4G to 5G networks and standard releases

ITU PITA Workshop on
Mobile network planning and security

Sami TABBANE
23-25 October 2019 – Nadi, Fiji Islands
Objectives

Provide an overview of various technologies and standards of 4G and future 5G
I. 4G and LTE networks

II. LTE Release 10 to 14

III. 5G
I. 4G and LTE networks
1. 4G motivations
Introduction


ITU determined that "LTE-Advanced" and "WirelessMAN-Advanced" should be accorded the official designation of IMT-Advanced:

- **3GPP LTE Advanced**: LTE Release 10, supporting both paired Frequency Division Duplex (FDD) and unpaired Time Division Duplex (TDD) spectrum;

- **Wireless MAN-Advanced**: Mobile WiMax 2, or IEEE 802.16m.
Needs for IMT-Advanced systems

- Need for **higher data rates** and greater spectral efficiency
- Need for a **Packet Switched only** optimized system
- Use of **licensed frequencies** to guarantee quality of services
- **Always-on experience** (reduce control plane latency significantly and reduce round trip delay)
- Need for **cheaper infrastructure**
- **Simplify architecture** of all network elements
Impact and requirements on LTE characteristics

- Architecture (flat)
- Frequencies (flexibility)
- Bitrates (higher)
- Latencies (lower)
- Cooperation with other technologies (all 3GPP and non-3GPP)
- Network sharing (part or full)
- Full-IP (QoS issues, protocols integration, lower costs)
- OFDMA
- Broadcast services
- Intelligent radio schemes
LTE Architecture

- LTE UE
- eNodeB
- MME
- HSS
- PCRF
- Serving Gateway (S-GW)
- PDN Gateway (P-GW)
- IP Networks
2. Evolution 3G-4G
Wireless technology evolution path

2005/2006

GSM/GPRS

EDGE, 200 kHz
DL: 473 kbps
UL: 473 kbps

UMTS
DL: 2.0 Mbps
UL: 2.0 Mbps

HSPA, 5 MHz
DL: 14.4 Mbps
UL: 2.0 Mbps

HSPA+, R7
DL: 28.0 Mbps
UL: 11.5 Mbps

HSPA+, R8
DL: 42.0 Mbps
UL: 11.5 Mbps

HSPA+ R9
DL: 84 Mbps
UL: 23 Mbps

HSPA+ R10
DL: 84 Mbps
UL: 23 Mbps

2007/2008

EDGEevo
DL: 1.9 Mbps
UL: 947 kbps

HSPA, 5 MHz
DL: 14.4 Mbps
UL: 5.76 Mbps

HSDPA, 5 MHz
DL: 14.4 Mbps
UL: 2.0 Mbps

HSPA+, R7
DL: 28.0 Mbps
UL: 11.5 Mbps

HSPA+ R8
DL: 42.0 Mbps
UL: 11.5 Mbps

HSPA+ R9
DL: 84 Mbps
UL: 23 Mbps

HSPA+ R10
DL: 84 Mbps
UL: 23 Mbps

2009/2010

LTE (4x4), R8+R9, 20MHZ
DL: 180 Mbps
UL: 75 Mbps

mobile WiMAX, 802.16e
Up to 20 MHz
DL: 70 Mbps (1x2)
UL: 28 Mbps (1x2)

2011/2012

VAMOS
Double Speech Capacity

DO-Advanced
DL: 32 Mbps and beyond
UL: 12.4 Mbps and beyond

DO-Advanced
DL: 1 Gbps (low mobility)
UL: 500 Mbps

LTE-Advanced R10
DL: 1 Gbps (low mobility)
UL: 500 Mbps

2013/2014

Advanced Mobile WiMAX, 802.16m
DL: 32 Mbps and beyond
UL: up to 100 Mbps

Mobile WiMAX, 802.16e
Up to 20 MHz
DL: 70 Mbps (1x2)
UL: 28 Mbps (1x2)

Advanced Mobile WiMAX, 802.16m
DL: 32 Mbps and beyond
UL: up to 100 Mbps

Fixed WiMAX scalable bandwidth
1.25 - 29 MHz
typical up to 15 Mbps

1xEV-DO, Rev. 0
1.25 MHz
DL: 2.4 Mbps
UL: 153 kbps

1xEV-DO, Rev. A
1.25 MHz
DL: 3.1 Mbps
UL: 1.8 Mbps

1xEV-DO, Rev. B
5.0 MHz
DL: 14.7 Mbps
UL: 4.9 Mbps

1xEV-DO, Rev. 0
1.25 MHz
DL: 2.4 Mbps
UL: 153 kbps

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1.25 - 29 MHz
typical up to 15 Mbps
3GPP Releases – main features from 3G to 4G

- **Release '99**
  - The basis for early 3G deployment

- **Release 4**
  - First steps towards IP-based operation
  - Also defines the low chip rate TDD mode (TD-SCDMA)

- **Release 5**
  - IMS - IP-based Multimedia Services
  - HSDPA - High Speed Downlink Packet Access

- **Release 6**
  - 2nd phase of IMS
  - High Speed Uplink

- **Release 7**
  - Enhanced uplink
  - Other spectrum
  - Multiple input multiple output antennas (MIMO)

- **Release 8**
  - Long Term Evolution (LTE) and System Architecture Evolution (SAE)

- **Release 9**
  - Enhancement of Release 8 features
  - Refinement of LTE
  - Preliminary studies into LTE Advanced

- **Release 10**
  - LTE Advanced
Main wireless broadband systems

<table>
<thead>
<tr>
<th></th>
<th>HSPA</th>
<th>3GPP LTE</th>
<th>IEEE 802.16e¹</th>
</tr>
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<tr>
<td>Standardization body</td>
<td>3GPP</td>
<td>3GPP</td>
<td>IEEE</td>
</tr>
<tr>
<td>Deployment frequencies (GHz)</td>
<td>All 3G bands</td>
<td>All 3G bands, 2.6GHz</td>
<td>2.5, 3.5, 5.8 GHz</td>
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<td>1.25, 2.5, 5, 10, 15, 20</td>
<td>5, 10, 20</td>
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<td>Uplink scheme</td>
<td>CDMA</td>
<td>SC-FDMA</td>
<td>OFDMA</td>
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<tr>
<td>Downlink scheme</td>
<td>CDMA</td>
<td>OFDMA</td>
<td>OFDMA</td>
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<tr>
<td>Preferred duplex scheme</td>
<td>FDD</td>
<td>FDD</td>
<td>TDD, FDD</td>
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</tbody>
</table>
3. Evolution R9 – R10
What is 3GPP?

3GPP history and members

Founded in December 1998

3GPP is a collaborative standardization activity between ETSI (Europe) and:

- ARIB (Japan-radio)
- TTC (Japan-network)
- TTA (Republic of Korea)
- CCSA (Peoples’ Republic of China)
- ATIS (North America)
3GPP family standards evolution

Standards availability

- **EDGE**: 384Kb/s
- **EDGE+**: 1Mb/s
- **W-CDMA**: 384Kb/s
- **HSPA**: 18Mb/s
- **HSPA+**: 42Mb/s
- **LTE**: 100Mb/s
- **LTE-Advanced**: 1000Mb/s

Timeline:
- 2000
- 2009
4. Performance Objectives
Introduction to LTE and SAE and performance objectives

Needs at the access level for LTE (Release 8)

- Radio interface bitrates: 100 Mbit/s DL and 50 Mbit/s UL.
- Data transmission delay: less than 5 ms between UE and the Access Gateway (AGW).
- Mobility: speeds between 120 and 350 km/h (or even up to 500 km/h depending on the frequency band).
- Co-existence and Interworking with 3G: HO between E-UTRAN and UTRAN should be achieved with less than 300 ms for real-time services and 500 ms for NRT services.
- Multicast support for multimedia applications.
Latency definitions

- **Latency** = time a message takes to traverse a system.

- In a computer network = time for a data packet data to get from one point to another.

- Depends on:
  - Speed of the transmission medium (e.g., copper wire, optical fiber or radio waves)
  - Delays in the transmission by devices (e.g., routers and modems).
  - Latency and bandwidth determine the network connection speed.

- A **low latency** = **high network efficiency**.

- Low enough latency ➔ no need for **local storage or computing** in a wireless device.

- **Latency increase = grow of local processing.**

<table>
<thead>
<tr>
<th>Context</th>
<th>Latency (ms)</th>
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<tbody>
<tr>
<td>Web</td>
<td>1 sec</td>
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<tr>
<td>Voice</td>
<td>150 ms</td>
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<tr>
<td>Traffic safety</td>
<td>100 ms</td>
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<td>Online gaming</td>
<td>50 ms</td>
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<tr>
<td>Cloud computing</td>
<td>5 ms</td>
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<td>Security (airplanes, ...)</td>
<td>&lt; 5 ms</td>
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<td>Health devices, safety or control mechanisms</td>
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</tr>
<tr>
<td>Electrical-distribution grid, financial trading</td>
<td>2-5 ms</td>
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<tr>
<td>Network protocols (e.g., CQI, ARQ), remote control of robots, tactile Internet applications</td>
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### Peak data rates DL and UL

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<thead>
<tr>
<th>Modulation coding</th>
<th>1.4 MHz</th>
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<th>15 MHz</th>
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<td>21.1</td>
<td>31.8</td>
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<td>171.1</td>
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</table>
5. Key features of LTE and LTE Advanced
Differences between HSPA and LTE

UMTS (HSDPA)

RNC
- Original IP packets
- HC
- Ciphering
- Outer ARQ
- HARQ

NodeB

LTE

eNodeB
- HC
- Ciphering
- Outer ARQ
- HARQ

HCed and ciphered IP packets
Key Features

Key Features of LTE (1)

- Multiple access scheme
  - Downlink: OFDMA
  - Uplink: Single Carrier FDMA (SC-FDMA)
- Adaptive modulation and coding
  - DL modulations: QPSK, 16QAM, and 64QAM
  - UL modulations: QPSK and 16QAM
  - Rel-6 Turbo code: Coding rate of 1/3, two 8-state constituent encoders, and a contention-free internal interleaver.
- Bandwidth scalability for efficient operation in differently sized allocated spectrum bands
- Single frequency network (SFN) operation to support MBMS
Key Features

Key Features of LTE (2)

- **MIMO** technology for enhanced data rate and performance.
- **ARQ** at the RLC sublayer and **Hybrid ARQ** at the MAC sublayer.
- **Power control** and **link adaptation**
- **Interference coordination** between eNBs
- Support for both FDD and TDD
- **Channel dependent scheduling**
- **Reduced radio-access-network nodes** to reduce cost, protocol-related processing time & call set-up time
Key Features

- **Always-on** connectivity to reduce sessions establishment and releases signaling overhead and connection setup time.

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<tr>
<td>07/04/14</td>
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</table>
Key techniques for enhancing network capacity

Growth dimensions for providing additional capacity

**Spectrum**
- 300 MHz
- 400 MHz
- 1500 MHz

**Technology**
- LTE
- HSPA
- MIMO
- AIR
- Adaptive antennas
- CA
- CoMP

**Densification**
- Macro, Micro, Pico, Wi-Fi
- Heterogenous networks
3GPP LTE objectives

- Scalable bandwidth: 1.25, 2.5, 5, 10, (15), 20MHz
- Peak data rate (scaling linearly with the spectrum allocation)
  - DL (2 Rx @ UE): 100Mb/s for 20MHz spectrum allocation
  - UL (1 Tx @ UE): 50Mb/s for 20MHz spectrum allocation
- Spectrum efficiency
  - DL: 3-4 times HSDPA for MIMO (2,2)
  - UL: 2-3 times HSUPA for MIMO(1,2)
- > Reference Antenna configurations (typical achievable targets)
  - DL: 2Tx and 2 Rx
  - UL: 1 Tx and 2 Rx
- Latency
  - C-plane: < 50-100ms to establish U-plane
  - U-plane: << 10ms from UE to AGW
- Capacity
  - 200 users for 5MHz, 400 users in larger spectrum allocations (active state)
- Mobility
  - LTE is optimized for speeds 0-15km/h up to 350km/h
Network and protocol architecture

Architecture
LTE architecture

System Architecture Evolution (SAE) goal: develop a framework for the evolution and migration of current systems to a system which supports the following:

- high data rates
- low latency
- packet-optimized (all IP network)
- provides service continuity across heterogeneous access networks

EPS = eUTRAN + ePC
Evolved UTRAN Architecture

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

• **E-UTRAN - Evolved UTRAN, known as LTE**
  • eNB - enhanced NodeB, base stations

• **Architecture simpler than UTRAN Release 6**
  • EPC/LTE – 2 user-plane nodes: eNB, S/P-GW
  • UTRAN R6 – 4 user-plane nodes: NodeB, RNC, SGSN, GGSN

➢ Consequences
  • **Ciphering** and **header compression** performed at eNBs
  • **Handovers between eNBs** handled through X2 interface rather than by the RNC
Evolved UTRAN Architecture

• **Flat architecture =**
  • Signaling messages reduction (up to 30% saving)
  • Network performance increase (up to 40%)
  • Integration of the features in a single equipment

→ OPEX and CAPEX reduction (up to 25% for the MME/SGSN and up to 35% for a SGW/PGW/GGSN)
  • Time and cost of maintenance reduced
User plane Overview

- User plane Traffic Architecture:
  - Cost efficient 2 types of nodes architecture
  - Fully meshed approach with tunneling mechanism over IP transport network
- Access Gateway (AGW)
- Enhanced Node B (ENB)
User plane Overview

S1-flex Mechanism

• Allows:
  • Network redundancy,
  • Load sharing of traffic across network elements in the CN, the MME and the SGW,

• Creates pools of MMEs and SGWs,

• Each eNB connected to multiple MMEs and SGWs in a pool.
Multiple Operator Core Network

- **MOCN** → service providers can have *separate core networks* (MME, SGW, PDN GW) and **E-UTRAN (eNBs) jointly shared**.
- Enabled by the S1-flex mechanism (each eNB can be connected to multiple core networks entities).
Introduction to ICIC

Motivations: Interference issues

ICIC

- Prevents from using the same PRB
- Or use the same PRB but with reduced interference
Introduction to ICIC
CoMP in Downlink

(a) Coordinated beamforming/Coordinated scheduling

Coordinated scheduling / beamforming: the UE receives the data from a unique eNB. Coding and scheduling coordinated between several eNB to minimize the interference and increase the throughput.

(b) Joint processing

Joint processing: coordination between several eNB transmitting or receiving simultaneously.
Downlink physical layer

1. Radio interface
Radio channel characteristics

$|H(f,t)| [\text{dB}]$

![Graph showing the magnitude of the frequency response $|H(f,t)|$ for different time values $t$ and frequencies $f$. The graph is a 3D representation with $t$ in milliseconds on the x-axis, $f$ in MHz on the y-axis, and $|H(f,t)|$ in dB on the z-axis. The data shows variations in the frequency response over time and frequency.](image-url)
Basics

• **Characteristics**
  
  • System based on FFT
  
  • Modulation and mapping
  
  • Orthogonality
  
  • Guard interval and cyclic extension
Basics

• **Principle**

  • *Multi-carrier modulation* = division of the binary stream into multiple streams and transmitted over different sub-carriers.

  • Bit rate on each of the N subcarriers ($R_N$) < total bitrate (R).
    - With $R_N \approx R/N$.

  • Number of subcarriers such that each subcarrier has a bandwidth (BN) less than its coherence bandwidth ($B_c = B/N$).

  • Elimination of the ISI by introducing a cyclic prefix.
Basics
OFDM Transmission – Robustness against fast fading

Radio channel effects
The IFFT converts input signals into parallel output sine wave modulated
OFDM operation

Input data flow: 1, 1, -1, -1, 1, 1, -1, -1, 1, 1, -1, -1, 1, ..., 1, 1, -1, -1, 1, 1, -1, -1, 1, 1, -1, -1, 1, ...

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<th>1</th>
<th>1</th>
<th>1</th>
<th>-1</th>
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<td>C4</td>
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</tbody>
</table>

Mapping

Serial to parallel

BPSK modulated signal for C1

BPSK modulated signal for C2

BPSK modulated signal for C3

BPSK modulated signal for C4

Final OFDM Signal = Sum of all signals

$$V(t) = \sum_{n=0}^{N-1} I_n(t) \sin(2\pi nt)$$
**LTE physical layer**

- **DL**: adaptive OFDM
  - Scheduling channel and link adaptation dependent in the time and frequency domain
- **UL**: SC-FDMA with a dynamic bandwidth (pre-coded OFDM)
  - PAPR ⇒ Better spectrum efficiency
  - Reduced UL interference (allows intra-cell orthogonality)
- Flexible bandwidth (with resolution of 180 kHz)
  - Possibility to deploy in bandwidth of <5 MHz to 20 MHz
- Multiple antennas, RBS and terminal
  - MIMO, antennas lobes, TX- and RX diversity, interference rejection
  - High bitrates and higher capacity
- Harmonised FDD and TDD concept
  - FDD and TDD maximum spectrum sharing
- Maximum UE capacity: BW = 20 MHz
Downlink physical resources

[Diagram showing downlink physical resources with frequency and time axes, and a note on one resource element and one OFDM symbol.]
DL physical resource

- Temporal structure:
  - 10 ms frame = 10 sub-frames of 1 ms
  - 1 sub-frame = 2 slots of 0.5 ms
  - 1 slot = 7 symbols OFDM (6 symbols if extended CP)

- Resource blocks:
  - 12 sub-carriers during 1 slot
  - Allocation by pair of 2 consecutive resource blocks

- DC carrier not used
Downlink physical resources

- Cyclic prefixes of different lengths can be used in different subframes
- Each Resource Block is composed of 12 subcarriers in a slot of 0.5 ms
  - Each Resource Block is composed of:
    - $12 \times 7 = 84$ Resource Elements for normal cyclic prefix
    - $12 \times 6 = 72$ Resource Elements for extended cyclic prefix

![Resource Block for a Normal Cyclic Prefix](image_url)
Signaling

• A DL resource contains signaling bits:
  • Specific reference signals (RS) of the Cell (channel estimation and CQI measurements)
  • L1/L2 signaling (for DL HARQ and scheduling info, UL scheduling, power commands)
  • Primary and secondary synchronization signals (Cell selection)
  • Broadcast and paging channel
LTE downlink frame
Example of resource block allocation in LTE-Advanced
Link adaptation

(a) FD modulation and FD coding

<table>
<thead>
<tr>
<th>COI index</th>
<th>modulation</th>
<th>code rate x 1024</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>out of</td>
<td>range</td>
</tr>
<tr>
<td>1</td>
<td>QPSK</td>
<td>78</td>
</tr>
<tr>
<td>2</td>
<td>QPSK</td>
<td>120</td>
</tr>
<tr>
<td>3</td>
<td>QPSK</td>
<td>193</td>
</tr>
<tr>
<td>4</td>
<td>QPSK</td>
<td>308</td>
</tr>
<tr>
<td>5</td>
<td>QPSK</td>
<td>449</td>
</tr>
<tr>
<td>6</td>
<td>QPSK</td>
<td>602</td>
</tr>
<tr>
<td>7</td>
<td>16QAM</td>
<td>378</td>
</tr>
<tr>
<td>8</td>
<td>16QAM</td>
<td>490</td>
</tr>
<tr>
<td>9</td>
<td>16QAM</td>
<td>616</td>
</tr>
<tr>
<td>10</td>
<td>64QAM</td>
<td>466</td>
</tr>
<tr>
<td>11</td>
<td>64QAM</td>
<td>567</td>
</tr>
<tr>
<td>12</td>
<td>64QAM</td>
<td>666</td>
</tr>
<tr>
<td>13</td>
<td>64QAM</td>
<td>772</td>
</tr>
<tr>
<td>14</td>
<td>64QAM</td>
<td>873</td>
</tr>
<tr>
<td>15</td>
<td>64QAM</td>
<td>948</td>
</tr>
</tbody>
</table>
Multiple Antennas in Reception

- Removing intra-cell interference (SDMA: Space Division Multiple Access) ⇒ Multiple terminals transmit simultaneously using the same frequency resource
MIMO and Beamforming

Tx Diversity extends coverage

Beamforming extends coverage

Spatial Multiplexing boosts capacity

Virtual-MIMO in UL

DL SU-MIMO

DL MU-MIMO
MIMO and Beamforming in Rel-10-11

Up to 8-layer MIMO/Beamforming in DL with Rel-10/11

1 layer BF in Rel-8 with 4 antennas

2 layer BF in Rel-9 with 8 antennas

8 layer BF in Rel-10 with 8 antennas

Up to 4-layer MIMO/Beamforming in UL with Rel-10/11

4 layer MIMO/BF in Rel-10 with 4 antennas
Uplink physical layer

Uplink physical resources
Uplink physical resources

- Unlike the uplink, the resource blocks assigned to the terminal in the uplink must be consecutive in the frequency domain.
- Same as in the downlink, a resource block in the uplink is composed of 12 DFTS-OFDM subcarriers in a slot of 0.5 ms.

Resource allocation in the uplink
Uplink physical resources

- Inter-slot frequency hopping can be used in the uplink. Physical resources used on the 2 slots do not occupy the same subcarriers.
- RF transmission band completely covers the spectrum in the uplink. The frequency hopping changes the DFT-IFFT mapping.
- Frequency hopping two benefits: Diversity and frequency diversity interference.
Uplink reference signal

Uplink reference signal Inserted in the 4th block of each slot (NormaCyclic Prefix I)

• Frequency hopping can be applied ⇒ Transmission of two slots on frequencies remote ⇒ interpolation between two reference symbols blocks.
II. Releases 10 to 13 main features
LTE Evolutions

**LTE** Rel-8 & Rel-9
- Scalable BW~20MHz
- Flat Architecture
- OFDMA@DL, SC-FDMA@UL
- MIMO

**LTE-A** Rel-10 & Rel-11
- 20 MHz Bandwidth, OFDMA
- Scalable BW~20MHz
- Flat Architecture
- OFDMA@DL, SC-FDMA@UL
- MIMO

**LTE-B** Rel-12 & Rel-13
- 4G Certification, Coverage Enh.
- Carrier Aggregation
- High-order MIMO
- Co-channel CoMP&eICIC

**LTE-C** Rel-14 & Rel-15
- Optimized diverse service support
- Capacity boosting
- LTE Hotspot Improvement and small cells
- Multi-stream aggregation
- 3D Beamforming
- Multi-RAT Operation Enhancement

**LTE-Advanced**
- 10x Connection; Diverse Services
- 800x Energy efficiency & 1000x Capacity
- 30x Capacity@LTE; 10x Cell-edge TP@LTE
- 10x Peak rate@LTE, 1.3x Cell-edge TP@LTE
LTE releases evolutions

- RAN enh. for Diverse Data Application
- RAN overload control for MTC
- Network Energy Saving
- NW-based positioning (UTDOA)
- In-device co-existence
- Enh. DL Control CH
- CoMP UL / DL
- MDT
- CA enhancements
- DL MIMO 8x8
- Relaying
- eICIC
- UL MIMO 4x4
- SON enhancements
- Carrier Aggregation
- Positioning
- Home eNodeB
- Enhanced SC-FDMA
- Public Warning System (PWS)
- Self Organizing Networks
- Service Continuity for eMBMS
- Dual Layer Beamforming
- eMBMS enhancements
- Multi carrier / Multi-RAT Base Stations

LTE Release 8 FDD / TDD
## LTE to LTE-M

<table>
<thead>
<tr>
<th>3GPP Releases</th>
<th>8 (Cat.4)</th>
<th>8 (Cat. 1)</th>
<th>12 (Cat.0) LTE-M</th>
<th>13 (Cat. 1,4 MHz) LTE-M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downlink peak rate (Mbps)</td>
<td>150</td>
<td>10</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Uplink peak rate (Mbps)</td>
<td>50</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of antennas (MIMO)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Duplex Mode</td>
<td>Full</td>
<td>Full</td>
<td>Half</td>
<td>Half</td>
</tr>
<tr>
<td>UE receive bandwidth (MHz)</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>1.4</td>
</tr>
<tr>
<td>UE Transmit power (dBm)</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>20</td>
</tr>
</tbody>
</table>

### Release 12
- New category of UE (“Cat-0”): **lower complexity** and low cost devices
- **Half duplex FDD** operation allowed
- **Single receiver**
- Lower data rate requirement (Max: 1 Mbps)

### Release 13
- Reduced receive bandwidth to 1.4 MHz
- **Lower device power** class of 20 dBm
- 15dB additional link budget: **better coverage**
- More **energy efficient** because of its extended discontinuous repetition cycle (eDRX)
Release 12 new network features
eMTC

Objectives

- Long battery life: \( \sim 10 \text{ years} \) of operation with 5 Watt Hour battery
- Low device cost: comparable to that of GPRS/GSM devices
- Extended coverage: \( >155.7 \text{ dB} \) maximum coupling loss (MCL)
- Variable rates: \( \sim 10 \text{ kbps to 1 Mbps} \) depending on coverage needs

Deployment

- Can be deployed in any LTE spectrum
- Coexist with other LTE services within the same bandwidth
- Support FDD, TDD and half duplex (HD) modes
- Reuse existing LTE base stations with software update

Main PHY/RF features

- Narrowband operation with 1.08 MHz bandwidth
- Frequency hopping
- TTI bundling/repetition to achieve large coverage enhancements
- New UE power class of 20 dBm.
Release 13 new radio features
NB-IoT Architecture

<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>Ultra Narrow Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>~ 11 Km</td>
</tr>
<tr>
<td>Throughput</td>
<td>~ 150 Kbps</td>
</tr>
</tbody>
</table>

HD-FDD
p/2 BPSK, p/4 QPSK
Class 3 (23 dBm)
Class 5 (20 dBm)
Full coverage for IoT

- In LTE-M 1.4 MHz and NB LTE-M 200 kHz: basic LTE design is used with modifications for support of coverage enhancements: Elimination of LTE DL control channels including PDCCH, PCFICH and PHICH. Only the EPDCCH is supported.
- In enhanced coverage mode, PSD (Power Spectral Density) boosting and repetition are used to reach devices in poor coverage.
- Coverage increased by operating in 200 kHz or 1.4 MHz (/20 MHz): 20 dB and 11.5 dB improvement.
- LTE-M allows output power reduction by 3 dB for lower implementation cost.
- Control and data signals can be repeated to reach the required coverage enhancements.

![Diagram showing PSD boosting and repetition in different coverage modes.](image-url)
III. 5G
5G Objectives
“Maybe along with the three legs that 5G stands on (massive Machine Type Communication (MTC), enhanced Mobile Broadband (eMBB), and Ultra Reliable Communication (URC)) we need to add a fourth leg of ultra low cost broadband (ULCBB).”

Alan Gatherer, Editor in Chief, ComSoc Technology News
IEEE defines the tactile internet as dealing with processes or objects in perceived real time.

Allows catch a falling object remotely, control a connected car at an intersection.

Automation, education, entertainment, gaming, farming, health care, industrial transportation, ...

Enables humans to control robots remotely in real time.
5G Main Objectives

- App coverage with data rates exceeding 10 Gbps
- Network latency under 1 millisecond
- Capacity expansion by a factor of 1,000
- Energy efficiency gains by a factor of 1,000 per transported bit

Optimize the bit/s/Hz/m²/Joule/$
5G three pillars

- **eMBB** (enhanced Mobile BroadBand)
- **mMTC** (massive Machine Type Communications)
- **URLLC** (Ultra-Reliable and Low Latency Communications)
5G Roadmap

5G Research, Prototype, Trial
- Rel 10
- Rel 11
- Rel 12
- Rel 13
- Rel 14
- Rel 15
- Rel 16

5G Standard

Product

Deployment

3GPP

ITU

Time


LTE-Advanced → LTE-B → LTE-C

IMT New Spectrum, Vision

Requirement

Technology Eval

WRC-12

WRC-15

WRC 2019

5G
• Initial technology submission: Meeting 32 (June 2019)
• Detailed specification submission: Meeting 36 (October 2020)
Challenges in ICT systems and new techniques introduced in 5G

Operators’ challenges:
• Reduce CAPEX and OPEX,
• Quickly introduce new standards in the networks,
• Allow flexible operation to cope with users’ needs and handsets constraints,

ยะ Require flexible/scalable/dynamic/… systems and networks
Last decade main evolutions in ICT and Radio technologies

• Virtualization,
• Clouding,
• Software radios,
• Big data,
• …
**SDN and NFV**

SDN and NFV will enable mobile operators to dynamically and automatically adapt capacity and signaling in lock-step with the rise and fall of customer demands on the network.
Slicing in 5G

Communication Services

Service 1

NSI A

NSSI - Best Effort

NSSI - Normal

NSSI - Premium

NSSI - HB

NSSI - Normal

Access Network

NSSI - Normal

Core Network

Service 2

NSI B

Service 3

NSI C

Slicing architecture
5G Network Slicing example

5G slice 1 (smartphones) - RAT1, RAT2
5G slice 2 (autonomous driving) - RAT1, RAT2, D2D
5G slice 3 (massive IoT) - RAT3, HAT1

Access node, Cloud node (edge & central), Networking node, Part of slice
Thank You