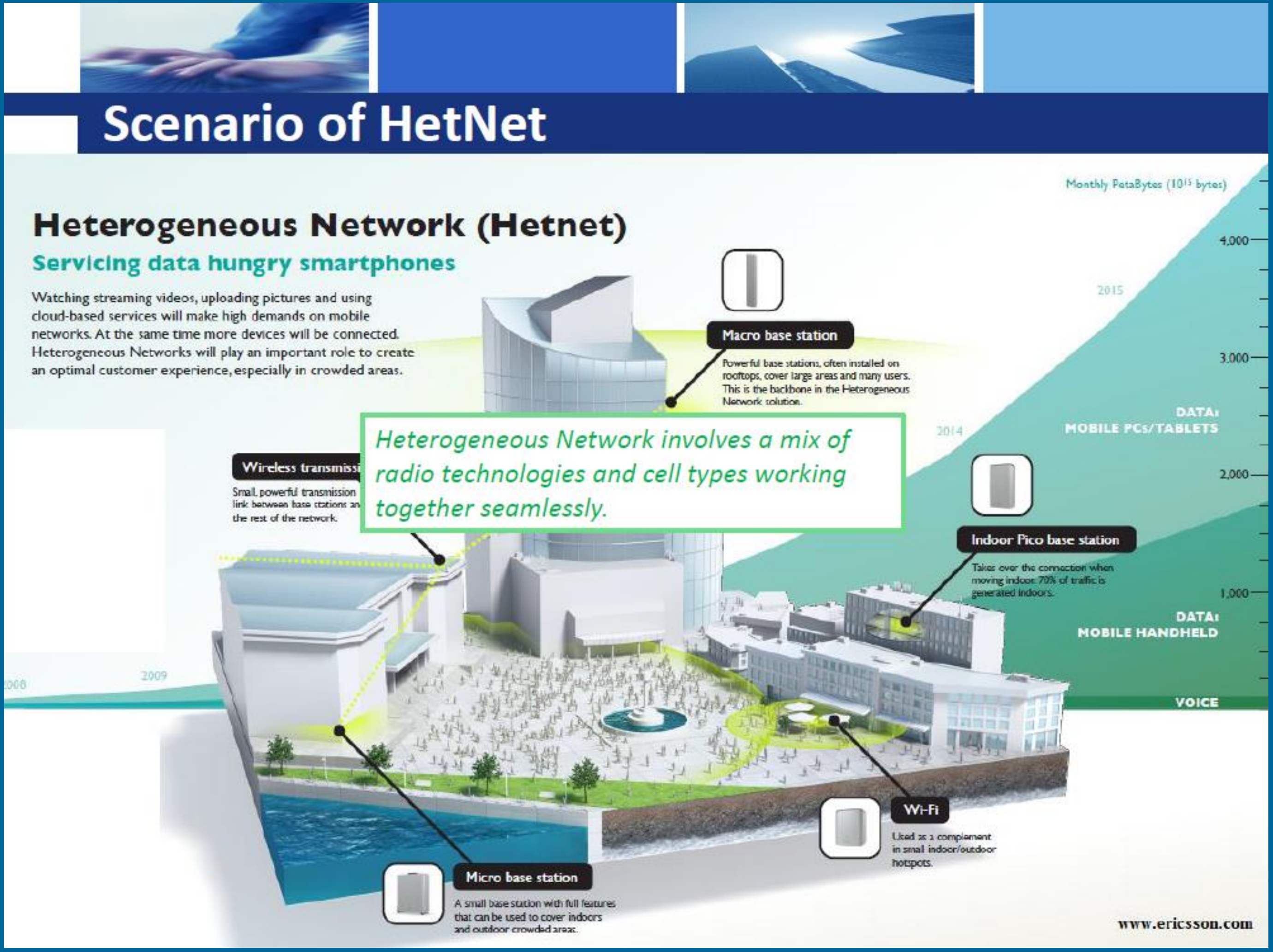
Heterogeneous Networks (Hetnets)

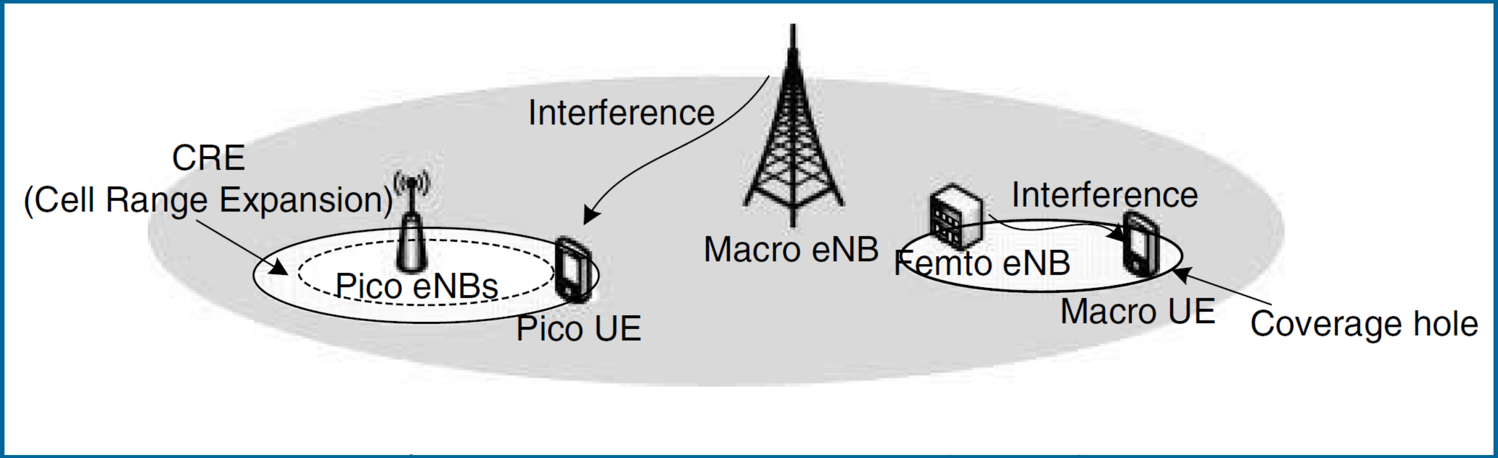
- Different types of cells to work in nearby regions



Challenges of Small Cells

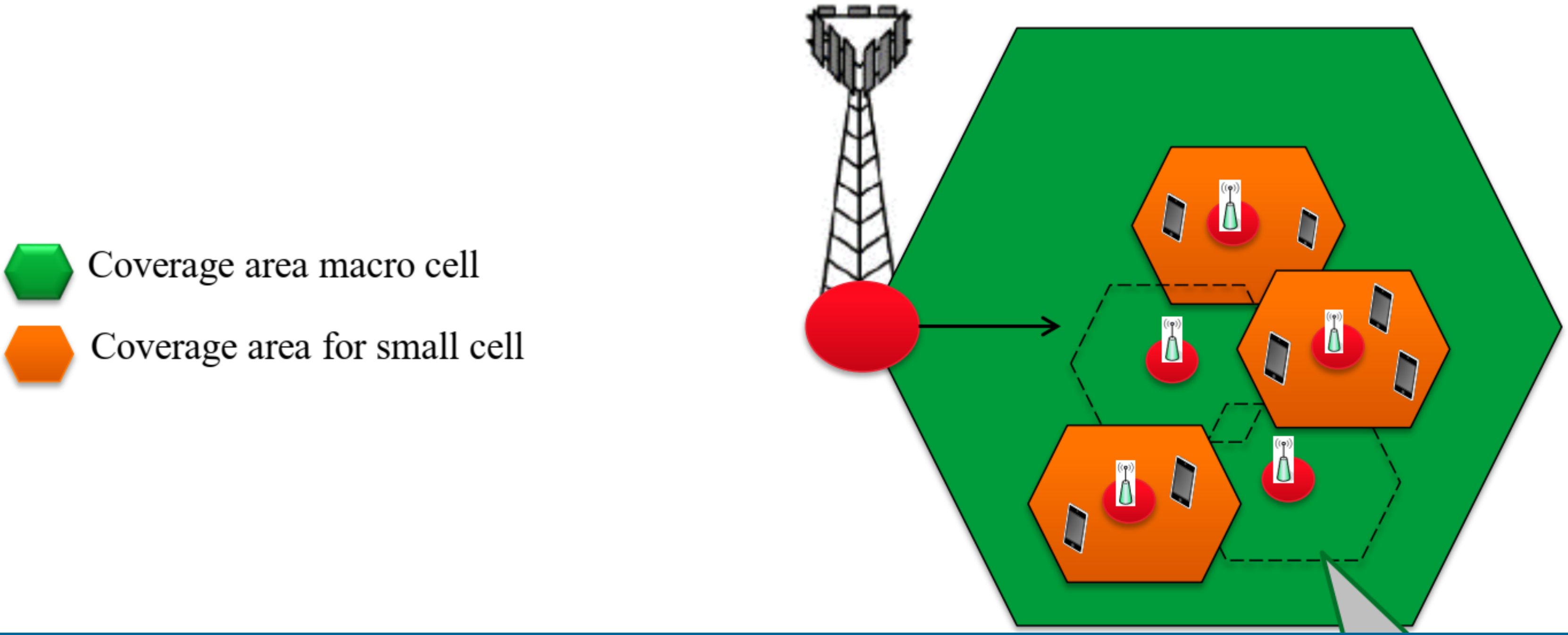
- More handovers and power needed for backhaul
- Interference between Macro and Femto cells

- eICIC: Enhanced Inter-Cell Interference Coordination
- Small cell ON/OFF for reduce interference and load balancing/shifting



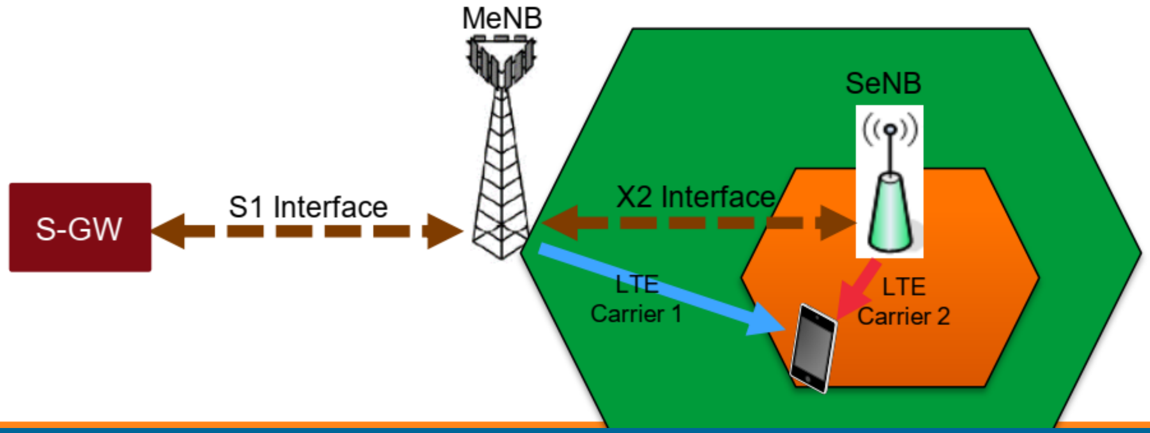
Small Cell ON/OFF/Discovery

- Using small cell ON/OFF to reduce interence
  - Small cell with no traffic stop transmitting reference signals (OFF state)
  - Small cell in OFF state, only send discovery signals once every ≥40ms to capture UEs that may wander into its coverage area



Additional Rate: Dual Connectivity

- Dual connectivity increases user throughput by allocating users with **component carriers from two different eNBs**
  - Also known as inter-site carrier aggregation (note: conventional carrier aggregation combines carriers from same eNB)
  - Initially specified in Release 12 (downlink only) and further refined in Release 13 (uplink added)
  - Master eNB (MeNB) and Secondary eNB (SeNB, typically a small cell)
  - Note: Dual connectivity differs from CoMP Joint Transmission because eNBs utilise different carriers (non-overlapping frequency bands) and are also not duplicating the data stream to the users!

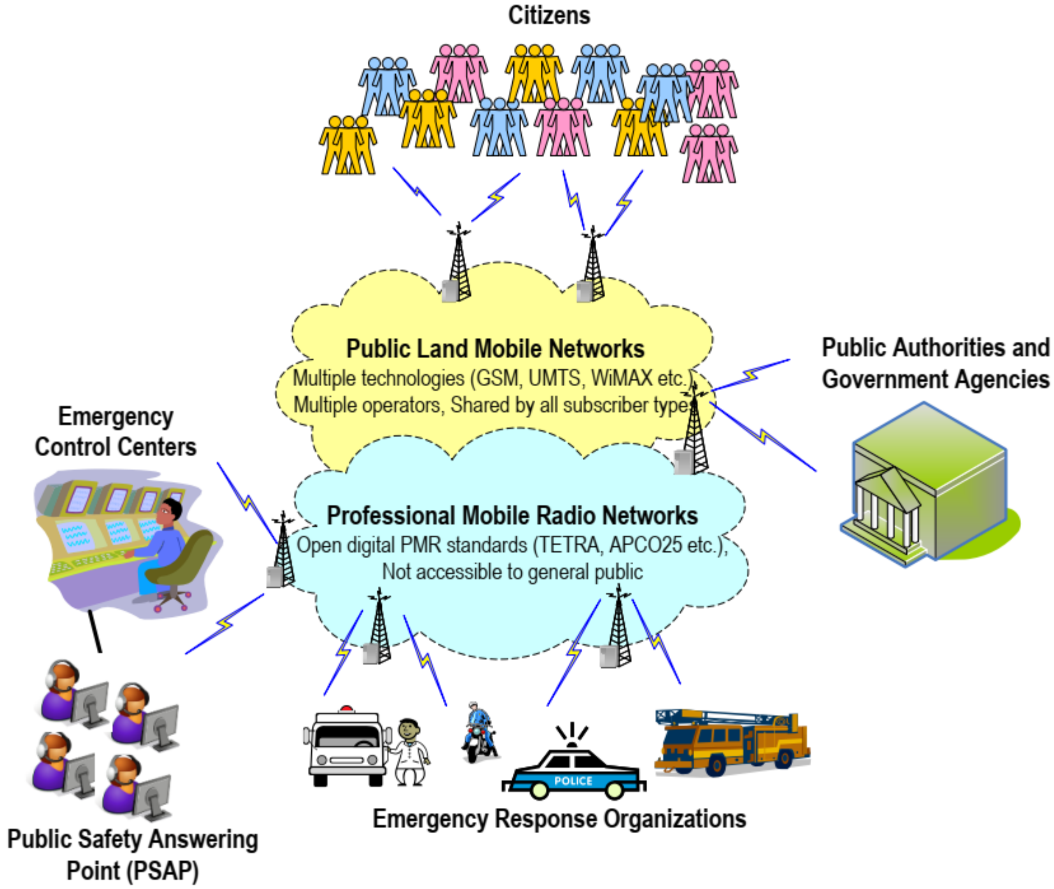


D2D in Rel 12: Proximity Services (ProSe)

- UEs directly talk to each other
- Main Motivation: Public Safety
- Device discovery is also motivated by commercial opportunity for mobile operators in offering a platform to third party (non public safety) service providers.

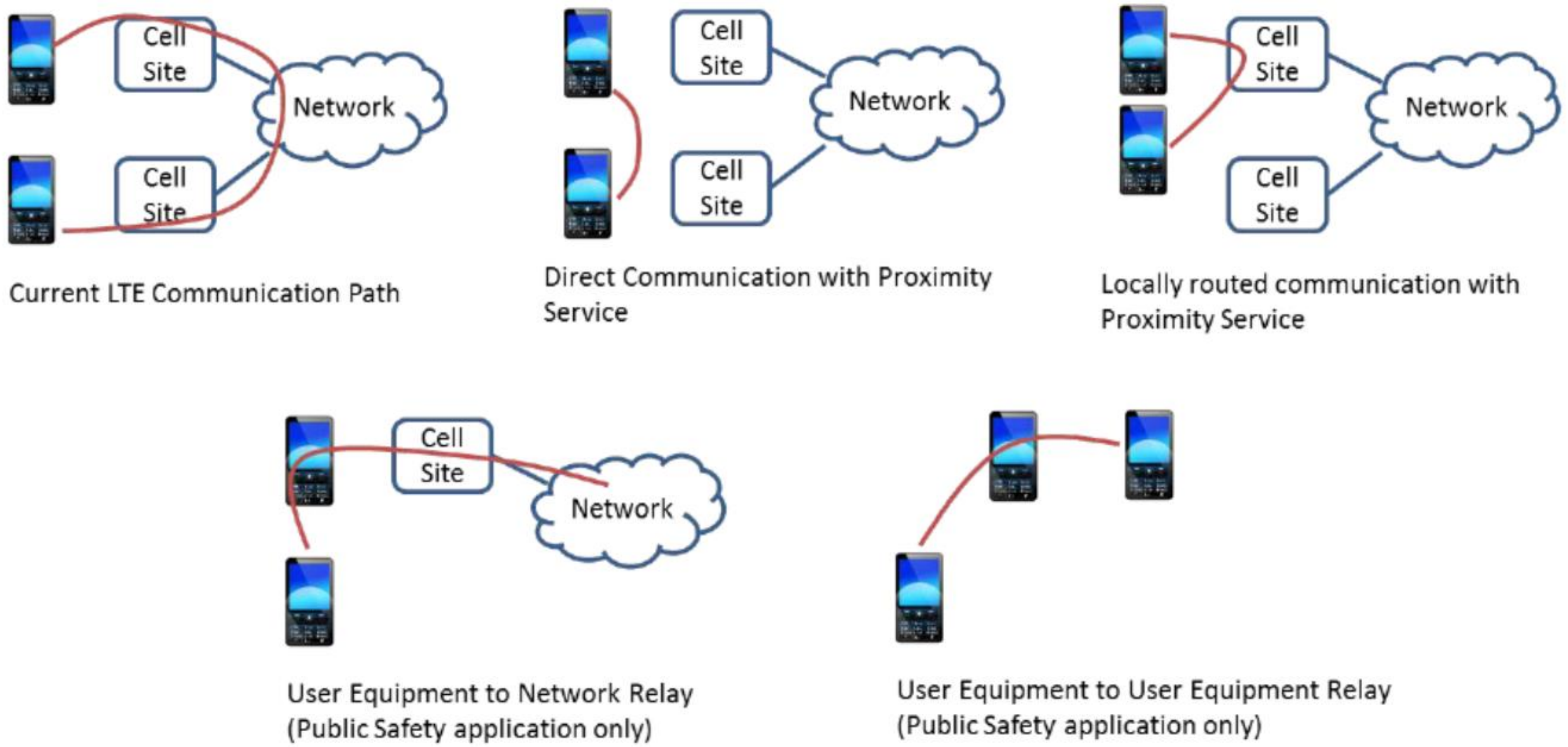
Need for Dedicated PMR networks

- Professional Mobile Radio (PMR) for public safety communications
  - Dedicated networks for authorities
  - Improved survivability to possible damage
  - More robust security
  - Supplementary services to support various operational requirements of users
- Example digital PMR standard
  - TErrestial Trunked RAdio (**TETRA**) specified by ETSI



LTE for Public Safety Communications

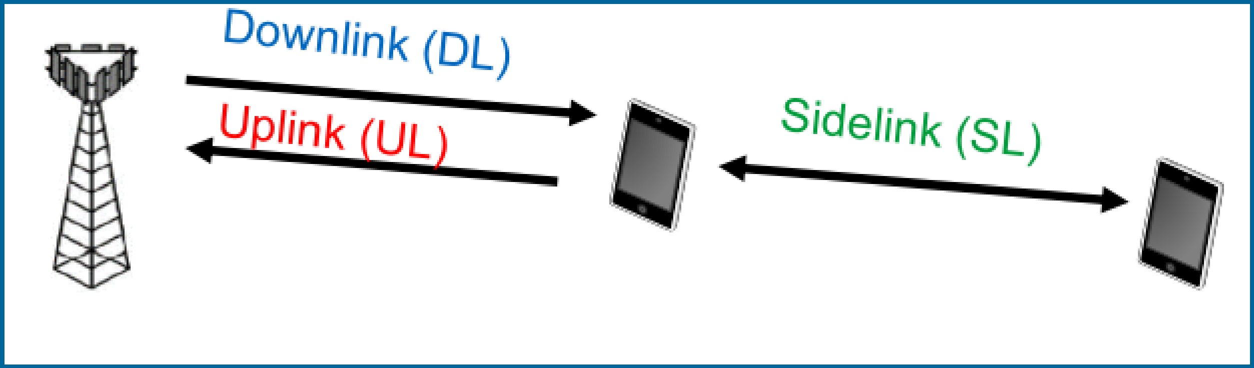
- ProSe for direct communications in public safety communications



Proximity Service Examples

- Why can’t two mobiles directly talk to each other in current LTE?!

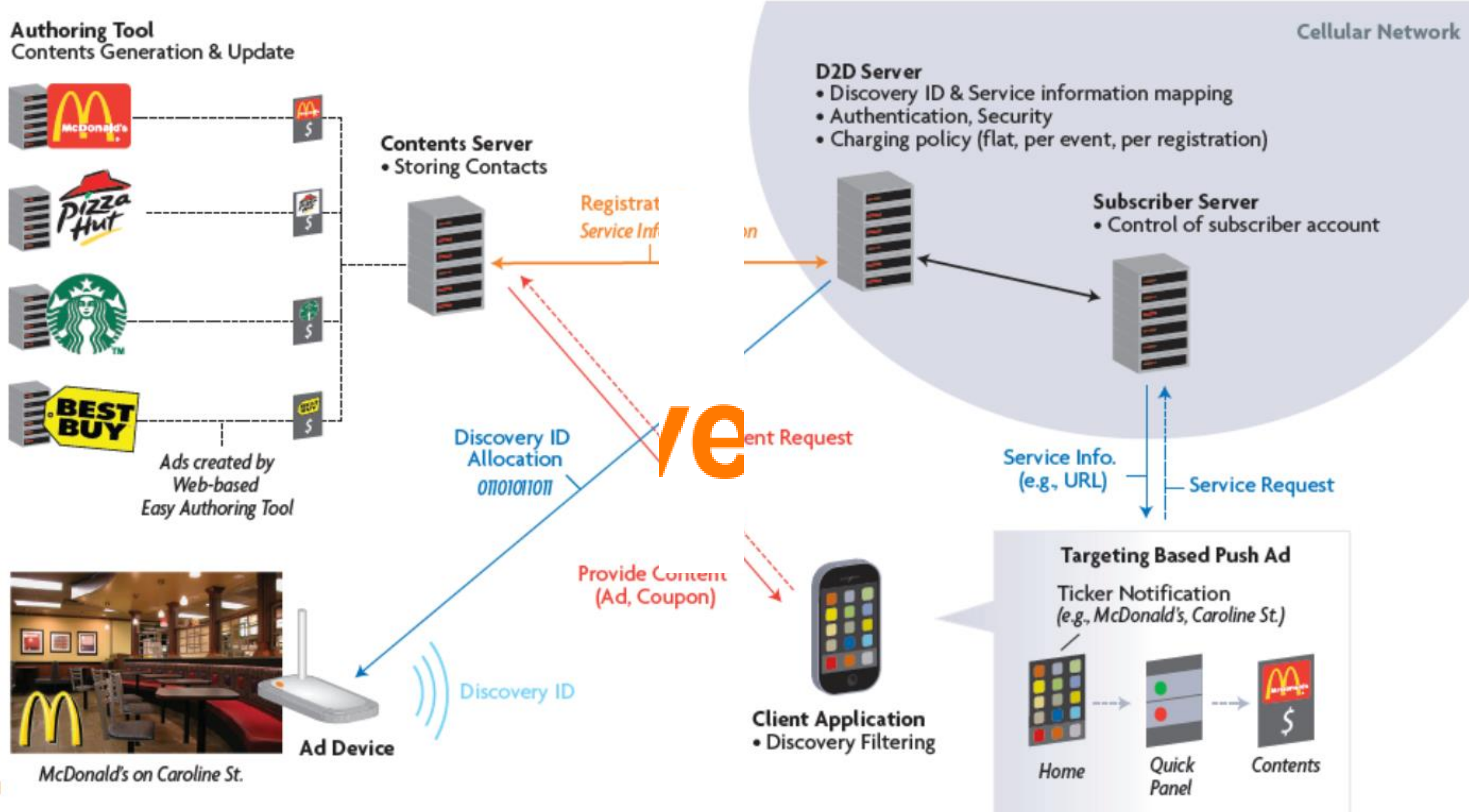
ProSe Architecture



- ProSe introduces a **sidelink (SL)** to existing uplink (UL) and downlink (DL)
- D2D sidelink uses resources allocated from the existing LTE UL
- D2D SL is itself TDD-based even if cellular LTE is FDD

Device Discovery use Cases

- Mostly commercial use cases (in-store pushed adverts, coupon retrieval etc.)



- Other solutions: iBeacon, Wifi Aware,..
- But LTE has much more coverage…

Rel 13

- Requirements/motivations for Rel. 13
  - Continue/complete developments of enhancements introduced in LTE-Advanced Release 12 (e.g. ProSe)
  - Enhance interworking with Wi-Fi
  - Enhance network for IoT
- The new label LTE-Advanced Pro introduced to describe enhancements of Rel. 13 and onwards

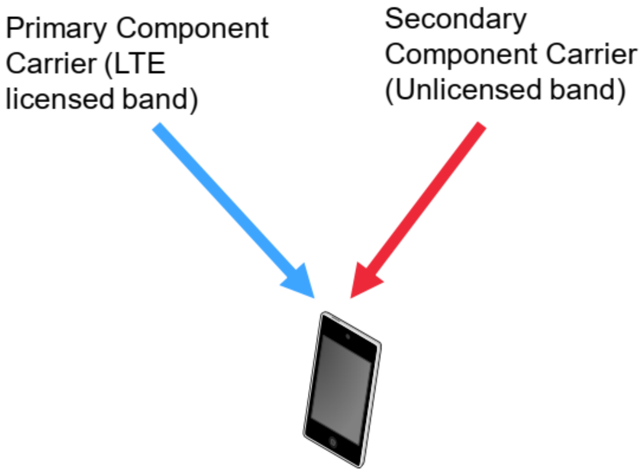
LTE-A Pro Rel. 13 E-UTRAN Highlights

- Self-Optimizing Networks (SON) for Active Antenna System (AAS) Deployments
- Elevation Beamforming (EBF) and Full Dimension (FD) Multi-Input Multi-Output (MIMO)
- Enhanced Signaling for Inter-eNB Coordinated Multi-Point (CoMP)
- Further LTE Physical Layer Enhancements for Machine Type Communication (MTC)
- Indoor Positioning Enhancements
- **Licensed Assisted Access (LAA) Using LTE**
- **Carrier Aggregation (CA) Enhancements**
- Downlink Multi-User Superposition Transmission (MUST)
- Radio Access Network (RAN) Aspects of RAN Sharing Enhancements
- Enhanced LTE Device-To-Device (D2D) Proximity Services (ProSe)
- Dual Connectivity Enhancements
- **LTE-Wireless Local Area Network (WLAN) Radio Level Integration**
- Radio Access Network (RAN) Enhancements for Extended Discontinuous Reception (DRX) in LTE

Licensed Assisted Access(LAA) and LTE-WLAN Aggregation (LWA)

LTE License Assisted Access (LAA)

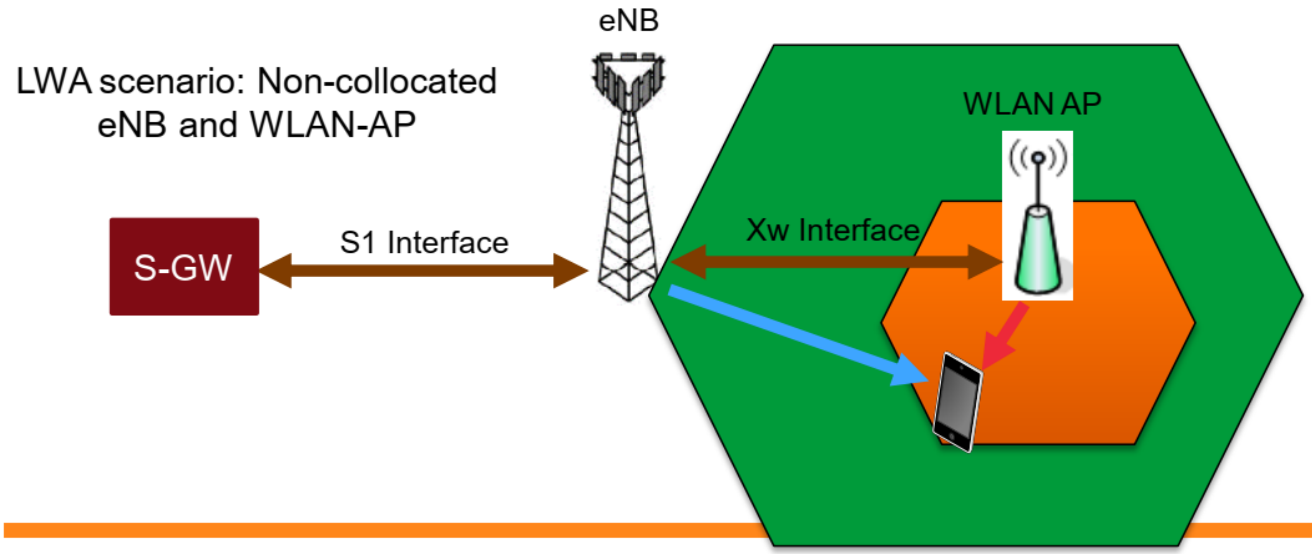
- In Release 13 LTE-LAA is essentially a downlink carrier aggregation technique
- Utilises component carriers from licensed and unlicensed bands
  - Primary component carrier is always from licensed band (licensed carrier for control and mobility)
  - One or more Secondary component carriers from 5 GHz unlicensed bands
- More component carriers in Release 13:
  - Release 10-12 carrier aggregation: up to 5 component carriers (20 MHz x 5 = 100 MHz)
  - Release 13 carrier aggregation: up to **32 component carriers (20 MHz x 32 = 640 MHz)**



- In 3GPP deployment scenarios:
  - Macro cells use only the licensed band
  - Small cells may use licensed or unlicensed band

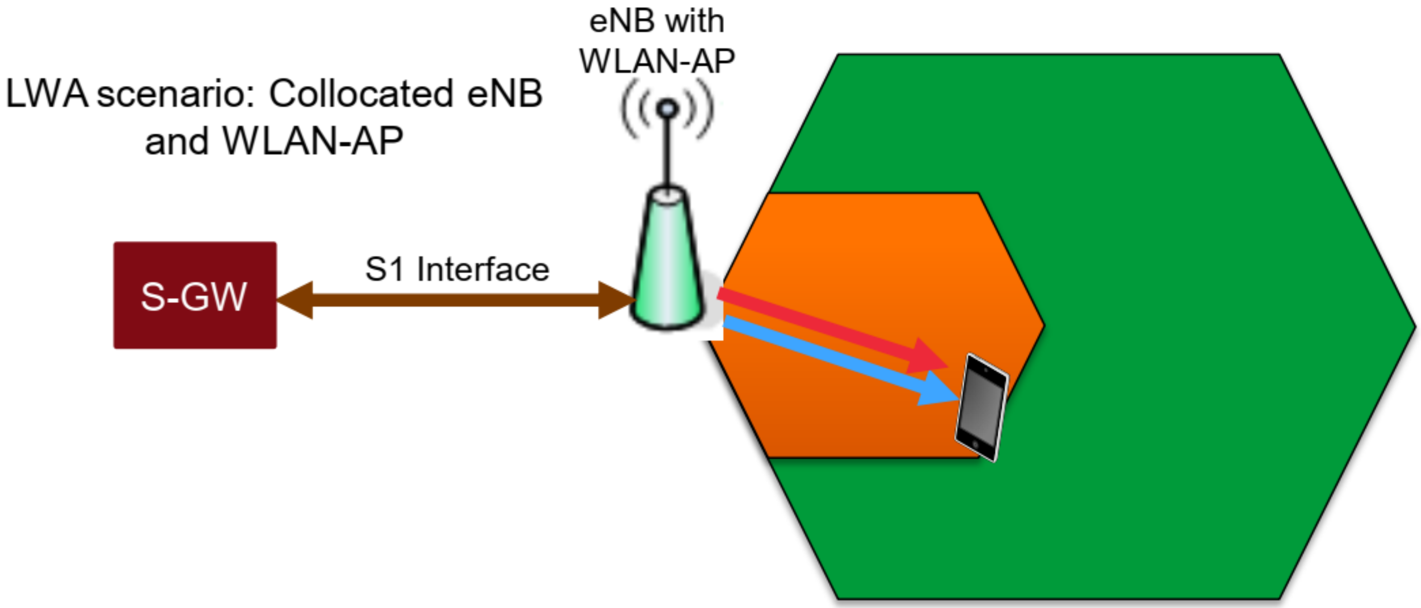
LTE-WLAN Aggregation (LWA)

- LWA increases user throughput by utilizing LTE and WLAN radio resources (carriers) simultaneously
  - A type of carrier aggregation with WLAN carrier being one of the component carriers
  - Similar to Release 12 Dual Connectivity, but the Secondary eNB (SeNB) is replaced by a WLAN access point (AP)
- Release 13 specifies a new interface (**Xw**) between eNB and WLAN AP



LTE-WLAN Aggregation (LWA)

- LWA deployment scenario for collocated eNB and WLAN-AP
  - Typical in multiradio small cells
  - Scenario could also be assumed for WLAN-AP with ideal backhaul to eNB

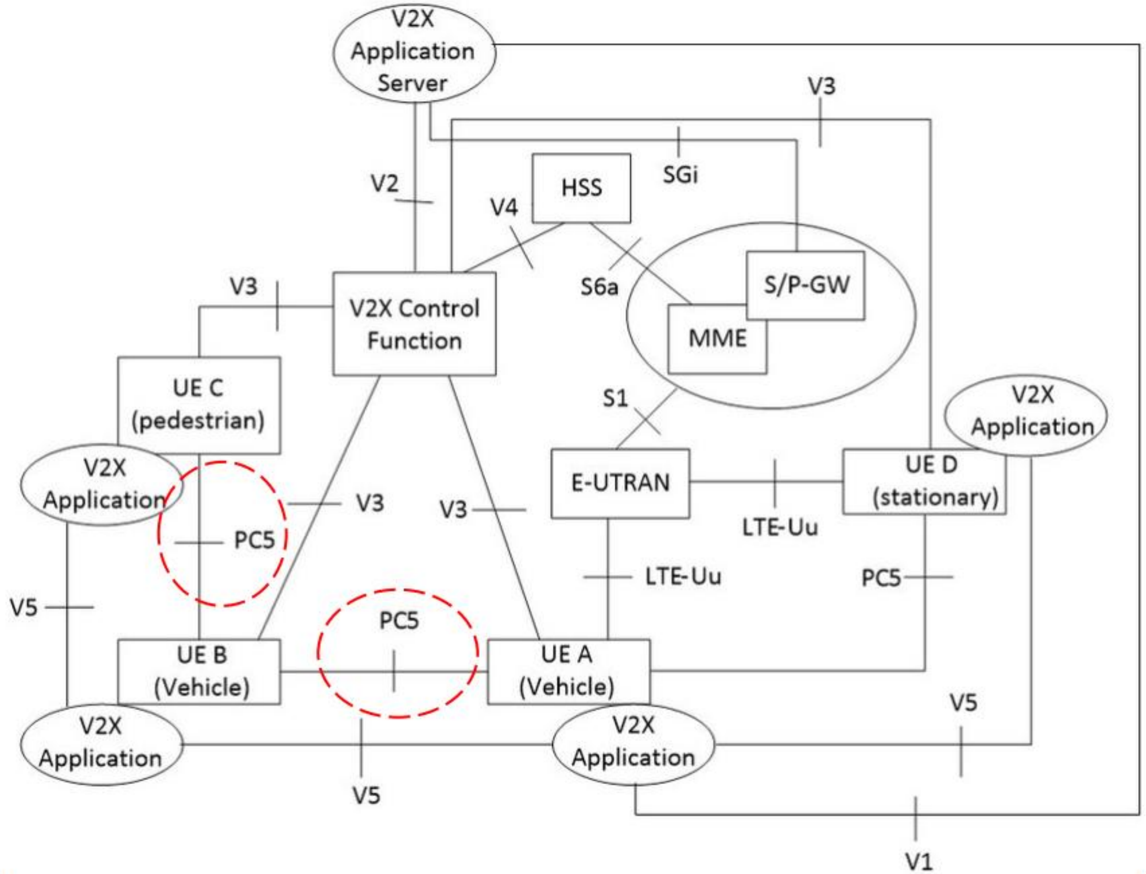


Rel 14 Highlights

- Improvement to LTE efficiency, such as,
  - Enhancements on FD-MIMO for LTE
  - Uplink Capacity Enhancements for LTE
  - Further enhancements to CoMP operation
  - Study on enhancement of VoLTE
  - L2 latency reduction techniques for LTE
  - Signalling reduction to enable light connection for LTE
  - Mobility enhancement in LTE
  - Flexible eNB-ID and Cell-ID in E-UTRAN
- Offload to unlicensed
  - **Enhanced LAA (eLAA)**
  - Enhanced LTE-WLAN Aggregation
- Enablers of new services / verticals, such as,
  - **Support for V2V services based on LTE sidelink**
  - eMBMS enhancements in LTE
  - Further Enhancements to LTE D2D
  - UE to Network Relays for IoT and Wearables
  - Further Indoor Positioning enhancements for UTRA and LTE

Support for connected vehicles based on LTE sidelink

- LTE sidelink (PC5 interface) critical part of the LTE-based cellular vehicle-to-everything communications (C-V2X) architecture



Different C-V2X scenarios

I = roadside infrastructure
N = cellular network
P = pedestrian
V = vehicle