COURSE 1
LTE SYSTEM. RADIO INTERFACE AND SYSTEM ARCHITECTURE

CONF. DR. ING. ZSOLT POLGÁR

Ș.L. DR. ING. ZSUZSANNA ȘUTA

COMMUNICATIONS DEPARTMENT

CONTENT

EVOLUTION TOWARDS LTE

- LTE specifications are included in the IMT 2000 specifications family
- Universal Mobile Telecommunications System (UMTS/HSxPA) specifications impose high speed packet transfer:
  - Up to 14.4 Mbps in downlink and 5.76 Mbps in uplink – first specifications
    - The specifications allow download at 28.8 Mbps or 43.2Mbps (Dual carrier)
  - The HSxPA system offer significant improvements compared to previous UMTS systems, but the performances are limited due to the previous versions compatibility requirements
  - Mobile broadband systems based on packet switching, like WiMAX 802.16e, imposed long term development strategies: Long Term Evolution – LTE of the UMTS system
    - Implementation of the LTE Evolved UMTS Terrestrial Radio (E-UTRA) system

EVOLUTION TOWARDS LTE

- Long term objectives:
  - Peak data rate: 100 Mbps downlink & 50 Mbps uplink
  - Reduced delay: 10ms “round-trip delay”
  - Increased system capacity & coverage
  - Reduced operating costs
  - Support for multi-antenna transmissions
  - Support for efficient packet transfer
  - Flexible bandwidth allocation – bandwidths up to 20 MHz
  - Possibility to integrate existing systems
- To achieve these objectives a new radio interface was necessary
- Requirements for the physical layer and a comparison with HSxPA are given in the following table:

EVOLUTION TOWARDS LTE

Requirements	HSxPA	LTE E-UTRA
Peak data rate	14Mbps DL / 5.76Mbps UL	100Mbps DL / 50Mbps UL
Spectral efficiency	0.6-0.8 DL / 0.35 UL [bps/Hz/sector]	Improvement 3-4x DL / 2-3x UL
Throughput packet call	64kbps DL / 5kbps UL	Improvement 3-4x DL / 2-3x UL
Average user trhoughput	900kbps DL / 150kbps UL	Improvement 3-4x DL / 2-3x UL
Delay – user plane	50ms	5ms
Connection setup time	2s	50ms
Broadcast throughput	384kbps	Improvement 6-8x
Mobility	Up to 250km/h	Up to 350km/h
Multi-antenna support	No	Yes
Bandwidth	5MHz	Scalable up to 20MHz

EVOLUTION TOWARDS LTE

- Other objectives of E-UTRA include:
  - Support for TDD & FDD working modes
  - Reduced system and terminal complexity
  - Frequency domain/band similar to IEEE 802.16
  - Support for advanced multi-antenna techniques
  - Improved uplink transmissions
  - Reduced delays and support for VoIP
  - Possibility to co-work with legacy systems, like UMTS
  - Support for increased mobility – maximum speed up to 350 km/h
  - Techniques for reduced power consumption of the mobile stations
  - Integration of unicast and broadcast transmissions

EVOLUTION TOWARDS LTE

- The scheduling techniques are an essential difference between HSxPA and LTE systems
- LTE allows both in DL and UL FDS (Frequency Domain/Selective Scheduling) and TDS (Time Domain Scheduling)

Requirements	HSxPA	LTE E-UTRA
TTI	2ms	1ms
Modulation	QPSK, 16QAM DL; QPSK, BPSK UL	QPSK, 16QAM, 64QAM DL; QPSK, 16QAM UL
HARQ + N-channel Stop&Wait	N=6 DL, N=8 UL asynchronous DL, synchronous UL; IR operations	asynchronous DL, synchronous UL; IR operations
Coding	Convolutional & turbo	Advanced coding techniques
Scheduling	TDS	TDS & FDS

EVOLUTION TOWARDS LTE

- FDS can improve the system capacity compared to TDS; 20-30% improvement
- TDS can be used for high speeds, operations at the cell limits, reduced overhead services, control channels

- Multi-Antenna Subsystem (MAS) and MIMO
  - To ensure the required peak data rate multi-antenna techniques have to be used:
    - Spatial multiplexing – multiplexing of several data flows toward a single mobile station
      - At least 2 or 4 transmission antennas are required; FDD duplexing is used
    - Multi-user MIMO
      - Different data flows from different users are transmitted using the same spatial resources; Spatial Division Multiple Access (SDMA) is used

EVOLUTION TOWARDS LTE

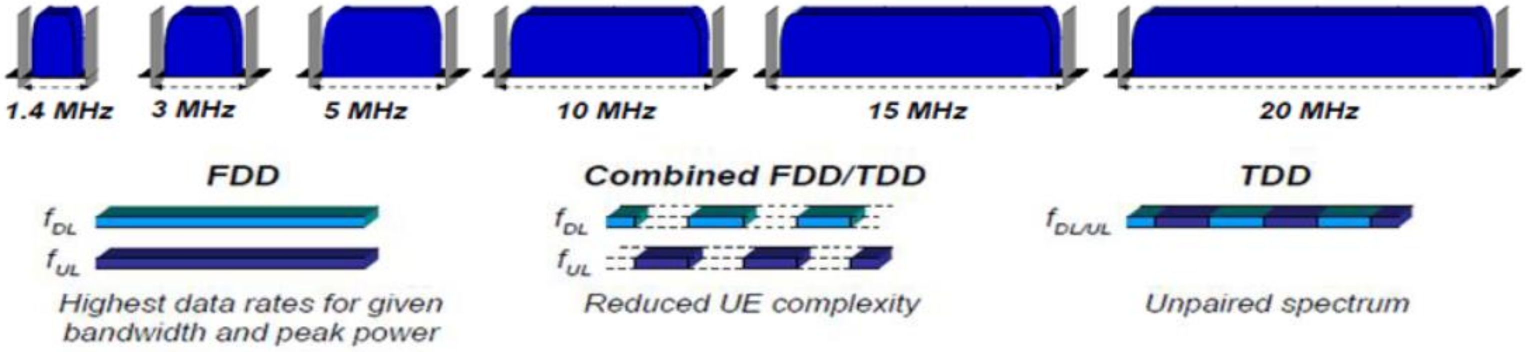
- Open loop MIMO diversity
  - Shift diversity or space-time block codes can be used
- Closed-loop MIMO diversity
  - A feedback about the channel state information or information about the precoding performed is necessary at the destination

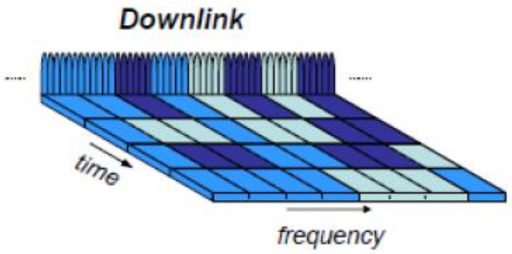
- Interference control:
  - To maximize the spectral efficiency the frequency reuse factor proposed is 1 both for UL & DL
    - The reuse factor with this value can cause severe interference for the mobile stations at the limit of the cells or in weak coverage areas
    - To control the interference the following are proposed:
      - Slow power control in uplink
      - Interference coordination/avoidance or interference mediation
      - Beam-forming techniques at the base station – for uplink transmissions

EVOLUTION TOWARDS LTE

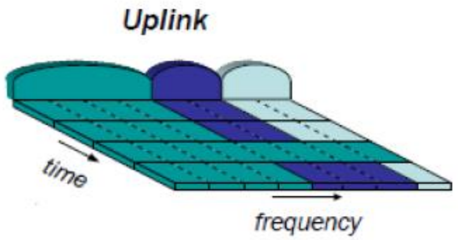
- Flexible spectrum allocation:
  - Multiple band allocations with different
  - Paired or unpaired spectrum allocations

LTE band allocation and resource usage



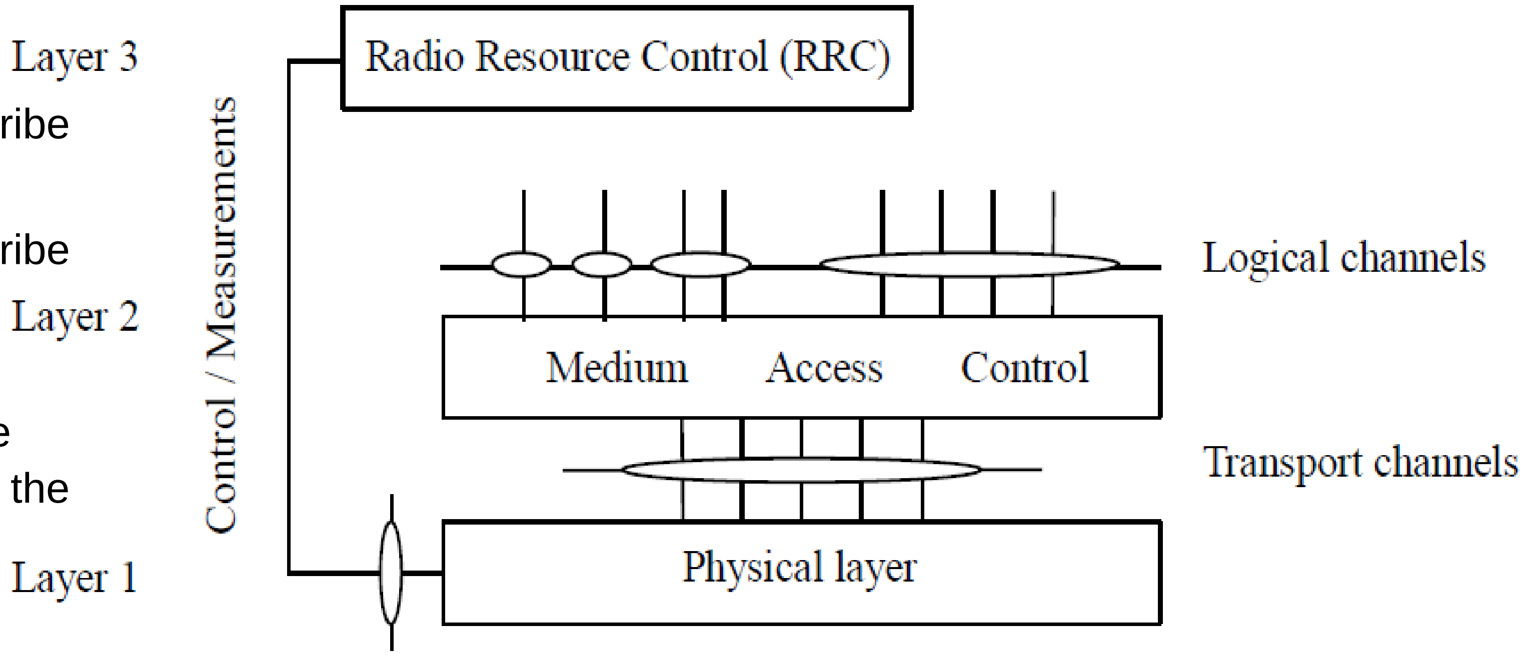


OFDM physical layer;
Scheduling granularity:
1ms/180kHz



LTE GENERAL DESCRIPTION

- General protocol structure:
  - The radio interface between the user equipment (UE) and the network is formed of 3 layers:
    - Layers 1, 2 and 3
    - TS 36.200 specifications describe layer 1 – physical layer
    - TS 36.300 specifications describe layers 2 (MAC+RLC) and 3 (RRC)
    - The circles identify the Service Access Points (SAP) between the layers



LTE GENERAL DESCRIPTION

- The physical layer offers transport channel for the MAC layer
  - The transport channel describes how the information is transmitted on the radio interface
- MAC offers logical channels for the Radio Link Control (RLC) sub-layer of layer 2
  - Logical channel is characterized by the information type transmitted
- The physical layer has to perform the following functions for data transmission:
  - Error detection on the transport channels and signaling of errors to higher layers
  - FEC coding/decoding of transport channels
  - H-ARQ with soft combining
  - Rate adaptation of the coded transport channel to the physical channel
  - Mapping of the coded transport channel into physical channels
  - Power adjustment of the physical channel
  - Physical channel modulation/demodulation
  - Frequency and time synchronization

LTE GENERAL DESCRIPTION

- Radio characteristics measurements and transmission to higher layers
- MIMO multi-antenna processing
- Transmission diversity
- Beamforming
- RF processing

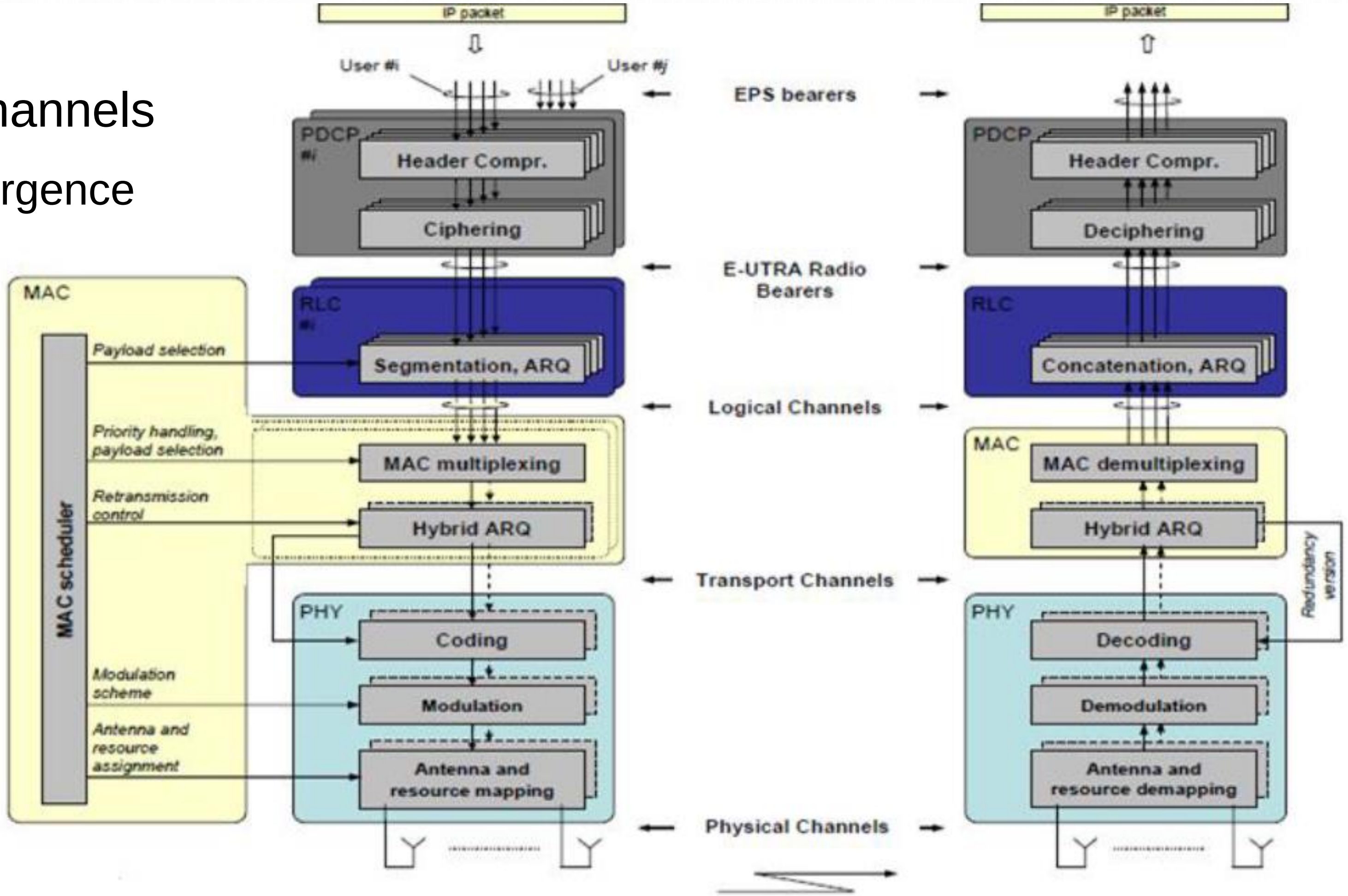
- Multiple access technique:
  - Is based on OFDM (Orthogonal Frequency Division Multiplexing) with cyclic prefix (CP) in DL and SC-FDMA (Single-Carrier Frequency Division Multiple Access) in UL
    - Allowed duplexing: FDD (Frequency Division Duplexing) and TDD (Time Division Duplexing)
  - Layer 1 allows the usage of multiple bandwidths: 1.4, 3, 5, 10, 15, 20MHz
    - The resource block is positioned on 12 sub-carriers with 15kHz separation or 24 sub-carriers with 7.5kHz separation and slot duration of 0.5ms

LTE GENERAL DESCRIPTION

- Mobility and coverage related aspects:
  - Mobility is one of the most important objectives of LTE
    - The system is optimized for speeds between 0 and 15 km/h
    - High performance is ensured for speeds between 15 and 120 km/h
    - Service can be provided also for speeds between 120 and 350 km/h
  - Support for voice and real-time services is offered for the entire speed range at a quality level at least as of the UTRAN systems
  - The coverage range is up to 5 km in good throughput conditions and high spectral efficiency in mobility conditions
  - The coverage range can be extended up to 30 km
    - Mobility is still ensured; certain degradation of throughput and spectral efficiency is accepted
  - The coverage range can be extended up to 100 km
    - Supported, but significant performance degradation has to be accepted

LTE GENERAL DESCRIPTION

- Processing chain and LTE channels
  - PDCP – Packet Data Convergence Protocol; RLC – Radio Link Control; EPS – Evolved Packet System



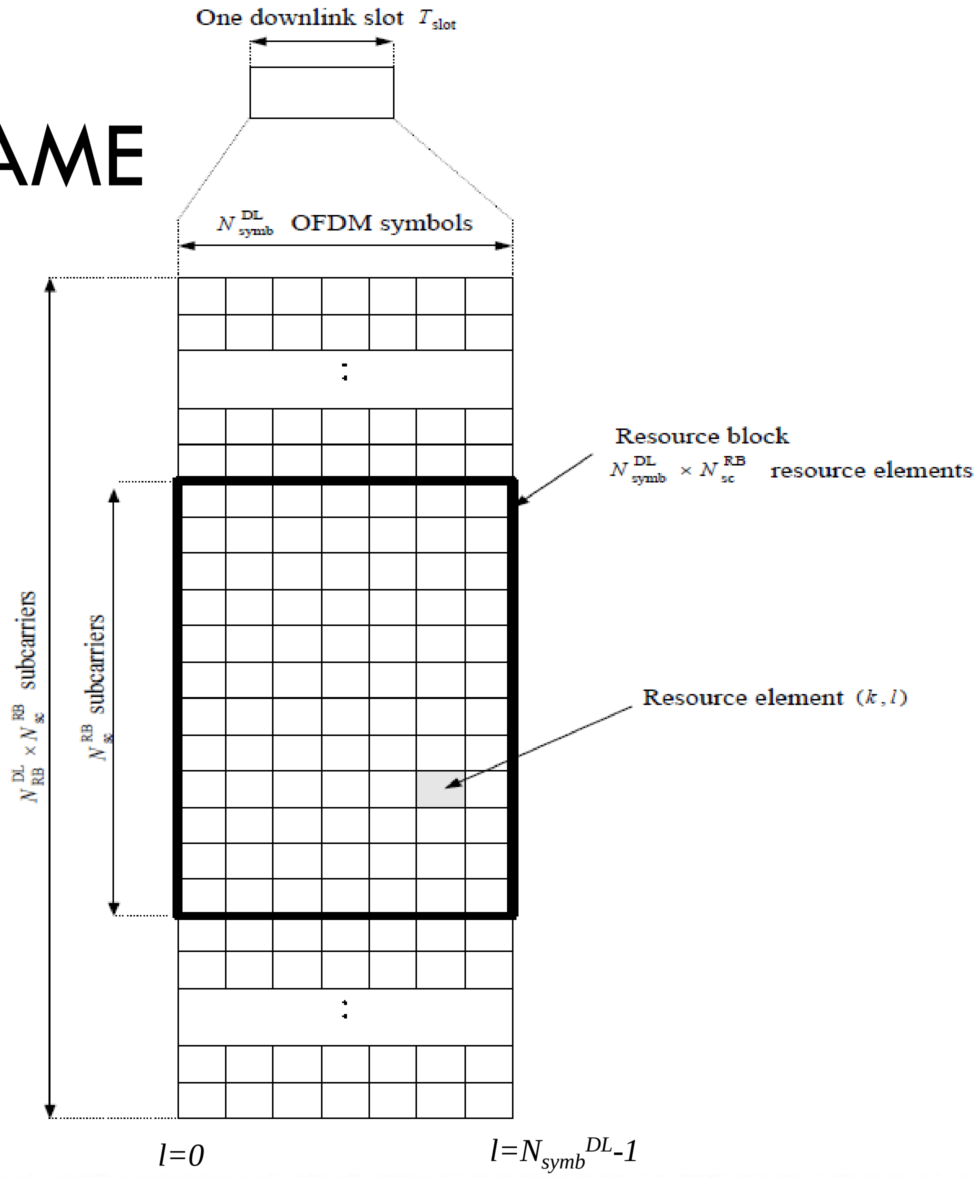
LTE RADIO FRAME

- DL resource block (RB) structure:
  - Resource element represents a basic frequency-time unit and is identified by an index pair (k, l)

$$k = 0,\ldots,N_{RB}^{DL}N_{sc}^{RB}-1$$

$$i = 0,\ldots,N_{symb}^{DL}-1$$

  - k – frequency index; l – time index
  - The indexing is done in a resource grid which is applied to an antenna port
    - Grid duration is 1 T_{slot}



LTE RADIO FRAME

- Both physical and virtual resource blocks are defined
  - One physical resource block is defined by N_{symb}^{DL} consecutive OFDM symbols in time and N_{sc}^{RB} consecutive sub-carriers in frequency
    - One physical resource block corresponds to one slot period and to 180 kHz
  - The relation between the number of the RB and resource elements in one slot is $n_{PRB} = \left\lfloor \frac{k}{N_{sc}^{RB}} \right\rfloor$

Configuration		N_{sc}^{RB}	N_{symb}^{DL}
Normal cyclic prefix	$\Delta f = 15\,\text{kHz}$	12	7
Extended cyclic prefix	$\Delta f = 15\,\text{kHz}$		6
	$\Delta f = 7.5\,\text{kHz}$	24	3

  - A virtual RB has the same dimension as a physical RB
  - Two types of virtual resource blocks can be defined
    - Distributed virtaual resource blocks and localized virtual resource blocks

LTE RADIO FRAME

- Virtual RBs are mapped on physical RBs depending on the diversity order
  - For diversity order 2 one virtual RB is mapped on one physical RB

- UL resource block structure:
  - The signal transmitted on each slot is described by a resource grid composed of $N_{RB}^{UL} N_{sc}^{RB}$ sub-carriers and N_{symb}^{UL} SC-FDMA symbols
    - The value of N_{RB}^{UL} depends on the transmission bandwidth UL: $6 \leq N_{RB}^{UL} \leq 110$
    - The number of SC-FDMA symbols from one slot:

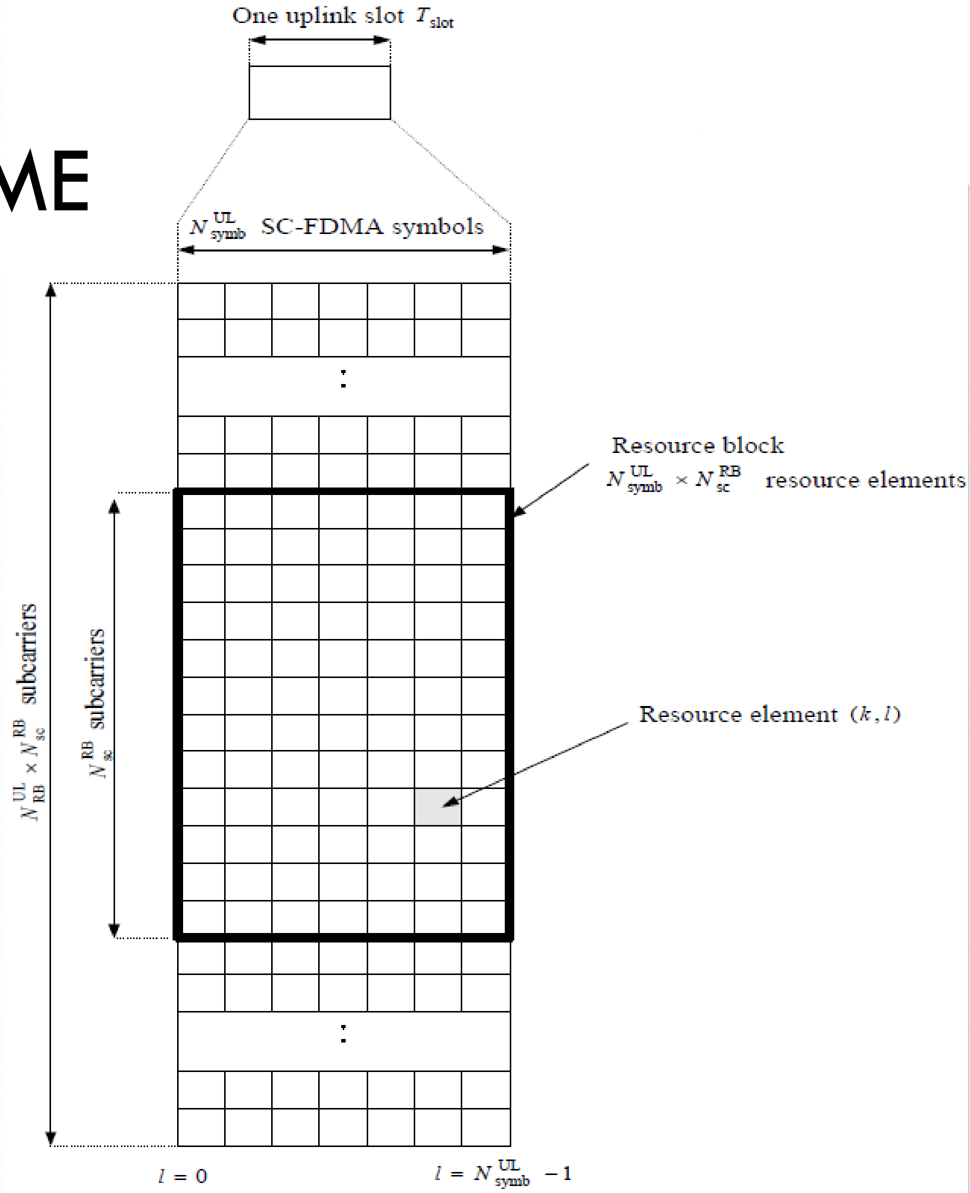
Configuration	N_{sc}^{RB}	N_{symb}^{UL}
Normal cyclic prefix	12	7
Extended cyclic prefix	12	6

    - Relation between the number of RB and the resource element identified by the index (k, l): $n_{PRB} = \left\lfloor \frac{k}{N_{sc}^{RB}} \right\rfloor$

LTE RADIO FRAME

- ○ Unused resource elements are set to zero

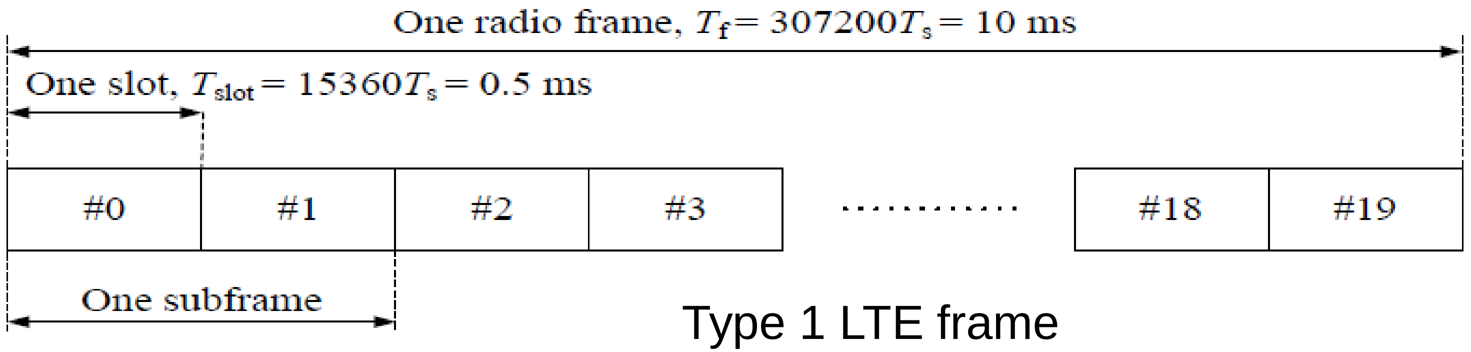
- ❑ Resource blocks:
  - ○ One resource block is defined by N_{symb}^{UL} consecutive SC-FDMA symbols in time and N_{sc}^{RB} consecutive sub-carriers in frequency
  - ○ The time duration is 1 slot and has a 180kHz bandwidth



LTE RADIO FRAME

- Frame structure:
  - The basic time unit is: T_s = 1/(15000*20148)
  - Transmissions both in DL and UL are organized in frames with a duration of: T_f = 307200*T_s = 10ms
  - 2 types of structures are defined:
    - Type 1 for FDD duplexing
    - Type 2 for TDD duplexing
- Type 1 frame structure:
  - Can be applied both to full duplex and half duplex FDD
  - Each frame has the duration of T_f = 10ms and is composed of 20 slots with duration T_{slot} = 15369*T_s = 0.5ms
  - One subframe *i* is defined as 2 consecutive slots 2*i* and 2*i*+1;
  - In case of FDD 10 subframes are available for DL transmissions and 10 subframes are available for UL transmissions in each 10 ms time interval

LTE RADIO FRAME

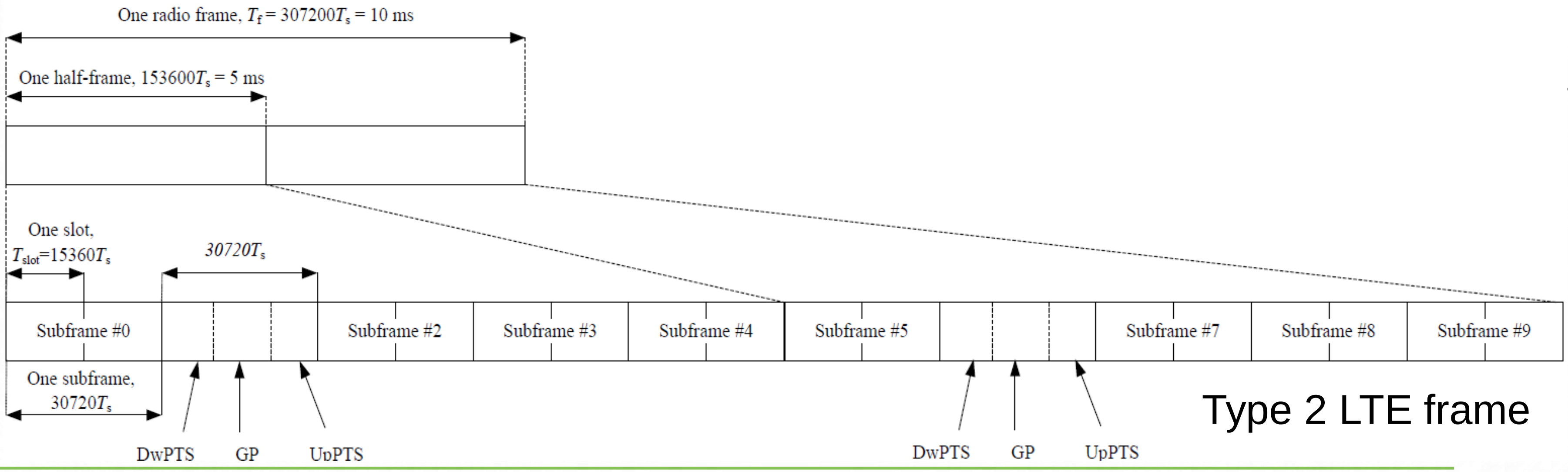


Type 1 LTE frame

- Type 2 frame structure:
  - Can be used in case of TDD
  - Each frame is composed of two half-frames of duration: T_f = 5ms
  - Each half-frame consists of 8 slots of duration T_{slot} = 0.5ms and 3 special fields: DwPTS, GP and UpPTS
  - The length of the fields DwPTS (Downlink Pilot Time Slot) and UpPTS (Uplink Pilot Time Slot) is configurable, but the the total length of the 3 fields must be 30720*T_s = 1ms
  - Subframes 1 and 6 consist of DwPTS, GP (Guard Period) and UpPTS; the other *i* subframes are composed of two slots 2*i* and 2*i*+1

LTE RADIO FRAME

- Subframes 0 and 5 and DwPTS are reserved for DL transmissions
- The switching point can have periodicity of 5 ms or 10 ms
  - In case of 5ms periodicity, UpPTS and subframes 2 and 7 are reserved for UL transmissions
  - In case of 10ms periodicity, DwPTS exists in both half-frames, while GP and UpPTS only in the first half-frame

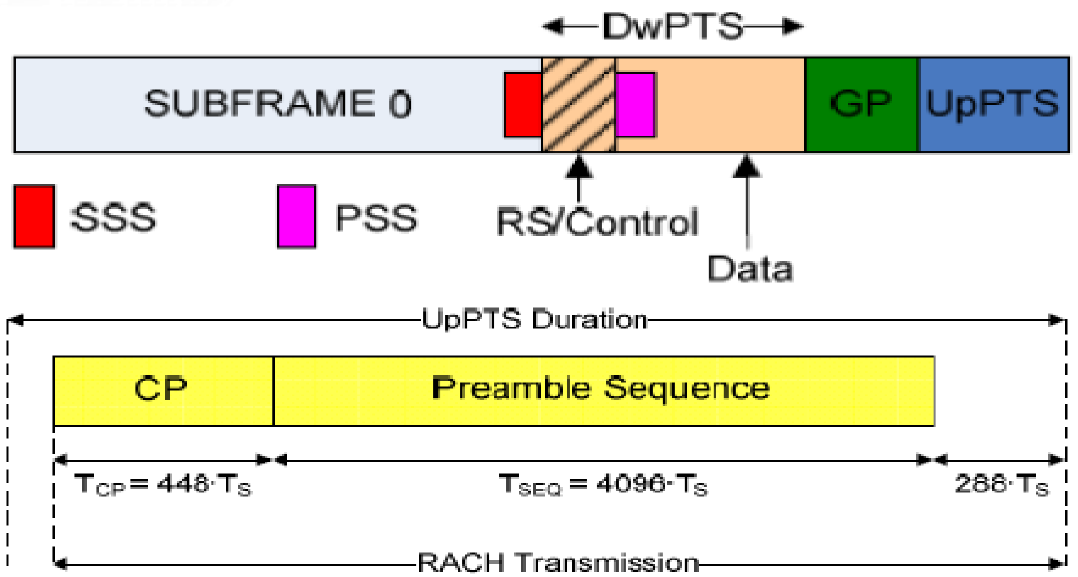


Type 2 LTE frame

LTE RADIO FRAME

- DwPTS: is used for cell lookup; carries the primary synchronization signal
  - Includes control information and reference signals as other DL subframes
  - Can carry also actual data depending on the scheduling algorithm
- UpTS: the usage is limited to carrying the sounding reference signals and to the random access (RACH signals)
- GP: guard period which ensures

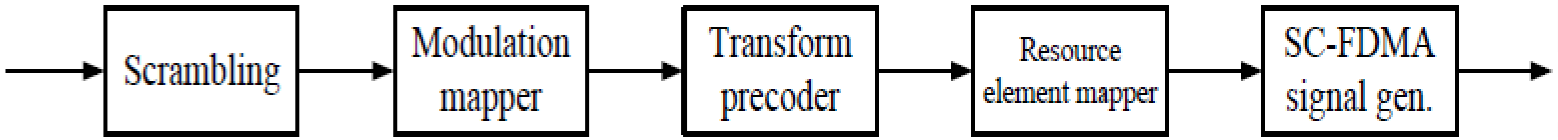
the switching between DL and UL



LTE PHYSICAL CHANNELS – UL

- Uplink channel:
  - A physical channel corresponds to a set of resource elements that carry information from higher levels
  - The following physical channels are defined:
    - Physical Uplink Shared Channel, PUSCH
    - Physical Uplink Control Channel, PUCCH
    - Physical Random Access Channel, PRACH
- Physical uplink shared channel – **PUSCH**
  - Baseband processing:
    - Randomization; modulation; precoding; mapping of complex symbols on resource elements; generating SC FDMA signals on each antenna port

LTE PHYSICAL CHANNELS – UL



- The modulation constellations used are:
  - QPSK, 16QAM, 64QAM
- Precoding (transformation precoding)
  - The block of complex symbols d(0),...,d(M_{symb}-1) is divided into M_{symb}/M_{sc}^{PUSCH} sets, each corresponding to a SC-FDMA symbol
  - The precoding is performed according to the rule:

$$z(lM_{sc}^{PUSCH}+k)=\sum_{i=0}^{M_{sc}^{PUSCH}-1} d(lM_{sc}^{PUSCH}+i)e^{-j\frac{2\pi ik}{M_{sc}^{PUSCH}}}, k=0,\dots,M_{sc}^{PUSCH}-1, l=0,\dots,\frac{M_{symb}}{M_{sc}^{PUSCH}}-1$$

    - The result is a block of complex modulating symbols z(0),...,z(M_{symb}-1)
    - The variable M_{sc}^{PUSCH} is the number of subcarriers used for PUSCH transmission in a SC-FDMA symbol

LTE PHYSICAL CHANNELS – UL

- The variable M_{sc}^{PUSCH} is: $M_{sc}^{PUSCH} = N_{sc}^{RB} * 2^{\alpha 2} * 3^{\alpha 3} * 5^{\alpha 5} \leq N_{sc}^{RB} N_{RB}^{UL}$, $\alpha i \geq 0$, $i = 2,3,5$

- Physical resource mapping involves:
  - Multiplying by an amplitude scaling factor
  - Mapping of complex modulating symbols on the resource block allocated to PUSCH transmission
    - Mapping involves the computation of indexes (k, l) of resource units
    - The l index starts from the first slot in the sub-frame
    - The k index is given by the relation: $k = k_0 + f_{hop}(),\ldots,k_0 + f_{hop}() + M_{sc}^{PUSCH} - 1$
      - k_0 represents the first index in the assigned block, $f_{hop}()$ represents the frequency hopping scheme

- Physical uplink control channel – **PUCCH**
  - The PUCCH channel carries control information in UL: ACK, band request; scheduling request, channel quality indicator, precoding matrix;
  - It is not transmitted simultaneously with PUSCH
    - For the type 2 frame structure, PUCCH is not transmitted in the UpPTS field

LTE PHYSICAL CHANNELS – UL

- PUCCH supports multiple formats as shown in the following table
- The transmission of control symbols involves a series of processing:
  - Multiplication by a cyclically shifted sequence
    - Different shifts apply to different SC-FDMA control symbols in a slot
  - A spreading is applied using orthogonal sequences
  - Amplitude scaling is applied
  - Mapping on resource elements with frequency hopping

PUCCH Format	Modulation scheme	No. bits / subframe
0	BPSK	1
1	QPSK	2
2	QPSK	20
3	N/A	N/A

- Reference signals:
  - Used to estimate/measure the radio channel

LTE PHYSICAL CHANNELS – UL

- Two types of reference signals are defined in UL:
  - Demodulation reference signal
    - They are associated with the transmission of PUSCH and PUCCH channels
  - Sounding reference signal
    - They are not associated to the transmission of PUSCH and PUCCH channels
    - They are necessary because the transmission takes place only on a limited set of subcarriers, but it is necessary to estimate the channel in the entire frequency band for the allocation of resources
- The same set of basic sequences (Zadoff-Chu signals) is used for the demodulation and measurement signals
  - The reference signals are obtained by cyclically shifting a base sequence
- Orthogonality of reference signals is obtained by frequency multiplexing on distinct sets of subcarriers
- The length of the sequence is equal to a multiple of the no. of subcarriers in the resource block

LTE PHYSICAL CHANNELS – UL

- The reference signals are multiplexed over time with the data on the subcarriers assigned to the UE
  - The power level of the reference signal is different from that of the data symbols transmitted on other SC-FDMA symbols – PAPR must be minimized on each SC-FDMA symbol
- Control information can also be multiplexed with data
- The PUCCH channel is used until there is no PUSCH allocated for the UE

SC-FDMA baseband signal generation

- Applies to all UL channels except the PRACH random access channel
- The continuous signal in time in the SC-FDMA symbol period with index l is:

$$s_l(t) = \sum_{k=-\lfloor N_{RB}^{UL} N_{SC}^{RB}/2 \rfloor}^{\lceil N_{RB}^{UL} N_{SC}^{RB}/2 \rceil - 1} a_{k^{(-)},l} e^{j2\pi(k+\frac{1}{2})\Delta f(t-N_{CP,l}T_s)}, 0 \leq t < (N_{CP,l}+N)T_s, N = 2048, \Delta f = 15kHz, k^{(-)} = k + \lfloor N_{RB}^{UL} N_{sc}^{RB}/2 \rfloor$$

  - $a_{k,l}$ is the complex symbol in the resource element (k,l), N_{CP}= 160, l=0 and 144, l=1 – 6 : normal cyclic prefix; = 512 : extended cyclic prefix

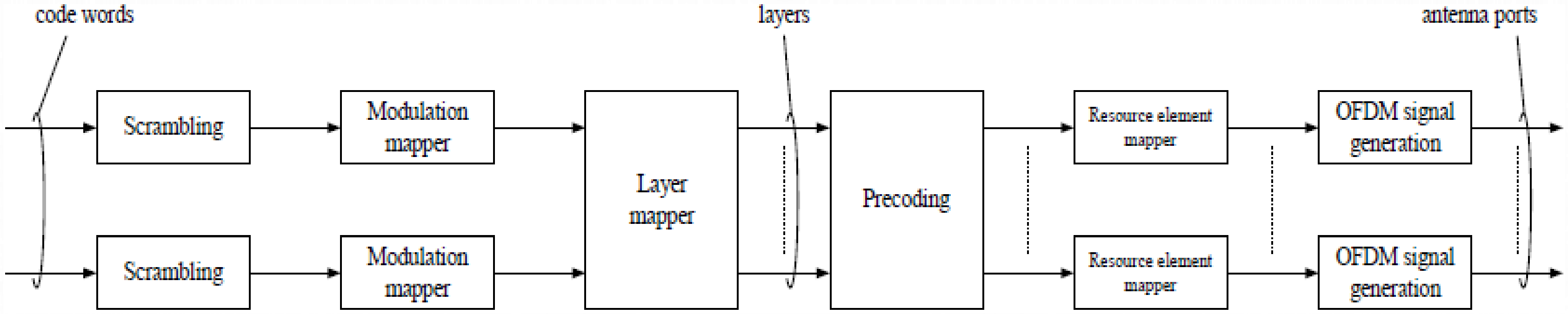
LTE PHYSICAL CHANNELS – UL

- Physical random-access channel – **PRACH**
  - The random-access preamble consists of a cyclic prefix of T_{CP} duration and a portion of a sequence of T_{SEQ} duration:
    - T_{CP} is between 0 and 21000 basic units T_s
    - T_{SEQ} is between 4096 and 49000 basic units T_s
    - The format is controlled by the upper layers
  - It is used to perform the initial synchronization in UL
    - The transmission on this channel is requested by MAC and takes place on certain time frequency resources:
      - In the frequency domain, the band corresponding to 6 resource blocks is used
      - In the case of type 1 frame, there is at most one PRACH resource per subframe
      - In the case of type 2 frame, there may be several PRACH resources per subframe
  - Random preamble sequences are obtained from Zadoff-Chu sequences obtained from one or more basic sequences, there are 64 sequences available in each cell

LTE PHYSICAL CHANNELS – DL

- Physical downlink channel:
  - A physical DL channel corresponds to a set of resource elements that carry information generated by the upper layers in the DL
  - The following physical downlink channels are defined:
    - Physical Downlink Shared Channel, PDSCH
    - Physical Broadcast Channel, PBCH
    - Physical Multicast Channel, PMCH
    - Physical Control Format Indicator Channel, PCFICH
    - Physical Downlink Control Channel, PDCCH
    - Physical Hybrid ARQ Indicator Channel, PHICH

LTE PHYSICAL CHANNELS – DL



- The processing performed on the downlink physical channels:
  - Randomization of the encoded bits in each code word transmitted on the physical channel
  - Modulation of randomized bits to generate complex modulated symbols
  - Mapping complex modulated signals into one or more transmission levels
  - Precoding of complex modulated signals in each level for transmission on antenna ports
  - Mapping complex modulated symbols for each antenna port to resource elements
  - Generating the complex OFDM signal in the time domain for each antenna port

LTE PHYSICAL CHANNELS – DL

- Randomization: bits of code words transmitted in a subframe are randomized according to an imposed rule
  - Two code words can be transmitted in a single subframe
- Modulation schemes:
  - PDSCH: QPSK, 16QAM, 64QAM; PMCH: QPSK, 16QAM, 64QAM
- Mapping on transmission levels
  - Required for the implementation of multi-antenna techniques
  - There may be 1, 2 or 4 transmission levels
  - Spatial multiplexing or diversity techniques can be used
- Precoding: implements multi-antenna techniques and is used in conjunction with mapping techniques
- Mapping on resource elements
  - Mapping on resource elements, not used for other purposes, on the antenna port is done by increasing the index k and then the index l starting with the first slot in the subframe

LTE PHYSICAL CHANNELS – DL

- Physical downlink shared channel – **PDSCH**:
  - If no user-specific reference signals are transmitted, antenna port 0,1,2 and 3 are used
  - If user-specific reference signals are transmitted, the antenna port used is 5
- Physical multicast channel – **PMCH**:
  - It is characterized by several restrictions:
    - No diversity schemes are used
    - There are certain limitations on symbols and subframes where PMCH can be transmitted
- Physical broadcast channel – **PBCH**:
  - A cell-specific randomization sequence is used
  - QPSK modulation is used, and multi-antenna techniques can be used
  - Mapping on resource elements is performed according to an imposed rule

LTE PHYSICAL CHANNELS – DL

- Physical control format indicator channel – **PCFICH**:
  - Carries information about the number of OFDM symbols (1,2 or 3) used to transmit the PDCCH channel in a subframe
  - Randomization is performed with a cell-specific sequence
  - Modulation used: QPSK
  - Multi-antenna techniques can be used; the same antenna ports must be used as for PBCH
  - Mapping on resource elements must consider multi-antenna techniques
- Physical downlink control channel – **PDCCH**:
  - Carries scheduling information and other control information
  - A physical control channel is transmitted using an aggregation of one or more control channel elements (CCE)

LTE PHYSICAL CHANNELS – DL

  - A CCE corresponds to a set of resource elements
  - Multiple PDCCHs can be transmitted in a subframe, and there are several PDCCH formats
  - Procedures for randomizing and multiplexing multiple channels in a subframe are defined
  - Modulation used: QPSK
  - Separate mapping procedures are defined

- Physical hybrid ARQ indicator channel – **PHICH**:
  - Carries ACK/NAK H-ARQ;
  - Multiple PHICHs mapped to the same set of resource elements form a PHICH group
  - The modulation used can be any of the defined ones
  - Level and resource mapping are described separately
  - Exact details can be found in the 3GPP, Release 8 standards

LTE PHYSICAL CHANNELS – DL

- Reference signals:
  - Three types of reference signals are defined:
    - Cell-specific signals associated with non-MBSFN (Multi-Media Broadcast over a Single Frequency Network) transmissions
    - MBSFN reference signals associated with MBSFN transmissions
    - UE specific reference signals
  - There is only one reference signal transmitted on the antenna port
- Cell-specific reference signals:
  - They are transmitted in all DL subframes in cells that support non-MBSFN transmissions
    - MBSFN: is a possible method for Multimedia Broadcast Multicast Service implementation
  - In case of subframes used for MBSFN, only the first two OFDM symbols in a subframe can be used to transmit cell-specific reference signals
  - They are transmitted on one or more antenna ports

LTE PHYSICAL CHANNELS – DL

- Sequence generation method:
  - Generation of the two-dimensional reference sequence $r_{m,n}(n_s)$ depends on the cyclic prefix; n_s represents the slot number in the radio frame
  - In the case of normal cyclic prefix, the two-dimensional reference sequence is obtained as the symbol-by-symbol product of two other two-dimensional sequences $_{rm,n}(n_s) = r_{m,n}^{OS} r_{m,n}^{PRS}(n_s)$
  - $r_{m,n}^{OS}$ is a two-dimensional orthogonal sequence; m and n define the sequence: n=0, 1; m=0, 1, ..., 219; there are 3 orthogonal sequences
  - $r_{m,n}^{PRS}(n_s)$ represents a two-dimensional pseudorandom sequence; there are 168 pseudorandom sequences
  - There is one-to-one mapping between the three identities within the cell-level cell identity group and the three orthogonal sequences
  - In the case of extended cyclic prefix $r_{m,n}(n_s)$ is generated form a two-dimensional pseudorandom sequence $r_{m,n}^{PRS}(n_s)$, there are 504 pseudorandom sequences
  - There is a one-to-one mapping between the identity of the cell and the pseudorandom sequences

LTE PHYSICAL CHANNELS – DL

- MBSFN reference signals:
  - MBSFN reference signals are transmitted only in the subframes allocated to MBFSN transmission and only on the antenna port 4
- UE specific reference signals:
  - They are supported by the PDSCH transmission on antenna port 5 and are selected by the upper layers
- Synchronization signals:
  - There are 504 unique cell identities at the physical level
    - These identities are grouped into 168 groups of three unique identities
    - Each cell identity at the physical level belongs to a single group
    - The group is identified by $N_{ID}^{(1)}$ and takes values between 0 and 167; the element in the group is identified by $N_{ID}^{(2)}$ and takes values between 0 and 2: $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$
      - The summation is modulo three

LTE PHYSICAL CHANNELS – DL

- Primary synchronization signal:
  - It is used to detect slot timing and identity within a group
  - It is generated from Zadoff-Chu sequences in the frequency domain
  - Mapping on resource elements depends on the frame structure
    - The antenna port to transmit this sequence is not specified
  - For the type 1 frame structure, the synchronization sequence is transmitted only in slots 0 and 10
  - For the type 2 frame structure, the primary synchronization signal is transmitted in the first symbol of the DwPTS field

LTE PHYSICAL CHANNELS – DL

- Secondary synchronization signal
  - It is used for:
    - Performing frame synchronization
    - Group identity determination
    - Cyclic prefix length determination
    - Duplexing mode identification
  - Represents a sequence of length 62, obtained from the interleaving of two binary sequences of length 31
    - The concatenated sequence is scrambled using a sequence that depends on the binary synchronization signal
    - It is transmitted on slots 0 and 10 in type 1 frames, and in slots 2 and 12 in type 2 frames

LTE PHYSICAL CHANNELS – DL

- Baseband OFDM signal generation:
  - Continuous signal in time on the antenna port p and in the symbol l:

$$s_l^{p}(t) = \sum_{k=-\lfloor N_{RB}^{UL} N_{sc}^{RB}/2 \rfloor}^{-1} a_{k^{(-)},l}^{p} e^{j2\pi k\Delta f (t - N_{CP,l} T_s)} + \sum_{k=1}^{\lceil N_{RB}^{UL} N_{sc}^{RB}/2 \rceil} a_{k^{(+)},l}^{p} e^{j2\pi k\Delta f (t - N_{CP,l} T_s)},$$

$$0 \le t < \left(N_{CP,l} + N\right) T_s, k^{(-)} = k + \left\lfloor \frac{N_{RB}^{UL} N_{sc}^{RB}}{2} \right\rfloor, k^{(+)} = k + \left\lfloor \frac{N_{RB}^{UL} N_{sc}^{RB}}{2} \right\rfloor - 1$$

    - Variable N is 2048 for 15kHz subcarrier separation and 4096 for 7.5kHz subcarrier separation
    - The OFDM symbols in a slot must be transmitted in ascending order of l

Configuration		Cyclic prefix length
Normal cyclic prefix	$\Delta f = 15\,\text{kHz}$	160 pt. $l = 0$ 144 pt. $l = 1, 2, ..., 6$
Ext. cyclic prefix	$\Delta f = 15\,\text{kHz}$	512 pt. $l = 0, 1, ..., 5$
	$\Delta f = 7.5\,\text{kHz}$	1024 pt. $l = 0, 1, 2$

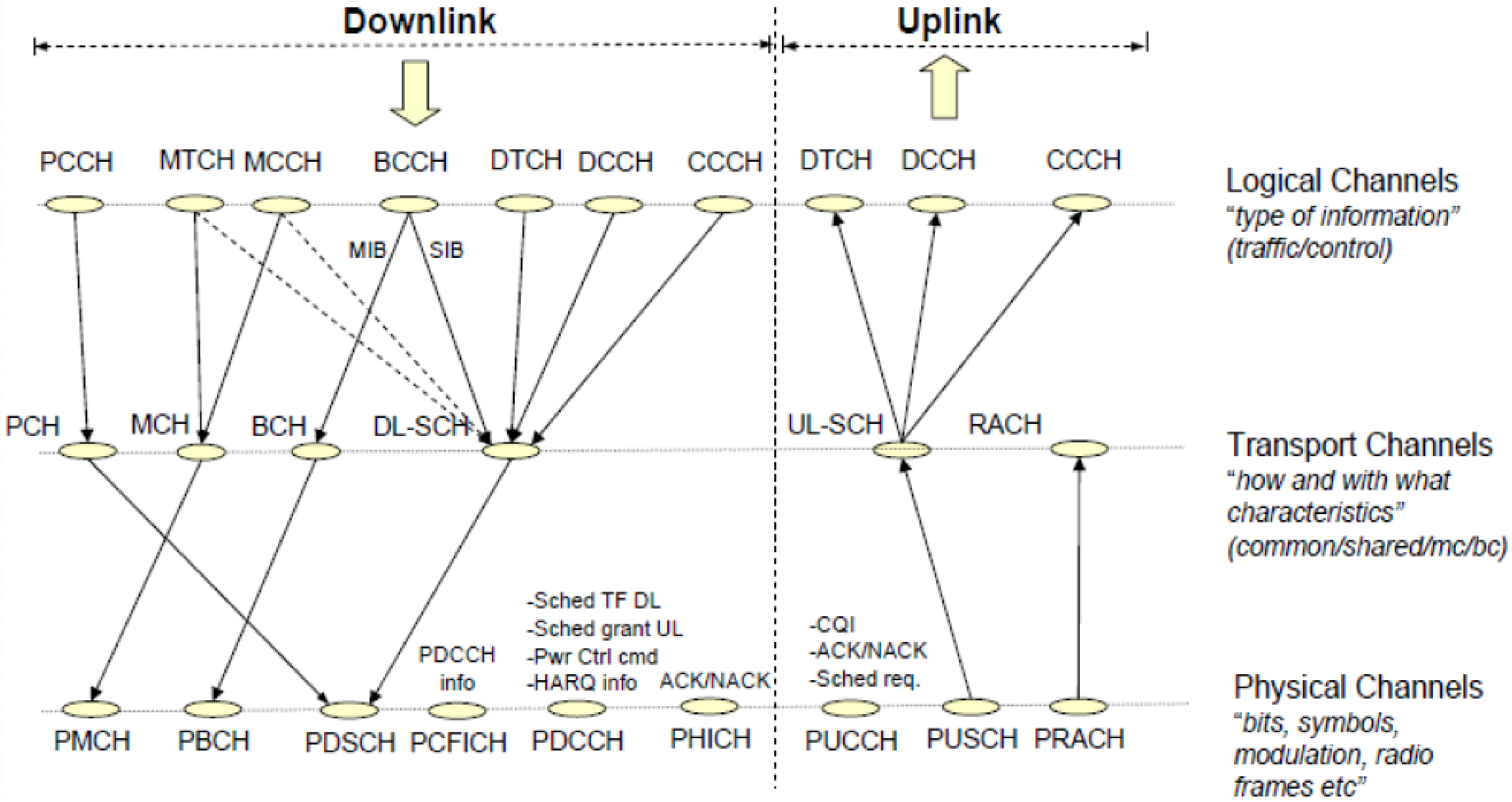
LTE LOGICAL AND TRANSPORT CHANNELS

- Transport channels:
  - To reduce the complexity of LTE protocol stack, the number of transport channels was reduced
    - Dedicated data channels are no longer defined, shared channels are used
  - The DL transport channels are the following:
    - Broadcast Channel (BCH)
    - Downlink Shared Channel (DL-SCH)
    - Paging Channel (PCH)
    - Multicast Channel (MCH)
  - The UL transport channels are the following:
    - Uplink Shared Channel (UL-SCH)
    - Random Access Channel (RACH)

LTE LOGICAL AND TRANSPORT CHANNELS

- Logical channels:
  - Logical channels can be classified into control and traffic channels
  - The control channels are the following:
    - Broadcast Control Channel (BCCH)
    - Paging Control Channel (PCCH)
    - Common Control Channel (CCCH)
    - Multicast Control Channel (MCCH)
    - Dedicated Control Channel (DCCH)
  - The traffic channels are the following:
    - Dedicated Traffic Channel (DTCH)
    - Multicast Traffic Channel (MTCH)

LTE LOGICAL AND TRANSPORT CHANNELS



SAE SYSTEM ARCHITECTURE

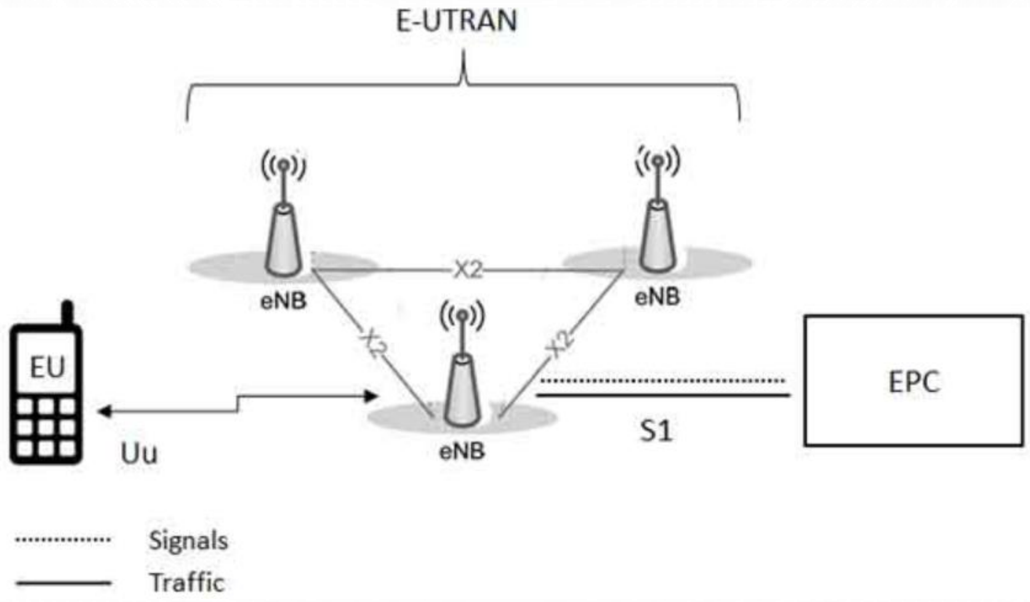
- The relation between LTE and SAE:
  - LTE implementation requires a high-performance core network
  - Implementing LTE without SAE is theoretically possible but does not make sense
    - The definition of LTE and SAE specifications was synchronized over time
- SAE: “System Architecture Evolution”
  - Defined by 3GPP for wireless systems
  - It is compatible with current 3GPP network implementations
  - Simplified architecture to ensure high throughput, low delays and QoS
  - Handover and interconnection with other 3GPP access technologies (UMTS, HSPA and HSPA+)
    - Ensures easy introduction of a new service

SAE SYSTEM ARCHITECTURE

- Terminology:
  - EPC = Evolved Packet Core
  - EPS = Evolved Packet System
    - Includes EPC, LTE and terminals
- LTE is a packet-switched access network
  - No circuit switching is used at all
  - It is optimized for IP-based services, including telephony services
  - Handover procedures to circuit-based networks are specified
  - The core packet network is transparent to the IMS module (practically incorporates IMS)
    - IP Multimedia Subsystem (IMS): the architecture module which provides multimedia IP services
  - Supports multiple 3GPP radio access technologies (GERAN, UTRAN)
  - Also incorporates non-3GPP access (e.g. WiMAX, WLAN)

SAE SYSTEM ARCHITECTURE

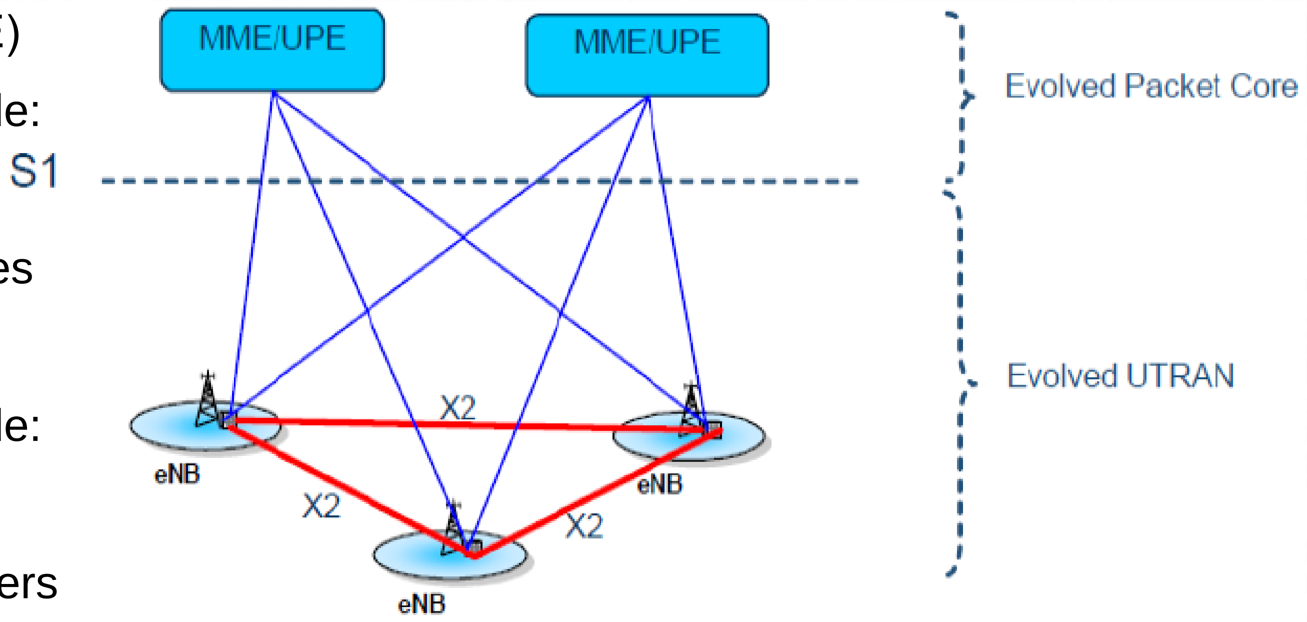
- In the LTE system most of the RNC functionalities are moved to eNodeB
  - UMTS RNC is no longer defined
  - eNodeB is directly connected to the Evolved Packet Core (EPC)



SAE SYSTEM ARCHITECTURE

- The LTE system ensures simplified mobility management
  - The MME/UPE modules are defined:
    - “Mobility Management Entity” (MME)
      - The tasks of this module include:
        - Mobile identification,

        Identification of mobility states
    - “User Plane Entity” (UPE)
      - The tasks of this module include:
        - Paging initiation
        - Setting bearer IP parameters



SAE SYSTEM ARCHITECTURE

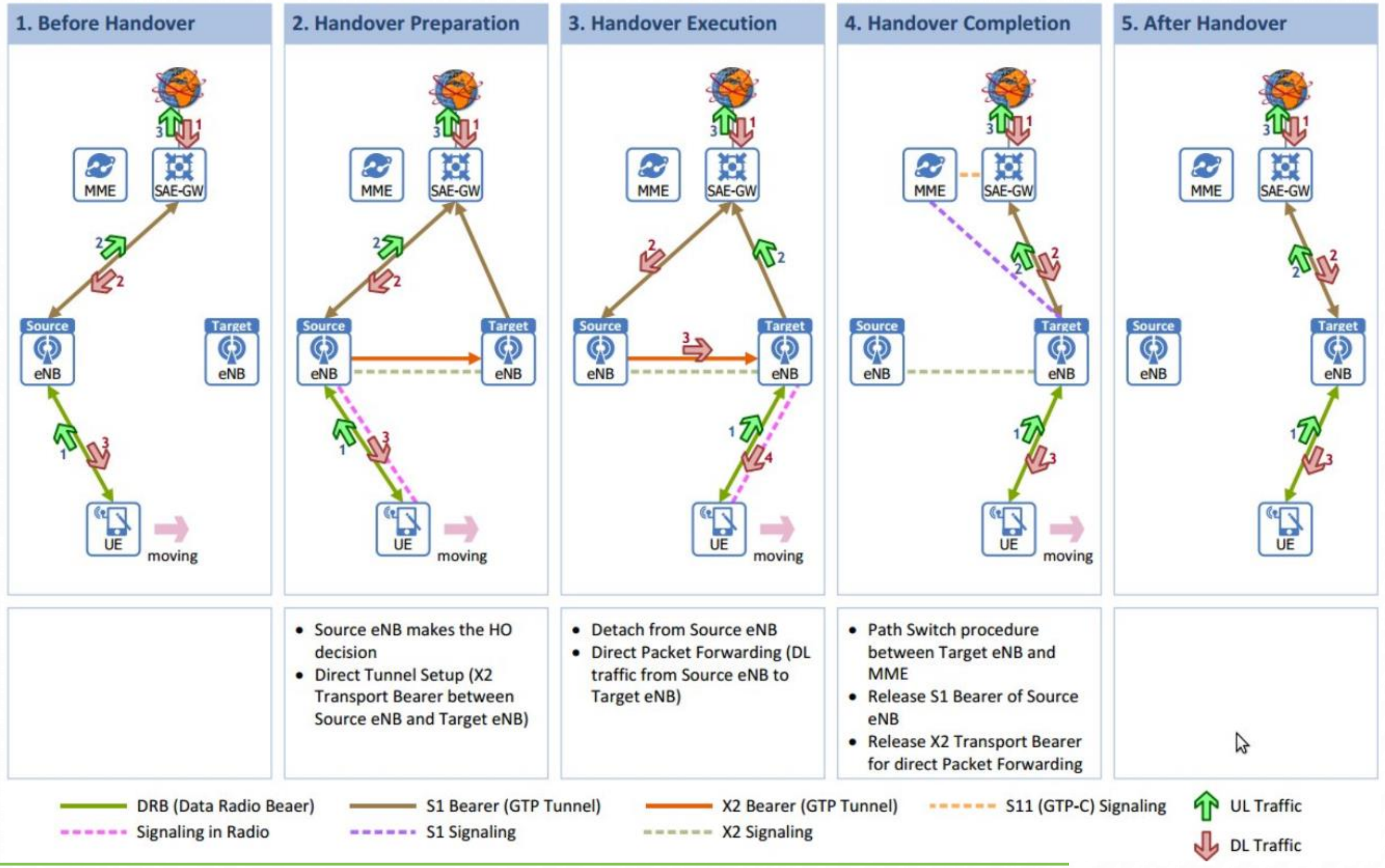
- Distribution of EPS functionalities:
  - Enhanced Node B (eNB) performs the following functions:
    - Radio Resource Management
    - Radio Bearer Control
    - Radio Admission Control
    - Connection Mobility Control
    - Scheduling – dynamic allocation of resources to UE both in the DL and the UL
    - IP header compression and user data stream encryption
    - Selection of an MME at UE connection
    - Routing data from the user plane to the SAE gateway
    - Carrying out measurements and reporting measurements for mobility and scheduling

SAE SYSTEM ARCHITECTURE

- The MME performs the following functions:
  - Distribution of paging messages to eNBs
  - Security control
  - Mobility control in Idle state
  - Control of SAE bearer
  - Encryption and protection of NAS signaling integrity
    - NAS: “Non-Access Stratum”; NAS signaling ends in MME and is responsible for generating and allocating temporary identifiers to the UE
- SAE Gateway performs the following functions:
  - Termination for U plane packets (user plane)
  - U plane switching to support UE mobility

HANDOVER IN LTE

- The intra-LTE handover process in the LTE / SAE architecture:
  - Two phases can be identified: Radio Handover and Path Update



HANDOVER IN LTE

- The handover process (intra-LTE HO) is controlled by the network
  - The decision is made by the eNodeB (source eNB)
  - There are two phases:
    - New eNB preparation phase for data transfer describing the communication process before the HO command
      - The core network is not involved in the preparation phase
    - Also in this phase, the data from the user plane is transferred between the source eNB and the new eNB
      - This approach is known as: “Make before brake approach”
    - Switching the path to aGW (MME & UPE)
    - Switching is done after establishing a new connection between the UE and the final eNB
      - No buffering to aGW

HANDOVER IN LTE

- Performance:
  - Short interruptions of the orde of 30 ms
  - The same HO procedure can be used both for real-time services (delay sensitive) and non-real-time services (not sensitive to delays)
  - Lossless soft handover
- HO process diagram and the signals involved