Mobile Communications

3GPP Public Land Mobile Networks: 4G (LTE)

Manuel P. Ricardo

Faculdade de Engenharia da Universidade do Porto

- *Why is OFDMA being increasingly used?*
- *What are the 4G/LTE solutions for increasing bitrate and reducing latency? What are the implications of it in the network architecture?*
- *What is a radio resource in LTE? What are the differences between radio resource management in LTE and in WCDMA?*

Long Term Evolution (LTE)

LTE - References

- » Beard and Stallings, Wireless Communications Networks and Systems, Chap. 14, 4th Generation Systems and Long Term Evolution
  - – (These slides follow the book; **read the book**)

- » Larmo, M. Lindström, M. Meyer, G. Pelletier, J. Torsner, and H. Wiemann, “The LTE Link-Layer Design”, IEEE Communications Magazine , April 2009

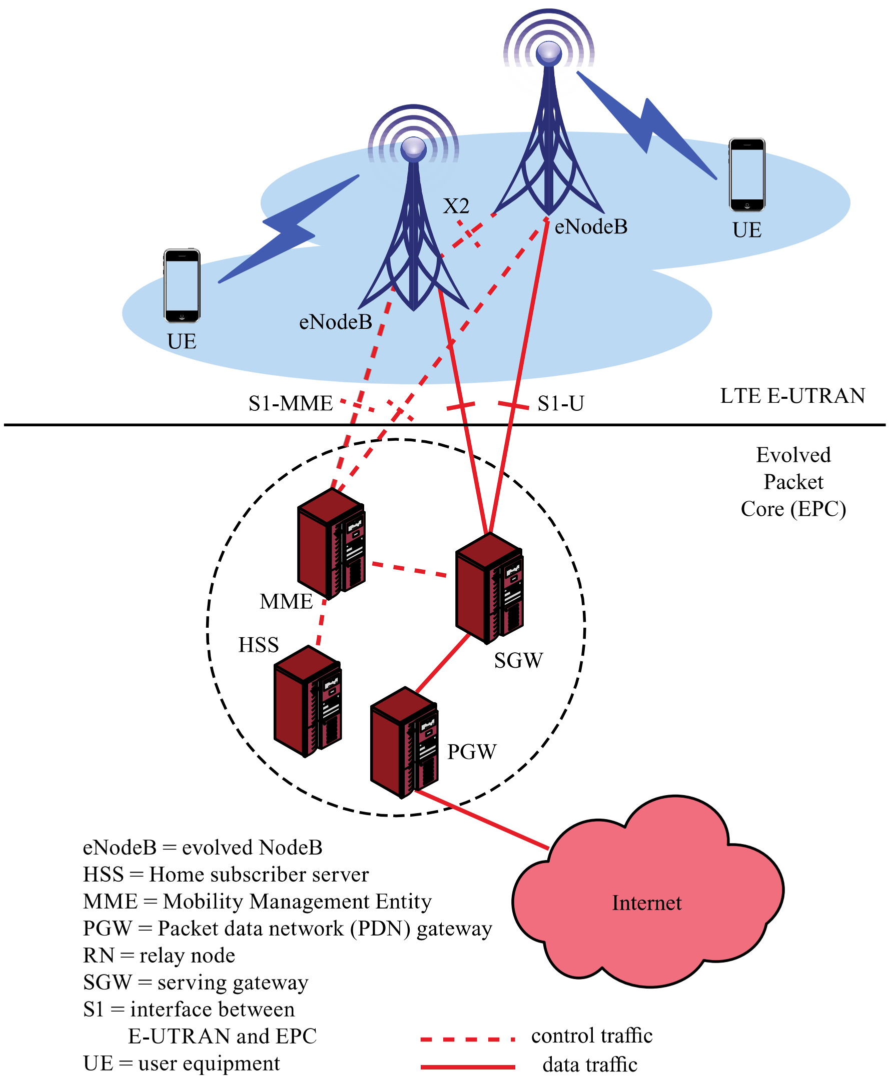
- » D. Astély, E. Dahlman, A. Furuskär, Y. Jading, M. Lindström, and S. Parkvall, LTE: The Evolution of Mobile Broadband, IEEE Communications Magazine , April 2009

LTE Purpose

- UTRAN – LTE
  - » Universal Mobile Telecommunications System (UMTS) terrestrial radio-access network (UTRAN) - Long Term Evolution (LTE)
  - » Evolution of UTRAN (3G)

- Aimed at providing
  - » All-IP packet switched network
    - – No support for circuit-switched voice!
  - » High bitrates (tens, hundreds of Mbit/s)
  - » Latency less than 5 ms (between terminal and base station)
  - » Handover in less than 1 RTT
  - » Uses OFDMA

Evolved UTRAN Architecture - Overview



eNodeB = evolved NodeB
HSS = Home subscriber server
MME = Mobility Management Entity
PGW = Packet data network (PDN) gateway
RN = relay node
SGW = serving gateway
S1 = interface between
E-UTRAN and EPC
UE = user equipment
X2 = interface between eNodeBs

EPS = Evolved Packet System
= LTE + EPC

EPC Components

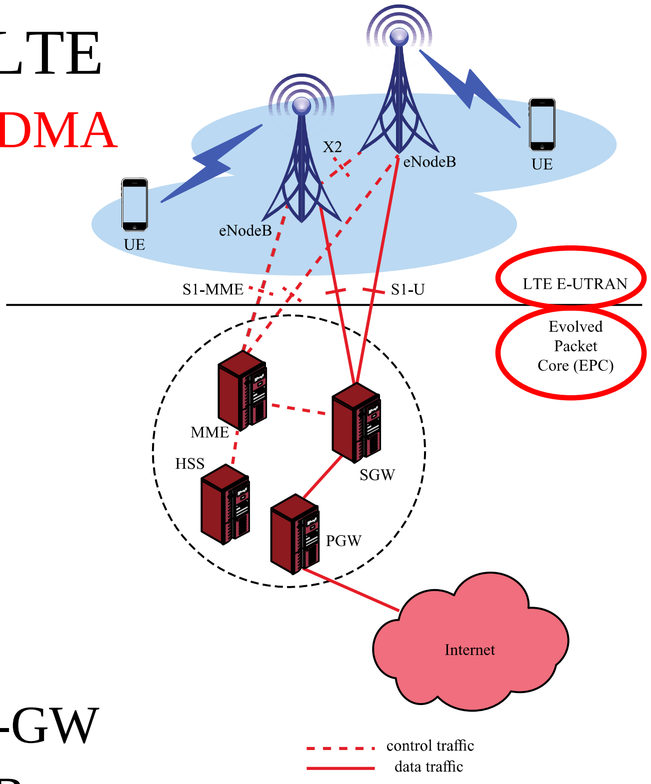
- Mobility Management Entity (MME)
  - Supports user equipment context, identity, authentication, and authorization
- Home Subscriber Server (HSS)
  - Database of user-related and subscriber-related information

- 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

- Relevant interfaces
  - S1 interface between the E-UTRAN and the EPC
    - For both control and data traffic
  - X2 interface for eNodeBs to interact with each other
    - For both control and data traffic

Evolved UTRAN Architecture – EPC/LTE

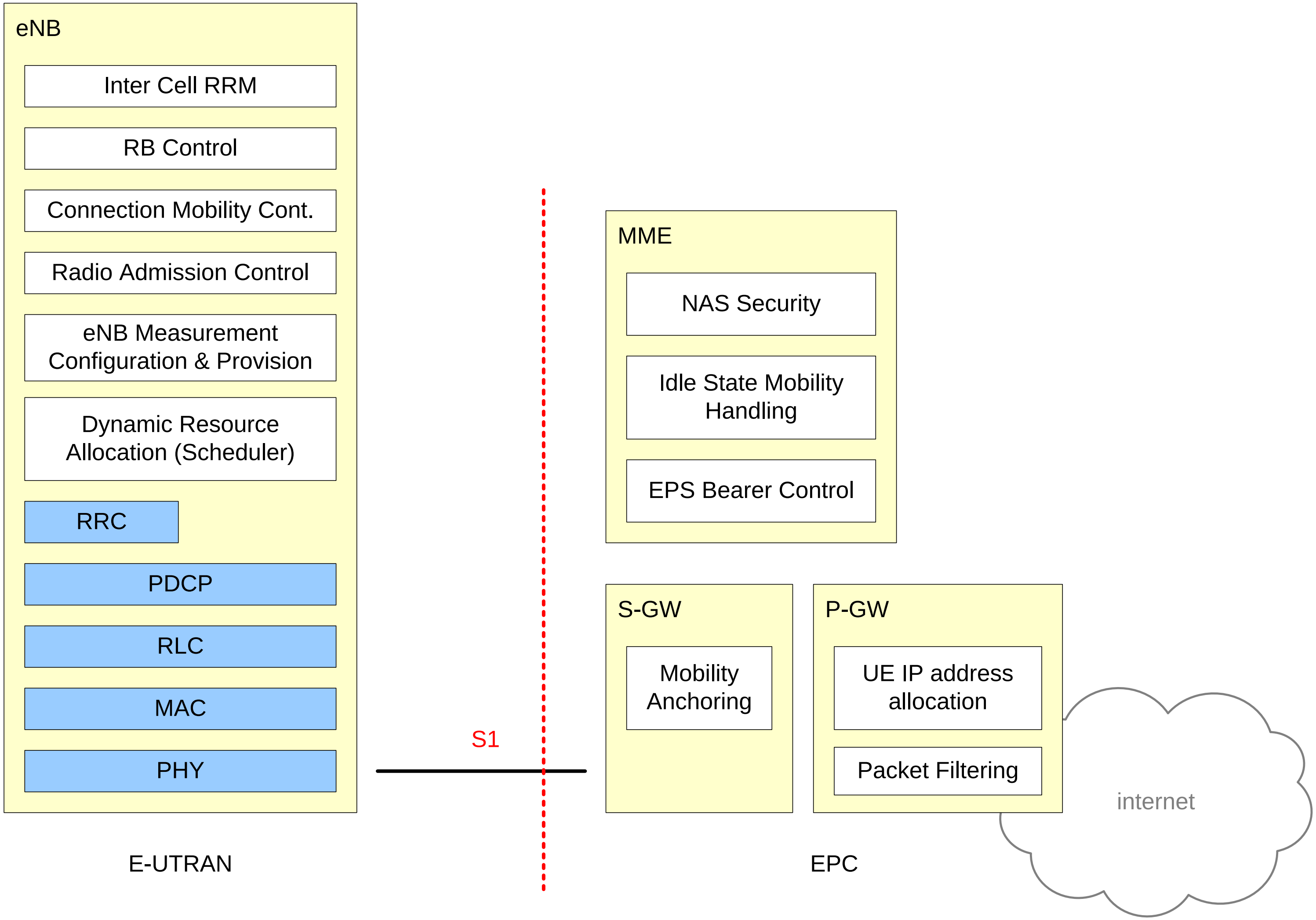
- E-UTRAN - Evolved UTRAN, known as LTE
  - » eNB - enhanced NodeB, base station: uses OFDMA



- EPC - Evolved Packet Core
  - » MME: Mobility Management Entity
  - » S-GW: Serving Gateway
  - » P-GW: Gateway for the Packet Data Network

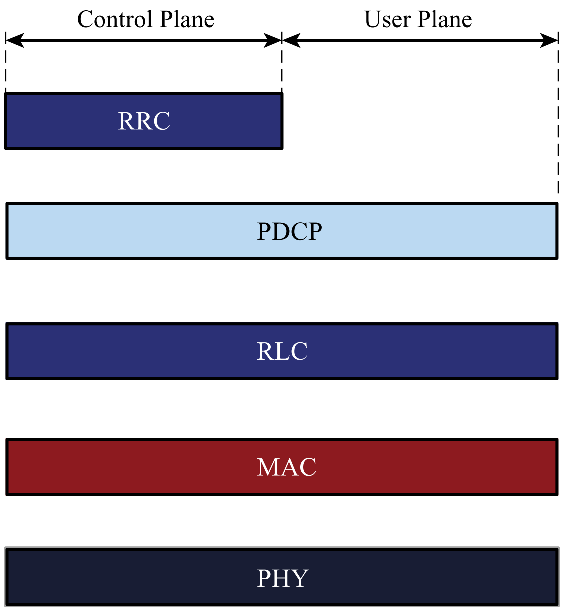
- Architecture simpler than 3G UTRAN
  - » EPC/LTE – 2 nodes in user-plane: eNB, S/P-GW
  - » Consequences: new functions performed at eNB
    - – Radio resource control, admission control
    - – Ciphering and header compression
    - – Handovers between eNBs handled through X2 interface

Functional Split Between E-UTRAN and EPC

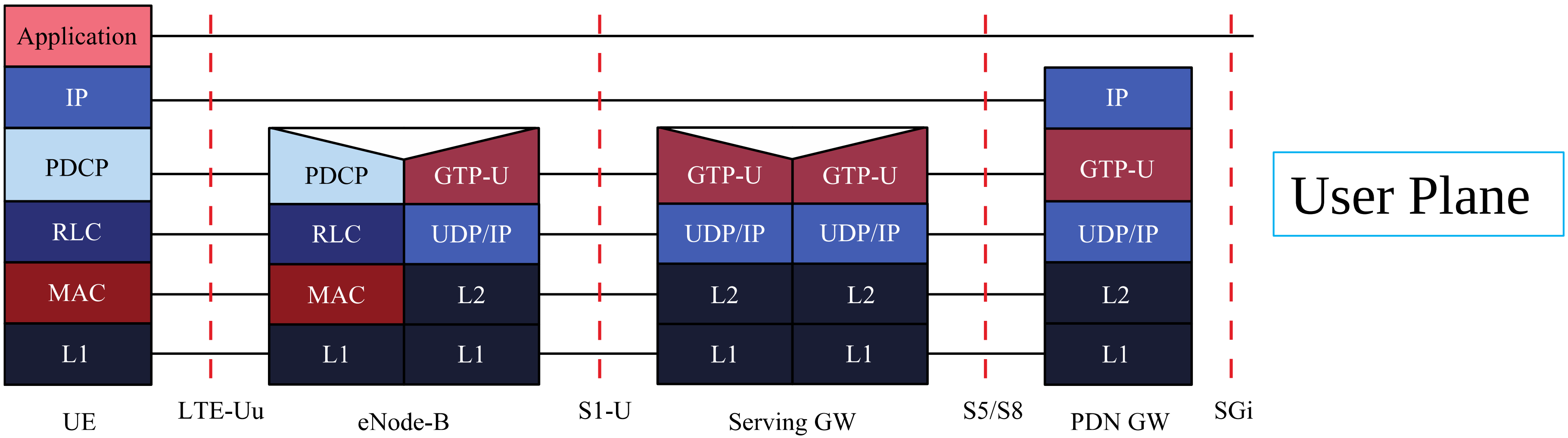


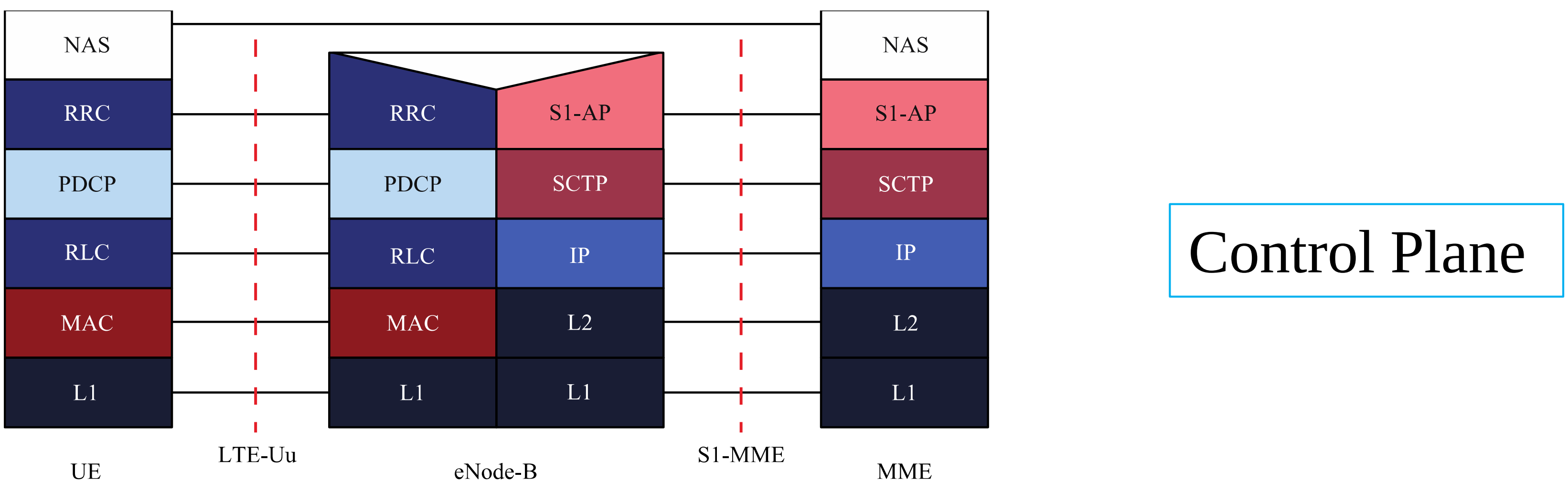
Protocol Layers – Radio Interface

- Radio Resource Control (RRC)
  - » control of radio resources
- Packet Data Convergence Protocol (PDCP)
  - » header compression, ciphering
  - » integrity protection, in-sequence delivery
  - » buffering/forwarding of packets during handover
- Radio Link Control (RLC)
  - » Segments or concatenates data units
  - » Performs ARQ when MAC layer H-ARQ fails
- Medium Access Control (MAC)
  - » Performs Hybrid-ARQ (H-ARQ)
  - » Prioritizes and decides which UEs and radio bearers will exchange data on which shared physical resources
  - » Decides modulation format, code rate, MIMO rank, power level
- Physical layer transmits the data



Protocol Stacks – User Plane and Control Plane





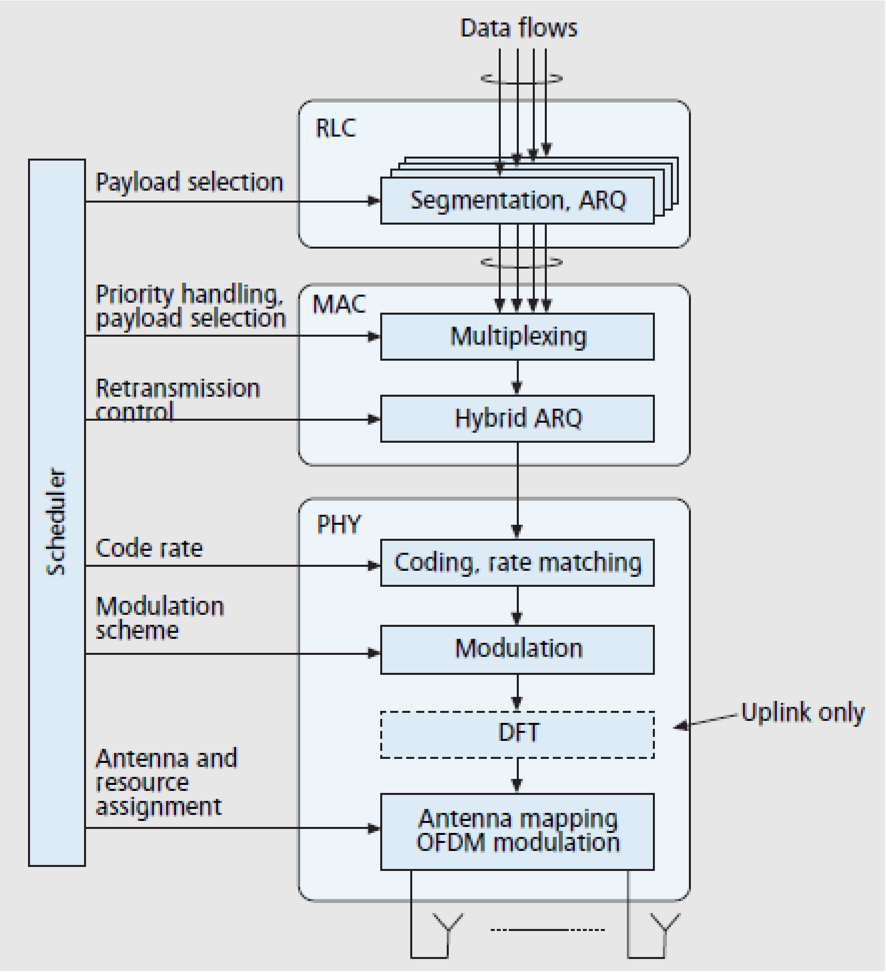
Non-Access Stratum (NAS) Protocols

- For interaction between the EPC and the UE
  - Not part of the *Access Stratum* that carries data

- EPS Mobility Management (EMM)
  - Manage the mobility of the UE

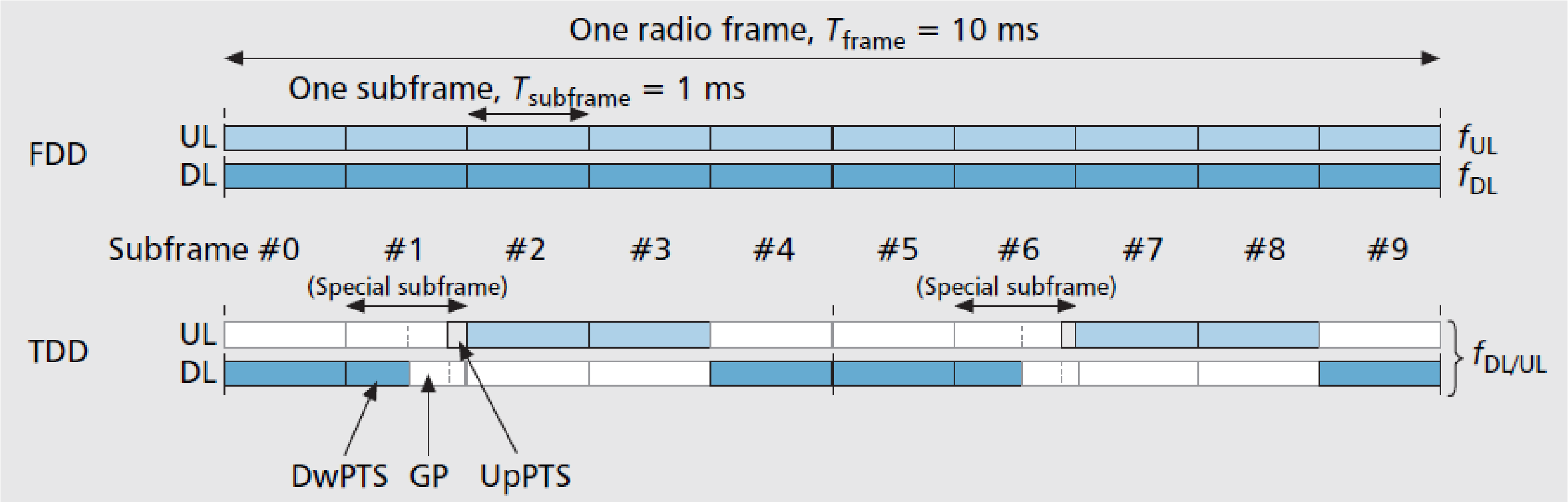
- EPS Session Management (ESM)
  - Activate, authenticate, modify, and de-activate user-plane channels for connections between the UE, SGW, and PGW

Radio Interface – Cross layer Design

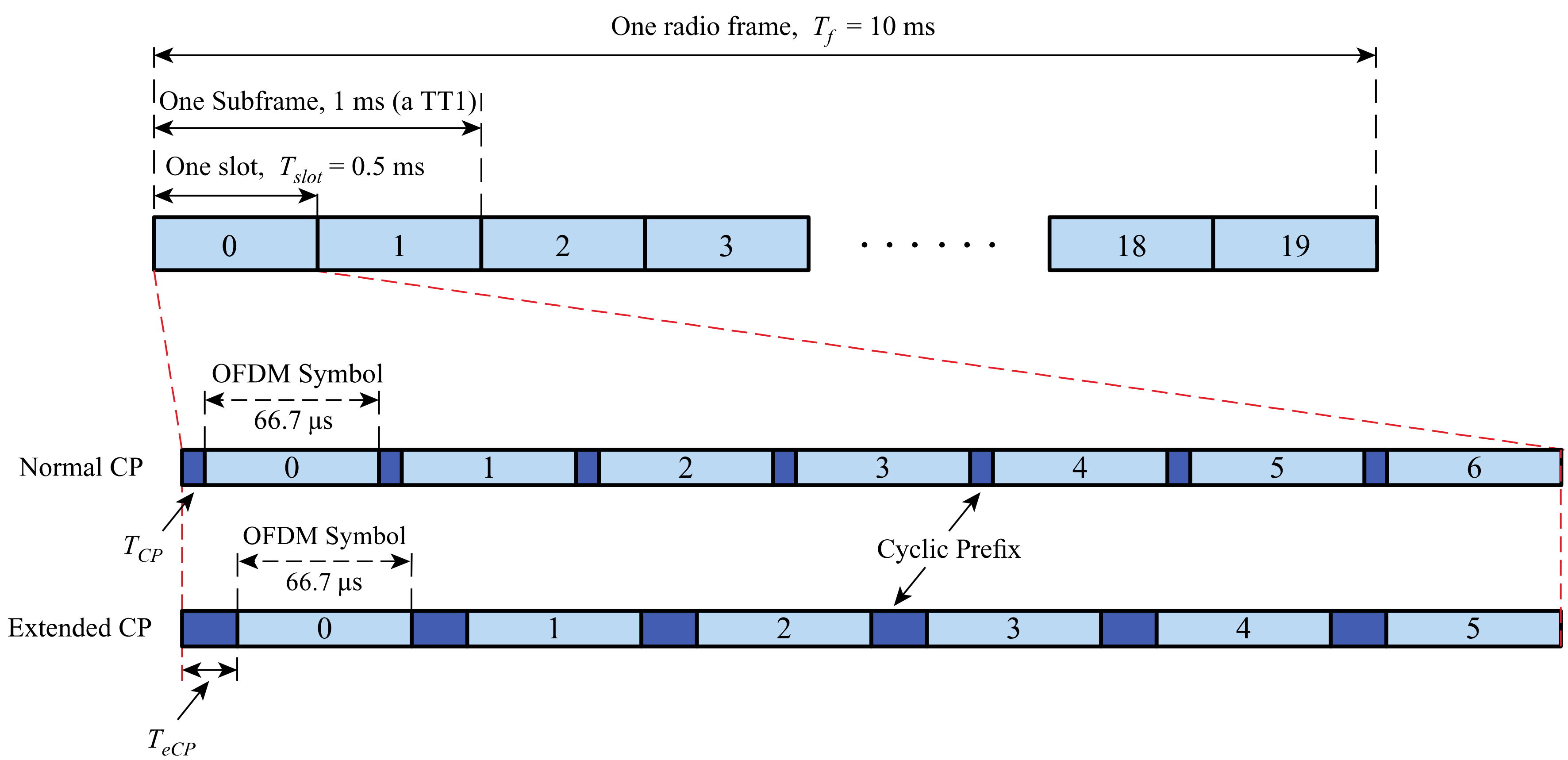


Transmission and Duplex

- LTE downlink radio transmission
  - » Orthogonal Frequency-Division Multiplexing Access: OFDMA
  - » narrow-band channels ~15kHz; bandwidth up to 20 MHz
- The LTE uplink radio transmission
  - » single-carrier frequency division multiple access SC-FDMA
- Duplex: FDD or TDD

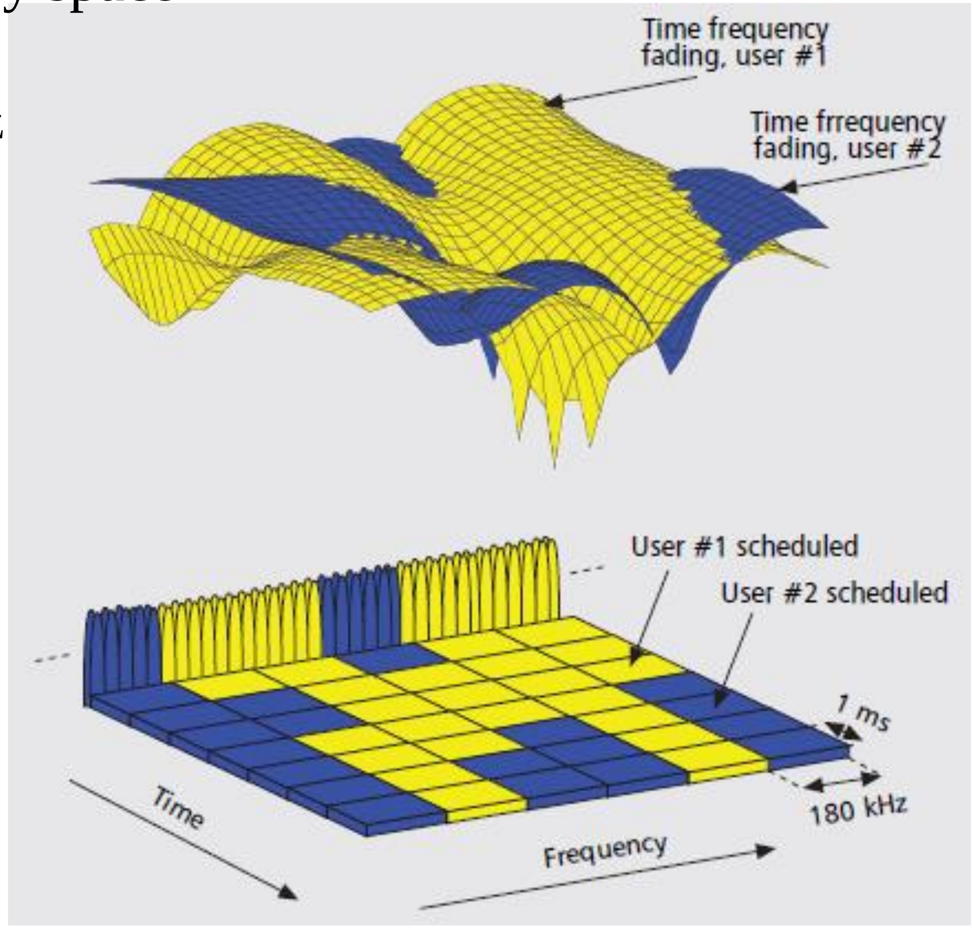


FDD Frame Structure (Type 1)



The LTE Radio Resource Block

- Addressable in the time-frequency space
  - » Frequency domain
    12 subcarriers * 15 kHz =180 kHz
  - » Time domain
    sub-frames of 1ms



- Resource Blocks are
  - » allocated to users/calls

- Wide range data rates supported by
  - » allocating resource blocks to users
  - » Using Adaptive Code-Modulation

Resource Blocks

- MIMO
  - 4×4 in LTE, 8×8 in LTE-Advanced
  - Separate resource grids per antenna port
- eNodeB assigns RBs with channel-dependent scheduling
- Multiuser diversity can be exploited
  - To increase efficiency
  - Assign resource blocks for UEs with favorable qualities on certain time slots and subcarriers

Physical Transmission

- eNodeB uses PDCCH (Physical Downlink **Control** Channel) to inform UEs about
  - Resource block allocations
  - Timing advances for synchronization
- UE determines a CQI index (modulation and code) that
  - provides the highest bitrate
  - while maintaining at most a 10% block error ratio
- Convolutional codes, ⅓ coding rate
- Modulations: QPSK, 16QAM, 64QAM (6 bit/symbol)

Power-On Procedures

1. Power on the UE
2. Select a network
3. Select a suitable cell
4. Use contention-based random access to contact an eNodeB
5. Establish an RRC connection (for control)
6. Attach: Register location with the MME; the network configures control and default EPS bearers
7. Transmit a packet
8. Mobile can then request improved quality of service. If so, it is given a dedicated bearer

LTE-Advanced

- Key improvements
  - Carrier aggregation
  - MIMO enhancements
  - Relay nodes
  - Heterogeneous networks involving small cells (femtocells, picocells, relays)

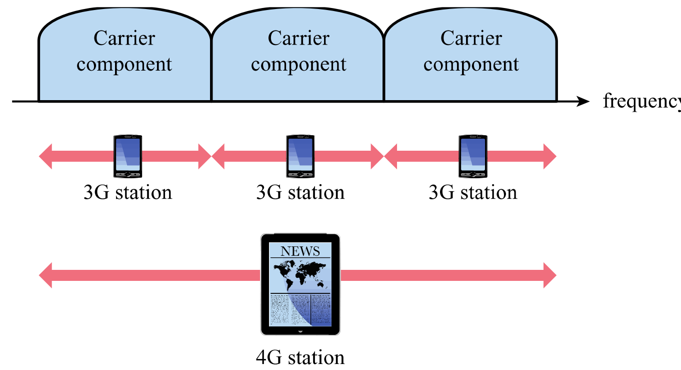
Table 14.2 Comparison of Performance Requirements for LTE and LTE-Advanced

System Performance		LTE	LTE-Advanced
Peak rate	Downlink	100 Mbps @20 MHz	1 Gbps @100 MHz
	Uplink	50 Mbps @20 MHz	500 Mbps @100 MHz
Control plane delay	Idle to connected	<100 ms	< 50 ms
	Dormant to active	<50 ms	< 10 ms
User plane delay		< 5ms	Lower than LTE
Spectral efficiency (peak)	Downlink	5 bps/Hz @2×2	30 bps/Hz @8×8
	Uplink	2.5 bps/Hz @1×2	15 bps/Hz @4×4
Mobility		Up to 350 km/h	Up to 350—500 km/h

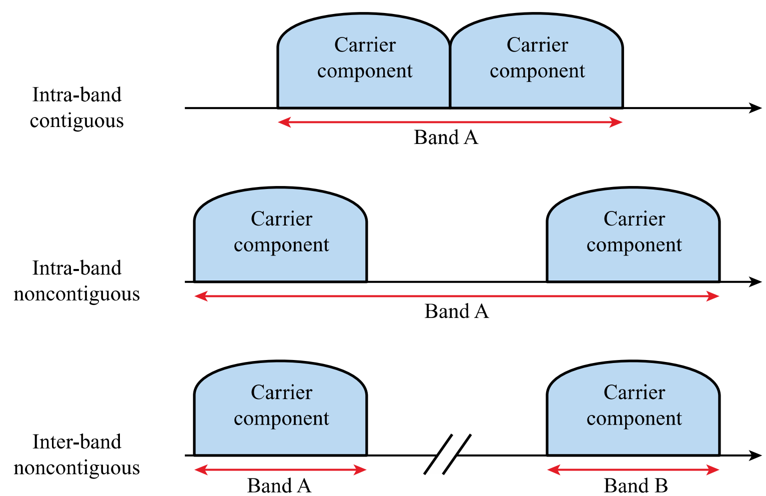
Carrier Aggregation

- LTE-Advanced may have 100 MHz
  - » Combine Component Carriers (CCs)
  - » Each CC can be 1.4, 3, 5, 10, 15, or 20 MHz
  - » Up to 100 MHz

- Three approaches to combine CCs
  - » Intra-band Contiguous
    - – carriers adjacent to each other
  - » Intra-band noncontiguous
    - – multiple CCs belonging to the same band used in a noncontiguous manner
  - » Inter-band noncontiguous
    - – use different bands



(a) Logical view of carrier aggregation

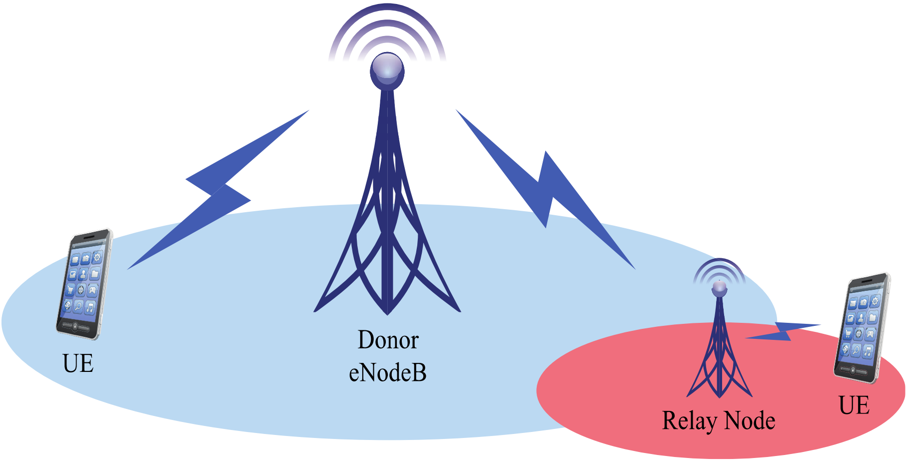


(b) Types of carrier aggregation

Relaying

- Relay nodes (RNs) extend the coverage area of an eNodeB
  - Receive, demodulate and decode the data from a UE
  - Apply error correction as needed
  - Then transmit a new signal to the base station

- RN functions as a new base station with smaller cell radius



Heterogeneous networks

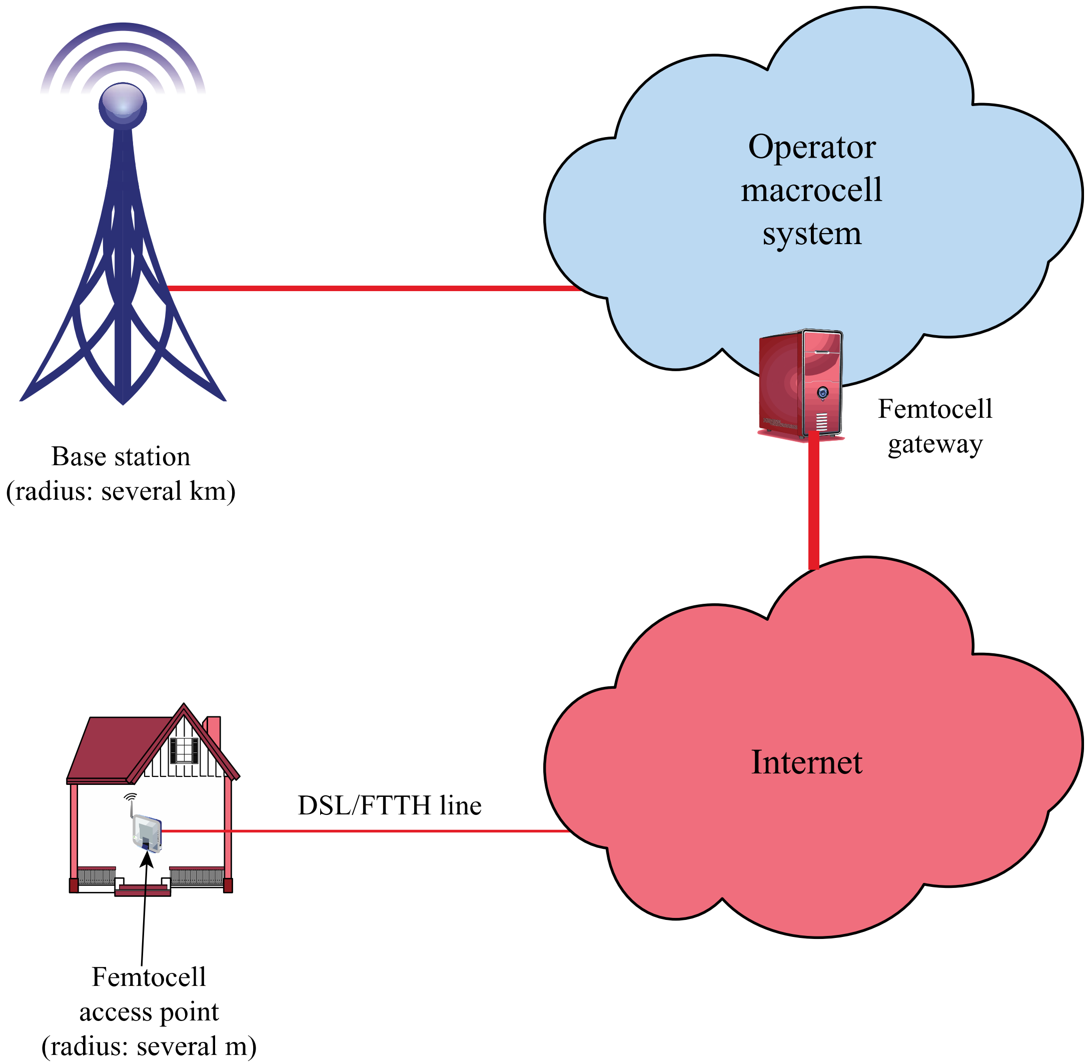
- Difficult to meet data transmission demands in densely populated areas

- *Small cells* provide low-powered access nodes
  - Operate in licensed or unlicensed spectrum
  - Range of 10 m to several hundred meters indoors or outdoors
  - Best for low speed or stationary users

- *Macro cells* provide typical cellular coverage
  - Range of several kilometers
  - Best for highly mobile users

- Femtocell
  - Low-power, short-range self-contained base station
  - In residential homes, deployed and use the home's broadband for backhaul

The Role of Femtocells



Homework

- Review slides

- LTE
  - » Use book: “Beard and Stallings, Wireless Communications Networks and Systems”
  - » Read Chap. 14 - 4th Generation Systems and Long Term Evolution

- Answer questions at moodle