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Carrier Aggregation and License Assisted Access

Evolution from LTE-Advanced to 5G

Florian Kaltenberger

Summer school on Spectrum Sharing and Aggregation for 5G

Sophia-Antipolis, 17.-19.10. 2016

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References

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6. 3GPP TS 36.211 V13.2.0 (2016-06) Physical channels and modulation
7. 3GPP TS 36.212 V13.2.0 (2016-06) Multiplexing and channel coding
8. 3GPP TS 36.213 V13.2.0 (2016-06) Physical layer procedures
9. 3GPP TS 36.300 V13.5.0 (2016-09) E-UTRAN Overall description
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11. http://www.sharetechnote.com/

Prerequisites

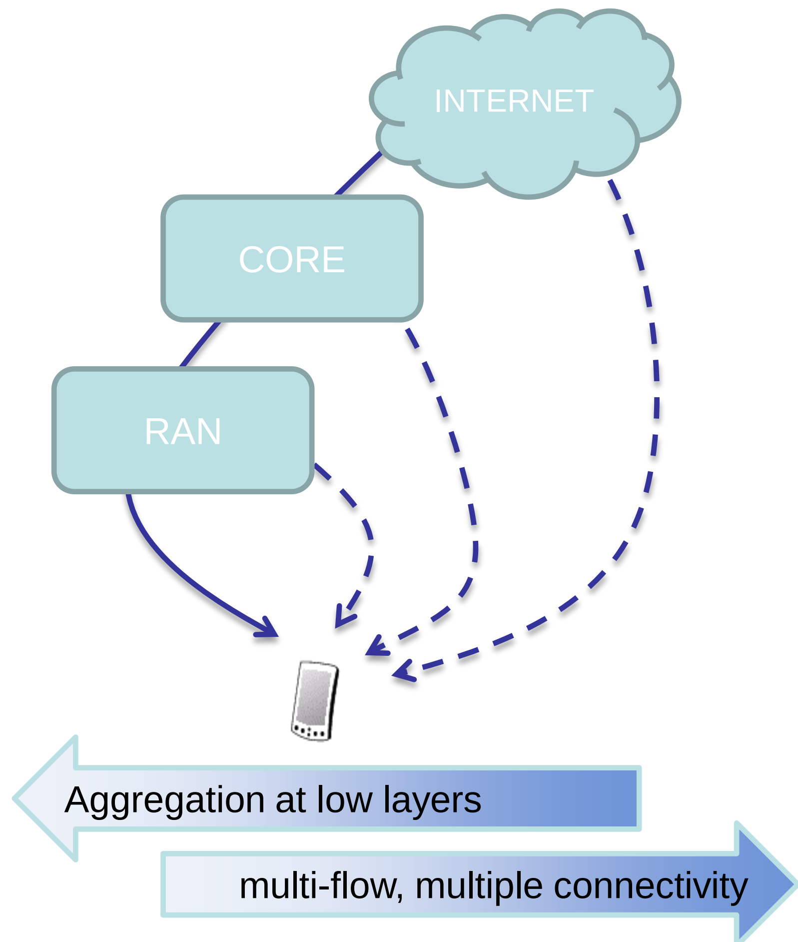
- **Basic knowledge of wireless communication systems**
- **Some knowledge of LTE**
- **Modulation, coding, multiple access (OFDMA, SC-FDMA, etc)**

Outline

- **Introduction**
  - Different types of aggregation
- **LTE basics (Rel. 8 and 9)**
- **LTE-Advanced (Rel. 10) carrier aggregation**
- **Enhancements in Rel. 11 and 12**
  - dual connectivity
- **LTE-Advanced Pro (Rel. 13) Licensed assisted access (LAA)**
  - spectrum considerations
  - deployment scenarios
  - physical layer aspects
  - higher layer aspects
  - Co-existance studies
- **Outlook to Rel. 14**
- **Alternatives to LAA**
- **OpenAirInterface Demo**

Various types of aggregation

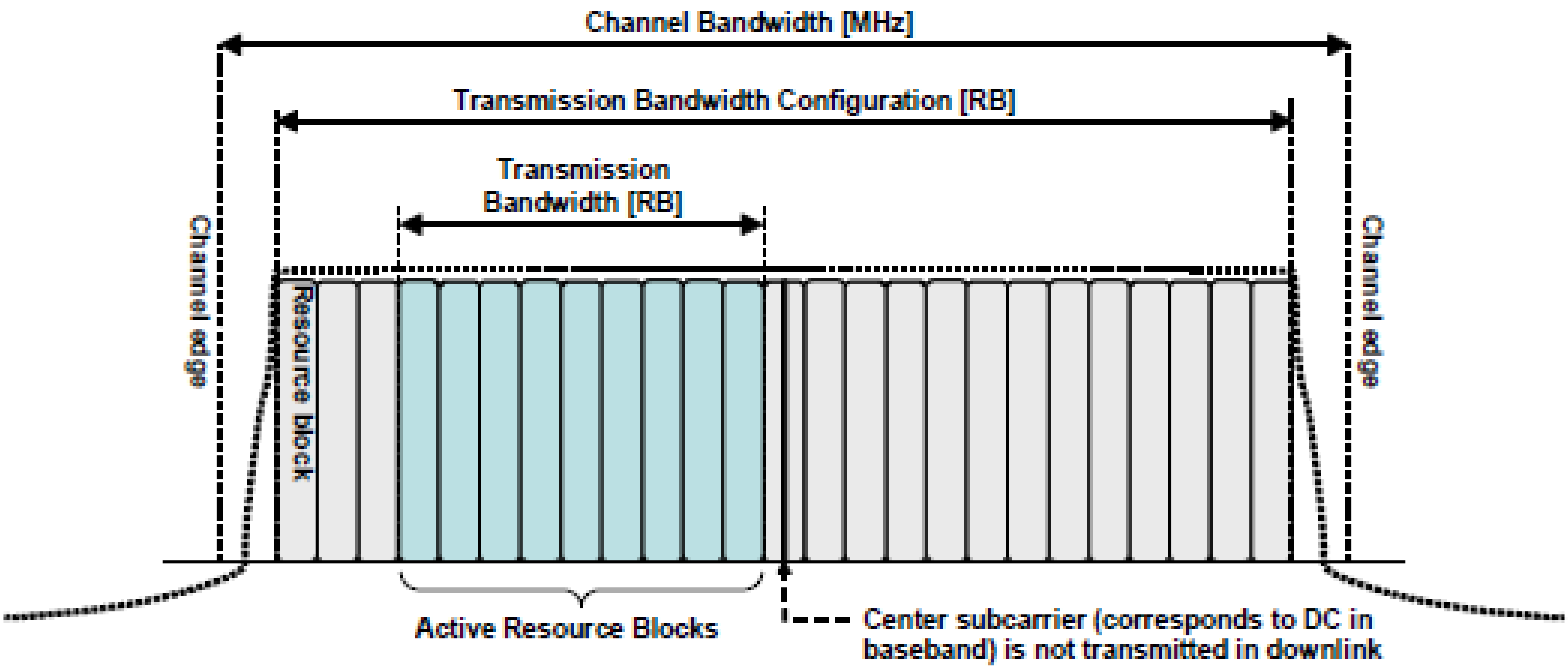
- **At Radio Access Network (RAN)**
  - MAC
    - LTE + LTE in licensed spectrum
    - LTE + LTE in unlicensed (LAA)
  - PDCP
    - LTE + LTE (Dual connectivity, split radio bearer)
    - LTE + WiFi (LWA)
  - IP
    - LTE + WiFi (LWIP)
- **At Core Network (EPC)**
  - LTE+LTE (dual connectivity, primary + secondary bearer)
  - WiFi offload based on ANDSF
- **At Service/Application Layer**
  - IP multi-homing
  - Multipath TCP



LTE in a Nutshell

- **Wireless Broadband Internet System**
  - Improved performance (throughput, latency, etc.) with respect to HSPA,HSPA+
  - Vastly lower cost per bit -> new business models, variety of devices
  - Competition/cooperation with mobile TV broadcast through eMBMS
- **Evolved network architectures**
  - All-IP core network with IP-based interconnection
  - Real time inter-basestation link (X2)
  - Ever-increasing number of pico/femto basestations
  - Support for heterogeneous interoperability (inter and intra-rat)
- **Evolved L1/L2 technologies**
  - Dynamic OFDMA/SC-FDMA instead of WCDMA
  - MIMO, MU-MIMO(LTE-Advanced) for spectral efficiencies > 10 bits/s/Hz
  - Fine-grain resource scheduling at basestation
  - All (almost) user and control plane data pass through shared transport channels
  - L1/L2 relaying (LTE-Advanced)
  - Lower latency framing and HARQ

Resource blocks



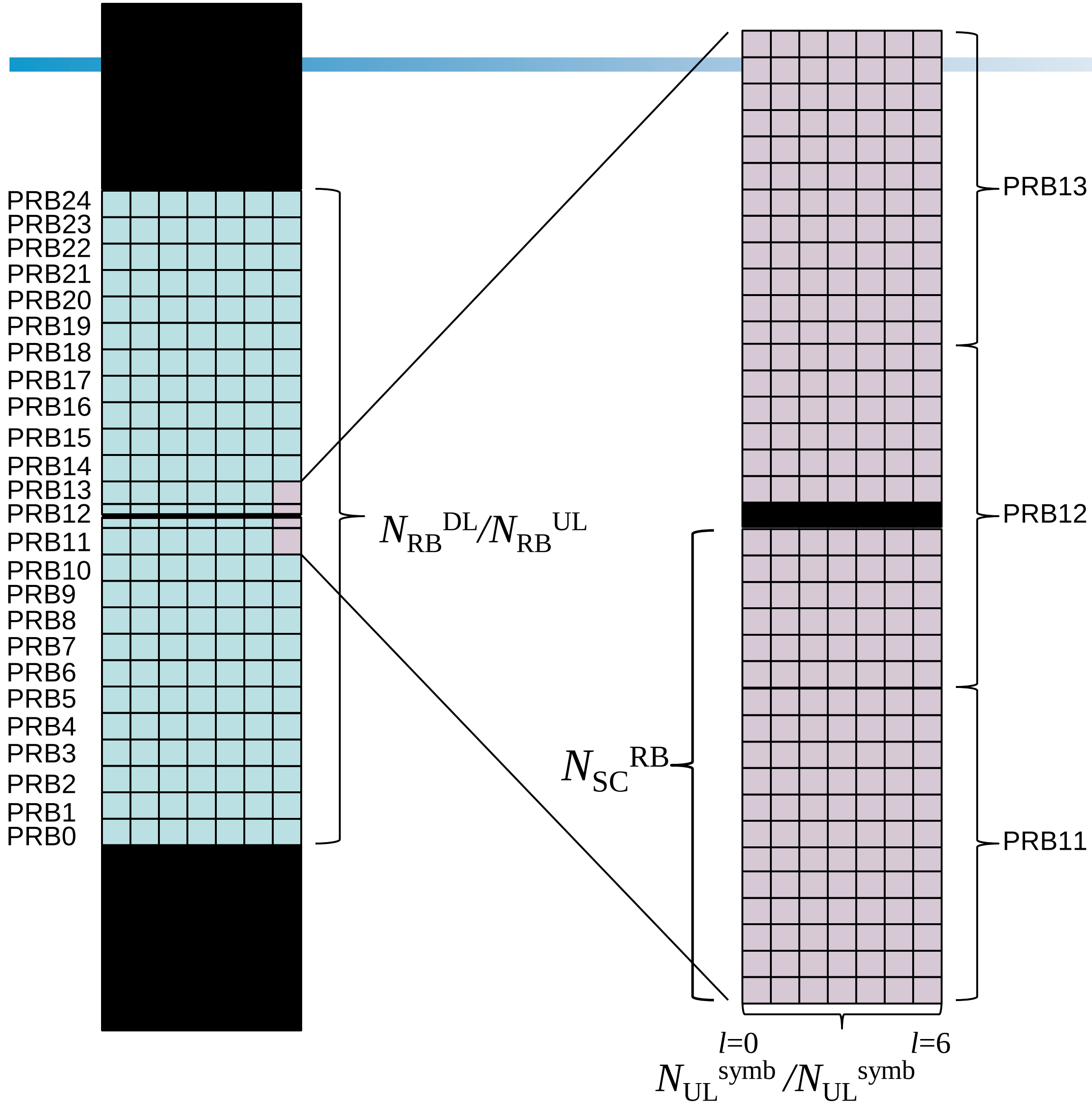
- **LTE defines the notion of a <u>resource block</u> which represents the minimal scheduling resource for both uplink and downlink transmissions**
- **A <u>physical resource block</u>(PRB) corresponds to 180 kHz of spectrum**

Common PRB Formats

Channel Bandwidth (MHz)	N_{RB}^{DL}/N_{RB}^{UL}	Typical IDFT size	Number of Non-Zero Sub-carriers (REs)
1.25	6	128	72
5	25	512	300
10	50	1024	600
15	75	1024 or 2048	900
20	100	2048	1200

- **PRBs are mapped onto contiguous OFDMA/SC-FDMA symbols in the time-domain (6 or 7)**
- **Each PRB is chosen to be equivalent to 12 (15 kHz spacing) sub-carriers of an OFDMA symbol in the frequency-domain**
  - A 7.5kHz spacing version exists with 24 carriers per sub
- **Because of a common PRB size over different channel bandwidths, the system scales naturally over different bandwidths**
  - UEs with different bandwidth constraints can still be served by an eNb with a wider channel bandwidth

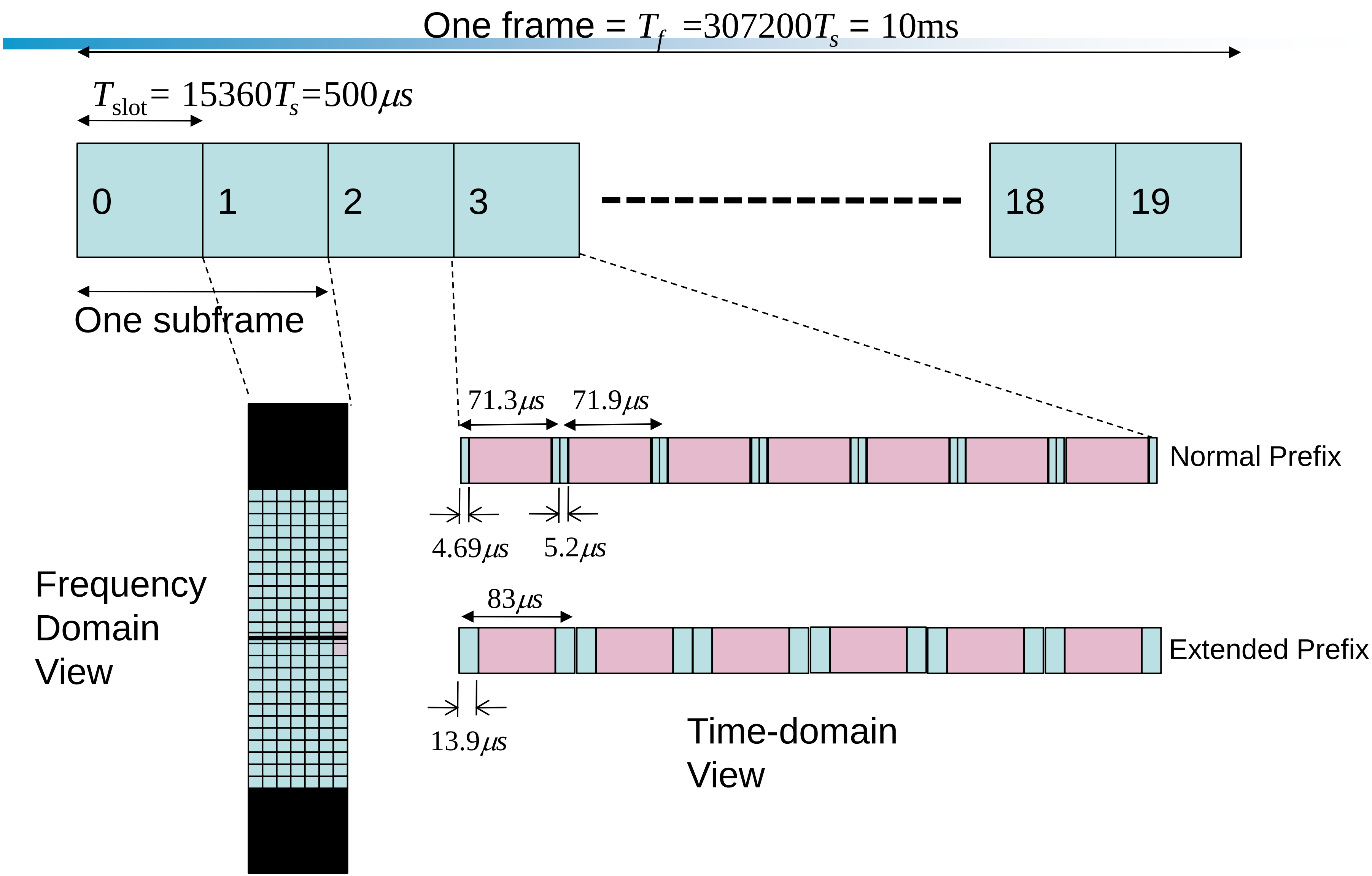
Example: 300 REs, 25 RBs (5 MHz channel)



“Normal” Cyclic Prefix Mode (7 symbols)

“Extended” Cyclic Prefix Mode (6 symbols)

Sub-frame and Frame



Downlink Physical Channels

- **Physical Downlink Shared Channel (PDSCH)**
  - Carries user and control plane traffic. It is dynamically scheduled every sub-frame by the eNb
- **Physical Broadcast Channel (PBCH)**
  - Carries a minimal amount of cell-specific control plane traffic (1 kbit/s)
- **Physical Multicast Channel (PMCH)**
  - Carries cell-specific user-plane broadcast/multicast traffic (e-MBMS)
- **Physical Control Format Indicator Channel (PCFICH)**
  - Carries cell-specific control format information. This channel indicates to the UE the control format (number of symbols comprising PDCCH, PHICH) of the current subframe.
- **Physical Downlink Control Channel (PDCCH)**
  - Carries user and cell-specific control information (scheduling, resource assignments, etc). This collection of channels provides the UE with the DLSCH assignments in the sub-frame
- **Physical Hybrid ARQ Indicator Channel (PHICH)**
  - Carries user-specific control information for HARQ (ACK/NACK)

Physical Signals

- **Reference Signals**
  - Cell-specific reference signals : Used for channel estimation and frequency-offset estimation in UE
  - User-specific reference signals: Used for channel estimation for a specific user receiving a tailored signal
- **Synchronization Signals**
  - Primary synchronization signal: Used for timing acquisition at UE
  - Secondary synchronization signal : Used for basic framing acquisition at UE allowing demodulation of physical channels

Uplink Physical Channels

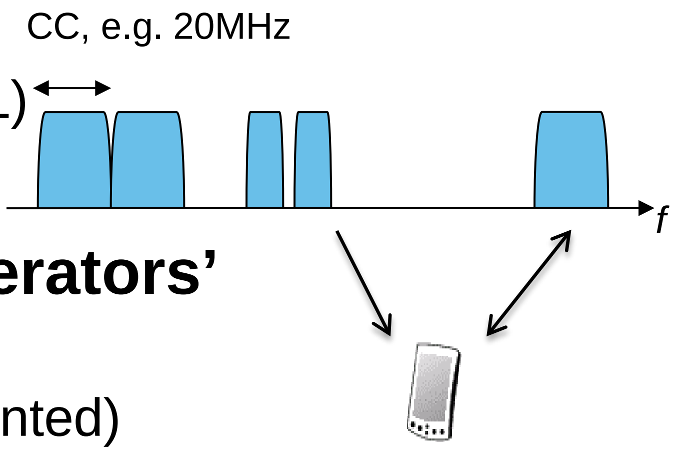
- **Physical Uplink Shared Channel (PUSCH)**
  - Carries user and control plane traffic. It is dynamically scheduled every sub-frame by the eNb
- **Physical Uplink Control Channel (PUCCH)**
  - Carries uplink control information such as ACK/NAK, scheduling request (SR), channel state information (CQI/PMI/RI)
- **Physical random access channel (PRACH)**
  - Used to establish a connection with eNB

Frame types

- **Frame type 1: Frequency division duplex (FDD)**
  - Most commonly used
- **Frame type 2: Time division duplex (TDD)**
  - Multiple configurations for different ration of UL/DL
  - 5 or 10ms switch point
  - More complex protocols

Carrier aggregation

- **Wider bandwidth for DL & UL**
  - Originally designed to reach IMT-A requirements: 3Gbit/s (DL) 1.5Gbit/s (UL)
  - Aggregating 5 CC, up to 100MHz

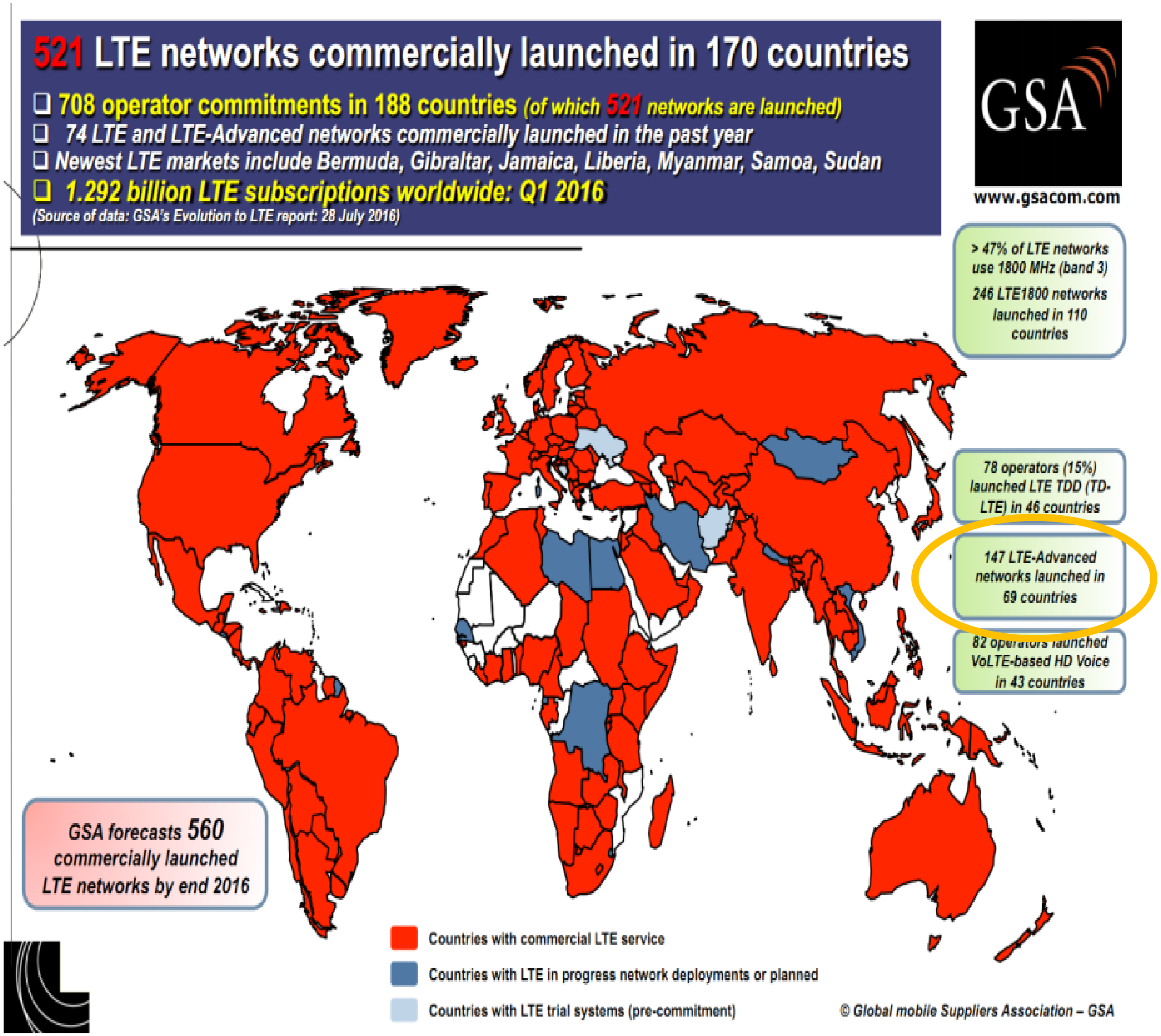


- **Progressively as an answer to operators' "real" concerns**
  - Better use of licensed spectrum (fragmented)
  - Interference management, load balancing
  - Backward compatibility and refarming
  - Trunking gain
- **Various possibilities:**
  - Intra-band (contiguous, non-contiguous), interband, same or different bandwidth, DL or UL+DL, FDD/TDD etc.

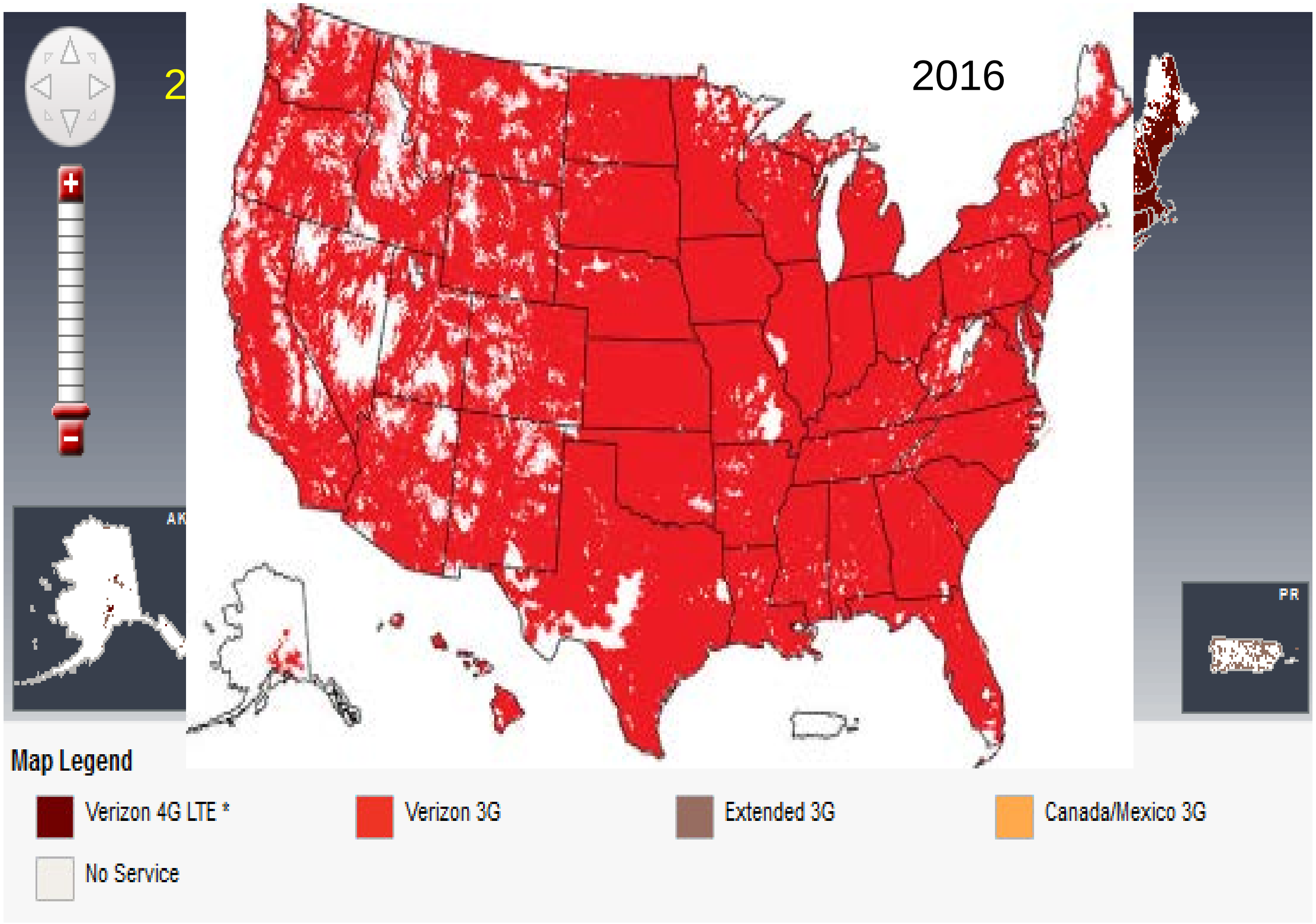
Carrier aggregation in 3GPP

- **The main feature of LTE-Advanced (LTE Rel.10)**
  - LTE-A was started in Dec. 2004
  - Foundation completed in Dec. 2010
  - Commercial deployements today
- **Being improved in Rel. 11, 12, 13 etc.**
  - Rel. 13 LTE-CA-enh. beyond 5 carriers
  - Rel. 13 LAA, Rel. 14: eLAA, Rel. 15: feLAA

LTE deployments

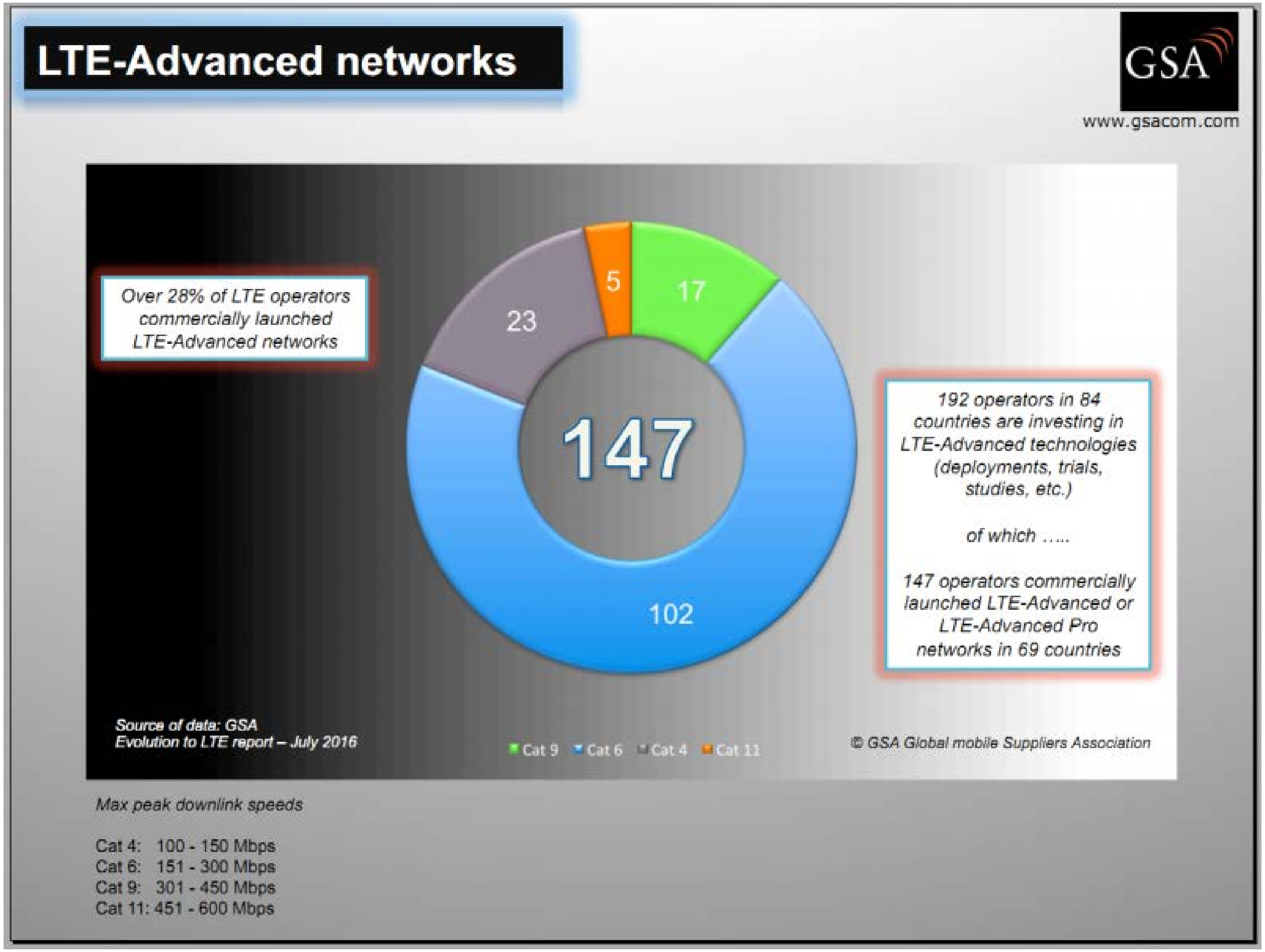


LTE deployments



Source: Verizon wireless

Carrier aggregation in the market



Carrier Aggregation

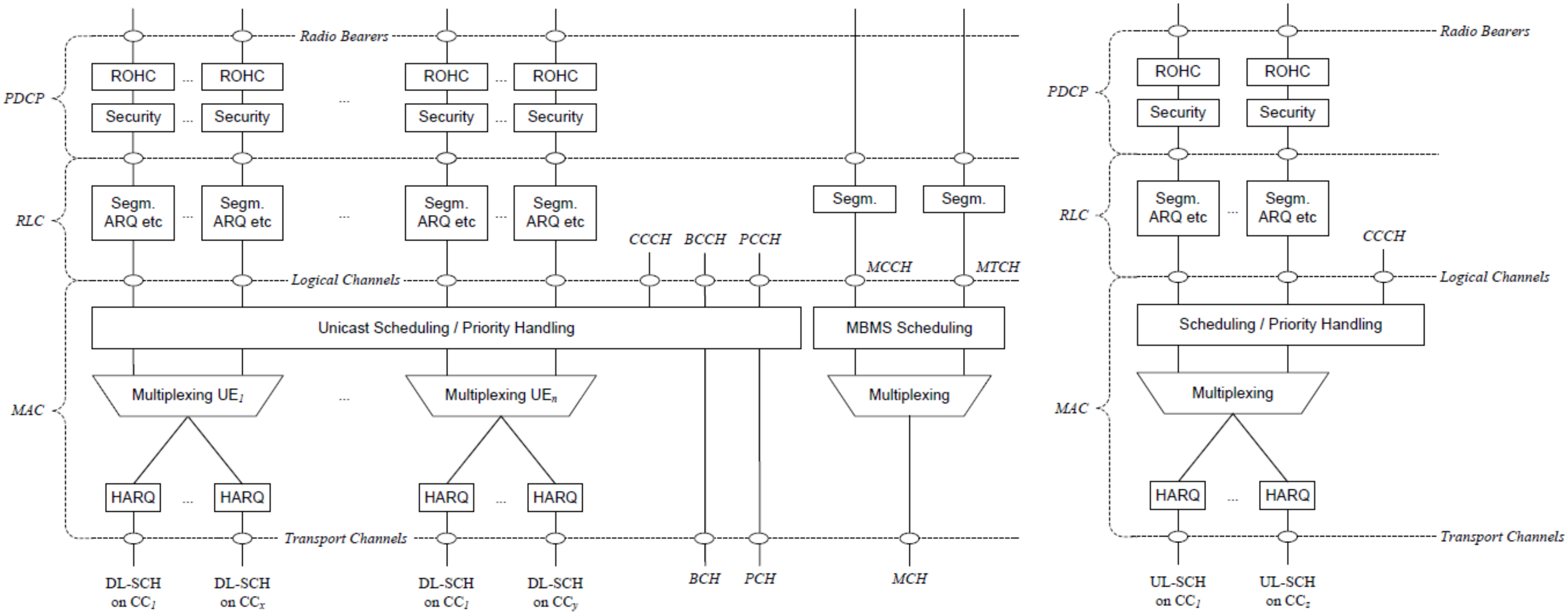
- **Carrier Aggregation (CA)**
  - two or more Component Carriers (CCs) are aggregated in order to support wider transmission bandwidths up to 100MHz. A UE may simultaneously receive or transmit on one or multiple CCs depending on its capabilities
- **Notions**
  - P-cell = cell to which UE has established a connection
    - All control signaling (i.e. RRC/DCCH) pass through P-cell only
      - Includes measurement (RSRP,RSRQ) and mobility
  - S-cell = cell on other CC which has been configured by P-cell
    - Up to 4 in Rel-10
    - Established during RRCConnectionReconfiguration
    - Can be DL only
    - No signaling (no DCCH)
    - Can be different bandwidth, different frequency band
    - SCell can be added / removed / reconfigured for a UE at any time by RRCConnectionReconfiguration
    - Fast activation/deactivation through MAC signaling

Carrier Aggregation

- **A non-CA capable UE can receive on a single CC and transmit on a single CC corresponding to one serving cell only**
- **It is possible to configure a UE to aggregate a different number of CCs originating from the same eNB and of possibly different bandwidths in the UL and the DL:**
  - The number of DL CCs that can be configured depends on the DL aggregation capability of the UE
- **The number of UL CCs that can be configured depends on the UL aggregation capability of the UE;**
  - It is not possible to configure a UE with more UL CCs than DL CCs;
  - In typical TDD deployments, the number of CCs and the bandwidth of each CC in UL and DL is the same.
  - The number of TAGs that can be configured depends on the TAG capability of the UE.
- **CCs originating from the same eNB need not to provide the same coverage.**
- **CCs shall be LTE Rel-8/9 compatible. Nevertheless, existing mechanisms (e.g. barring) may be used to avoid Rel-8/9 UEs to camp on a CC.**

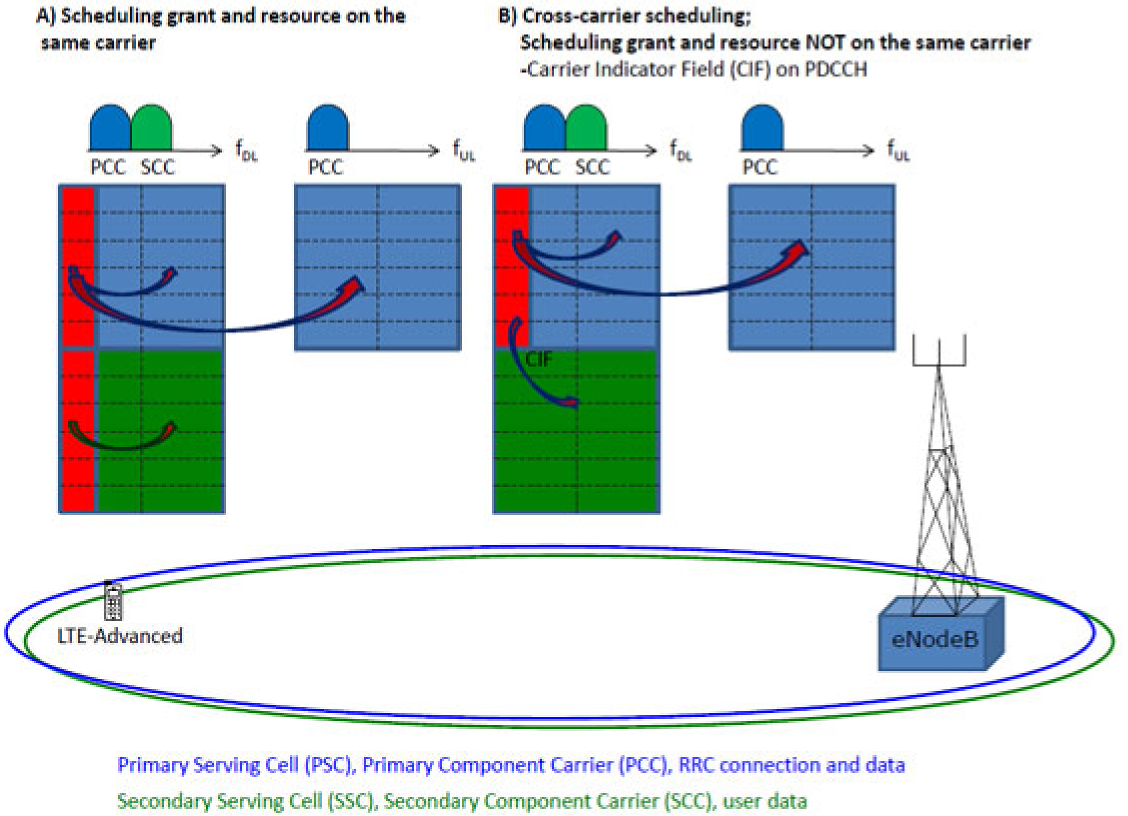
Carrier Aggregation

- **In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell;**
  - In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per TTI per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.



Carrier Aggregation

- **Cross-carrier scheduling**
  - Control information for PDSCH and PUSCH can be scheduled on a different carrier

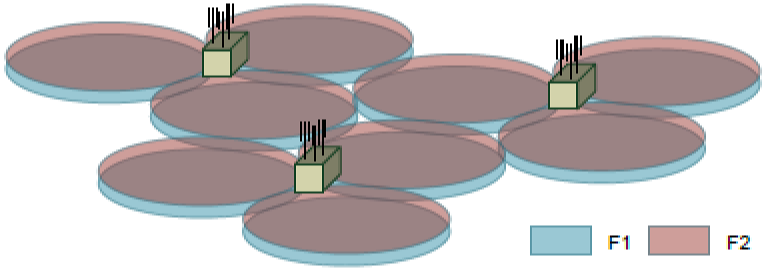
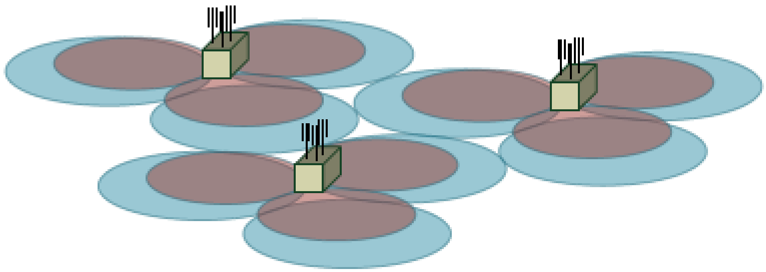


Carrier Aggregation

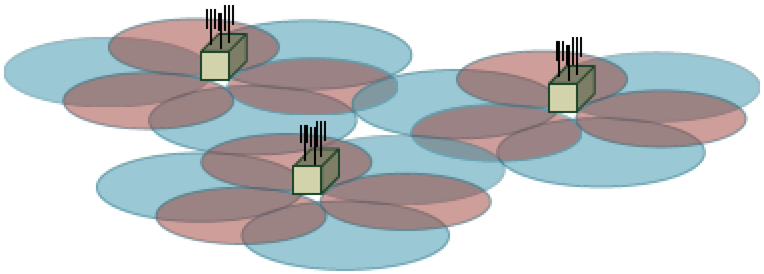
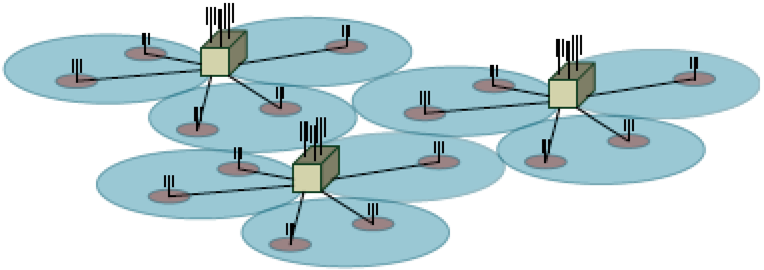
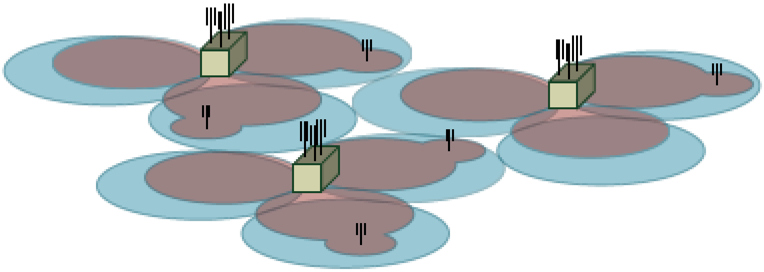
- **UL control signaling**
  - Format 1b (with channel selection): for up to two DL cells,
  - New PUCCH format 3 for multi-cell ACK/NAK + CSI (CQI,PMI,PTI)
- **MAC activation/deactivation**
  - Carriers can be activated/deactivated (after having been configured by RRC) through MAC control element (part of MAC header) within 8ms.

Carrier Aggregation

Table J.1-1: CA Deployment Scenarios (F2 > F1).

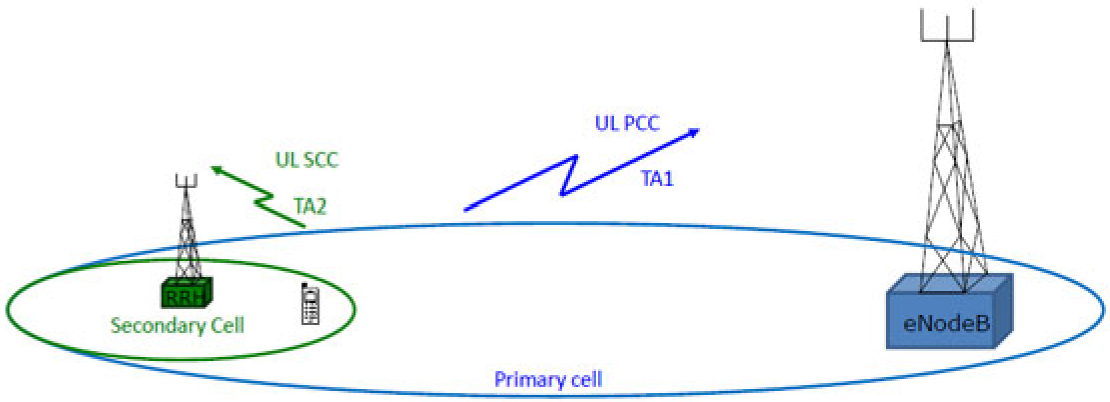
#	Description	Example
1	F1 and F2 cells are co-located and overlaid, providing nearly the same coverage. Both layers provide sufficient coverage and mobility can be supported on both layers. Likely scenario is when F1 and F2 are of the same band, e.g., 2 GHz, 800 MHz, etc. It is expected that aggregation is possible between overlaid F1 and F2 cells.	
2	F1 and F2 cells are co-located and overlaid, but F2 has smaller coverage due to larger path loss. Only F1 provides sufficient coverage and F2 is used to improve throughput. Mobility is performed based on F1 coverage. Likely scenario when F1 and F2 are of different bands, e.g., F1 = {800 MHz, 2 GHz} and F2 = {3.5 GHz}, etc. It is expected that aggregation is possible between overlaid F1 and F2 cells.	

Carrier Aggregation

3	F1 and F2 cells are co-located but F2 antennas are directed to the cell boundaries of F1 so that cell edge throughput is increased. F1 provides sufficient coverage but F2 potentially has holes, e.g., due to larger path loss. Mobility is based on F1 coverage. Likely scenario is when F1 and F2 are of different bands, e.g., F1 = {800 MHz, 2 GHz} and F2 = {3.5 GHz}, etc. It is expected that F1 and F2 cells of the same eNB can be aggregated where coverage overlaps.	
4	F1 provides macro coverage and on F2 Remote Radio Heads (RRHs) are used to improve throughput at hot spots. Mobility is performed based on F1 coverage. Likely scenario is when F1 and F2 are of different bands, e.g., F1 = {800 MHz, 2 GHz} and F2 = {3.5 GHz}, etc. It is expected that F2 RRHs cells can be aggregated with the underlying F1 macro cells.	
5	Similar to scenario #2, but frequency selective repeaters are deployed so that coverage is extended for one of the carrier frequencies. It is expected that F1 and F2 cells of the same eNB can be aggregated where coverage overlaps.	

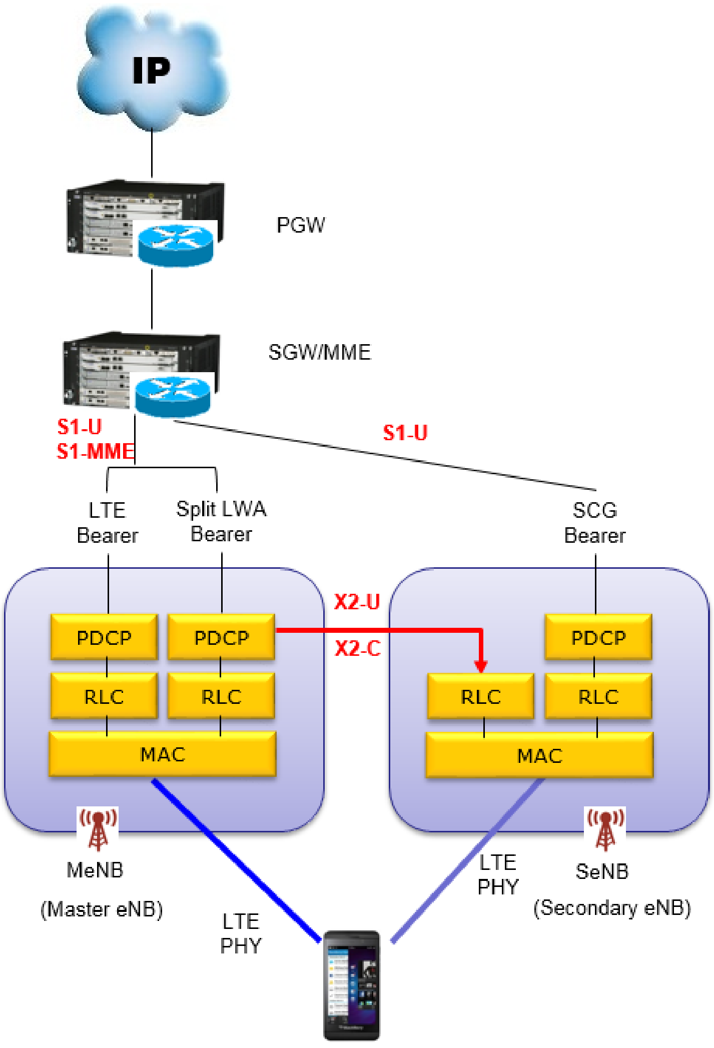
Rel-11 Enhancements

- **Different UL/DL configurations in TDD between P-Cell and S-Cell**
  - Issue for common band (e.g. 2.6 + 2.6)
  - Less so for different bands (e.g. 2.6 + 3.5)
  - Reason: More UL in lower band (better coverage)
- **Possibility to support serving cells with different Timing Advance (TA).**



Rel-12 Enhancements

- **Dual Connectivity**: Operation where a given UE consumes radio resources provided by at least two different network points (Master and Secondary eNBs) connected with non-ideal backhaul while in RRC_CONNECTED.
- **Bearer Split**: in dual connectivity, refers to the ability to split a bearer over multiple eNBs**.**
- **Master eNB:** in dual connectivity, the eNB which terminates at least S1-MME and therefore act as mobility anchor towards the CN.
- **Secondary eNB:** in dual connectivity, an eNB providing additional radio resources for the UE, which is not the Master eNB.
- **X2-U, X2-C:** interface between MeNB and SeNB for user and control plane



Further Rel 12 Enhancements

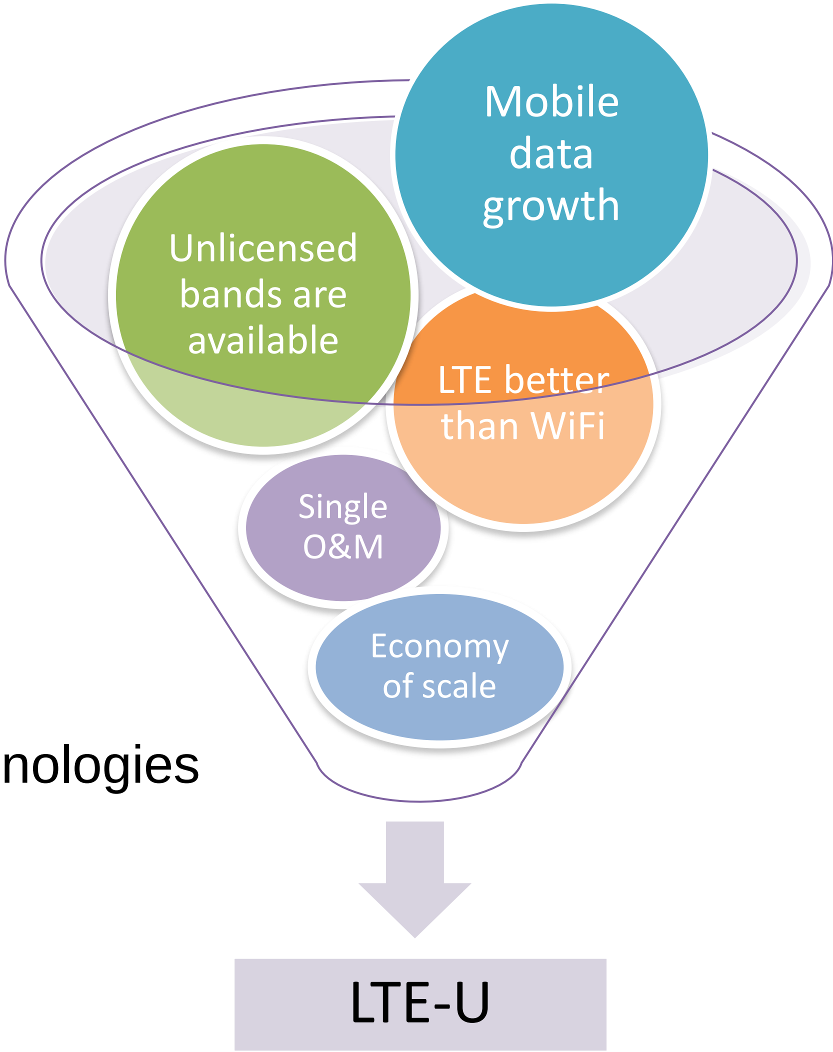
- **Aggregation of FDD and TDD**
  - Impact on protocols and signaling
- **Discovery Reference Signal (DRS) for fast on/off switching of dormant cells**
  - Scells do not need to be on all the time (when deactivated for all users)
  - In this case Ues cannot make measurements and network cannot efficiently decide when to turn Scell back on
  - DRS consist of the first 5 subframes of a frame (PSS, SSS, PBCH, RS) transmitted with a periodicity of [40,80,160]ms (configured by RRC)

LTE-ADVANCED PRO (REL 13)

LTE-U/LAA

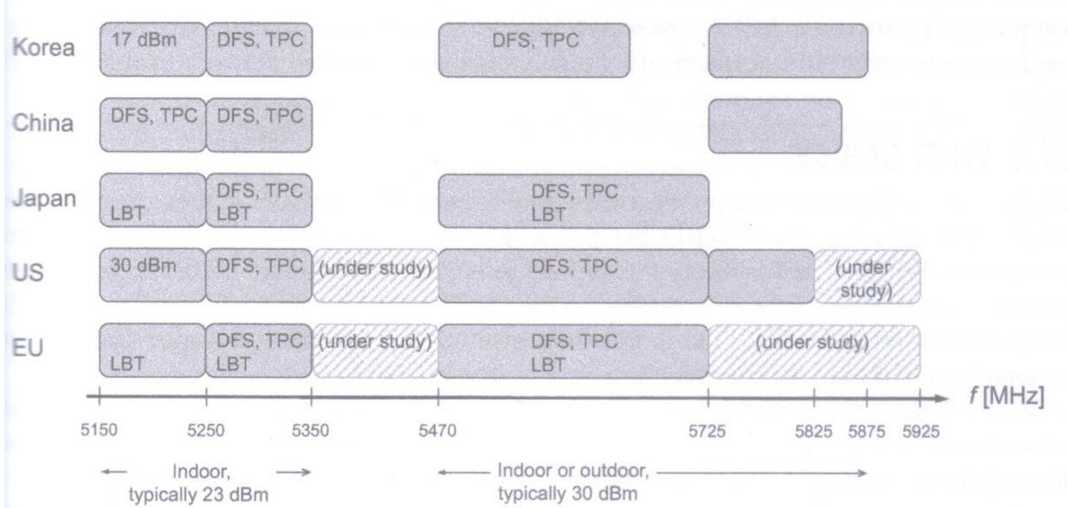
- **Definitions**
  - LTE-U = LTE in Unlicensed band
  - LAA = Licensed Assisted Access
- **Licensed spectrum**
  - Top priority for cellular operators
  - Exclusive use
- **Unlicensed spectrum**
  - Unpredictable QoS
  - To be (fairly!) shared with other technologies
  - Seen as complementary

➔ Notion of LAA leveraging CA



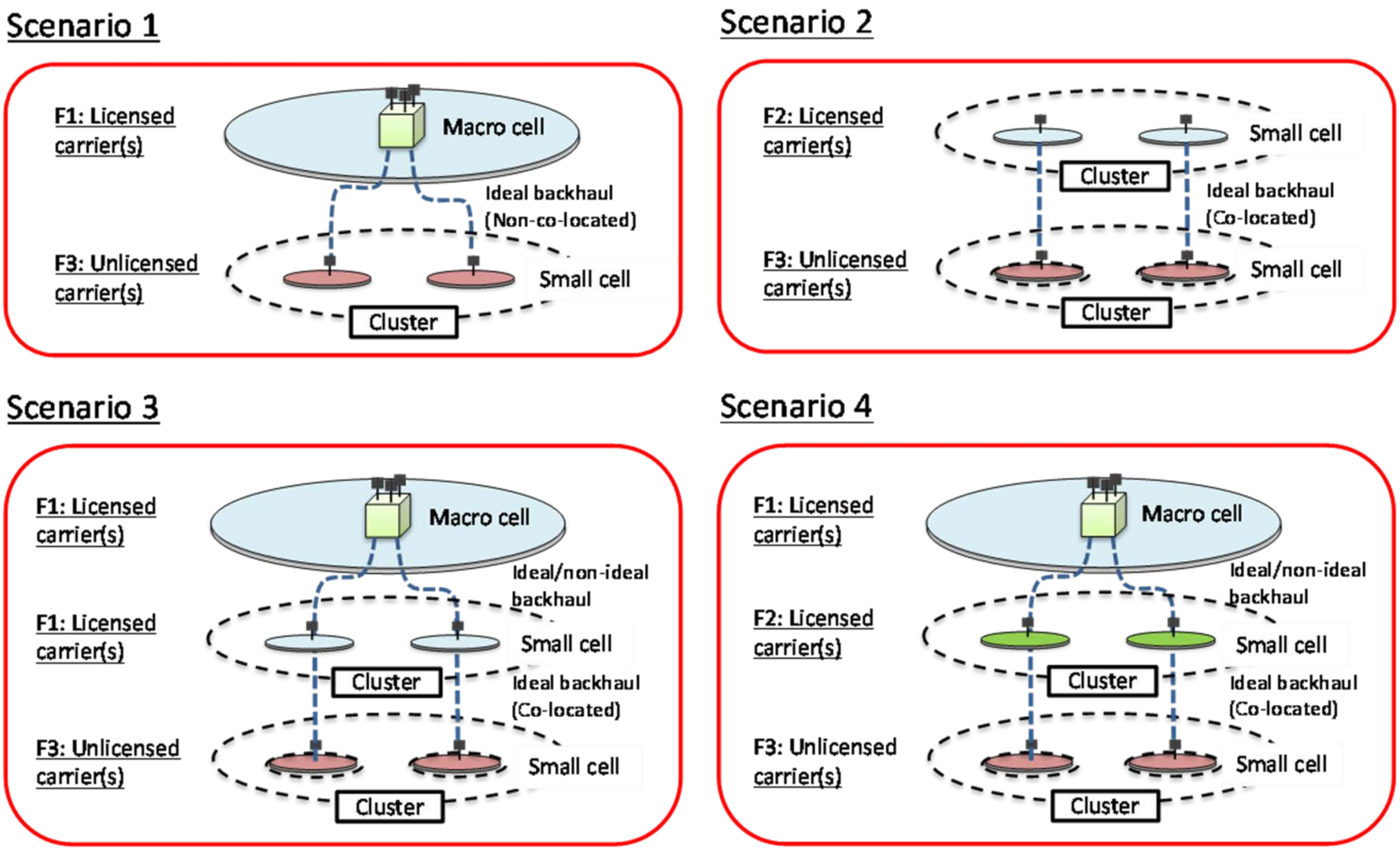
Spectrum Considerations

TPC: transmit power control
DFS: dynamic frequency switching
LBT: listen before talk



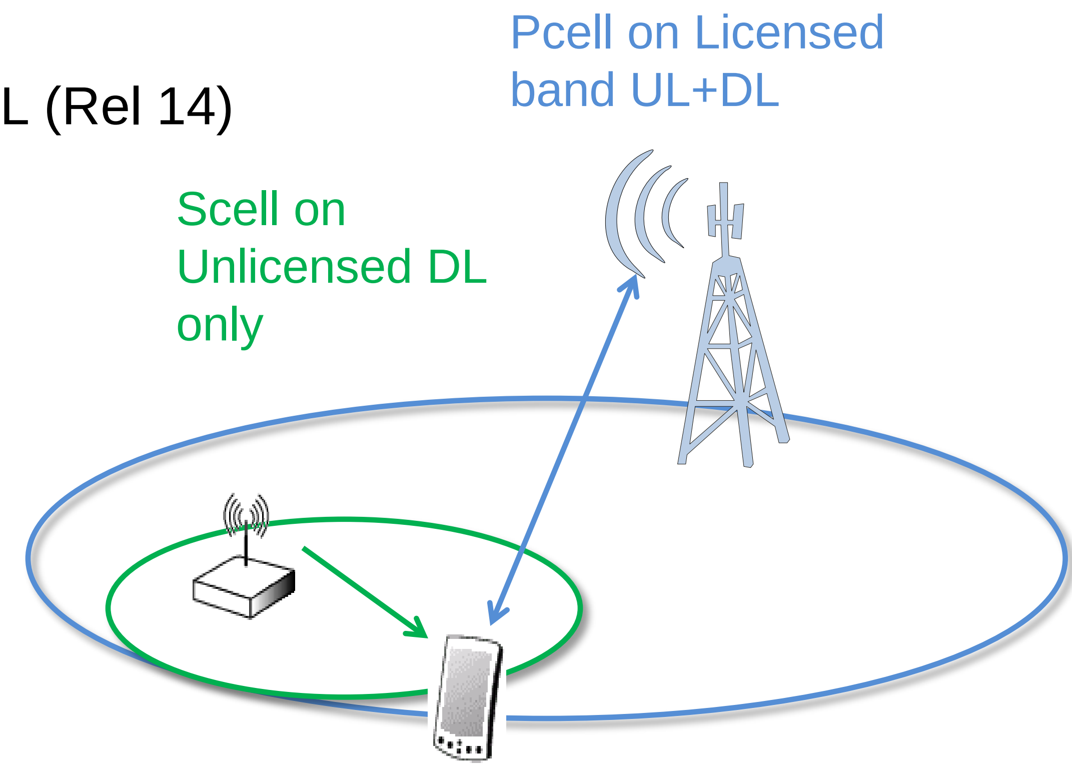
- **Target band for LAA: 5150-5925 MHz**
  - Regulations differ per country
  - **5150-5350 and 5470-5725 MHz:** allocated on a co-primary basis to the mobile service for the implementation of “wireless access systems (WAS), including radio local area networks (RLANs)”.
  - **5725-5850 MHz:** Industrial Scientific Medical band
  - **5850-5925 MHz:** Intelligent Transport Systems
- **Shared mainly with WiFi (802.11a/h/j/n/ac)**
  - But also others like weather and satellite radar

Deployment scenarios



CA role in LAA

- **Primary Carrier always in licensed spectrum**
  - Mobility, control, QoS critical traffic
- **Secondary carrier in unlicensed spectrum**
  - Best effort
  - DL only (Rel 13) or DL+UL (Rel 14)
- **See also SDL**
  - Supplementary DL
- **Alternatives**
  - Dual connectivity (LWA)
  - Stand-alone operation (LTE-U)



LAA in 3GPP

- **LAA ➔ basic building blocks (DL)**
  - Early discussion end of 2013
  - (Rel. 13) SI from September 2014 to June 2015
  - (Rel. 13) WI from June 2015 to Dec 15 (core part)
- **eLAA ➔ UL, still in LAA**
  - (Rel. 14) WI Approved in Dec 2015
  - it was expected to be completed for June RAN plenary, but postponed to Sep 2016
- **feLAA ➔ towards standalone operation**
  - Not yet approved, but most likely to happen

LAA 3GPP design challenges

- **Fairness with other users of the unlicensed band**
  - LBT (Listen Before Talk)
  - Collision control mechanism to make sure the “fair” co-existence between different technologies
- **Regulatory requirements need to be satisfied:**
  - PSD constraints
    - Minimum channel occupation bandwidth per device
    - Maximum power density per MHz
  - Discontinuous transmission, radar detection
- **To maximize the efficiency under the restrictions (be better than WiFi!), new designs were introduced**

LAA Main outcomes

- **A new frame structure 3**
  - Similar as TDD but any subframe could be DL or UL
- **A set of LBT procedures including the management of contention window**
  - LBE (Load Based Equipment) type LBT was selected
- **Energy detection**
  - The ED threshold is both channel type and output power related
    - -72dBm for 23dBm PUSCH
    - -62dBm for DRS (Discovery Reference Signal)
- **Partial subframe**
  - It includes partial initial subframe and partial ending subframe
  - Necessary to efficiently exploit Maximum Channel Occupacy Time (MCOS)
- **Measurement and report for the unlicensed spectrum**
  - RSSI needs to be report to aid the carrier selection at the eNB
- **Discontinuous transmission**
  - To respect duty cycle required in certain regions
- **Carrier selection**
  - To achieve good coexistence

LAA: frame type 3

- **Framing**
  - Same as TDD/FDD
  - DL only (for Rel 13)
- **Discovery signal**
  - Same as in Rel 12 but
  - Consist of 12 OFDM symbols (PSS, SSS, pilots)
  - Can be transmitted any subframe within the configured periodicity if channel is busy
- **No PBCH**
- **DL transmission could**
  - start on slot boundary
  - use consecutive subframes
  - use incomplete subframe
  - → new DCI format

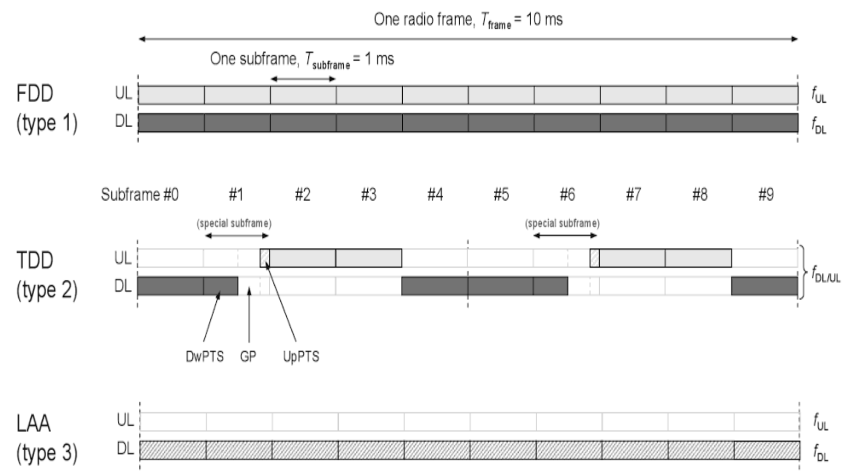


FIGURE 5.5

Uplink/downlink time–frequency structure in case of FDD and TDD.

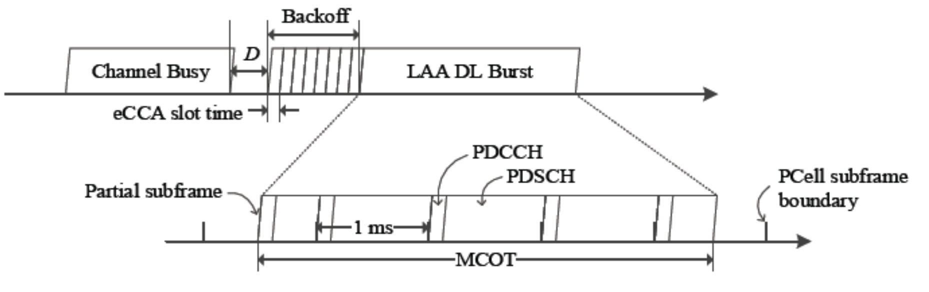
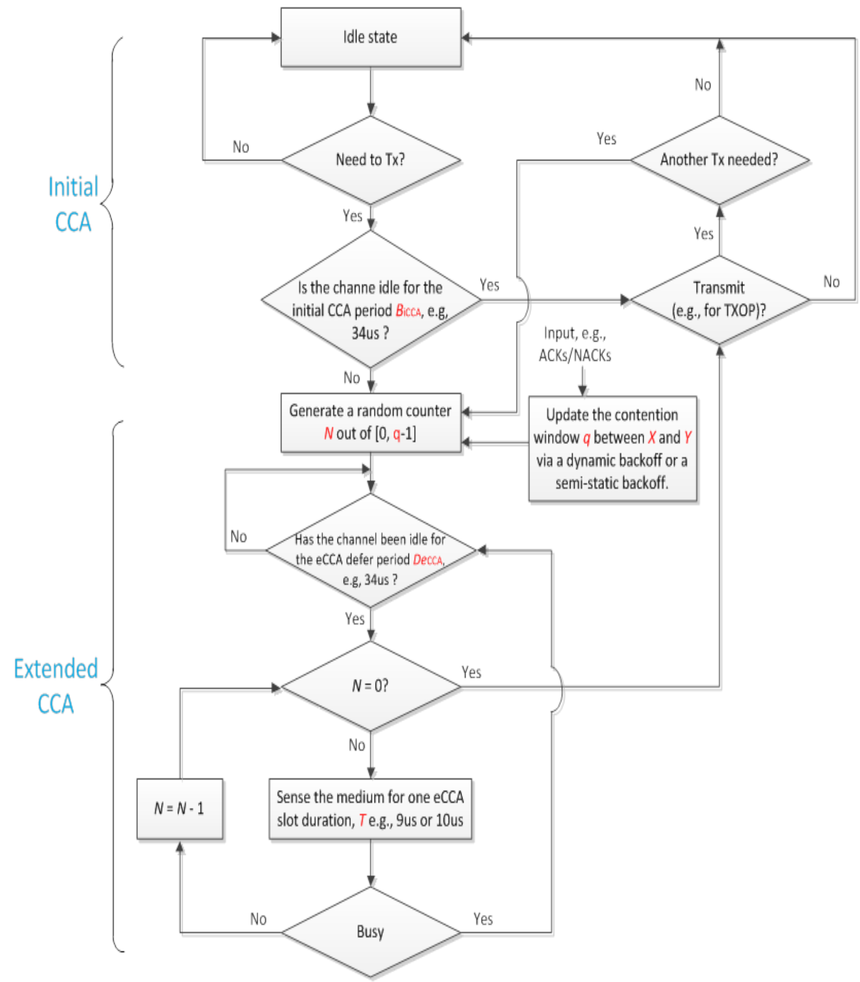


Fig. 3. Illustration of an LAA DL burst transmission

LAA: Listen Before Talk (LBT)

- **LBT = Listen before Talk**
  - The mechanism an equipment applies CCA before using the channel
- **CCA: clear channel assessment**
  - The evaluation of presence/absence of other signals
  - Using at last energy detection
- **4 categories of LBT were considered**
  - Cat-1: no LBT
  - Cat-2: LBT without random back-off
  - Cat-3: LBT with random back-off and fixed CW
  - Cat-4: LBT with random back-off and variable CW
- **Potential failure of LBT impacts LTE operation**
  - Especially for standalone operation
  - E.g. synchronous ACK/NACK not anymore feasible



Source TS36.889: Flowchart DL Cat 4 LBT procedure

Other Rel 13 enhancements

- **Support for 32 carriers**
  - Allowing a total aggregated bandwidth of 640 MHz
- **Modifications in RRC signaling**
- **No changes in DCI signaling**
  - Cross-carrier scheduling only for up to 8 carriers.
  - Otherwise self-scheduling
- **Highest impact on feedback signaling**
  - UCI (ACK/NACK, SR, CSI, RI, PMI) transmitted on either PUSCH or PUCCH on primary carrier only
  - Rel 12 PUCCH format 3 can transport 48 bits
  - New PUCCH formats 4 and 5 using tail biting convolutional codes
  - PUCCH format 4: more than 128 bits
  - PUCCH format 5: between 48 and 128 bits

Configuration			HARQ-ACK payload (bits)
FDD			32
TDD	0	TDD CA	32
		TDD-FDD CA	63
	1	TDD CA	64
		TDD-FDD CA	95
	2	TDD CA	128
		TDD-FDD CA	159
	3	TDD CA	96
		TDD-FDD CA	189
	4	TDD CA	128
		TDD-FDD CA	190
	5	TDD CA	288
		TDD-FDD CA	319
	6	TDD CA	32
		TDD-FDD CA	64

Table 1. HARQ-ACK feedback payload for different TDD-FDD configurations. [5]

eLAA: UL regulation issues and solutions

- **Regulatory constraints**
  - Occupied bandwidth shall be between 80% and 100% of the declared bandwidth
    - The Occupied Channel Bandwidth is the bandwidth containing 99 % of the power of the signal
    - Test procedure allows filtering
  - Maximum PSD per MHz
    - You cannot concentrate power on few RBs

4.3.2 Limits

The Nominal Channel Bandwidth shall be at least 5 MHz at all times.

The Occupied Channel Bandwidth shall be between 80 % and 100 % of the declared Nominal Channel Bandwidth. In case of smart antenna systems (devices with multiple transmit chains) each of the transmit chains shall meet this requirement.

Table 1: Mean e.i.r.p. limits for RF output power and power density at the highest power level

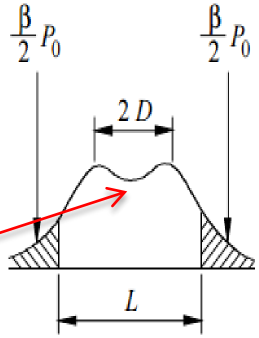
Frequency range [MHz]	Mean e.i.r.p. limit [dBm]		Mean e.i.r.p. density limit [dBm/MHz]	
	with TPC	without TPC	with TPC	without TPC
5 150 to 5 350	23	20/23 (see note 1)	10	7/10 (see note 2)
5 470 to 5 725	30 (see note 3)	27 (see note 3)	17 (see note 3)	14 (see note 3)

NOTE 1: The applicable limit is 20 dBm, except for transmissions whose nominal bandwidth falls completely within the band 5 150 MHz to 5 250 MHz, in which case the applicable limit is 23 dBm.

NOTE 2: The applicable limit is 7 dBm/MHz, except for transmissions whose nominal bandwidth falls completely within the band 5 150 MHz to 5 250 MHz, in which case the applicable limit is 10 dBm/MHz.

NOTE 3: Slave devices without a Radar Interference Detection function shall comply with the limits for the band 5 250 MHz to 5 350 MHz.

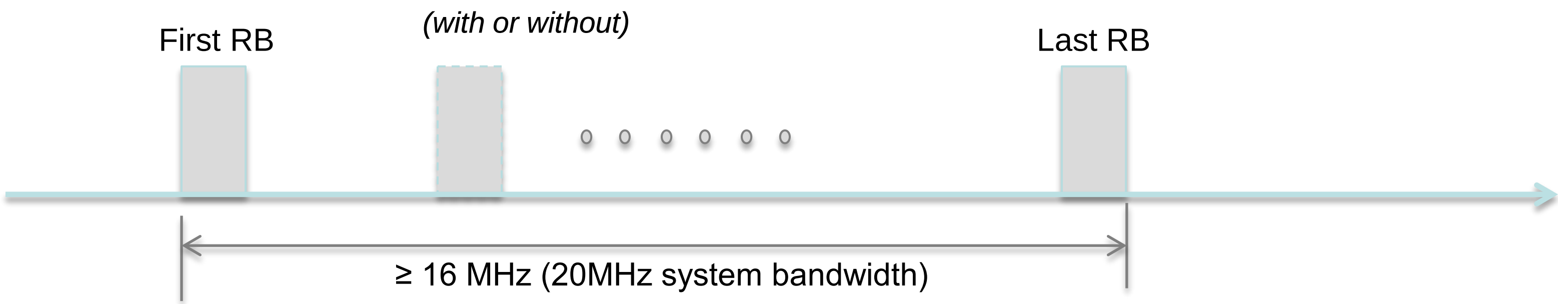
Spectrum in the middle can be left as unused which will not impact the 80% channel occupation test.
(R1-151841, from Nokia Networks)



eLAA UL: Summary of constraints

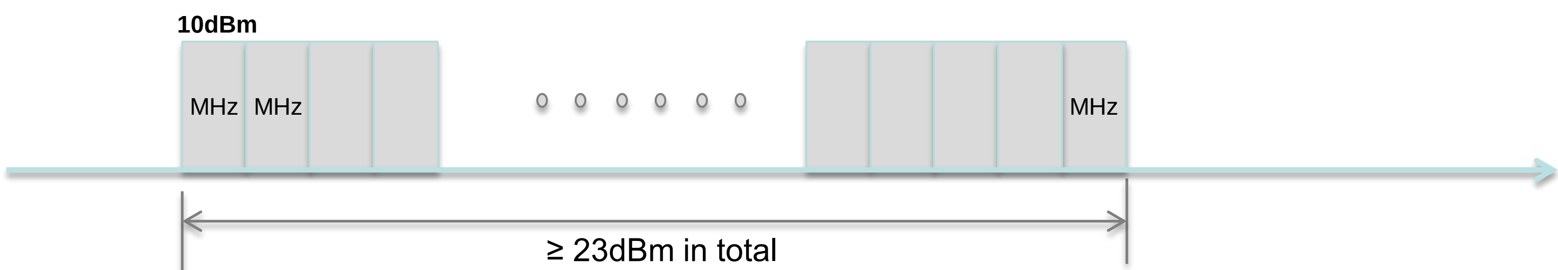
- **80% bandwidth occupation – it can simply schedule two RBs with enough distance in between or one RB with two slots interleaved with enough distance in frequency;**

1. try to make the first RB and the last RB separated far enough to cover 80% of the system bandwidth.



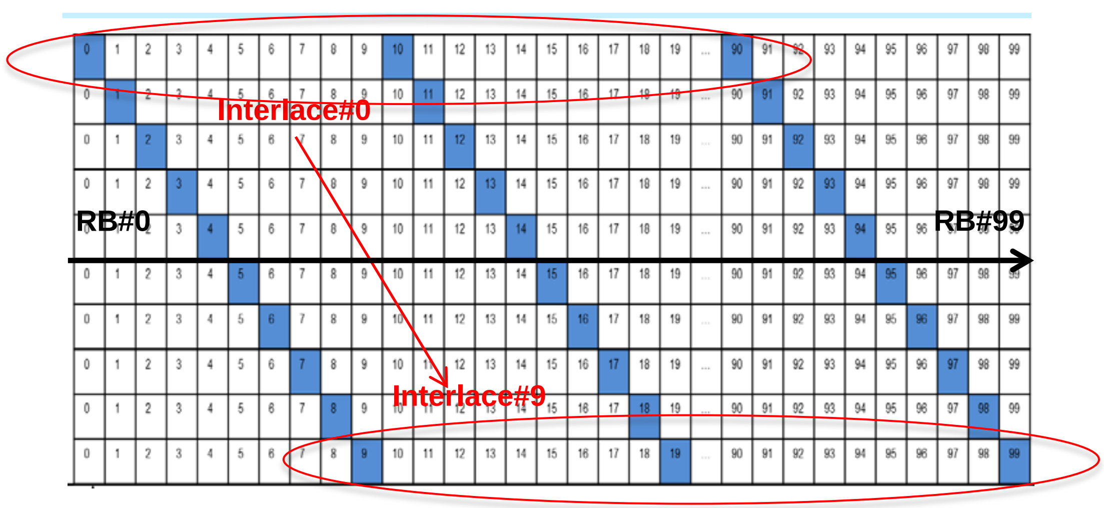
- **PSD per MHz constraint** – output power per any MHz cannot exceed the limit specified by the regulation.

2. Try to occupy as many MHz as possible either in RB or in subcarrier to gain a best output power.



eLAA UL: 3GPP approach

- **An interlace based waveform was agreed**
  - Each interlace includes 10 equally separated RBs
  - One or more interlaces can be scheduled to one UE
  - Performance degradation due to the discontinuous DMRS in frequency
  - Details still to be finalized (e.g. PUCCH postponed to next Work Item)



Higher layer issues

- **Random access**
  - Not possible on LAA cell
- **HARQ process**
  - HARQ in DL is asynchronous
  - However, channel might not be available anymore for 3rd retransmission
  - Solution: choose MCS, such that almost surely max 2 transmissions are necessary and let RLC handle possible retransmissions

Co-existance LAA and WiFi

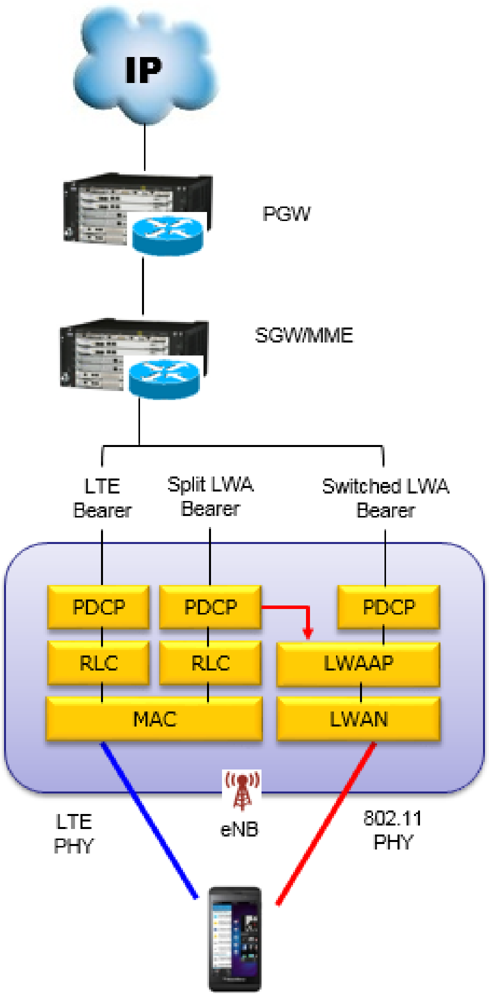
- **Still ongoing research , very little experimental results**
  - LAA specs only finished recently (June 2016)
  - First chipsets coming out now (end 2016)
- **Careful when comparing results**
  - Do not confuse LTE-U with LAA!
- **Simulation studies by 3GPP members summarized in TR 36.889 [10]**
  - Focused on layer 1
  - "A majority of sources providing evaluation results showed at least one LBT scheme for LAA that does not impact Wi-Fi more than another Wi-Fi network."
- **System level study done by NS3 LAA-WiFi-Coexistence project [4]**
  - Includes higher layers
  - https://www.nsnam.org/wiki/LAA-WiFi-Coexistence

NS3 LAA-WiFi-Coexistence main results

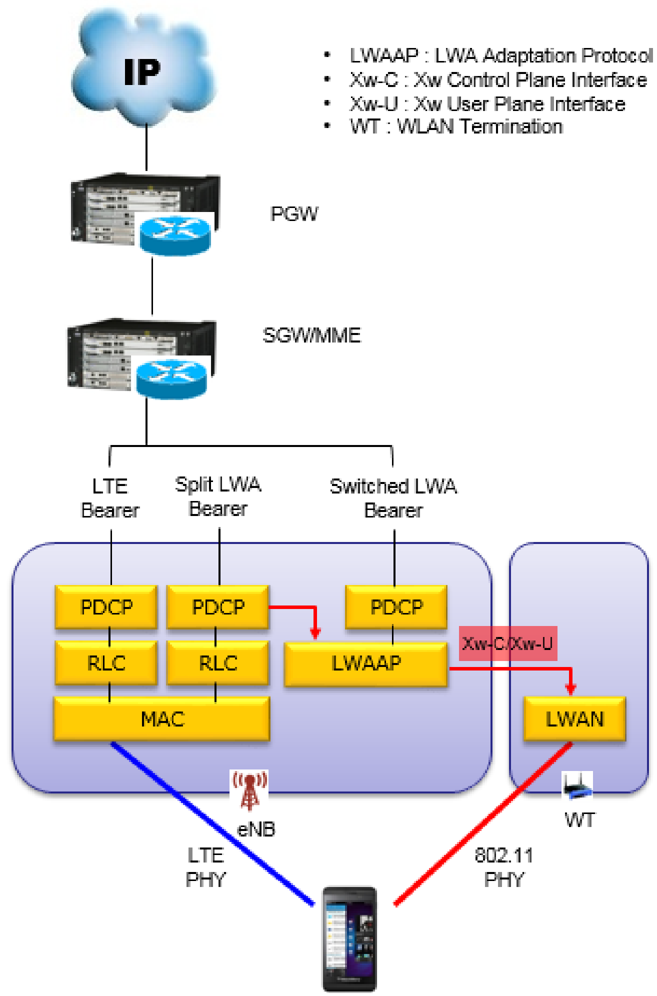
- Coexistence performance is **highly sensitive to factors that affect the channel occupancy** (e.g. control signals), even more than to the parameter choices in the LBT CCA and backoff algorithms.
- **Channel occupancy, and consequently coexistence, is highly affected by the behavior of the upper layer protocols, such as TCP and RLC.**
- A bursty traffic pattern, such as the FTP run over TCP, may cause LAA to occupy the channel more frequently and inefficiently and impact the coexistence with other technologies.
- **HARQ-based CWS update as specified today might be inefficient** as it is not really detecting collisions.
- Either CTS2self, which allows Wi-Fi to preamble detect LAA, or support for lower Wi-Fi energy detection thresholds, seems to be a fundamental functionality to be supported by LAA/Wi-Fi to allow coexistence with Wi-Fi, and to protect the LAA performance in the presence of hidden nodes.

ALTERNATIVES TO LAA

LTE-WLAN aggregation (LWA)

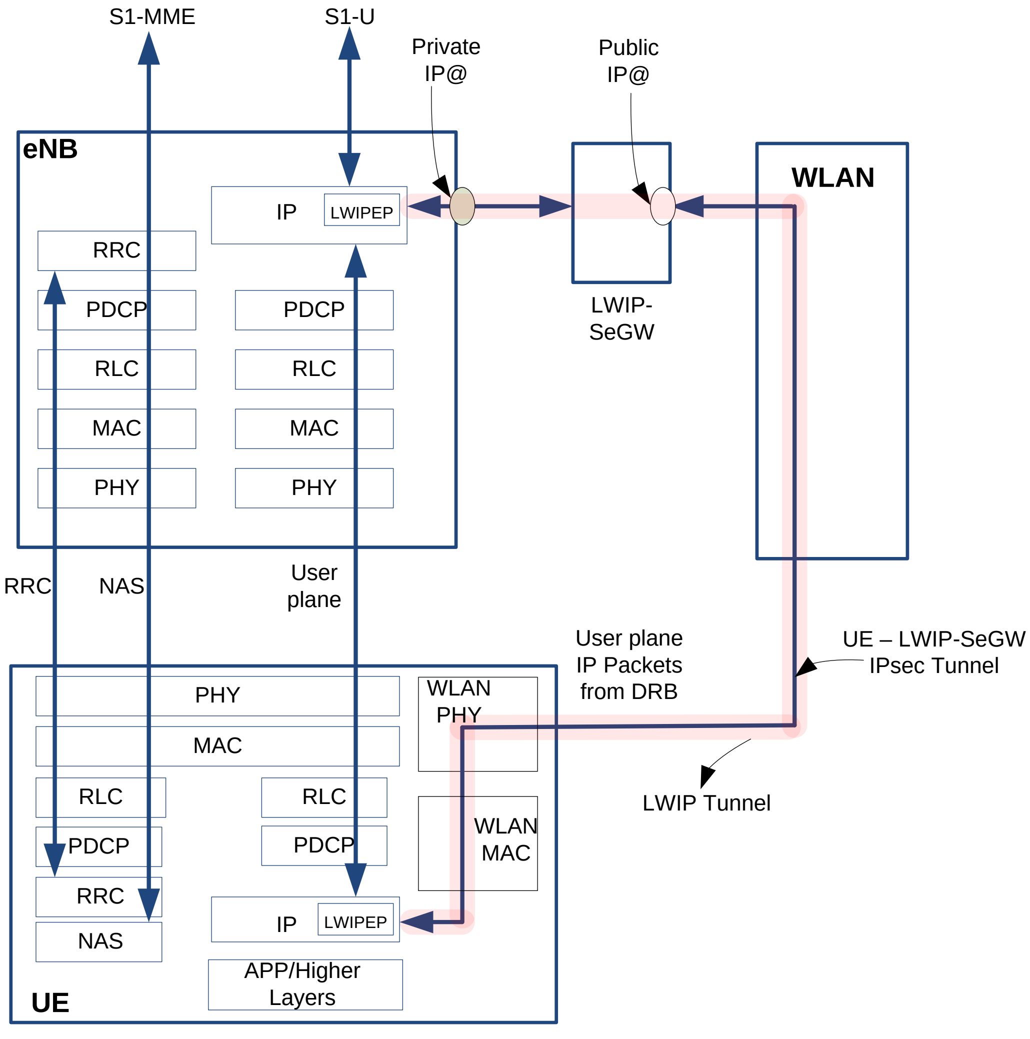


< LWA Network Architecture for Colocated Scenario >



< LWA Network Architecture for Non-Colocated Scenario >

LTE-WiFi aggregation at IP (LWIP)



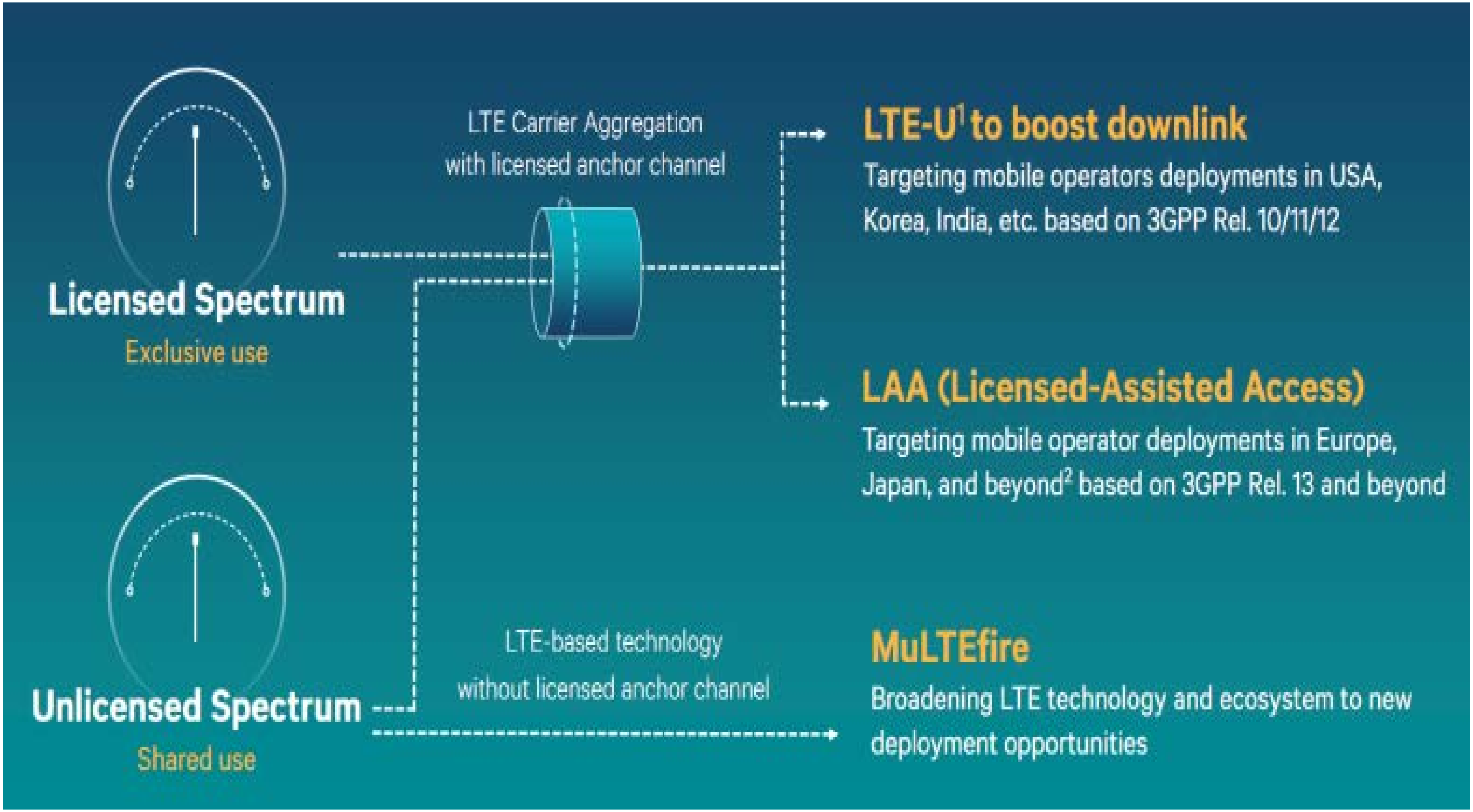
LTE-U / LAA / MultiFire

- **LTE-U**
  - LTE-U Forum / US
  - Based on Rel 12 CA
  - PCell FDD only
  - SCell U-NII band (region without LBT requirement)
  - Duty cycle only (using DRS)
  - Frame Type 1 (FDD)
  - Carrier Sense Adaptive Transmission (CSAT)
  - See www.lteuforum.org

- **LAA**
  - 3GPP / Worldwide
  - Based on Rel 13 CA
  - PCell TDD or FDD
  - SCell in B46
  - LBT
  - Frame Type 3
  - See www.3GPP.org

- **MuLTEfire**
  - Proprietary name (alliance)
  - Standalone use of LTE in unlicensed band
  - See www.multefire.org

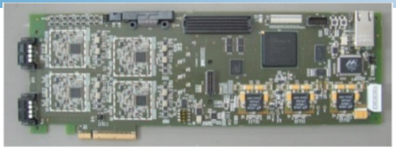
MuLTEFire

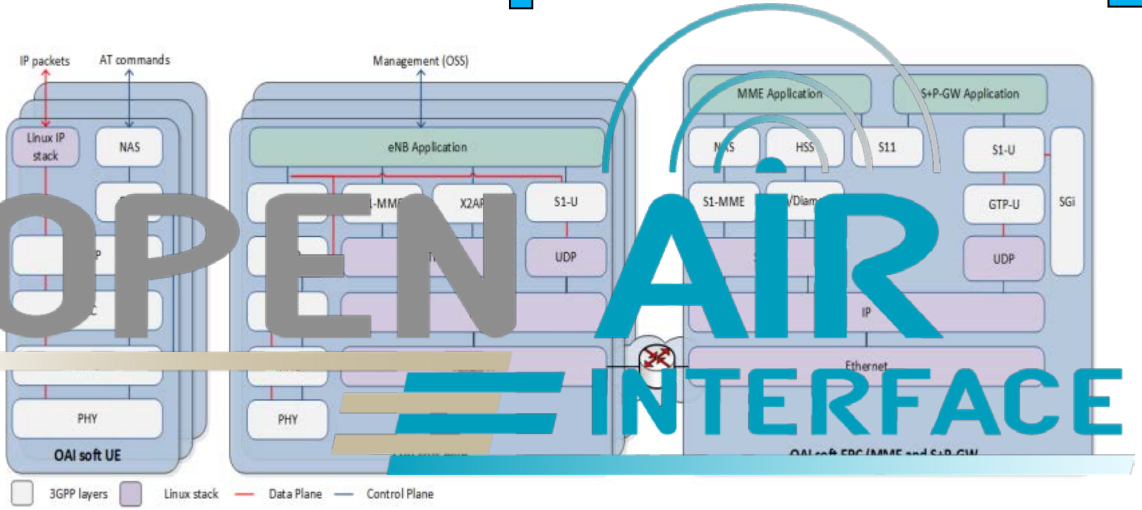


Source: presentation Qualcomm

OPENAIRINTERFACE DEMO

OpenAirInterface today





Introduction

- **OpenAirInterface**
  - Open-source implementation of 4G LTE/5G (UE, eNB, EPC)
  - Works with popular SDR boards (ExpressMIMO, USRP, bladeRF)
  - Allows real-time experimentation with commercial equipment
- **Objectives**
  - Bring academia closer to complex real-world systems
  - Open-source tools to ensure a common R&D and prototyping framework for rapid proof-of-concept designs
- **Other use cases**
  - Interoperability with 3rd party components (UE, eNB, EPC)
  - Matlab/Octave tools for non real-time experimentation
  - Real-time channel sounding (EMOS)
  - 802.11p Modem
  - System and unitary simulations

Evolution of LTE Carrier Aggregation

3GPP Rel. 10
- Intra-band contiguous carriers (FDD or TDD)
- Inter-band non-contiguous carriers (FDD only)
- Framework for up to 5 carriers
- Maximum 2 carriers

Experimental support in OAI

3GPP Rel. 11
- Intra-band non-contiguous carriers (FDD or TDD)
- Different TDD configurations
- Multiple Timing Advances

3GPP Rel. 12
- Dual connectivity
- 3 downlink/ 1 uplink carrier
- 2 contiguous uplink carriers
- FDD-TDD carrier aggregation

3GPP Rel. 13
- Aggregation between carriers in licensed and unlicensed spectrum (licensed assisted access - LAA)
- Framework for aggregation of 32 carriers

3GPP Rel. 14
- LAA for uplink

More carrier combinations →

Release 10 carrier aggregation features in OAI*

- **2 DL carriers, 1 UL carrier**
  - Feedback (ACK/NACK & CQI) for both DL carriers on UL carrier (PUCCH format 1b with channel selection)
- **UE can connect on either carrier**
- **RRC (re-)configuration of secondary component carrier (SCC)**
- **Dynamic activation and de-activation of SCC through MAC signaling**
- **Simple round-robin scheduler**
  - No load balancing or fairness

* Available from gitlab.eurecom.fr/oai/openairinterface5g, branch feature-15-carrier-aggregation

Demo setup

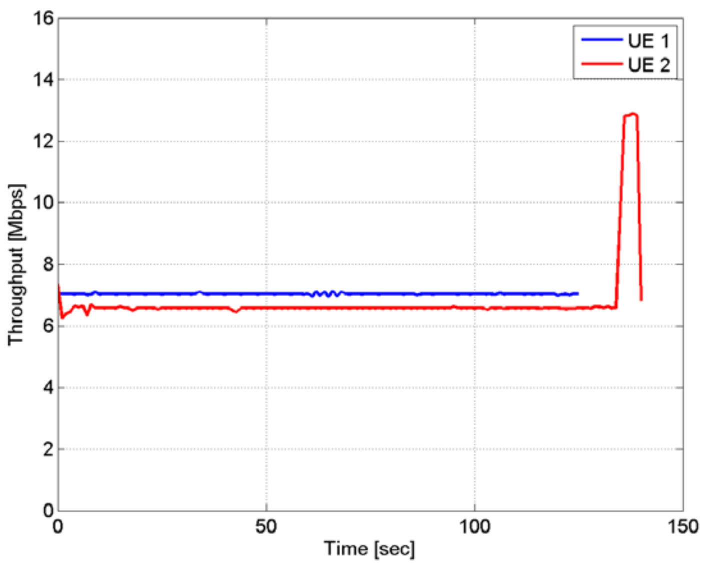
Case	No. UEs	No. CCs	Traffic	Scenario
1a	1,	1,	UDP traffic (16Mbps),	static (eNB and UE in same room)
1b	1,	1,	TCP traffic	static (eNB and UE in same room)
2a	2,	1,	UDP traffic (8Mbps per UE simultaneously),	static (eNB and UEs in same room)
2b	2,	1,	UDP traffic (8Mbps per UE time shifted),	static (eNB and UEs in same room)
2c	2,	1,	TCP traffic simultaneously	static (eNB and UEs in same room)

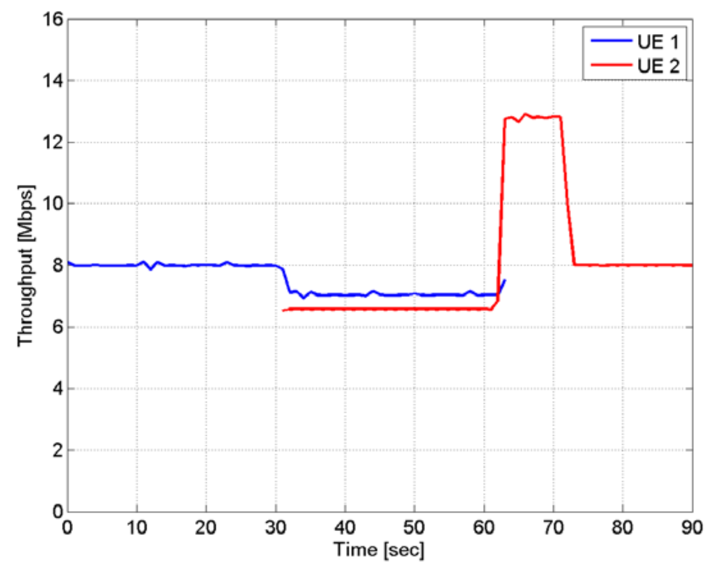
Things to observe

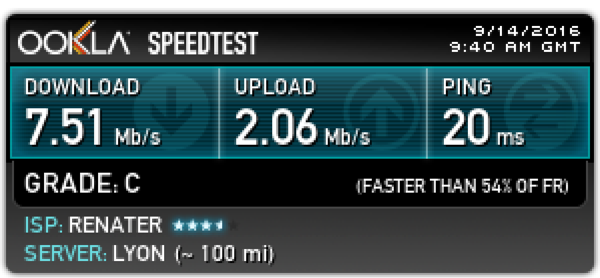
- **Power up eNB and observe spectrum**
- **Power up UE and observe RRC messages**
  - Look for configuration of secondary cell in RRCConnectionReconfiguration message
- **Launch a throughput test using iperf**
- **Activate and deactivate second carrier**

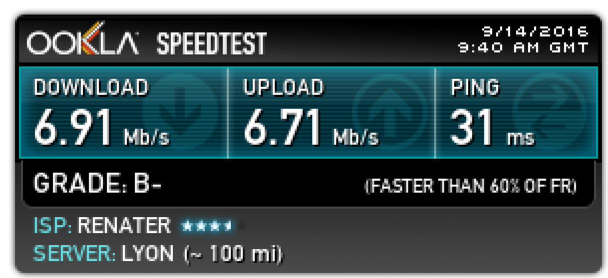
Real-time results

	UE1	UE2
RSRP	-90.19dBm	-107.76dBm
CINR	19.22dB	15.47dB









THE OPENAIRINTERFACE 5G SOFTWARE ALLIANCE

The OpenAirInterface 5G Software Alliance

- **Legal entity (French “Fonds de Dotation”) to support and manage the OpenAirInterface.org development**
  - Similar to other open-source projects
- **Make trusted environment**
  - Contributors and users need to secure themselves
  - Clear open source rules
  - Any individual person or non-profit organization can become a member for free
  - Membership conditions for companies
- **Increase quality & simplify access**
  - Simple and well described binary build procedures for all the LTE components
  - Friendly to various RF systems (RRH, SmallCell, etc.)
  - Anybody can build a fully open-source 4G network comprising a couple of eNBs + EPC for less than 10K€ and 1 human week of effort

OAI Alliance Members

Founding Member

EURECOM
Sophia Antipolis

Strategic Members

orange™

TCL
创意感动生活
The Creative Life

ERCOM

Associate Members

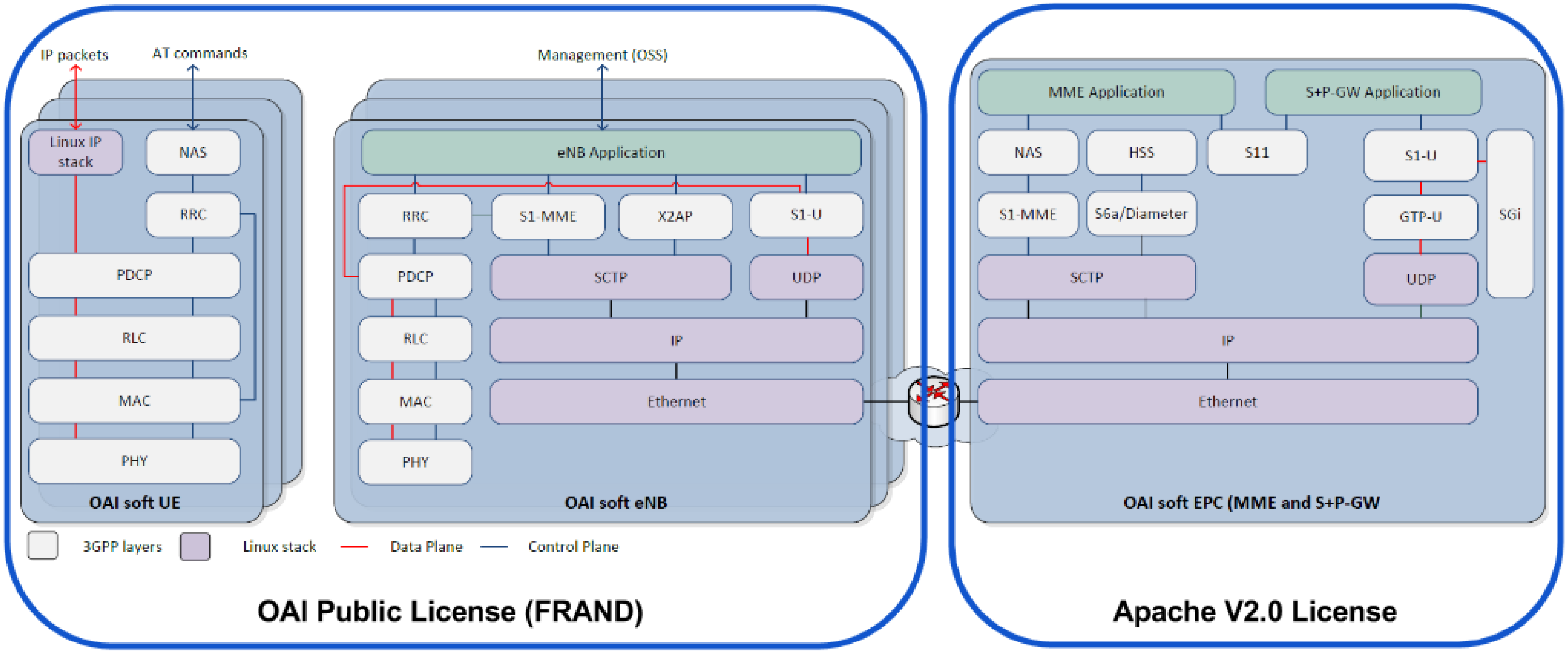
- University of Kent
- IIIT-D INDRAPRASTHA INSTITUTE of INFORMATION TECHNOLOGY DELHI
- UNIVERSITY of WASHINGTON
- 中国科学院
- iMinds
- THE UNIVERSITY OF UTAH
- b<>com
- 北京邮电大学 Beijing University of Posts and Telecommunications
- instituto de telecomunicações
- THE UNIVERSITY of EDINBURGH
- u^b UNIVERSITÄT BERN
- Universidad Carlos III de Madrid
- University of Essex
- TNO innovation for life
- 电子科技大学
- IIT Hyderabad
- UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
- com4innov INNOVATE TOGETHER
- RUTGERS WINLAB | Wireless Information Network Laboratory
- RUB
- UNIVERSITY OF THESSALY
- UNIVERSIDAD DE MÁLAGA
- INSTITUT Mines-Télécom
- UPMC SORBONNE UNIVERSITÉS
- POLITECHNIKA POZNAŃSKA Poznan University of Technology
- Technische Universität München
- Amirkabir University of Technology
- technische universität dortmund
- Inria INVENTEURS DU MONDE NUMÉRIQUE
- 財團法人資訊工業策進會 INSTITUTE FOR INFORMATION INDUSTRY

Membership Models

- **Strategic members**
  - ~100k€ per year (reduced to 40k€ with agreed effort)
  - Strong voice in decision process (limited number of members)
  - Ability to run projects (e.g. porting for industrial HW targets)
  - Ability to attend and host meetings
- **Associate members**
  - ~10k€ per year, free for non-profit organizations
  - limited voice or no voice in decision process (only if merit warrants this)
  - Use of logo / SW certification
  - Attend meetings
- **Ordinary (Individual) members**
  - Free
  - Main “workforce”, can commit to codebase
  - Can attend meetings and join projects

OSA Licensing Model

- **FRAND License allows committing software with patent rights into OSA and still keep licensing rights -> Inline with 3GPP fair use licensing policy**
- **We are working closely with ETSI for licensing/certification**
- **Future 5G Core Network developed within eNB/UE will inherit FRAND license (subject to approval from OSA Board)**



Other OAI Projects

- **OAI Alliance Project 6: LTE-LAA**
  - Implement LTE-LAA in OAI.
  - Conduct LTE/WiFi coexistence studies
  - Ongoing work with iMinds
- **LTE-WiFi aggregation at PDCP**
  - Similar to Rel 12 dual connectivity (but not standard compliant)
  - Developed by Telecom Bretagne
  - Younes Khadraoui, Xavier Lagrange, Annie Gravey, "TCP performance for practical implementation of very tight coupling between LTE and WiFi," VTC 2016-Fall, Montreal, Canada.
- **LTE-WiFi aggregation at IP**
  - Similar to Rel 12 LWIP (but not standard compliant)
  - Developed by IIT-Hyderabad
  - http://www.openairinterface.org/?page_id=1885

Get involved with OAI

- **Get started: www.openairinterface.org**
- **Join our mailing list**
- **Join the alliance**
- **Contribute to one of our projects**

OPEN AIR 5G INTERFACE

5G SOFTWARE ALLIANCE