Integrated Digital Networks

1. Handover types in 3G networks.

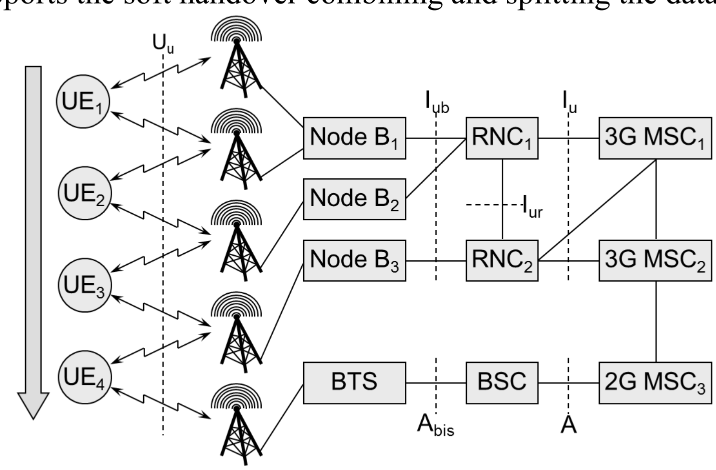
https://intranet.etc.upt.ro/~DIG_INT_NET/course/6_Mobile%20networks17_10.pdf, 46, 50, 51

Handover

- Transfer of a link between 2 neighboring cells/antennas
- UMTS main handover classes:
    - Hard handover
        - Similar to GSM handover
        - Includes
            - Inter-frequency handover (change carrier frequency)
            - Inter-system handover (between UMTS and other systems)
    - Soft handover (new in UMTS)
        - Only available with FDD
        - Uses macrodiversity
            - fundamental characteristic of CDMA systems
            - mobile equipment communicates with up to 3 antennas simultaneously

Handover types in 3G

- Intra-nod B, intra-RNC (softer handover)
    - UE_1 moves between 2 different antennas of the same Node B (Node B_1)
    - Node B_1 combines and splits the data streams
- Inter-nod B, intra-RNC (soft handover)
    - UE_2 moves from Node B_1 to Node B_2
    - RNC_1 supports the soft handover combining and splitting the data streams



- Inter-RNC
    - UE_3 moves from Node B_2 toward Node B_3=> 2 possible situations
        - Internal (soft) inter-RNC handover, with RNC_1 acting as SRNC and RNC_2 acting as DRNC

- External (hard) inter-RNC handover with relocation of the I_u interface

- Inter-MSC
  - MSC_2 takes over the connection and realizes a hard handover
- Inter-system (hard handover)
  - UE_4 moves from the 3G network to a 2G network
  - Important for areas with no 3G coverage

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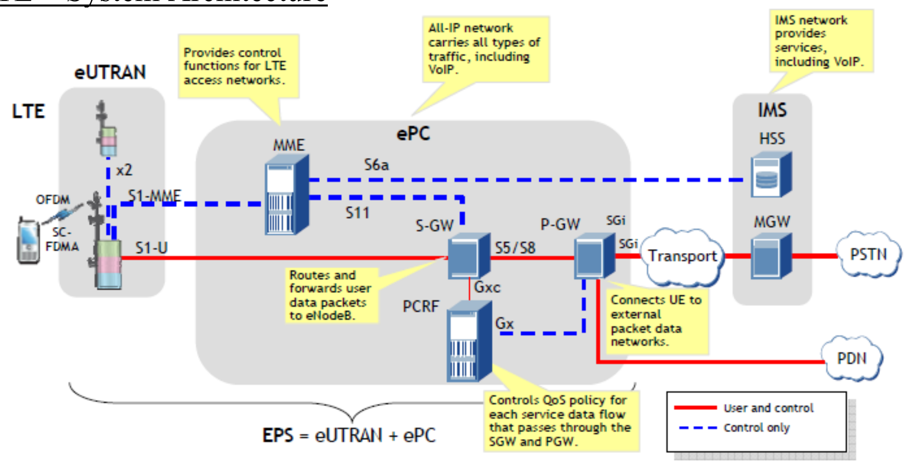
2. LTE architecture – enumerate the functional blocks and briefly explain their main functions for 3 of them.

https://intranet.etc.upt.ro/~DIG_INT_NET/course/7_LTE_20.pdf, 10-12, 16-19

<u>LTE – System Architecture</u>

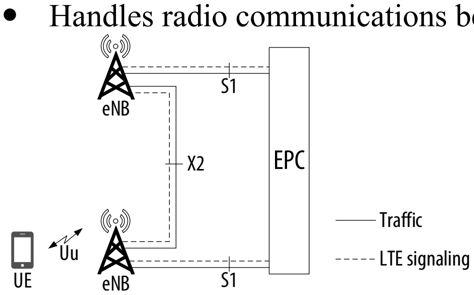


IMS - IP Multimedia Subsystem - delivers voice and other multimedia services over IP in mobile networks

EPS – Evolved Packet System

<u>E-UTRAN</u>

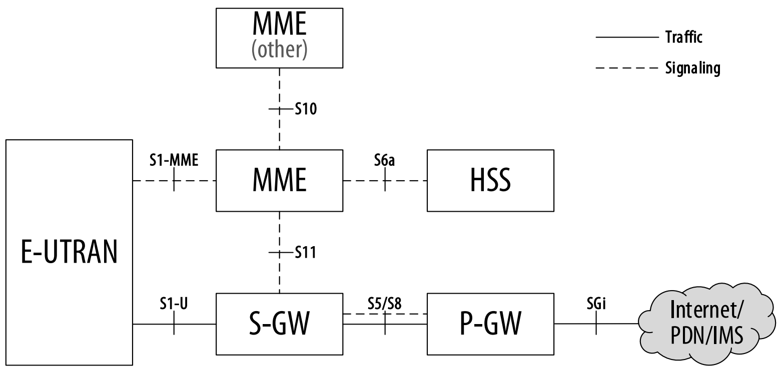
- Handles radio communications between mobile terminals and EPC



- Evolved Node B (**eNB**) – the only component of E-UTRAN
  - Base station which controls mobiles in one ore more cells
  - Uses analog and digital signal processing functions to
    - send radio transmissions to all mobile on DL
    - receive radio transmissions from all mobiles on UL

- Controls low-level operation of all mobiles using signaling messages (e.g. handover commands)
- Interfaces
    - S1 to EPC
    - X2 to nearby eNBs (optional)
- used for signaling and packet forwarding during handover
- A mobile communicates with only one eNB at a time – **serving eNB**

EPC



- HSS – Home Subscriber Server
    - central database with information about all network operator's subscribers
- P-GW – PDN (Packet Data Network) GateWay
    - exchanges data with one or more external devices or PDNs
        - servers of the network operator
        - internet
        - IMS (IP Multimedia Subsystem)
    - P-GWs which provide connection to PDNs to a mobile terminal do not change during the lifetime of the connections
        - when the mobile switches on, it is assigned to a default P-GW at to have always on connectivity to a default PDN (e.g.internet)
        - later, the mobile can be assigned to one or more additional P-GWs for connectivity to other PDNs (e.g. IMS, corporate network)
    - several P-GWs in a typical network
- S-GW – Serving GateWay
    - router forwarding data between enBs and P-GWs
    - a S-GW serves the mobiles in a given geographical area
    - a connected mobile is assigned to a single S-GW
        - the S-GW may change during the connection if the mobile moves to the coverage area of another S-GW (handover/cell reselection)
    - S-GW service area – geographical area covered by 1 or more S-GWs
        - mobiles moving within a S-GW service area don't need to change the S-GW
    - Several S-GWs in a typical network
- MME – Mobility Management Entity
    - controls high level operation of mobiles through signaling messages
        - security
        - management of data streams (not on the radio interface)

- a MME serves the mobiles in a given geographical area
- a connected mobile is assigned to a single MME (serving MME)
  - the MME may change during the connection if the mobile moves to the coverage area of another MME (handover/cell reselection)
- MME pool area – geographical area served by 1 or more MME
  - mobiles moving within an MME pool area don't need to change serving MME
- Several MMEs in a typical network

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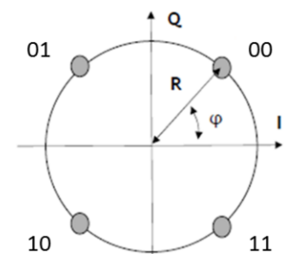
3. Digital modulation techniques used in LTE – list, characteristics and comparison.

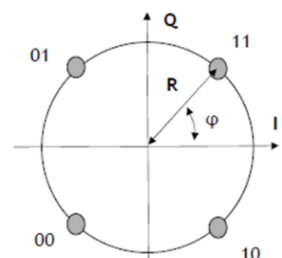
https://intranet.etc.upt.ro/~DIG_INT_NET/course/7_LTE_20.pdf, 22, 26

Digital modulations in LTE

- QPSK
  - Robust, less efficient
- QAM
  - High efficiency, less robust
- Gray encoding
  - neighboring symbols in constellation
  - only 1 bit different
  - limits the number of bit errors



Binary encoded QPSK



Gray encoded QPSK

LTE modulation summary

Modulation	**No. of symbols**	**Bits/ symbol**	**Bit rate/ Baud rate**	**Robustness**	**No. of amplitudes**	**No. of phases**
QPSK (4QAM)	4	2	2/1	+	1	4
16QAM	16	4	4/1	+/–	3	12
64QAM	64	6	6/1	–	9	52

4. OFDMA – principle of sub-carrier orthogonality, application in LTE.
https://intranet.etc.upt.ro/~DIG_INT_NET/course/7_LTE_20.pdf, 30, 35, 38

LTE multiple access

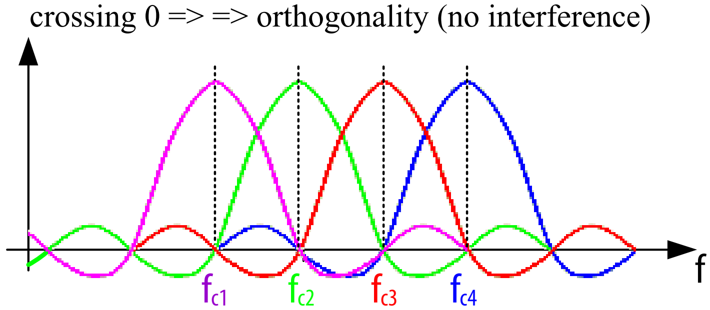
- OFDMA (Orthogonal Frequency Division Multiple Access)
  - Multiple equally spaced orthogonal subcarriers
  - Data stream is split in multiple sub-streams
    - Each sub-stream modulates a subcarrier using 64QAM, 16 QAM or QPSK
  - used on DL
- SC-FDMA (Single Carrier Frequency Division Multiple Access)
  - Uses only a reduced number of sub-carriers (contiguous group)
  - lower PAPR (Peak to Average Power Ratio) compared to OFDMA
  - used on UL
  - Unappropriate for DL
    - eNB uses all available sub-carriers
    - eNB transmits to multiple UEs at the same time

OFDMA

- Data stream is split into multiple sub-streams
- Frequency bandwidth divided into multiple sub-bands (sub-carriers)
- Each data sub-stream modulates (QPSK, 16QAM or 64QAM) a sub-carrier
- Sub-carrier orthogonality
  - the signal sent on a carrier does not interfere with signals sent on other carriers
  - achieved by proper choice of sub-carrier spacing
    - $\Delta f = 1/T$ (T – OFDMA symbol period)
    - in LTE, T = 66.7 µs => Δf = 15 kHz

Orthogonal carriers

- OFDM spectrum example:
  - 4 carriers spaced by $\Delta f = 1/T$ (= 15 kHz for LTE)
  - at each carrier frequency (e.g. f_{c2})
    - there is a maximum of the spectrum of the signal transmitted on that carrier (f_{c2})
    - all spectra of signals transmitted on other subcarriers (f_{c1}, f_{c3} and f_{c4}) are crossing 0 => => orthogonality (no interference)

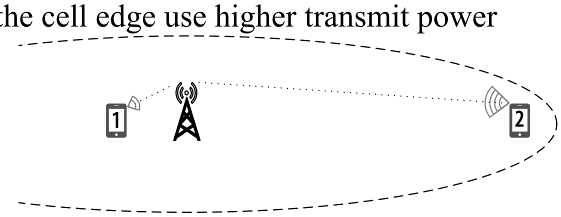


5. LTE uplink power control.

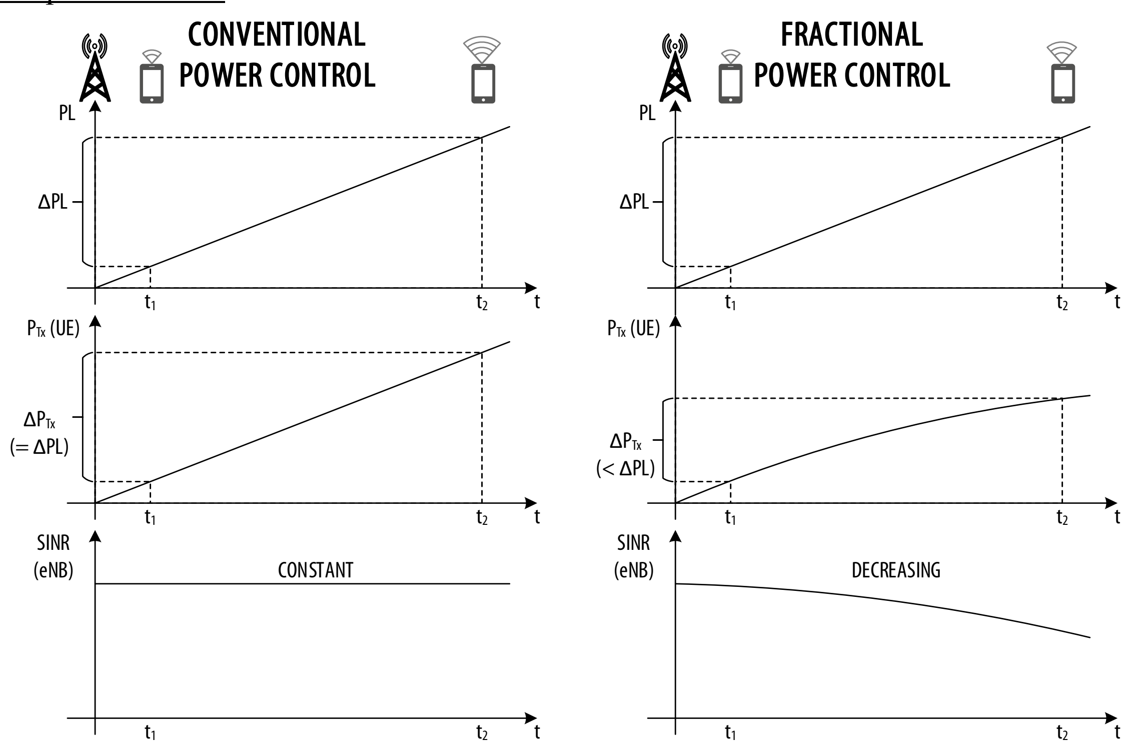
https://intranet.etc.upt.ro/~DIG_INT_NET/course/7_LTE_20.pdf, 105-110

Need for power control

- Wireless channel conditions vary
  - UE position in the cell
  - time
- The transmitted signal is adjusted to compensate for the varying conditions
  - Power control
  - Rate control – MCS (Modulation and Coding Scheme)
- Power control
  - Transmit power is varied → constant data rate
- Rate control
  - Data rate is varied → constant transmit power
- On DL eNB transmits with maximum power on all PRBs
- On UL UE follows a power control strategy to adjust transmit power
  - reduce power consumption
  - reduce inter-cell interference
- UEs situated near the center of the cell use lower transmit power
- UEs situated near the cell edge use higher transmit power



UL power control



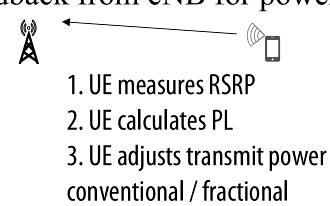
- Conventional power control
    - Target: fully compensate the PL (Path Loss)
    - Amount of increase in UE transmit power = amount of increase in path loss
    - Advantage: maintains constant SINR at eNB side
    - Disadvantage: increased inter-cell interference
- Fractional power control
    - Target: partially compensate the path loss
    - Amount of increase in UE transmit power < amount of increase in path loss
    - Advantages:
        - reduced intercell interference
        - increased average cell throughput
    - Disadvantage: worse SINR from UEs near cell edge => lower data rates
- Open loop power control
    - UE calculates the DL path loss

    PL = Reference eNB transmit power – measured RSRP

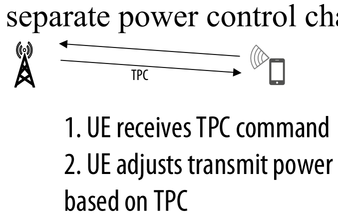
    - UE uses conventional or fractional power control attempting to compensate the PL

    $PTx = \min(\text{Desired eNB Power} + \alpha PL; P_{max})$

        - α – fractional power control factor; $0 < \alpha \leq 1$
        - Pmax – UE maximum transmit power (typically 23 dBm)
    - UE receives no feedback from eNB for power control



- Closed loop power control
    - Allows dynamic UE transmit power adjustment based on TPC commands issued by eNB
    - TPC (Transmit Power Control) commands have up to 2 bits (1 QPSK symbol)
        - Absolute values
        - Accumulated values
        - Transmitted
            - inside UL scheduling grant
            - on a separate power control channel



6. Calculate the frequency bandwidth required for a LTE-advanced cell to achieve a data rate of 450 Mb/s on DL with the spectral efficiency of 15 bits/s/Hz. Find a solution to obtain the necessary bandwidth using standard LTE frequency bands.

https://intranet.etc.upt.ro/~DIG_INT_NET/course/7_LTE_20.pdf, 5, 31, 32

Hints:

Use the rule of three to find the amount of necessary bandwidth

15 bits/s …………………………………………..1 Hz

450Mbits/s ………………………………………..B Hz

B=….

The standard LTE channel bandwidths are 1.4, 3, 5, 10 and 20 MHz.

If the value of B is lower or equal to 20 MHz, then it is possible to use 1 frequency band with the smaller standard bandwidth equal or higher than B.

If B exceeds 20MHz, then carrier aggregation must be used (obtain the desired bandwidth by combining up to 5 frequency bands having standard bandwidths). Examples of carrier aggregation to obtain 40 MHz:

2 bands of 20 MHz or

1 band of 20 MHz and 2 bands of 10 MHz.

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7. Calculate the maximum theoretical DL data rate for a LTE cell with a bandwidth of 10 MHz, using 2 antennas.

https://intranet.etc.upt.ro/~DIG_INT_NET/course/7_LTE_20.pdf, 60, 75

Hints:

- D = (no. of antennas) × (no. of symbols/s) × (no. of bits/symbol)
- Max. theoretical data rate
  - All REs are taken into account => **168 [RE/PRB]**
  - 10 MHz => 50 PRBs/ms => 50[PRB]×168[RE/PRB] = 8400 [RE/ms]
  - Each RE carries 1 symbol => **8.4×10^6 [symbols/s]**
  - The modulation is 64QAM (**6 bits/symbol**) for all symbols (in order to transmit as many bits/symbol as possible)
  - D_t = 2[antennas] × 8.4×10^6 [symbols/s] × 6[bits/symbol]= **100.8 Mb/s**