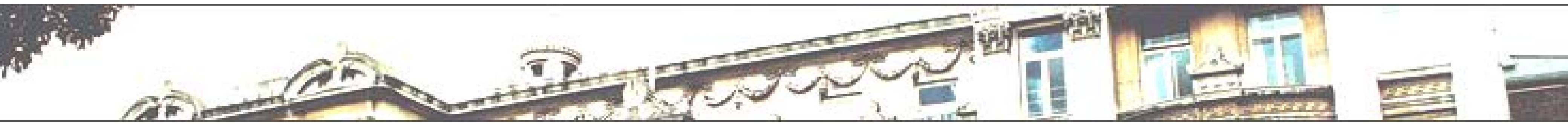
School of Electronic Engineering and Computer Sciences

LTE-Advanced

Evolution to 4G Mobile Technologies



“LTE the UMTS Long Term Evolution from Theory to Practice”, Wiley, ISBN:978-0-470-66025-6.

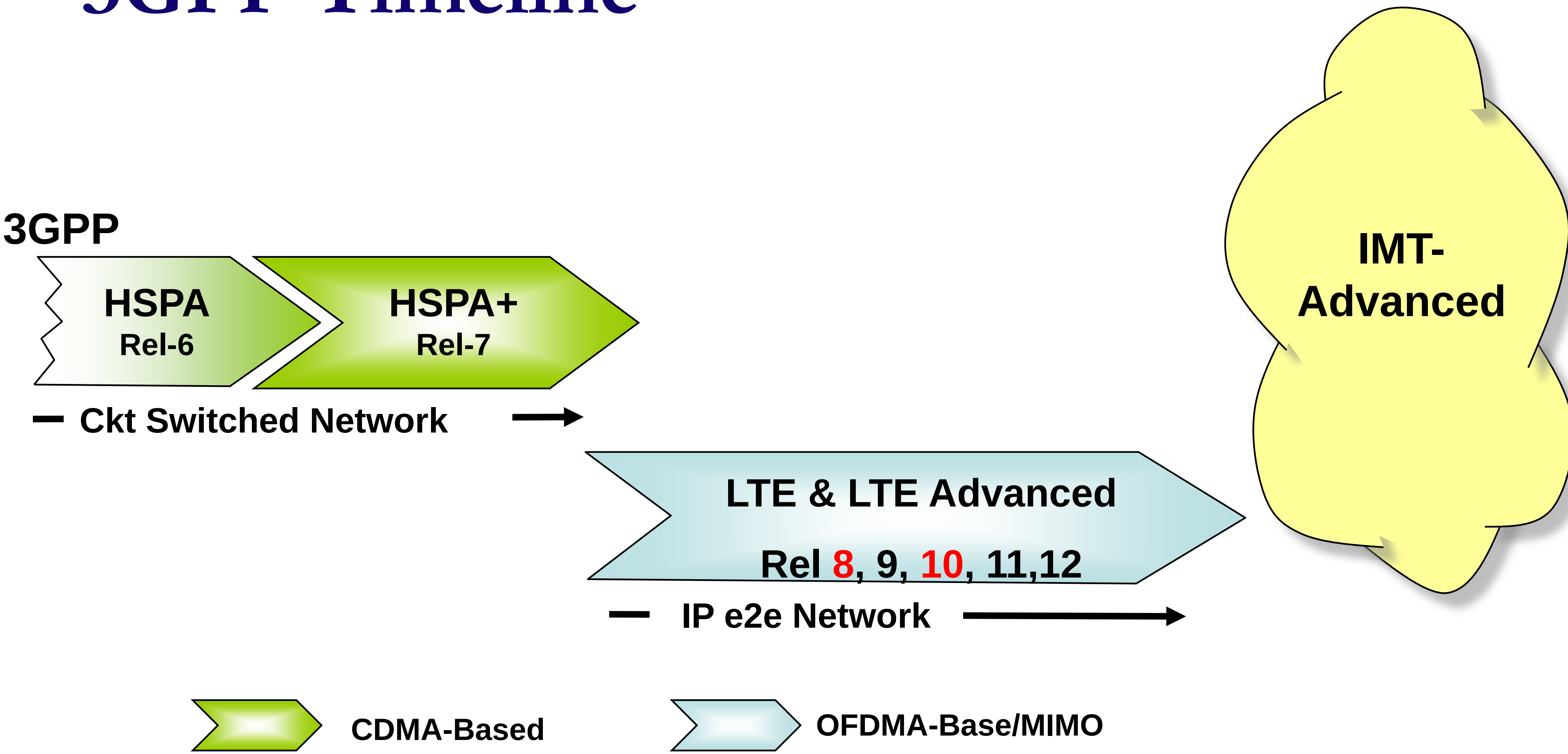
Queen Mary
University of London

Outline

- Last Lecture
  - UMTS Evolved Architecture
  - HSDPA
  - HSUPA
  - HSPA+

- This Lecture
  - LTE bands
  - 4G Network Architecture
  - LTE Radio Access scheme
  - LTE hand over
  - LTE-A Key technologies
    - Carrier Aggregation in LTE-A
    - Enhanced Multi-antenna Techniques in Downlink
    - CoMP transmission/reception
    - Relaying

3GPP Timeline



2008	2009	2010 /11	2012/13	2014

3GPP Releases: LTE

- Release 8 (last freeze December 2008)
  - New radio system (LTE) based on OFDM, (the LTE baseline release)
  - Simultaneous use of 64QAM and MIMO on a single carrier
    - downlink peak rate: LTE 160Mbps, HSPA 42Mbps ; uplink peak rate: LTE 50Mbps
    - Coupled with improvements in the radio access network for continuous packet connectivity, HSPA+ will allow Uplink speeds of 11Mbps and Downlink speeds of 42Mbps within the Release 8 time frame.
  - Definition of Dual Carrier HSDPA - or Dual cell, specifying carrier aggregation for increased spectrum efficiency and load balancing across the carriers.
  - Single Radio Voice Call Continuity to hand-over voice calls from a packet to a circuit switched bearer
  - Femtocell definition (Home NodeBs)
  - ICE (In Case of Emergency) information storage on the SIM card and retrieval in a standardized way to help first responders to contact your family and friends in case something has happened to you.

- Release 9 (last freeze December 2009)
  - This added further enhancements to the SAE as well as allowing for WiMax and LTE/UMTS interoperability.
  - Separate dual carriers to simultaneously transmit downlink data in the 900 and 2100 MHz band.
  - Dual carrier in the uplink
  - Inclusion of the European Digital Dividend band

3GPP Releases: LTE - Advanced

- Release 10 (last freeze March 2011)
  - This release of the 3GPP standard detailed the 4G LTE Advanced technology.
  - up to 3Gbit/s downlink and 1.5Gbit/s uplink
  - carrier aggregation (CA), allowing the combination of up to five separate carriers to enable bandwidths up to 100MHz
  - higher order MIMO antenna configurations up to 8×8 downlink and 4×4 uplink
  - relay nodes to support Heterogeneous Networks ("HetNets") containing a wide variety of cell sizes
  - enhanced inter-cell interference coordination (eICIC) to improve performance towards the edge of cells.

- Release 11 – (last freeze 2013)
  - Release 11 will build on the platform of Release 10 with a number of refinements to existing capabilities, including:
  - enhancements to Carrier Aggregation, MIMO, relay nodes and eICIC
  - introduction of new frequency bands
  - coordinated multipoint transmission and reception to enable simultaneous communication with multiple cells
  - advanced receivers.

- Release 12 – (last freeze 2014)
  - enhanced small cells for LTE, introducing a number of features to improve the support of HetNets
  - inter-site carrier aggregation, to mix and match the capabilities and backhaul of adjacent cells
  - new antenna techniques and advanced receivers to maximise the potential of large cells
  - interworking between LTE and WiFi or HSPDA
  - further developments of previous technologies

LTE vs UMTS

- The RF transmitter must generate a clean signal within the assigned spectrum portion, and aims to keep Inter-Carrier Interference (ICI) within acceptable levels.
- The receiver likewise must reliably demodulate the wanted signal, in order to avoid requiring excessive energy to be transmitted, whilst also rejecting interference from neighbouring carriers.

	UMTS	**LTE**
UE operation bandwidth	5 MHz	1.4, 3, 5, 10 & 20 MHz
Bandwidth operation requirements	Frequency Division Duplex (FDD)	A set of RF requirements for each BW
UE receive Antennas	Single	≥2; multiple RF signal paths
Data rates vs SINR	Less adaptive	More adaptive (64QAM .. QPSK)
RF aspects response to signals	WCDMA	Signal structure itself alters which specific RF aspects are most critical (OFDM)
…	…	…

Frequency Bands and Arrangements

- **UMTS and LTE frequency bands for FDD.**

Band Number	Uplink (MHz)	Downlink (MHz)	Band Gap (MHz)	Duplex Separation (MHz)	UMTS Usage	LTE Usage
	$F_{UL\ low}$–$F_{UL\ high}$	$F_{DL\ low}$–$F_{DL\ high}$				
1	1920–1980	2110–2170	130	190	Y	Y
2	1850–1910	1930–1990	20	80	Y	Y
3	1710–1785	1805–1880	20	95	Y	Y
4	1710–1755	2110–2155	355	400	Y	Y
5	824–849	869–894	20	45	Y	Y
6*	830–840	875–885	35	45	Y	Y
7	2500–2570	2620–2690	50	120	Y	Y
8	880–915	925–960	10	45	Y	Y
9	1749.9–1784.9	1844.9–1879.9	60	95	Y	Y
10	1710–1770	2110–2170	340	400	Y	Y
11	1427.9–1447.9	1475.9–1495.9	28	48	Y	Y
12	698–716	728–746	12	30	Y	Y
13	777–787	746–756	21	31	Y	Y
14	788–798	758–768	20	30	Y	Y
17	704–716	734–746	18	30	N	Y
18**	815–830	860–875	30	45	N	Y
19**	830–845	875–890	30	45	Y	Y
20**	832–862	791–821	11	41	Y	Y
21**	1447.9–1462.9	1495.9–1510.9	33	48	Y	Y
23***	2000–2020	2180–2200	160	180	N	Y
24***	1626.5–1660.5	1525–1559	-135.5	-101.5	N	Y
25***	1850–1915	1930–1995	15	80	Y	Y
26****	814–849	859–894	10	45	Y	Y

* This band was defined in the context of Release 8; it is replaced by Band 19 for later releases (Release 9 and 10). Only legacy terminals would use band 6.
** These bands were specified in the timeframe of Release 9, although all bands are release-independent and can be implemented by UEs conforming to any release.
*** These bands were specified in the timeframe of Release 10, although all bands are release-independent and can be implemented by UEs conforming to any release.
**** This band was under consideration at the time of going to press.

*Reproduced from "LTE the UMTS Long Term Evolution from Theory to Practice", Wiley, ISBN:978-0-470-66025-6.

Frequency Bands and Arrangements

- **UMTS and LTE frequency bands for TDD.**

*Reproduced from "LTE the UMTS Long Term Evolution from Theory to Practice", Wiley, ISBN:978-0-470-66025-6.

Band	F_{low}–F_{high} (MHz)	UMTS	LTE
33	1900–1920	Y	Y
34	2010–2025	Y	Y
35	1850–1910	Y	Y
36	1930–1990	Y	Y
37	1910–1930	Y	Y
38	2570–2620	Y	Y
39	1880–1920	N	Y
40	2300–2400	Y	Y
41*	2496–2690	N	Y
42*	3400–3600	N	Y
43*	3600–3800	N	Y

* These bands were specified in the timeframe of Release 10, although all bands are release-independent and can be implemented by UEs conforming to any release.

Licence award of the 800 MHz and 2.6 GHz spectrum bands

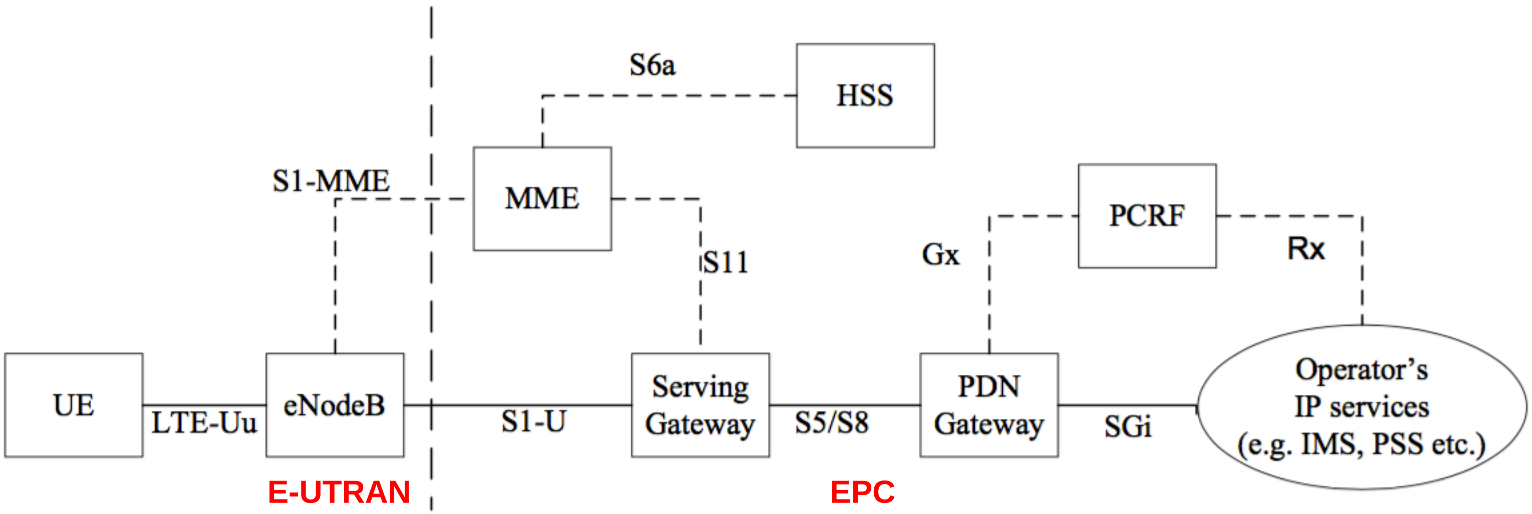
Licensee	Frequencies assigned	Spectrum own
Everything Everywhere Ltd	796-801 MHz 837-842 MHz	2 x 5 MHz of 800 MHz
Everything Everywhere Ltd	2535-2570 MHz 2655-2690 MHz	2 x 35 MHz of 2.6 GHz
Hutchison 3G UK Ltd	791-796 MHz 832-837 MHz	2 x 5 MHz of 800 MHz
Niche Spectrum Ventures Ltd	2520-2535 MHz 2640-2655 MHz	2 x 15 MHz of 2.6 GHz
Niche Spectrum Ventures Ltd	2595-2620 MHz	1 x 20 MHz of 2.6 GHz
Telefonica UK Ltd	811-821 MHz 852-862 MHz	2 x 10 MHz of 800 MHz
Vodafone Ltd	801-811 MHz 842-852 MHz	2 x 10 MHz of 800 MHz
Vodafone Ltd	2500-2520 MHz 2620-2640 MHz	2 x 20 MHz of 2.6 GHz
Vodafone Ltd	2570-2595 MHz	1 x 25 MHz of 2.6 GHz

Reproduced from Ofcom documents, URLs:

- http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/awards-in-progress/notices/4g-final-results.pdf
- http://media.ofcom.org.uk/2013/02/20/ofcom-announces-winners-of-the-4g-mobile-auction/

4G Overall Network Architecture

- The network consists of access network (**E**volved-**UTRAN**) and core network (EPC: **E**volved **P**acket **C**ore network)
- Support only packet-switched services, no circuit-switched service
- Provide seamless IP connectivity between UE and **P**acket **D**ata **N**etwork



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MME: Mobility management Entity
PCRF: Policy and Charging Rules Function

4G Overall Network Architecture

- **P-GW(PDN-GW).** The P-GW is responsible for IP address allocation for the UE, as well as QoS enforcement and flow-based charging according to rules from the PCRF. The P-GW is responsible for the filtering of downlink user IP packets into the different QoS based bearers. This is performed based on Traffic Flow Templates (TFTs). The P-GW performs QoS enforcement for Guaranteed Bit Rate (GBR) bearers. It also serves as the mobility anchor for inter-working with non-3GPP technologies such as CDMA2000 and WiMAX networks.

- **S-GW(Serving-GW).** All user IP packets are transferred through the S-GW, which serves as the local mobility anchor for the data bearers when the UE moves between eNodeBs. It also retains the information about the bearers when the UE is in idle state (known as ECM- IDLE) and temporarily buffers downlink data while the MME initiates paging of the UE to re-establish the bearers. In addition, the S-GW performs some administrative functions in the visited network such as collecting information for charging (e.g. the volume of data sent to or received from the user), and legal interception. It also serves as the mobility anchor for inter-working with other 3GPP technologies such as GPRS and UMTS.

4G Overall Network Architecture

- **PCRF.** It is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF) which resides in the P-GW. The PCRF provides the QoS authorization (QoS class identifier and bitrates) that decides how a certain data flow will be treated in the PCEF and ensures that this is in accordance with the user's subscription profile.

- **Home Location Register (HSS).** The HLR contains users' SAE(System Architecture Evolution) subscription data such as the EPS-subscribed QoS profile and any access restrictions for roaming (see Section 2.2.3). It also holds information about the PDNs to which the user can connect. This could be in the form of an Access Point Name (APN) (which is a label according to DNS1 naming conventions describing the access point to the PDN), or a PDN Address (indicating subscribed IP address(es)). In addition the HLR holds dynamic information such as the identity of the MME to which the user is currently attached or registered. The HLR may also integrate the Authentication Centre (AuC) which generates the vectors for authentication and security keys.

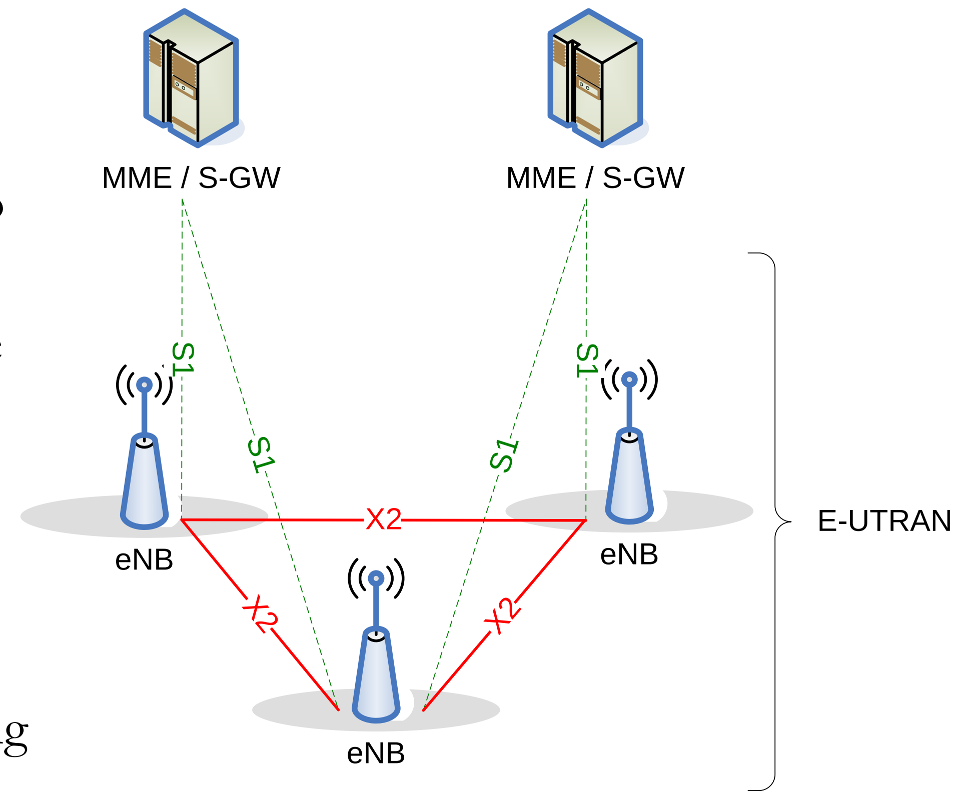
*Reproduced from "LTE the UMTS Long Term Evolution from Theory to Practice", Wiley, ISBN:978-0-470-66025-6.

4G Overall Network Architecture

- **VoLTE(Voice over LTE)**. is a standard for high-speed wireless communication for mobile phones and data terminals—including IoT devices and wearables. It is based on the IP Multimedia Subsystem (IMS) network, with specific profiles for control and media planes of voice service on LTE. This approach results in the voice service (control and media planes) being delivered as data flows within the LTE data bearer. This means that there is no dependency on (or ultimately, requirement for) the legacy circuit-switched voice network to be maintained. VoLTE has up to three times more voice and data capacity than 3G UMTS and up to six times more than 2G GSM. Furthermore, it frees up bandwidth because VoLTE's packets headers are smaller than those of unoptimized VoIP/LTE.

LTE Radio Access Network

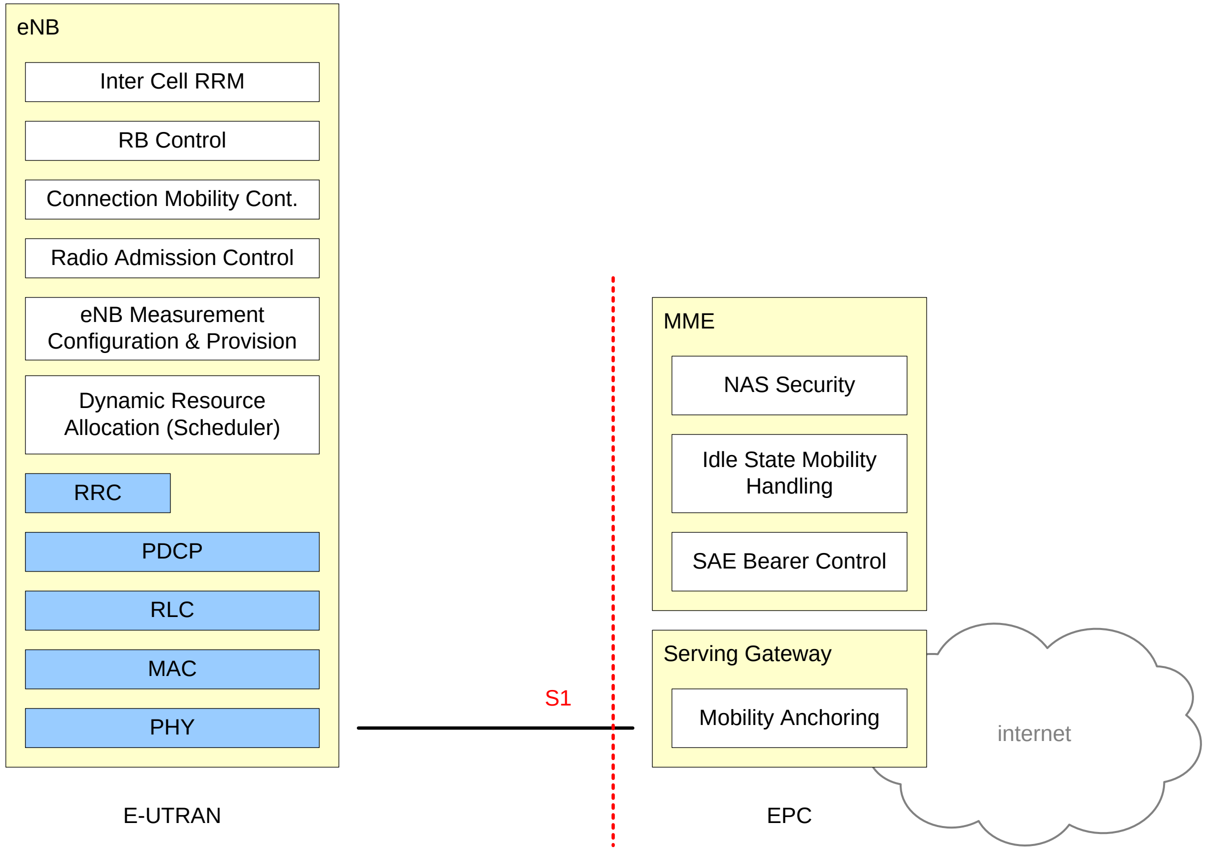
- The radio controller function in 2G and 3G is integrates into the eNodeB in order to reduce latency and improve efficiency.
- As the UE moves, the network transfers all information related to a UE from one eNB to another through X2 interface
- Multiple CN nodes (MME/S-GWs) can serve a common geographical area, by being connected by a mesh network to the set of eNBs through S1 interface, which allows Ues controlled by one eNB to be shared between multiple CN nodes, thereby providing a possibility for load sharing and also eliminating single points of failure for the CN nodes.



*Reproduced from "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2"

Network Functional Split

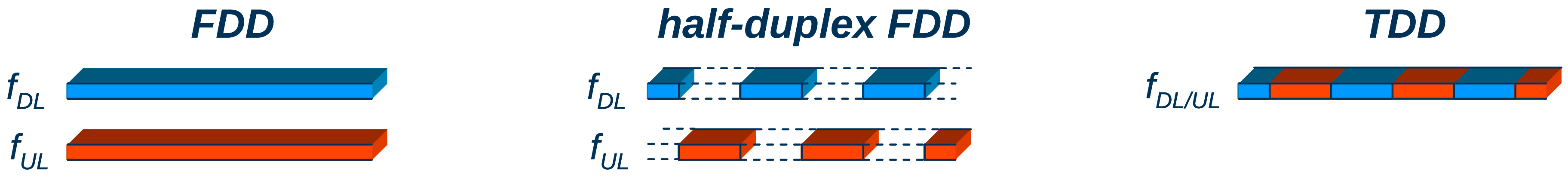
- Yellow Box: logical nodes
- White Box: functional entities of the control plane
- Blue boxes: the radio protocol layers



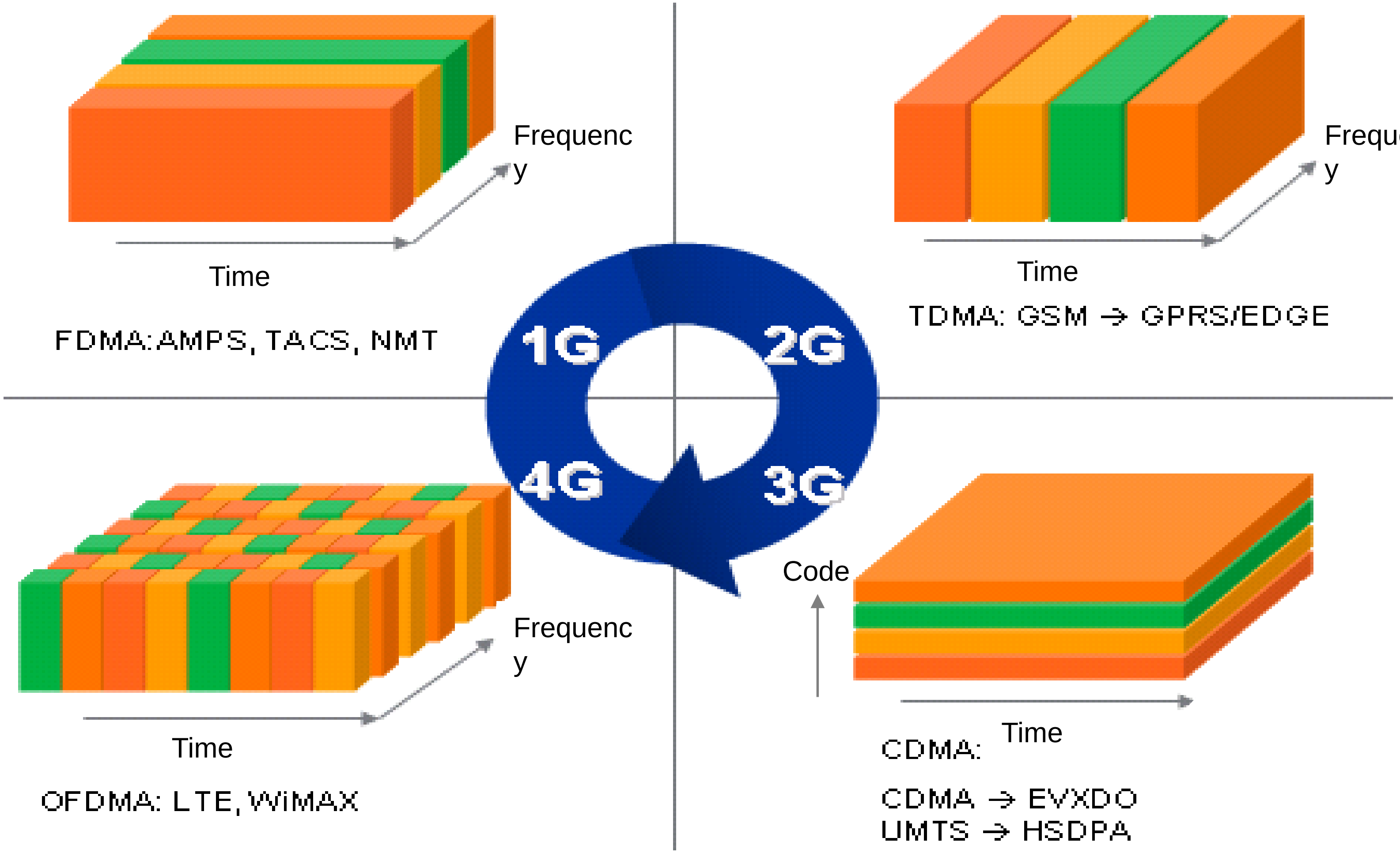
*Reproduced from "LTE; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2"

LTE Duplex Modes

- *Frequency Division Duplex* (FDD): Downlink and uplink transmission take place in different, sufficiently separated, frequency bands.
- *Time Division Duplex* (TDD): Downlink and uplink transmission take place in different, non-overlapping time slots.
- *half-duplex* FDD at the terminal: Transmission and reception at a specific terminal are separated in both frequency and time. The base station still uses full duplex as it simultaneously may schedule different terminals in uplink and downlink

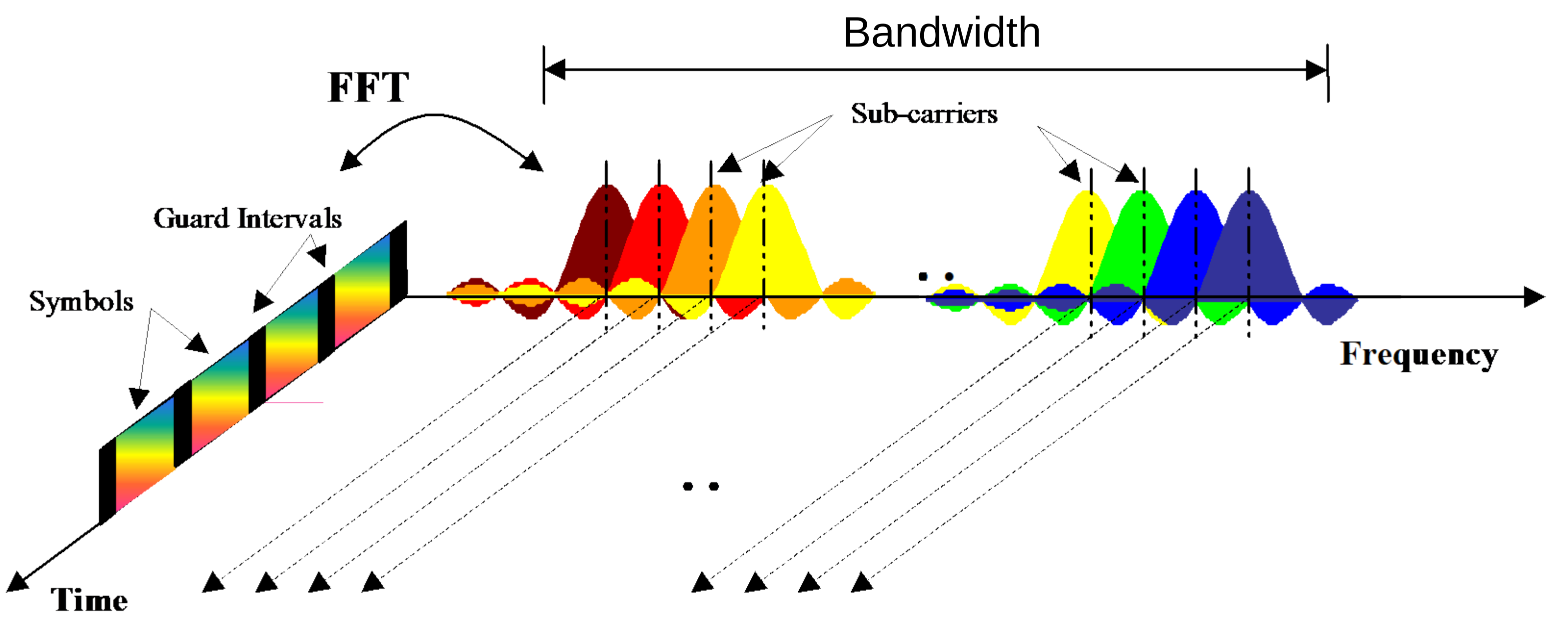


Evolution of Radio Access Techniques



LTE Radio Access Scheme

- Downlink: *Orthogonal Frequency Division Multiple Access* (OFDMA)
  - In OFDM, the frequency-selective wideband channel is divided into the non-frequency-selective narrowband subchannels, which are overlapping but orthogonal.
  - In OFDM, the high-rate stream of data symbols is serial-to-parallel converted for modulation onto M parallel subcarriers



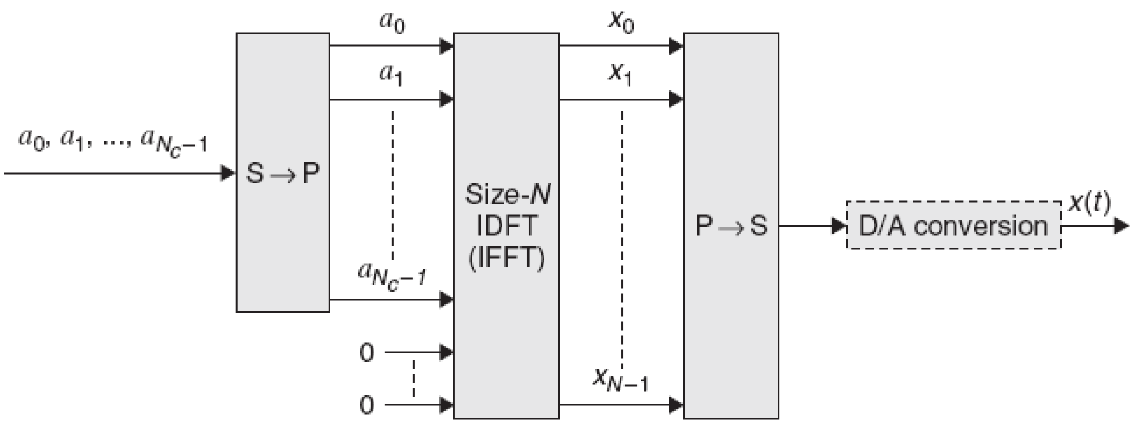
LTE Radio Access Scheme

- OFDM Implementation by using IFFT/FFT Processing

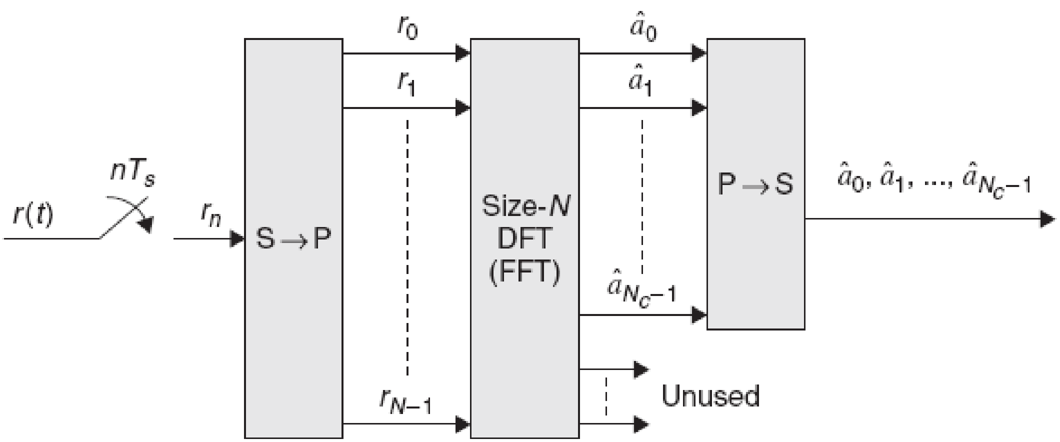
$$x_n = x(nT_s) = \sum_{k=0}^{Nc-1} a_k e^{j2\pi k \Delta f n T_s}$$

$$= \boxed{\sum_{k=0}^{Nc-1} a_k e^{j2\pi kn/N}} \quad \text{IDFT}$$

$$= \boxed{\sum_{k=0}^{N-1} a'_k \, e^{j2\pi kn/N} \qquad a'_k = \begin{cases} a_k & 0 \le k < N_c \\ 0 & N_c \le k < N \end{cases}} \quad \text{IFFT}$$



OFDM Modulation

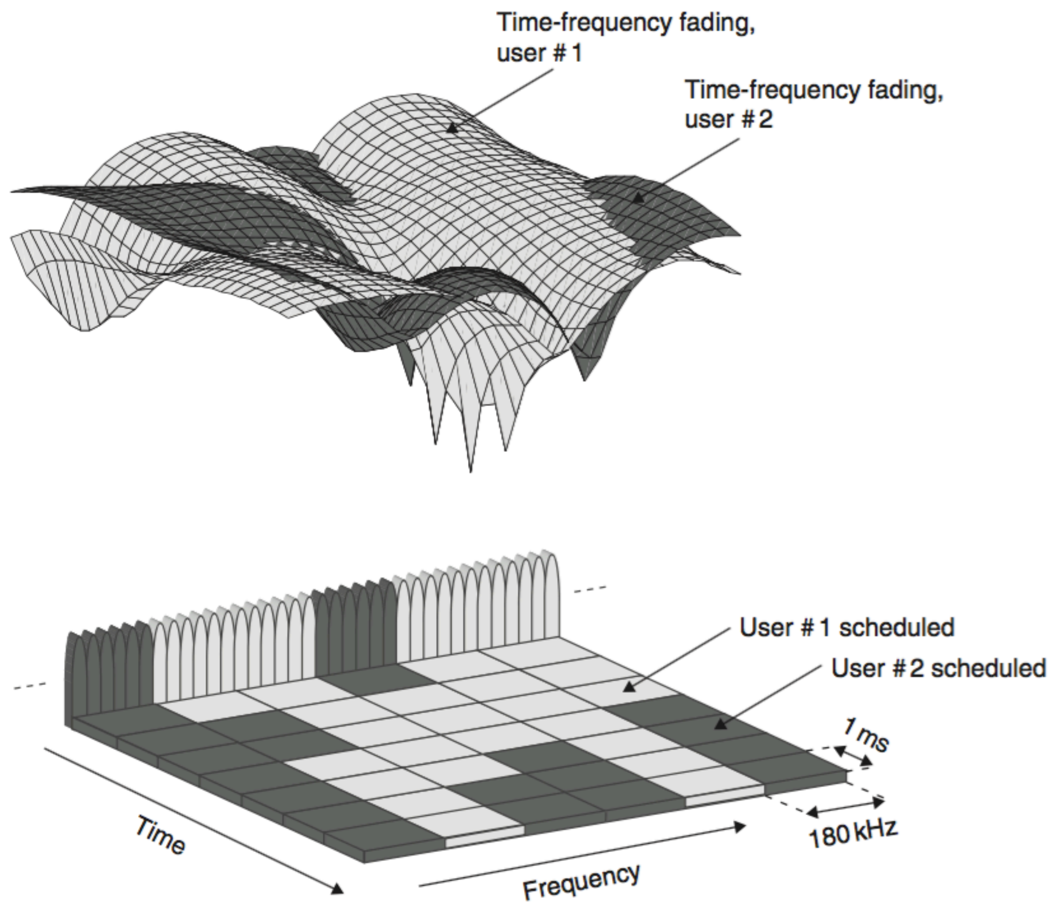


OFDM Demodulation

LTE Radio Access Scheme

- Downlink: *Orthogonal Frequency Division Multiple Access* (OFDMA)

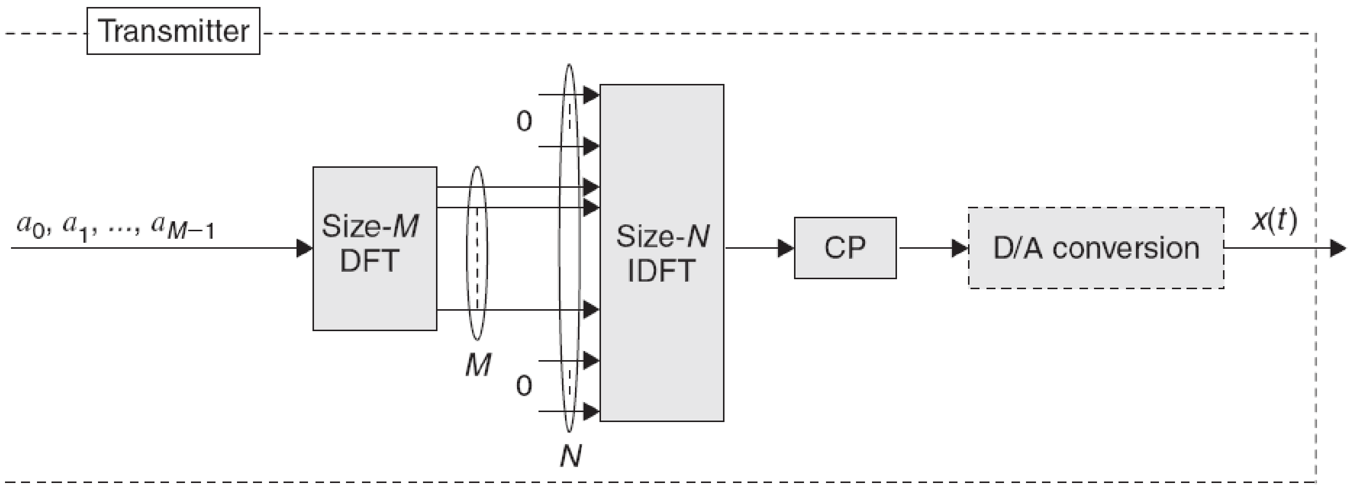
  - OFDMA distributes subcarriers to different users at the same time, so that multiple users can be scheduled to receive data simultaneously.
  - In addition to the time domain, the scheduler can, for each frequency region, select the user with the best channel conditions. In other words, scheduling in LTE can take channel variations into account both in the time domain but also in the frequency domain
  - For LTE, scheduling decisions can be taken as often as once every 1 ms and the granularity in the frequency domain is 180kHz.



*Source: "3G Evolution HSPA and LTE for Mobile Broadband Second edition 2008 "

LTE Radio Access Scheme

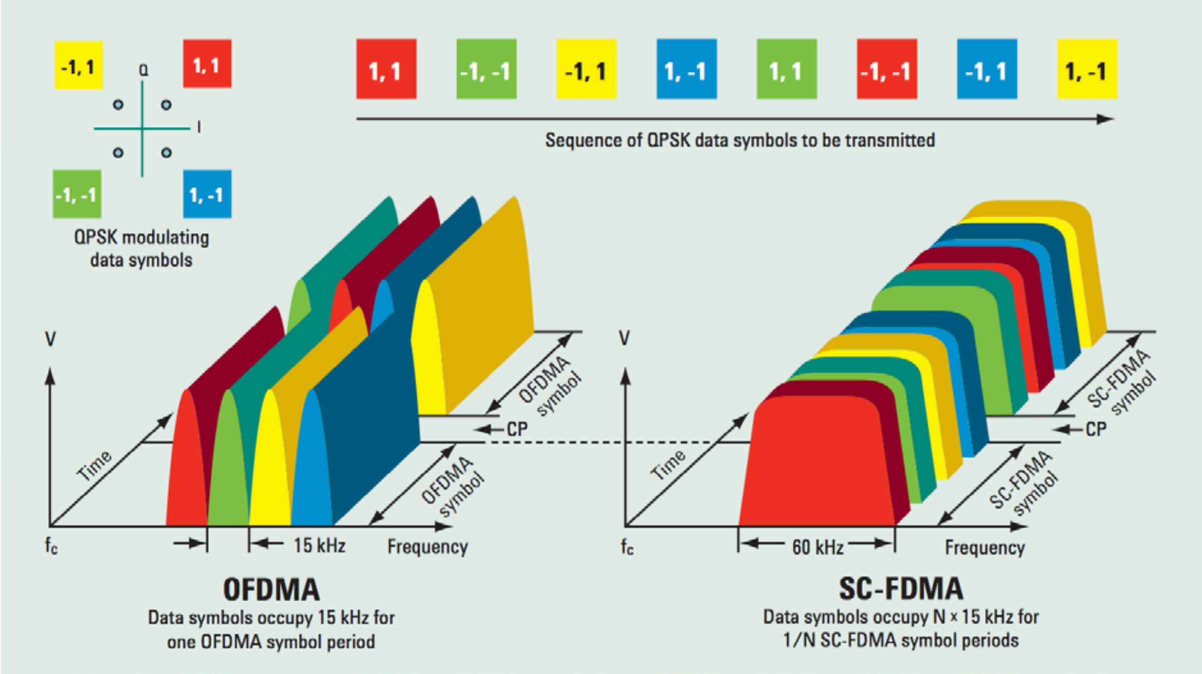
- Uplink: *DFT-spread OFDM* (DFTS-OFDM) (Also known as **S**ingle**C**arrier-FDMA)
  - One of the major drawbacks is that the OFDM signal has a high Peak-to-Average Power Ratio (PAPR). The amplitude variations of the OFDM modulated signal can therefore be very high, which leads to inefficient amplification and/or expensive transmitters considering the limited linear range of practical Power Amplifiers (PAs) of RF transmitters.
  - DFTS-OFDM properties:
    - Small variations in the instantaneous power of the transmitted signal
    - Possibility for low-complexity high-quality equalization in the frequency domain



LTE Radio Access Scheme

- Comparing Downlink OFDMA and Uplink SC-FDMA by an Example
  - **OFDMA**: N adjacent 15 kHz subcarriers are each modulated for the OFDMA symbol period by one QPSK data symbol. It transmits the four QPSK data symbols in parallel, one per subcarrier.
  - **SC-FDMA**: SC-FDMA transmits the 4 QPSK data symbols in series at N times the rate of OFDMA, with each data symbol occupying N x 15 kHz bandwidth.

Visually, the OFDMA signal is clearly multi-carrier and the SC-FDMA signal looks more like single-carrier, which explains the “SC” in its name.



*Source: Agilent, “3GPP LTE: Introducing Single-Carrier FDMA”

LTE Handover

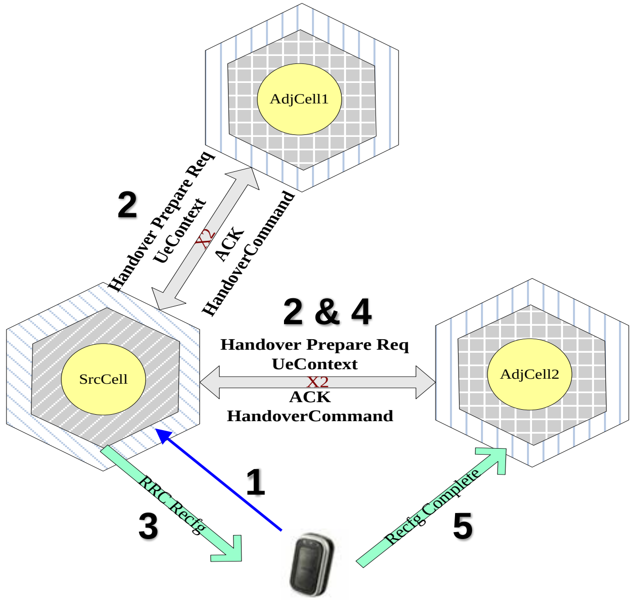
Handovers can be initiated by the eNodeB for several different reasons:

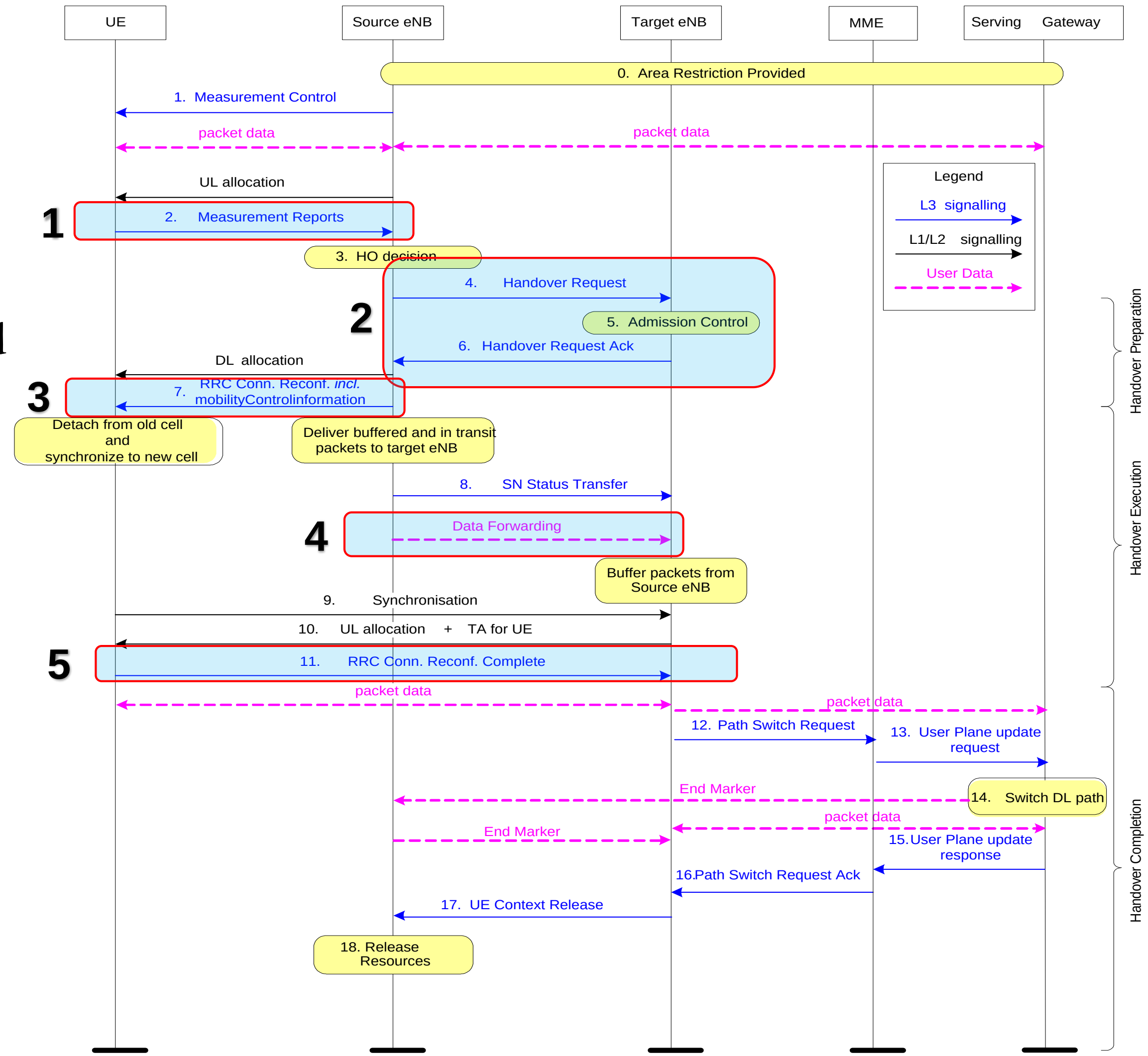
- **Quality-based handovers**. Typically these handovers are initiated as a result of a UE measurement report indicating that the UE can communicate with a neighbour cell with a better channel quality than that of the current serving cell.
- **Coverage-based handovers**. These handovers move the connection to another RAT because the UE is losing coverage for the current RAT. For example, a UE could be moving away from an urban area and losing LTE coverage. As a result the network hands over the connection to the second preferred RAT which the UE has detected, such as UMTS or GSM.
- **Load-based handovers**. These handovers are performed by the network in order to spread the load more evenly between different RATs belonging to the same operator when a given cell is overloaded. For example, if an LTE cell is congested then some users may be moved to nearby LTE cells or nearby UMTS cells.

*Source "LTE the UMTS Long Term Evolution from Theory to Practice", Wiley, ISBN:978-0-470-66025-6.

LTE Handover Procedures

1. Triggered by measurement report (MR)
2. Negotiate HO information
3. Indicate UE target cell & HO information
4. Forward UE data from Source eNB to destination eNB
5. Notify target eNB HO has been completed
6. Notify MME HO is successful, source eNB release UE context





LTE Handover

Comparing Handover Techniques:

- A **mobile assisted handover (MAHO)** is a process used in cellular networks where a mobile phone assists/helps the cellular base station to transfer a call to another base station. It is a technique used in mobile telecom to transfer a mobile phone to a new radio channel with stronger signal strength and improved channel quality.
- In the **network-controlled handover (NCHO)** mode, the surrounding access points (e.g., BSs) measure the signal from the mobile station. The network initiates the handover process when certain handover criteria are met.
- **Hard handover** means that all the old radio links in the UE are removed before the new radio links are established
- Soft handover means that the radio links are added and removed in a way that the UE always keeps at least one radio link to the UTRAN.

Handover Techniques	1G	2G	3G	4G
Handover Type	Hard Handover	Hard Handover	Soft Handover	Hard Handover
Handover Process Control	NCHO	MAHO	MAHO	MAHO
Decision making	MSC	MSC	RNC	eNB

*Source "Mobility Management", Springer, ISBN:978-3-662-52726-9.

Radio Parameters

- **LTE-A vs. LTE**

<table>
<tr><th colspan="2">Parameters</th><th>LTE (Rel.8)</th><th>LTE-A (Rel.10)</th></tr>
<tr><td rowspan="2">Access Scheme</td><td>UL</td><td>DFTS-OFDM</td><td rowspan="3">Aggregated Component Carriers in Rel.8.</td></tr>
<tr><td>DL</td><td>OFDMA</td></tr>
<tr><td colspan="2">Bandwidth Configuration</td><td>1.4,3,5,10,15,20MHz</td></tr>
<tr><td colspan="2">Operating bands</td><td>LTE operating bands</td><td>LTE operating bands (+ possible ITU IMT bands)</td></tr>
<tr><td colspan="2">UE transmit power</td><td>BC3: 23dBm (Max)</td><td>Subset of Rel.8</td></tr>
</table>

Reproduced from: http://www.3gpp.org/ftp/workshop/2009-12-17_ITU-R_IMT-Adv_eval/docs/pdf/REV-090006.pdf

LTE-A Key Technologies

- Carrier Aggregation in LTE-A
  - Protocols
  - Physical Layer Aspects
- Enhanced Multi-antenna Techniques in Downlink
- CoMP transmission/reception
- Relaying

Carrier Aggregation

Spectrum utilisation in LTE-A

- To meet LTE-A requirements, support of wider transmission bandwidths is required than the 20 MHz bandwidth specified in 3GPP Rel. 8/9.

- Enhanced performance can be achieved in two ways:
  - Using more spectrum.
  - Using the available spectrum more efficiently.

Carrier Aggregation

- Carrier aggregation is of the most distinct features of the LTE-A.
- It allows expansion of effective bandwidth delivered to a user terminal through concurrent utilisation of radio resources across multiple carriers.
- Multiple component carriers are aggregated to form a larger overall transmission bandwidth.

- **<u>Carrier aggregation</u>:** Larger continuous bandwidths can be achieved using this method.
  - Entire system bandwidth, e.g. up to 100MHz, comprises multiple basic frequency blocks called component carriers (CC's)

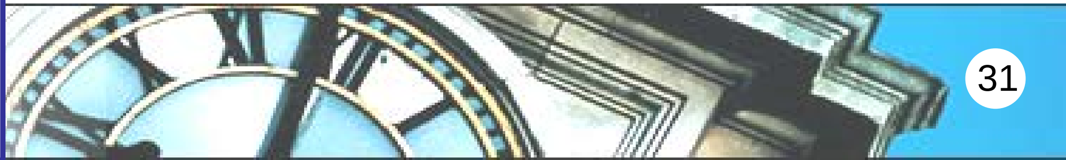
    ➔ Satisfies the requirements for peak data rate.
  - Each CC is backward compatible with Rel. 8 LTE

    ➔ Maintains backward compatibility with Rel. 8 LTE.
  - Carrier aggregation supports both continuous and non-contiguous spectrums, and asymmetric bandwidth for FDD

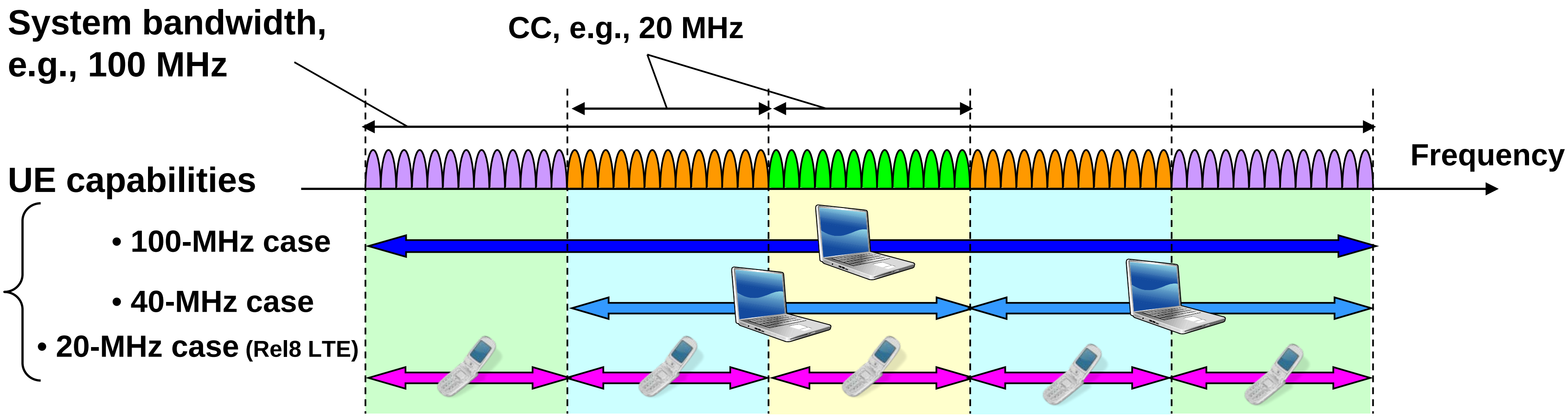
    ➔ Achieves flexible spectrum usage.

Improved spectrum flexibility

- Wider bandwidth (up to 100MHz)
- Spectrum & carrier aggregation
- Facilitate efficient use of fragmented spectrum
- Efficient interference management for control channels in heterogeneous networks

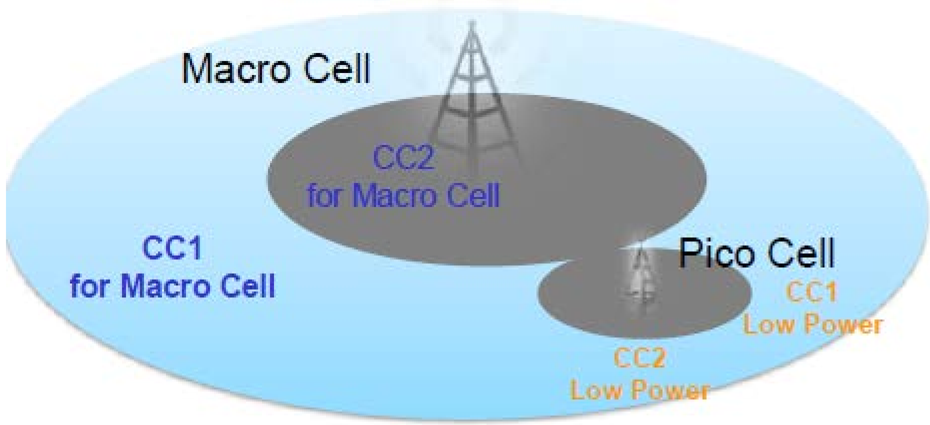


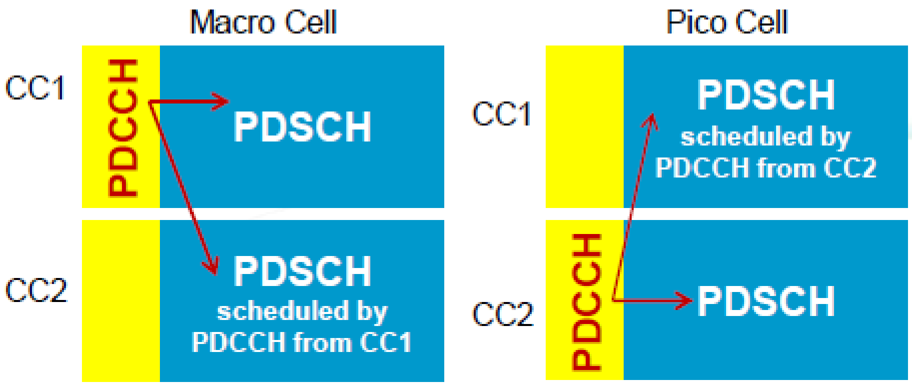
Carrier Aggregation



Cross-Carrier Scheduling:

Interference management for control channels in heterogeneous networks





- Cross-carrier scheduling provides interference management for control channels known as Inter-Cell Interference Coordination (ICIC) for PDCCH.
- In this example, CC1 of Macro Cell would cause high interference to CC1 of pico cell, therefore pico cell uses CC2 for PDCCH messages to schedule PDSCH transmission on CC1
- Macro cell uses CC1 to schedule PDSCH transmission on both CC1 and CC2

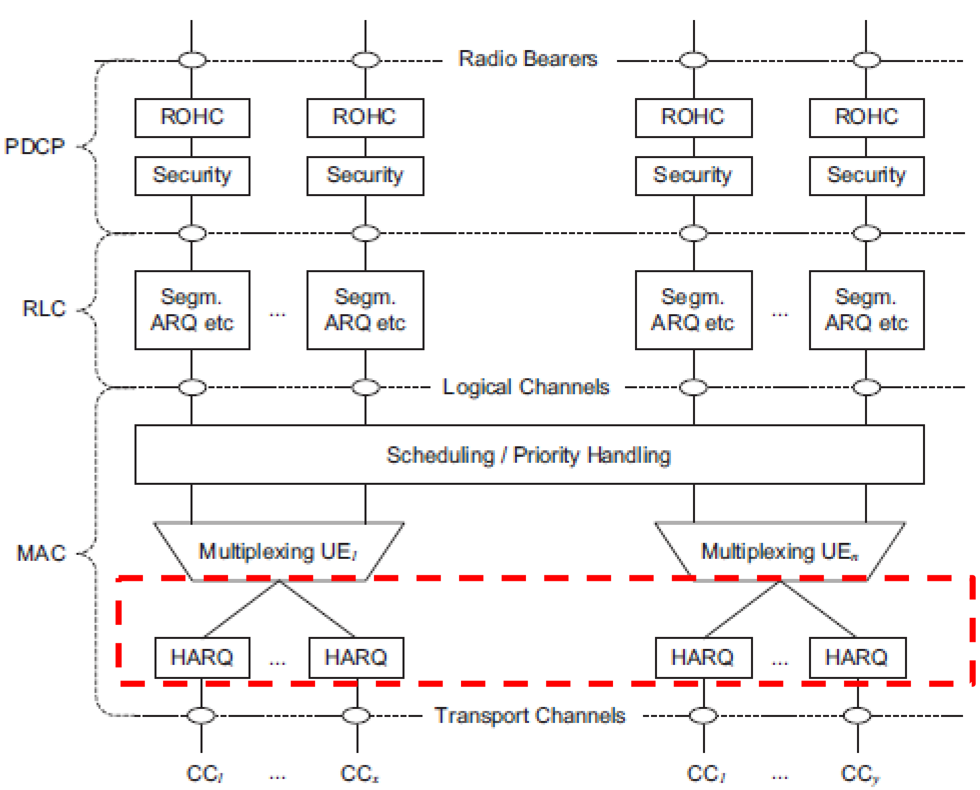
Cross-carrier scheduling avoids control channel interference

Protocol Aspects

- Generally speaking, the signalling for CA affects only certain layers, not the entire protocol stack.
- The device is permanently connected via its PCC to the serving Primary Cell (PCell). Non-Access Stratum (NAS) functionality such as security key exchange and mobility information are provided by the PCell.
- All secondary component carriers, or secondary cells, are understood as additional transmission resources. For the Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) layer, carrier aggregation signalling is transparent.
- Compared to Rel.8, the RLC layer only needs to support the higher data rates by having a larger buffer.
- The buffer size is defined by the UE category that a device belongs to.
- A terminal is configured on the Radio Resource Control (RRC) layer to handle secondary component carriers, provided by secondary cells. Moreover, on RRC the parameters of the SCell(s) are set, i.e. configured. The Medium Access Control (MAC) layer acts as a multiplexing entity for the aggregated component carriers as they are activated or deactivated by MAC control elements.

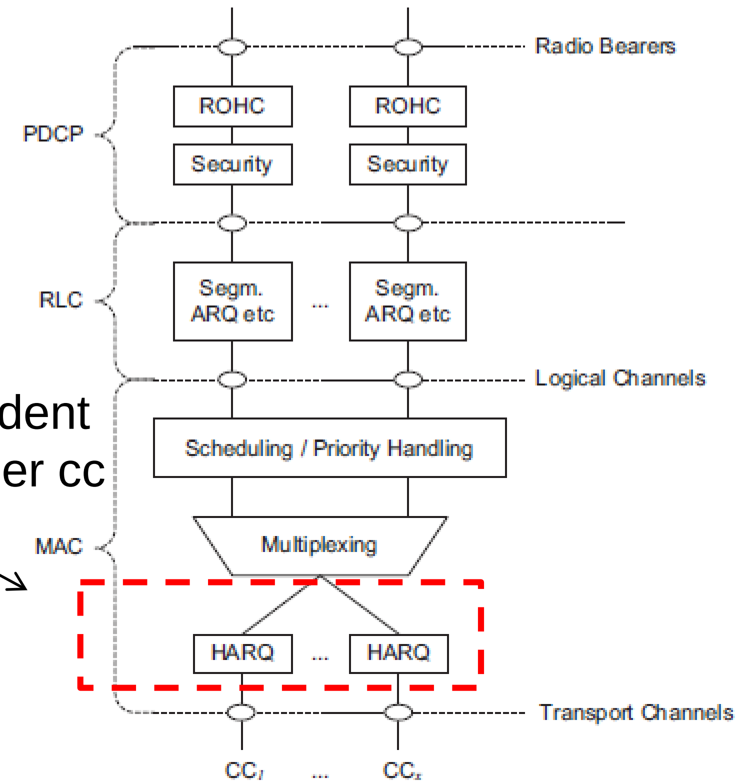
UP Protocols

- Data aggregation happens in MAC layer, the multi-carrier nature of CA not visible to core network
- The MAC layer divides the data between different CCs and separate HARQ processes for each CC



Downlink Layer 2 protocol structure for carrier aggregation.

Independent HARQ per cc

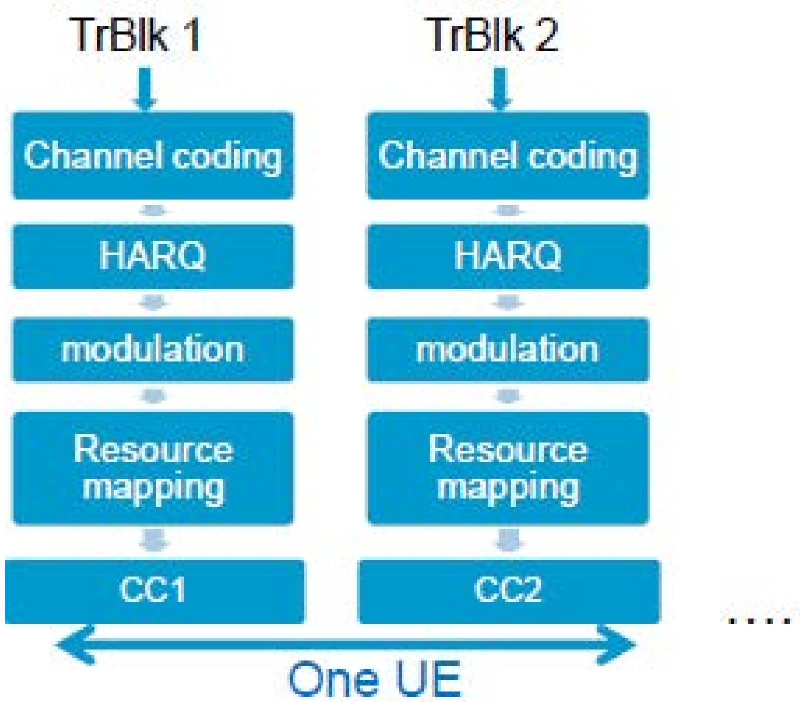


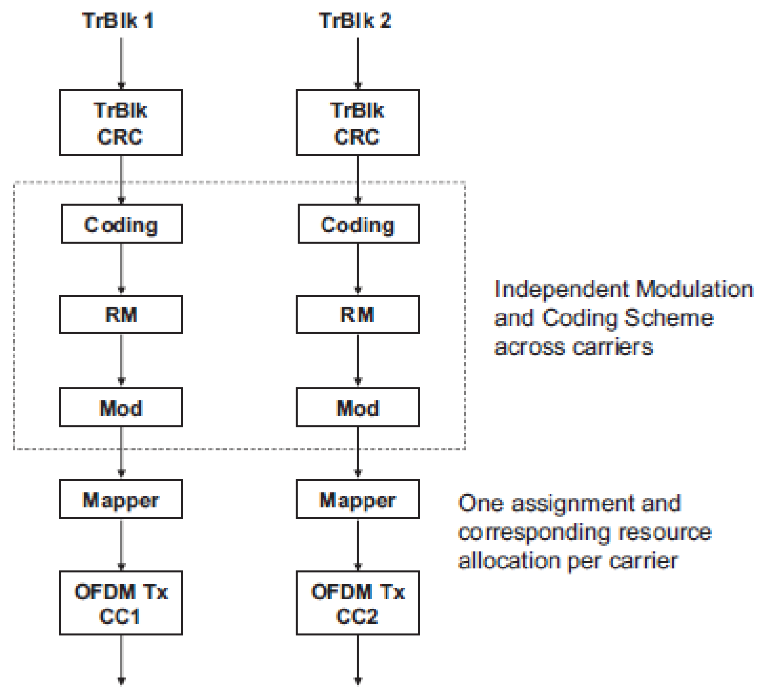
Uplink Layer 2 protocol structure for carrier aggregation.

MAC to Physical Layer Mapping for CA

- There is one transport block, up to two in case of spatial multiplexing, and <u>one HARQ entity per scheduled component carrier</u>

- A UE can be scheduled over multiple component carriers simultaneously, but one random access procedure at any time





MAC to physical layer mapping for carrier aggregation.

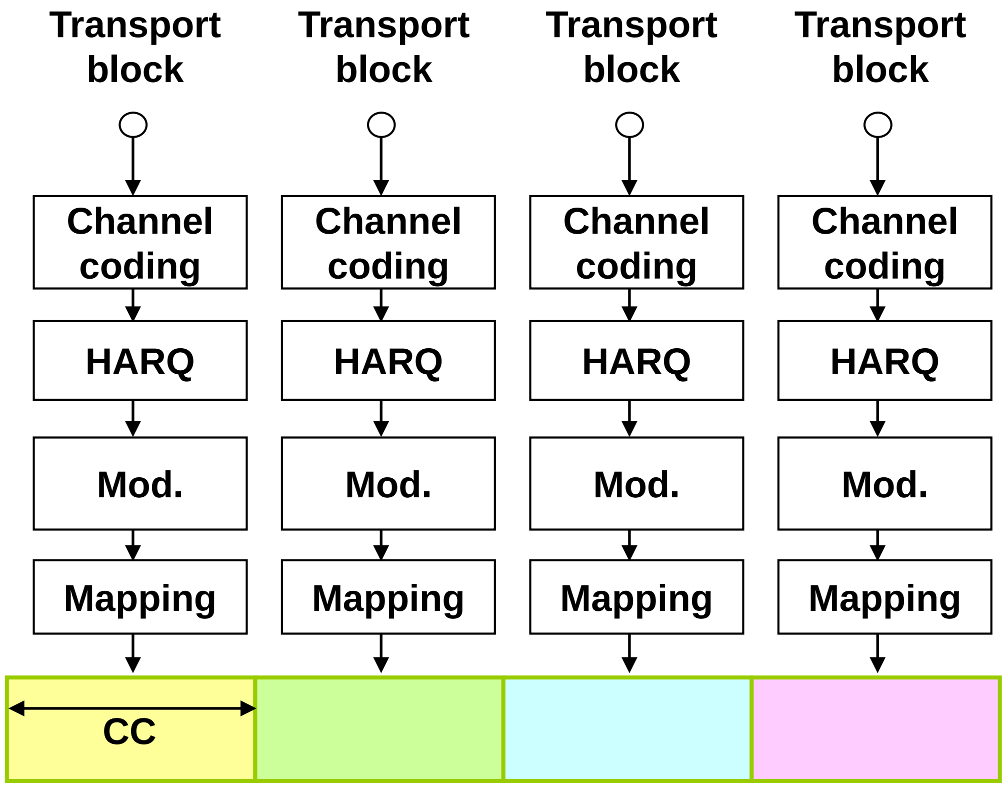
Downlink Multiple Access Scheme

■**Downlink: OFDMA with component carrier (CC) based structure**

➔ **Priority given to reusing Rel.8 specification for low-cost and fast development**

- **One transport block (TB), which corresponds to a channel coding block and a retransmission unit, is mapped within one CC**
- **Parallel-type transmission for multi-CC transmission**

- **Good affinity to Rel.8 LTE specifications**



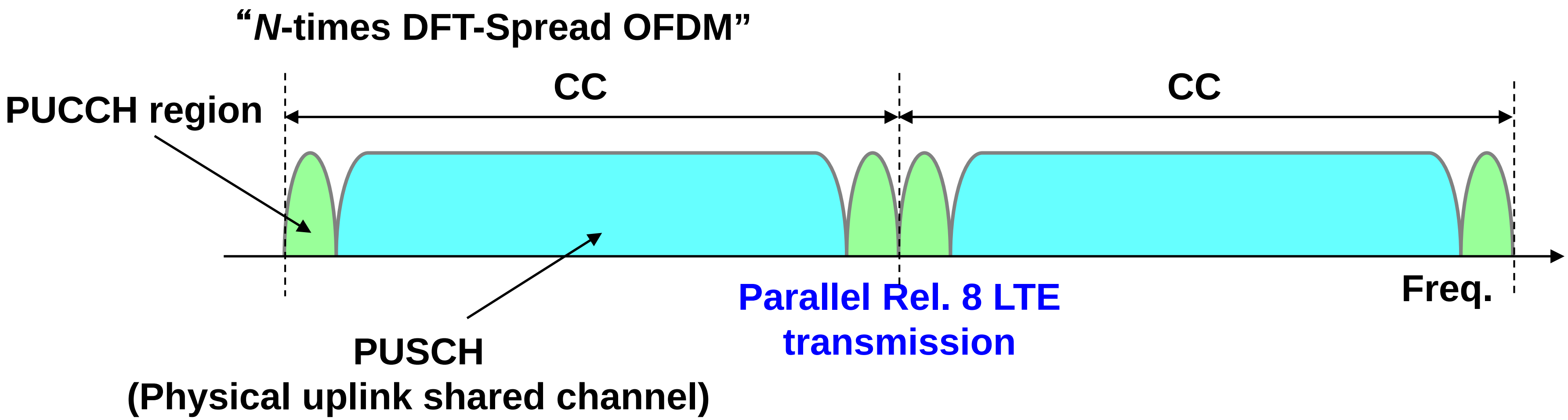
Uplink Multiple Access Scheme

- **Uplink: *N*-times DFT-Spread OFDM**

  Achieve wider bandwidth by adopting parallel multi-CC transmission

  ➔ Satisfy requirements for peak data rate while maintaining backward compatibility

  ➔ Low-cost and fast development by reusing Rel. 8 specification



Enhanced Multiple Antenna Techniques

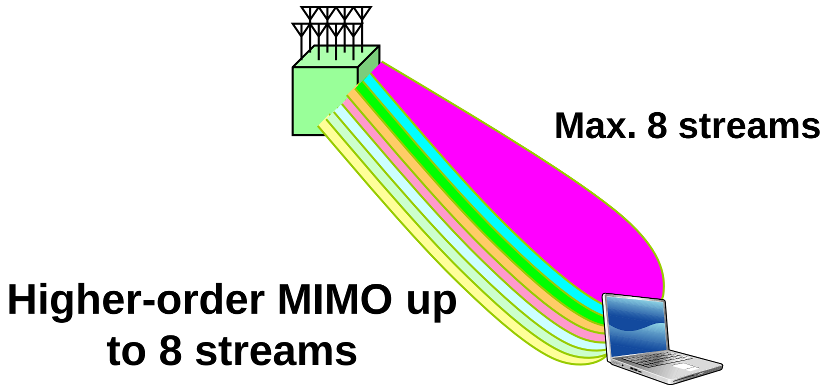
Enhanced Multi-antenna Techniques in Downlink

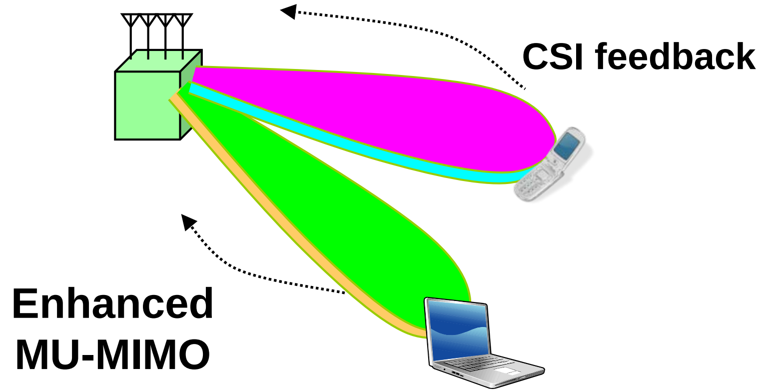
■**Extension up to 8-stream transmission**

- Rel. 8 LTE supports up to 4-stream transmission, LTE-A supports up to 8-stream transmission
  - ➔ Satisfy the requirement for peak spectrum efficiency, i.e., 30 bps/Hz

■**Specify additional reference signals (RS)**

- Two RSs are specified in addition to Rel. 8 common RS (CRS)
  - -Channel State Information RS (CSI-RS)
  - -UE-specific DeModulation RS (DM-RS)
  - ✓UE-specific CSI-RS, which is precoded, makes it possible to apply non-codebook-based precoding
  - ✓UE-specific DM-RS will enable application of enhanced multi-user beamforming such as zero forcing (ZF) for, e.g., 4-by-2 MIMO





Enhanced Multi-antenna Techniques in Uplink

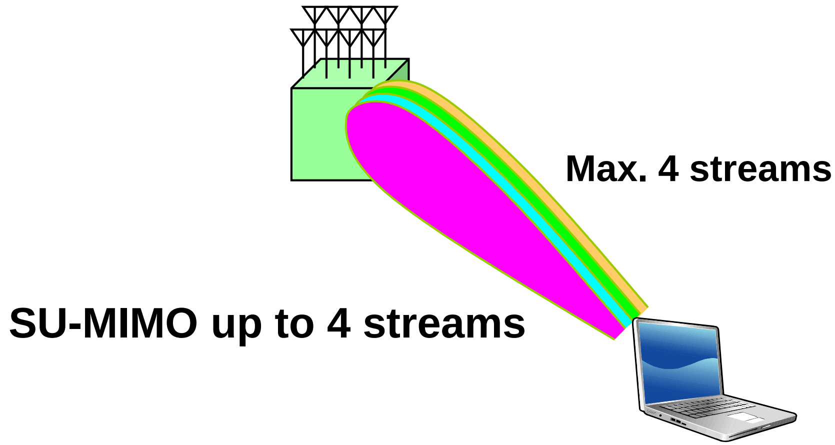
■Introduction of single user (SU)-MIMO up to 4-stream transmission

- Whereas Rel. 8 LTE does not support SU-MIMO, LTE-A supports up to 4-stream transmission

➔Satisfy the requirement for peak spectrum efficiency, i.e., 15 bps/Hz

■Signal detection scheme with affinity to DFT-Spread OFDM for SU-MIMO

➔ Improve user throughput, while maintaining single-carrier based signal transmission



CoMP transmission/reception

- The target date rate of cell edge users are the most challenging. Not only is the signal lower in strength because of the distance from the base station (eNB), but also interference levels from neighbouring eNBs are likely to be higher as the UE will be closer to them.

- Coordinated multipoint transmission and reception actually refers to a wide range of techniques that enable dynamic coordination or transmission and reception with multiple geographically separated eNBs.

- CoMP turns the inter-cell interference into useful signal, especially at the cell borders where performance may be degraded.

CoMP Advantages

Improves network utilisation: By providing connections to several base stations at once, using CoMP, data can be passed through least loaded base stations for better resource utilisation.

Multiple site reception increases received power: The joint reception from multiple base stations enables the overall received power at the handset to be increased.

Interference reduction: By using specialised combining techniques it is possible to utilise the interference constructively rather than destructively, thereby reducing interference levels.

CoMP Transmission in Downlink

■CoMP transmission schemes in downlink

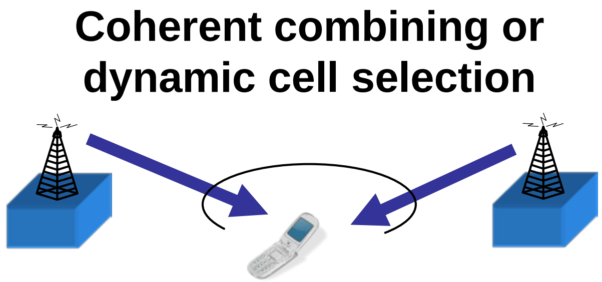
•**Joint Processing (JP)**

✓Joint transmission (JT): Downlink physical shared channel (PDSCH) is transmitted from multiple cells with precoding using DM-RS among coordinated cells

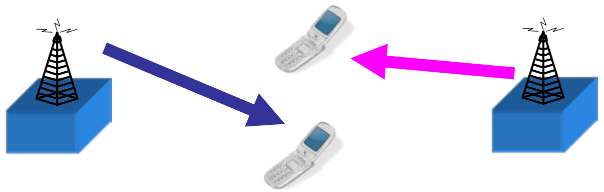
✓Dynamic cell selection: PDSCH is transmitted from one cell, which is dynamically selected

•**Coordinated scheduling/beamforming (CS/CB)**

PDSCH is transmitted only from one cell site, & scheduling/beamforming is coordinated among cells



Joint transmission/dynamic cell selection

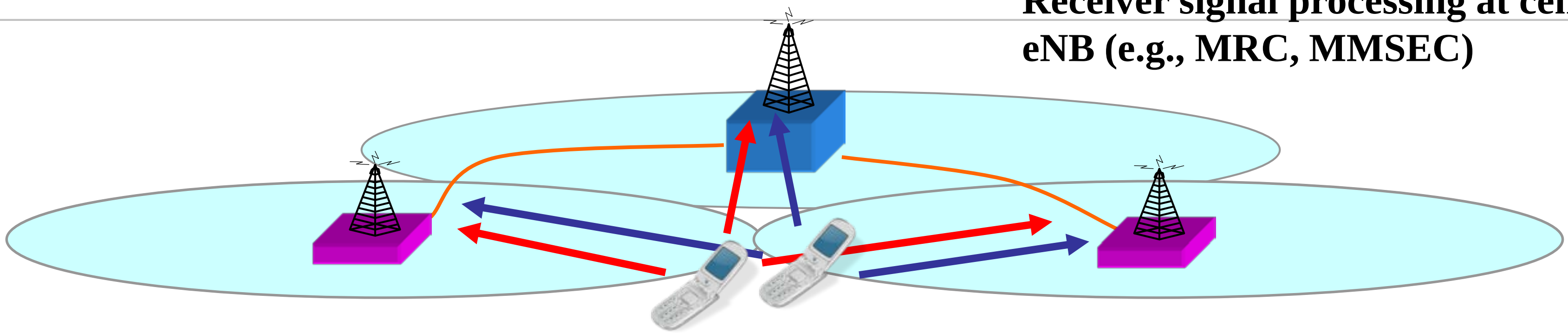


Coordinated scheduling/beamforming

CoMP Reception in Uplink

- CoMP reception scheme in uplink
  - •Physical uplink shared channel (PUSCH) is received at multiple cells
  - •Scheduling is coordinated among the cells
  - ➔ Improve especially cell-edge user throughput
  - •Note that CoMP reception in uplink is implementation matter and does not require any change to radio interface

Receiver signal processing at central eNB (e.g., MRC, MMSEC)

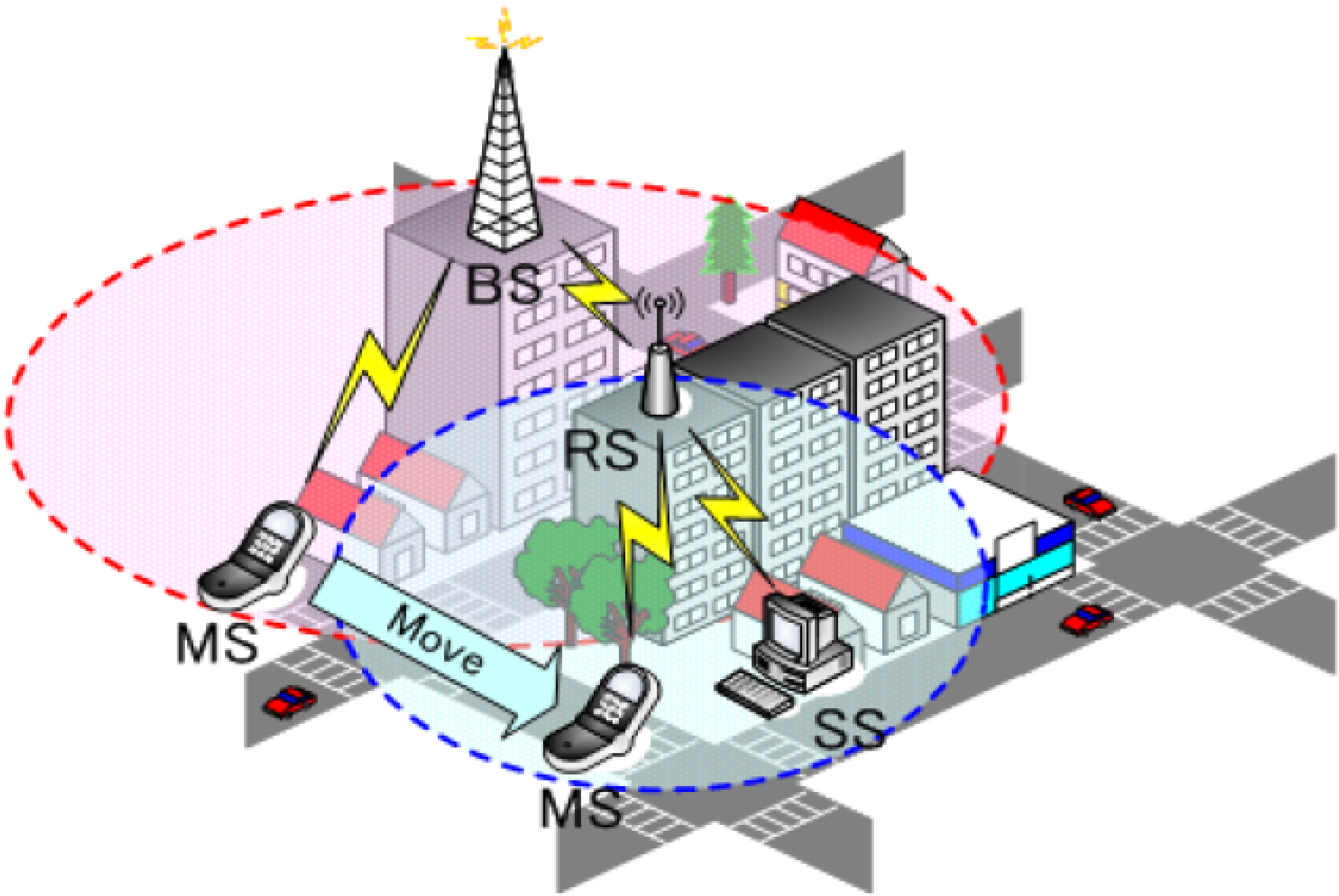


Multipoint reception

Relaying

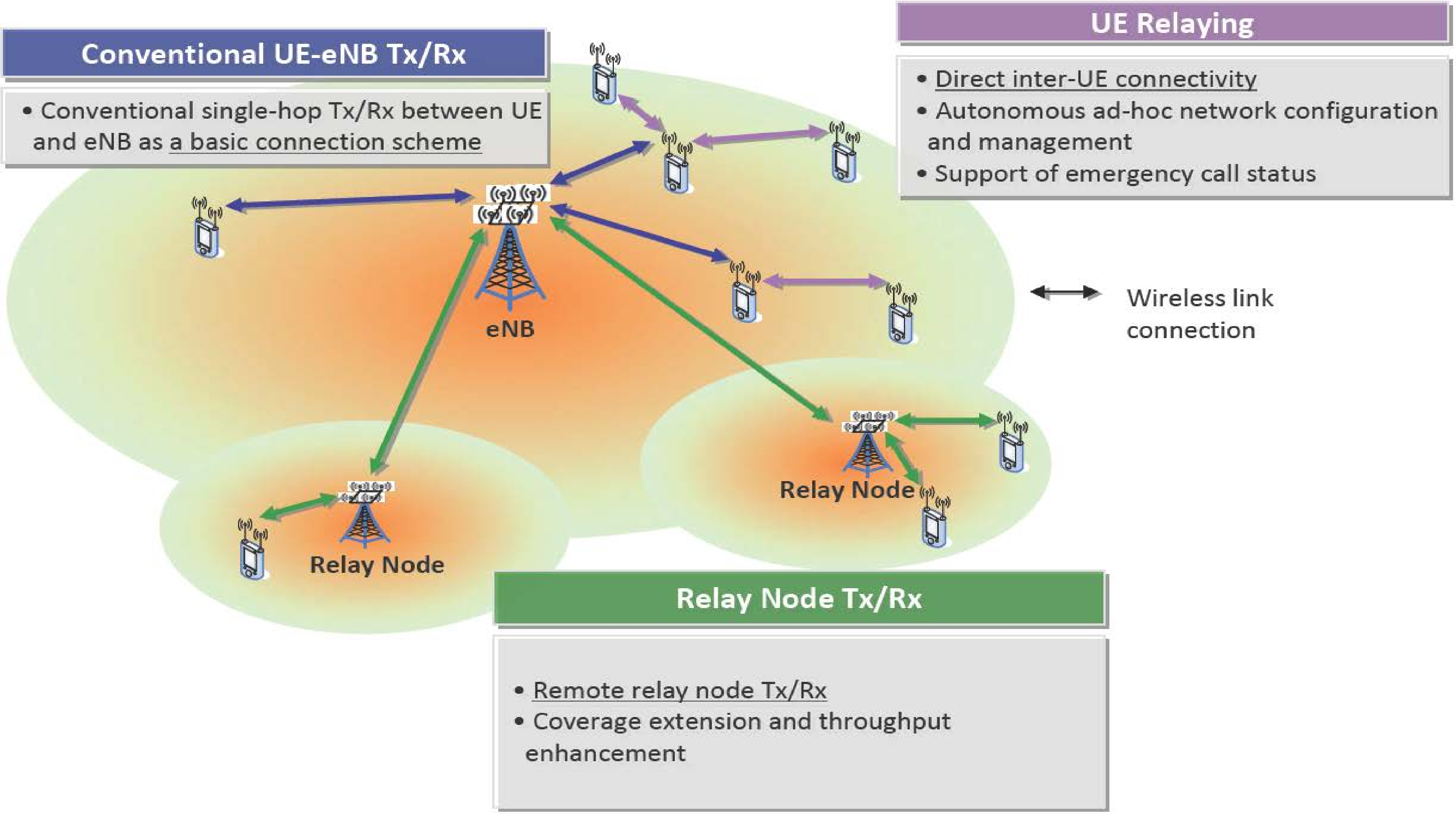
Relaying

- Coverage Extension and Throughput Enhancement by introducing the relay stations



Relaying

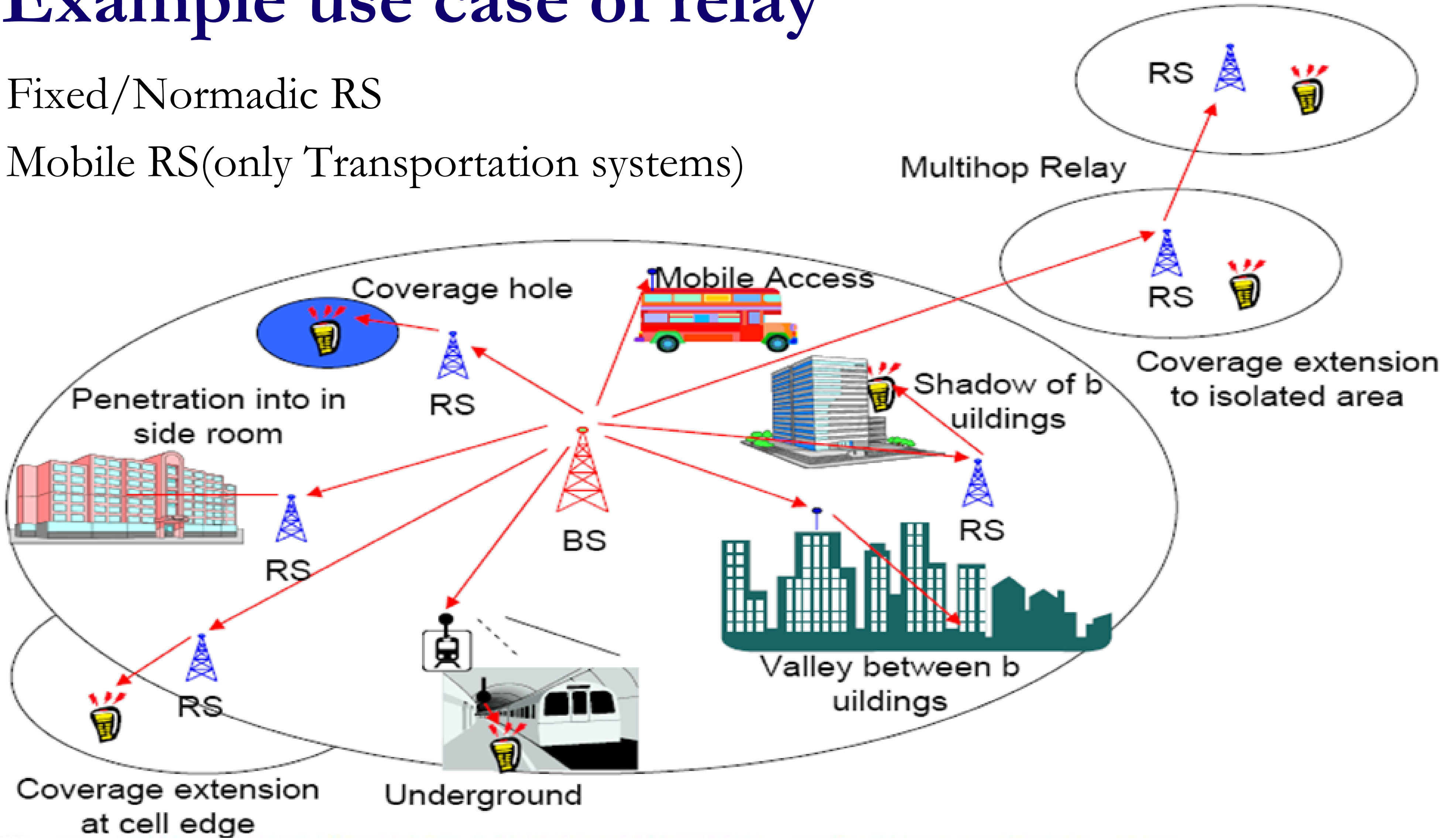
- Transmission types



Example use case of relay

Fixed/Normadic RS

Mobile RS(only Transportation systems)



Relaying

- Relaying is considered for LTE-A as a tool to improve e.g. the coverage of high data rates, group mobility, temporary network deployment, the cell-edge throughput and/or to provide coverage in new areas.
- The relay node is wirelessly connected to the radio-access network via a *donor cell*.

Need for LTE relay technology

- One of the main drivers for the use of LTE is the high data rates that can be achieved. However all technologies suffer from reduced data rates at the cell edge where signal levels are lower and interference levels are typically higher.

- The use of technologies such as MIMO, OFDM and advanced error correction techniques improve throughput under many conditions, but do not fully mitigate the problems experienced at the cell edge.

- As cell edge performance is becoming more critical, with some of the technologies being pushed towards their limits, it is necessary to look at solutions that will enhance performance at the cell edge for a comparatively low cost. One solution that is being investigated and proposed is that of the use of LTE relays.

LTE relay basics

- LTE relaying is different to the use of a repeater which re-broadcasts the signal. A relay will actually receives, demodulates and decodes the data, apply any error correction, etc to it and then re-transmitting a new signal. In this way, the signal quality is enhanced with an LTE relay, rather than suffering degradation from a reduced signal to noise ratio when using a repeater.

- Relay nodes can optionally support higher layer functionality, for example decode user data from the donor eNB and re-encode the data before transmission to the UE.

- The LTE relay is a fixed relay - infrastructure without a wired backhaul connection.

Class Quiz

- What is the 4G network architecture?
- What is 4G radio access scheme?
- How is 4G hand over oranised?
- What are LTE-A key features?