Cellular systems: from 2G to 4G

Wireless Systems, a.a. 2019/2020

Un. of Rome "La Sapienza"

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2G+ Cellular systems

a.a. 2019/2020

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Beyond GSM

- Challenges:
  - Widespread Internet usage raises demand for data communication (not only voice!)
  - Packet Switching vs. Circuit Switching
  - Data rates must increase
  - Data encoding quality must increase
  - Need to extend the functionalities of a mobile operator systems to allow to provide more complex services

  → First answers to these needs already provided by 2G+ systems (EDGE, GPRS)

  → Evolutionary approach: systems have been built over GSM approach with very limited impact on the cell operator core network. A real non evolutionary approach is under discussion for the future and part of 5G discussion (where however solutions are still under debate)

2G+ innovation

- Enhanced full rate codec based on ACELP (Algebraic Code Excited Linear Prediction)←13Kbit/s
- Adaptive MultiRate←new generation codec that adapts to available channels (half rate or full rate) and changes rate depending on channel propagation conditions
- Tandem Free Operation←limits use of transcoding (which implies degradation of voice quality), allowing multiplexing of flows of coded speech signal (e.g. using full rate or enhanced full rate codecs) on the PCM channels in case of MS-MS communication.
- Enhanced data rates achieved through improvements of phy layer, and allocation of multiple slots to the same MS

2G+ innovation

- Location services ←triangolarization among BTS allows to achieve a localization around 100m
- Number portability← user can maintain its own telephone number even when changing telecom operator
- Cordless telephony system ←to use a MS as cordless, connecting to a Home Base Station (HBS) and from there to the cellular operator network
- SIM application toolkit←change of paradigm. The ME is no longer the master and the SIM the slave. The SIM can initiate communication with the ME; downloads via the radio link to the SIM are possible.
  - SIM can ask the ME to perform actions such as:
    - ✓ Set up of a call to a number in the SIM;
    - ✓ Send telephone numbers the ME is dialing to the SIM that can analyze, modify and bar the call
    - ✓ Tone generation
    - ✓ Pass to the SIM information
    - ✓ Execute a command sent by the SIM
    - ✓ Launch the microbrowser in the ME redirecting it to a particular WEB address
- Environments for application/service support, customization, personalization ←Mobile Execution Environment; CAMEL.

EDGE

- Improvements on the radio interface have increased the MS achievable data rate without changing the mobile cellular system architecture
- EDGE is a radio access technology:
  - 3/8 shifted 8PSK modulation (phase modulation) →three times more bits per symbol
  - with channel encoding EDGE achieves a gross data rate of 59,2 Kbit/s vs. the 22,8Kbit/s of GSM
  - Features
    - ✓ Carrier bandwdith: 200 kHz
    - ✓ Timeslots per frame: 8; frame duration: 4,615 ms
    - ✓ radio interface symbol rate: 270ksymbols/s (vs. 270kbits/s in GSM)
    - ✓ Normal burst: 384 payload bits (116 in GSM)
    - ✓ Max gross bit rate per time slot: 59,2 kbit/s (22,8 Kbit/s in GSM)

Adaptive modulation

- Limits of high rate modulation: at low SNR (or better SNIR) it results in high BER
- Improves EGPRS deploys the adaptation of the code rate (8PSK vs GMSK, the former achieving 3 times as much data rate).
- A dynamic selection of channel coding and modulation is implemented, which is based on the SNR of the radio channel
- The net trasmission data rate is reduced or increased depending on the quality of the radio channel

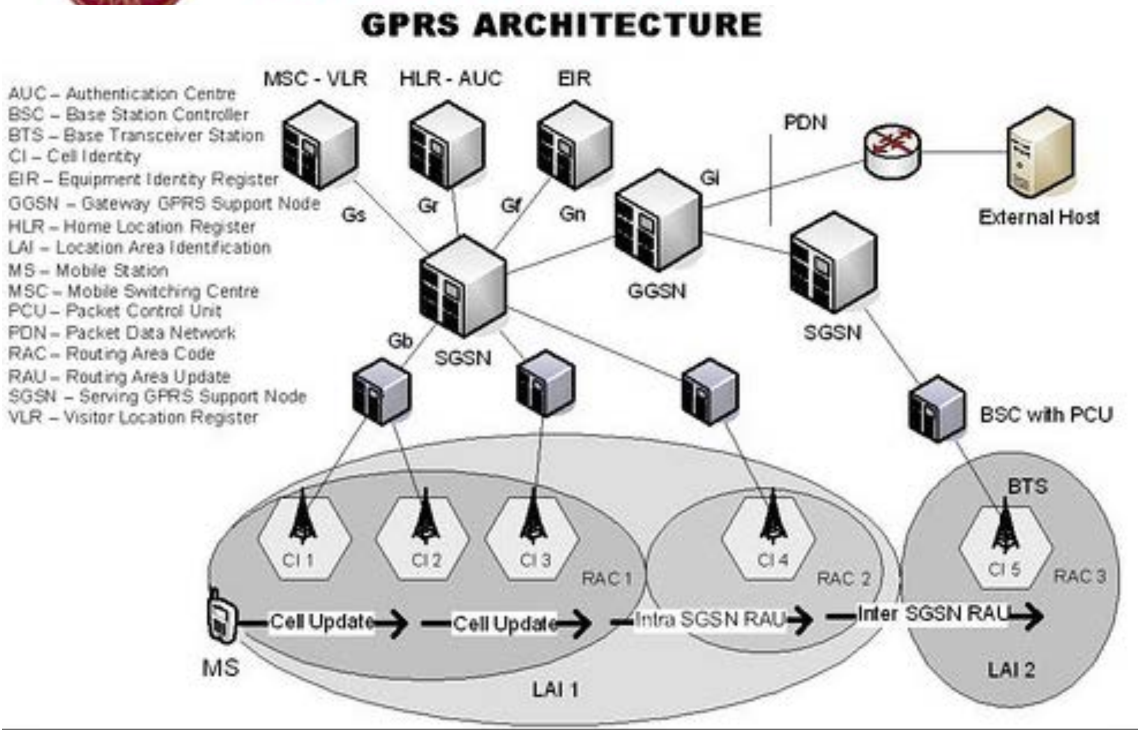
GPRS

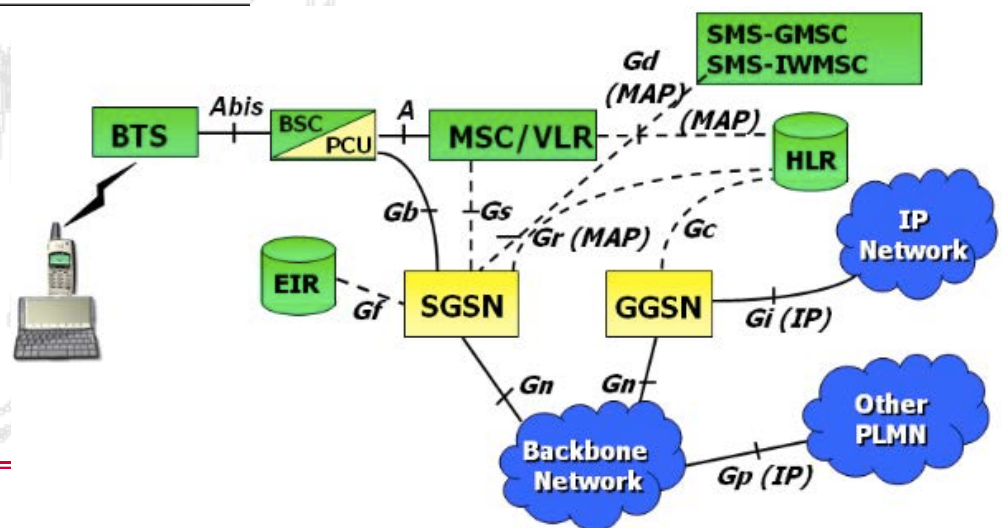
- Internet widespread use has raised the need to combine circuit switched and packet switched communication in cellular systems, and support data transmission (not only voice)
- The technology which has first supported this evolution is GPRS (General Packet Radio Service)
- IP backbone used for packet switching, integrated with the circuit switching networks

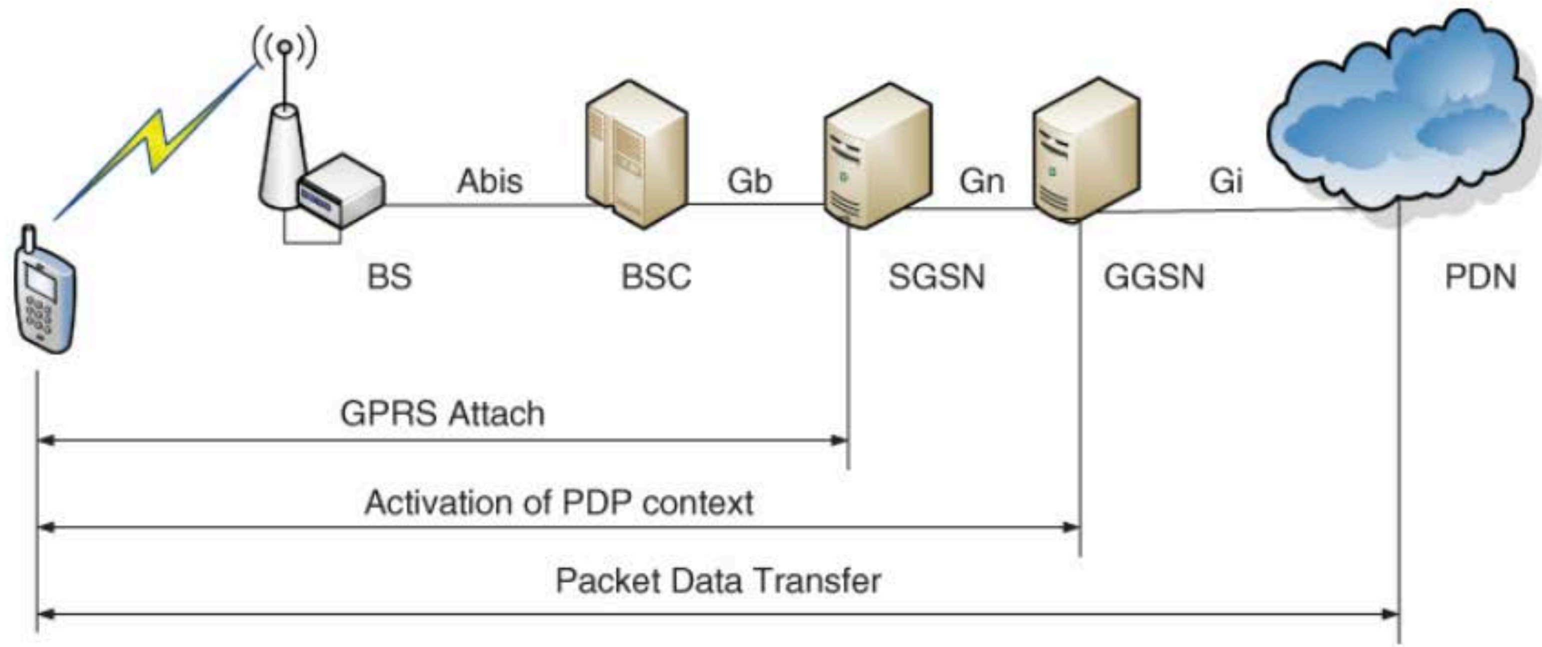
What changes in the architecture

- Added nodes to support packet switching data communication
- GSN (GPRS Support Node) are IP routers supporting mobility management)
  - SGSN (or Serving GPRS Support Node) route IP packets from/to a set of MS under their area
    - ✓ Area splitted in finer grain routing areas (localization is finer grain, at least at the routing area level)
  - GGSN (or Gateway GPRS Support Node) interfaces the cellular network with external packet data networks
  - SGSNs and GGSN interconnected through an IP backbone
  - Network elements must be associated IP addresses
- At the BSSS level a new functional entity is added denoted PCU or Packet Control Unit to manage data transmission over the radio links

What changes in the architecture







During PDP context activation the network provides an IP Address to the MS

PDP Context Activation

PDP Context Activation can be requested only after a static IP address is allocated to the MS.
PDP context contains
- PDP Type (e.g., IPV4)
- Requested QoS class
- The address of a GGSN that serves

As the access point to the external Network.
- PDP context is stored in all SGSN and
- GGSN

Multiple PDP Contexts can be created for The same user

Additional network elements

- PCU – Packet Control unit
  - Deals with dynamic resource allocation between GSM CS and GPRS, and to interconnect MS and SGSN for packet data exchange
    - ✓ Segmentation and reassembly
    - ✓ Physical channel scheduling
    - ✓ Error detection and management (ACK/NAK, buffering, retransmissions)
    - ✓ Access request management and resource allocation
    - ✓ Channel management (power control, congestion management, broadcasting of control messages etc.)

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Additional network elements

- SGNS-Serving GPRS Support Node
  - Handles user authentication and checks it is entitled to access the service; coordinates encryption.
  - Performs mobility management
  - Together with BSS radio resource management it reserves radio resources needed to support the requested QoS
  - Gathers information useful for billing
  - Routes information flows from/to the MS
  - Performs encapsulation and tunneling of packets
  - Performs logical connections management to/from the MS

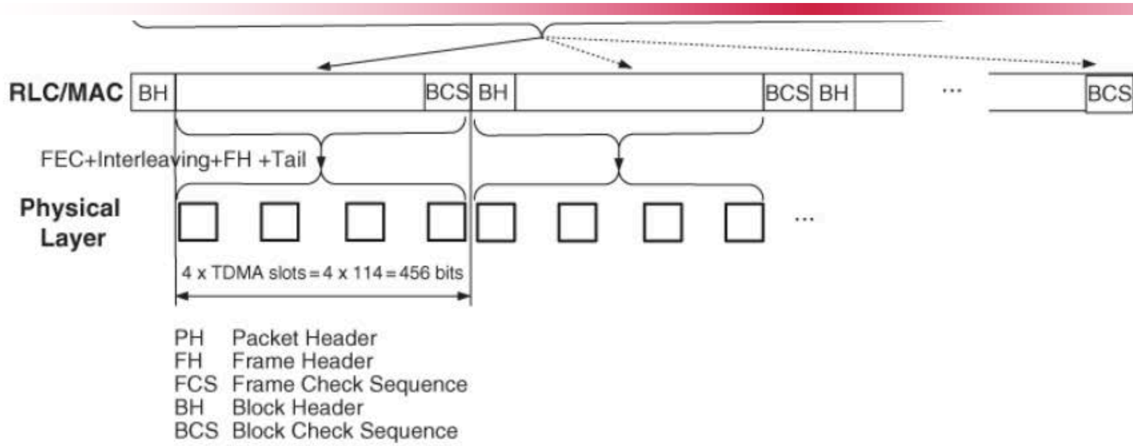
Additional network elements

- GGSN-Gateway GPRS Support Node
  - It interfaces the cellular operator network with external packet data networks
  - Performs routing tasks, encapsulation/decapsulation, analyzes and filters arriving messages, and gather info needed for accounting and billing
  - Stores in its location register the address of the SGSN who are serving the different MS, MS user profiles, and active/standby MS PDP context
    - ✓ Upon request it creates the PDP context: used protocol (e.g., IPv4), MS IP address, requested QoS,…

Physical and logical channels

- PDCH –Packet Data Channel← Physical channels allocated for data transmission
- Same FDMA/TDMA structure as in GSM
- PDCH is allocated only for the time needed to transmit data and then released.
- More information flows (up to 8) can be multiplexed over the same PDCH
- PDCH supports transmission of radio blocks
  - RLC/MAC block + Block Check Sequence
  - 456 bits transmitted in 4 normal bursts → 4 slots in consecutive frames
- More slots can be allocated in parallel to the same MS

Physical and logical channels



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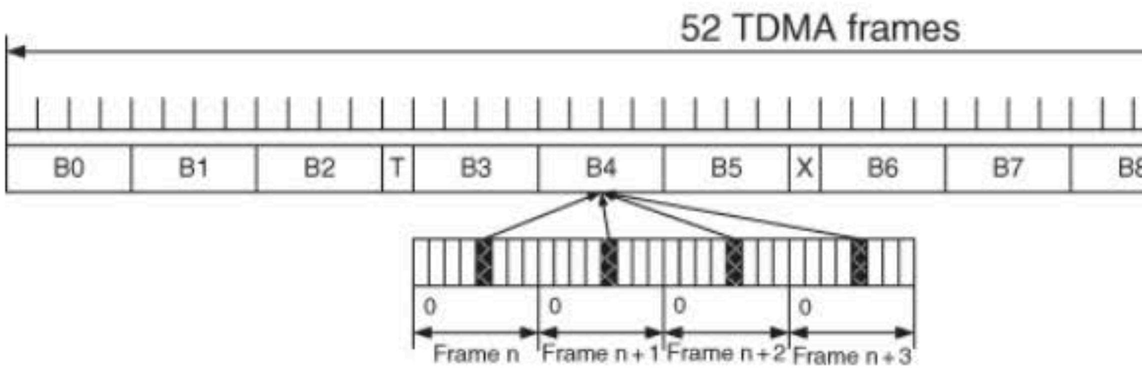
Radio Blocks, Multiplexing/demultiplexing



One radio block is allocated four slots in successive frames, that is, one block comprises 4 × 114 = 456 bits, see Figure 4.8. Most of the slots in a Packet Traffic Channel (PTCH) are used for data transfer (PDTCH: Packet Data Traffic Channel) but a small fraction of the slots is used for signalling via a PACCH (Packet Associated Control Channel)

Several subscribers may share a radio channel on the DL. Therefore, in each DL radio block a TFI is necessary for determining the owner of each packet.

The Packet Data Traffic Channel (PDTCH) is a channel resource allocated to a single MS on one physical channel for user data transmission. In multislot operation, one MS may use multiple time slots in parallel for individual packet transfer. PDCH is a unidirectional channel.

Several mobiles may also share a radio channel on the UL. These mobiles must be informed when it is their turn to send. Therefore, an additional parameter is sent in each DL radio block: the USF. It indicates which subscriber can send next on the relevant

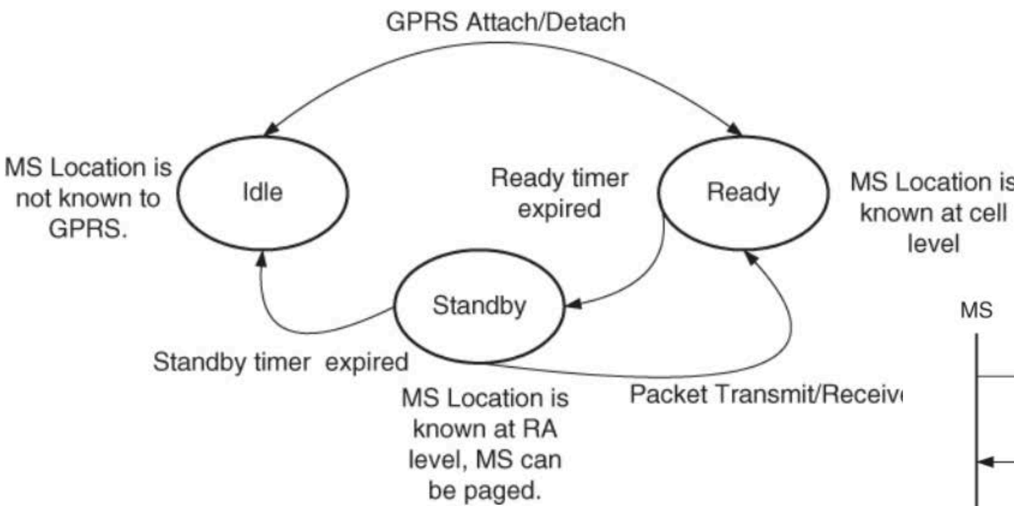
Physical and logical channels

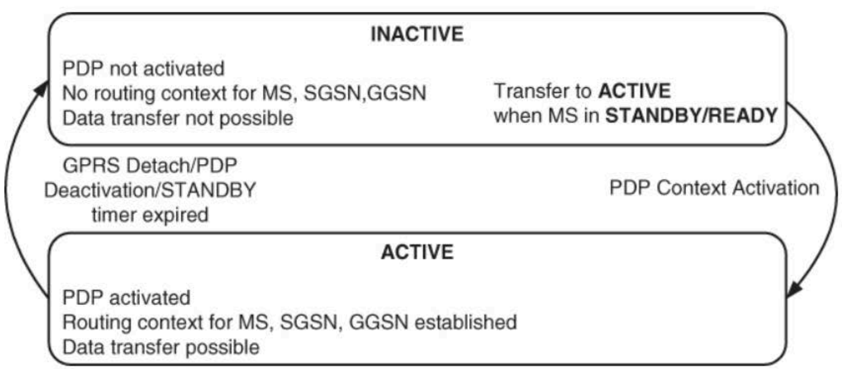
- Resource allocation:
  - the network allocates resources as a Temporary Flow Block (TBF), which has associated an identity (Temporary Flow Identity-TFI)
  - Before an MS can communicate it has to request a TBF
  - Once PDU have been transmitted the TBF is released
  - Statistical multiplexing: the network must allocate resources so that different flows can be multiplexed over the same physical channel
    - ✓ when communicating in downlink the network piggybacks the information or which MS should communicate in uplink in the next frame
    - ✓ scheduling

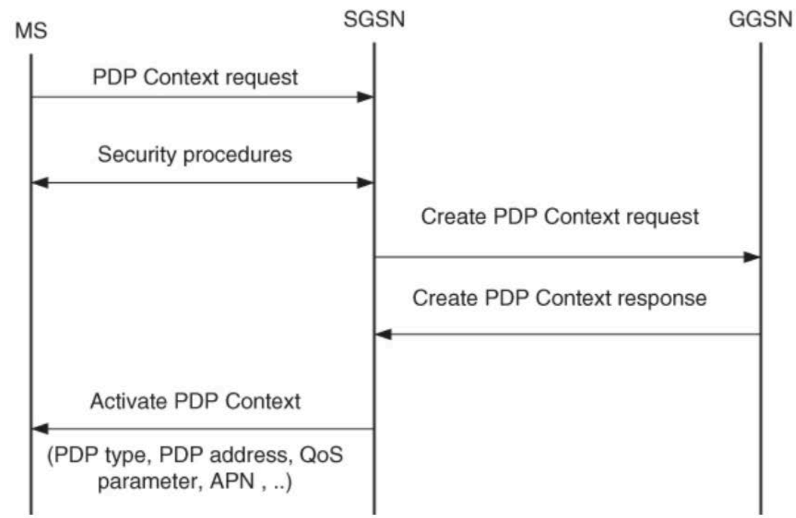
Physical and logical channels

- Control channels:
  - Packet Common Control Channels
    - ✓ PPCH - Packet Paging Channel
    - ✓ PRACH - Packet Random Access
    - ✓ PACGH - Packet Access Grant Channel
    - ✓ PNCH - Packet Notification Channel → downlink channel used to notify a group of MS that there is traffic for them (point to multipoint – multicast)
  - [Packet Broadcast Control Channel – PBCCH]
  - Dedicated control channels
    - ✓ PACCH – Packet Associated Control Channel. Bidirectional channel over which control information associated to one or more PDTCH are transmitted
      - info transmitted: power control, ACK/NAK, reassignment of resources, assignment of a downlink PDTCH for MS using an uplink PDTCH,…
    - ✓ Packet Timing Advance Control Channel

PDP Context Activation







MS States

- Ready: Location of an MS known at cell level. Data exchange without paging.
- Standby: State entered after some inactive period. Location area is divided into routing areas (RA). In standby it is likely that it maybe needed to page a user and start exchange data again so info on its position is maintained at the level of routing area (for packet exchange only). If data exhange MS moves back to Ready;
- Idle: After an MS detach or after a timer expires in Standby (no exchange of data in Standy) MS move to Idle. Info on location if known at LA level.

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Cellular systems: 3G systems

Universal Mobile Telecommunication System

Wireless Systems, a.a. 2016/2017

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3G objective

- Objective: overcome bandwdith/data rate limitations of 2G/2G+ systems (reaching Mbps)
- Full support of a variety of services and of multimedia applications
  - different classes of traffic
  - Heterogeneous QoS demands
  - QoS support

Traffic class	Conversational class	Streaming class	Interactive class	Background
Fundamental characteristics	Preserve time relation between information entities of the stream Conversational pattern (stringent and low delay)	Preserve time relation between information entities of the stream	Request response pattern Preserve data integrity	Destination is not expecting the data within a certain time Preserve data integrity
Example of the application	Voice, videotelephony, video games	Streaming multimedia	Web browsing, network games	Background download of emails

- Integration of mobile and satellite communications

3G features

- Hierarchical organization: Macrocell→Microcell→Picocell
- 3G bandwdith: 1885-2025Mhz; 2110-2200Mhz (155MHz for terrestrial and 75Mhz for satellite networks)
  - Splitted into 5MHz channels
  - TDD and FDD to divide resources among uplink and downlink
  - Support also of asymmetric services
  - Increase of bandwidth to 500MHz planned from the beginning

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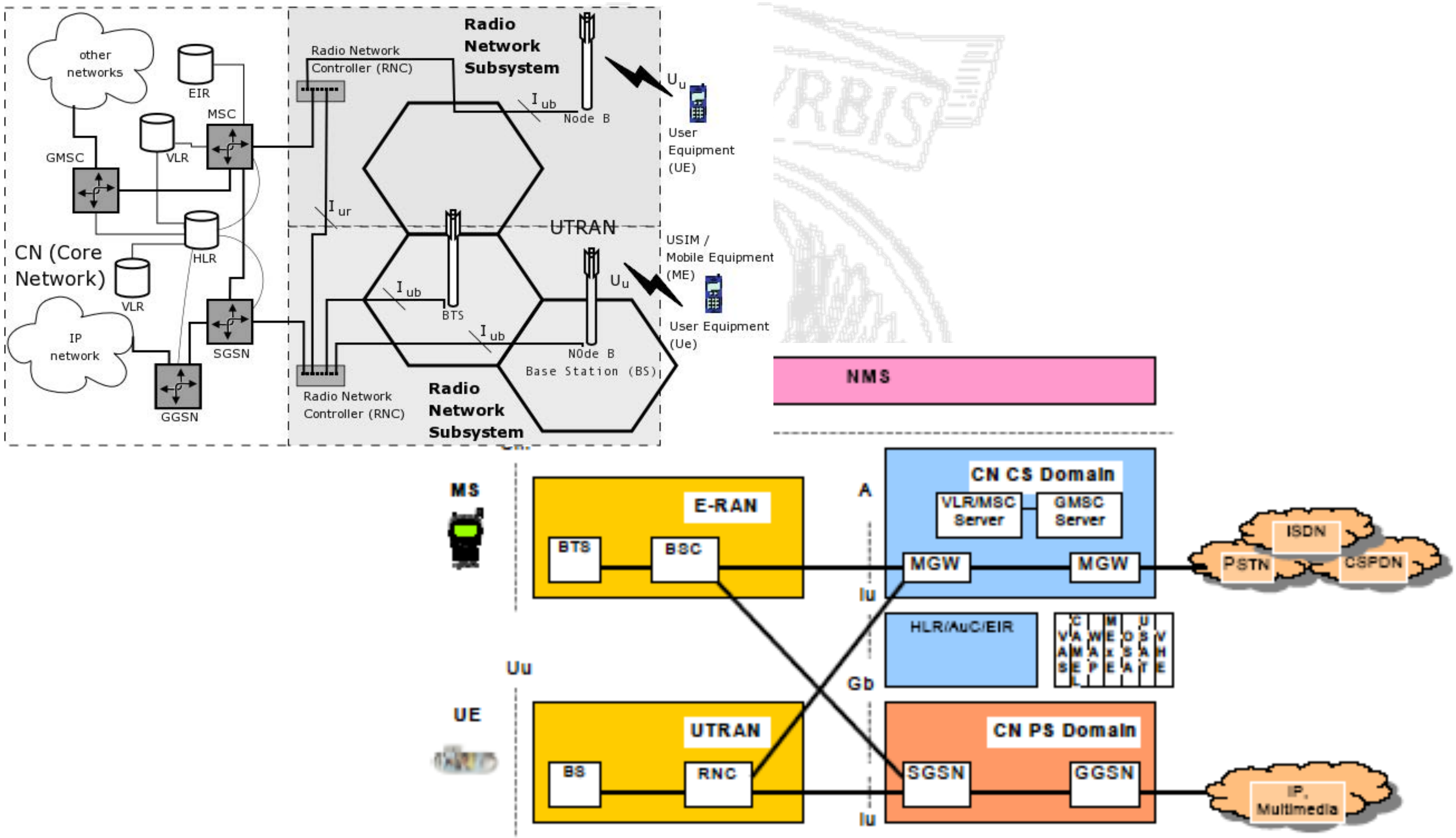
3G architecture



UTRAN functions

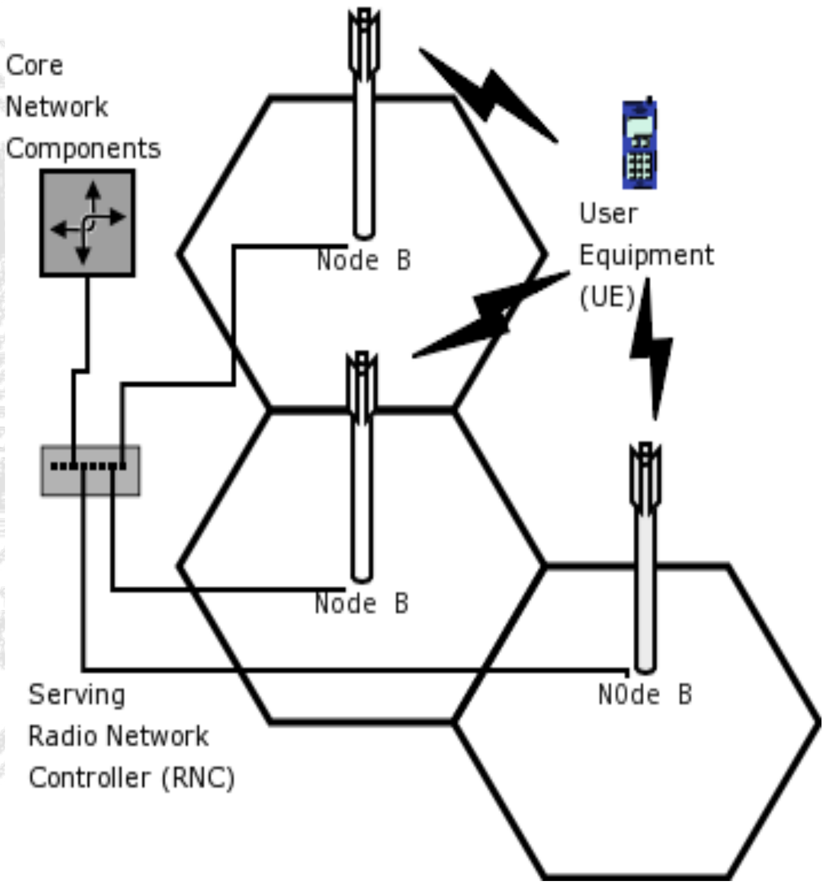
- UTRAN functions
  - Controls cell capacity and interference in order to provide an optimal utilization of the wireless interface resources
  - Includes Algorithms for Power Control, Handover, **Packet Scheduling, Call Admission Control and Load Control**
  - Encryption of the radio channel
  - Congestion control to handle situations of network overload
  - System information broadcasting
  - Micro and macro diversity

UTRAN functions

- Network based functions
  - Packet Scheduling
    - ✓Controls the UMTS packet access
    - ✓Handles all non real time traffic, (packet data users)
    - ✓Decides when a packet transmission is initiated and the bit rate to be used
  - Load Control
    - ✓Ensures system stability and that the network does not enter an overload state
  - Admission control to avoid network overload
    - ✓Decides whether or not a call is allowed to generate traffic in the network

Macrodiversity

- Same data stream is sent over different physical channels
- Uplink – UE sends its data to different Node B
- Data stream is reassembled, reconstructed in Node B, SRNC or NC
- Downlink – receiving same data from different cells on different spread codes



CDMA

- unique "code" assigned to each user; i.e., code set partitioning
- all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

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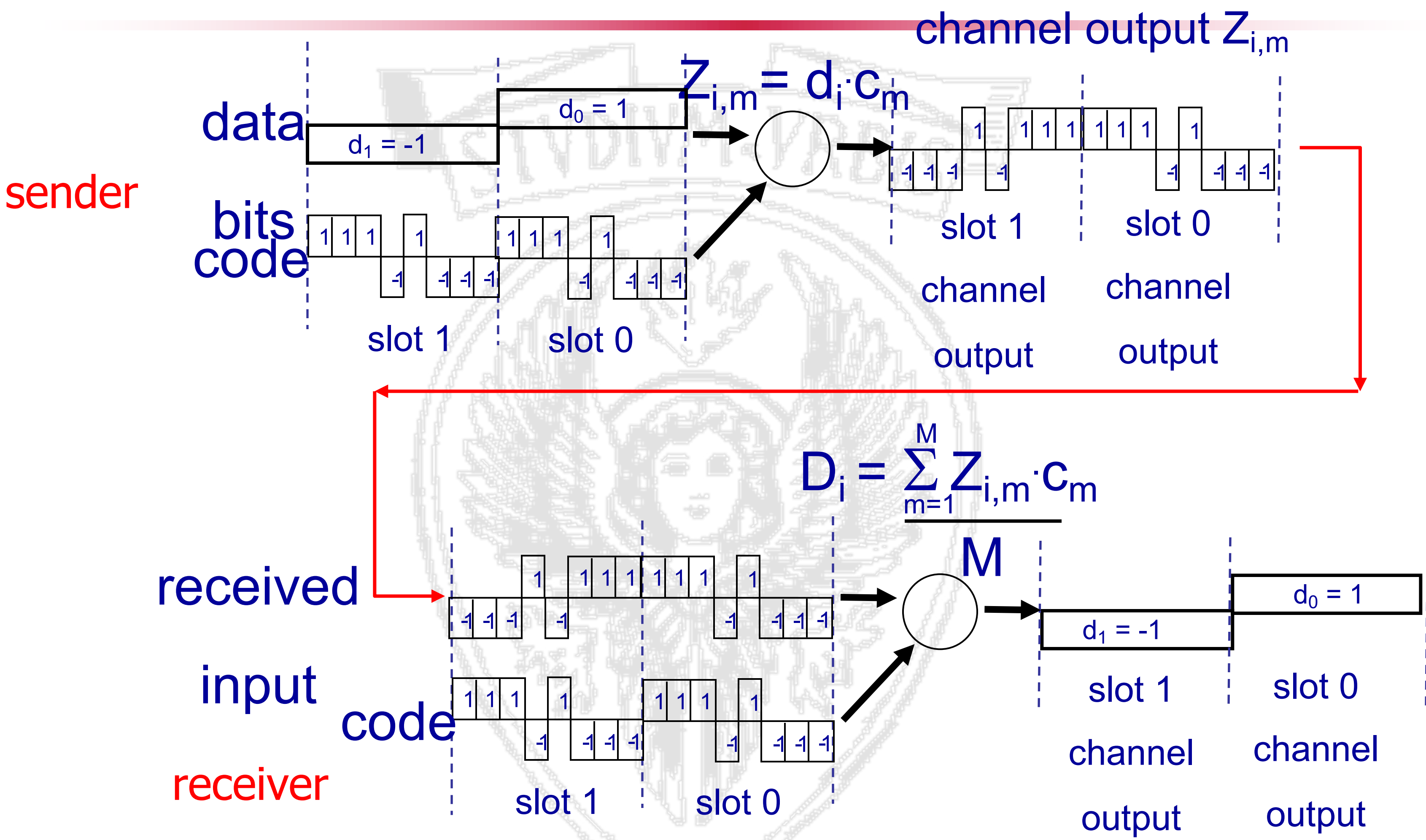
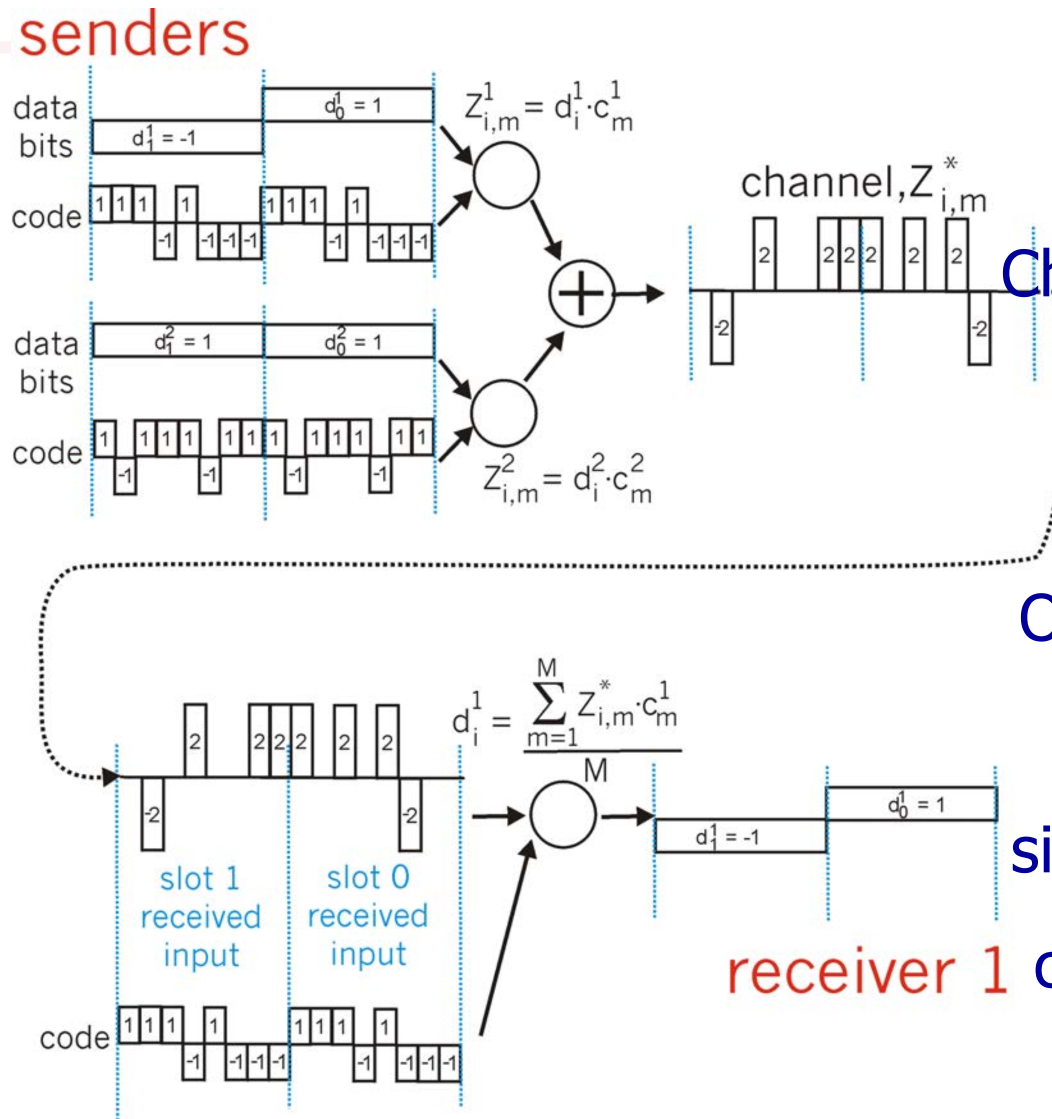
CDMA Encode/Decode



CDMA: two-sender interference



Chipping codes must be orthogonal

Other requirements such as the fact signals arrivere with comparable power

Cellular systems: 4G

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Emerging needs

- Requirements for LTE (2005)
  - Increased user data rates
  - Uniformity of service provisioning (even at cell edge)
  - Improved spectral efficiency
  - Greater flexibility of spectrum usage
  - Reduced delays (connection establishment and transmission latency)
  - Low energy consumption at the mobile
  - Seamless mobility and simplified network architecture
- Cellular systems aggregated data rate:

Bandwidth * Spectral efficiency

Bandwidth: Regulation and licences — ITU-R, FCC, regional regulators

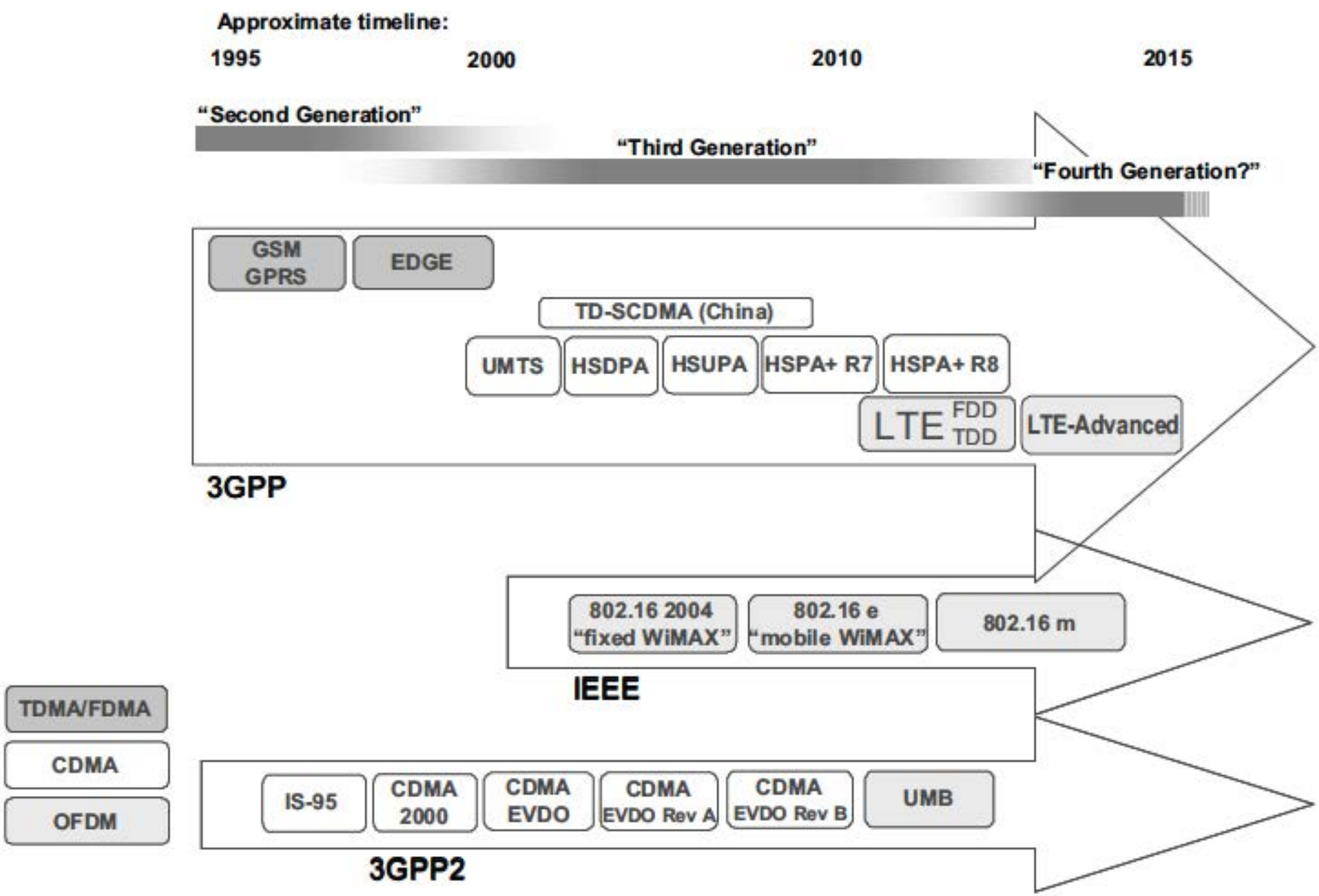
High cost of spectrum
Licences, spectrum almost completely allocated

Spectral efficiency: Technology and standards

		Absolute requirement	Comparison to Release 6	Comment
Downlink	Peak transmission rate	> 100 Mbps	7 × 14.4 Mbps	LTE in 20 MHz FDD, 2 × 2 spatial multiplexing. Reference: HSDPA in 5 MHz FDD, single antenna transmission
	Peak spectral efficiency	> 5 bps/Hz	3 bps/Hz	
	Average cell spectral efficiency	> 1.6 – 2.1 bps/Hz/cell	3 – 4 × 0.53 bps/Hz/cell	LTE: 2 × 2 spatial multiplexing, Interference Rejection Combining (IRC) receiver [3]. Reference: HSDPA, Rake receiver [4], 2 receive antennas
	Cell edge spectral efficiency	> 0.04 – 0.06 bps/Hz/user	2-3 × 0.02 bps/Hz	As above, 10 users assumed per cell
	Broadcast spectral efficiency	> 1 bps/Hz	N/A	Dedicated carrier for broadcast mode
Uplink	Peak transmission rate	> 50 Mbps	5 × 11 Mbps	LTE in 20 MHz FDD, single antenna transmission. Reference: HSUPA in 5 MHz FDD, single antenna transmission
	Peak spectral efficiency	> 2.5 bps/Hz	2 bps/Hz	
	Average cell spectral efficiency	> 0.66 – 1.0 bps/Hz/cell	2 – 3 × 0.33 bps/Hz	LTE: single antenna transmission, IRC receiver [3]. Reference: HSUPA, Rake receiver [4], 2 receive antennas
	Cell edge spectral efficiency	> 0.02 – 0.03 bps/Hz/user	2 – 3 × 0.01 bps/Hz	As above, 10 users assumed per cell
System	User plane latency (two way radio delay)	< 10 ms	One fifth	
	Connection set-up latency	< 100 ms		Idle state → active state
	Operating bandwidth	1.4 – 20 MHz	5 MHz	(initial requirement started at 1.25 MHz)
	VoIP capacity	NGMN preferred target expressed in [2] is > 60 sessions/MHz/cell		

Standard Evolution

- GSM/GPRS/EDGE ← TDMA/FDMA based, designed for voice, extended for data



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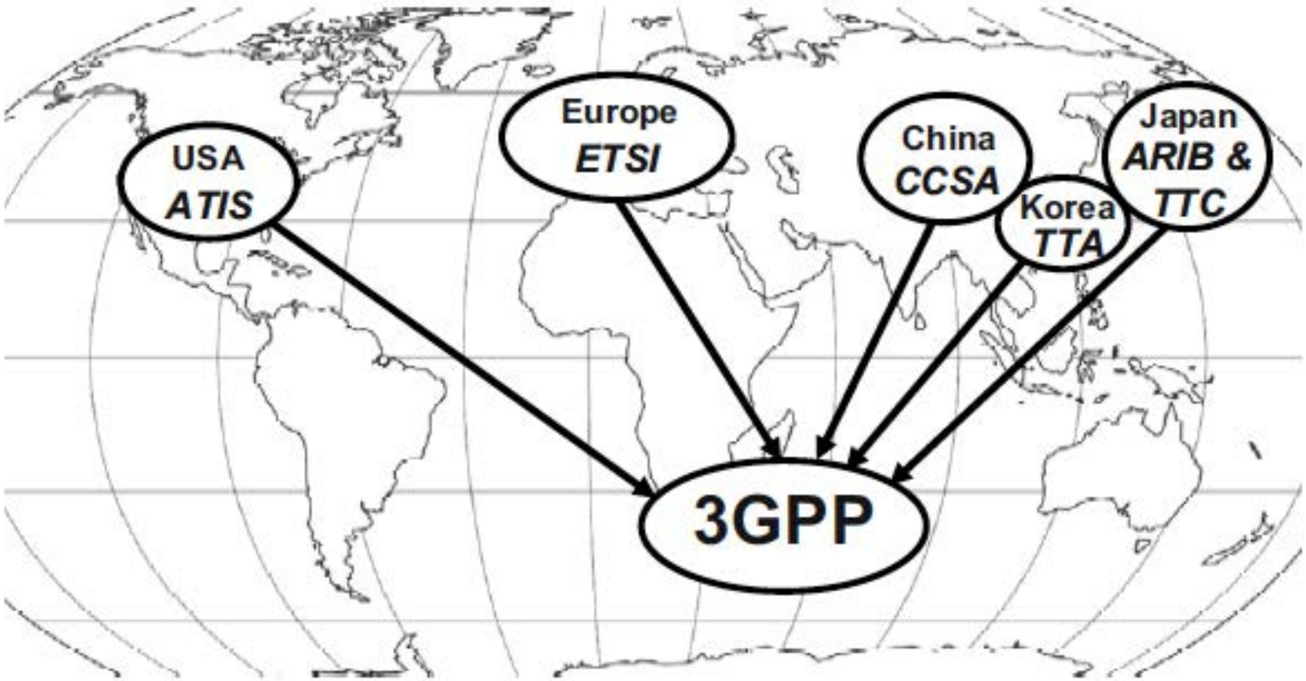
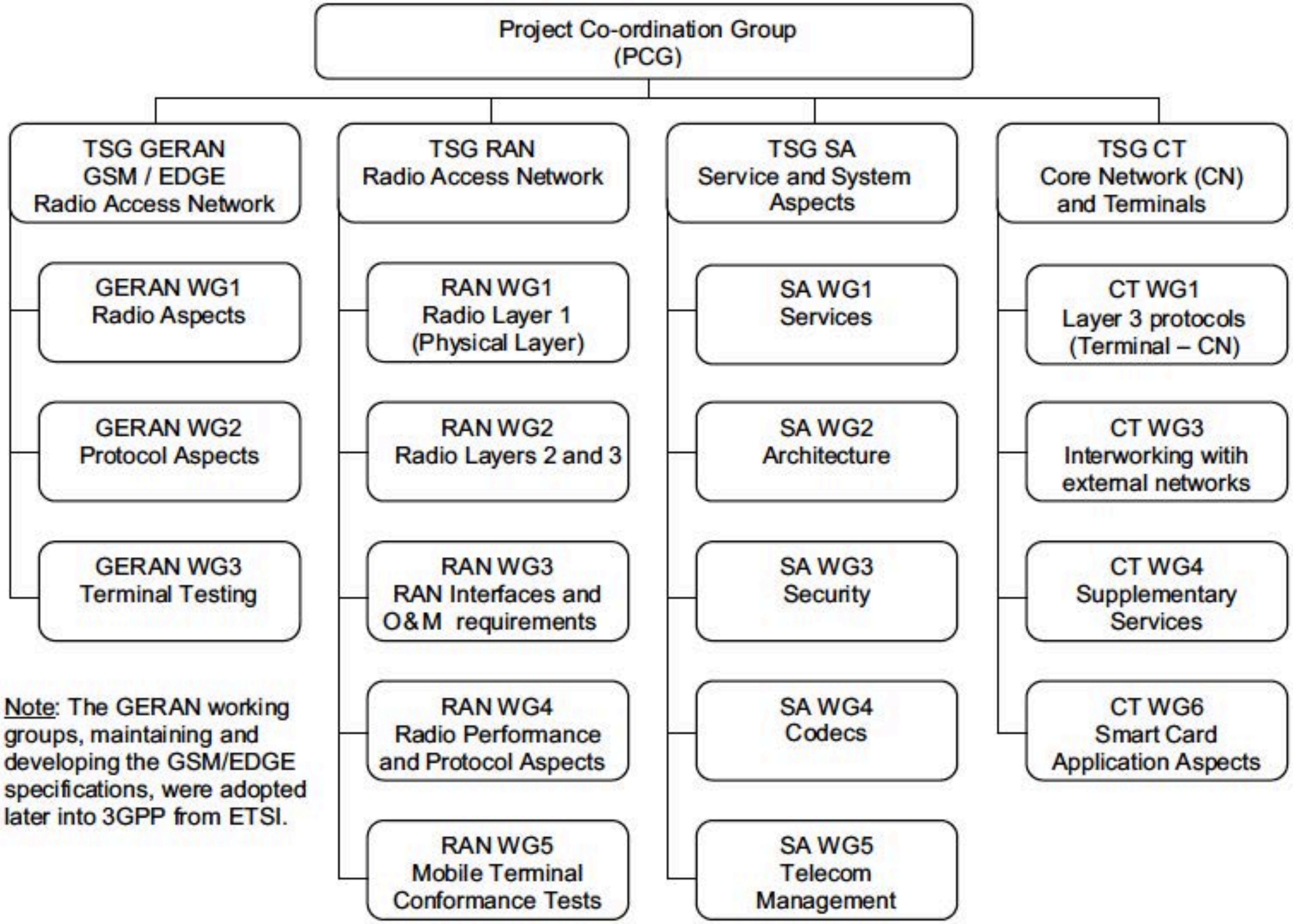


Specification through consensus in Working Groups part of

Technical Specification Groups ←accounting for performance, implementation cost, complexity, backward compatibility

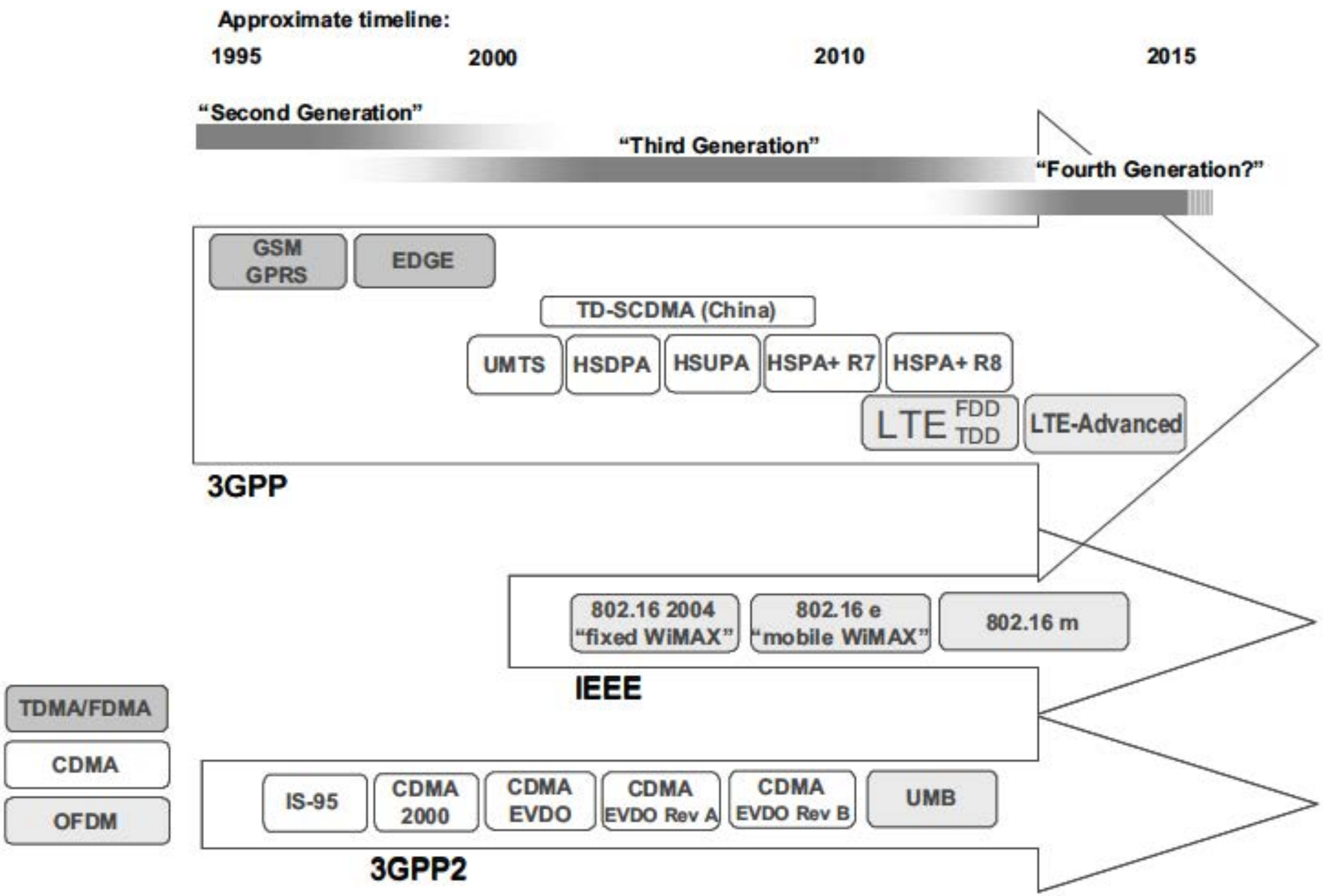
Standardization



Note: The GERAN working groups, maintaining and developing the GSM/EDGE specifications, were adopted later into 3GPP from ETSI.

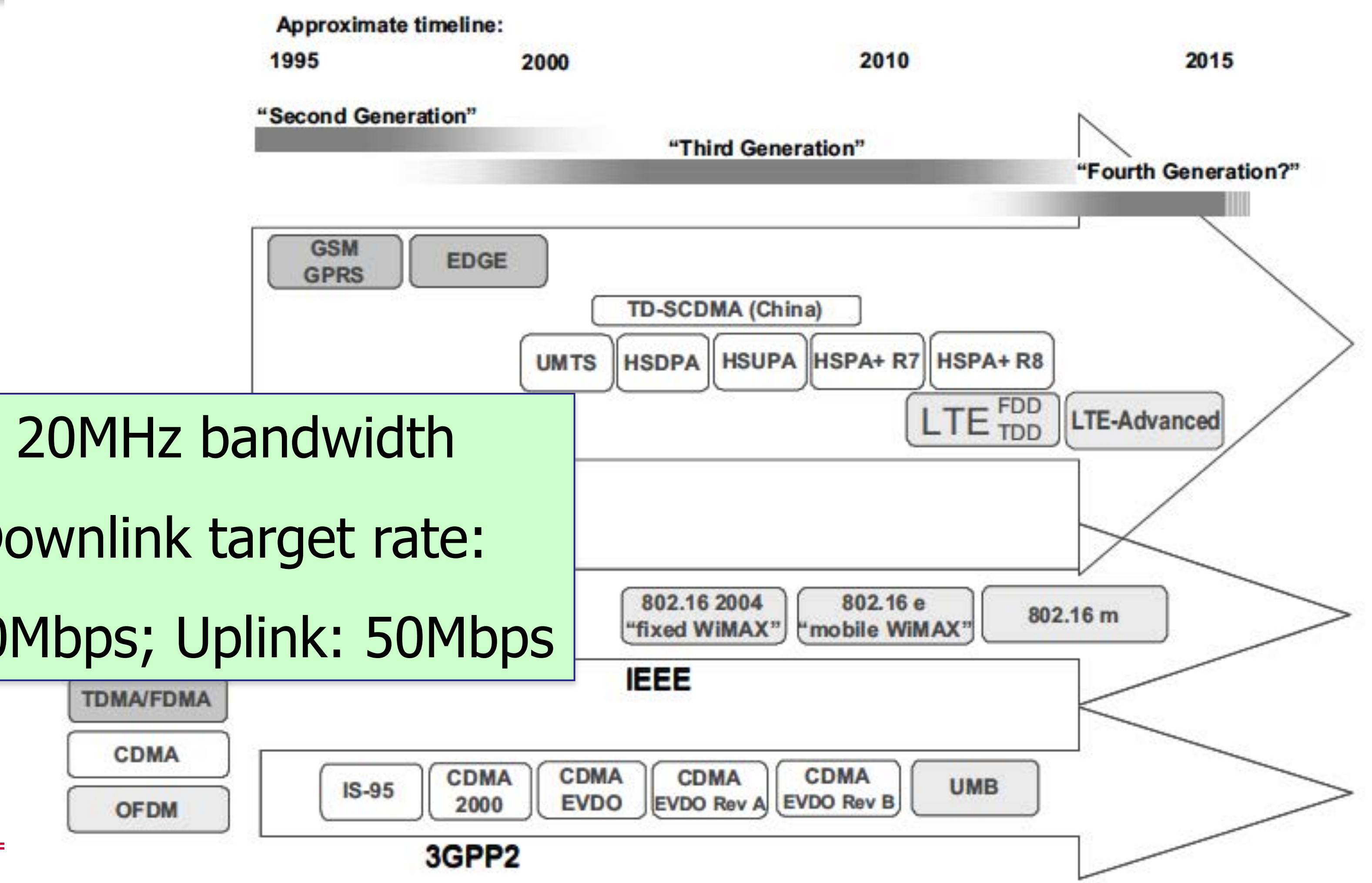
Standard Evolution

- UMTS ← CDMA based, up to high frequency, MIMO, multiservice support



Standard Evolution

- LTE←OFDM based, designed from the very beginning based on a packet switched model, complete realization of the multiservice model



20MHz bandwidth

Downlink target rate:

100Mbps; Uplink: 50Mbps

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System	VoIP capacity	NGMN preferred target expressed in [2] is > 60 sessions/MHz/cell		

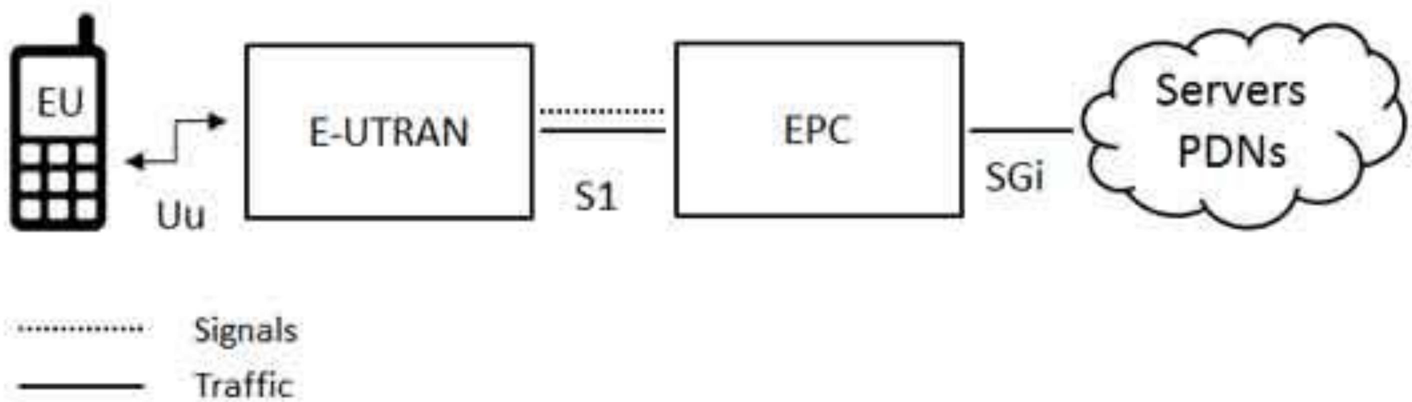
- Requirements for LTE
  - Able to operate in a wide range of frequency bands and sizes of spectrum allocations (from 1.4 up to 20MHz per carrier)
  - Fast connection time (less than 100ms), at least 200 active state users per cell supported by control signaling up to 5MHz and at least 400 users per cell for wider spectrum allocation, one way packet latency =5ms in light traffic.
  - Increased peak rate, uniform performance (requirements on cell edge performance as 5° percentile of performance)
  - Support of mobility up to 350-500Km/h, cells radius 5-100Km
  - Flexible interoperation with other radio access technologies (service continuity in the migration phase), in particular earlier 3GPP technologies, and non 3GPP technologies (WiFi, CDMA 2000, WiMax)
  - Low terminal complexity and power consumption
  - Cost effective deployment
    - ✓ One type of node, the BS, named eNodeB
    - ✓ Open interfaces, multivendor interoperability
    - ✓ Self optimization and easy management
    - ✓ Packet switched services
    - ✓ Easy deployment and configuration of home base station

Technologies for LTE

- Multicarrier technology
  - OFDMA for downlink+ SC-FDMA for uplink
    - ✓ Flexible, adaptable, robust
    - ✓ Low complexity receivers
- Multiantenna technology
- Packet switching
  - System architecture evolution
    - ✓ Concept of Evolved packet system bearer to route IP packets from a gateway of the Packet Data Network to the User Equipment
      - Internet traffic, VoIP traffic
    - ✓ Bearer = IP packet flow with a given QoS between the gateway and the UE (set up and released by the radio access and the evolved packet core together)
      - Multiple bearers can be established for an end user providing different QoS

Network architecture

- The high-level network architecture of LTE is comprised of following three main components:
  - The User Equipment (UE).
  - The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN).
  - The Evolved Packet Core (EPC).

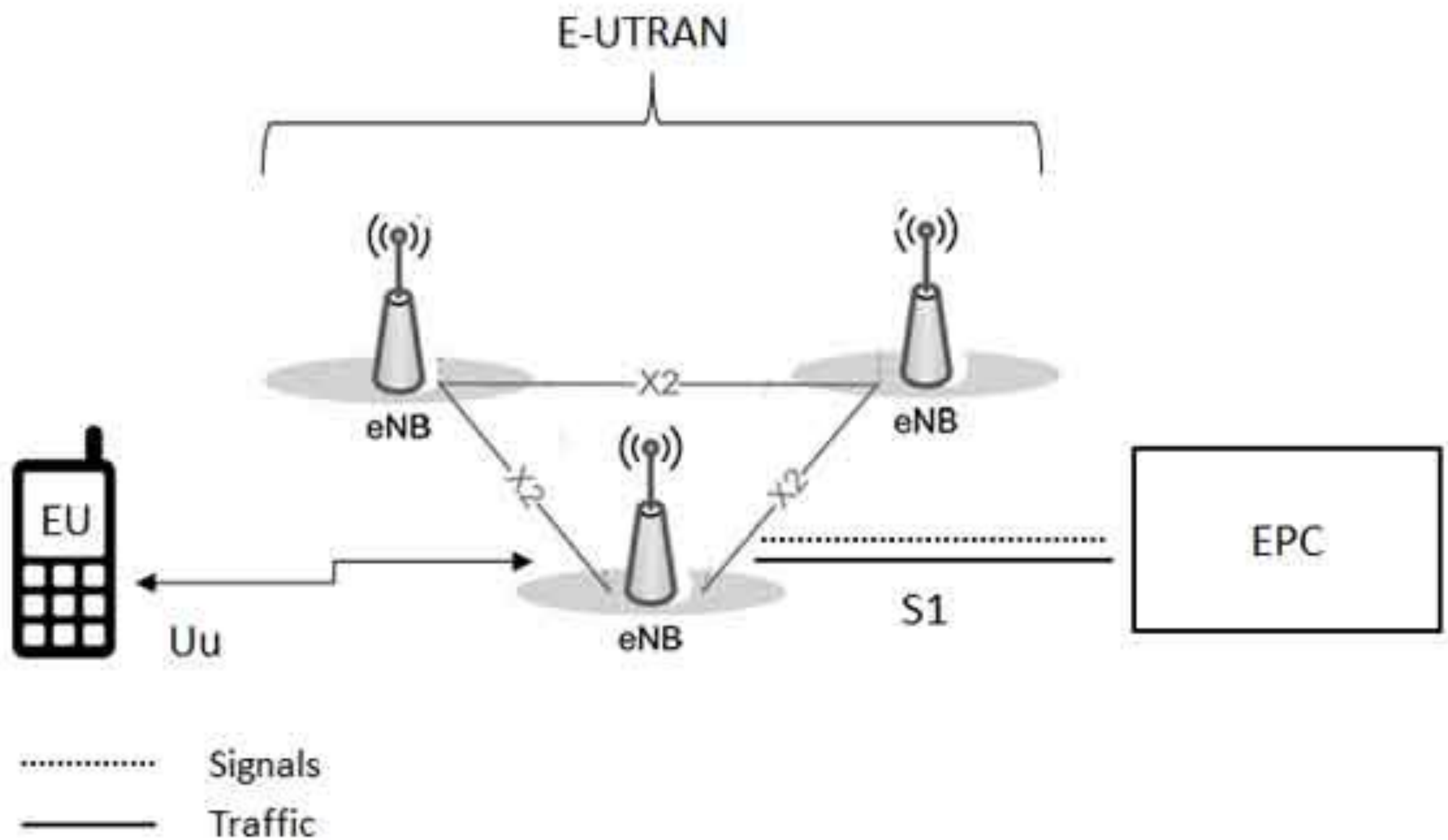


Access Network

Core network

Network architecture

E-UTRAN



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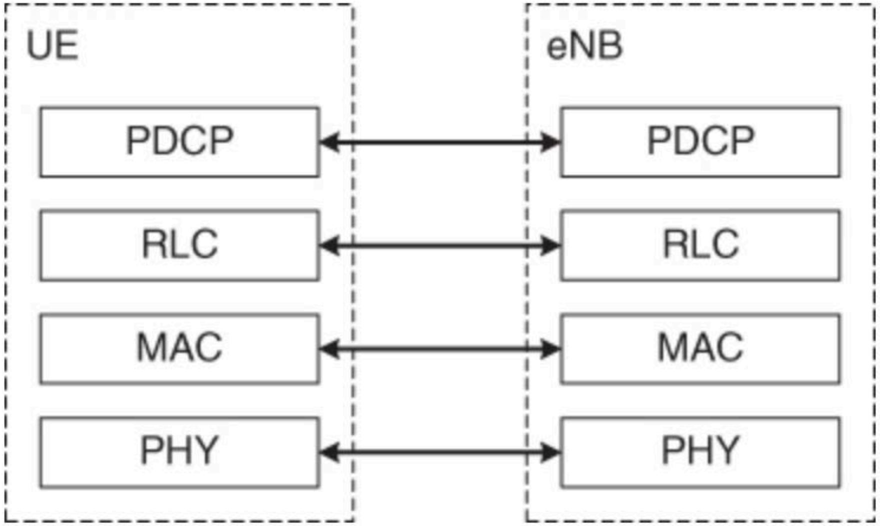
Handles radio communication between the UE and EPC

Comprises only evolved base station →eNB or eNodeB

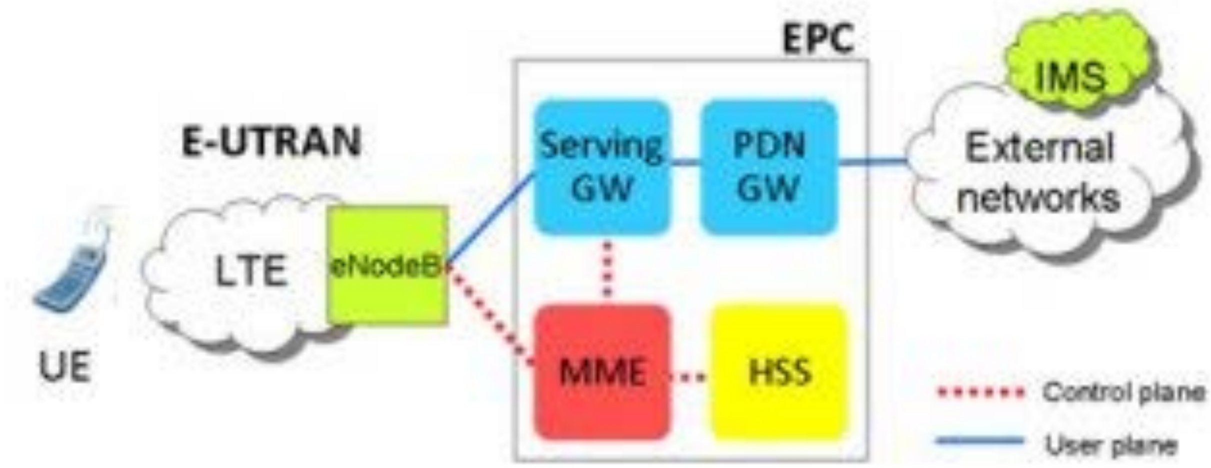
RAN Architecture



The scheduler is a part of the eNodeB MAC layer, it controls the assignment of uplink and downlink resources in terms of resource-block pairs in time and the frequency domain. The

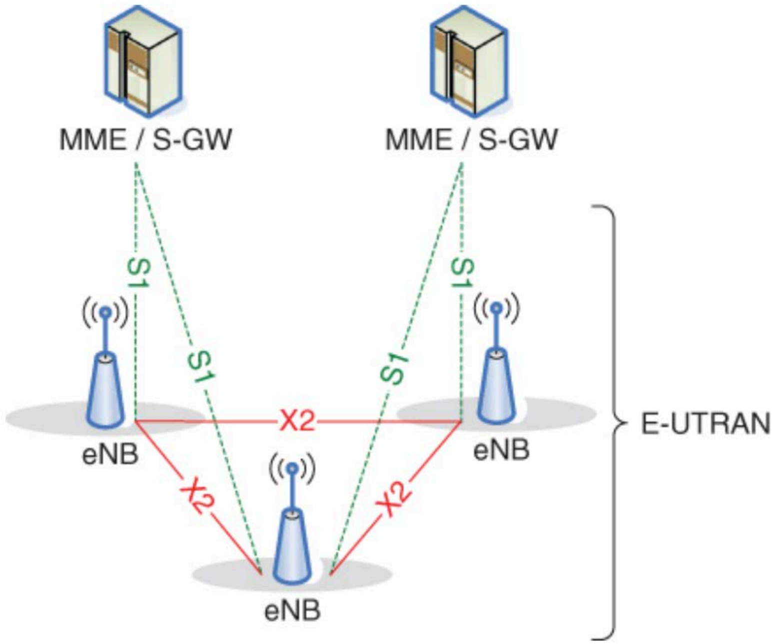
- PDCP performs IP header compression and produces output PDCP-PDU.
- The RLC protocol is responsible for segmenting (and concatenation on uplink) of the PDCP-PDUs for radio interface transmission. It also performs error correction with the Automatic Repeat Request (ARQ) method.
- Medium Access Control (MAC): The MAC layer is responsible for scheduling the data according to priorities and multiplexing data to Layer 1 transport blocks. The MAC layer also provides error correction with Hybrid-ARQ.
- PHY performs coding, modulation, antenna and resource mapping.

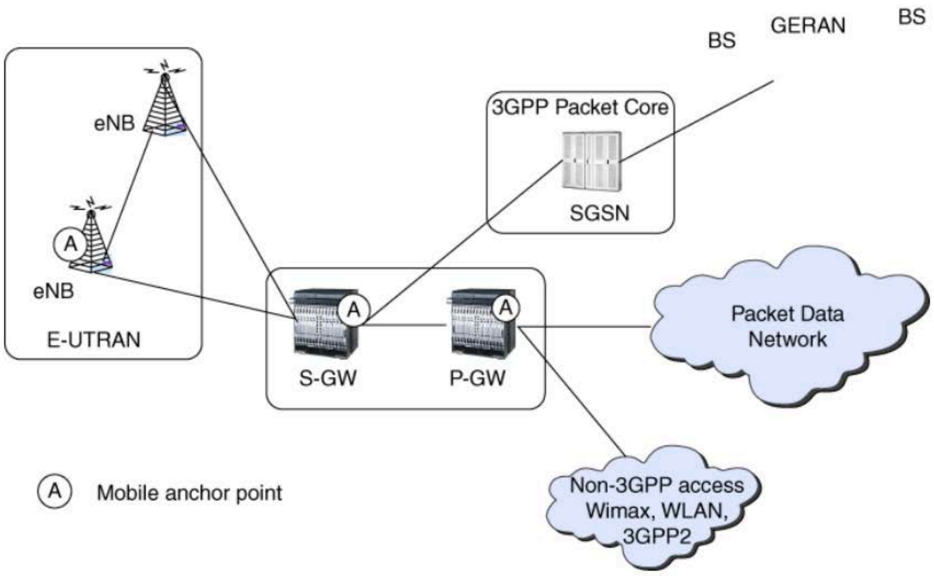
Network architecture



- HSS (Home Subscriber Server)
  - User subscription data, PDNs to which the user can connect, identity of the MME the user is connected to, authentication center
  - HLR+AuC
- P-GW: IP address allocation to UE+ QoS enforcement in downlink+interworking with non 3GPP technologies
- S-GW:tranports the IP data traffic between the User Equipment and the external networks.
- MME (Mobility Management Entity): connection set up including paging within a tracking area; security

LTE Architecture

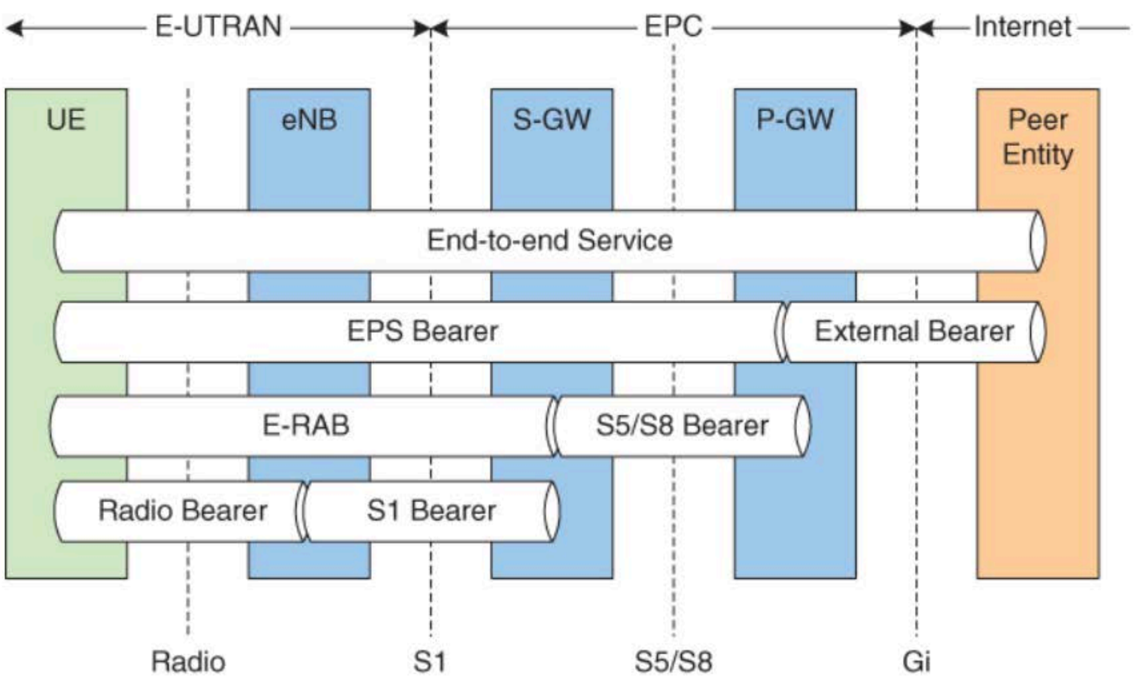




QoS and bearers

- Bearers
  - Minimum guaranteed bit rate
  - Non GBR bearers
- The eNodeB in the access network ensures the necessary QoS for a bearer over the radio interface
- Each bearer has an associated QoS Class Identifier and an Allocation and Retention Priority(the latter used for call admission)
  - QCI: priority, packet delay budget, acceptable packet loss rate
  - Determining how to perform scheduling, which queue management policy to use, with which priority

QoS Support



4	5	300 ms	1.00E-06	Non-conversational video (buffered streaming)	
65	0.7	75 ms	1.00E-02	Mission critical user-plane push to talk voice (e.g. MCPTT)	
66	2	100 ms	1.00E-02	Non-mission-critical user-plane push to talk voice	
75	2.5	50 ms	1.00E-02	V2X messages	
5	1	100 ms	1.00E-06	IMS signalling	
6	6	300 ms	1.00E-06	Video (buffered streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)	
7		100 ms	1.00E-03	Voice, Video (live streaming) interactive gaming	Non-GBR
8	8	300 ms	1.00E-06	Video (buffered streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video etc.)	
9	9	300 ms	1.00E-06	Video (buffered streaming) TCP-based (e.g. www, e-mail, chat, ftp, p2p file sharing, progressive video etc.)	
69	0.5	60 ms	1.00E-06	Mission critical delay sensitive signalling (e.g. MC-PTT signalling)	

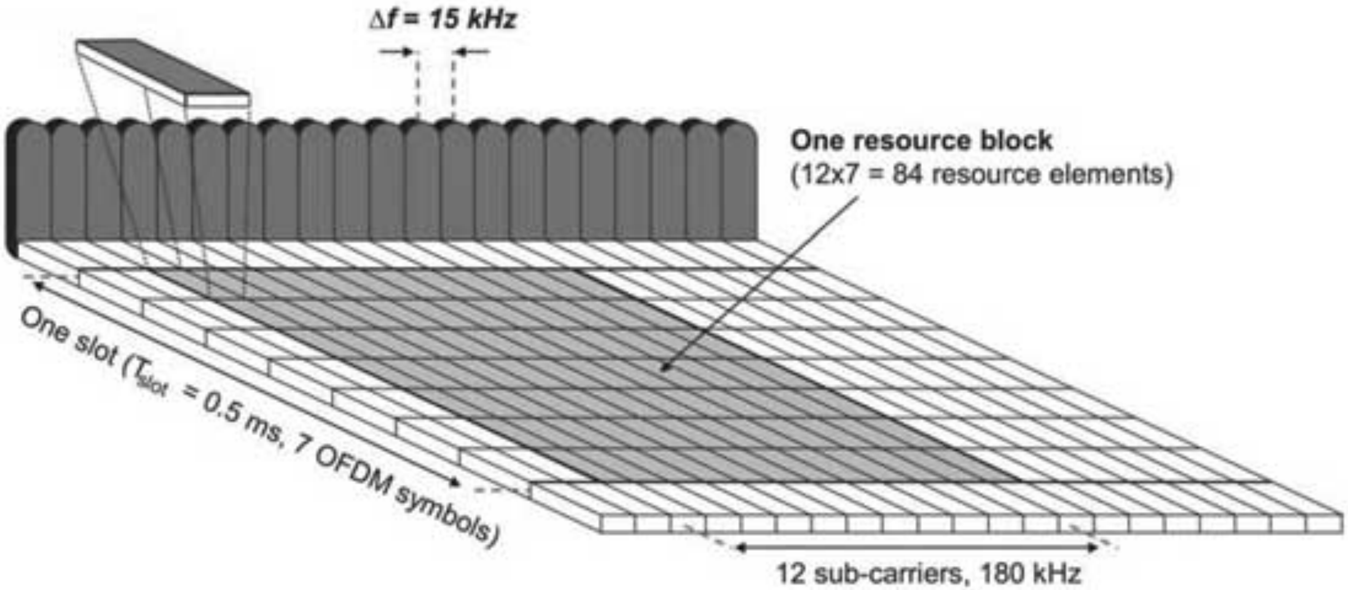
70	5.5	200 ms	1.00E-06	Mission critical data (example services are the same as QCI 6/8/9)	
79	6.5	50 ms	1.00E-02	V2X messages	

Scheduling

- The scheduler in the eNodeB distributes the available radio resources in one cell among the UEs, and among the radio bearers of each UE.
- eNodeB allocates downlink or uplink radio resources to each UE based on the downlink data buffered in the eNodeB and on Buffer Status Reports (BSRs) received from the UE, and based on channel quality indicator reports.
- eNodeB considers the QoS requirements of each configured radio bearer
  - *dynamic scheduling*: assignment of downlink transmission resources and uplink grant messages for the allocation of uplink transmission resources;
    - ✓ valid for specific single subframes, tx on Physical Downlink Control Channel
  - *persistent scheduling*: resources are semi-statically configured and allocated to a UE for a longer time period

Resource blocks and OFDMA

- LTE is based on orthogonal frequency-division multiplexing (OFDM)
- The OFDM symbols are grouped into resource blocks. The resource blocks have a total size of 180kHz in the frequency domain and 0.5ms in the time domain.



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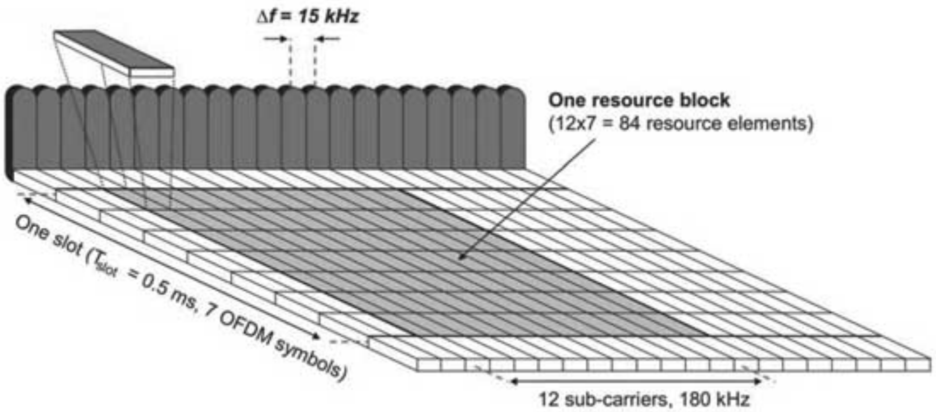
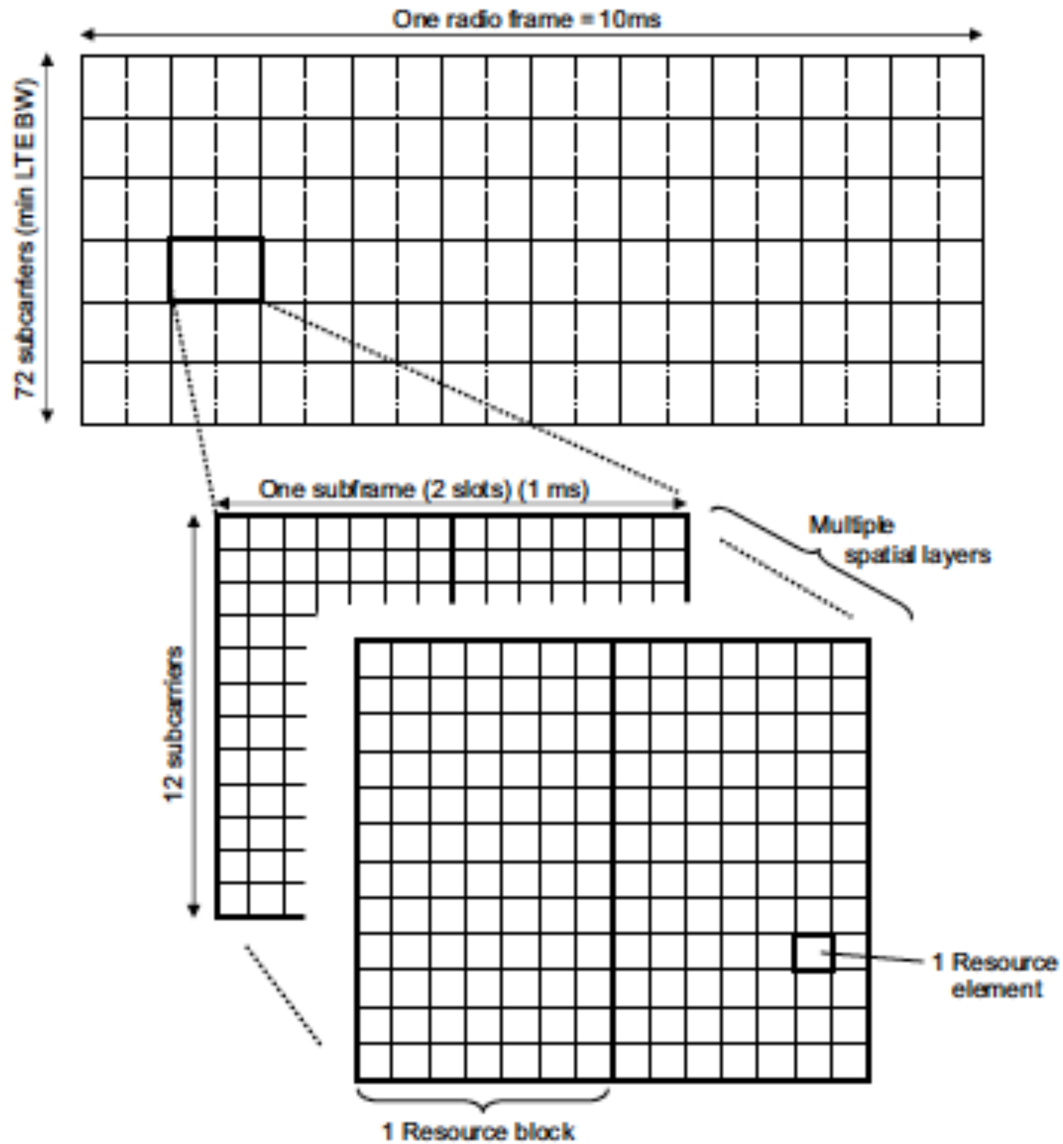
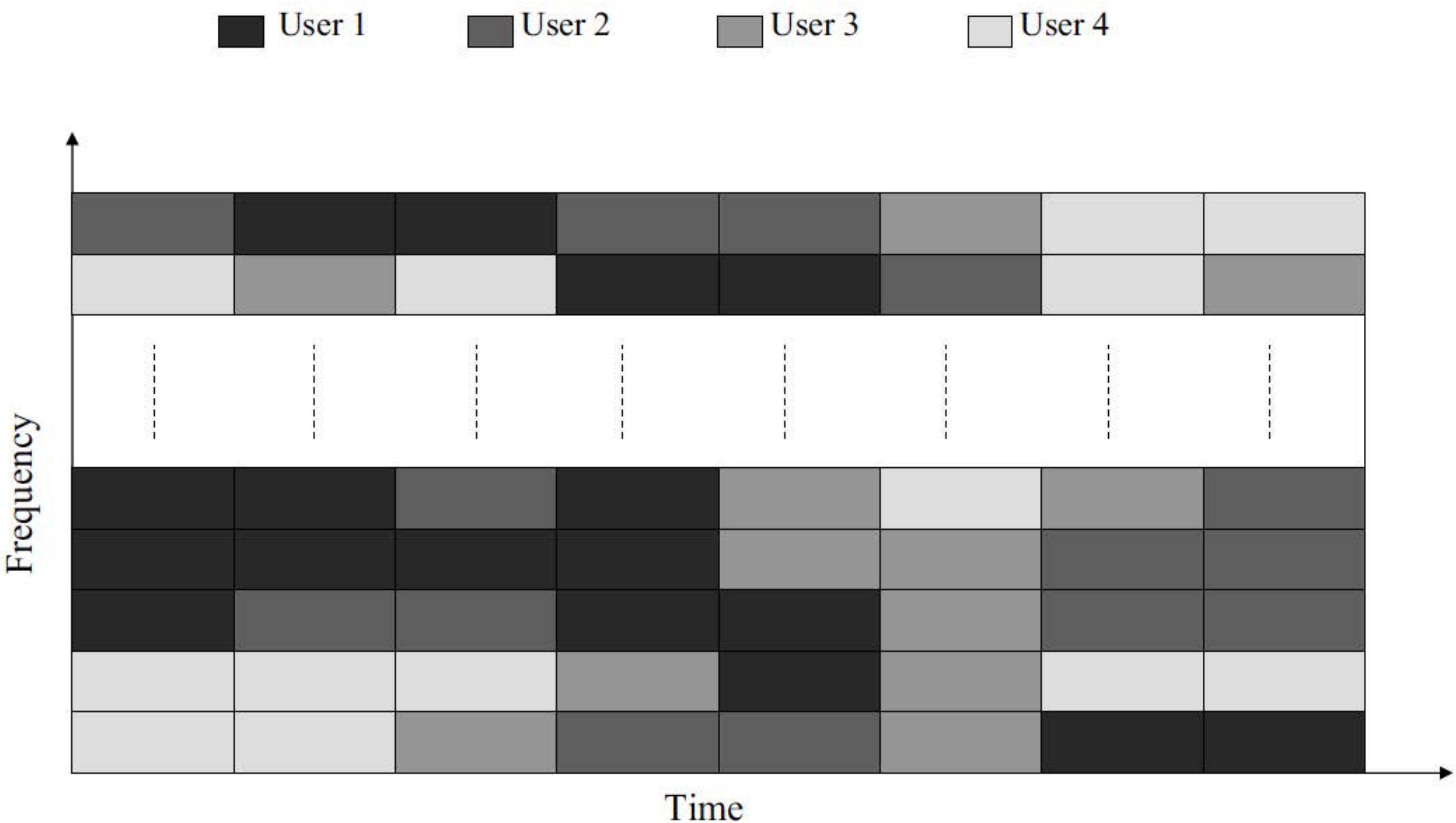


- Each user is allocated a number of so-called resource blocks in the time-frequency grid.
- The more resource blocks a user gets, and the higher the modulation used in the resource elements, the higher the bit-rate.
- Advanced scheduling techniques are used
- Based on feedback information about the frequency-selective channel conditions from each user, adaptive user-to-subcarrier assignment can be performed, enhancing considerably the total system spectral efficiency

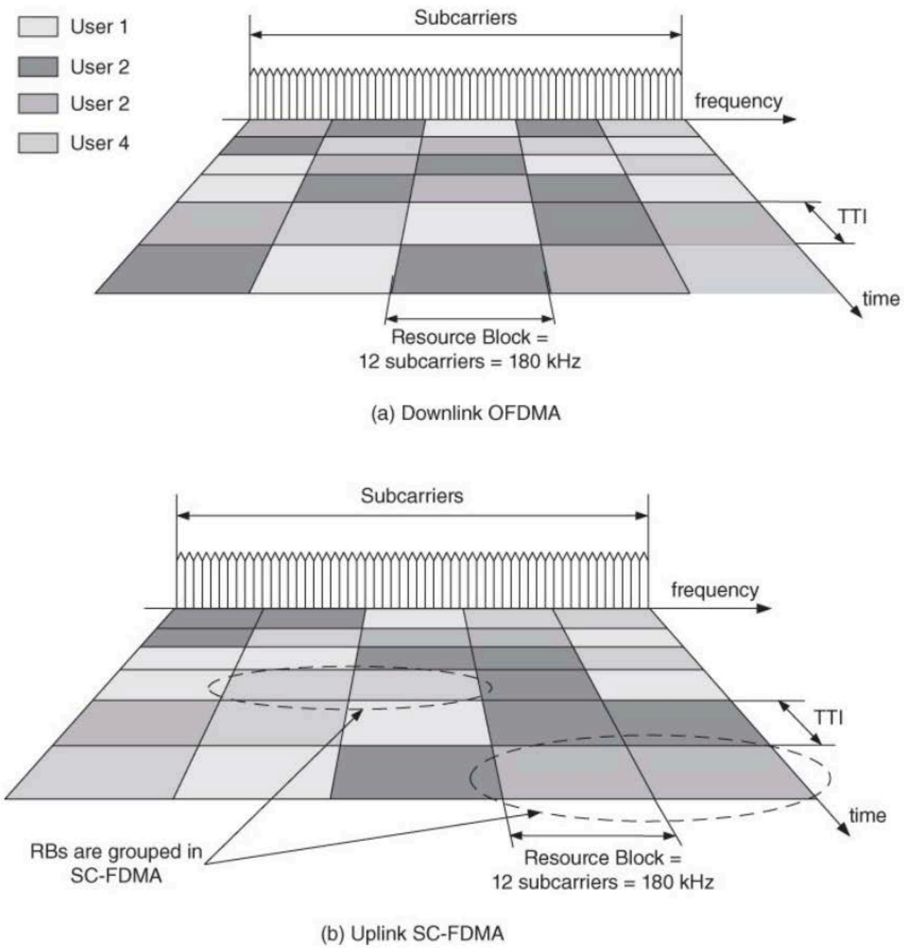
Resource blocks



Resource block allocation
An example



Resource Allocation



eNodeB in each TTI = 1 ms interval takes a scheduling decision and sends scheduling information to the selected set of terminals. The resource allocation is based on resource blocks (RBs), each consisting of 12 subcarriers occupying 180 kHz.

Phy layer adaptation

- Modulation scheme, code rate are dynamically selected based on predicted channel conditions

- Channel Quality Indicator provided as feedback by the UEs are used to estimate different channels conditions (based on user perceived quality of transmitted reference signals)

The femto cell concept

Brings to the home the QoS and high spectrum utilization features of LTE technology

LTE summary

- LTE brings up to 50 times performance improvement and much better spectral efficiency to cellular networks.
- 300Mbps peak downlink and 75 Mbps peak uplink.
- LTE supports flexible carrier bandwidths, from 1.4 MHz up to 20 MHz as well as both FDD and TDD.
- All LTE devices have to support MIMO transmissions, allowing the base station to transmit several data streams over the same carrier simultaneously
- All interfaces between network nodes are now IP based
- Quality of Service (QoS) mechanism have been standardized on all interfaces
- Works with GSM/EDGE/UMTS systems utilizing existing 2G and 3G spectrum and new spectrum. Supports hand-over and roaming to existing mobile networks.

5G Cellular systems

Wireless Systems, a.a. 2019/2020

Un. of Rome "La Sapienza"

Chiara Petrioli[†]

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5G vision

- 2014 technologies: Connectivity at High Speed + Cheap high computing power (over the Cloud, and at the edges of the network ← fog/edge computing technologies)
- Mobile access does not meet the required QoS
  - achievable coverage, data rates, latency, reliability, energy consumption
- Strong need for next generation ubiquitous ultra-high broadband mobile computing infrastructure

  → 5G under discussion ← many paradigms shifts to overcome current barriers in terms of performance and scalability

  → Objective: provide delay critical, ultra reliable, dependable secure broaband communications services to mobile users

    → not only to humans but also to tens of bilions of smart objects, cyber physical systems (e.g., cars, robots, drones) that are being deployed as part of the Internet of Things emerging paradigm

5G vision

- Convergence of different wireless systems
  - Vision: moving away from one architecture fits all towards a "Multiple architectures adapted to each service" concept
    - ✓ LTE, 3G, 2G, WiFi and satellite networks should cooperate and interwork seamlessy
    - ✓ Multi technology (different phy but also different kinds of network)
  - 5G pan european research infrastructures
  - Security, privacy and IoT support some of the key aspects of the vision
  - To change user experience disruptive change in performance & system optimization; service support; change in business models
    - → Examples: extension of usable bandwidth; Reduction of cost per bit; Programmable network; Low energy consumption & long lifetimes (also through harvesting); Security by design,…

5G KPIs

- Throughput: provide 1000x more available throughput in aggregate, as well as 10x more speed to individual end users (full immersive experience)
- Latency: down to 1ms when needed for tactile Internet
- Energy efficiency: 5% of global energy consumption is due to ICT
  - 90% increase in energy efficiency
  - 10x better battery lifetime for low power devices
- Coverage (really everywhere everytime: from planes, to trains etc.)
- Novel business models (service based)+ reduction of service creation times

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System level challenges

- Privacy by design
- Quality of Service/Quality of Experience challenge: differentiated services across various dimensions (throughput, latency, resilience, costs but also security, availability, resilience)
- Simplicity challenge (seamless service provisioning even for inter RAT switching)
- Multi-tenancy challenge: provide services across different infrastructure ownership, with different networks coexisting and providing an integrated efficient interaction between mobile systems and the backhaul
- Density challenge (e.g., brought in by IoT devices)

System level challenges

- Diversity challenge
  - must support the increasing diversity of optimized wireless solutions, the diversity in traffic types and number of connected devices
- Harnessing challenge: exploit any communication capability, including device to device for optimizing communication at each time
- Harvesting challenge: exploit energy harvesting to improve lifetime
- Mobility challenge: seamless mobility across networks/technologies
- Location and context information challenge: submeter localization accuracy
- Hardening challenge: making communication system robust to attacks and natural disasters

System level challenges

- Resource management challenge
  - provide access agnostic control, policy and charging mechanisms and protocols for dynamic establishment, configuration, reconfiguration and release of any type of resource (bandwidth, computation, memory, storage) for any type of device and service.
- Flexibility challenge: device truly flexible control mechanisms and protocols for relocating functions, protocol entities an states relying on technologies such as SDN and NFV
- Identity challenge: provide identity management for any type of device with access agnostic authentication mechanisms
- Manageability: improve menageability of networks (reducing human intervention)

Flexibility, programmability, openness

5G Areas some examples

-**Cognitive access**, frequency agile

-Large bandwidth (**mmwave comm.**)

-Novel air interfaces

-Different communication models (unicast/multicast/ Broadcast/**D2D**),

Extensive reprogrammability & reconfigurability

System optimization and adaptive

cognitive operation based on context

Use of data analytics, **NVF and SDN**

Harmonization of processes

(Wireless/wired technologies)

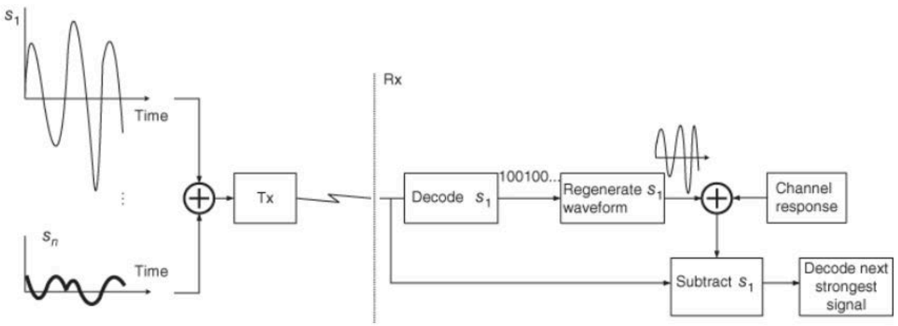
Authentication/authorization

QoS

Network view

IoT Support

Phy Layer Asdvancements



different users are superimposed into a single waveform. The receiver tries to decode the strongest signal while the other signals are treated as interference. The decoded signal is then regenerated into a waveform and subtracted from the composite received signal. The process is iterated for all desired signals. This method is called Successive Interference Cancellation (SIC), illustrated in Figure 13.2 for n user signals, $s_1 \dots s_n$, where s_1 is a strongest signal.

Antenna Arrays,
MIMO, Beamforming,
Novel Modulations,
SW Defined approaches

From orthogonal to
Non orthogonal
Approaches

Beyond radio?
Hybrid VLC/Radio
For higher densification

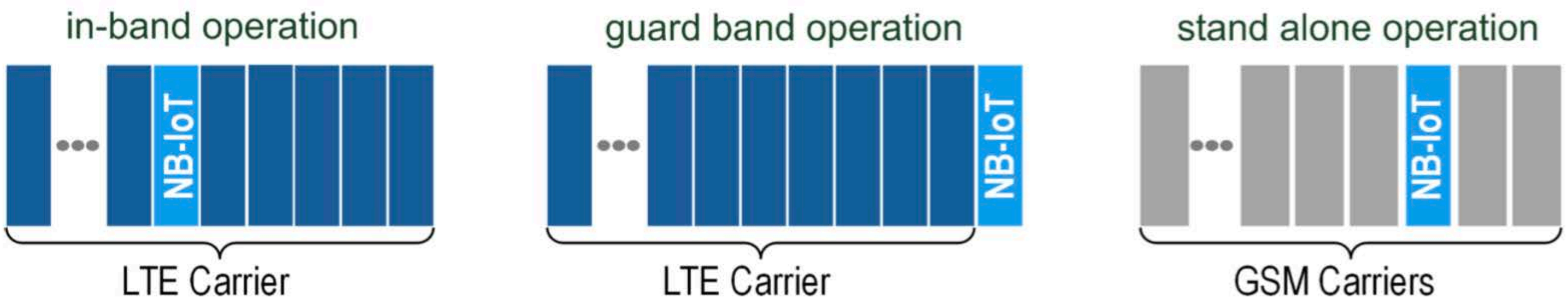


Table 3-1: Allowed LTE PRB indices for cell connection in NB-IoT in-band operation

LTE system bandwidth	**3 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
LTE PRB indices for NB-IoT synchronization	2, 12	2, 7, 17, 22	4, 9, 14, 19, 30, 35, 40, 45	2, 7, 12, 17, 22, 27, 32, 42, 47, 52, 57, 62, 67, 72	4, 9, 14, 19, 24, 29, 34, 39, 44, 55, 60, 65, 70, 75, 80, 85, 90, 95