

Introduction to LTE (*Long Term Evolution*)

Dr. Małgorzata Langer

More than 30 years of the history - I

- **1G** — in eighties of XX century - “private” persons could communicate one with the other by voice during moving
- **2G** – early nineties - persons could communicate one with the other not only by voice but also text messages (CDMA, GSM)

More than 30 years of the history - II

- **3G** – late nineties – persons could (and can) communicate one with the other by services connected with data transfer and many new applications (WCDMA – UMTS)

3G is a wireless (radio) technology, that is characterised by fast transmission rate, developed access to multimedia and global roaming. It gives the possibility to connect the phone to internet or other networks based on IP. One may connect to the network using the voice, video, loading and/or sending data.

BUT:

There are problems relating to scaling and costs that stop the network development in many geographical areas.

4G

- **4G** networks support various personalised applications, mainly multimedia ones, as multimedia conferences, video-phones, video/movie-on-demand, education-on-demand, streams for various media, multimedia messages, etc.
- In December 2010 main „standardisation body” in telecommunications – ITU (International Telecommunications Union) stated, that **not only WiMAX-2 and LTE-Advanced (future technologies), but also WiMAX and LTE (implemented already) are network technologies that can be characterised as 4G**

LTE

- Nowadays 4G technologies allow (they offer more) for more than several hundred Mb/s in download and less upload. OFDMA and other processing systems in frequency domain, MIMO applications, dynamic allocations of channels and resource granting depending on the channel allow for more and more.
- **LTE-A has been planned for 1 Gb/s download and 500 Mb/s upload.**

TDMA - Time Division Multiple Access

- Time Division Multiple Access was historically the first in satellite networks, then in mobile
- The access to medium is divided in time into slots. Each user is granted with a number of slots for its transmission
- For example (2G) - 6 slots in a single frequency channel; each user gets 2 slots

FDMA - Frequency-Division Multiple Access

- **Frequency-Division Multiple Access**
- It is the system of sharing the transmission medium by granting suitable frequencies
- The oldest method – used in analogue telephony
- In GSM one may meet hybride systems - FDMA/TDMA, where as frequency as time access exist.

CDMA - Code Division Multiple Access

- The code is different
- It is one of code and access to radio medium methods
- Many users use the same channel at the same time, but each user has his own dissipating sequence – so the receiver recognizes the transmission sent to it.

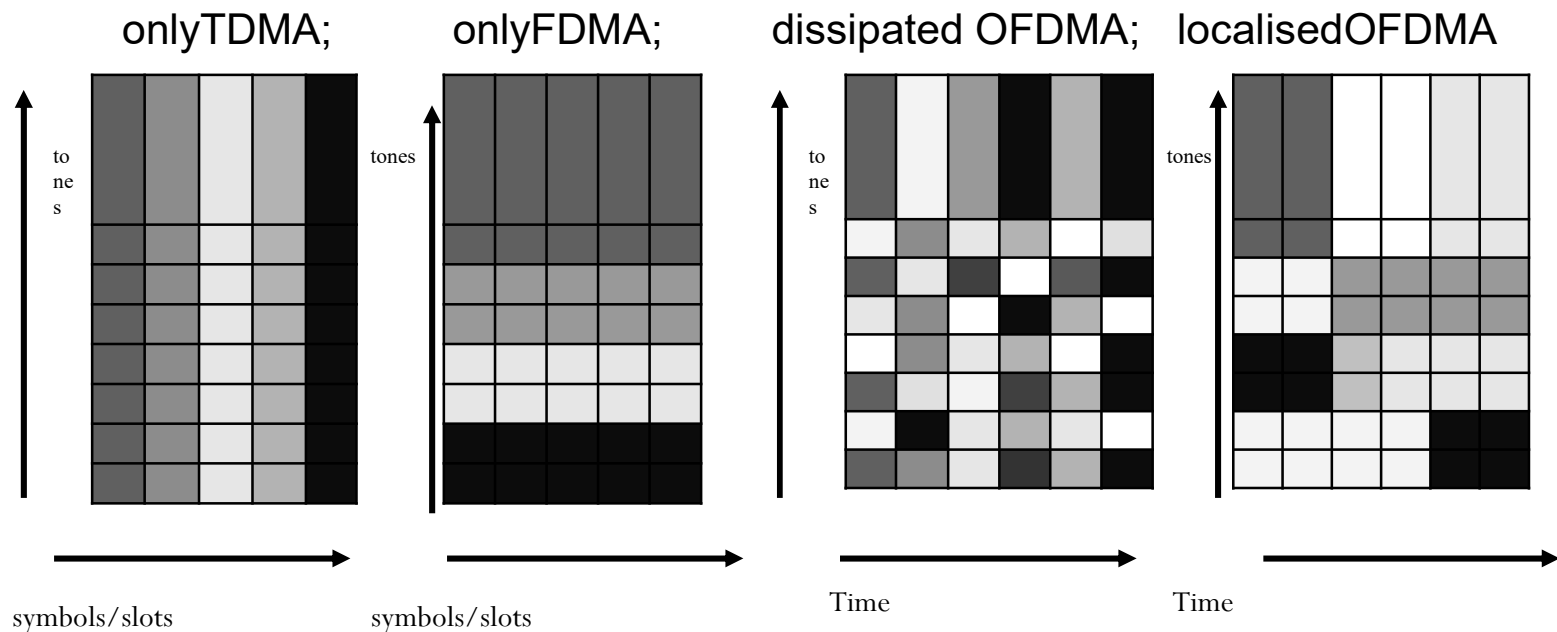
OFDMA - Orthogonal Frequency Division Multiple Access

- The modulation method that allows for transmitting many data streams at the same time on orthogonal carrier frequencies
- Instead of one fast transmission – we have many slow streams
- Orthogonality – carriers are so selected, that transmissions on them are fully independent and there is no inter-channel penetration

Differences between 3G and 4G

Up to UMTS (3G) the transmission was (and has been) realised in **time** domain.
The main difference for 4G is the realised transmission in **frequency** domain.

Multiple Access resource allocation



GSM - Global System for Mobile Communications

- *The acronym originates of „Groupe Spécial Mobile”*
- It was the European initiative to create one open standard of mobile cell telephony (the group was created in 1982)
- In 1987 The European Council gave the directive that resulted in reserving the bands with 890–915 and 935–960 MHz frequencies for a new, mobile telecommunication system needs - 2G, and in the same year 15 operators from 13 countries obliged to implement GSM technology.

UMTS - Universal Mobile Telecommunications System

- The next standard after GSM (developed by the same group **3GPP – 3rd Generation Partnership Project**) – the most popular standard for the third generation of the mobile technology
- There are standards of several technologies - HSPA (*High Speed Packet Access*) - (HSDPA i HSUPA), that originated basing on WCDMA
- Names „UMTS networks” and „WCDMA networks” are often used as the same

WCDMA - Wideband Code Division Multiple Access

- The specification, issued in 1999, assumed to reach 2 Mb/s bandwidth (and never was reached); the option of 384 Kb/s was implemented
- Only (at least theoretically) using HSPA technique allows for 21.6 Mb/s downlink and (HSDPA) and 5.6 Mb/s uplink (HSUPA)
- WCDMA - the dissipation of the transmission takes place in a wider band (about 5 MHz) than in CDMA

WiMAX - Worldwide Interoperability for Microwave Access

- Wireless, radio transmission of data, based on IEEE 802.16 standards; frequency band from 2 to 11 GHz (from IEEE 802.16a)
- WiMAX technology is applied for data transport mainly and used to pay services for wideband, wireless access to internet.
- IEEE 802.16m-2011 – Mobile WiMAX Release 2 makes possible to reach transfer even to 1 Gbit/s for stationary connections and up to 100 Mbit/s for mobile ones.

LTE - Long Term Evolution

- Downlink– OFDM
- Uplink– SC-FDMA (Single Carrier – Frequency Division Multiple Access)
- Frequencies in Europe: 800, 900, 1800, 2100, 2600, 3400, 3600 Mhz
- In Poland the beginning was 1800 MHz, now 800 and 2600, Play tests also 2100 MHz

Development of Technology– successive Releases

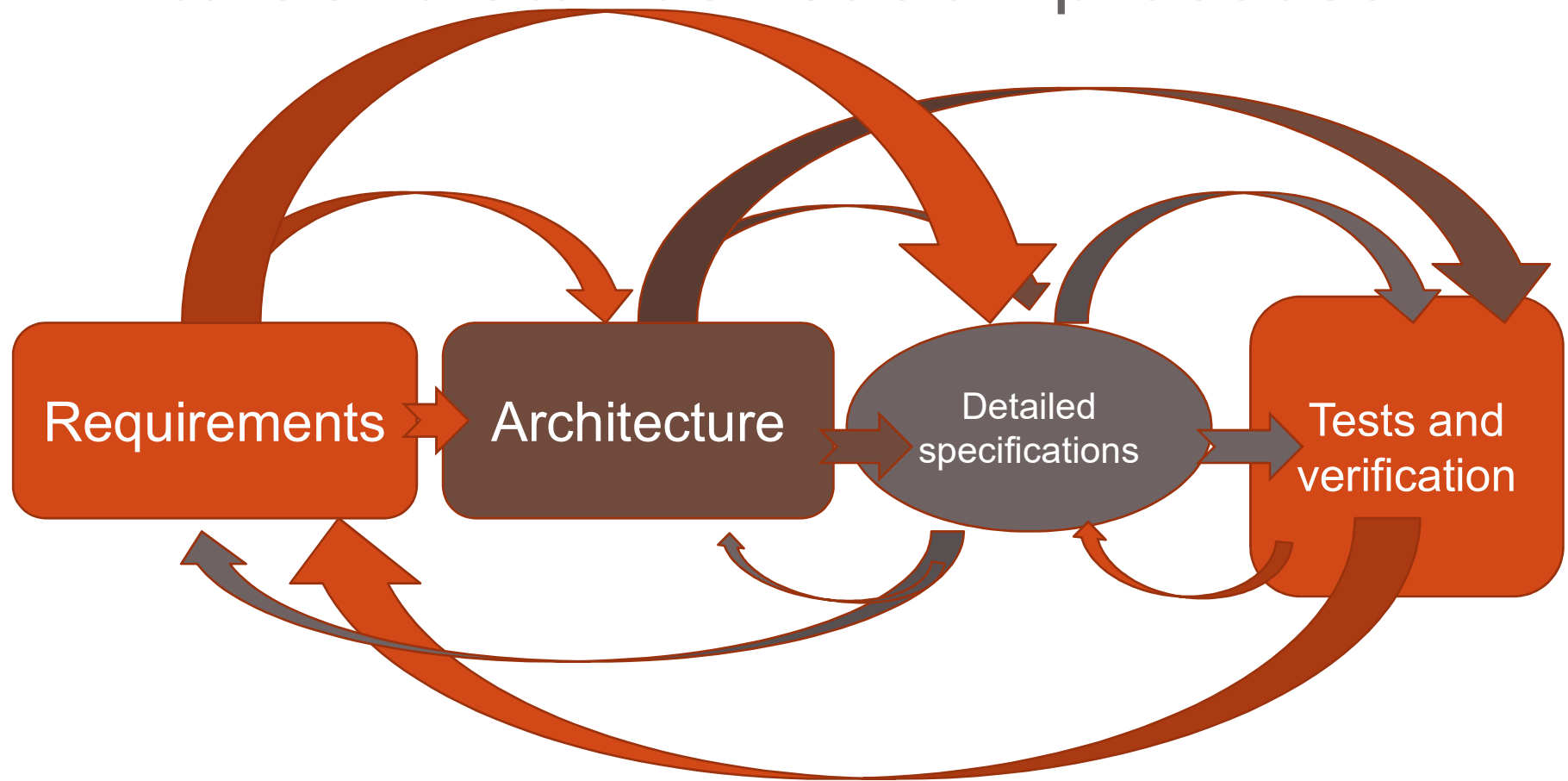
- **3GPP** (*3rd Generation Partnership Project*) – COOPERATION AGREEMENT among Standard Development Organisations – **SDOs**, as ETSI (Europe), ATIS (USA), TTA (Korea), TTC (Japan), CCSA (China) + some business; 1998;
in general with the task to develop global standards for 3G, *the history has run another way...*
- 3GPP develops and maintains technical specifications and reports for successive wireless technologies in form of successively numbered „Releases”

Let's look at the matrix...



<http://www.3gpp.org/specifications/67-releases>

Iterative standardisation process



Successive milestones in Releases

- 2000 – Release 99 (**3G UMTS**)
- 2001 – Release 4 (**UMTS Enhancements**)
- 2002 – Release 5 (**HSDPA**)
- 2004 – Release 6 (**HSUPA, MBMS**)
- 2007 – Release 7 (**HSPA, MIMO...**)
- 2008 – Release 8 (**UMTS – HSPA Dual Carrier**)
- 2009 – Release 9 (**LTE/SAE Long Term Evolution/ System Architecture Evolution**)

Continued: Release

- 2011 – Release 10 (June) - Introduction of LTE-Advanced
- 2013 – Release 11 (June) – Carrier Aggregation; IPv6 Migration; IMS based Peer-to-Peer Content Distribution Services
- 2014 – Release 12 (December) – Codec for Enhanced Voice Services; Service Continuity of IP Data Session...

Release 13

- In addition to enhancements to existing services and features, this release saw the completion of the first set of specifications covering mission-critical services, in particular mission-critical Push-To-Talk, the essential functionality for LTE to be used by 'blue light' services for private mobile radio voice communication.
- Work continued on security issues to ensure that new services are free from the threat of hacking, denial of service attacks etc. For the first time, serious investigations were conducted into network virtualisation and how this might be realised in the context of a 3GPP network

Release 14 (still open)

- *5G requirements (SMARTER, NexGen) Multimedia Broadcast Supplement for Public Warning System, User Control over spoofed calls, Location services, Mission Critical Video over LTE, MC DATA, LTE support for V2X services, Enhancement for TV Video service, eFMSS, S8 Home Routing Architecture, Ph2 Emergency services over WLAN, Control and User Plane Separation of EPC nodes, Overload Control for Diameter Charging Applications, Latency reduction techniques for LTE, High Power LTE UE for Band 41, Channel model above 6 GHz, SRVCC Enhancements, Service Domain Centralization, Robust Call Setup for VoLTE subscriber in LTE, OAM (energy efficiency and SON for AAS-based deployments), UICC power optimization for MTC, Requirements for Next Generation Access Technologies, Multi-Carrier Enhancements for UMTS...*

UMTS-UTRAN

- First standards in Release 99; **last (frozen) in R9 – December 2009**
- In R5 HSDPA (*High Speed Downlink Packet Access*) *was added*
- In R6 HSUPA (*High Speed Uplink Packet Access*)
- From R7 introduced modifications to HSPA are called **eHSPA** (*Evolved HSPA*), or **HSPA+**

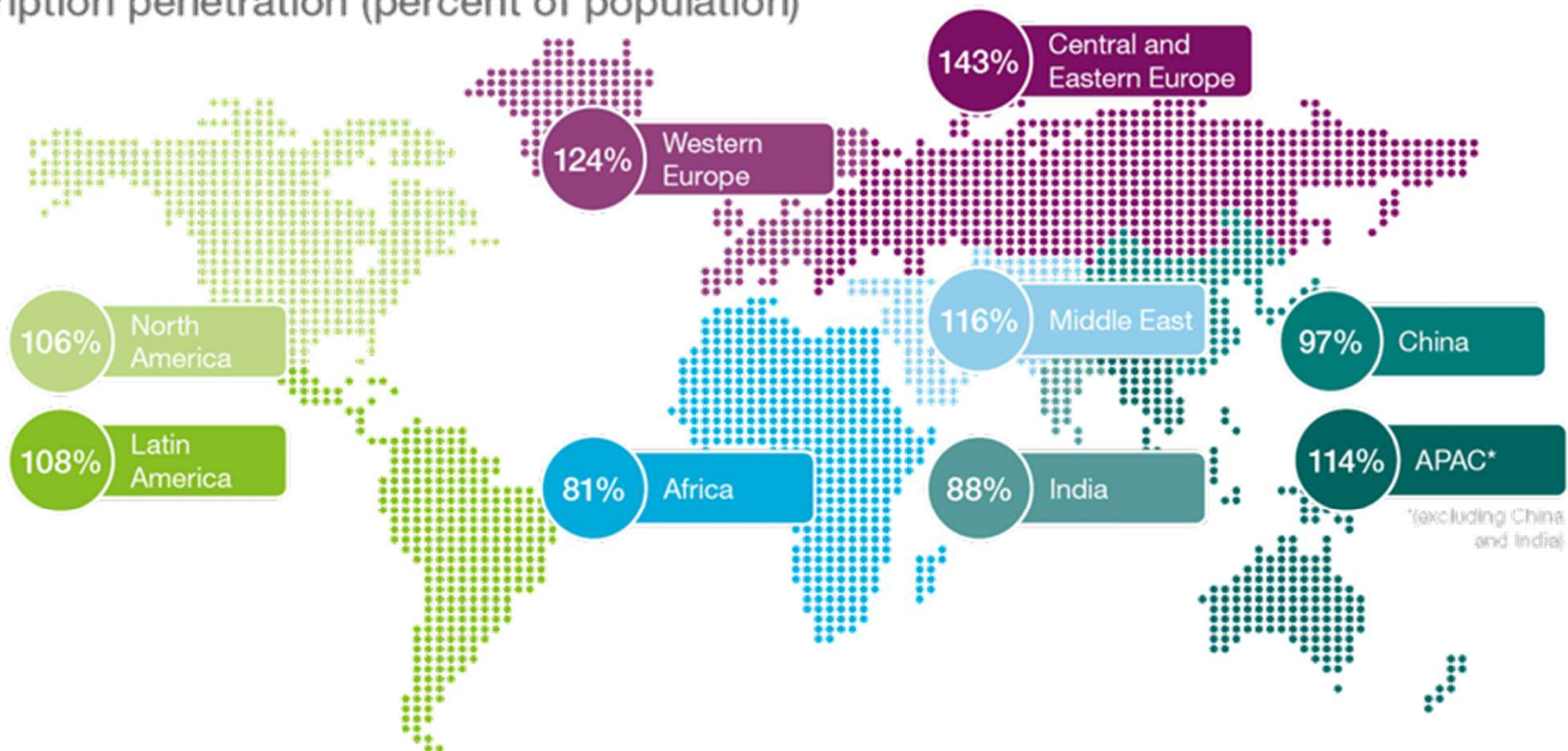
4G Systems today:

- At the end of 2013 - 6.7 billions of mobile users were registered (some of them have several devices). Within this number 109 millions of new subscribers were added in one quarter
- In 2017 - 1.9 B
- One forwards 5 B in 2022

5G Standards: 3GPP Release 15, 16, and beyond.

(Release 15 was issued on Dec 2018, though works
are going on, still)

Subscription penetration (percent of population)



[[Ericsson Mobility Report](#)]; June 2017

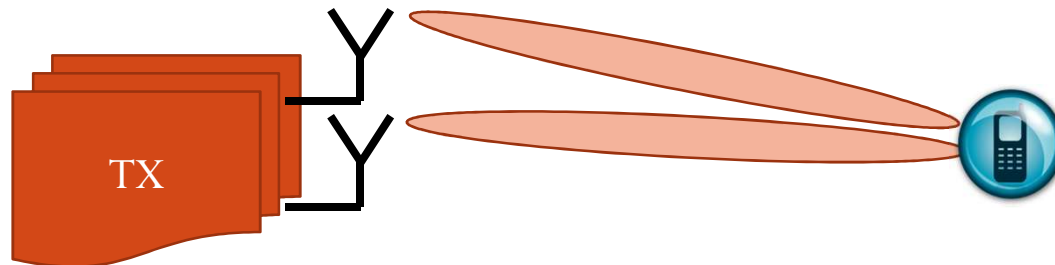
MBMS - Multimedia Broadcast Multicast Services (first in Rel.6)

- Interface of type „one point broadcasts – many points receive” (*point-to-multipoint*)
- Aim: for mobile IPTV and mobile radio, emergency messages (disasters, emergency...), special localisations
- Upgraded version of: Multimedia Broadcast/Multicast Service (MBMS); Protocols and codecs (3GPP TS 26.346 version 11.3.0 Release 11 and next)

MIMO - Multiple Input, Multiple Output

(first Rel 7)

- Multi-antenna transmission (as sender as receiver) *spatial multiplexing*
- Release 7 – 2 x 2 MIMO
- Release 8 – 2 x MIMO + 64 QAM



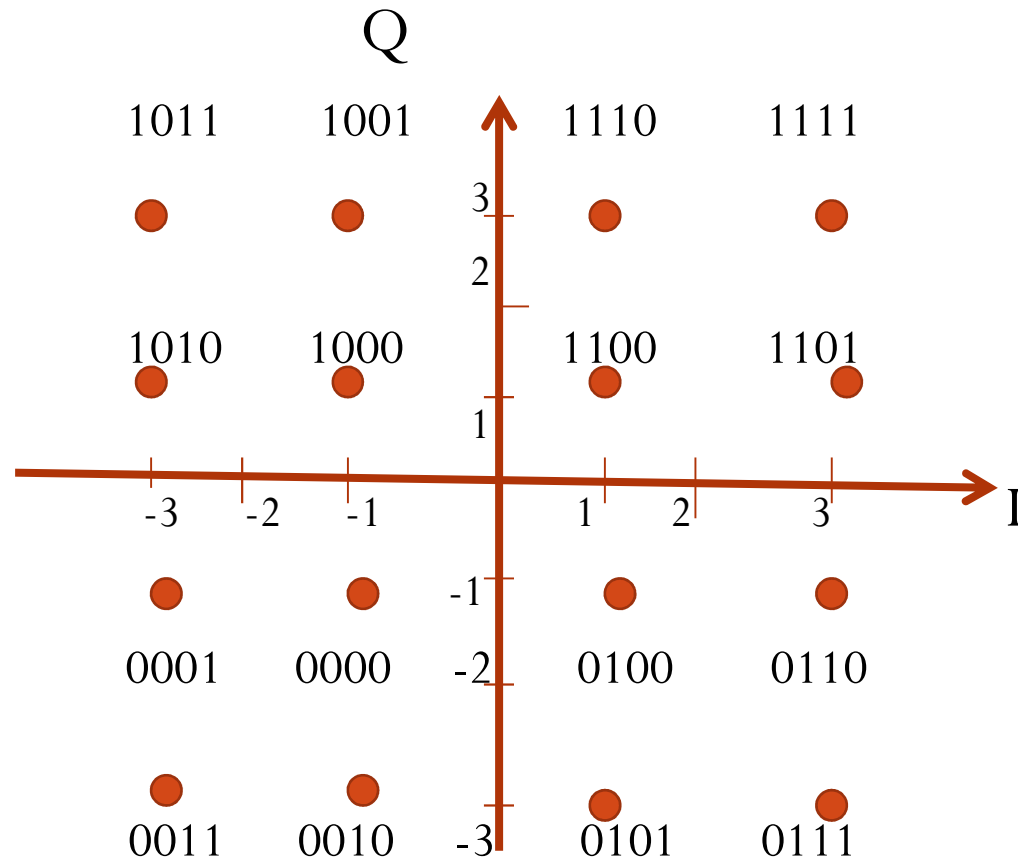
QAM (*Quadrature Amplitude Modulation*)

- **Phase and Amplitude Modulation (Quadrature)**
- Digital data is divided into 2 streams, each of them is shaped into analogue signal. One of these signals is multiplied by a carrier, the second one by the carrier, shifted in phase by $\pi/2$. Both signals are added and sent as the single QAM signal.
- In a receiver the signals are divided, data is extracted and linked together restoring the original information

Example: 16 QAM (in Rel. 5 – HSDPA)

- The input sequence is divided into groups of 2 bits and placed in two channels alternately.
- We have 4 possible levels (values) for each channel, which we place symmetrically:
 $00 \rightarrow 1$ $01 \rightarrow 3$ $10 \rightarrow -1$ $11 \rightarrow -3$
- Example: 4 bits „1011” is divided into „10” – to signal I (value: -1) and „11” – to Q (value: 3); so its representation in the constellation diagram will be the point (-1,3)

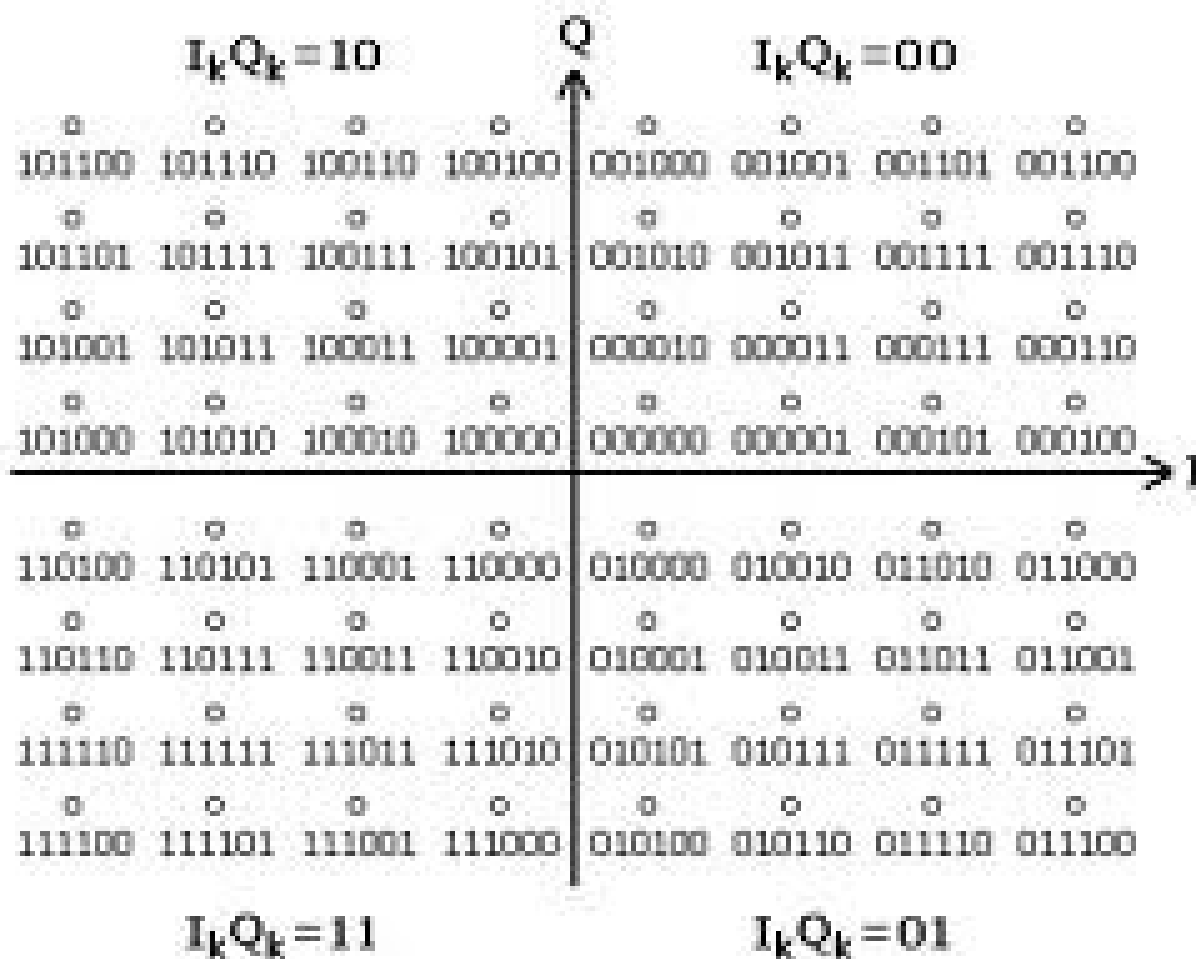
Constellation Diagram for 16 QAM



Comparison of QAM

- Amount of bits in one symbol:
4 bits for 16 QAM; 5 bits for 32 QAM; 6 bits for 64 QAM; 7 bits for 128 QAM; 8 for 256 QAM
- The higher amount of bits per symbol the higher amount of data is but the lower resistance against interferences

64 QAM



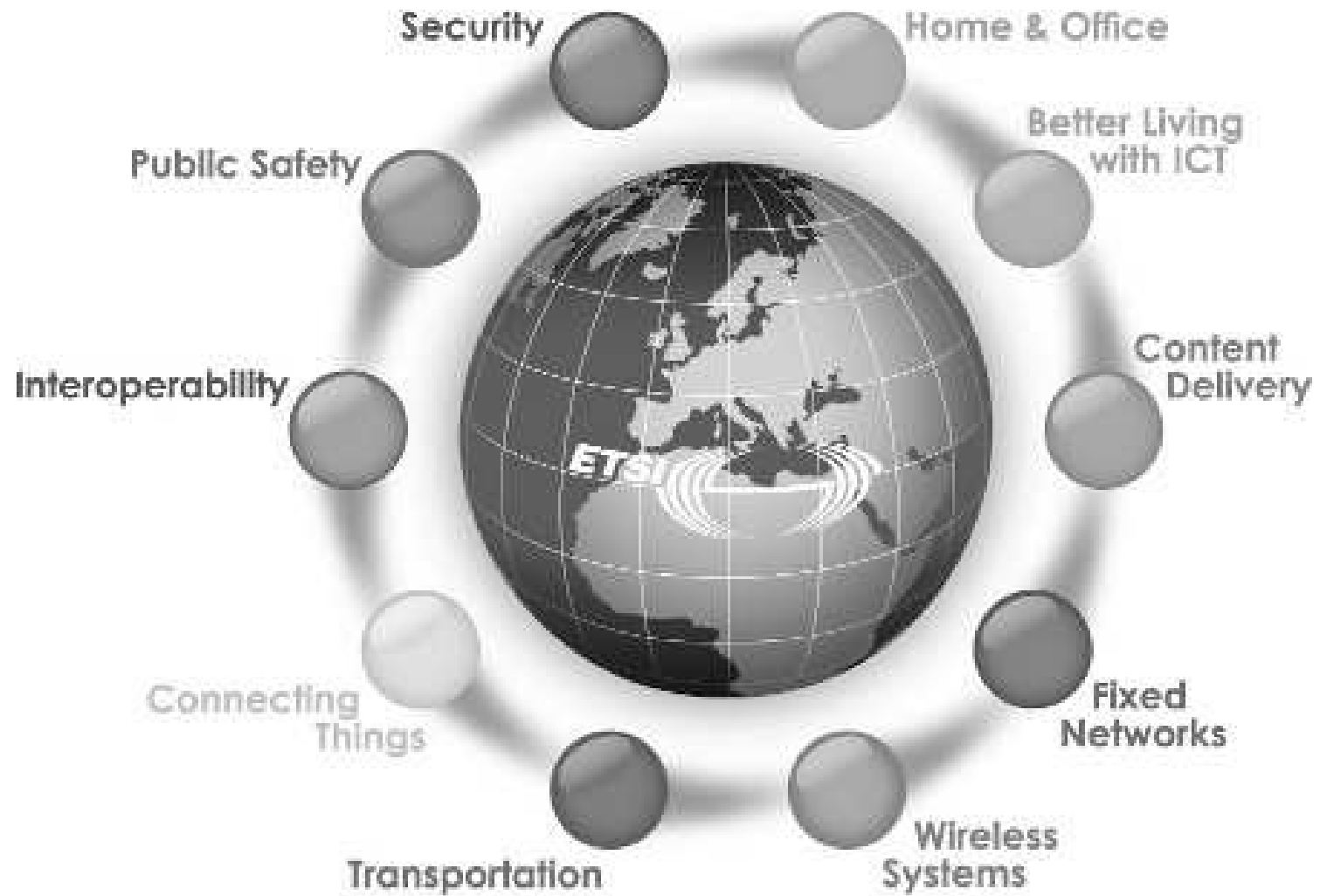
Specifications of LTE –36 series

Some of them:

- 36.100 radio
- 36.200 Physical layer (**layer 1**)
- 36.300 layer 2 and interface signals of layer 3
- 36.400 **network signalling**
- 36.500 tests of user equipment compatibility

A Connected World

[ETSI]



What does a user want?

Main mobile services

Voice

- Requirements relating to **delay** for a circuit switched service (CS) - is **about 400 ms**. Such a delay does not disturb any human to converse. **4G was not necessary for meeting „the delay” requirement.**
- Voice transmission in 4G requires frequent frames with a small data content, minimised jitter and a „not-disturbing” end-to-end delay.

Real time applications

- Games (the highest requirements)
- Servers should meet ping time even in several micro, but always less than 50 ms
- Small data amounts, low delays, very low jitter

Interactive applications based on files

- Introduce your examples 😊
- Requirements are different for uplink and downlink

Files in background

- One may send and receive great files as the background of other activities.
Example: email
- The service accepts lower speeds varying jitters
- But: The same IP address must be kept (the same session – (impossible before 4G))
- High requirements for errors checking
(it may be done in higher OSI layers)

Television

- It is a downlink to many users at the same time (if in HD – and for big screens – the required speeds are rising...).
- Streams must be synchronised, jitter must be reduced to minimum. End-to-end delays are tolerated

QoS and QoE

Quality of **Service** and Quality of **Experience**

- **Let's discuss**

Cost and Effectiveness – what an operator wants...

- The technology development allows to implement new services
- IP Technologies allow for a rapid rise of possibilities and new services, but also for cost reduction (a lot of problems may be solved in higher OSI levels, without additional system infrastructure)
- But it means that the market must be open for „new players” (new software and new UE)

Operator...

- Operator must deliver new services to any user. Nowadays not only „a few” users require low delays, high speeds, etc.
- The technology develops devices (smartphones, IPTV equipment) which require widebands...
- The smaller number of e-NBs = lower cost (at least some of them) = higher power, overloads ...

But...

- Meeting the highest requirements does not meet the economy thinking
- The market is open; any user can change an operator whenever he/she wants
- New players enter the market
- New technologies come...

3rd Generation Partnership Project (3GPP) members meet regularly to collaborate and create cellular communications standards. Currently, 3GPP is defining standards for 5G.

The International Telecommunication Union (ITU) has put forth some requirements for 5G that focus on fulfilling three key performance indicators (KPIs):

- >10 Gb/s peak data rates for the enhanced mobile broadband (eMBB)
- >1 M/km² connections for massive machine-type communications (MMTC)
- <1 ms latency for ultra-reliable low-latency communications (URLLC).

The table below provides an overview of specific technical requirements laid out as the 2020 minimum requirements. *[IEEE Spectrum]*

Metric	Requirement	Comments
Peak Data Rate	DL: 20 Gb/s UL: 10 Gb/s	Single eMBB mobile in ideal scenarios assuming all resources utilized
Peak Spectral Efficiency	DL: 30 b/s/Hz (assuming 8 streams) UL: 15 b/s/Hz (assuming 4 streams)	Single eMBB mobile in ideal scenarios assuming all resources utilized
User Experienced Data Rate	DL: 100 Mb/s UL: 50 Mb/s	5% CDF of the eMBB user throughput
Area Traffic Capacity	Indoor hotspot DL: 10 Mb/s/m ²	eMBB
User Plane Latency	eMBB: 4 ms URLLC: 1 ms	Single user for small IP packets, for both DL and UL (eMBB and URLLC)
Control Plane Latency	20 ms (encouraged to consider 10 ms)	Transition from Idle to Active (eMBB and URLLC)
Connection Density	1M devices per km ²	For mMTC
Reliability	99.9999% success prob.	32 L2 bytes within 1 ms at cell edge
Bandwidth	>100 MHz; up to 1 GHz in > 6 GHz	Carrier aggregation allowed

Differences between LTE and NR (New Radio)

	LTE	NR
Frequency of Operation	Up to 6 GHz	Up to 6 GHz, ~28 GHz, ~39 GHz, other mmWave bands (Upto 52 GHz)
Carrier Bandwidth	Max: 20 MHz	Max: 100 MHz (at <6 GHz) Max: 1 GHz (at >6 GHz)
Carrier Aggregation	Up to 32	Up to 16
Analog Beamforming (dynamic)	Not Supported	Supported
Digital Beamforming	Up to 8 Layers	Up to 12 Layers
Channel Coding	Data: Turbo Coding Control: Convolutional Coding	Data: LDPC Coding Control: Polar Coding
Subcarrier Spacing	15 kHz	15 kHz, 30 kHz, 60 kHz, 120 kHz, 240 kHz
Self-Contained Subframe	Not Supported	Can Be Implemented
Spectrum Occupancy	90% of Channel BW	Up to 98% of Channel BW

To keep straight which devices can communicate with each other, **new terminology has been introduced:**

- LTE eNB—Device that can connect to the EPC or the current LTE core network
- eLTE eNB—Evolution of the LTE eNB that can connect to the EPC and NextGen core
- gNB —5G NR equivalent of the LTE eNB
- NG—Interface between the NextGen core and the gNB
- NG2—Control plane interface between core network and RAN (S1-C in LTE)
- NG3—User plane interface between the core network and RAN (S1-U in LTE)

Various deployment scenarios for 5G NR *[IEEE Spectrum]*

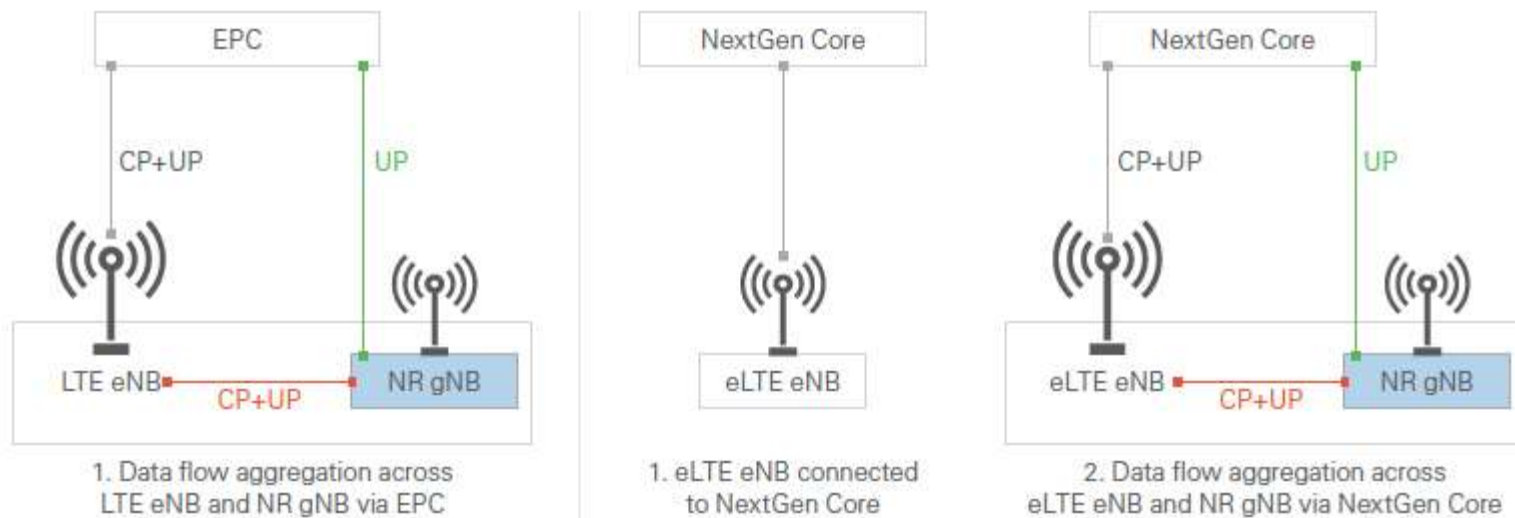


Figure 4. NSA Deployments With LTE eNB as Master (left) and Evolution to Add NextGen Core (right)

