Οικονομικό Πανεπιστήμιο Αθηνών
Τμήμα Πληροφορικής

Ευφυή Κινητά Δίκτυα:
4G

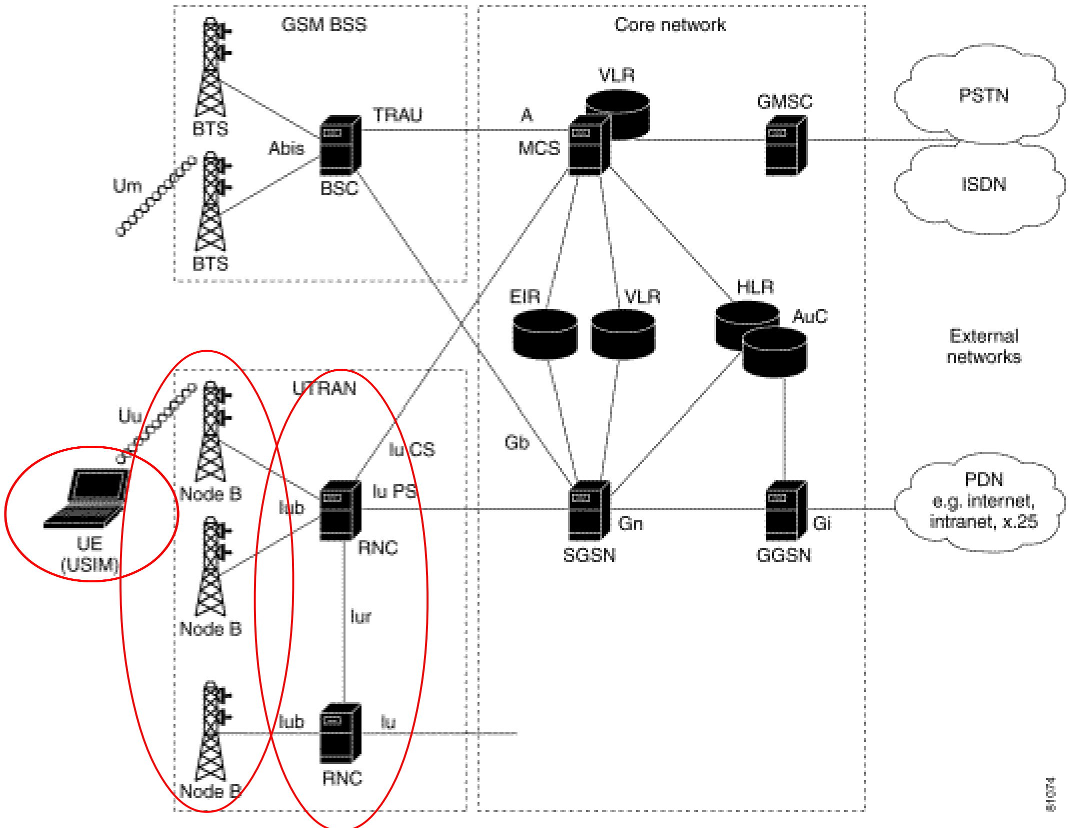
Εαρινό Εξάμηνο 2023-24

Γιάννης Θωμάς

(Βασισμένο σε διαφάνειες του Βασίλειου Σύρη)

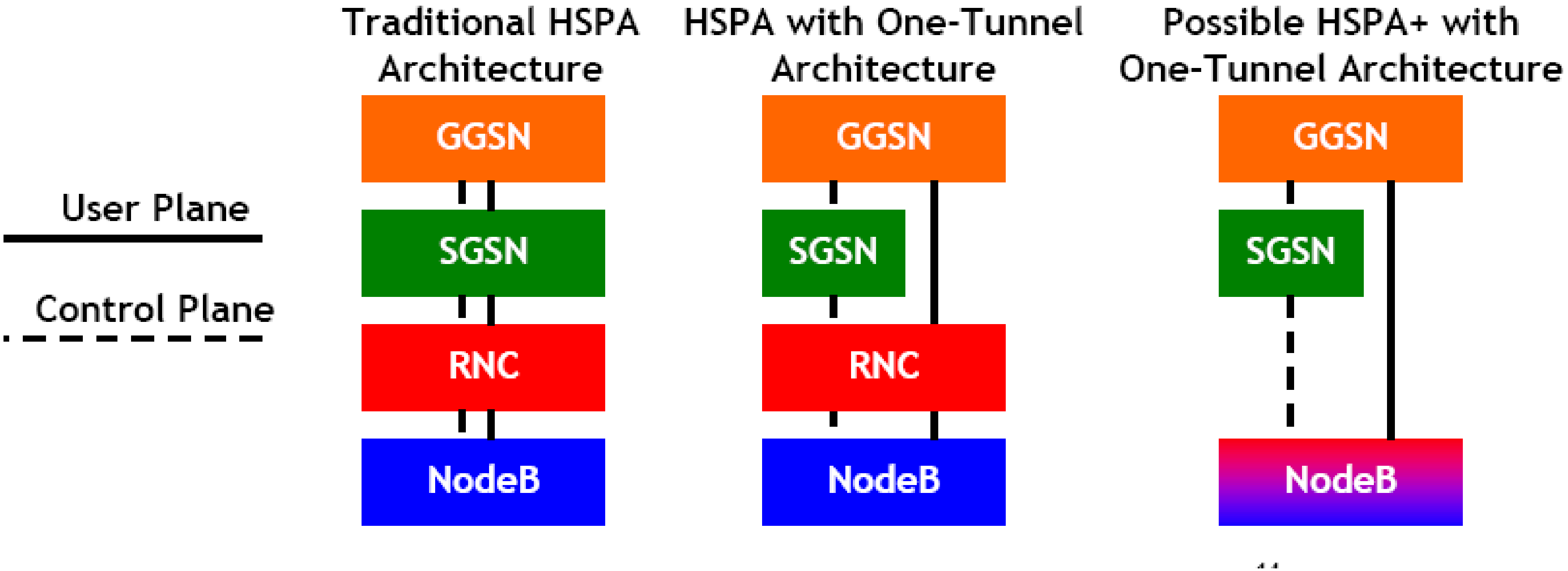
UMTS architecture - Rel. '99

- Based on GPRS top
  - Circuit switched
    - MSC, VLR, MSC
  - Packet switched
    - SGSN, GGSN
  - Both
    - EIR, HLR, AuC
- UMTS-specific
  - User equipment (UE)
  - UMTS terrestrial radio access network (UTRAN)

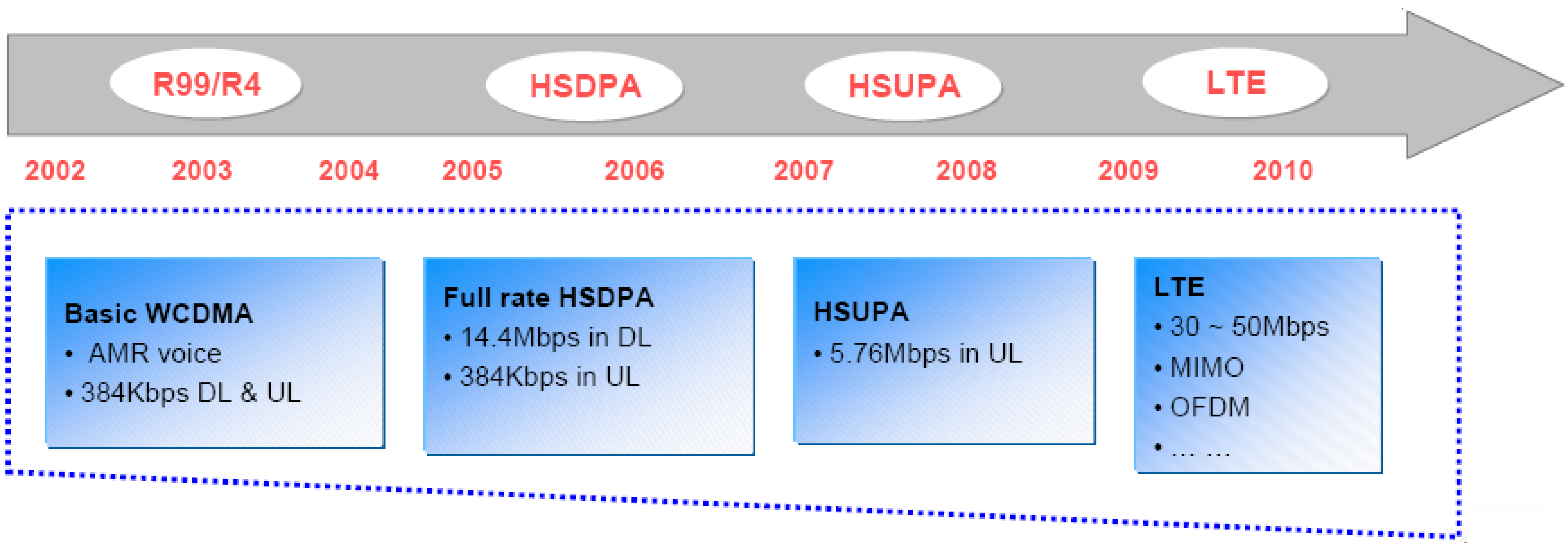


Src:https://docstore.mik.ua/univercd/cc/td/doc/product/wireless/moblwrls/cmx/mmg_sg/cmxgsm.htm#1057304

Towards a simpler architecture



UMTS evolution towards LTE



- 3G LTE: next step in evolution of 3GPP radio interfaces to deliver Global Mobile Broadband
- Not 4G, but beyond 3G: 3.9G

Fourth-generation (4G)

- **high-speed**, **universally** accessible wireless service capability.
- Focus on Long-Term Evolution (**LTE**) and its 4G enhancement, LTE-**Advanced**
- **ultra-broadband** Internet access for various
  - mobile devices
    - laptops, smartphones, tablets, and d2d
  - high-bandwidth applications
    - high-definition mobile TV, mobile video conferencing, and gaming services

4G requirements

- According to the ITU:
  - Be based on an **all-IP** packet-switched network.
    - do not support traditional circuit-switched telephony service
  - Support peak data rates of up to approximately **100 Mbps** for high-mobility mobile access and up to approximately **1 Gbps** for low-mobility access such as local wireless access.
  - **Dynamically** share and use the network resources to support more simultaneous users per cell
  - Support **smooth handovers** across heterogeneous networks, including 2G and 3G networks, small cells such as picocells, femtocells, and relays, and WLANs.
  - Support high quality of service for **next-generation multimedia** applications.

From 1 to 4G

Technology	1G	2G	2.5G	3G	4G
Design began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2012
Services	Analog voice	Digital voice	Higher capacity packetized data	Higher capacity, broadband	Completely IP based
Data rate	1.9. kbps	14.4 kbps	384 kbps	2 Mbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	OFDMA, SC-FDMA
Core network	PSTN	PSTN	PSTN, packet network	Packet network	IP backbone

4G efforts

- WiMAX and LTE
- Both use OFDMA
  - WiMAX: both uplink and downlink
  - LTE uplink: single-carrier frequency-division multiple access (SC-FDMA)
- LTE has become the universal standard for 4G wireless
  - US, China, Europe

LTE architecture - EPS

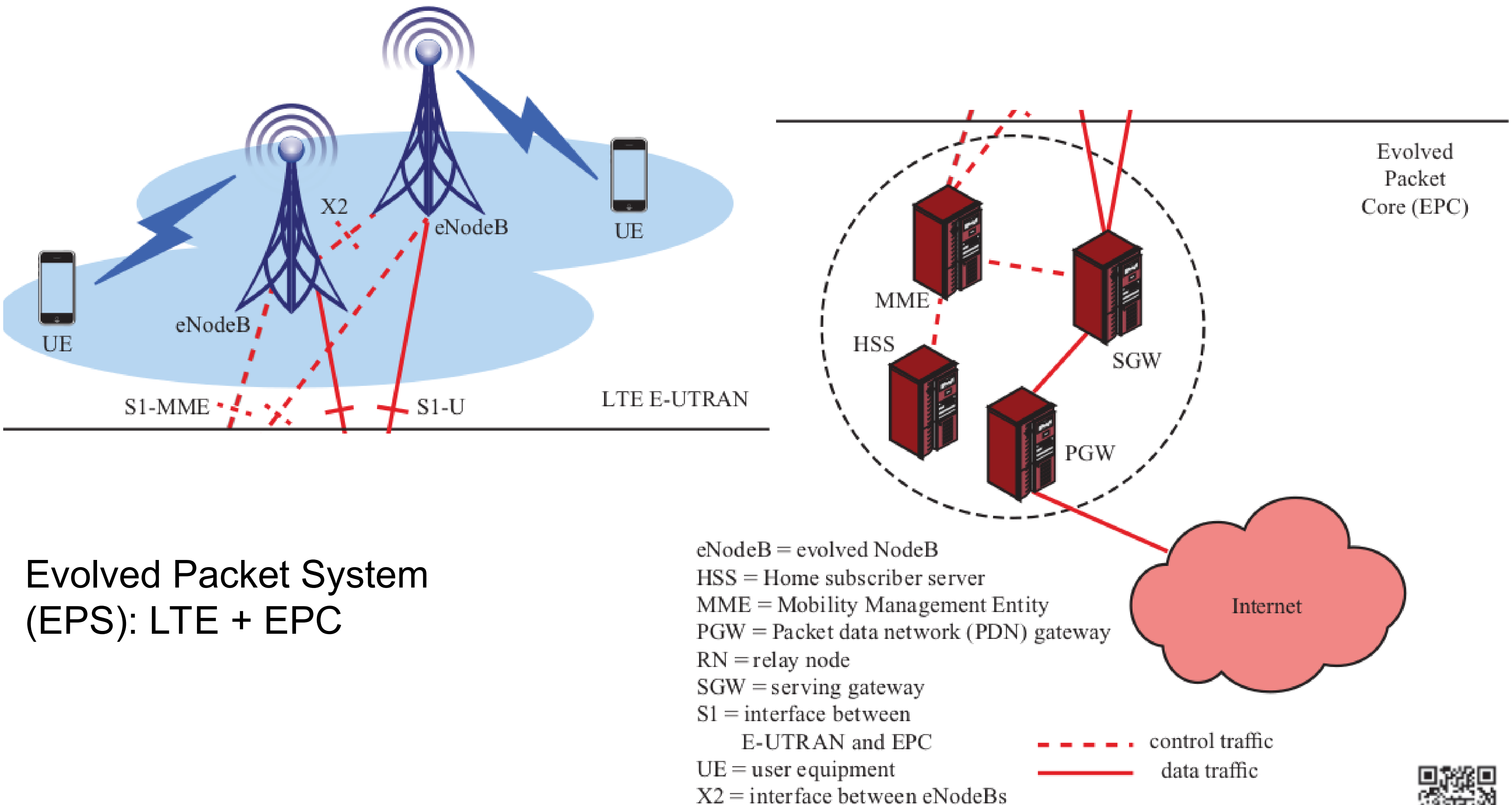
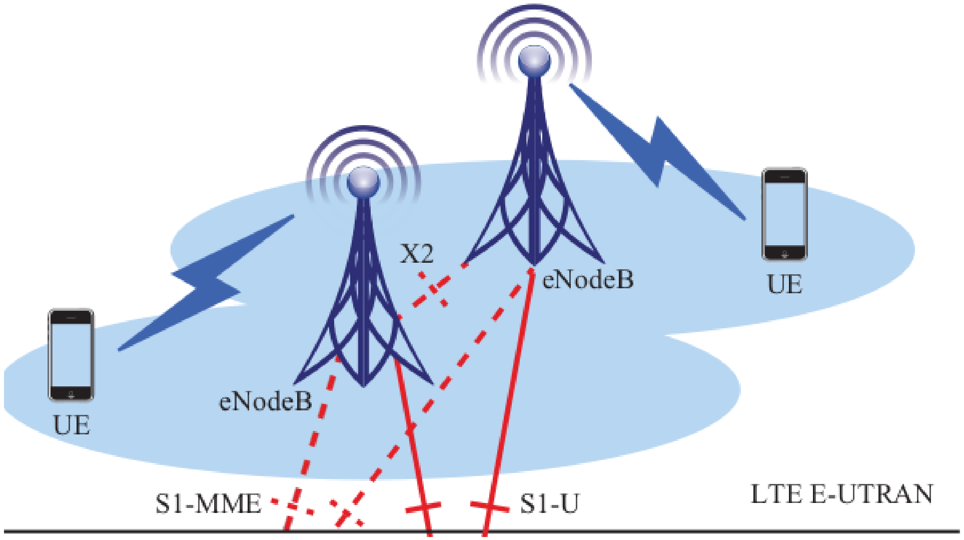


Figure 14.2 Overview of the EPC/LTE Architecture

Evolved Packet System (EPS): LTE + EPC

LTE architecture - eNodeB



Key diff to NodeB:

- The NodeB station interface with subscriber stations is based on CDMA, whereas the eNodeB air interface is based on **OFDMA**.
- eNodeB embeds its own control functionality, rather than using an RNC (Radio Network Controller) as does a NodeB.
  - supports radio resource control, admission control, and mobility management, (originally responsibility of the RNC)

LTE architecture – E-UTRAN

Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)

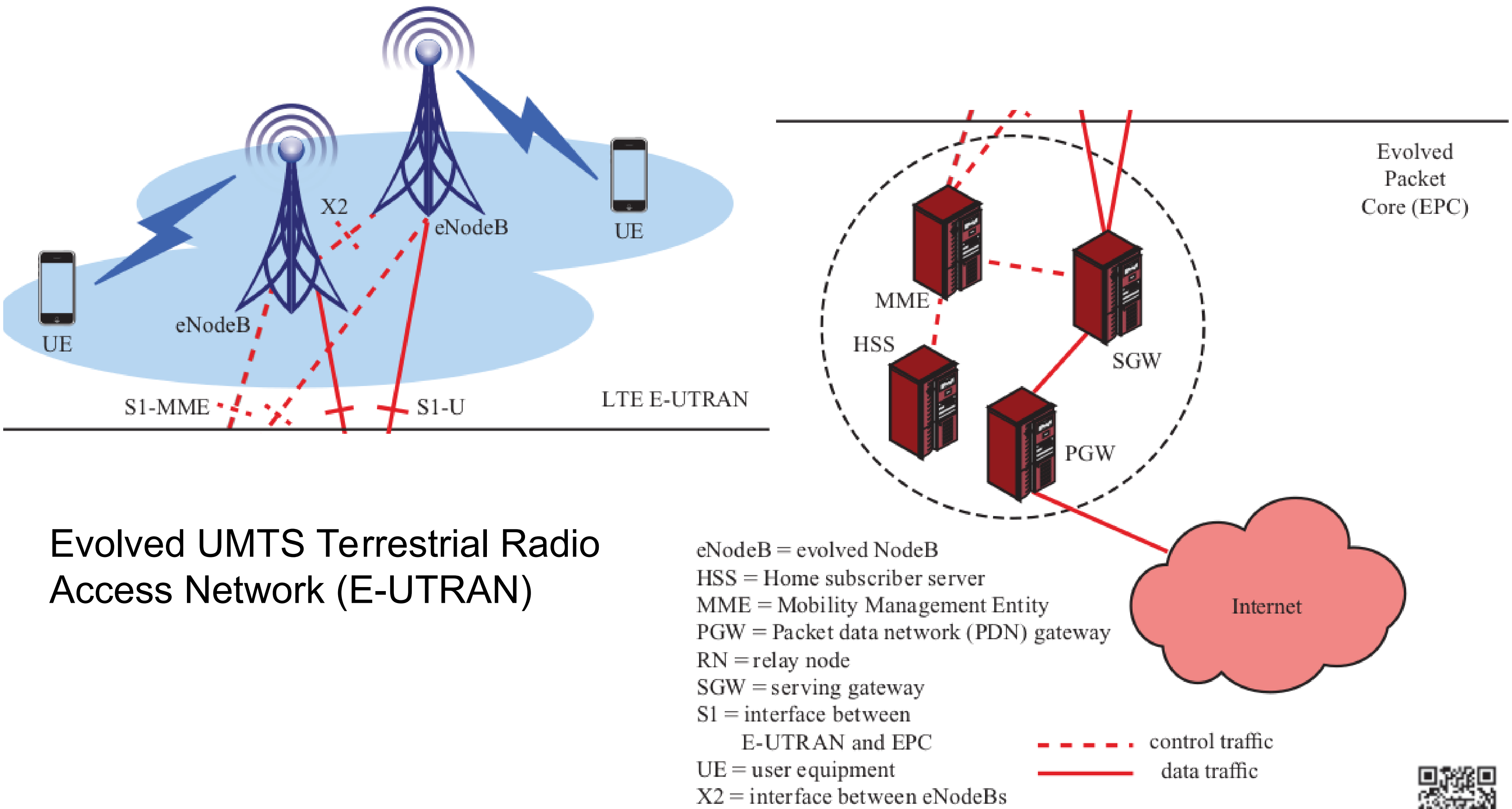


Figure 14.2 Overview of the EPC/LTE Architecture

LTE architecture – EPC

- **Mobility Management Entity (MME):** Supports user equipment context, identity, authentication, and authorization.
- **Serving Gateway (SGW):** Receives and sends packets between the eNodeB and the core network.
- **Packet Data Network Gateway (PGW):** Connects the EPC with external networks.
- **Home Subscriber Server (HSS):** Database of user-related and subscriber-related information.

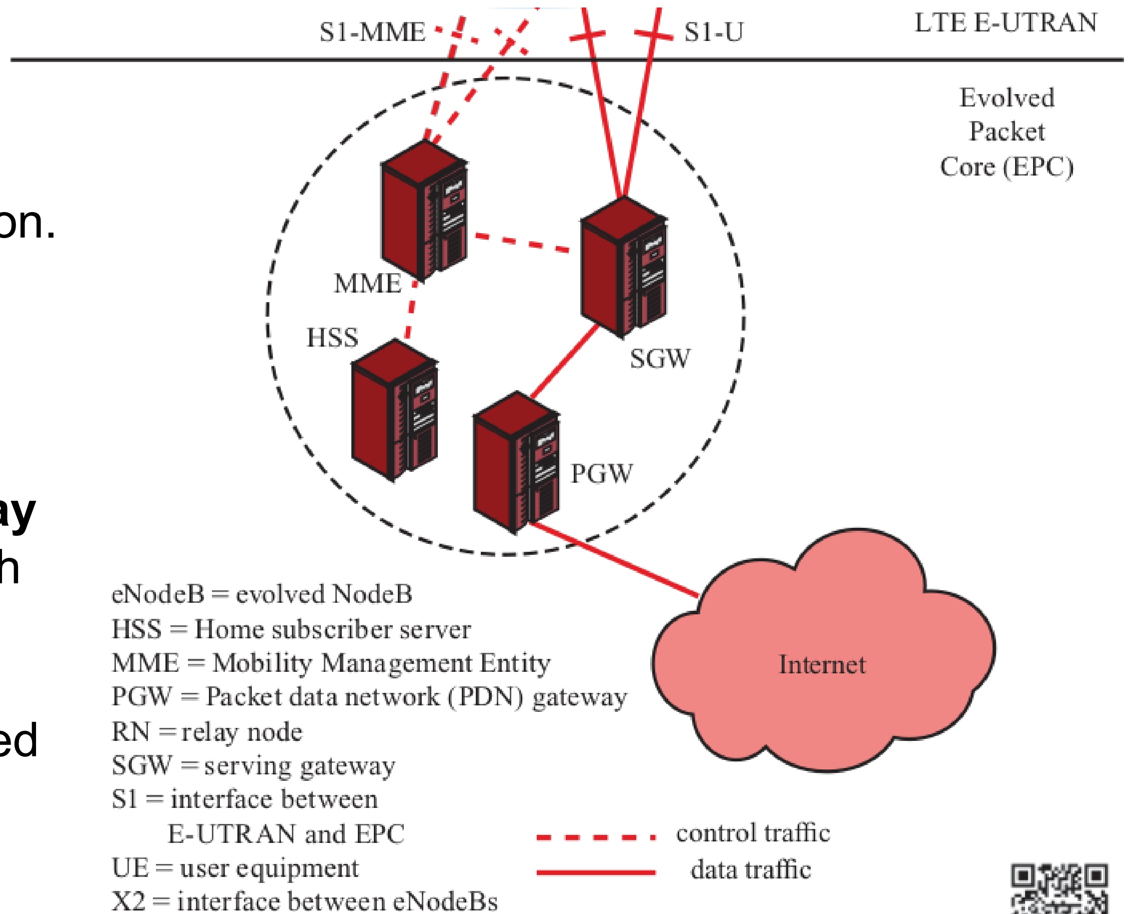
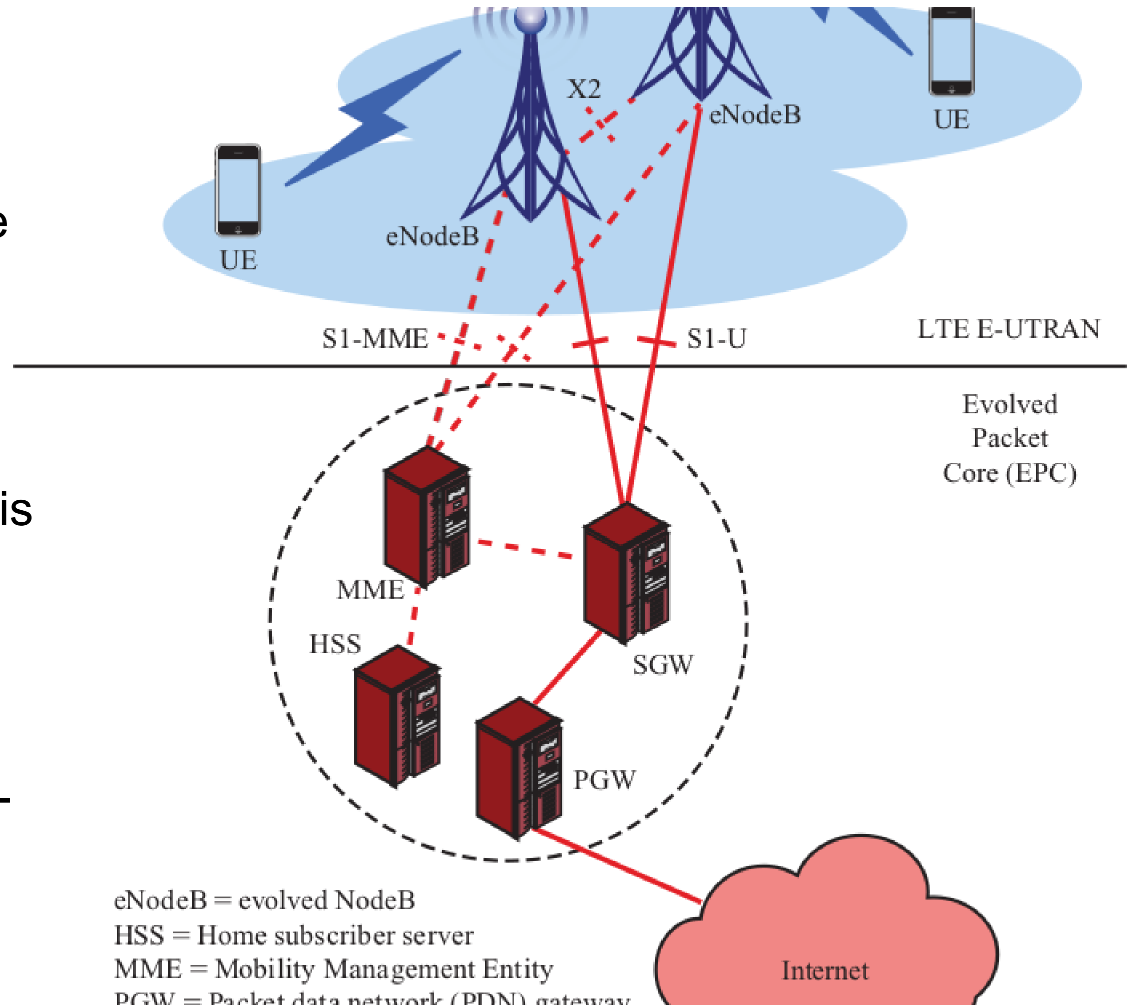


Figure 14.2 Overview of the EPC/LTE Architecture

LTE architecture – EPC (cont.)

- **S1 interface**: communication between the E-UTRAN and the EPC. For control purposes, the eNodeBs communicate with the MMEs through the S1-MME interface. The S1-U is for user plane data traffic between the eNodeB and the SGW.
- **X2 interface**: The X2 interface is used for eNodeBs to interact with each other. Although not shown in Figure 14.2, there are actually two X2 interfaces, the X2-U for user plane and the X2-C for control plane protocols.

In Practice: Multiple instance of EPC elements



LTE QoS

- LTE uses the concept of **bearers** for QoS control
- Being packet switched from end to end, a bearer is LTE’s central element of QoS
  - instead of a circuit.
- Bearer maps to specific QoS parameters such as data rate, delay, and packet error rate.
- **Traffic** flowing between applications are differentiated by separate **Service Data Flows (SDFs)**.
  - These SDFs must be mapped to **bearers** for QoS treatment.
- 2 Bearer types
  - Guaranteed Bit Rate (GBR): voice, video, real-time gaming
  - Non-Guaranteed Bit Rate (non-GBR):email, file transfer, www

LTE QoS classes (QCIs)

QCI	Resource Type	Priority	Packet Delay Budget	Packet Error Loss Rate	Example Services
1	GBR	2	100 ms	10^{-2}	Conversational Voice
2		4	150 ms	10^{-3}	Conversational Video (live streaming)
3		3	50 ms	10^{-3}	Real-Time Gaming
4		5	300 ms	10^{-6}	Nonconversational Video (buff-ered streaming)
5	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
6		6	300 ms	10^{-6}	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100 ms	10^{-3}	Voice, Video (live streaming) Interactive Gaming
8		8	300 ms	10^{-6}	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9*		9			

LTE Mobility Management

mobility within the LTE system **and** mobility to other 3GPP systems

- X2 interface can be used if moving within the same RAN
- If moving to a different RAN (with diff MMEs), the S1 interface is used.
- Rel 8: hard handovers; the UE can only be connected to one eNodeB at a time

LTE – S1 mobility (steps)

I. Preparation:
   - the destination MME and eNodeB have been identified, so the network needs to allocate resources at the destination.
   - The MME sends a handover request to the destination eNodeB. Once this eNodeB has allocated resources, it responds with an acknowledgement (ACK) to the MME.
   - The MME then sends the handover command to the UE.

II. Execution:
   - the source eNodeB transfers the PDCP context of the UE to the destination eNodeB.
   - The source eNodeB also sends the data in its PDCP buffer to the target eNodeB.
   - Once all is completed and the UE has established a new Radio Access Bearer (RAB) with the destination eNodeB, the source eNodeB sends the handover confirmation message.

III. Completion:
   - The target eNodeB notifies the MME.
   - The MME directs the source eNodeB to release the resources that had been used by the UE.

LTE – X2 mobility (steps)

1. Preparation:
   - source eNodeB sends a handover request message to the destination eNodeB.
   - destination eNodeB works with the MME and SGW to establish resources for the UE.
   - destination eNodeB responds with an ACK once it is ready.
2. Execution:
   - source eNodeB signals the UE, and in response the UE performs RAN-related procedures for the handover.
   - source eNodeB transfers status and data to the destination eNodeB on a per-Radio Access Bearer (RAB) basis.
3. Completion:
   - UE sends a handoff complete message to the MME/SGW and the SGW switches the GTP tunnel to the destination eNodeB.
   - When the data path is established, the destination eNodeB sends a message for the source eNodeB to release the resources for the UE.

LTE Inter-Cell Interference Coordination (ICIC)

- when the same frequency is used for a UE in a neighboring cell. This ICI limits the capacity of cellular systems.
- LTE uses universal frequency reuse, that is, all frequencies are reused in each cell.
  - a cluster size of N = 1 and a reuse factor of 1

Frequency reuse of 1
Single-sector eNBs
Same spectrum channel used by all eNBs

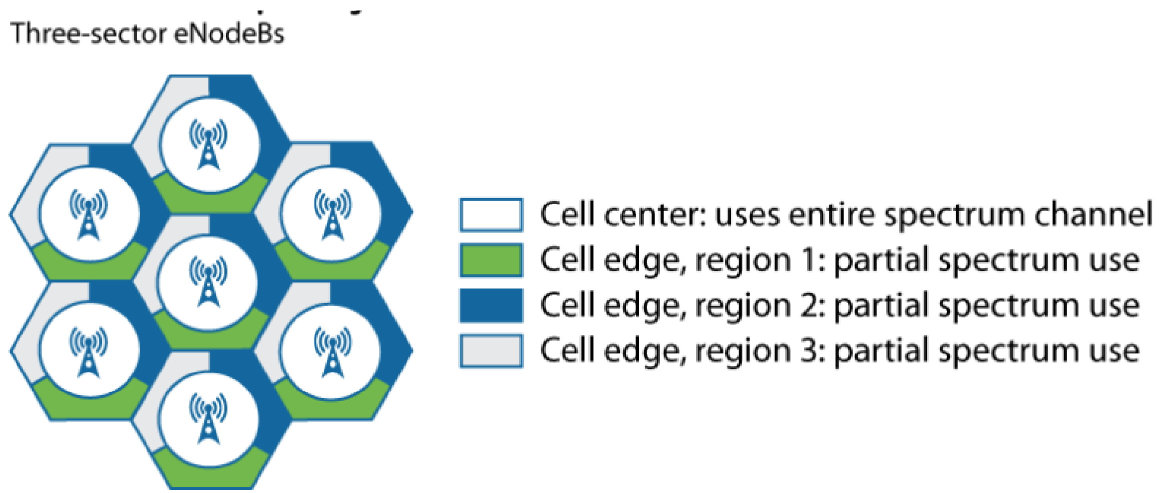
Frequency reuse of 3
Single-sector eNBs
Three spectrum channels (different colors) used to ensure that at the cell edge there is an non-overlapping channel

Frequency reuse of 3
Three-sector eNBs

https://www.sequans.com/wp-content/uploads/2013/07/SenzaFili_InterferenceInLTE.pdf

Fractional Frequency Reuse (FFR)

- static mechanism
- Limits transmissions in different parts the cell-edge areas to different portions of the spectrum channel used in the network.
- This approach is comparable to using a frequency reuse of 1 in the area immediately surrounding the cell site and a frequency reuse of 3 at the cell edge



https://www.sequans.com/wp-content/uploads/2013/07/SenzaFili_InterferenceInLTE.pdf

LTE Radio Channel

- Relay on **OFDMA**/ **SC-FDMA** and **MIMO** antennas
  - OFDMA downlink/ SC-FDMA uplink
  - up to **four** transmit and **four** receive MIMO
- subcarriers **15** kHz apart.
- Mod: QPSK, 16QAM, 64QAM,
  - depending on channel conditions and UE capabilities.
- maximum **FFT** size is 2048 → basic time unit in LTE of Ts = 1/(15,000 * 2048) = 1/30,720,000 s.
- downlink and uplink are organized into 10ms radio frames → 307,200Ts .
- Separation of uplink and downlink
  - Frequency Division Duplex (**FDD**): different freq bands for UL, DL
  - Time Division Duplex (**TDD**): the UL and DL transmissions operate in the same band but alternate in the time domain

FDD Vs. TDD

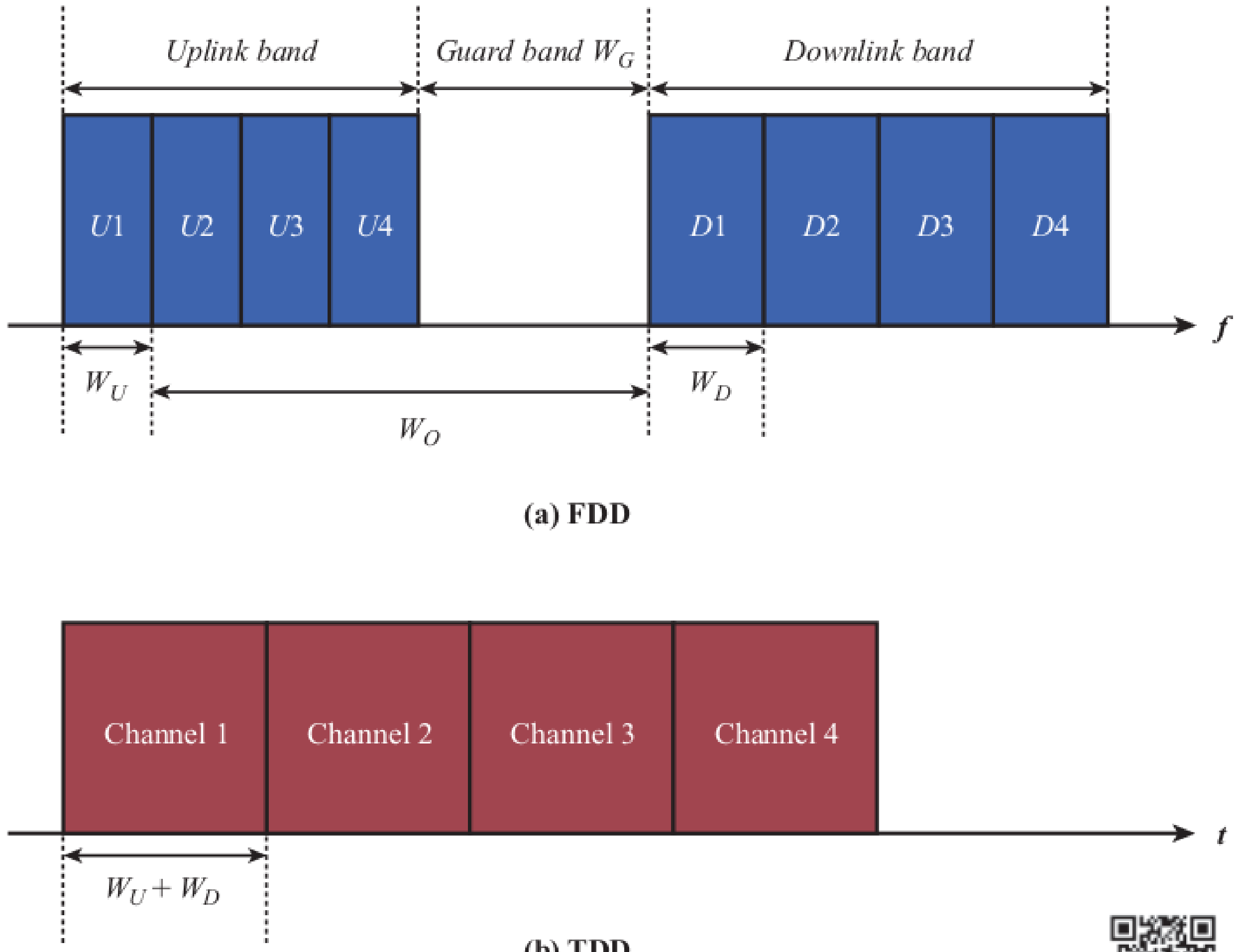


Figure 14.10 Spectrum Allocation for FDD and TDD

FDD Vs. TDD (cont.)

Parameter	LTE-THD	LTE-FDD
Paired spectrum	Does not require paired spectrum as both transmit and receive occur on the same channel.	Requires paired spectrum with sufficient frequency separation to allow simultaneous transmission and reception.
Hardware cost	Lower cost as no diplexer is needed to isolate the transmitter and receiver. As cost of the UEs is of major importance because of the vast numbers that are produced, this is a key aspect.	Diplexer is needed and cost is higher.
Channel reciprocity	Channel propagation is the same in both directions which enables transmit and receive to use one set of parameters.	Channel characteristics are different in the two directions as a result of the use of different frequencies.
UL/DL asymmetry	It is possible to dynamically change the UL and DL capacity ratio to match demand.	UL/DL capacity is determined by frequency allocation set out by the regulatory authorities. It is therefore not possible to make dynamic changes to match capacity. Regulatory changes would normally be required and capacity is normally allocated so that it is the same in either direction.

FDD Vs. TDD (cont.)

Parameter	LTE-THD	LTE-FDD
Discontinuous transmission	Discontinuous transmission is required to allow both uplink and downlink transmissions. This can degrade the performance of the RF power amplifier in the transmitter.	Continuous transmission is required.
Cross slot interference	Base stations need to be synchronized with respect to the uplink and downlink transmission times. If neighboring base stations use different uplink and downlink assignments and share the same channel, then interference may occur between cells.	Not applicable.
Guard period/guard band	Guard period required to ensure uplink and downlink transmissions do not clash. Large guard period will limit capacity. Larger guard period normally required if distances are increased to accommodate larger propagation times.	Guard band required to provide sufficient isolation between uplink and downlink. Large guard band does not impact capacity.

SC-FDMA

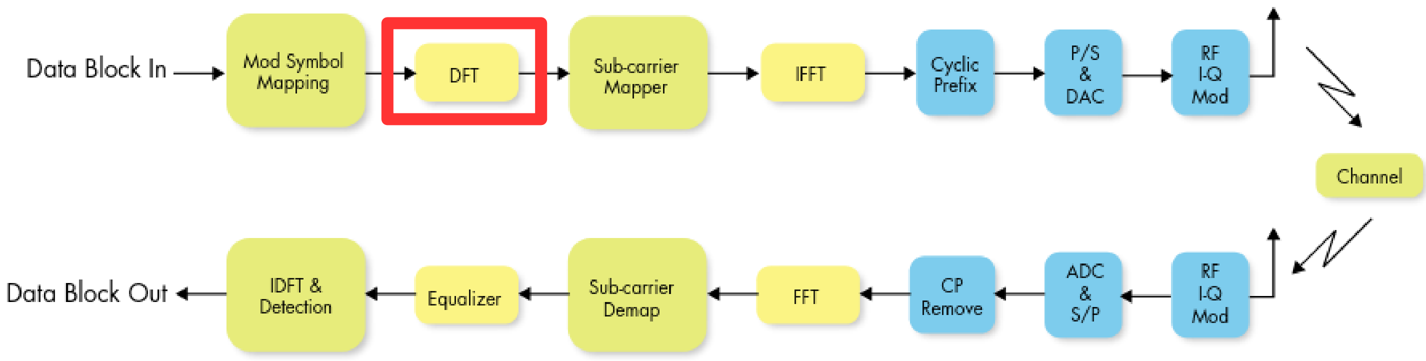


Figure 4. SC-FDMA Transmitter and Receiver

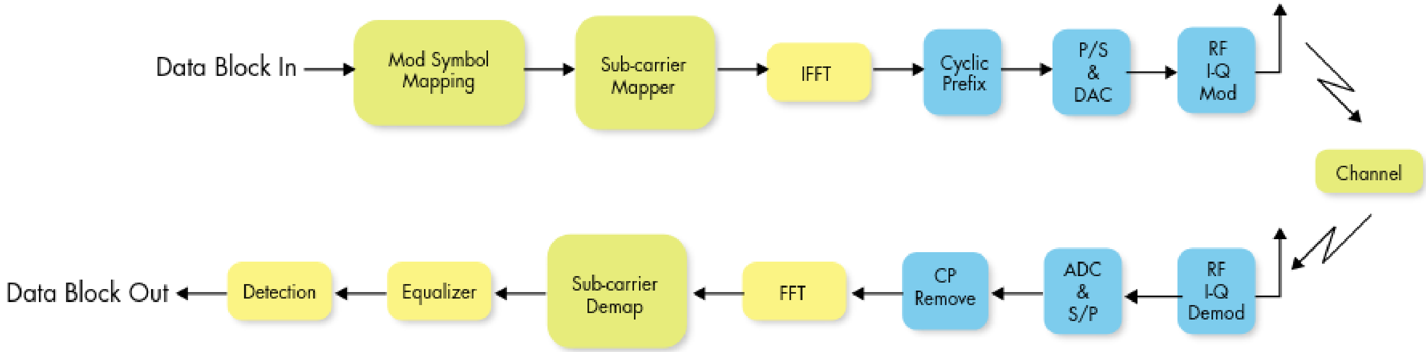


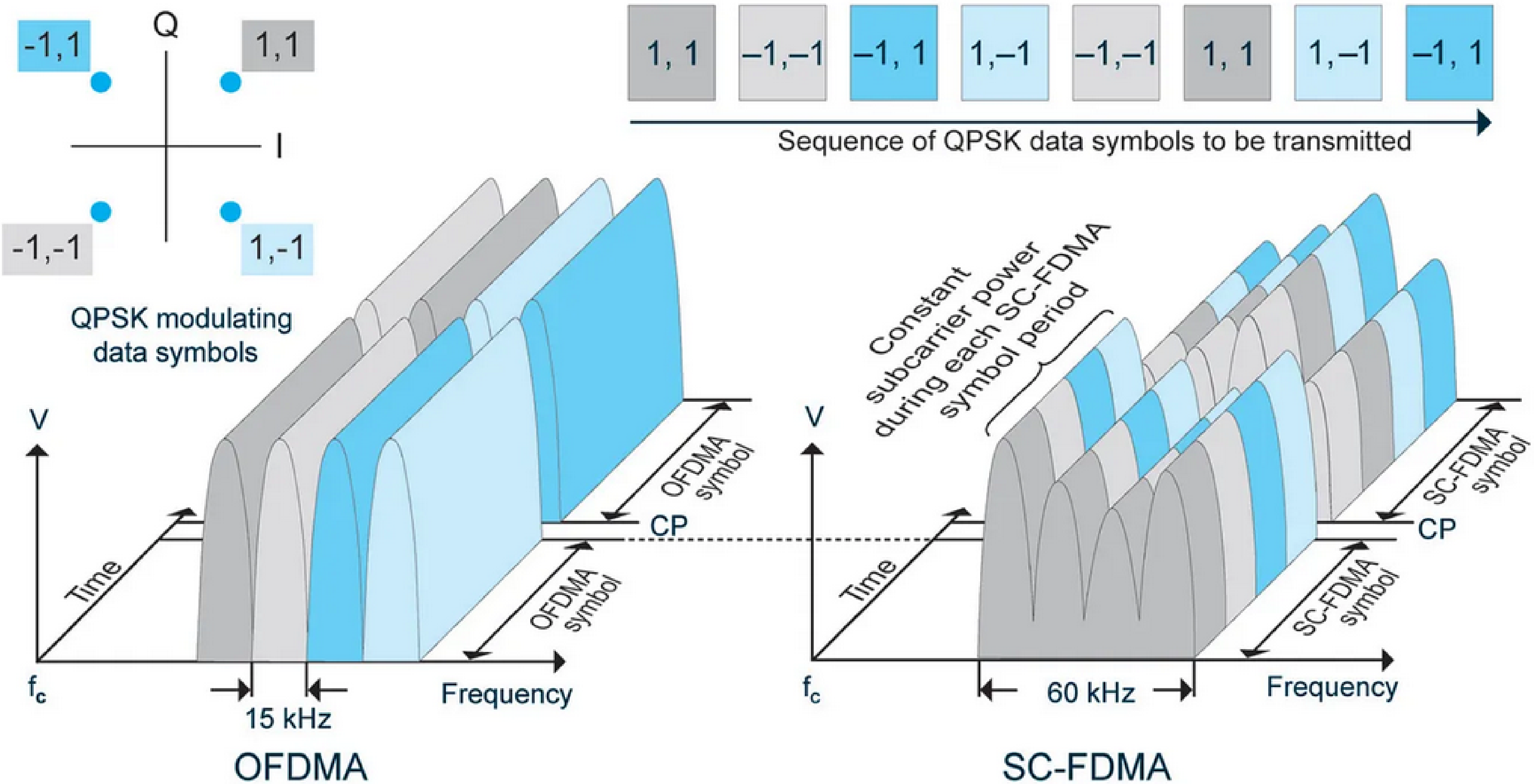
Figure 5. OFDM Transmitter and Receiver

https://support.ixiacom.com/sites/default/files/resources/whitepaper/sc-fdma-indd.pdf

SC-FDMA pros-cons

- OFDM signals have a high peak-to-average power ratio (PAPR),
  - require linear power amplifier → **low efficiency** and **high cost**.
  - acceptable for base station transmitters on the downlink,
- **Complex** SC-FDMA has a lower PAPR
  - better suited to implementation in **energy constrained** devices
    - Smartphones, tablets etc

SC-FDMA



-1,1
Q
1,1
I
-1,-1
1,-1
QPSK modulating data symbols
1, 1
–1,–1
–1, 1
1,–1
–1,–1
1, 1
1,–1
–1, 1
Sequence of QPSK data symbols to be transmitted
Constant subcarrier power during each SC-FDMA symbol period
V
Time
f_c
15 kHz
Frequency
OFDMA symbol
CP
OFDMA symbol
OFDMA
V
Time
f_c
60 kHz
Frequency
SC-FDMA symbol
CP
SC-FDMA symbol
SC-FDMA

LTE Advanced (Rel 10)

- The true 4G
- Novelties:
  - carrier aggregation (100MHz)
  - 256-QAM Modulation (Rel 12)
  - MIMO enhancements to support higher dimensional
    - 8 receivers, 8 transmitters
    - Can send to the same UE → BW aggregation → **Gigabit LTE**
  - Relay nodes
  - heterogeneous networks/ small cells
    - femtocells, picocells, and relays
  - cooperative multipoint transmission and enhanced intercell interference coordination
  - voice over LTE

LTE Enhanced – Relay Nodes

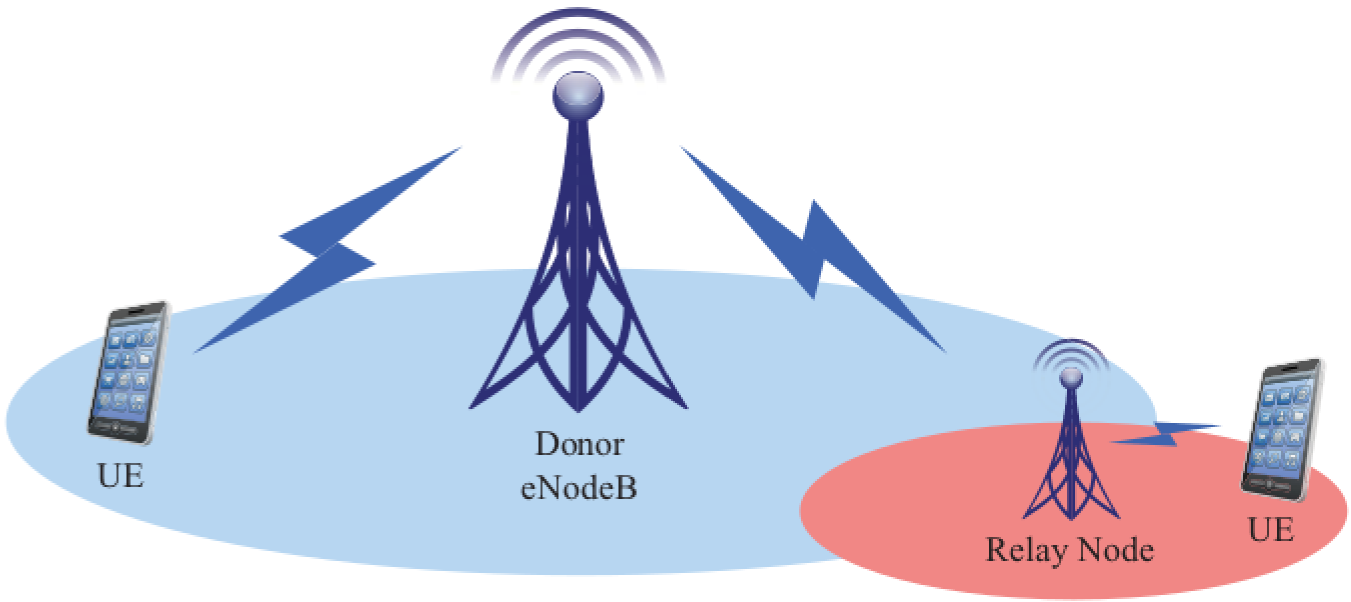


Figure 14.15 Relay Nodes

Problem: lower signal levels and higher interference levels near cell boundaries. RMs have smaller radius than small cells

- not simply signal repeaters that amplify a received signal, amplifying both the signal and noise.
- receive, demodulate, and decode the data and applies error correction as needed, and then transmits a new signal to the base station

LTE Enhanced - HetNet

- Problem/Goal: Increase transmission rate at densely populated and remote rural areas
- **Femtocell**:
  - Low-power, short-range, self-contained BS
    - Home, enterprise, rural and metropolitan areas
  - Energy efficient, low deployment cost
  - “WiFi-like cell”
  - Typically connected to Internet via **DSL**
- **Smallcells** Vs. **Macrocell**:
  - Range: 10m Vs. 10’s Km
  - Users: Stationary Vs. Mobile

Coordinated MultiPoint transmission (CoMP)

- Problem: inter-cell interference (especially at edges)
- Antennas **cooperate** to increase power to mobiles and reduce interference <u>at cell edges</u>
- Techniques:
  - Coordinated Scheduling/Coordinated Beamforming (CS/CB): steers antenna beam nulls and mainlobes
    - Optimization problem, complex
  - Joint Transmission (JT): transmits simultaneously from multiple transmission points to the same UE
    - multipath/ multisource, data available at N locations, Synched transmissions
  - Dynamic Point Selection (DPS): transmit from multiple transmission points but only one at a time.
    - Single-source, data at N location, non-synched

CoMP weaknesses

- Perfect synchronization of transmission and reception of a signal from different cells.
  - needs help of satellite synchronization of all base stations.
  - Otherwise, due to inconsistent transmission, interference occurs
    → causes even more trouble than without this technology.
- Less resource efficient for network.
  - transmit or receive a signal from two different cells requires uniform capacity
- CoMP technology is often enabled only on signaling and voice
  - **Reliability** and sensitive to channel quality

https://forum.huawei.com/enterprise/en/what-is-relay/thread/667286058074783744-667213872962088960