Οικονομικό Πανεπιστήμιο Αθηνών
Τμήμα Πληροφορικής

# Ευφυή Κινητά Δίκτυα: 3G UMTS, HSPA, LTE/4G, 5G

Χειμερινό Εξάμηνο 2022-23

Βασίλειος Σύρης

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# 1G to 5G

| Generation | Requirements | Comments |
|---|---|---|
| **1G** | No official requirements.<br>Analog technology. | Deployed in the 1980s. |
| **2G** | No official requirements.<br>Digital technology. | First digital systems.<br>Deployed in the 1990s.<br>New services such as SMS and low-rate data.<br>Primary technologies include IS-95 CDMA (cdmaOne) and GSM. |
| **3G** | ITU's IMT-2000 required 144 Kbps mobile, 384 Kbps pedestrian, 2 Mbps indoors | First deployment in 2000.<br>Primary technologies include CDMA2000 1X/EV-DO and UMTS-HSPA.<br>WiMAX. |
| **4G (Initial Technical Designation)** | ITU's IMT-Advanced requirements include ability to operate in up to 40 MHz radio channels and with very high spectral efficiency. | First deployment in 2010.<br>IEEE 802.16m and LTE-Advanced meet the requirements. |
| **4G (Current Marketing Designation)** | Systems that significantly exceed the performance of initial 3G networks. No quantitative requirements. | Today's HSPA+, LTE, and WiMAX networks meet this requirement. |
| **5G** | ITU IMT-2020 requirements are in progress and may represent initial technical requirements for 5G. | Expected in 2020 timeframe.<br>Term applied to generation of technology that follows LTE-Advanced. |

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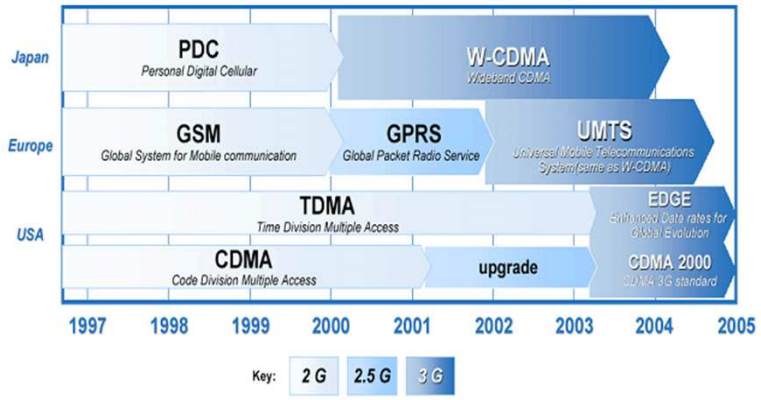
# From 2G to 3G

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# Standardization

- 3rd Generation Partnership Project (3GPP)
  - collaboration between telecommunication associations: ETSI, ARIB/TTC (Japan), CCSA (China), ATIS (North America), TTA (South Korea)
  - develop 3G mobile system specification within scope of IMT-2000 (ITU)
  - focus on radio, core network, service architecture
    - GSM, UMTS 3G, HSDPA/HSUPA/HSPA,3G LTE
- Different from 3GPP2
  - focus on IS-95 (CDMA2000)

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# UMTS bands

| | Up to | |
|---|---|---|
| 2600 | 190 MHz | New 3G Band |
| 2100 | 2x60 MHz | Mainstream WCDMA band |
| 1900 | 2x60 MHz | U.S. and Americas |
| 1700/ 2100 | 2x45 MHz | New 3G band in U.S. |
| 1800 | 2x75 MHz | Europe, Asia, Brazil |
| 1700 | 2x30 MHz | Japan, China |
| 900 | 2x35 MHz | Europe, Asia, Brazil |
| 800, 850 | 2x25 MHz | Americas, Japan, Asia |
| 700 | TBD | New band in the U.S. |

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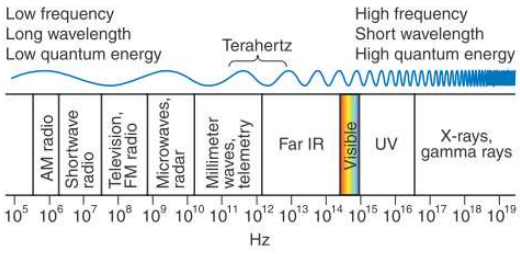
# 5G: Moving to higher frequencies ...




- Ongoing 5G auction in Greece: 700 MHz, 2 GHz, 3.4-3.8 GHz, 26 GHz
  - 3G/4G bands: 800 MHz, 1.8 GHz, 2.1 GHz, 2.6 GHz
- mm-wave: 26-300 GHz (802.11ad/ay,WiGig: 60 GHz)

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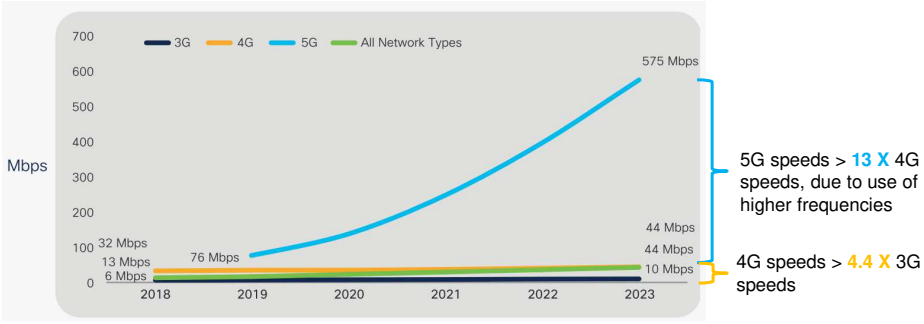
# Higher frequency benefits




Source: Cisco Annual Internet Report, 2018–2023

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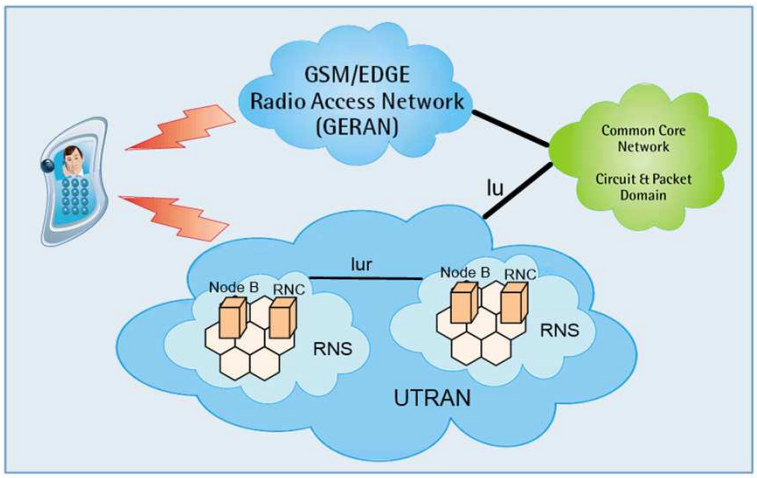
# UMTS architecture

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# UMTS architecture

- UTRAN is composed of several Radio Network Subsystems (RNSs) connected to the Core Network through the Iu interface.
- Every Radio Network Subsystem is composed of a
  - Radio Network Controller (RNC).
    - RNSs can be directly interconnected through the Iur interface (interconnection of the RNCs).
    - RNC is responsible for the local handover process and the combining/multicasting functions related to macro-diversity between different Node-Bs.
    - RNC also handles radio resource management (RRM) operations.
  - one or more "Node Bs".
    - A Node-B may contain a single BTS or more than one (typically 3) controlled by a site controller.
- Above entities are responsible for the radio resource control of the assigned cells

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# UTRAN: Node B

- Node B (commonly called Base Station)
  - comparable to Base Transceiver Station in GSM
  - responsible for air interface layer
- Key Node B functions
  - modulation and spreading
  - RF processing
  - inner loop power control
  - macro diversity

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# UTRAN: RNC

- RNC (Radio Network Controller) controls multiple base stations
  - comparable to Base Station Controller in GSM
  - layer 2 processing
  - Radio Resource Management
- Key functions
  - outer-loop power control
  - handover
  - admission control
  - code allocation
  - packet scheduling
  - macro diversity across base stations

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# Core network

- SGSN (Serving GPRS Support Node)
  - The SGSN is mainly responsible for Mobility Management related issues like Routing Area update, location registration, packet paging and controlling and security mechanisms related to the packet communication
- GGSN
  - The GGSN node maintains the connections towards other packet switch networks such as the internet. The Session Management responsibility is also located on the GGSN.

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## Radio Resource Management (RRM)

- Handles **QoS provisioning** over the wireless interface
- **Controls cell capacity and interference** in order to provide an optimal utilization of the wireless interface resources.
- Includes Algorithms for **Power Control, Handover, Packet Scheduling, Call Admission Control** and **Load Control**

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## RRM (cont)

- **Power Control**
  - Ensures that transmission powers are kept at a minimum level and that there is adequate signal quality and level at the receiving end
- **Packet Scheduling**
  - Controls the UMTS packet access
- **Call Admission Control**
  - Decides whether or not a call is allowed to generate traffic in the network
- **Load Control**
  - Ensures system stability and that the network does not enter an overload state
- **Handover**
  - guarantees user mobility in a mobile communications network

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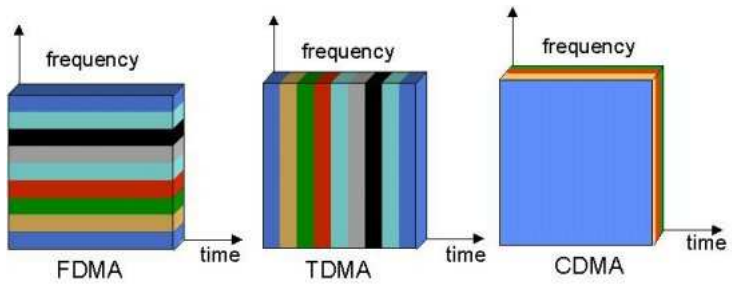
# Multi-Access Radio Techniques




Courtesy of Petri Possi, UMTS World

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# Wideband CDMA

- Bandwidth >= 5MHz
- Multirate: variable spreading and multicode
- Power control:
  - open power control
  - fast closed-loop power control
- Frame length: 10ms/20ms (optional)

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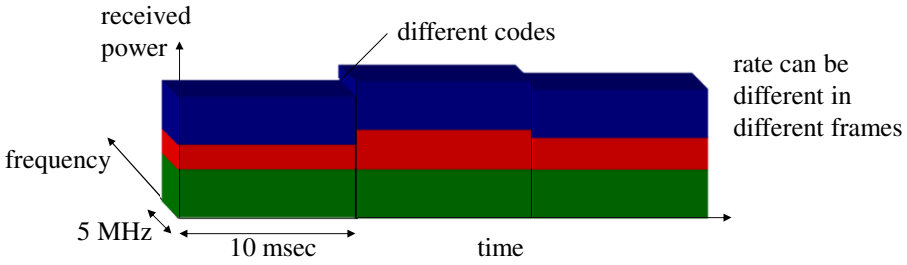
# WCDMA and rate

- Signals from different mobiles separated based on unique codes
- Transmission rate can change between frames

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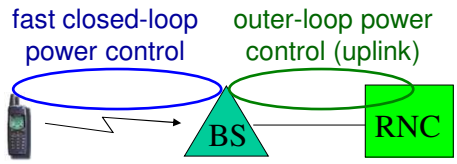
# Power control in WCDMA




- Fast closed-loop power control: between MS and BS
  - Adjusts transmission power to achieve target signal quality (Signal-to-Interference Ratio, SIR)
  - Both uplink & downlink, frequency: 1500 Hz
- Uplink outer-loop power control: between BS and RNC
  - Adjusts target SIR to achieve given frame error rate (data: 10-20%, voice: 1%), frequency < 100 Hz
- Increase power when interference increases
- Diverge when signal qualities are infeasible

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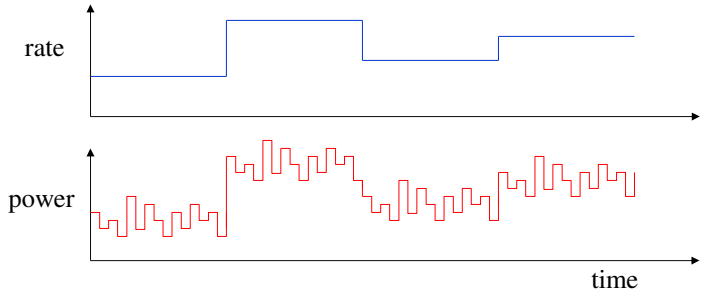
# Power and rate control

- WCDMA: rates fixed within single frame (10ms)
- Fast closed-loop power control (Mobile-BS) operates at 1500 Hz (0.67ms)




- Outer loop power control (BS-RNC) adjusts target $E_b/N_0$ to achieve specific frame or block error rate

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# Quality of Service

| Traffic Class | Conversational Class | Streaming Class | Interactive Class | Background Class |
|---|---|---|---|---|
| Fundamental Characteristics | • Preserve time relation of (variation) between information entities of the stream<br>• Conversational pattern (stringent and low delay) | • Preserve time relation of (variation) between information entities of the stream | • Request response pattern<br>• Preserve payload content | • Destination is not expecting the data within a certain time<br>• Preserve payload content |
| Example of application | voice | streaming video | web browsing | background download of emails |

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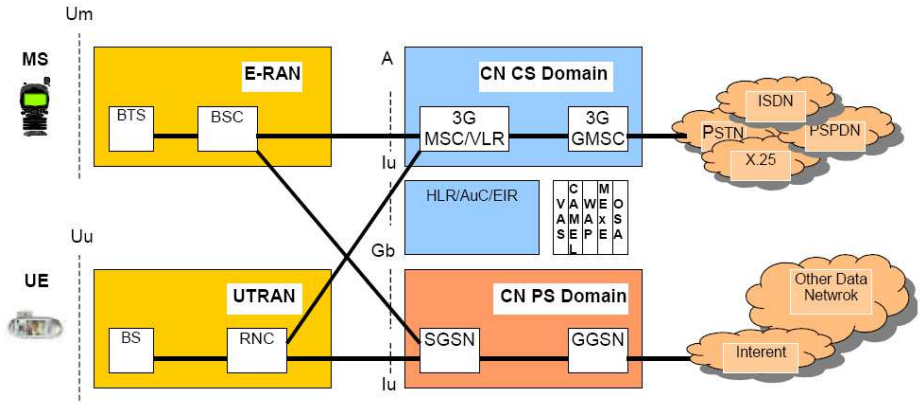
# UMTS architecture (rel99)

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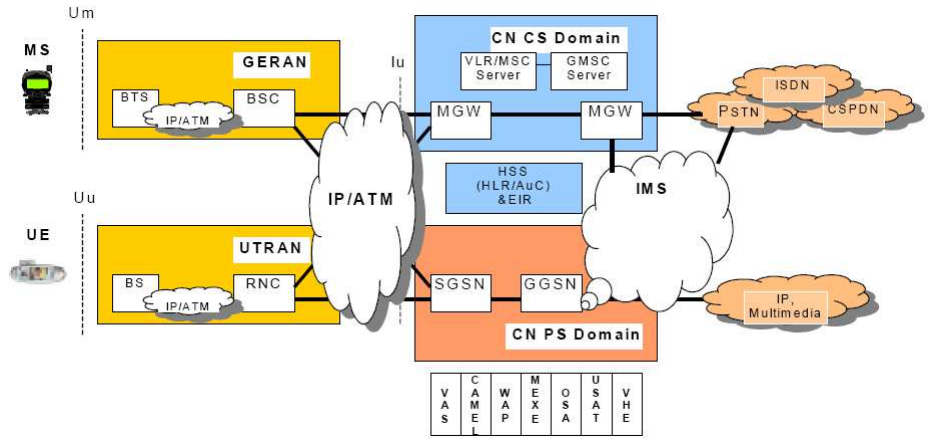
# UMTS architecture (3GPP Rel.5)

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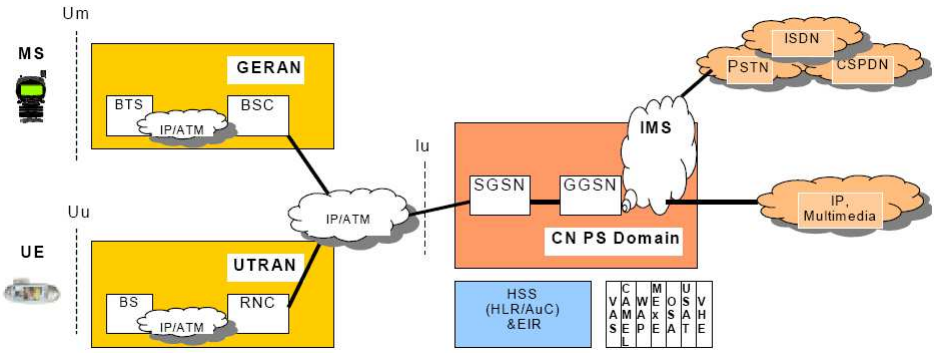
# UMTS all-IP




- Realized in 4G

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# 3GPP releases

- Rel-99 (3/2000)
  - first deployable version of UMTS
  - GSM/GPRS/EDGE/WCDMA radio access
- Rel.4 (3/2001)
  - multimedia messaging
  - efficient IP-based interconnection of core network
- Rel.5 (3/2002)
  - HSDPA (up to 14.4 Mbps, 1.8,3.6,7.2Mbps avail. up to 2008)
  - first phase IMS
  - IP UTRAN
- Rel.6 (3/2005)
  - HSUPA (up to 5.76 Mbps)
  - enhanced MBMS
  - second phase IMS
- Rel. 7
  - HDPA+
  - flat radio access network

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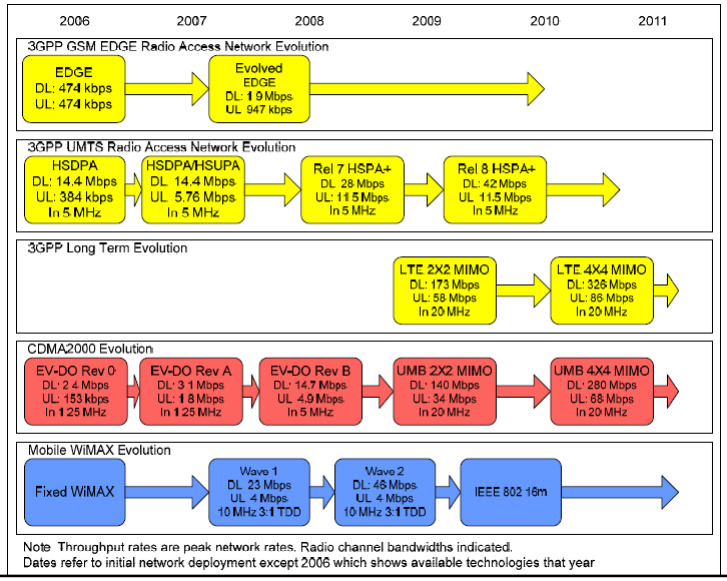
# Evolution of cellular technologies

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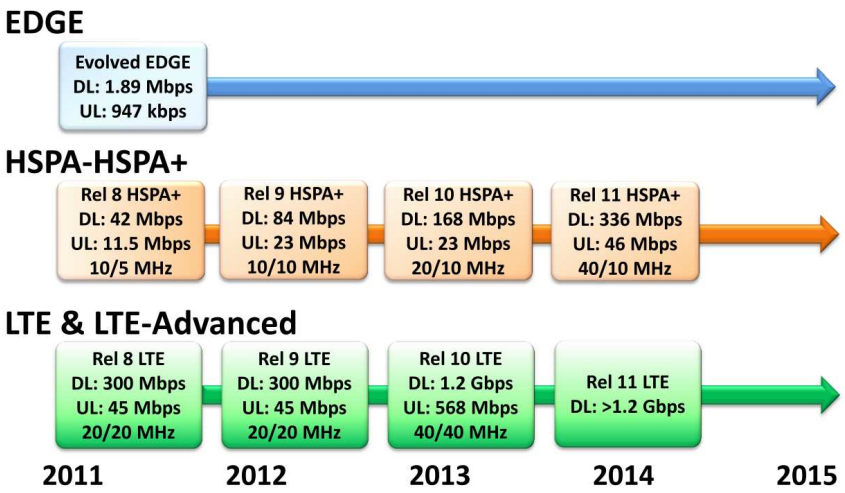
# Evolution of cellular technologies




Source: 4G Americas

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# HSDPA

- High speed shared channels (15@5MHz)
  - sharing in both code and time domains
- Fast scheduling and user diversity
  - shorter TTI (Transmission Time Interval): 2ms
- Adaptive Modulation and Coding (AMC)
  - Higher order modulation: QPSK and 16-QAM
  - Fast link adaptation: different FEC (channel coding)
- Fast hybrid ARQ
  - fast combined with scheduling/link adaptation
  - hybrid: combine repeated data transmissions with prior transmissions to improve successful decoding

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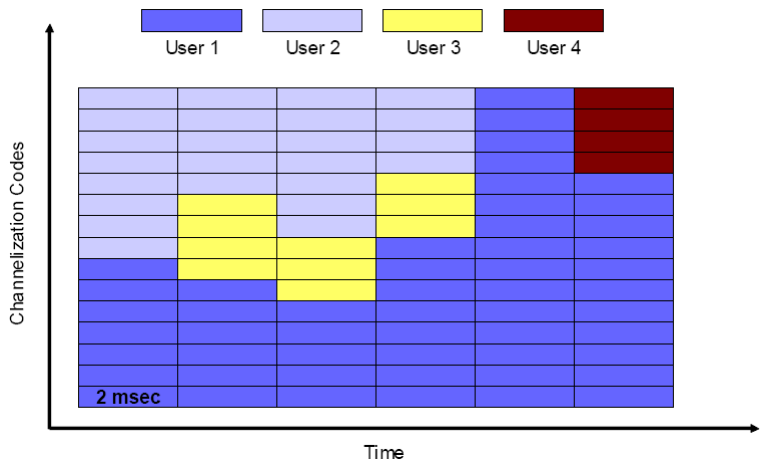
# Fast scheduling and user diversity

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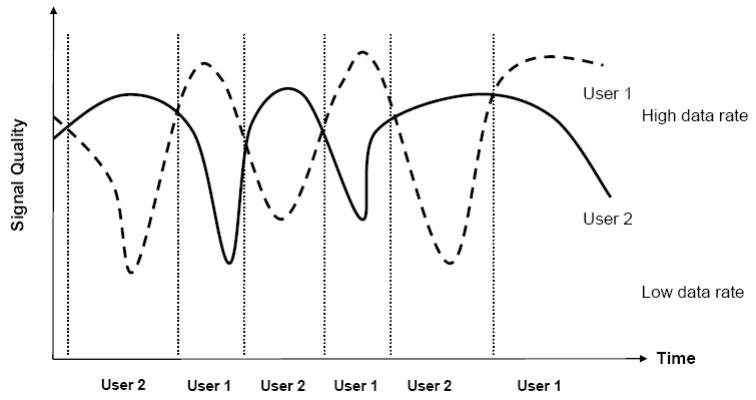
# User diversity

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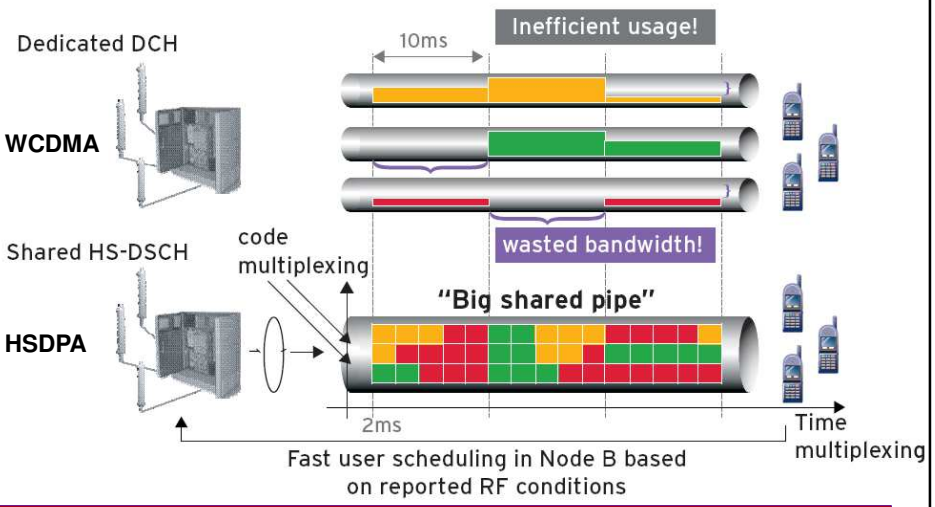
# HSDPA vs. WCDMA

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## HSUPA

- Enhanced dedicated physical channel
- Fast scheduling with short TTI (2ms)
- Fast hybrid ARQ

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## HSPA and HSPA+

- HSPA (Rel. 6)
  - DL: 14.4 Mbps, UL: 5.76 Mbps
- HSPA+ goals
  - exploit full potential of CDMA before moving to OFDMA (3G LTE)
  - operation of packet-only mode for voice and data
- HSPA+: many versions
  - Rel.7 HSPA+ (DL 64 QAM, UL 16 QAM): DL: 21Mbps, UL: 11.5Mbps
  - Rel.7 HSPA+ (2X2 MIMO, DL 16 QAM, UL 16 QAM): DL: 28Mbps, UL: 11.5Mbps
  - Rel. 8 HSPA+ (2X2 MIMO, DL 64 QAM, UL 16 QAM): DL: 42.2Mbps, UL: 11.5Mbps

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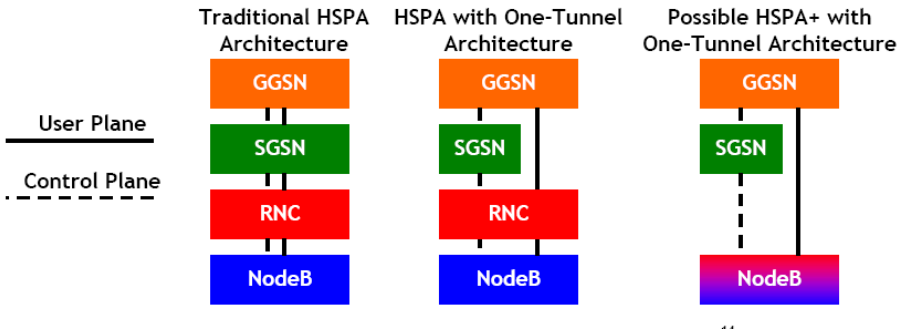
# Towards a simpler architecture

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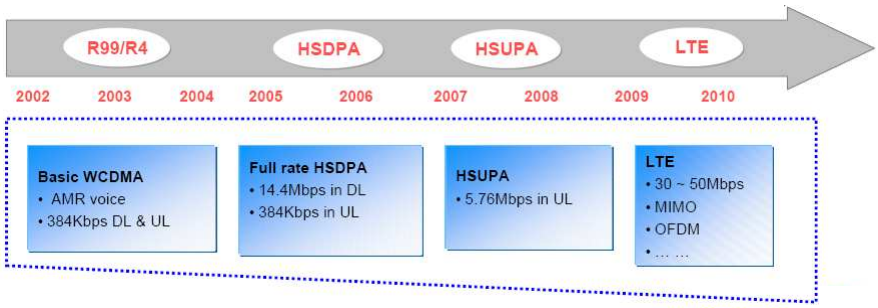
# UMTS evolution towards LTE




- 3G LTE: next step in evolution of 3GPP radio interfaces to deliver Global Mobile Broadband
- Not 4G, but beyond 3G: 3.9G

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# LTE targets

- Increased data rates
  - Peak data rate: above 100 Mbps (downlink) and 50 Mbps (uplink)
  - Increase “cell edge bitrate” whilst maintaining same site locations as deployed today
- Improved spectrum efficiency
  - 2-4X Rel 6 HSPA
- Reduced latencies:
  - network latency < 10 ms
  - inactive-to-active latency < 100 ms
- Designed for IP traffic
  - Efficient support packet services (e.g. Voice over IP, Presence)
- Enhanced IMS and core network
- Enhanced MBMS (broadcasting)

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# LTE targets (cont)

- Spectrum and deployment flexibility
  - Scaleable bandwidth: 1.25,2.5,5,10,15,20 MHz
  - Both TDD and FDD modes
- High mobility
  - optimized for speeds 0-15 Km/h
  - support high performance for 15-120 Km/h
  - support mobility for 120-350 Km/h
- Cost effective introduction
  - Cost effective migration from Rel-6 UTRAN
  - inter-working with existing 3G and non-3GPP systems (WiMAX, WLAN)
  - simplified Radio Access Network (RAN)

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# LTE features

- Downlink based on OFDMA
- Uplink based on SC-FDMA
- Only packet switched: no circuit switched connectivity
- LTE time slot (TTI): 1 ms
- MIMO: use more than one TX/RX antennas

| LTE Configuration | Downlink (Mbps) Peak Data Rate | Uplink (Mbps) Peak Data Rate |
|---|---|---|
| Using 2X2 MIMO in the Downlink and 16 QAM in the Uplink, 10+10 MHz | 70.0 | 22.0 |
| Using 4X4 MIMO in the Downlink and 64 QAM in the Uplink, 20+20 MHz | 300.0 | 71.0 |

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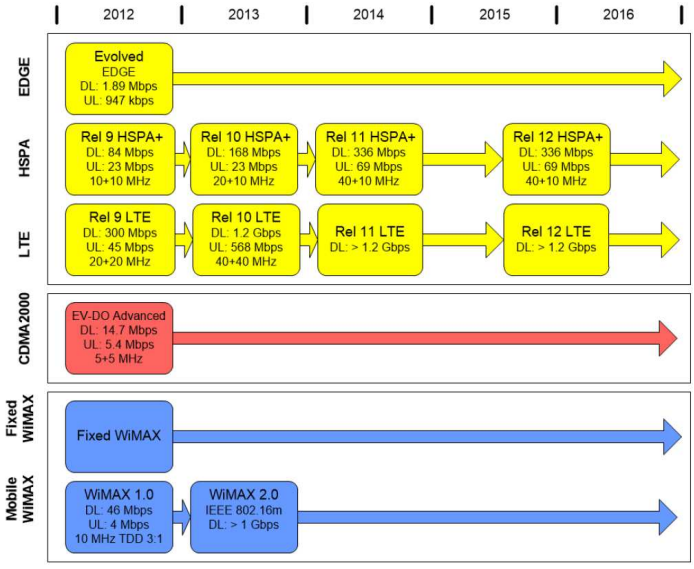
# Evolution > 2012

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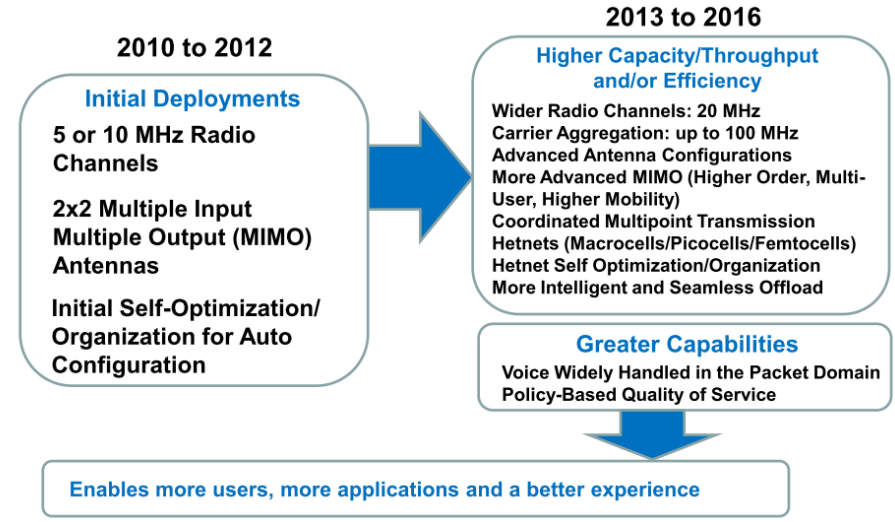
# LTE Advanced (Rel. 12)




Source: 4G Americas, 2015

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# Air interface technologies

| Approach | Technologies Employing Approach | Comments |
|---|---|---|
| **TDMA** | GSM, GPRS, EDGE, Telecommunications Industry Association/Electronics Industry Association (TIA/EIA)-136 TDMA | First digital cellular approach. Hugely successful with GSM.<br>New enhancements being designed for GSM/EDGE. |
| **CDMA** | CDMA2000 1xRTT, CDMA2000 EV-DO, WCDMA, HSPA, Institute of Electrical and Electronic Engineers (IEEE) 802.11b | Basis for nearly all new 3G networks. Mature, efficient, and will dominate wide-area wireless systems for the remainder of this decade. |
| **OFDM/OFDMA** | 802.16/WiMAX, Flarion Fast Low-Latency Access with Seamless Handoff OFDM (Flash OFDM), 3GPP LTE, IEEE 802.11a, IEEE 802.11g, IEEE 802.20, Third Generation Partnership Project 2 (3GPP2) UMB, 3GPP2 Enhanced Broadcast Multicast Services (EBCMCS), Digital Video Broadcasting-H (DVB-H), Forward Link Only (FLO) | Effective approach for broadcast systems, higher bandwidth radio systems, and high peak data rates in large blocks of spectrum.<br>Also provides flexibility in the amount of spectrum used. Well suited for systems planned for the next decade. |

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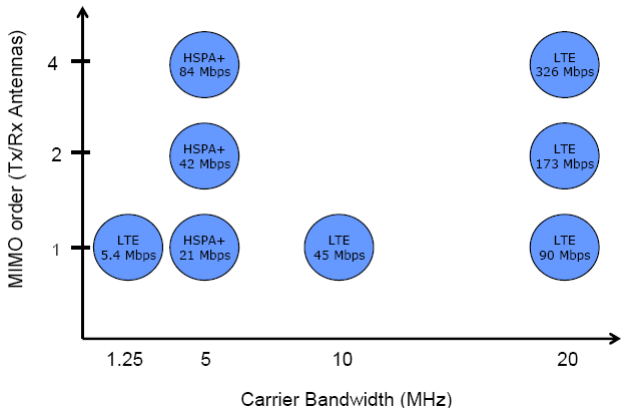
# MIMO and carrier bandwidth

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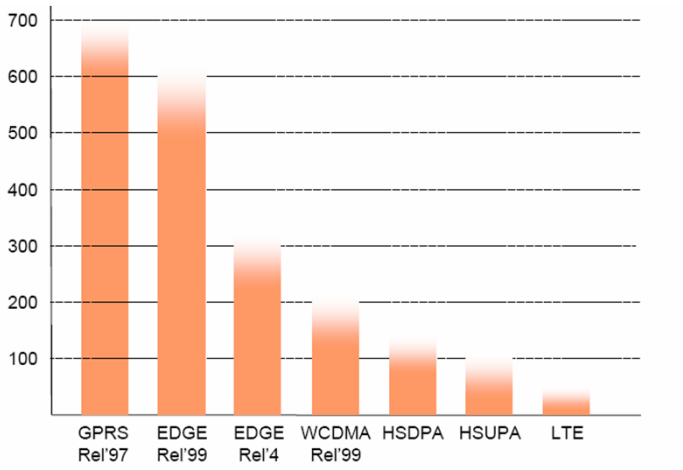
# Latency comparison

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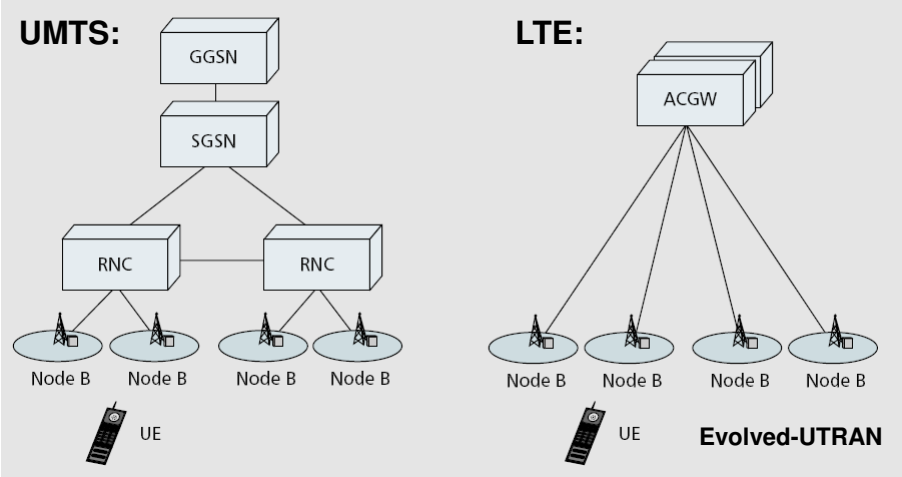
# LTE Radio Access Network

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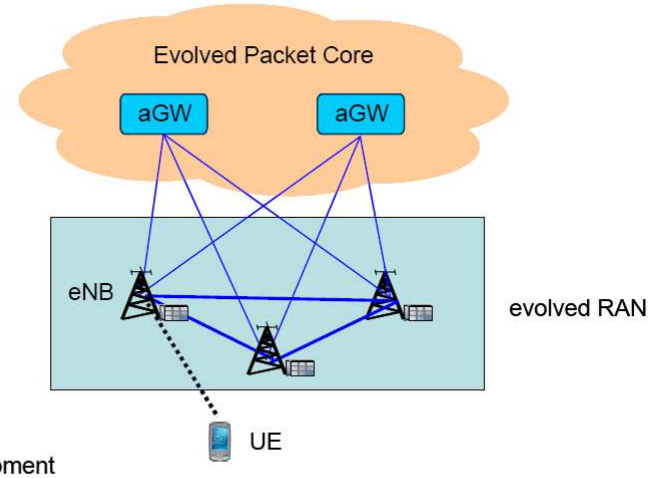
# 3G LTE Evolved-UTRAN




UE: User Equipment
aGW: Access Gateway
eNB: enhanced Node B

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# LTE simplified architecture

Evolved UTRAN (EUTRAN):

- Most RNC functionalities moved to eNodeB
- RNC removed
- eNodeB connects to evolved packet core

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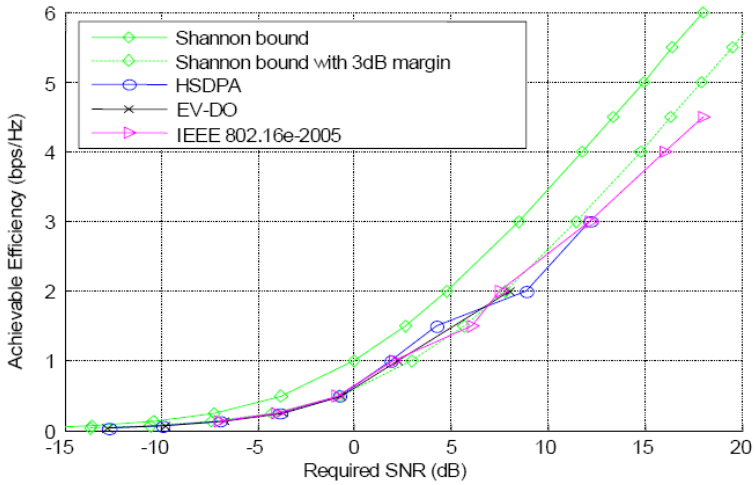
# Spectral efficiency




Source: 4G Americas, 2015

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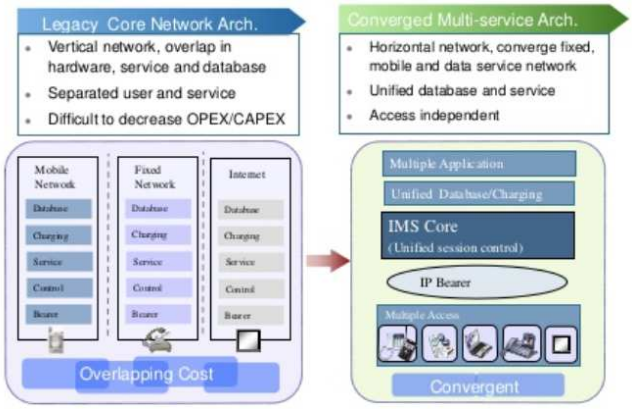
# IP Multimedia Subsystem (IMS)

- IP Multimedia Subsystem (IMS): unified service architecture for all networks (fixed and mobile) based on IP

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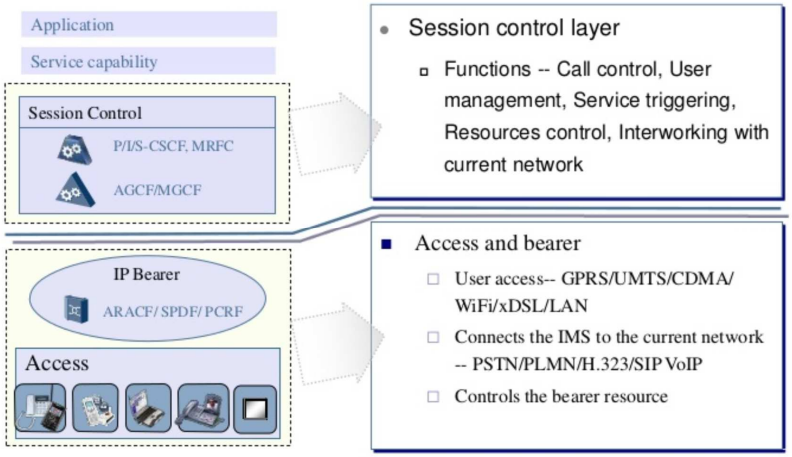
# IMS Network Layers

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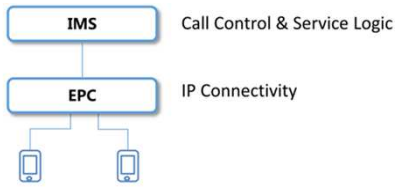
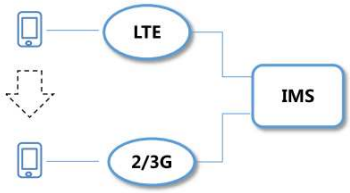
# IMS and EPC: VoLTE

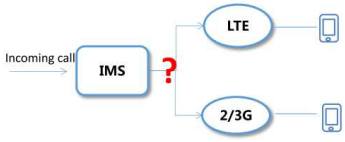
- LTE core (EPC) only provides IP
- IMS is overlay providing call control and service logic for telephony service




- VoLTE - 2/3G session continuity




- Termination selection

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# Frequency ranges


**Range of Frequencies Designed For Entertainment**



Slides from Liberty Global, VoLTE Presentation, 2018

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# Telephony range of frequencies

300 Hz 3,400 Hz

Telephony

50 Hz 7,000 Hz

HD Voice

50 Hz 20,000 Hz

HD Voice & Music

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# Mobile phone codecs

Standard Voice (GSM & 3G)

AMR-NB codec
12 kbps
3,400 Hz

HD Voice (VoLTE)

AMR-WB Codec
12 kbps
7,000 Hz

GSM, 3G and VoLTE use Quality of Service (QOS) technology to guarantee service levels


Music over Skype or WhatsApp

OPUS Codec
8 kbps and 4,000 Hz
increasing to
64 kbps and 20,000 Hz

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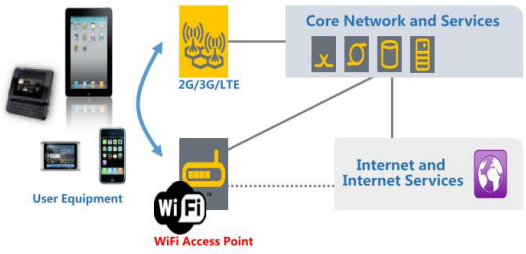
# VoWiFi (VoLTE Wifi offload)




- Voice continuity between LTE and Wifi
- Better indoor coverage when higher LTE frequency bands are used.
- Widely available and supported by UEs/handsets, tablets, laptops.
- Lower charging strategy especially when roaming.

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# Proximity Services (LTE Rel. 12)

- Direct discovery: identifies UE that are in direct proximity of each other
- Direct communication: device-to-device communication between UEs
  - both in presence and in absence of LTE network

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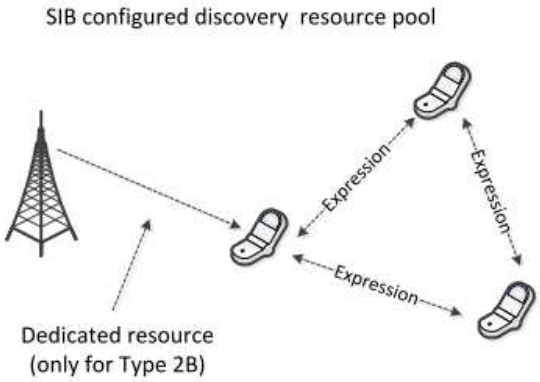
# Direct Discovery




- Type 1: UE selects resource from resource pool
- Type 2B: LTE network allocates resources

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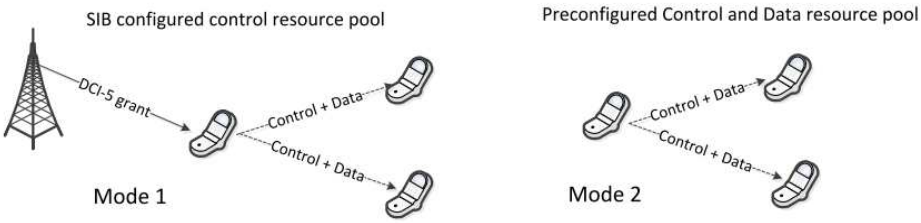
# Direct Communication




- Mode 1: LTE network explicitly assigns resources
- Mode 2: UEs select resources for control & data from resource pool

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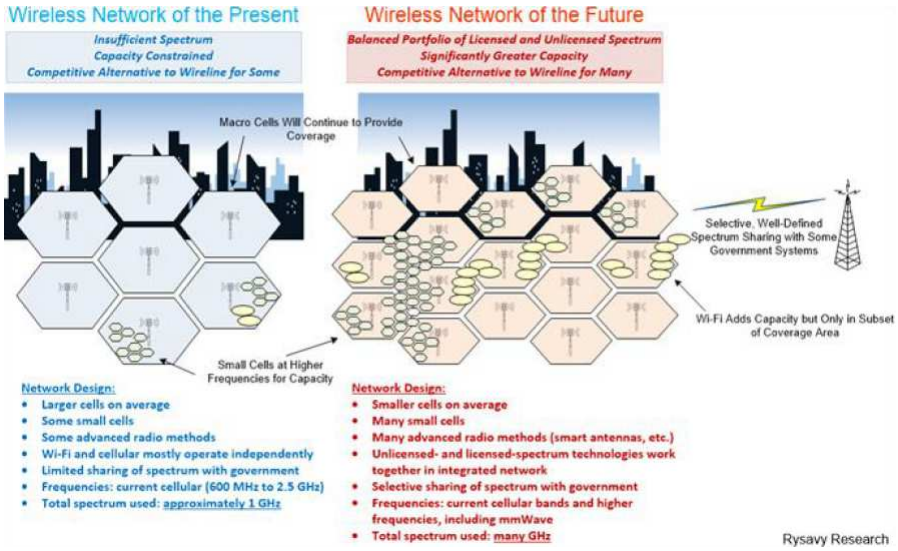
# Small cells

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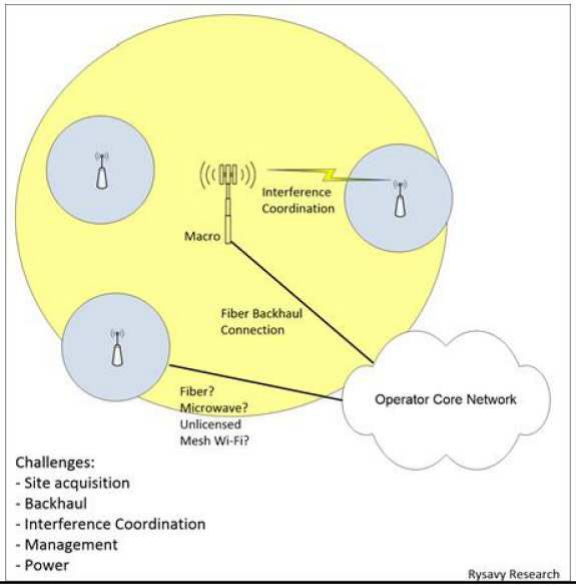
# Small cell challenges

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# Small cell approaches

| Small Cell Approach | Characteristics |
|---|---|
| Macro plus small cells in select areas. | Significant standards support. Femtocells or picocells can use same radio carriers as macro (less total spectrum needed) or can use different radio carriers (greater total capacity). |
| Macro plus LTE operation in unlicensed bands | Being considered for 3GPP Release 13 and available for deployment 2017 or 2018. Promising approach for augmenting LTE capacity in scenarios where operator is deploying LTE small cells. |
| Macro plus Wi-Fi | Extensively used today with increased use anticipated. Particularly attractive for expanding capacity in coverage areas where Wi-Fi infrastructure exists but small cells with LTE do not. |
| Wi-Fi only | Low-cost approach for high-capacity mobile broadband coverage, but impossible to provide large-area continuous coverage without cellular component. |

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# Types of cells

| Type of Cell | Characteristics |
|---|---|
| Macro cell | Wide area coverage. LTE supports cells up to 100 km of range, but typical distances are .5 to 5 km radius. Always installed outdoors. |
| Microcell | Covers a smaller area, such as a hotel or mall. Range to 2 km, 5-10W, 256-512 users. Usually installed outdoors. |
| Picocell | Indoor or outdoor. Outdoor cells also called "metrocells." Typical range 15 to 200 meters outdoors and 10 to 25 meters indoors, 1-2W, 64-128 users. Deployed by operators primarily to expand capacity. |
| Consumer Femtocell | Indoors. Range to 10 meters, less than 50 mW, 4 to 6 users. Capacity and coverage benefit. Usually deployed by end users using their own backhaul. |
| Enterprise Femtocell | Indoors. Range to 25 meters, 100-250 mW, 16-32 users. Capacity and coverage benefit. Deployed by operators. |
| Distributed antenna system. | Expands indoor coverage. Same hardware can support multiple operators (neutral host) since antenna can support broad frequency range and multiple technologies. Usually deployed in larger indoor spaces. Can also be used outdoors. |
| Remote radio head (RRH) | Uses baseband at existing macro site or centralized baseband equipment. If centralized, the system is called "Cloud RAN." Requires fiber connection. |
| Wi-Fi | Primarily provides capacity expansion. Neutral-host capability allows multiple operators to share infrastructure. |
| "Super Wi-Fi" | Name used by some people for white-space technology. Not true Wi-Fi. Better suited for fixed wireless than mobile wireless. |

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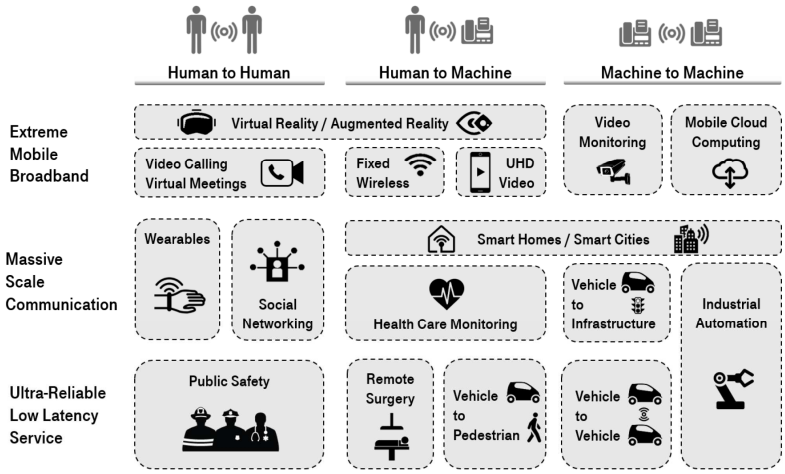
# 5G use cases

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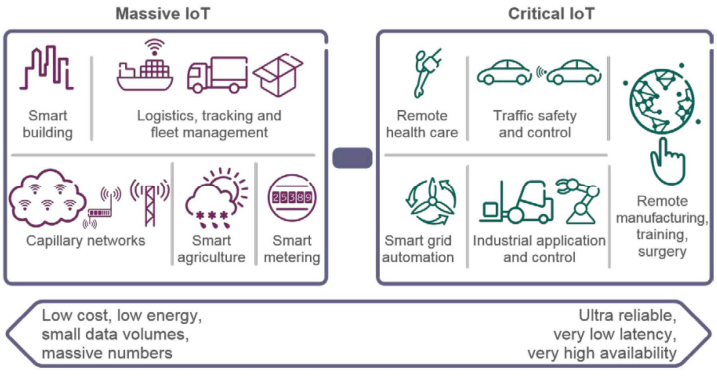
# IoT requirements

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# 3GPP Release 12 and 13

- Rel.12: Cellular Internet of Things
- Rel.13:
  - LTE-M (LTE Category M1): data rates up to 1 Mbps with 1.08 MHz, VoLTE
  - NB-IoT: 200 kHz

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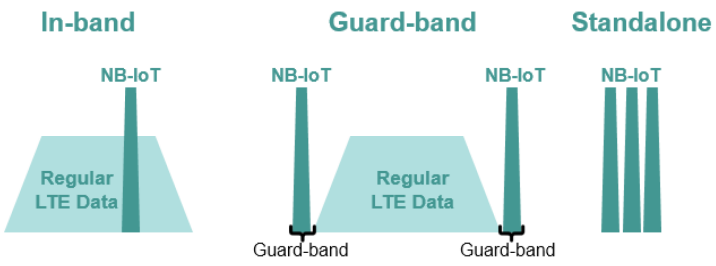
# NB-IoT deployment options

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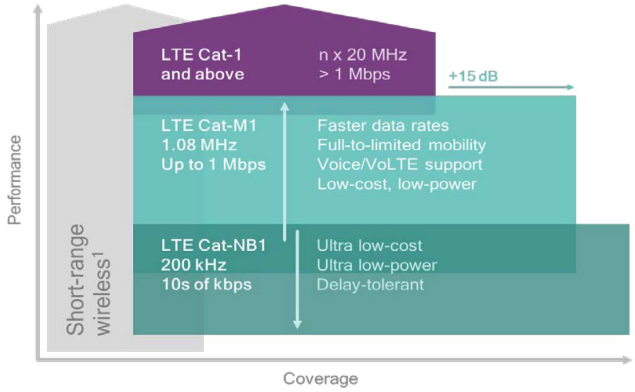
# LTE support for IoT

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| | LTE Cat-1 (Today) | LTE Cat-M1 (Rel-13) | LTE Cat-NB1 (Rel-13) |
|---|---|---|---|
| Peak data rate | DL: 10 Mbps<br>UL: 5 Mbps | DL: 1 Mbps<br>UL: 1 Mbps | DL: ~30 kbps<br>UL: ~60 kbps |
| Bandwidth | 20 MHz | 1.4 MHz | 200 kHz |
| Rx antenna | MIMO | Single Rx | Single Rx |
| Duplex mode | Full duplex<br>FDD/TDD | Supports half duplex<br>FDD/TDD | Half duplex<br>FDD only |
| Transmit power | 23 dBm | 20 dBm or 23 dBm | 20 dBm or 23 dBm |

Higher throughput, lower latency, full mobility

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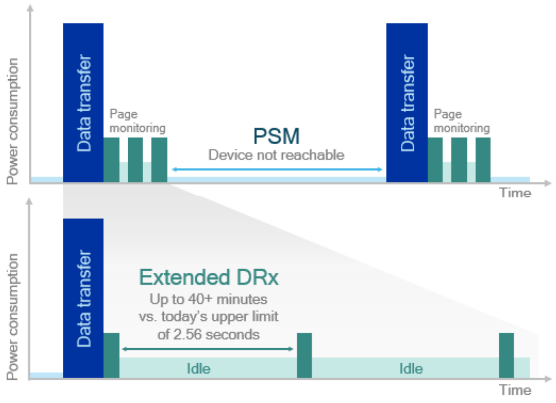
# Power Save Mode (PSM) and Extended Discontinuous Reception (eDRx) – Rel. 13

- Power Save Mode (PSM): allows device to skip periodic page monitoring cycles
  - device-originated or scheduled applications, where device initiates communication with network
- eDRx extends maximum time between control channel monitoring/data reception from network in connected mode to 10.24 s and time between page monitoring and tracking update in idle mode up to 430.69 min for Cat-M1 and up to about 3 hours for Cat-NB1
  - allows network & device to synchronize sleep periods so device can check for messages less frequently

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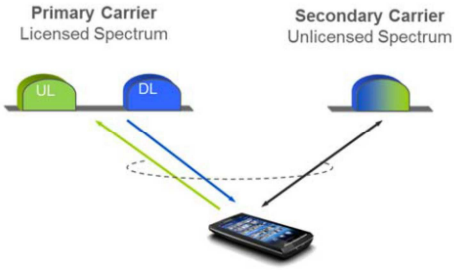
# 3GPP Release 14

- Massive MIMO
- Licensed Assisted Access (LAA): aggregate carriers across licensed and unlicensed 5 GHz

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# 3GPP Release 14

- Low latency enhancements
- NB-IoT enhancements

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# 3GPP release overview

- Rel.8: LTE, 4x4 MIMO, flat architecture, low latency, multi-band
- Rel.9: Evolved Multimedia Broadcast Multicast (eMBMS), voice over LTE, femto cells, Self-Organizing Network (SON)

3.9G

- Rel.10 (Jun 2011): LTE-Advanced (4G), carrier aggregation, relays, inter-cell interference coordination
- Rel.11 (Mar 2011): Coordinated Multipoint (CoMP), enhanced carrier aggregation, new control channels, new mobile categories
- Rel.12 (Mar 2015): small cells, dual connectivity, device-to-device, simpler MTC

4G

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# 3GPP release overview (cont)

- Rel.13 (Mar 2016): Licensed Assisted Access (LAA), improved MTC, carrier aggregation, device-to-device
- Rel.14 (Jun 2017): improved LAA, vehicle-to-everything (V2X), wide-area broadcast with reduced subcarrier spacing

4,5G

- Rel.15 (Sep 2018): 5G phase 1, New Radio (NR), Non-Stand-Alone (NSA), low latency, improved massive MIMO/beamforming, network slicing, service-based arch, control/user-plane split…
- Rel.16 (upcoming 2020): 5G phase 2, massive MTC, V2X phase 3, URLLC, Industrial IoT, slicing, NR-based access to unlicensed spectrum, satellite access, 5G efficiency (interference, positioning, power consumption, dual connectivity, mobility, …)

5G

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# 3GPP roadmap

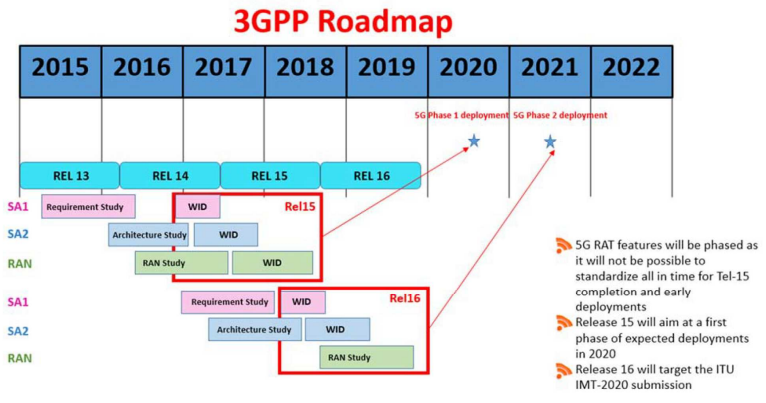


Figure 1.1. 3GPP Timeline Releases 13 to 16.

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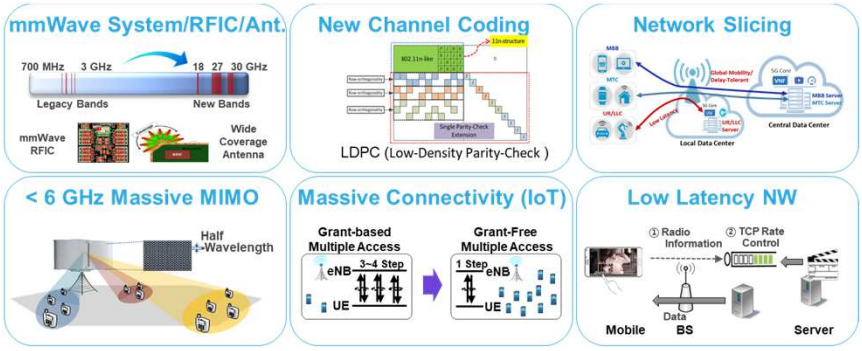
# 5G enablers

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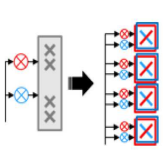
# New air interface technologies

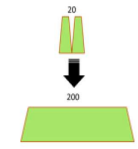


**Spectral Efficiency**

- Massive MIMO and FD-MIMO concepts are central to the 5G theme.
- Potentially large capacity and coverage improvement.
- FD-MIMO work in LTE-advanced is a starting point for developing these concepts for 5G
- Other spectral efficiency improvement through new waveform and overhead reduction

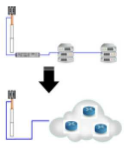
**Densification**

- Densification via small cell build-out key to RAN evolution.
- Current small cell solution is not scalable beyond a certain point.
- Radically new concepts such as separation of control and data plane, new system architecture are key to achieving an ultra-dense network




**Spectrum**

- Design system to operate in much larger channel bandwidth. This requires a careful tradeoff between spectral efficiency and power efficiency
- Operate across new licensing scenarios such a unlicensed, or shared licensed
- Operation in low frequency and in mmWave



**SDN/NFV**

- A key and central requirement to AT&T as a part of Domain 2.0 efforts.
- Apart from implementation challenges of SDN/NVF for 5G, we also need to develop the 5G RAT which allows for L1/L2/L3 functionality to be distributed


**Massive Connectivity**

- Design the 5G RAT to allow for network slicing down to the physical layer.
- Lightweight or weightless protocol to support massive connectivity.
- Power efficiency and coverage enhancements

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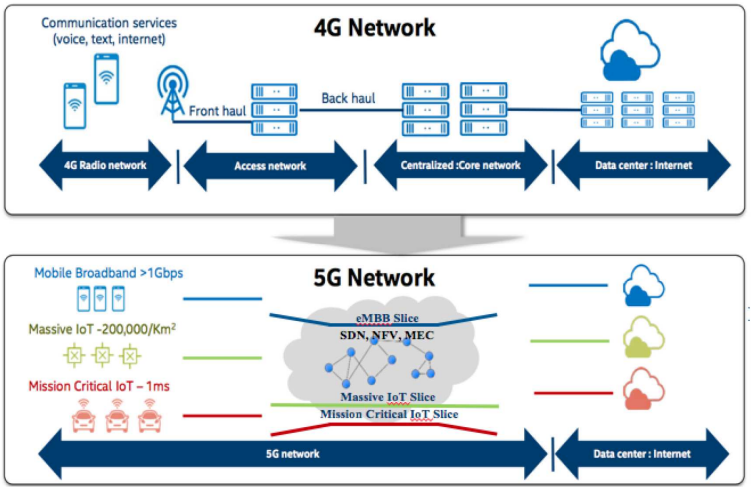
# 4G to 5G transition

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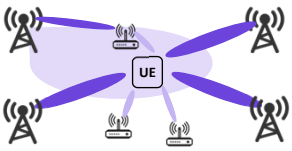
# RAN extensions




New Air Interface

- **CP-OFDM** – to introduce flexibility in OFDM and mitigate Inter Symbol Interference
- **Massive MIMO** – large numbers of bearers to increase bandwidth in sub-6GHz bands
- **mmWave** – provides access to broad frequency bands for higher bandwidths
- **Beam Forming** – extends range/cell size for mmWave bands
- **Shortened TTI** – reduces latency
- **Flexibility in band sizing** – allows previously unavailable bands to be used

Other RAN innovations

- **CoMP** – UE attached to multiple cells to provide greater reliability
- **Small cell support** – greater indoor coverage, increased cell density, self-backhauling
- **5G-NR in unlicensed bands** – extension of mobile ecosystem
- **Session management split from mobility management** – enabler for RAN slicing
- **D2D, V2X** – devices connecting directly, with no network

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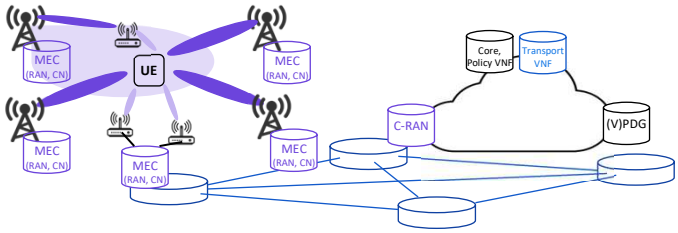
# 5G flexibility




- 'Softwarisation' of the network
- NFV and SDN – enabling flexibility in where functions are deployed and scaled
- CP/UP split – decoupling of user plane traffic from control plane functions
- C-RAN – removal of functionality from cell sites to consolidation point in the network
- MEC – pushing Core Network functions and content ingress to cell sites

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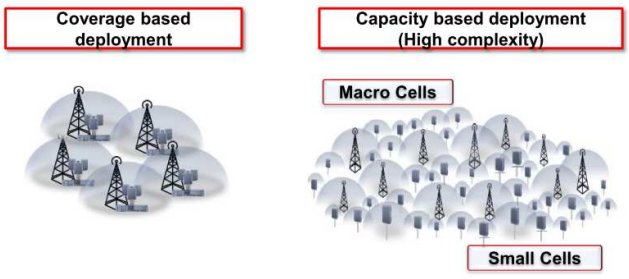
# From coverage to capacity deployments




- Installation/Maintenance/Interference optimization is important
- Centralization necessary => Cloud RANs
- Intelligence necessary

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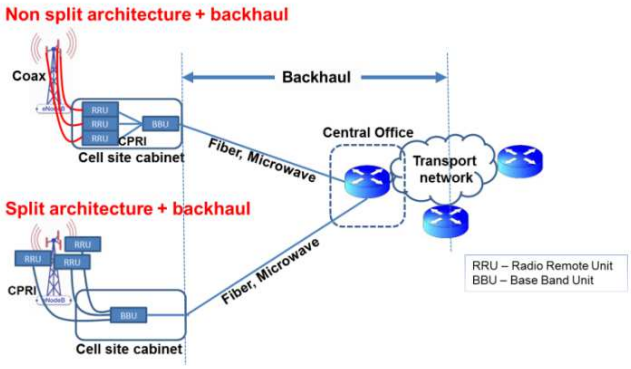
# RRU-BBU separation




- RRU (Radio Remote Unit): creates analog RF signal from baseband signal and sends it to the antenna digitizes RF receive signal
- BBU (BaseBand Unit): generates and processes digitized baseband signal, also referred to as digital unit

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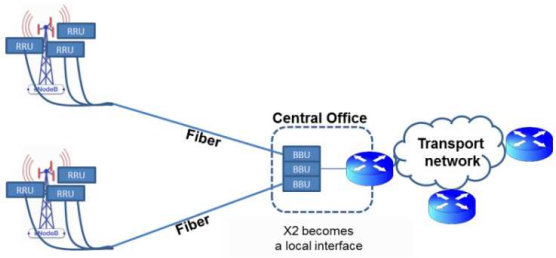
# BBU centralization and pooling: Cloud RAN

BBU centralization:

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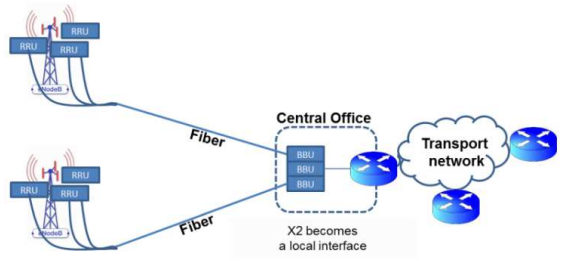
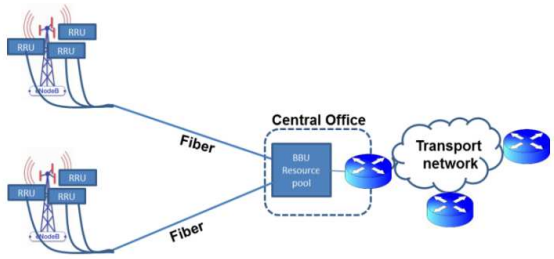
# BBU centralization and pooling: Cloud RAN

BBU centralization:




BBU pooling (Cloud RAN):

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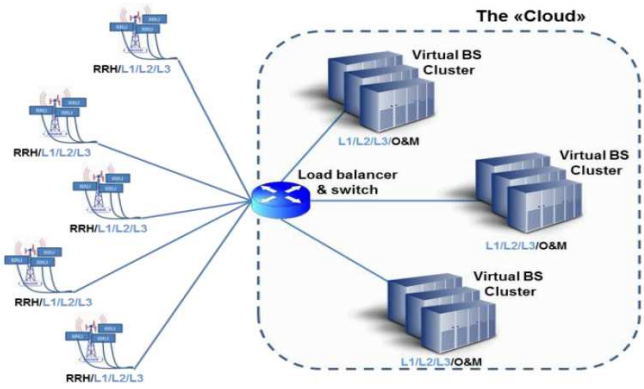
# Cloud RAN with virtualization

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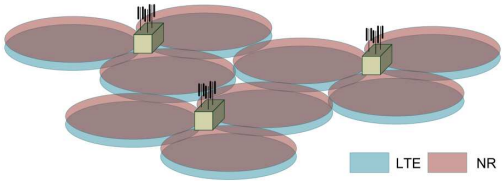
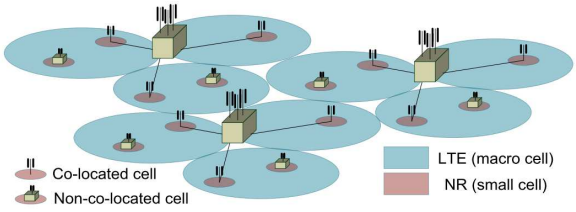
# LTE – NR (New Radio) dual connectivity




LTE and NR cells co-located & overlaid and provide same coverage




LTE and NR cells provide different coverage; can be co-located or non-co-located

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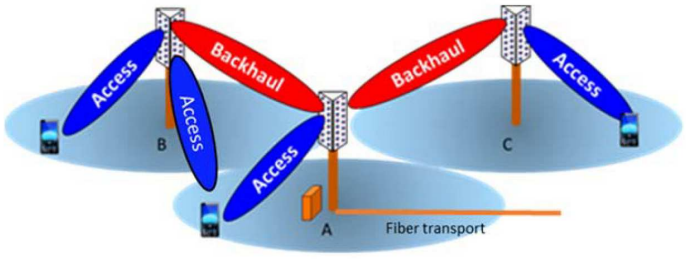
# Integrated access and backhaul

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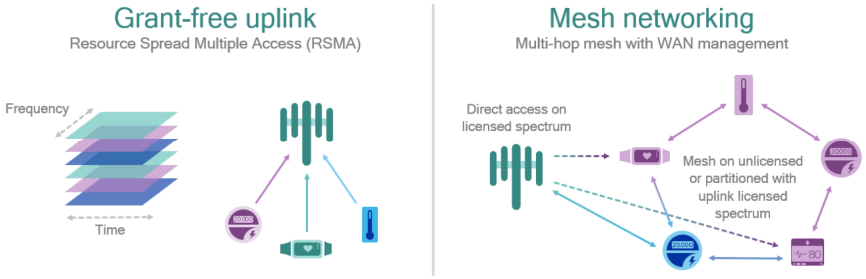
# New capabilities for IoT

- RSMA is an asynchronous contention-based uplink multiple access that allows IoT devices to transmit without prior network scheduling
- Multi-hop mesh allows out-of-coverage devices to connect directly with devices that can relay data back to access network

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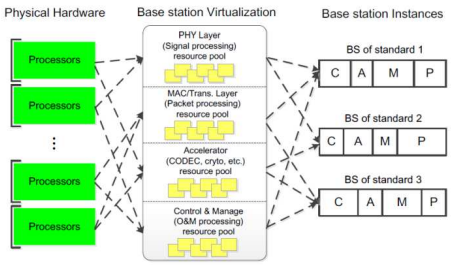
# Virtualization gains

- HW and SW totally decoupled
- Operator can dynamically allocate processing resources within a centralized baseband pool to different virtualized base stations and different air interface standards
- simpler inter-vendor interoperability
- cost reduction to manage, maintain, expand and upgrade base station

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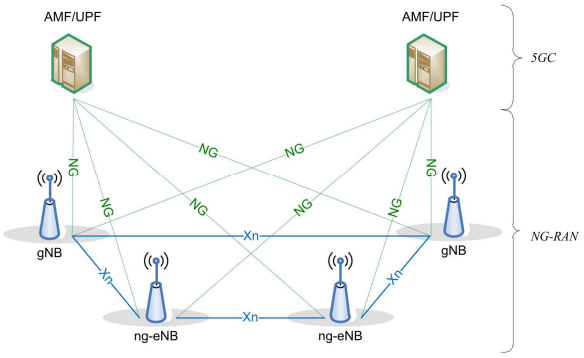
# 5G RAN architecture

- gNB: 5G base station providing NR user plane and control plane services
- ng-eNB provides LTE/E-UTRAN services

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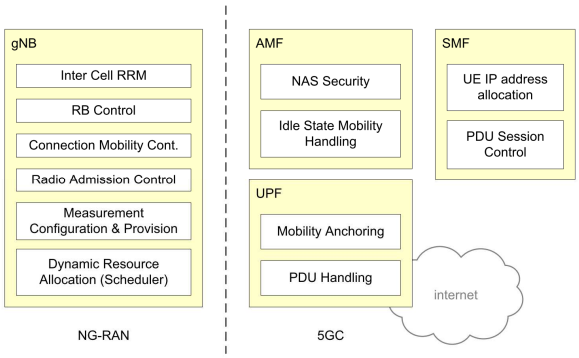
# Functional split between NG-RAN and 5GC

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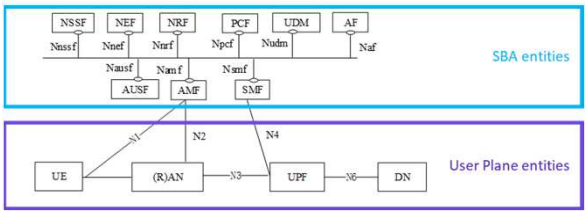
# 5G Core Network (5GC)

- Exploits NFV, SDN, MEC
- Service-Based Architecture (SBA)




Authentication Server Function (AUSF)
Access and Mobility Management Function (AMF)
Session Management Function (SMF)
Network Slice Selection Function (NSSF)
Network Exposure Function (NEF)
NF Repository Function (NRF)
Policy Control Function (PCF)
Unified Data Management (UDM)
Application Function (AF)

Unified Data Repository (UDR)
Unstructured Data Storage Function (UDSF)
5G-Equipment Identity Register (5G-EIR)
Security Edge Protection Proxy (SEPP)
Network Data Analytics Function (NWDAF)

User Plane Function (UPF)
Data Network (DN), e.g. operator services, Internet access or 3rd party services
User Equipment (UE)
(Radio) Access Network ((R)AN)

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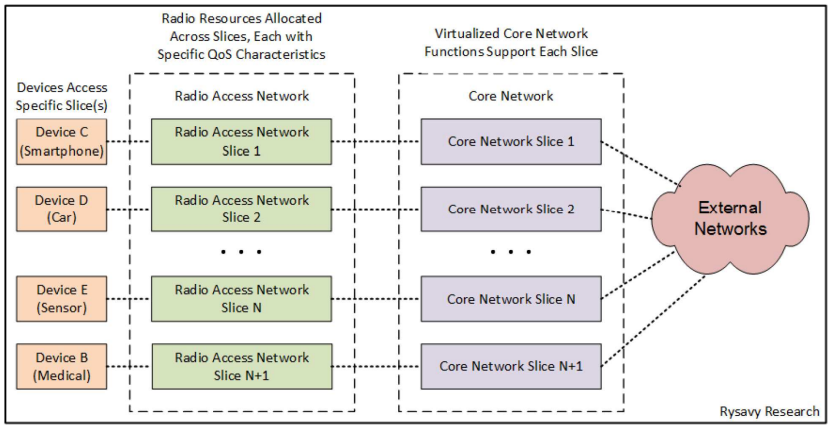
# Network slicing architecture

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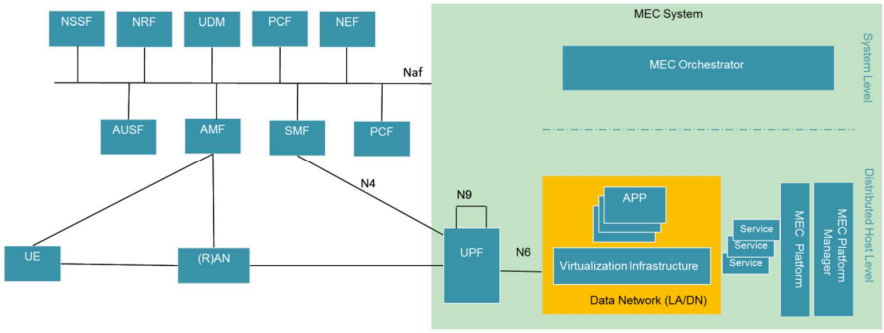
# Integrated MEC in 5G

- UPF supports Uplink Classifier functionality that diverts (locally) traffic matching traffic filters provided by Session Management Function (SMF)

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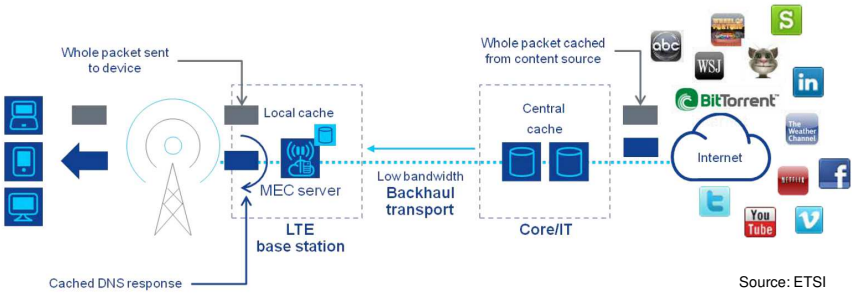
# Mobile Edge Computing: Caching




Source: ETSI

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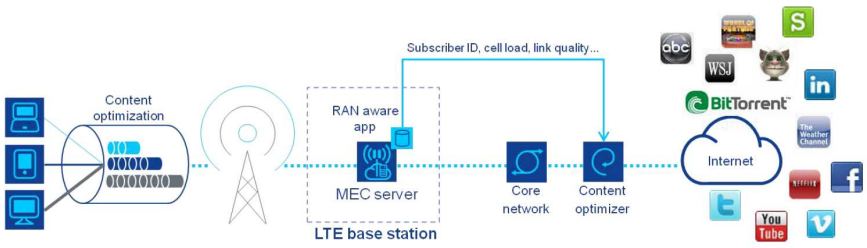
# MEC: Content optimization




Source: ETSI

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