This lecture is being recorded

18-452/18-750
Wireless Networks and Applications
Lecture 15: GPRS and LTE

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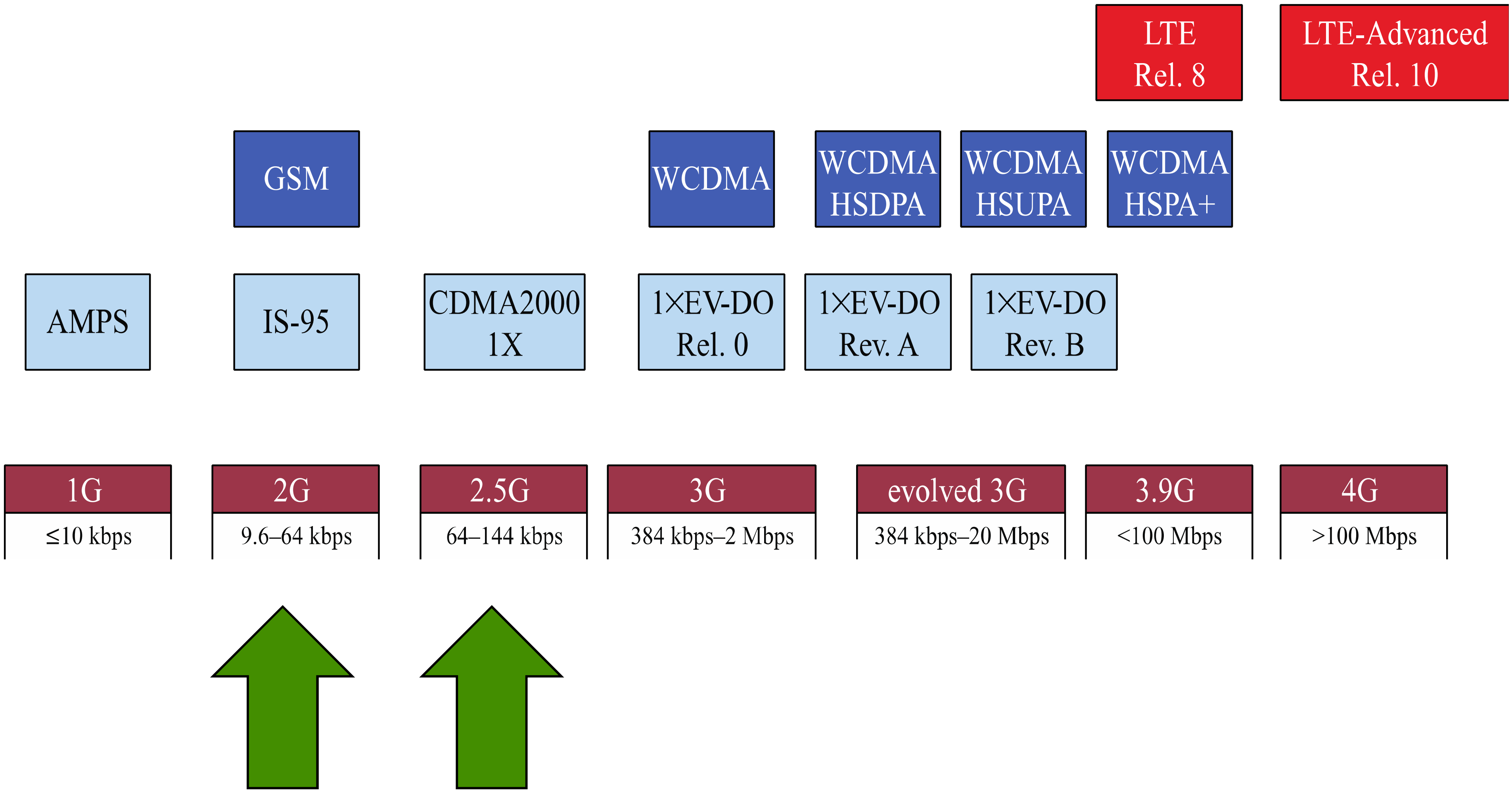
Spring Semester 2022

http://www.cs.cmu.edu/~prs/wirelessS22/

Announcements

- **We have been having some problems with sound for the recordings**
  - » **Likely cause is a loose USB connector for microphone**
  - » **We should be able to fix this soon**
- **For P2:**
  - » **I have promised to send you something during the P2 meeting and you have not received it, please remind me**
  - » **If you have questions/ideas/plan for the P2 hardware you need please contact me as asap**
  - » **RPs – what kind?**

Evolution of Cellular Wireless Systems



GSM Multiple Access Example

- Combination of FDMA and TDMA
  - » More on this later
- 890-915 MHz for uplink
- 935-960 MHz for downlink
- Each of those 25 MHz bands is sub divided into 124 single carrier channel of 200 KHz
  - » Each with a data rate of 270.833 kbps
- In each uplink/downlink band there is a 200 KHz guard band
- Each 200 KHz channel carries 8 TDMA channels

Additional GSM Features

- GSM uses GMSK modulation
  - » Gaussian Minimum Shift Keying
  - » Optimized version of Frequency Shift Keying (FM)
- Slow frequency hopping: successive TDMA frames are sent over a different frequency
  - » Switches every 4.615 msec
  - » Spreads out effect of multipath fading
  - » Also helps with co-channel interference
- Delay equalization
  - » Mobile stations sharing a frame can be at different distances from the base station
  - » Tail bits and guard bits provide margin to avoid overlap

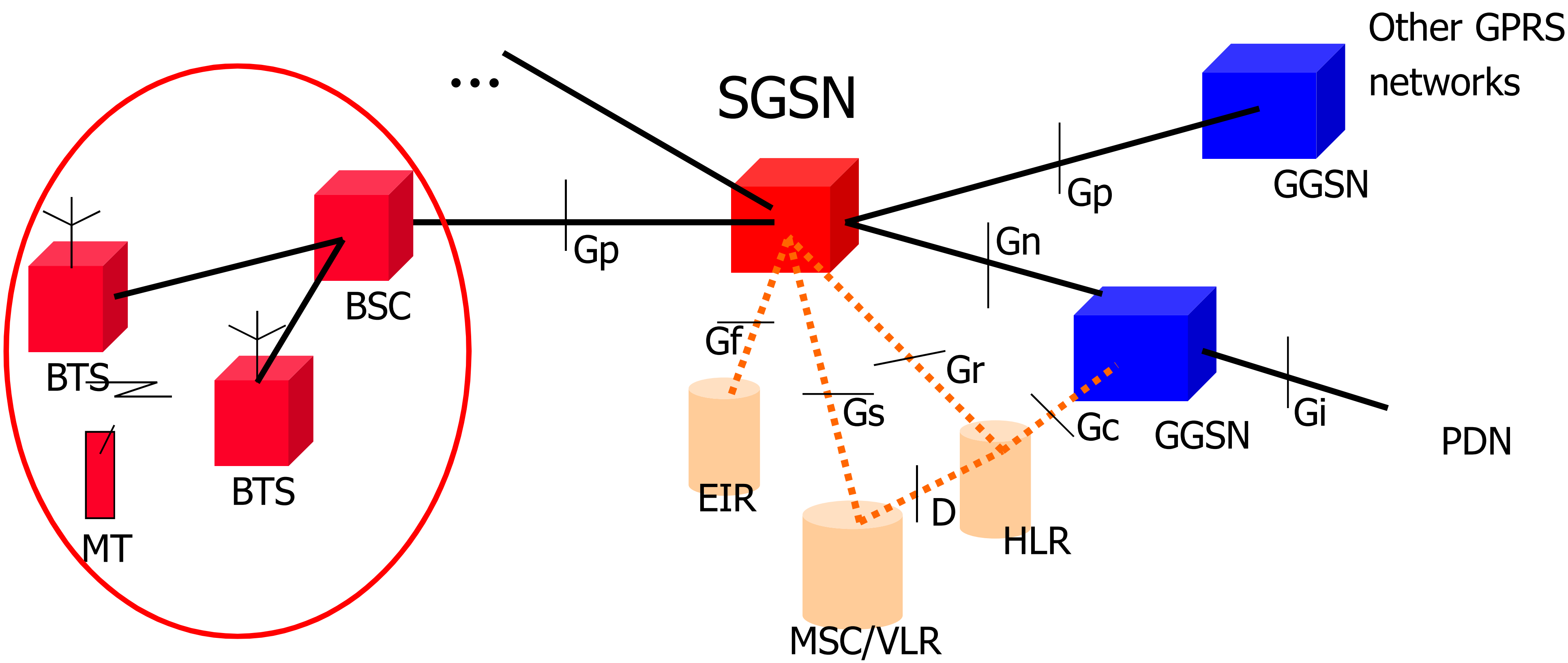
Generalized Packet Radio Service (GPRS)

- Packet-oriented data transport service
  - » Bursty, non-periodic traffic typical for Internet access
- Uses a new architecture for data traffic
  - » Allows users to open a persistent data connection
  - » Sending data traffic over a voice connection would add too much setup and teardown overhead
- Uses the same frame structure as voice
  - » 21.4 kbps from a 22.8 kbps gross data rate
  - » Can combine up to 8 GSM connections
    - – Overall throughputs up to 171.2 kbps
  - » Enhanced Data Rates for GSM Evolution (EDGE) further increased rates using a more aggressive PHY

GPRS Architecture

- Network Subsystem includes several new entities:
  - Serving GPRS Support Node (SGSN): data transfer between Base Station and Network Subsystem
  - Gateway GPRS Support Node: connects to other GPRS networks and the packet data network (Internet)
  - New interfaces between the various entities
- Transmission plane
  - Data packets are transmitted by a tunnel mechanisms
- Control plane
  - Protocol for tunnel management: create, remove, …
  - GPRS Tunnel Protocol
- Radio interface
  - Changes the logical channels and how they are managed

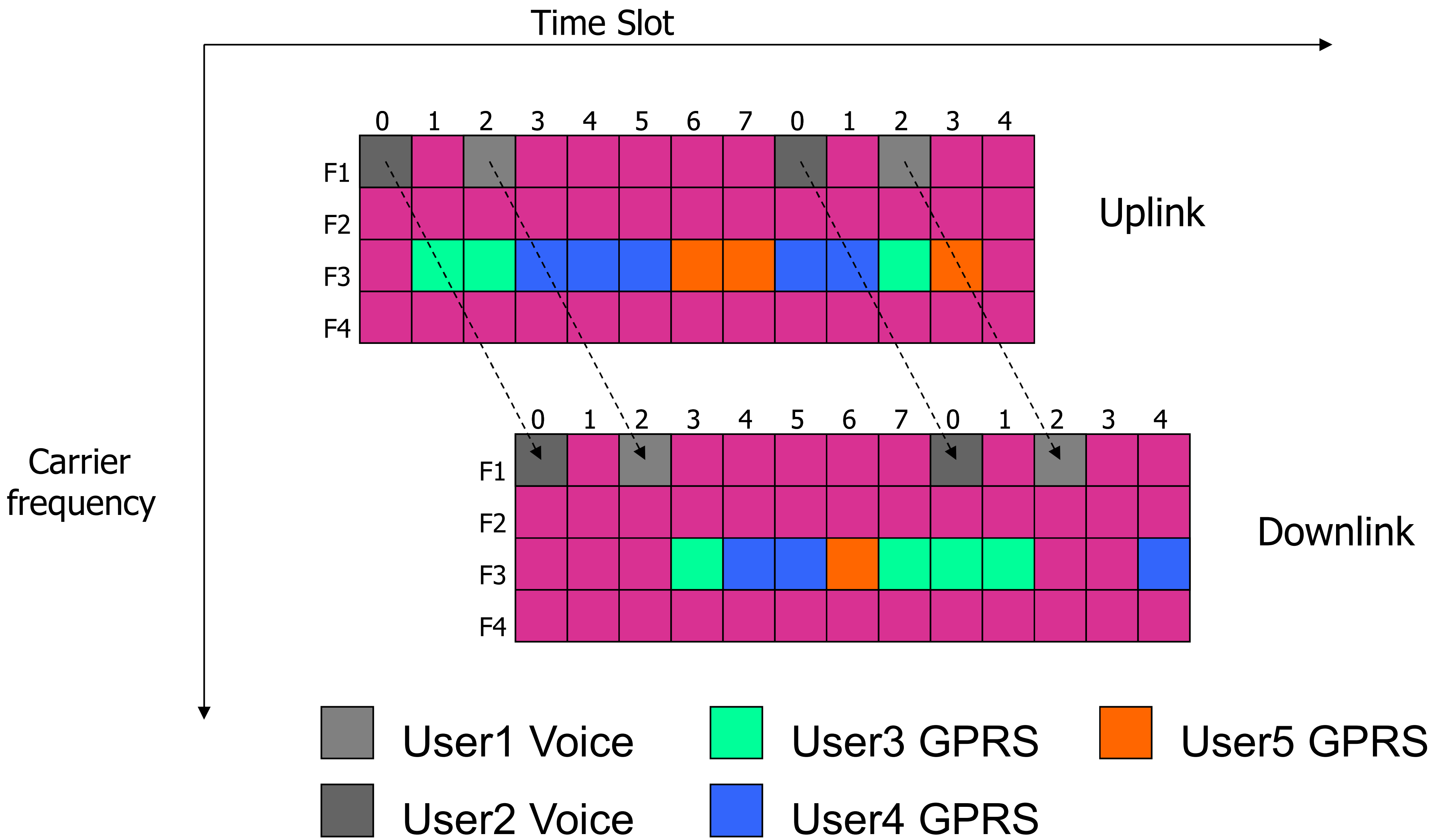
GPRS Architecture



Base Station Subsystem

SGSN – Serving GPRS Support Node
GGSN – Gateway GPRS Support Node

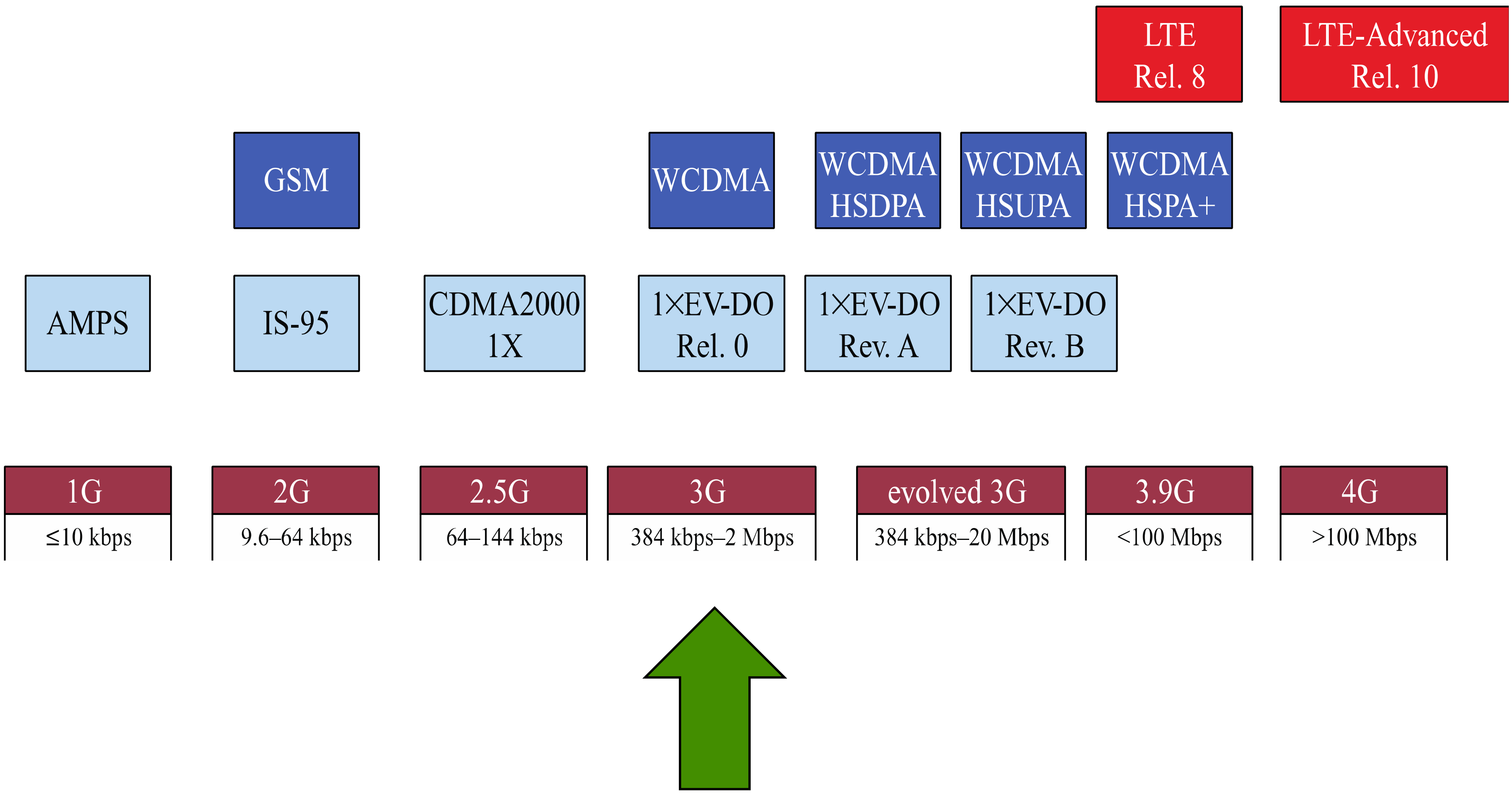
GPRS Radio Interface



Bandwidth Allocation for Devices

- The allocation of transmit resources to devices is controlled by the basestation
- Control channels are used for coordination
  - » Effectively slots in the resource grid (previous slide)
- Downstream: basestation can send data to devices at will
  - » Uses the control channel to identify target devices
- Upstream: devices must request slots to transmit data when they have packet pending
  - » Again uses the control channel for request & response
  - » Adds delay – traditionally quite high in cellular!

Evolution of Cellular Wireless Systems



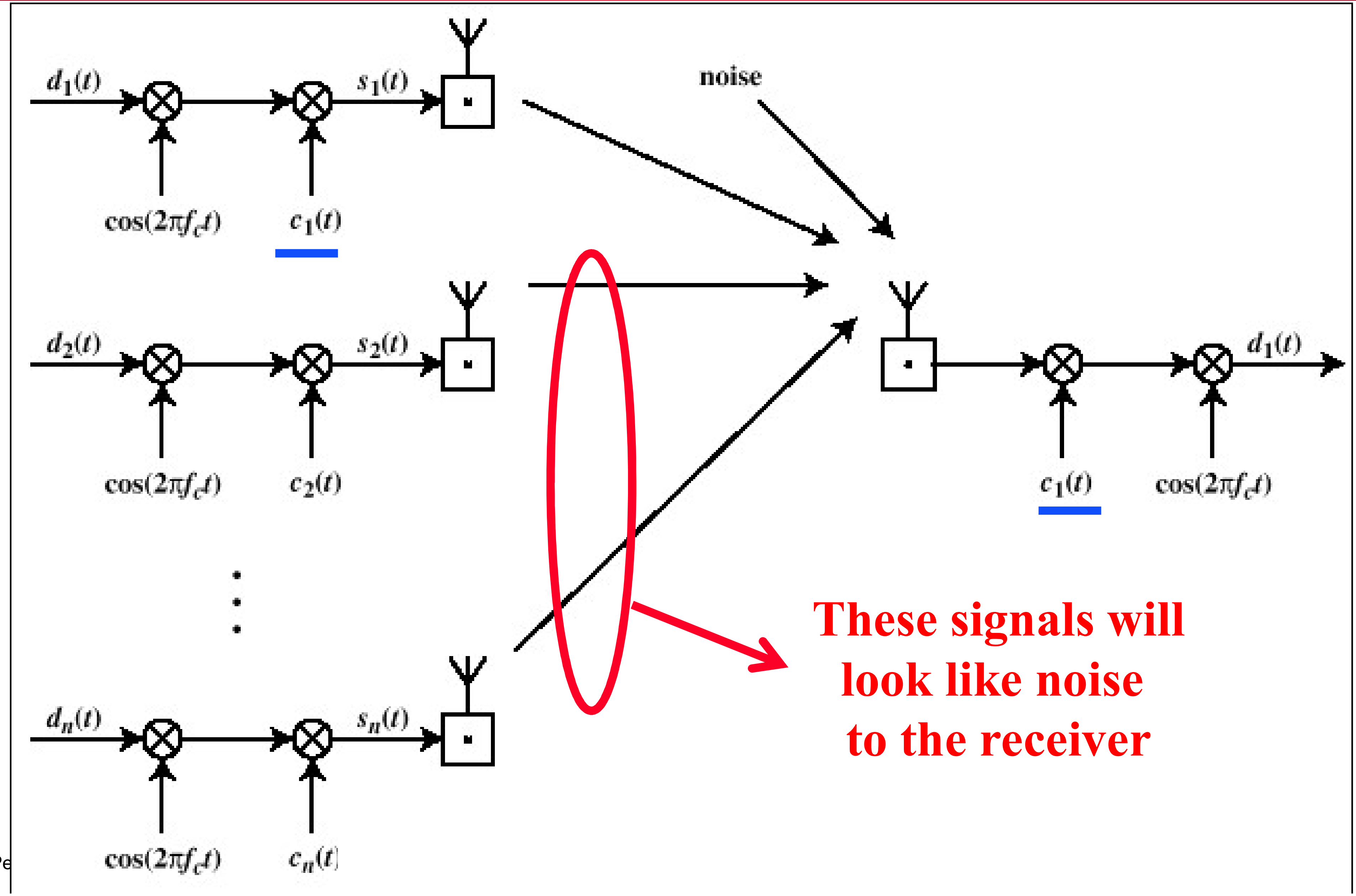
Who is Who

- International Telecommunications Union (ITU) - agency of the United Nations responsible for:
  - » Assisting in the development and coordination of world-wide standards
  - » Coordinate shared use of the global spectrum
  - » Defined the International Mobile Telecommunications 2000 (IMT-2000) project for 3G telecommunications
- Third Generation Partnership Project (3GPP)
  - » A group of telecommunications associations that represent large markets world-wide
  - » Defined a group of 3G standards as part of the IMT-2000 framework in 1999
  - » Originally defined GSM, EDGE, and GPRS
  - » Later defined follow-on releases and also LTE (4G)

UMTS and WCDMA

- Part of a group of 3G standards defined as part of the IMT-2000 framework by 3GPP
- Universal Mobile Telecommunications System (UMTS)
  - » Successor of GSM
- W-CDMA is the air interface for UMTS
  - » Wide-band CDMA
  - » Originally 144 kbps to 2 Mbps, depending on mobility
- Basically same architecture as GSM
  - » Many GSM functions were carried over WCDMA
  - » But they changed all the names!

Reminder: CDMA - Direct Sequence Spread Spectrum



Later Releases Improved Performance

- High Speed Downlink Packet Access (HSDPA): 1.8 to 14.4 Mbps downlink
  - Adaptive modulation and coding, hybrid ARQ, and fast scheduling
- High Speed Uplink Packet Access (HSUPA): Uplink rates up to 5.76 Mbps
- High Speed Packet Access Plus (HSPA+): Maximum data rates increased from 21 Mbps up to 336 Mbps
  - 64 QAM, 2×2 and 4×4 MIMO, and dual or multi-carrier combinations
- Eventually led to the definition of LTE

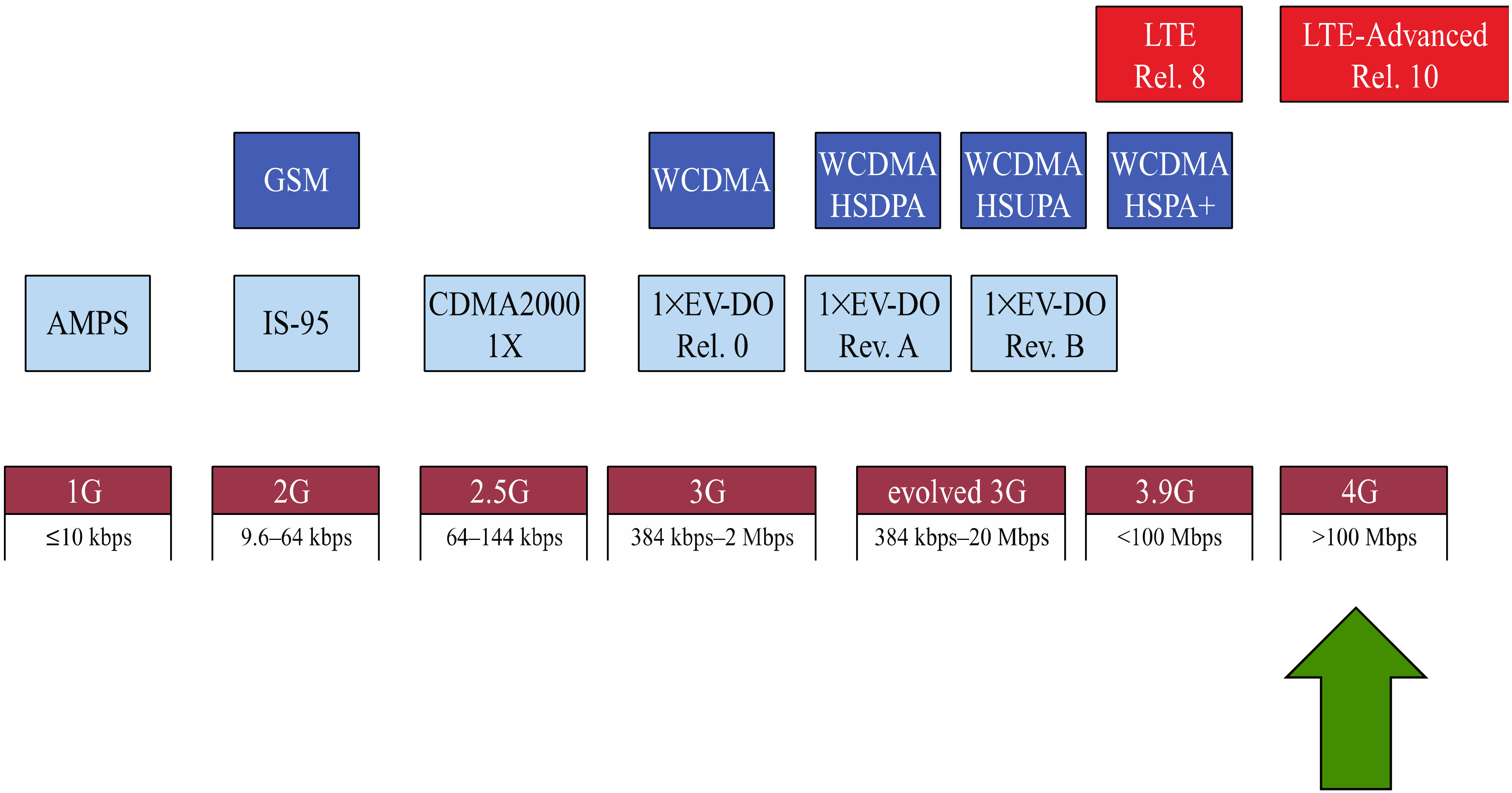
Advantages of CDMA for Cellular systems

- Frequency diversity – frequency-dependent transmission impairments have less effect on signal
- Multipath resistance – chipping codes used for CDMA exhibit low cross correlation and low autocorrelation
- Privacy – privacy is inherent since spread spectrum is obtained by use of noise-like signals
- Graceful degradation – system only gradually degrades as more users access the system

Mobile Wireless CDMA Soft Hand-off

- Soft Handoff – mobile station temporarily connected to more than one base station simultaneously
- Requires that the mobile acquire a new cell before it relinquishes the old
- More complex than hard handoff used in FDMA and TDMA schemes

Evolution of Cellular Wireless Systems



Overview LTE

- Motivation
- Architecture
- Resource management
- LTE protocols
- Radio access network
  - OFDM refresher
- LTE advanced

Some slides based on material from
"Wireless Communication Networks and Systems"

Purpose, motivation, and approach to 4G

- Defined by ITU directives for International Mobile Telecommunications Advanced (IMT-Advanced)
- All-IP packet switched network.
- Ultra-mobile broadband access
- Peak data rates
  - » Up to 100 Mbps for high-mobility mobile access
  - » Up to 1 Gbps for low-mobility access
- Dynamically share and use network resources
- Smooth handovers across heterogeneous networks
  - » 2G and 3G networks, small cells such as picocells, femtocells, and relays, and WLANs
- High quality of service for multimedia applications

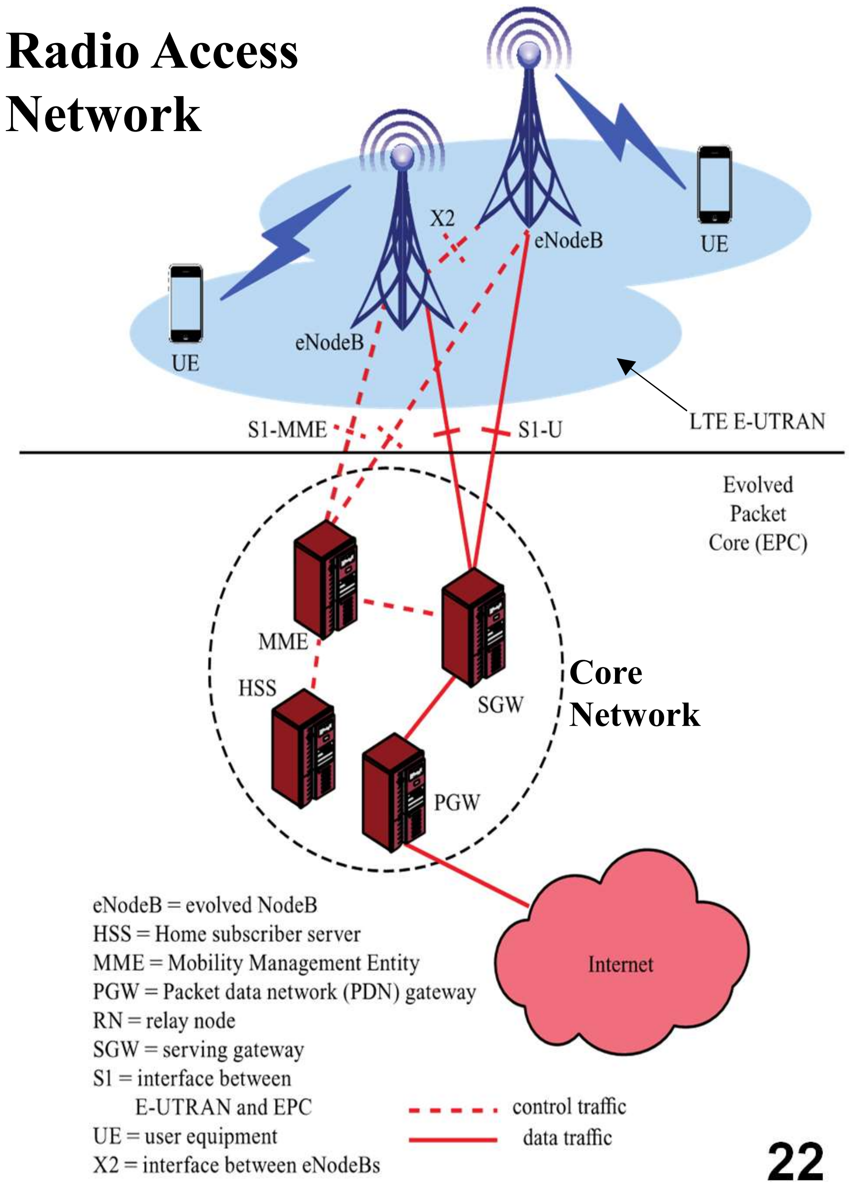
High Level Features

- No support for circuit-switched voice
  - » Instead providing Voice over LTE (VoLTE)
- Replace spread spectrum/CDMA with OFDM

Technology	1G	2G	2.5G	3G	4G
Design began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2012
Services	Analog voice	Digital voice	Higher capacity packetized data	Higher capacity, broadband	Completely IP based
Data rate	1.9. kbps	14.4 kbps	384 kbps	2 Mbps	200 Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	OFDMA, SC-FDMA
Core network	PSTN	PSTN	PSTN, packet network	Packet network	IP backbone

LTE Architecture

- **evolved NodeB (eNodeB)**
  - » Most devices connect into the network through the eNodeB
- **Evolution of the previous 3GPP NodeB (~2G BTS)**
  - » Uses OFDM instead of CDMA
- **Has its own control functionality**
  - » Dropped the Radio Network Controller (RNC - ~2G BSC)
  - » eNodeB supports radio resource control, admission control, and mobility management (handover)
  - » Was originally the responsibility of the RNC



Evolved Packet System

- Overall architecture is called the Evolved Packet System (EPS)
- 3GPP standards divide the network into
- Radio access network (RAN): cell towers and connections to mobile devices
- Core network (CN): management and connectivity to other networks
- Each can evolve independently
    - » Driven by different technologies: optimizing spectrum use versus management and control or traffic

Evolved Packet System Components

- Long Term Evolution (LTE) is the RAN
  - » RAN: Radio Area Network
  - » Called Evolved UMTS Terrestrial Radio Access (E-UTRA)
  - » Enhancement of 3GPP's 3G RAN
  - » eNodeB is the only logical node in the E-UTRAN
  - » No Radio Network Controller (RNC)
- Evolved Packet Core (EPC)
  - » Operator or carrier core network –core of the system
- Traditionally circuit switched but now entirely packet switched
  - » Based on IP - Voice supported using voice over IP (VoIP)

Design Principles of the EPS

- Packet-switched transport for traffic belonging to all QoS classes
  - Voice, streaming, real-time, non-real-time, background
- Comprehensive radio resource management
  - End-to-end QoS, transport for higher layers
  - Load sharing/balancing
  - Policy management across different radio access technologies
- Integration with existing 3GPP 2G and 3G networks
- Scalable bandwidth from 1.4 MHz to 20 MHz
- Carrier aggregation for overall bandwidths up to 100 MHz

Evolved Packet Core Components

- **Mobility Management Entity (MME)**
  - » Supports user equipment context, identity, authentication, and authorization
- **Serving Gateway (SGW)**
  - » Receives and sends packets between the eNodeB and the core network
- **Packet Data Network Gateway (PGW)**
  - » Connects the EPC with external networks
- **Home Subscriber Server (HSS)**
  - » Database of user-related and subscriber-related information
- **Interfaces**
  - » S1 interface between the E-UTRAN and the EPC
    - – For both control purposes and for user plane data traffic
  - » X2 interface for eNodeBs to interact with each other
    - – Again for both control purposes and for user plane data traffic

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LTE Resource Management

- LTE uses *bearers* for quality of service (QoS) control instead of circuits
- EPS bearers
  - » Between entire path between PGW and UE
  - » Maps to specific QoS parameters such as data rate, delay, and packet error rate
- Service Data Flows (SDFs) differentiate traffic flowing between applications on a client and a service
  - » SDFs must be mapped to EPS bearers for QoS treatment
  - » SDFs allow traffic types to be given different treatment
- End-to-end service is not completely controlled by LTE

Bearer Management based on QoS Class Identifier (QCI)

QCI	Resource Type	Priority	Packet Delay Budget	Packet Error Loss Rate	Example Services
1	GBR	2	100 ms	10^{-2}	Conversational Voice
2		4	150 ms	10^{-3}	Conversational Video (live streaming)
3		3	50 ms	10^{-3}	Real Time Gaming
4		5	300 ms	10^{-6}	Non-Conversational Video (buffered streaming)
5	Non-GBR	1	100 ms	10^{-6}	IMS Signalling
6		6	300 ms	10^{-6}	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		7	100 ms	10^{-3}	Voice, Video (live streaming) Interactive Gaming
8		8	300 ms	10^{-6}	Video (buffered streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9*		9			

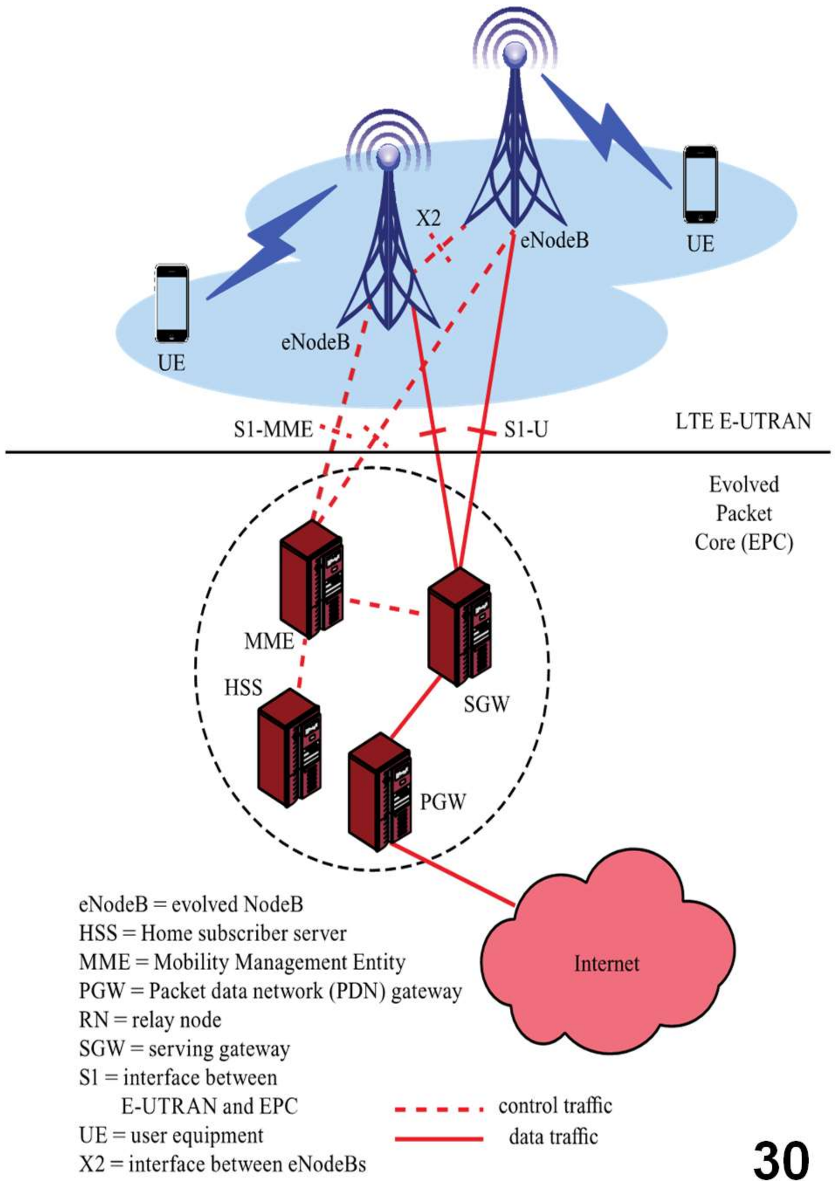
* QCI value typicaly used for the default bearer

Guaranteed (minimum) Bit Rate (QCI 1–4)

No Guarantees (QCI 5–9)

EPC: Mobility Management

- **X2 interface used when moving within a RAN coordinated under the same Mobility Management Entity (MME)**
- **S1 interface used to move to another MME**
- ***Hard handovers* are used: A UE is connected to only one eNodeB at a time**



EPC: Inter-cell Interference Coordination (ICIC)

- Reduces interference when the same frequency is used in a neighboring cell
- Goal is universal frequency reuse
  - *N* = 1 in “Cellular principles” lecture
  - Must avoid interference when mobile devices are near each other at cell edges
  - Interference randomization, cancellation, coordination, and avoidance are used
- eNodeBs send *indicators*
  - Relative Narrowband Transmit Power, High Interference, and Overload indicators
- Later releases of LTE have improved interference control
  - “Cloud RAN”: use a cloud to manage interference, spectrum

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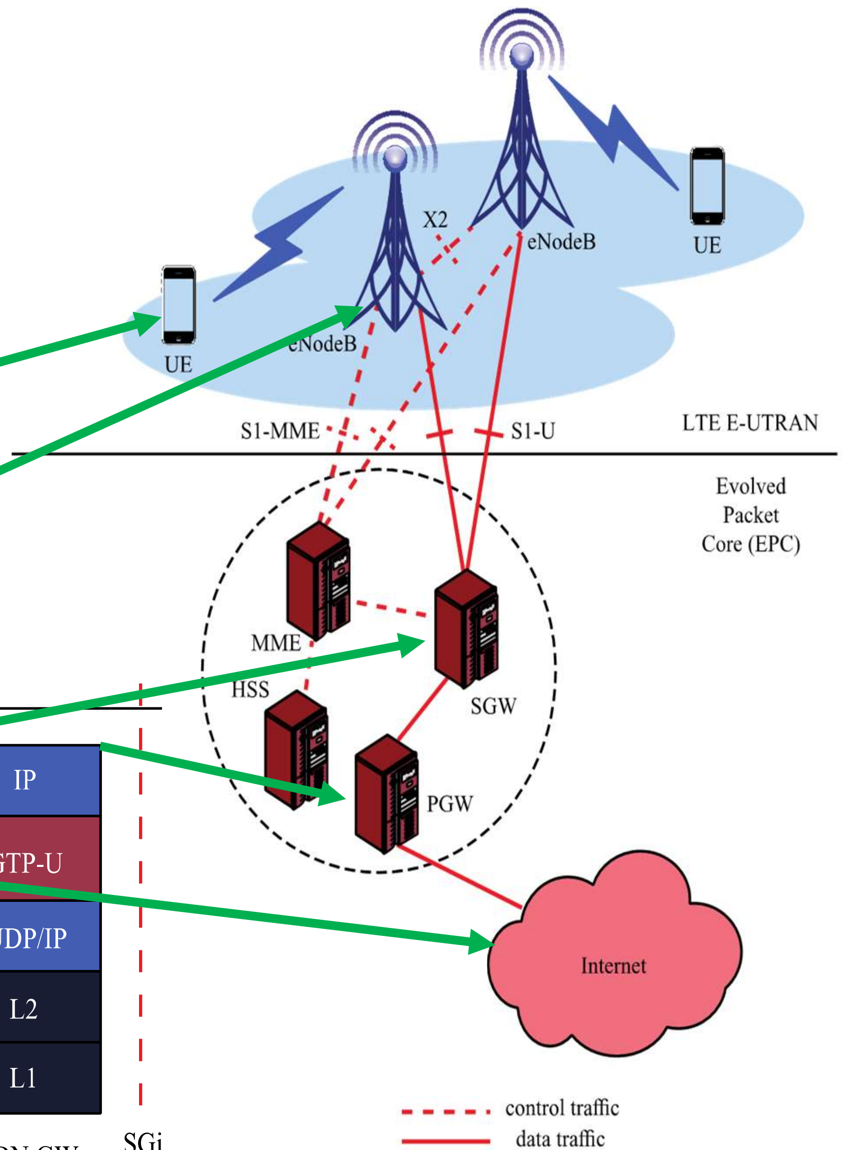
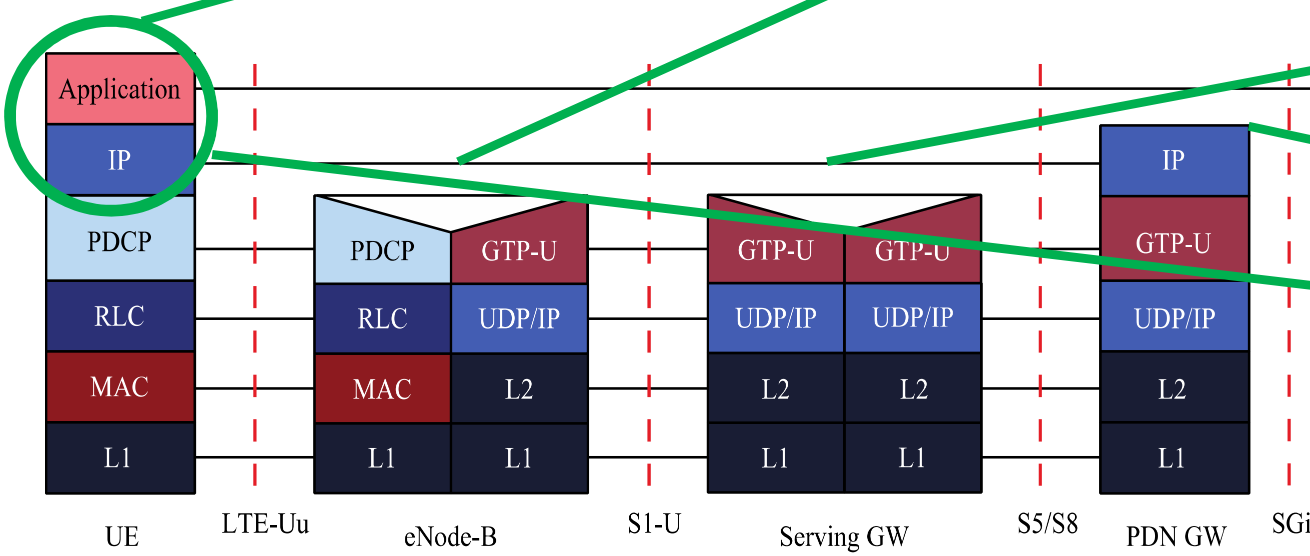
Protocol Layers in Cellular Network

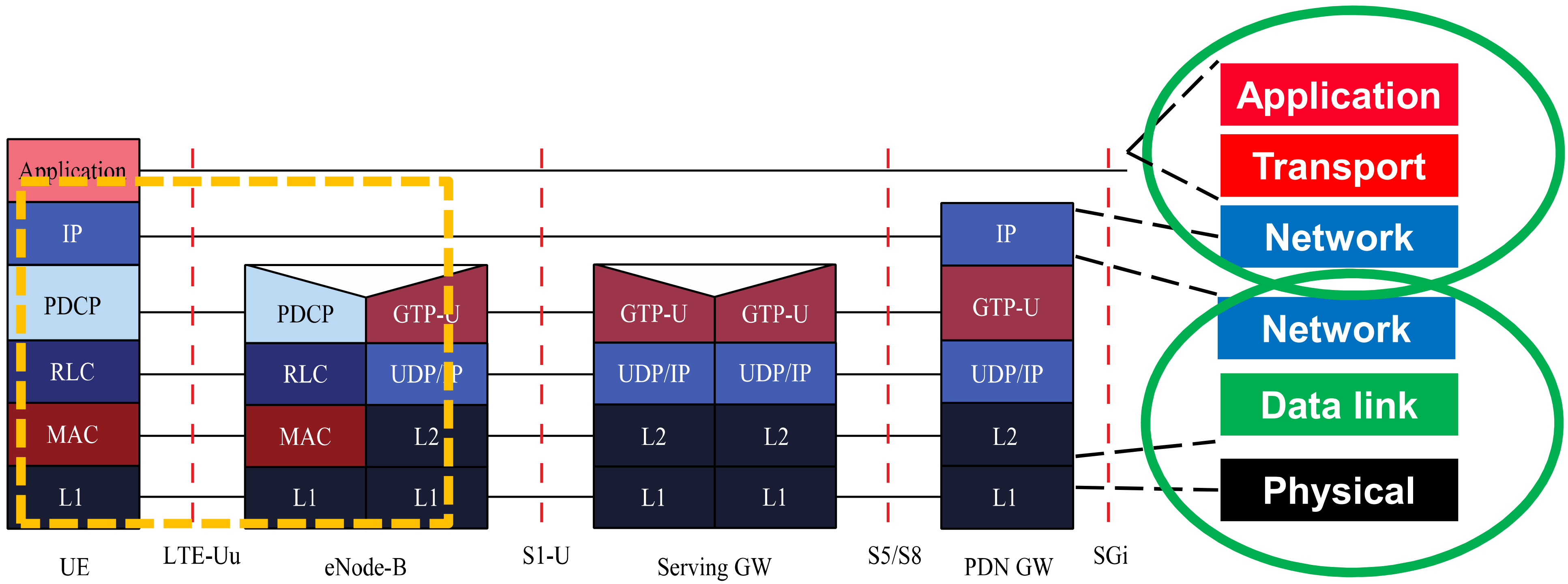
- EPC is an IP network
- It acts as a "tunnel" for the IP traffic sent/received by the mobile devices
  - IP packets sent/received by mobile devices are treated as data by the EPC IP network





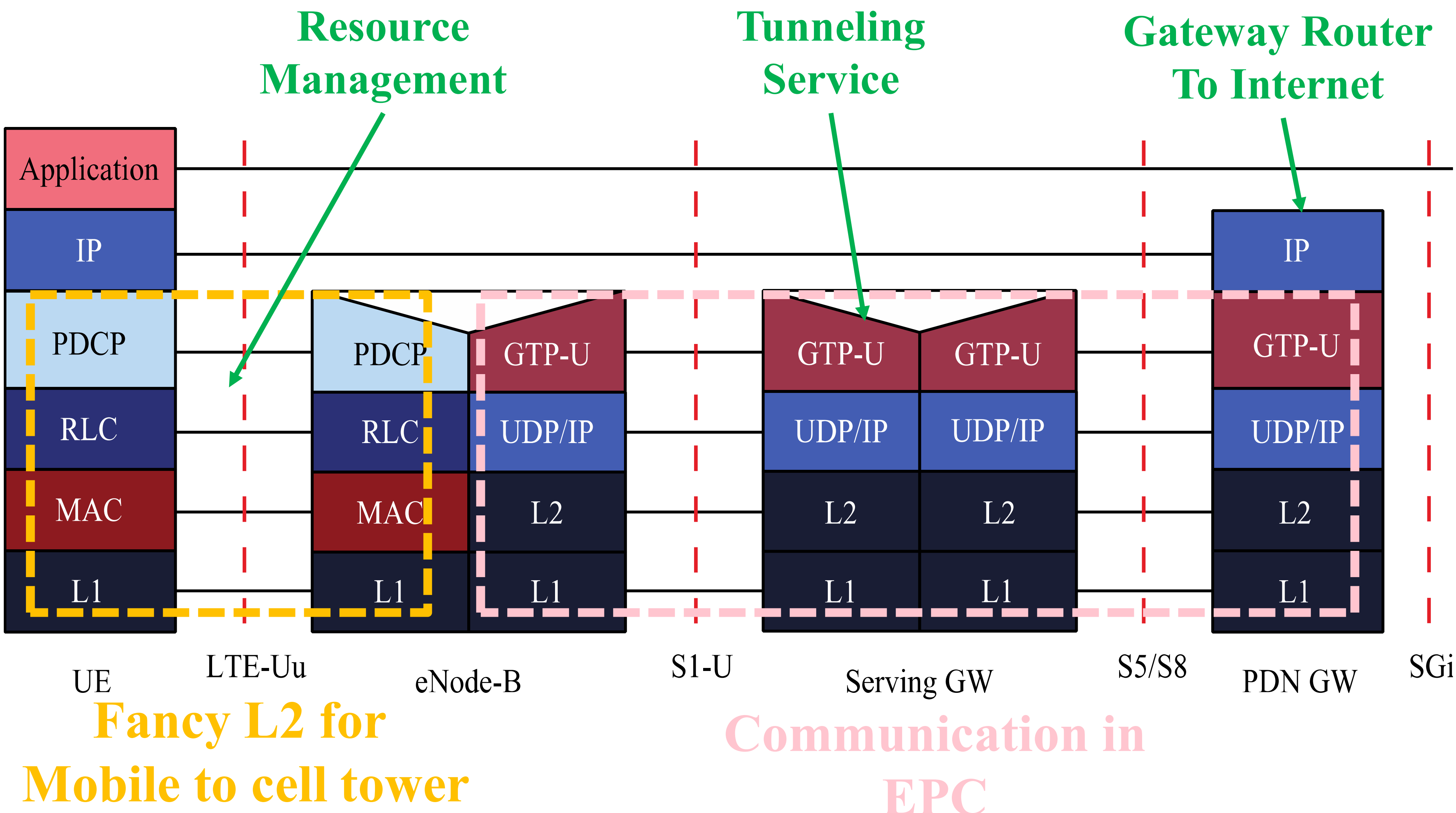
Protocol Layers End-to-End

Used End-End
“Data” for EPC

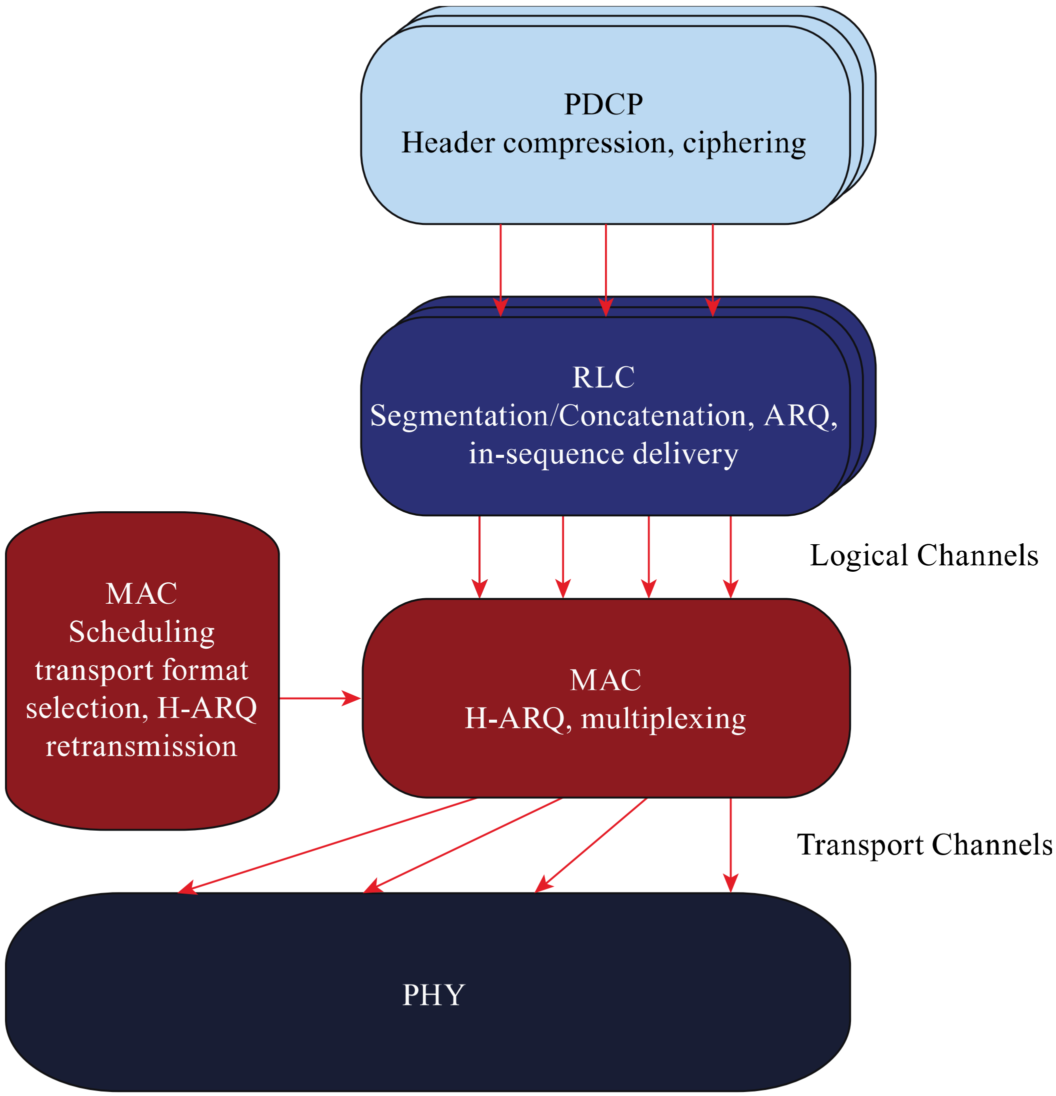


Used in RAN-Core
Link and in EPC

Protocol Layers End-to-End

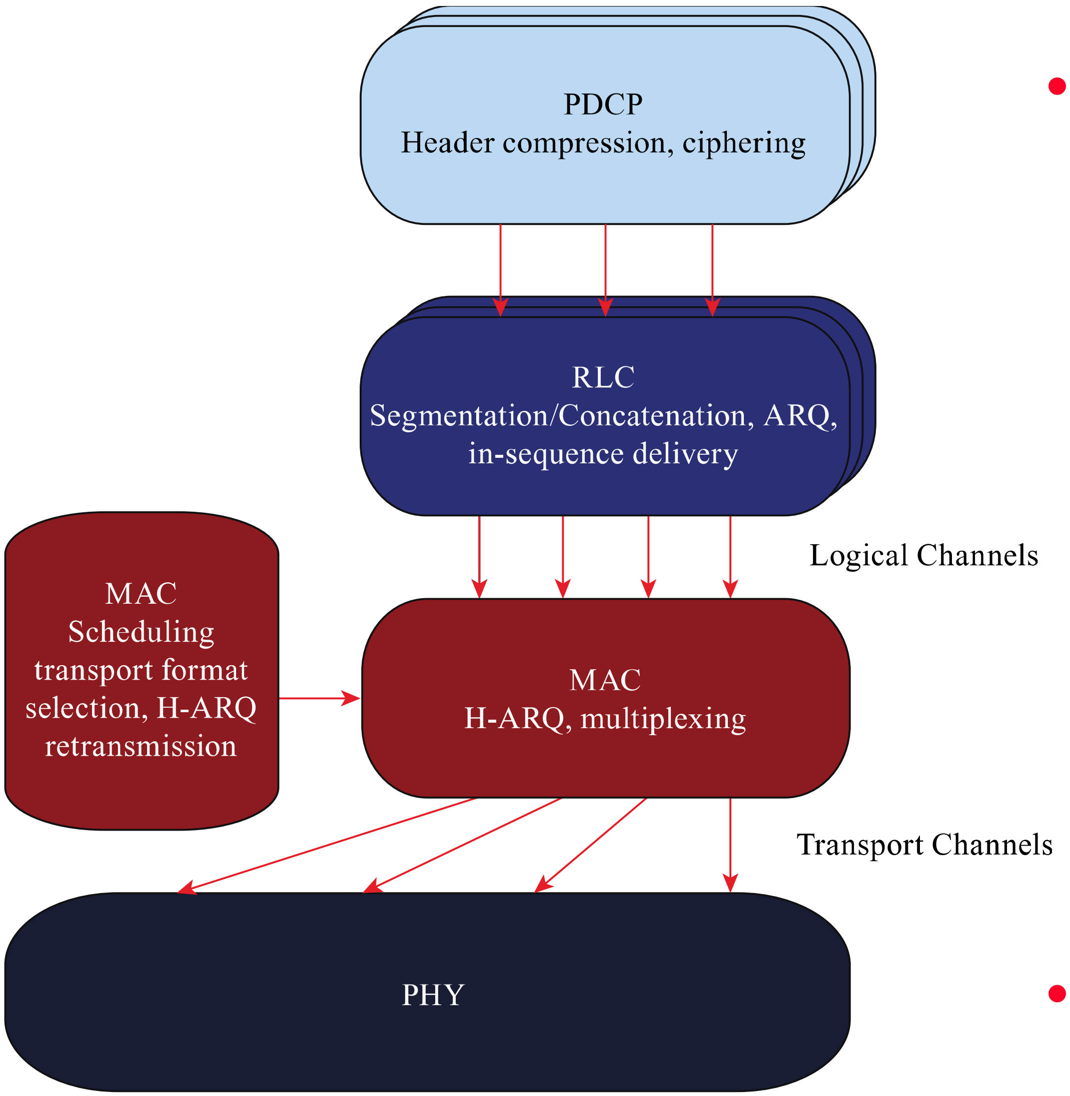


Protocol Layers PDCP and RLC



- **Packet Data Convergence Protocol (PDCP)**
  - » **Delivers packets from UE to eNodeB**
  - » **Involves header compression, ciphering, integrity protection, in-sequence delivery, buffering and forwarding of packets during handover**
- **Radio Link Control (RLC)**
  - » **Segments or concatenates data units**
  - » **Performs ARQ**
    - – **Recover from when MAC layer H-ARQ failures**
    - – **ARQ: Automatic Repeat Request (retransmission)**
    - – **H-ARQ: Hybrid ARQ – combines FEC and ARQ**

Protocol Layers MAC and PHY



- Medium Access Control (MAC)
  - Performs H-ARQ: combines FEC and retransmission (ARQ)
  - Prioritizes and decides which UEs and radio bearers will send or receive data on which shared physical resources
  - Decides the transmission format, i.e., the modulation format, code rate, MIMO rank, and power level
- Physical layer actually transmits the data