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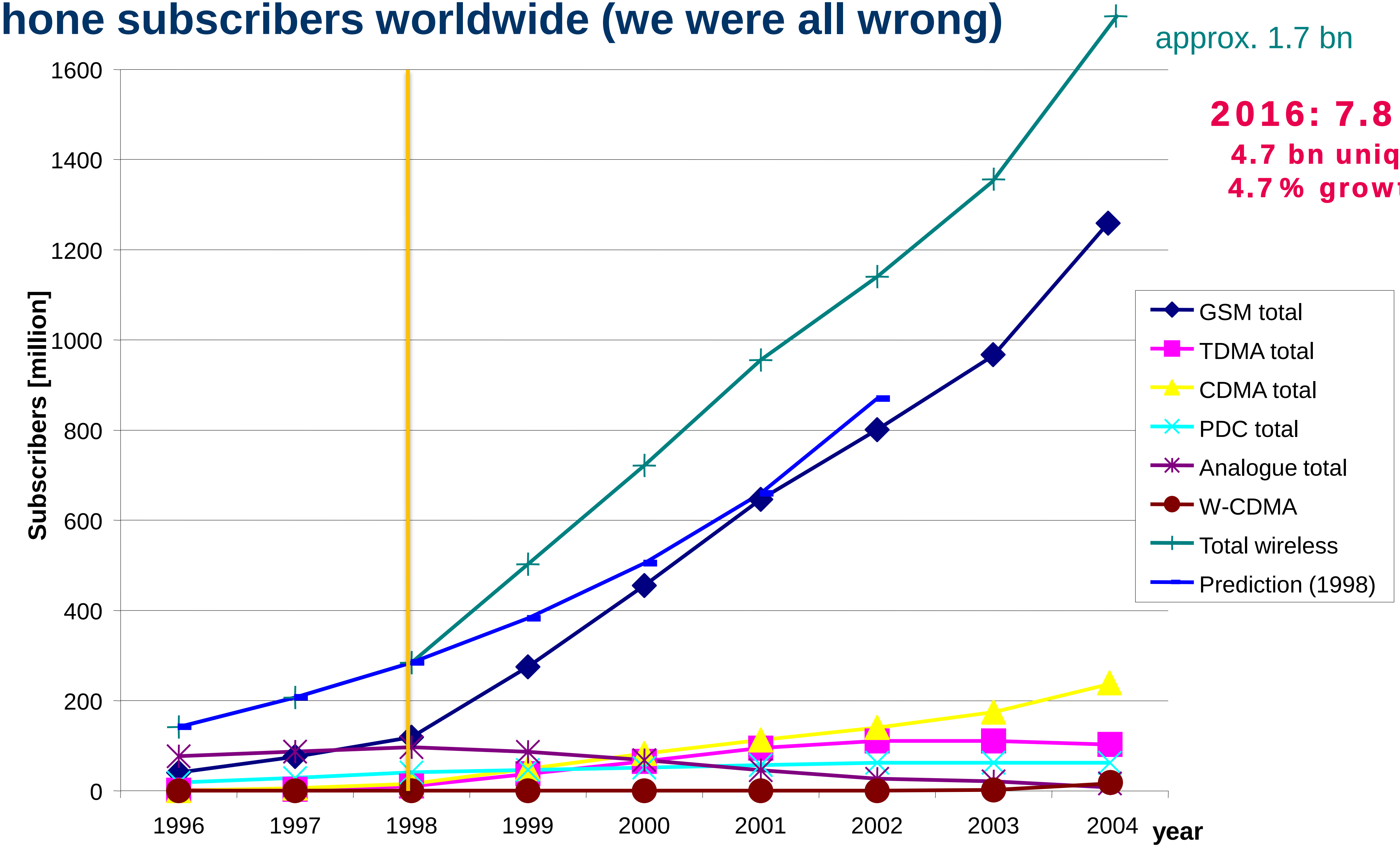
Mobile Communications
Chapter 4: Wireless Telecommunication Systems

Market
GSM
TETRA
UMTS/IMT-2000
LTE/LTE advanced

Mobile phone subscribers worldwide (we were all wrong)



2016: 7.8 bn total
4.7 bn unique human
4.7 % growth / year

Some current numbers (2019/2020)

TOTAL CELLULAR CONNECTIONS

Including licensed cellular IoT - May 2020

10,041,194,857

▲ 7.70%

UNIQUE MOBILE SUBSCRIBERS

May 2020

5,283,009,802

▲ 2.28%

Source: GSMAIntelligence

WIRELESS TELECOM SPENDING WORLDWIDE

844bn USD

WORLDWIDE VOICE TELECOM SPENDING

425bn USD

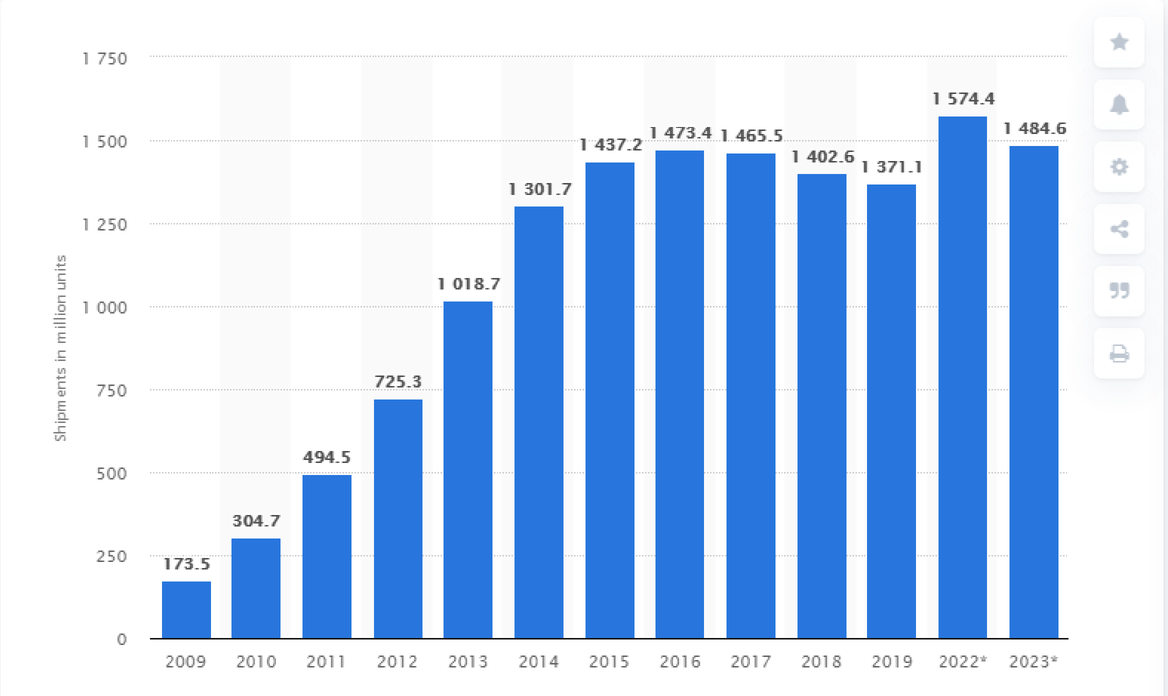
WIRELESS DATA TELECOM SPENDING WORLDWIDE

425bn USD

Source: statista

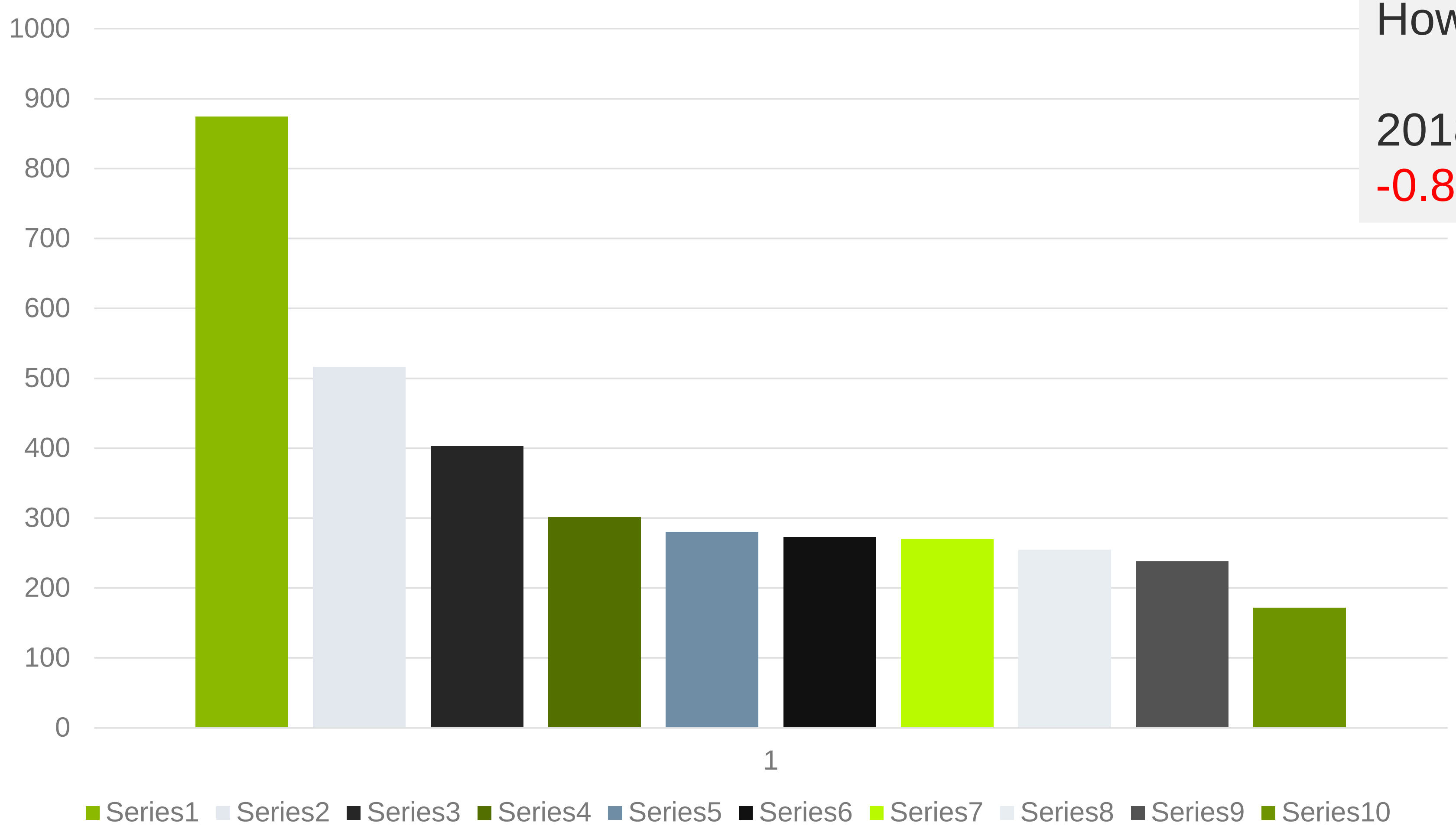
Global smartphone shipments forecast from 2010 to 2023

(in million units)



Source: statista

World largest mobile network operators 2019

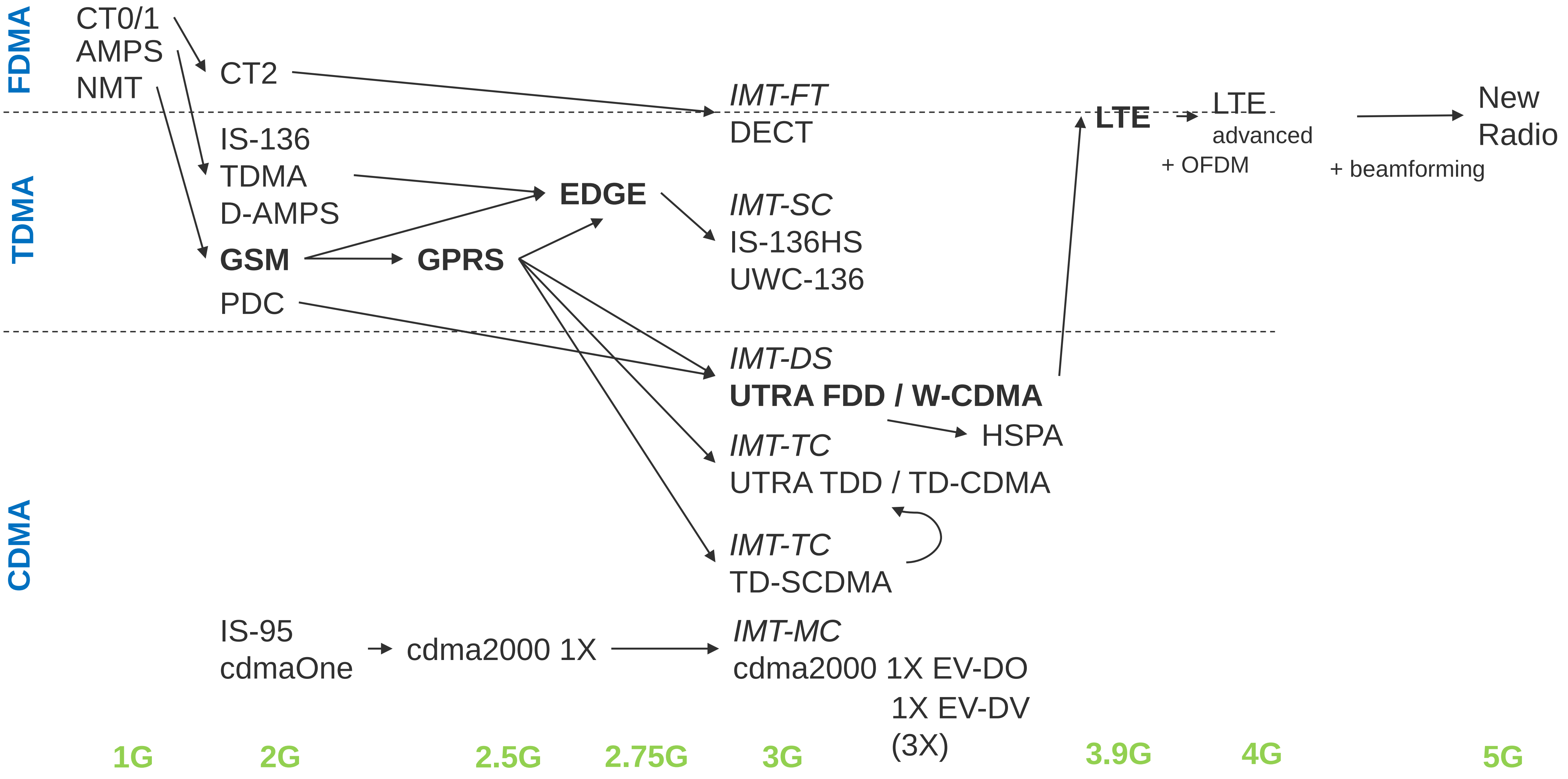


2014: $10.25 ARPU/month
However: -2.8% growth/year

2018: $8.45 ARPU/month
-0.8% growth/year

Source: The Daily Records

Development of mobile telecommunication systems



Some press news…

16th April 2008: The GSMA, the global trade group for the mobile industry, today announced that total connections to GSM mobile communications networks have now passed the **3 Billion** mark globally. The third billion landmark has been reached just four years after the GSM industry surpassed its first billion, and just two years from the second billionth connection. The 3 Billion landmark has been surpassed just 17 years after the first GSM network launch in 1991. Today more than 700 mobile operators across 218 countries and territories of the world are adding **new connections at the rate of 15 per second, or 1.3 million per day**.

11 February 2009: The GSMA today announced that the mobile world has celebrated its **four billionth connection**, according to Wireless Intelligence, the GSMA's market intelligence unit. This milestone underscores the continued strong growth of the mobile industry and puts the global market on the path to reach a staggering **six billion connections by 2013**.

By **2014 3.4bn** people have **broadband**, 80% mobile!

2018: more than **8.5 billion mobile connections**, more than 5 billion unique subscribers, $9,49 ARPU/month (https://www.gsmaintelligence.com/)

2020: 5G networks and phones start spreading worldwide

How does it work?

How can the system locate a user?

Why don't all phones ring at the same time?

What happens if two users talk simultaneously?

Why don't I get the bill from my neighbor?

Why can an Australian use her phone in Berlin?

Why can't I simply overhear the neighbor's communication?

How secure is the mobile phone system?

What are the key components of the mobile phone network?

Questions & Tasks

- Why do we have so many more connections compared to subscribers?
- Who/what is driving mobile communications in the future?
- What are consequences of a shrinking ARPU? What can companies do?
- Who defines the generations of mobile telecommunication systems?
- Visit some of the statistics pages and check-out the newest numbers!
- Go through the simple questions and keep them in mind. These are the questions you definitively have to able to answer after this chapter for all systems presented!

GSM – the most successful 2G system: Overview

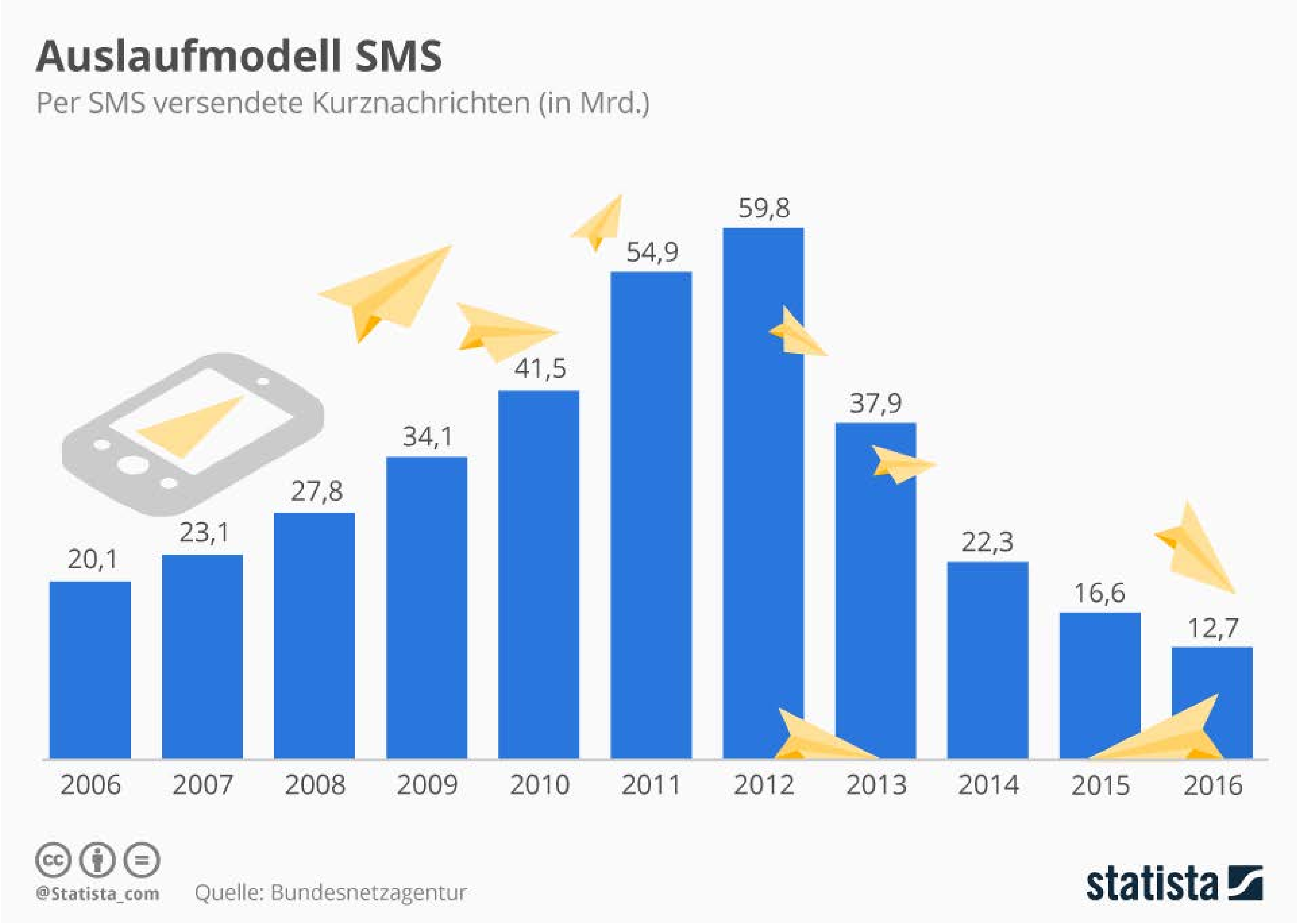
GSM

- formerly: Groupe Spéciale Mobile (founded 1982)
- now: Global System for Mobile Communication
- Pan-European standard (ETSI, European Telecommunications Standardisation Institute)
- simultaneous introduction of essential services in three phases (1991, 1994, 1996) by the European telecommunication administrations (Germany: D1 and D2)
  ➔ seamless roaming within Europe possible

2008: many providers all over the world use GSM (almost all countries in Asia, Africa, Europe, Australia, America)

- more than 4.2 billion subscribers in more than 700 networks
- more than 75% of all digital mobile phones use GSM
- over 29 billion SMS in Germany in 2008 (> 10% of the revenues for many operators)
  [be aware: these are only rough numbers…]

Good bye SMS!?


Auslaufmodell SMS
Per SMS versendete Kurznachrichten (in Mrd.)
20,1
23,1
27,8
34,1
41,5
54,9
59,8
37,9
22,3
16,6
12,7
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
@Statista_com
Quelle: Bundesnetzagentur
statista

Performance characteristics of GSM (wrt. analog sys.)

Communication

mobile, wireless communication; support for voice and data services

Total mobility

international access, chip-card enables use of access points of different providers

Worldwide connectivity

one number, the network handles localization

High capacity

better frequency efficiency, smaller cells, more customers per cell

High transmission quality

high audio quality and reliability for wireless, uninterrupted phone calls at higher speeds (e.g., from cars, trains)

Security functions

access control, authentication via chip-card and PIN

Disadvantages of GSM

There is no perfect system!!

- no end-to-end encryption of user data
- no full ISDN bandwidth of 64 kbit/s to the user, no transparent B-channel
- reduced concentration while driving
- electromagnetic radiation
- abuse of private data possible
- roaming profiles accessible
- high complexity of the system
- several optional capabilities within the GSM standards

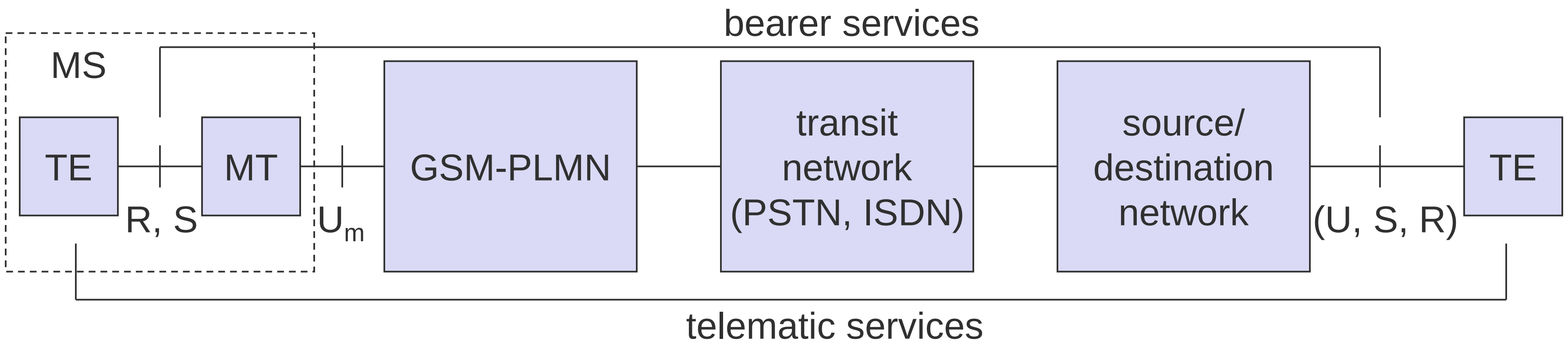
GSM: Mobile Services

GSM offers

- several types of connections
- voice connections, data connections, short message service
- multi-service options (combination of basic services)

Three service domains

- Bearer Services
- Telematic Services
- Supplementary Services



Bearer Services

Telecommunication services to transfer data between access points

Specification of services up to the terminal interface (OSI layers 1-3)

Different data rates for voice and data (original standard)

- data service (circuit switched)
  - synchronous: 2.4, 4.8 or 9.6 kbit/s
  - asynchronous: 300 - 1200 bit/s
- data service (packet switched)
  - synchronous: 2.4, 4.8 or 9.6 kbit/s
  - asynchronous: 300 - 9600 bit/s

Today (classical GSM!):

- data rates of approx. 50 kbit/s possible – will be covered later!
- far more with new modulation scheme

Tele Services I

Telecommunication services that enable voice communication via mobile phones

All these basic services have to obey cellular functions, security measurements etc.

Offered services

- mobile telephony
  - primary goal of GSM was to enable mobile telephony offering the traditional bandwidth of 3.1 kHz
- emergency number
  - common number throughout Europe (112)
  - mandatory for all service providers
  - free of charge
  - connection with the highest priority (preemption of other connections possible)
- multi-numbering
  - several ISDN phone numbers per user possible

Tele Services II

Additional services

- Non-Voice-Teleservices
  - group 3 fax
  - voice mailbox (implemented in the fixed network supporting the mobile terminals)
  - electronic mail (MHS, Message Handling System, implemented in the fixed network)
  - ...

- Short Message Service (SMS)
  - alphanumeric data transmission to/from the mobile terminal (160 characters) using the signaling channel, thus allowing simultaneous use of basic services and SMS
  - almost ignored in the beginning then the most successful add-on!
    - but more and more replaced by IP-based messaging

Supplementary services

Services in addition to the basic services, cannot be offered stand-alone

Similar to ISDN services besides lower bandwidth due to the radio link

May differ between different service providers, countries and protocol versions

Important services

- identification: forwarding of caller number
- suppression of number forwarding
- automatic call-back
- conferencing with up to 7 participants
- locking of the mobile terminal (incoming or outgoing calls)
- ...

Questions & Tasks

- What is SMS still used for? What do the replacements require?
- Why was GSM such a big success?
- What are the main differences between GSM and ISDN (at a high level)?
- What is required in the background of 112?
- Look at the characteristics of GSM and its disadvantages. What has changed, what is the same if you compare GSM with today's systems?

Architecture of the GSM system

GSM is a PLMN (Public Land Mobile Network)

- several providers setup mobile networks following the GSM standard within each country
- components
  - MS (mobile station)
  - BS (base station)
  - MSC (mobile switching center)
  - LR (location register)
- subsystems
  - RSS (radio subsystem): covers all radio aspects
  - NSS (network and switching subsystem): call forwarding, handover, switching
  - OSS (operation subsystem): management of the network

Ingredients 1: Mobile Phones, Smartphones & Co.

Source: Tech Best, https://www.youtube.com/watch?v=g7i00InEzhI

Source: Time Magazine, 09/14

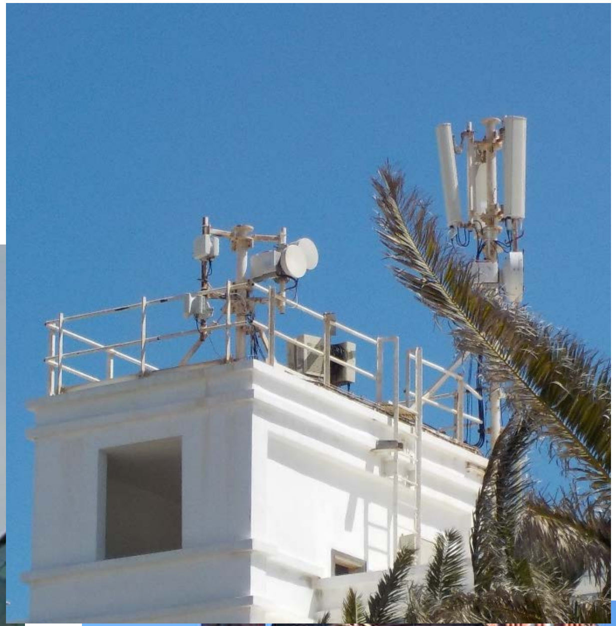
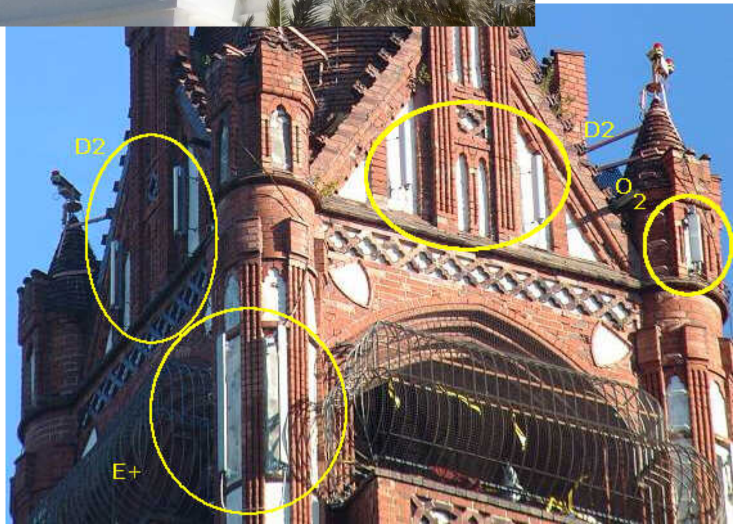
Source: www.riot-os.org

The visible but smallest part of the network!

Ingredients 2: Antennas





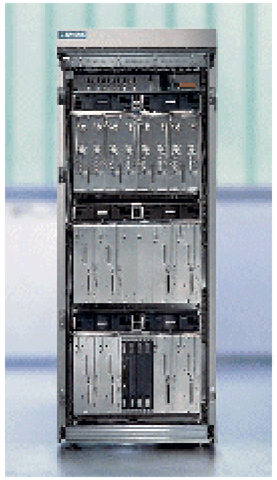




Still visible – cause many discussions…

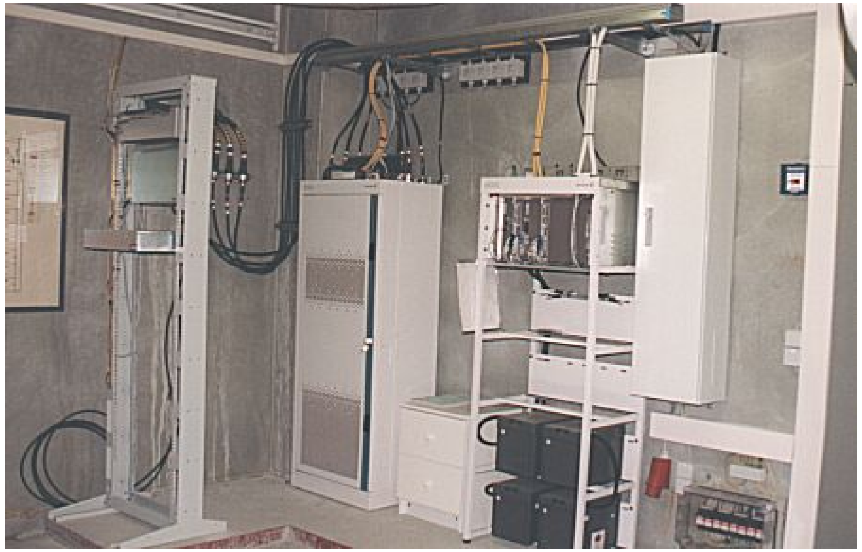
Ingredients 3: Infrastructure 1

Base Stations

Cabling



Microwave links



Ingredients 3: Infrastructure 2

Not „visible“, but comprise the major part of the network (also from an investment point of view…)

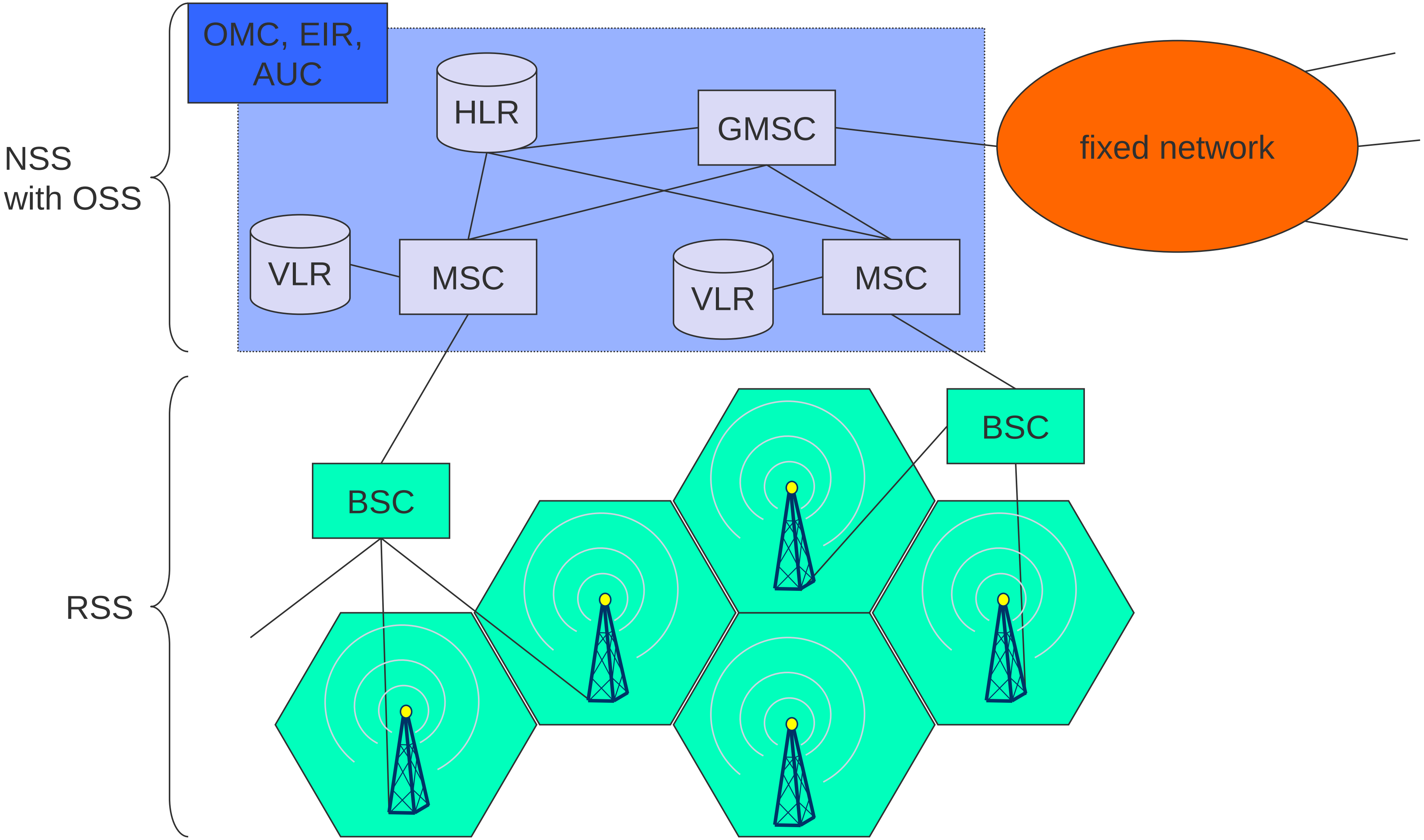
Management

Data bases

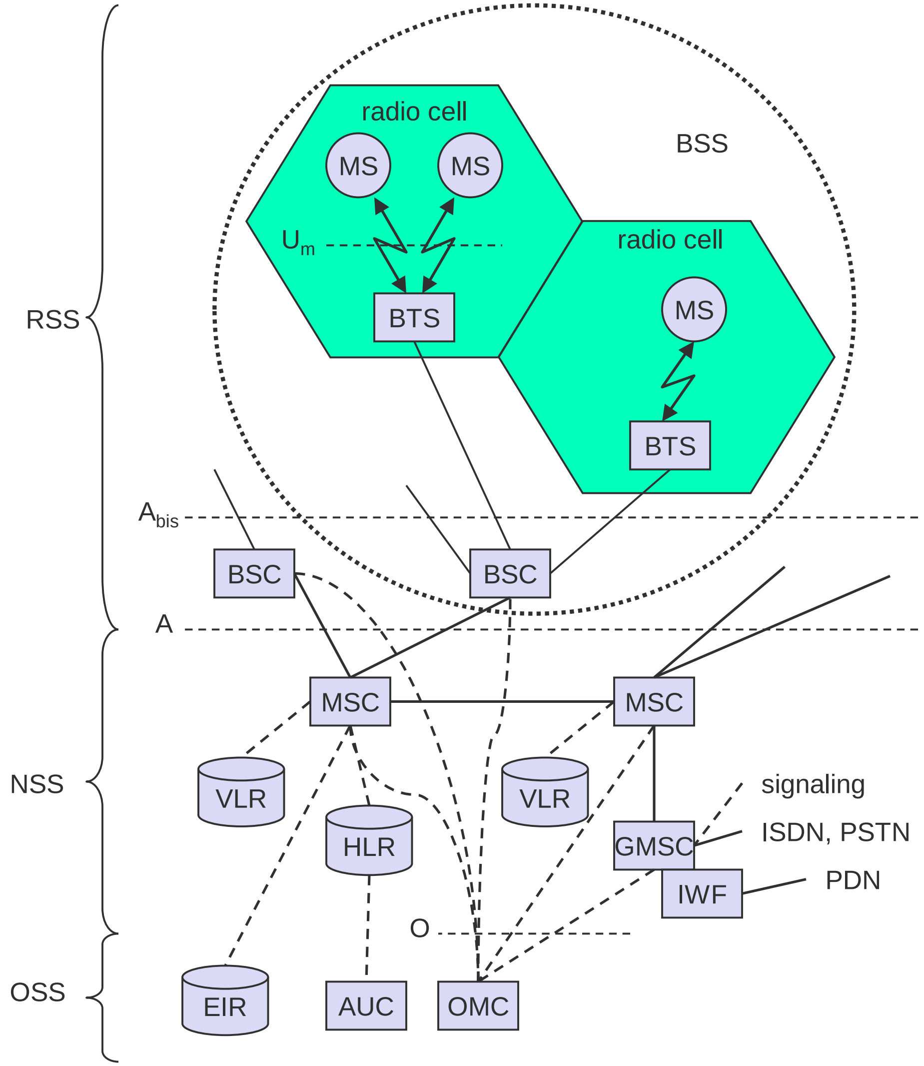
Switching units

Monitoring

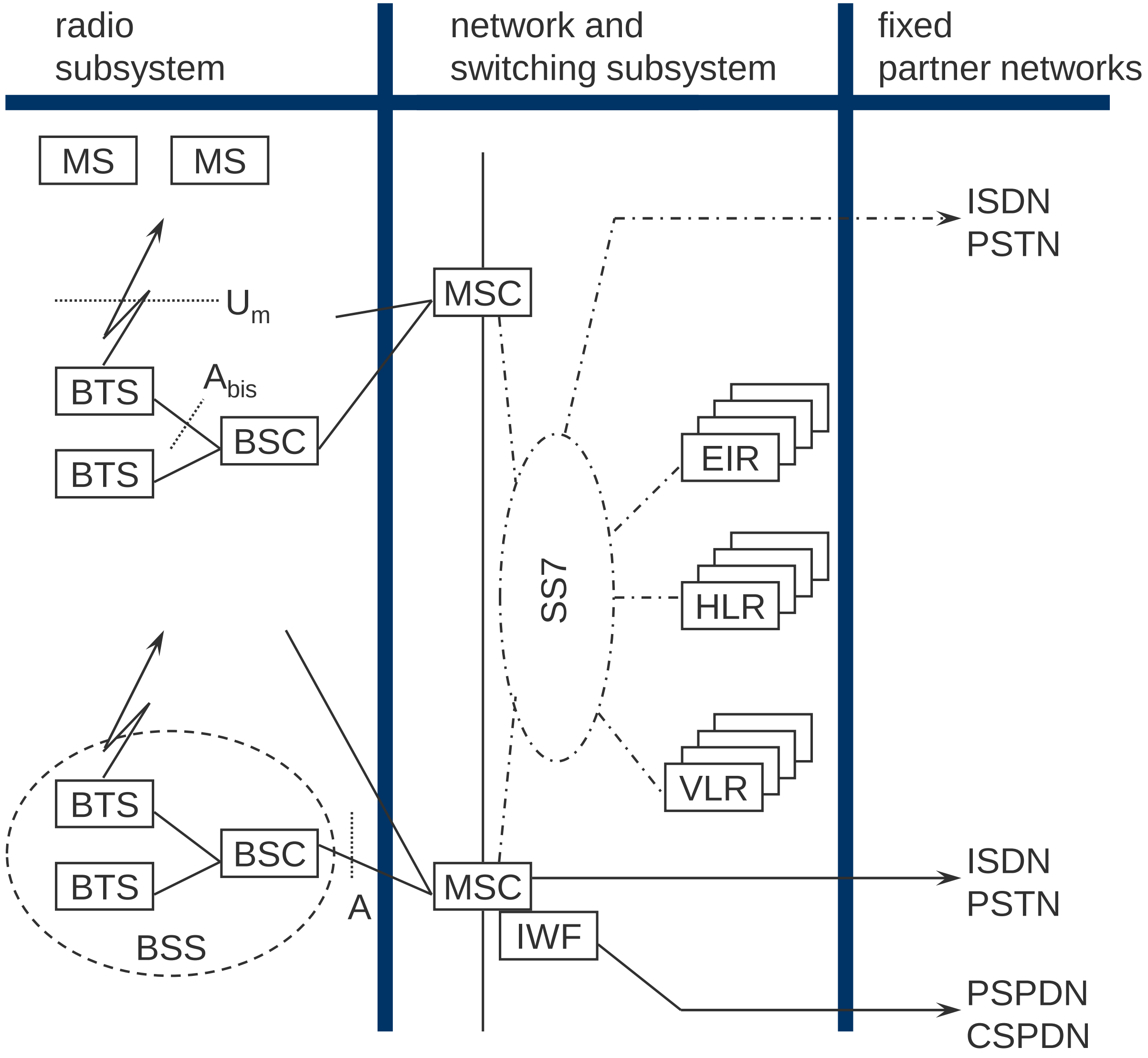
GSM: overview



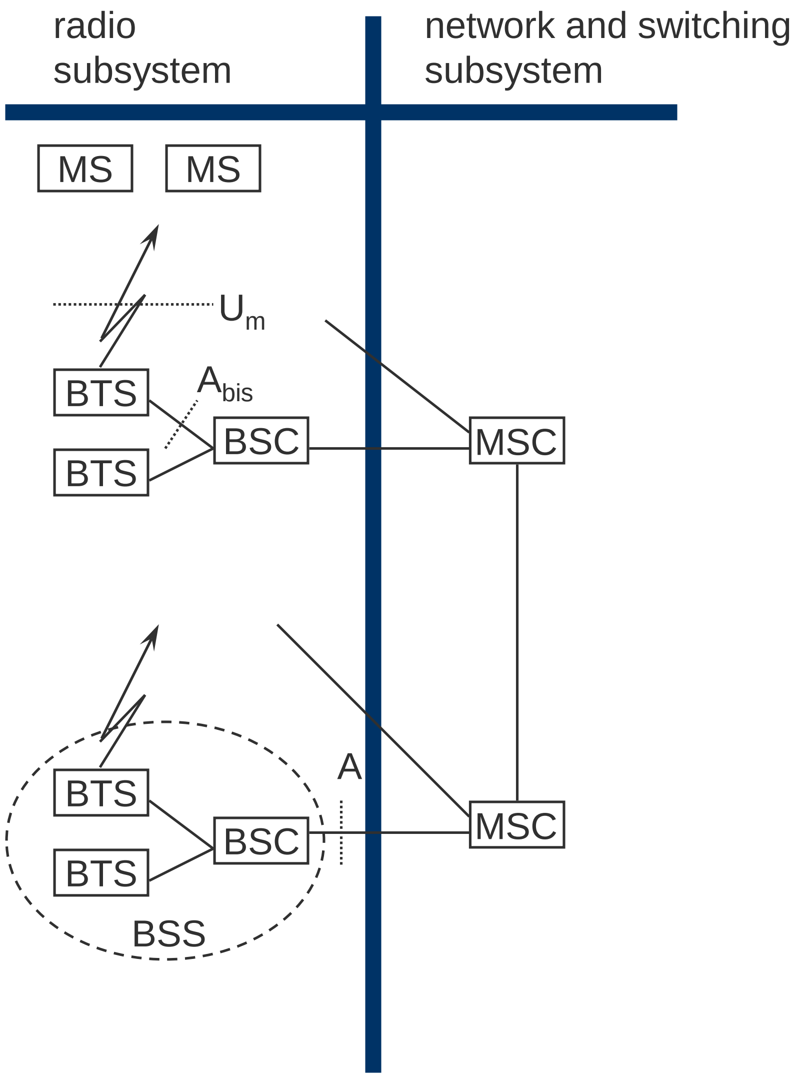
GSM: elements and interfaces



GSM: system architecture



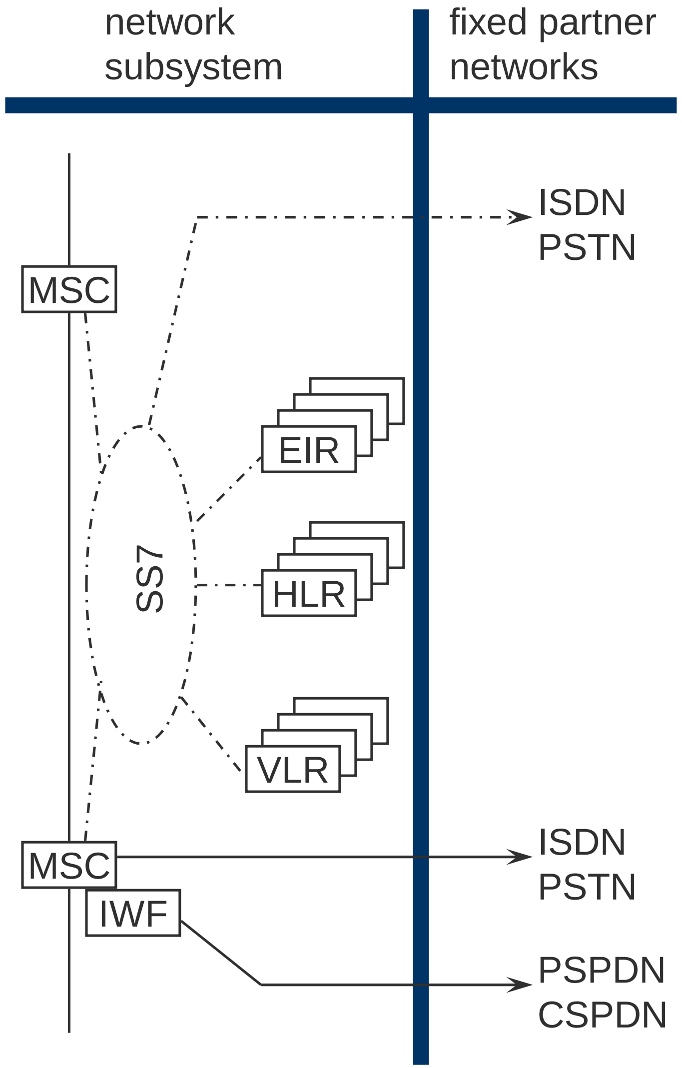
System architecture: radio subsystem



Components
- *MS* (Mobile Station)
- *BSS* (Base Station Subsystem): consisting of
  - *BTS* (Base Transceiver Station): sender and receiver
  - *BSC* (Base Station Controller): controlling several transceivers

Interfaces
- U_m : radio interface
- A_{bis} : standardized, open interface with 16 kbit/s user channels
- *A*: standardized, open interface with 64 kbit/s user channels

System architecture: network and switching subsystem



- Components
  - MSC (Mobile Services Switching Center):
  - IWF (Interworking Functions)
  - ISDN (Integrated Services Digital Network)
  - PSTN (Public Switched Telephone Network)
  - PSPDN (Packet Switched Public Data Net.)
  - CSPDN (Circuit Switched Public Data Net.)

- Databases
  - HLR (Home Location Register)
  - VLR (Visitor Location Register)
  - EIR (Equipment Identity Register)

Radio subsystem

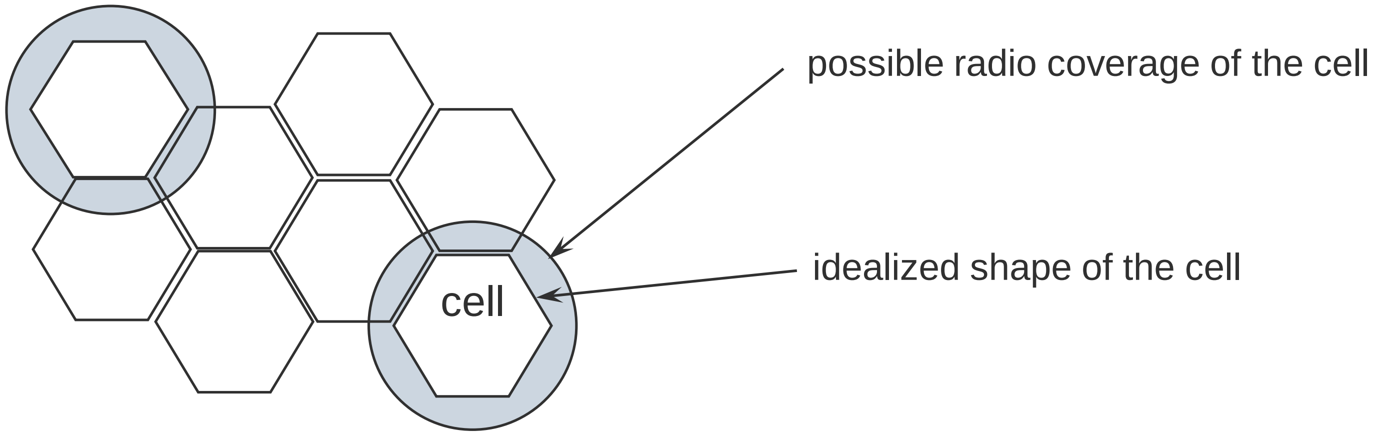
The Radio Subsystem (RSS) comprises the cellular mobile network up to the switching centers

Components

- Base Station Subsystem (BSS):
  - Base Transceiver Station (BTS): radio components including sender, receiver, antenna - if directed antennas are used one BTS can cover several cells
  - Base Station Controller (BSC): switching between BTSs, controlling BTSs, managing of network resources, mapping of radio channels (U_m) onto terrestrial channels (A interface)
  - BSS = BSC + sum(BTS) + interconnection
- Mobile Stations (MS)

GSM: cellular network

segmentation of the area into cells



- use of several carrier frequencies
- not the same frequency in adjoining cells
- cell sizes vary from some 100 m up to 35 km depending on user density, geography, transceiver power etc.
- hexagonal shape of cells is idealized (cells overlap, shapes depend on geography)
- if a mobile user changes cells handover of the connection to the neighbor cell

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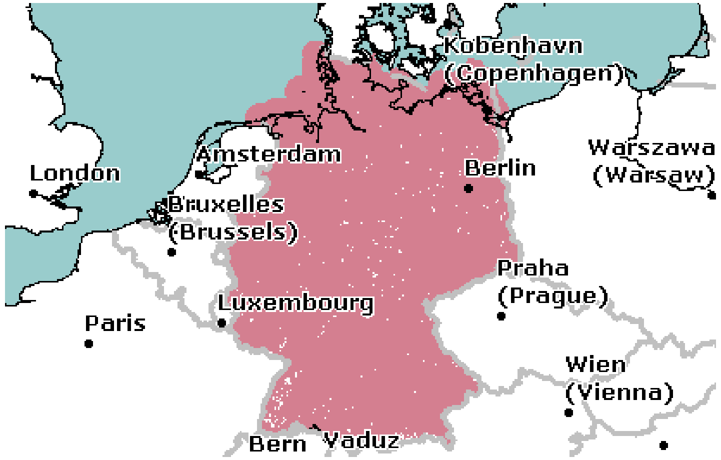
GSM frequency bands (examples)

Type	Channels	Uplink [MHz]	Downlink [MHz]
GSM 850	128-251	824-849	869-894
GSM 900 classical extended	0-124, 955-1023 124 channels +49 channels	876-915 890-915 880-915	921-960 935-960 925-960
GSM 1800	512-885	1710-1785	1805-1880
GSM 1900	512-810	1850-1910	1930-1990
GSM-R exclusive	955-1024, 0-124 69 channels	876-915 876-880	921-960 921-925

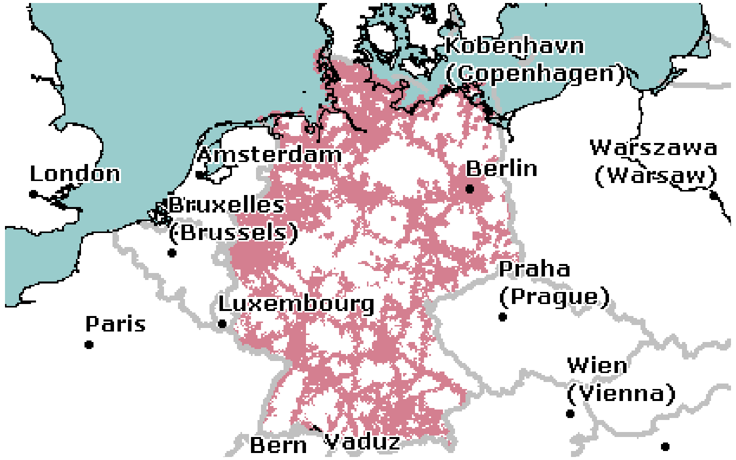
- Additionally: GSM 400 (also named GSM 450 or GSM 480 at 450-458/460-468 or 479-486/489-496 MHz)
- Please note: frequency ranges may vary depending on the country!
- Channels at the lower/upper edge of a frequency band are typically not used

Example coverage of GSM networks (historical from www.gsmworld.com)

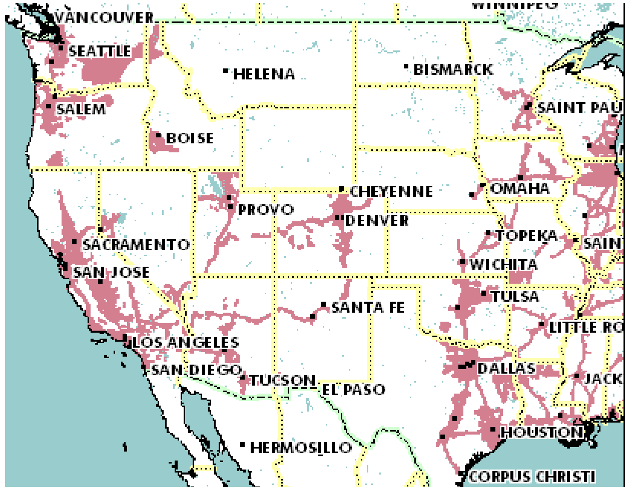
T-Mobile (GSM-900/1800) Germany



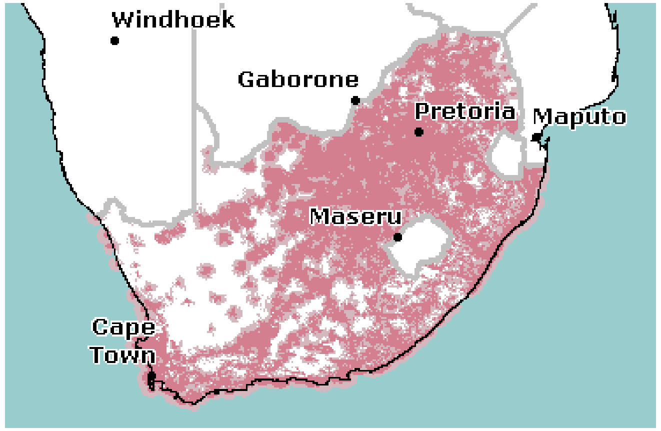
O_2 (GSM-1800) Germany



AT&T (GSM-850/1900) USA



Vodacom (GSM-900) South Africa



Base Transceiver Station and Base Station Controller

Tasks of a BSS are distributed over BSC and BTS

BTS comprises radio specific functions

BSC is the switching center for radio channels

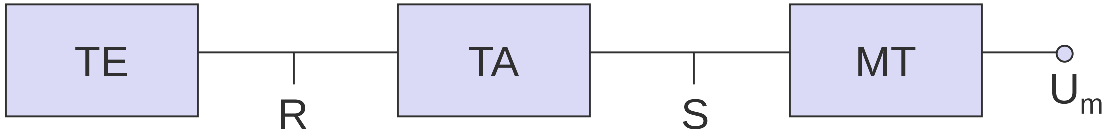
Functions	BTS	BSC
Management of radio channels		X
Frequency hopping (FH)	X	X
Management of terrestrial channels		X
Mapping of terrestrial onto radio channels		X
Channel coding and decoding	X	
Rate adaptation	X	
Encryption and decryption	X	X
Paging	X	X
Uplink signal measurements	X	
Traffic measurement		X
Authentication		X
Location registry, location update		X
Handover management		X

Mobile station

Terminal for the use of GSM services

A mobile station (MS) comprises several functional groups
- MT (Mobile Terminal):
  - offers common functions used by all services the MS offers
  - corresponds to the network termination (NT) of an ISDN access
  - end-point of the radio interface (Um)
- TA (Terminal Adapter):
  - terminal adaptation, hides radio specific characteristics
- TE (Terminal Equipment):
  - peripheral device of the MS, offers services to a user
  - does not contain GSM specific functions
- SIM (Subscriber Identity Module):
  - personalization of the mobile terminal, stores user parameters – more and more replaced by eSIM

Source: geektrooper.wordpress.com



Network and switching subsystem

NSS is the main component of the public mobile network GSM

- switching, mobility management, interconnection to other networks, system control

Components

- Mobile Services Switching Center (MSC)
  controls all connections via a separated network to/from a mobile terminal within the domain of the MSC - several BSC can belong to a MSC
- Databases (important: scalability, high capacity, low delay)
  - Home Location Register (HLR)
    central master database containing user data, permanent and semi-permanent data of all subscribers assigned to the HLR (one provider can have several HLRs)
  - Visitor Location Register (VLR)
    local database for a subset of user data, including data about all user currently in the domain of the VLR

Mobile Services Switching Center

The MSC (mobile services switching center) plays a central role in GSM

- switching functions
- additional functions for mobility support
- management of network resources
- interworking functions via Gateway MSC (GMSC)
- integration of several databases

Functions of an MSC

- specific functions for paging and call forwarding
- termination of SS7 (signaling system no. 7)
- mobility specific signaling
- location registration and forwarding of location information
- provision of new services (fax, data calls)
- support of short message service (SMS)
- generation and forwarding of accounting and billing information

Operation subsystem

The OSS (Operation Subsystem) enables centralized operation, management, and maintenance of all GSM subsystems

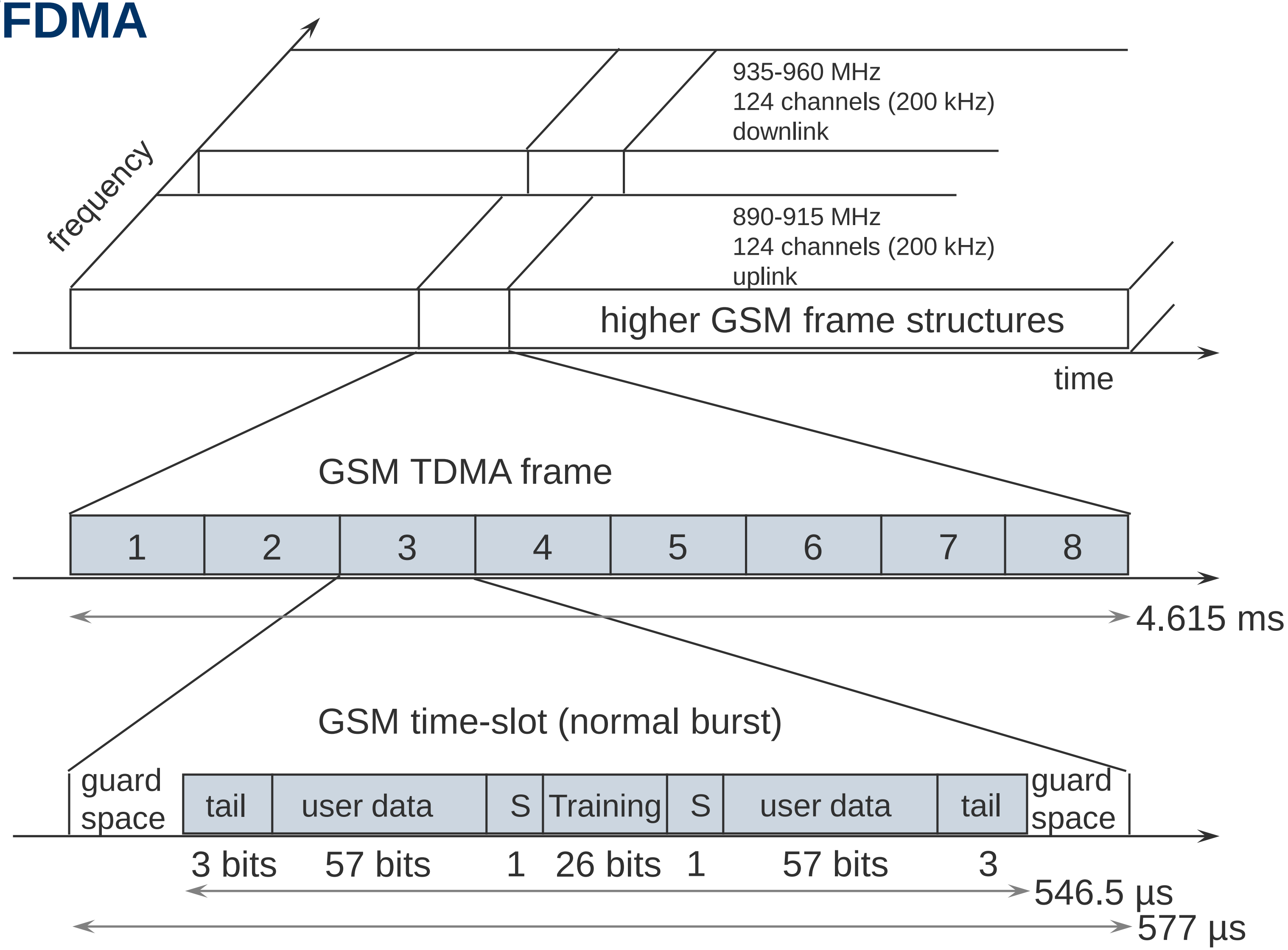
Components

- Authentication Center (AUC)
  - generates user specific authentication parameters on request of a VLR
  - authentication parameters used for authentication of mobile terminals and encryption of user data on the air interface within the GSM system
- Equipment Identity Register (EIR)
  - registers GSM mobile stations and user rights
  - stolen or malfunctioning mobile stations can be locked and sometimes even localized
- Operation and Maintenance Center (OMC)
  - different control capabilities for the radio subsystem and the network subsystem

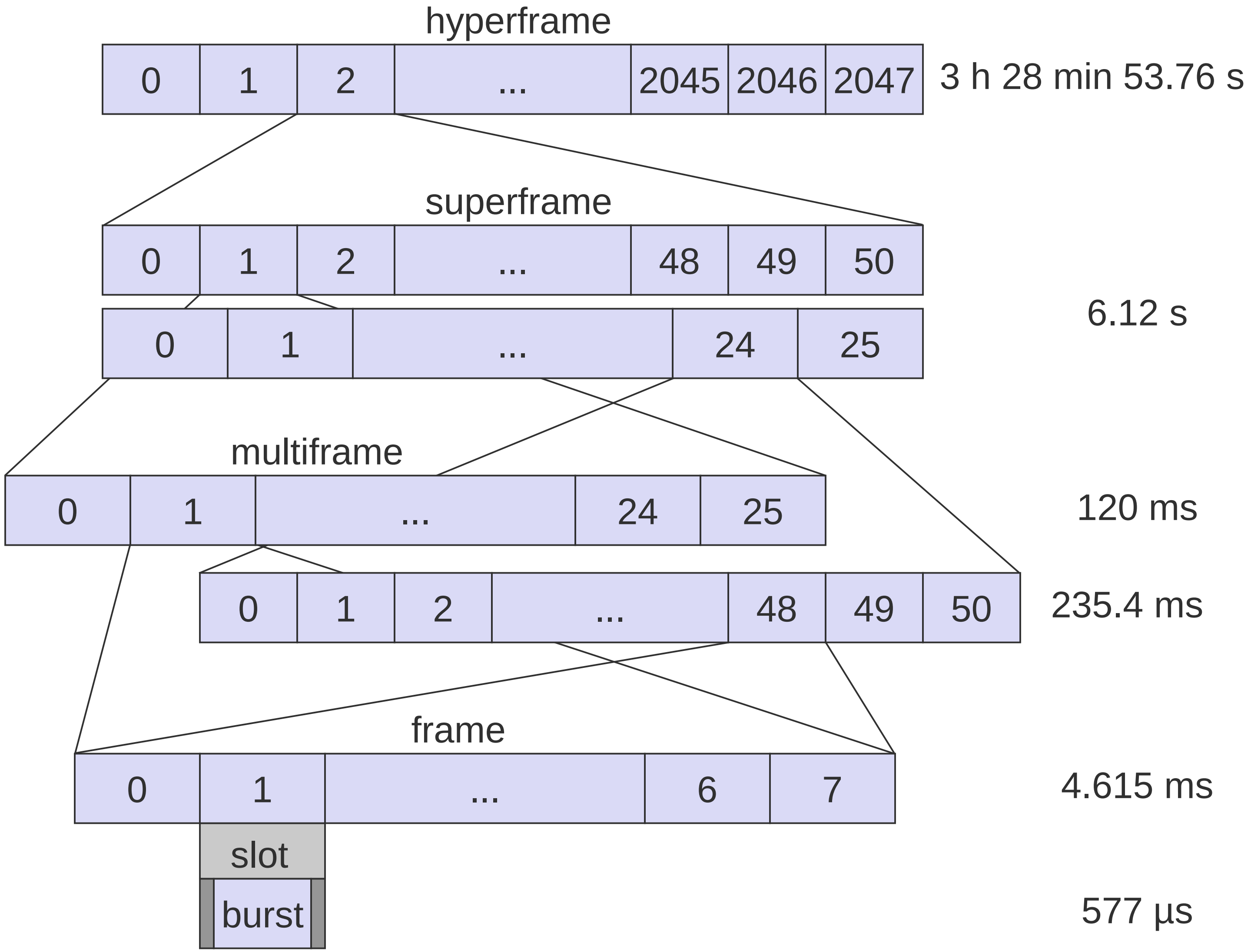
Questions & Tasks

- You should be able to draw the architecture of the classical GSM system and to describe the functionality of the components!
- What are the advantages of specifying not only the radio interface but also all internal interfaces of the GSM system?
- Could there be a single point of failure in the GSM architecture? How to avoid it?
- In which database is a roaming tourist registered?
- How could the system block all stolen GSM phones?
- How can the system localizes mobile phones (at least to a certain precision…)?
- Why does GSM separate the MS and SIM?
- What is the advantage/disadvantage of an eSIM?

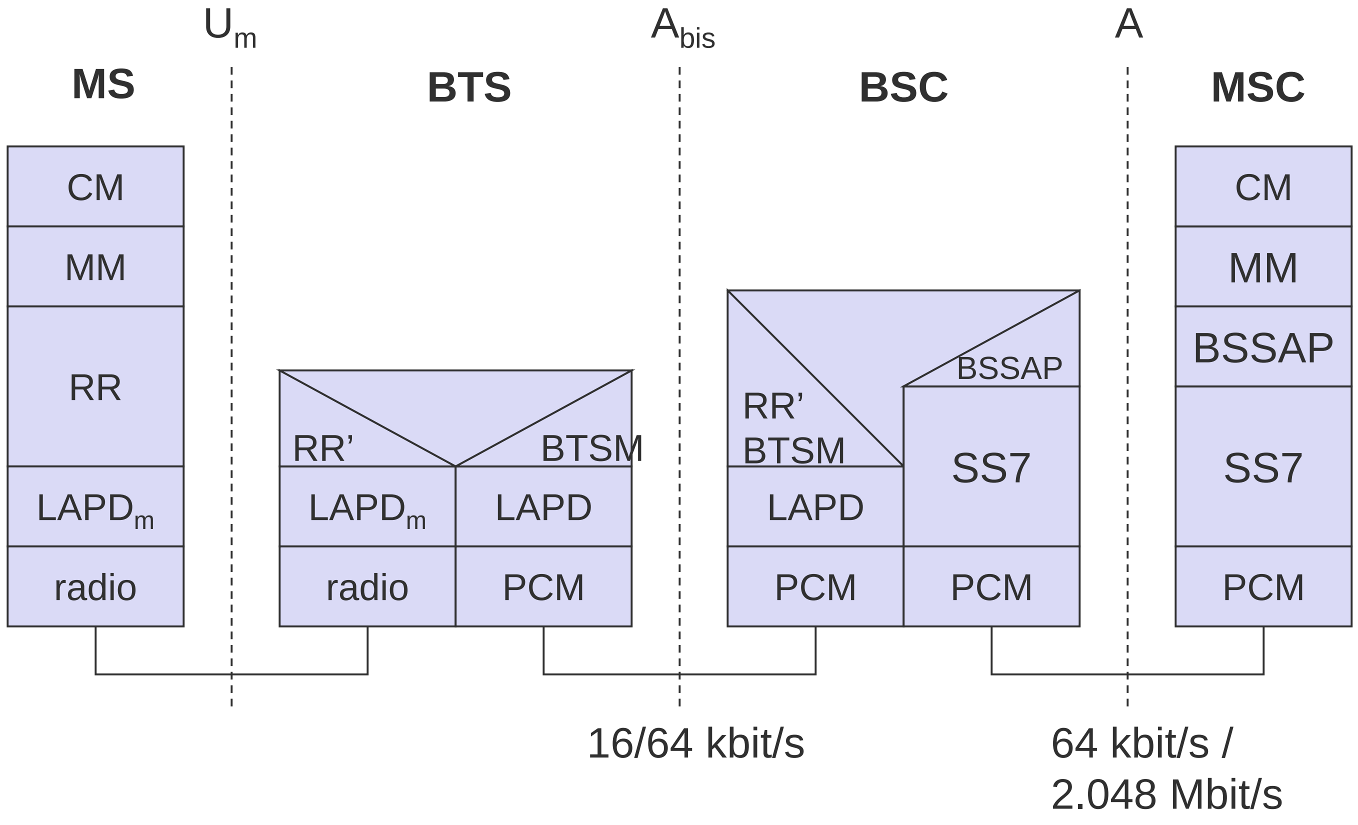
GSM - TDMA/FDMA



GSM hierarchy of frames



GSM protocol layers for signaling

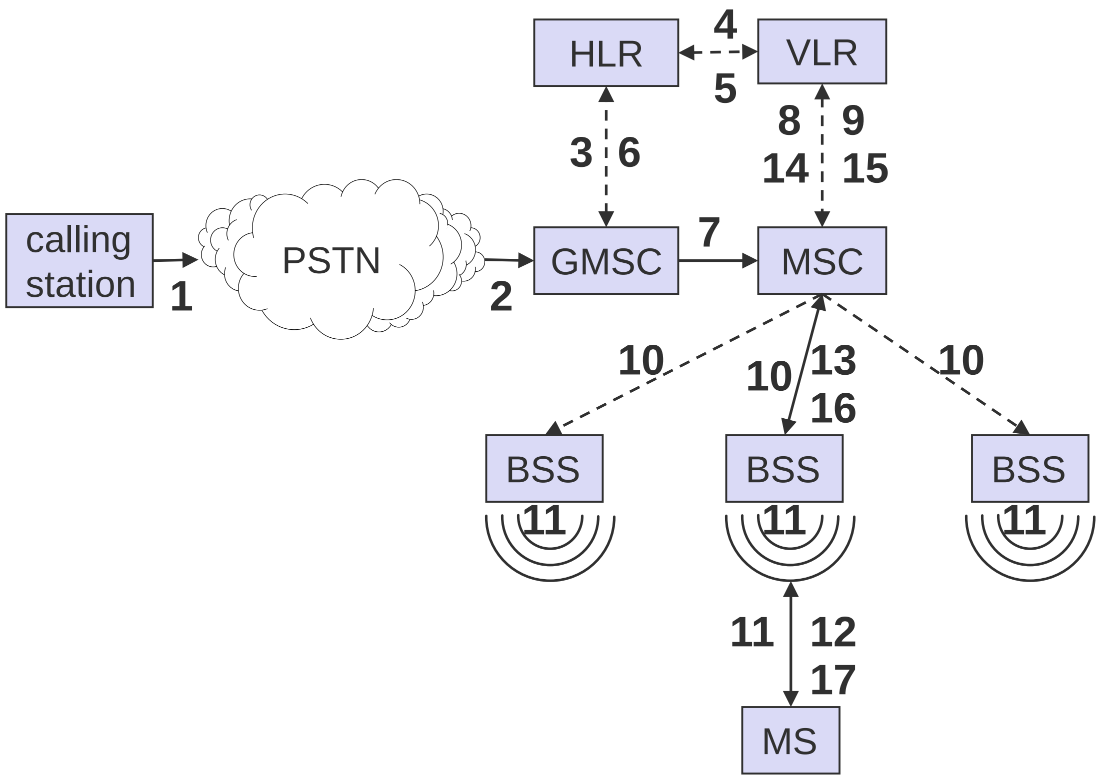


Questions & Tasks

- Go once more through the channel/slot structure and understand where GSM applies what type of multiplexing!
- How does GSM adapt to varying distances between MS and BTS? What is the role of the guard spaces?
- What limits the radius of a GSM cell?
- What is the maximum data rate per time slot? Why is the real data rate offered that much lower?

Mobile Terminated Call

1: calling a GSM subscriber
2: forwarding call to GMSC
3: signal call setup to HLR
4, 5: request MSRN from VLR
6: forward responsible MSC to GMSC
7: forward call to current MSC
8, 9: get current status of MS
10, 11: paging of MS
12, 13: MS answers
14, 15: security checks
16, 17: set up connection



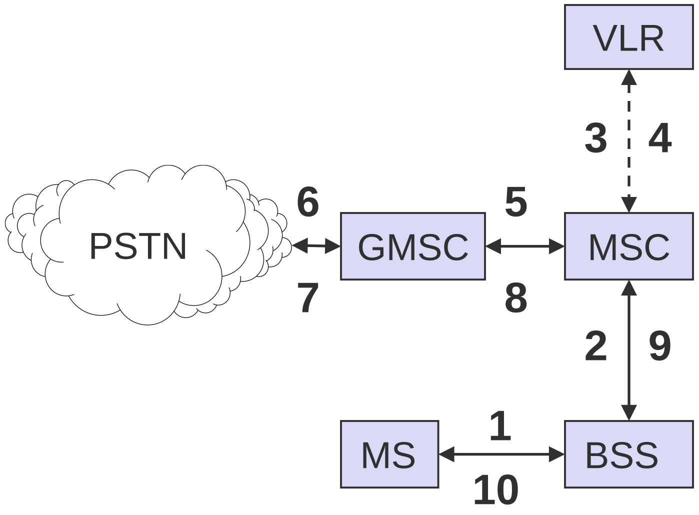
Mobile Originated Call

1, 2: connection request

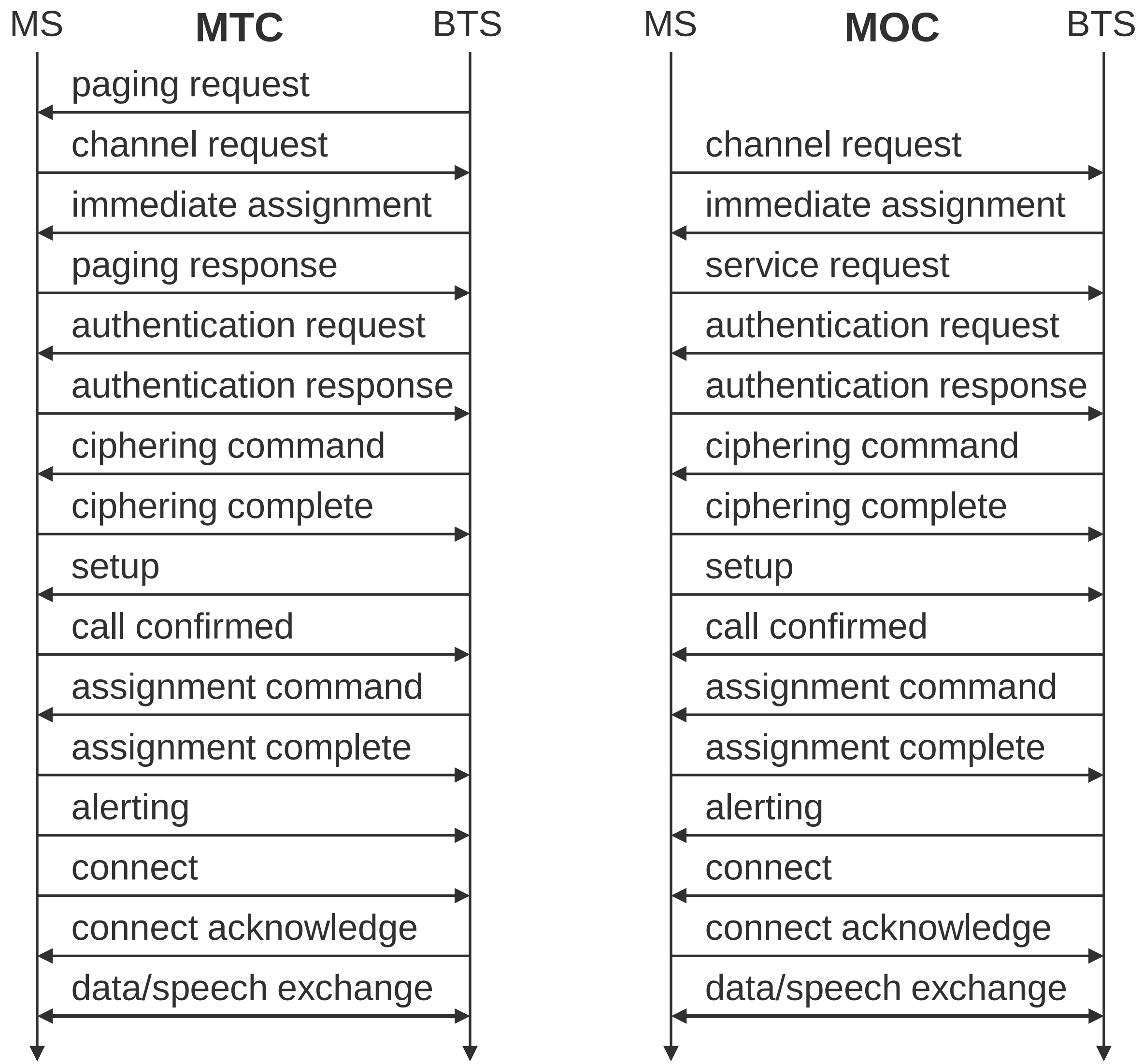
3, 4: security check

5-8: check resources (free circuit)

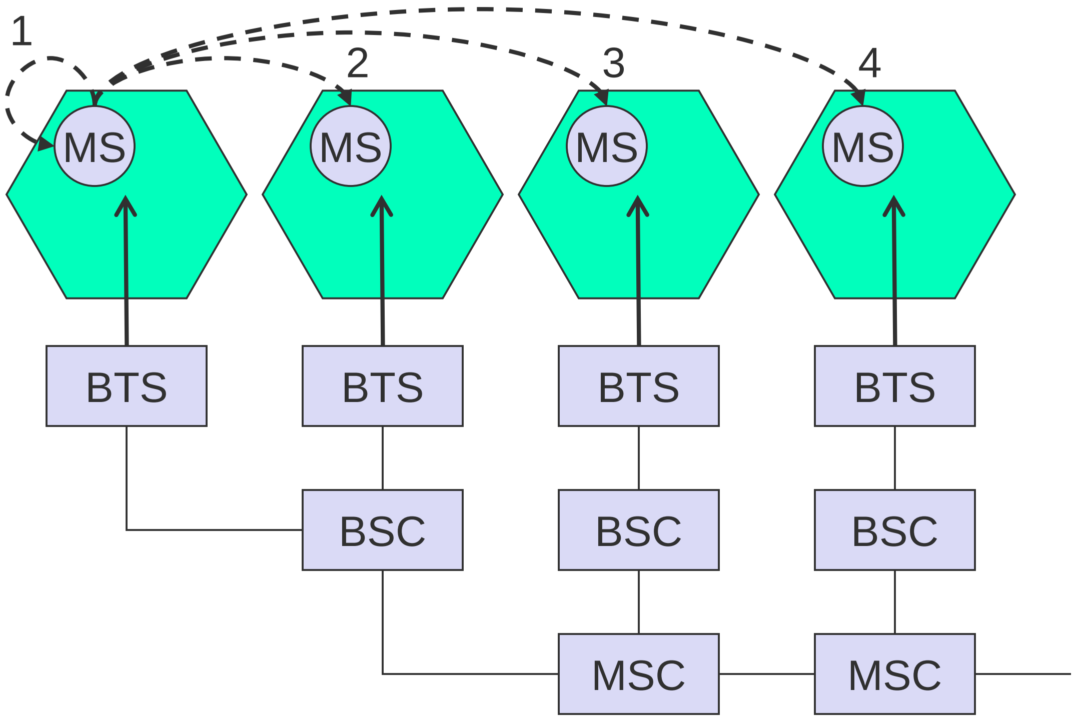
9-10: set up call



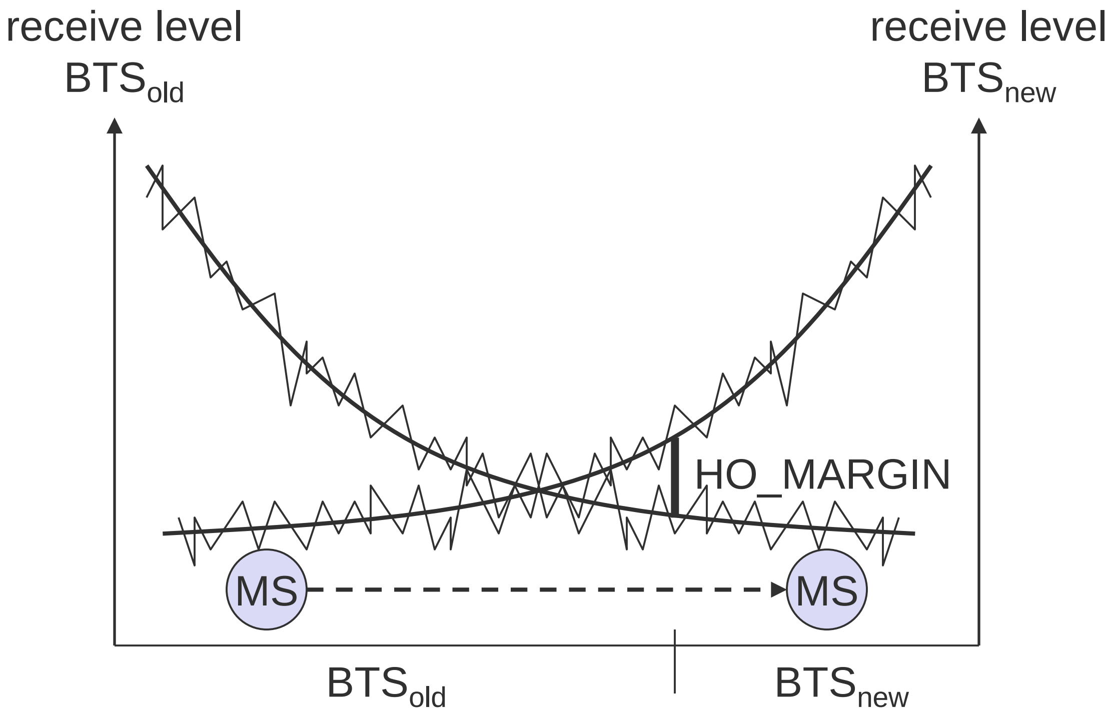
MTC/MOC


MS
MTC
BTS
paging request
channel request
immediate assignment
paging response
authentication request
authentication response
ciphering command
ciphering complete
setup
call confirmed
assignment command
assignment complete
alerting
connect
connect acknowledge
data/speech exchange
MS
MOC
BTS
channel request
immediate assignment
service request
authentication request
authentication response
ciphering command
ciphering complete
setup
call confirmed
assignment command
assignment complete
alerting
connect
connect acknowledge
data/speech exchange

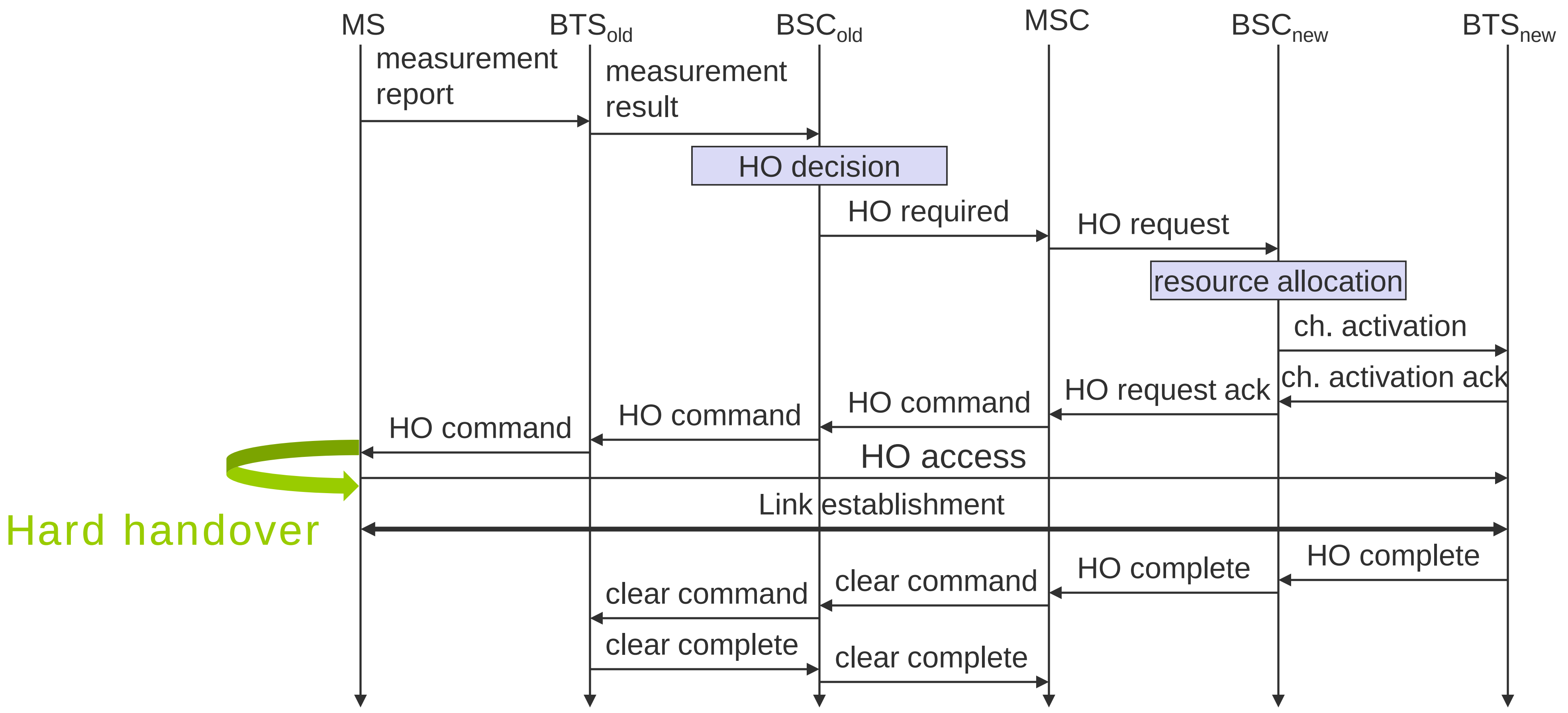
4 types of handover



Handover decision



Handover procedure



Questions & Tasks

- How does the GSM system locate an MS? How precise is the localization?
- Why does the system use a handover margin?
- Why is the hand over called “hard”?
- How and where is user-related data represented/stored in the GSM system?

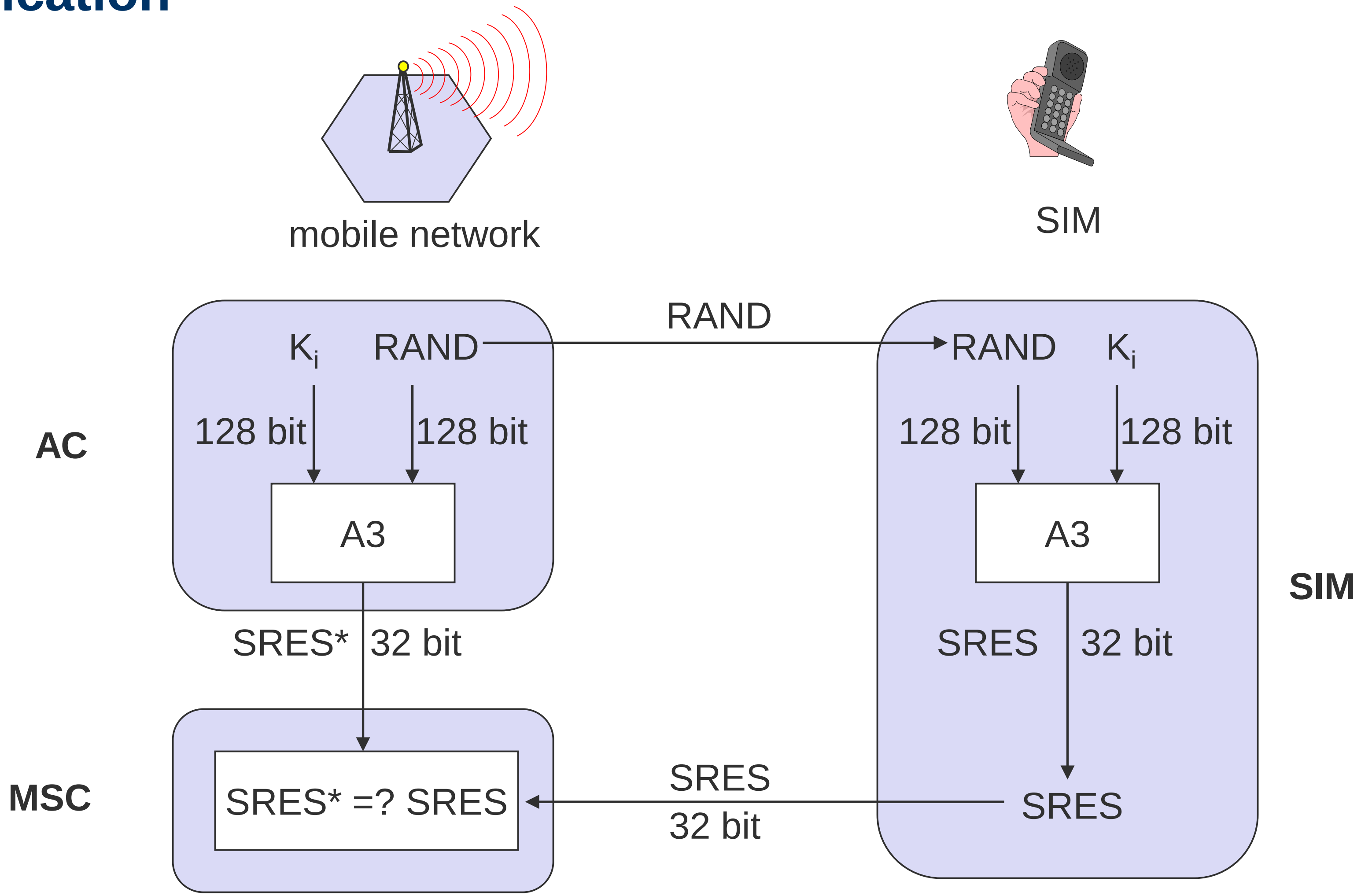
Security in GSM

Security services
- access control/authentication
  - user ⇔ SIM (Subscriber Identity Module): secret PIN (personal identification number)
  - SIM ⇔ network: challenge response method
- confidentiality
  - voice and signaling encrypted on the wireless link (after successful authentication)
- anonymity
  - temporary identity TMSI
    (Temporary Mobile Subscriber Identity)
  - newly assigned at each new location update (LUP)
  - encrypted transmission

3 algorithms specified in GSM
- A3 for authentication (“secret”, open interface)
- A5 for encryption (standardized)
- A8 for key generation (“secret”, open interface)

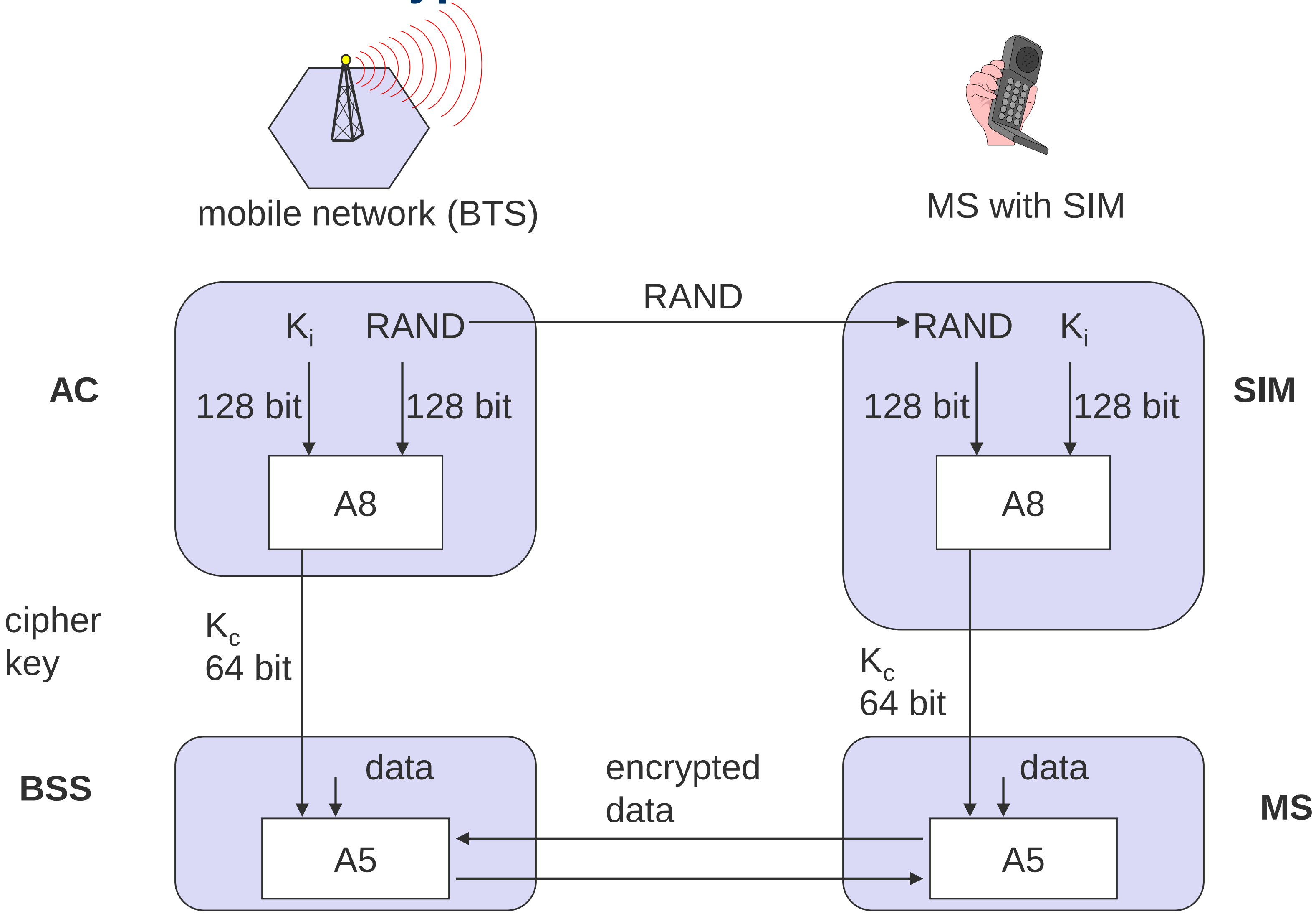
“secret”:
- A3 and A8 available via the Internet
- network providers can (and do) use stronger mechanisms

GSM - authentication



K_i: individual subscriber authentication key   SRES: signed response

GSM - key generation and encryption



Questions & Tasks

- What is protected by the GSM security mechanisms?
- What is missing compared to today’s communication systems?
- What are reasons for this decision?

Data services in GSM I

Data transmission standardized with only 9.6 kbit/s
- advanced coding allows 14.4 kbit/s
- not enough for Internet and multimedia applications

HSCSD (High-Speed Circuit Switched Data)
- mainly software update
- bundling of several time-slots to get higher AIUR (Air Interface User Rate, e.g., 57.6 kbit/s using 4 slots @ 14.4)
- advantage: ready to use, constant quality, simple
- disadvantage: channels blocked for voice transmission

AIUR [kbit/s]	TCH/F4.8	TCH/F9.6	TCH/F14.4
4.8	1		
9.6	2	1	
14.4	3		1
19.2	4	2	
28.8		3	2
38.4		4	
43.2			3
57.6			4

Data services in GSM II

GPRS (General Packet Radio Service)

- packet switching
- using free slots only if data packets ready to send
  (e.g., 50 kbit/s using 4 slots temporarily)
- standardization 1998, introduction 2001
- advantage: one step towards UMTS, more flexible
- disadvantage: more investment needed (new hardware)

GPRS network elements

- GSN (GPRS Support Nodes): GGSN and SGSN
- GGSN (Gateway GSN)
  - interworking unit between GPRS and PDN (Packet Data Network)
- SGSN (Serving GSN)
  - supports the MS (location, billing, security)
- GR (GPRS Register)
  - user addresses

GPRS quality of service

Reliability class	Lost SDU probability	Duplicate SDU probability	Out of sequence SDU probability	Corrupt SDU probability
1	10^{-9}	10^{-9}	10^{-9}	10^{-9}
2	10^{-4}	10^{-5}	10^{-5}	10^{-6}
3	10^{-2}	10^{-5}	10^{-5}	10^{-2}

Delay class	SDU size 128 byte		SDU size 1024 byte	
	mean	95 percentile	mean	95 percentile
1	< 0.5 s	< 1.5 s	< 2 s	< 7 s
2	< 5 s	< 25 s	< 15 s	< 75 s
3	< 50 s	< 250 s	< 75 s	< 375 s
4	unspecified			

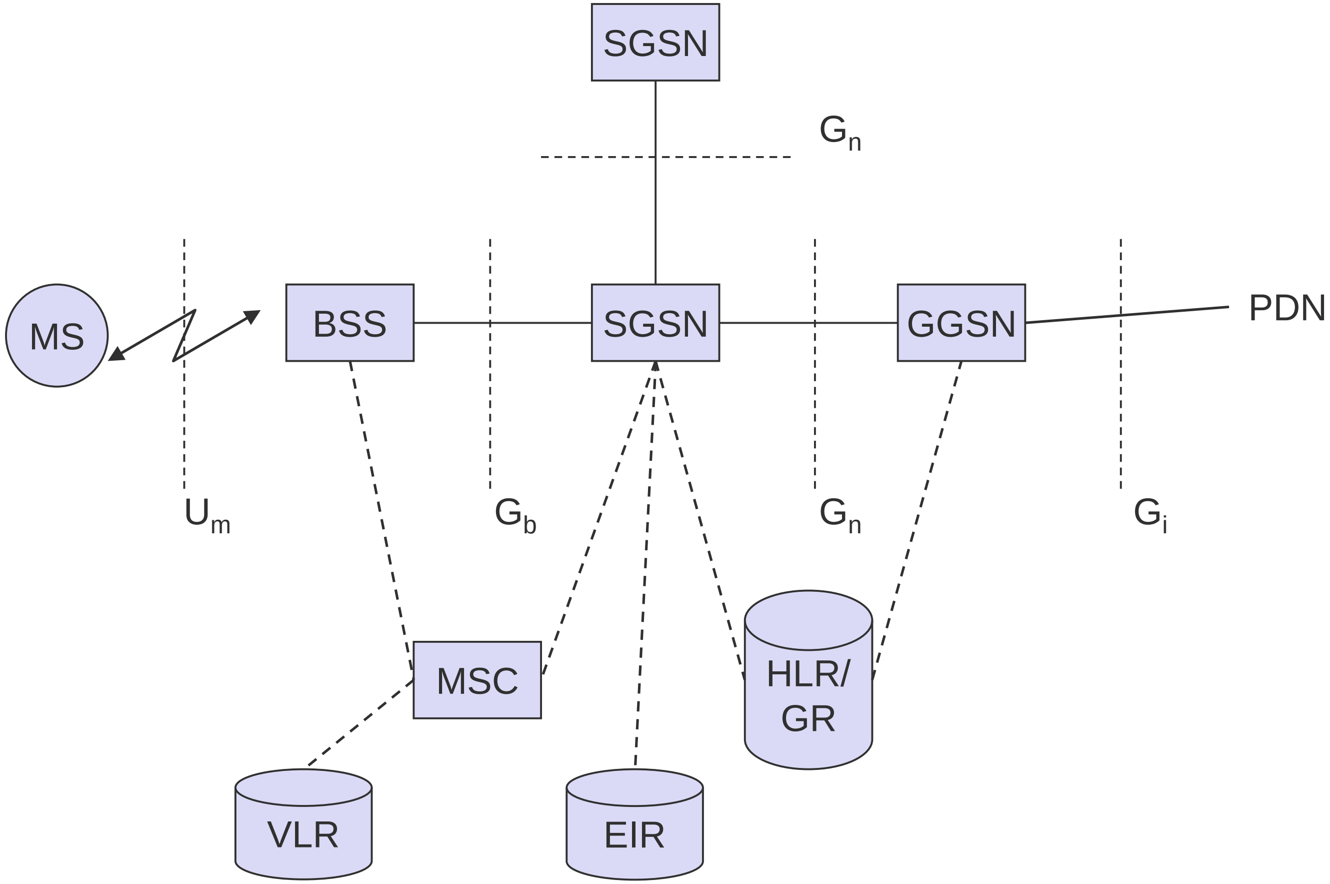
Examples for GPRS device classes

Class	Receiving slots	Sending slots	Maximum number of slots
1	1	1	2
2	2	1	3
3	2	2	3
5	2	2	4
8	4	1	5
10	4	2	5
12	4	4	5

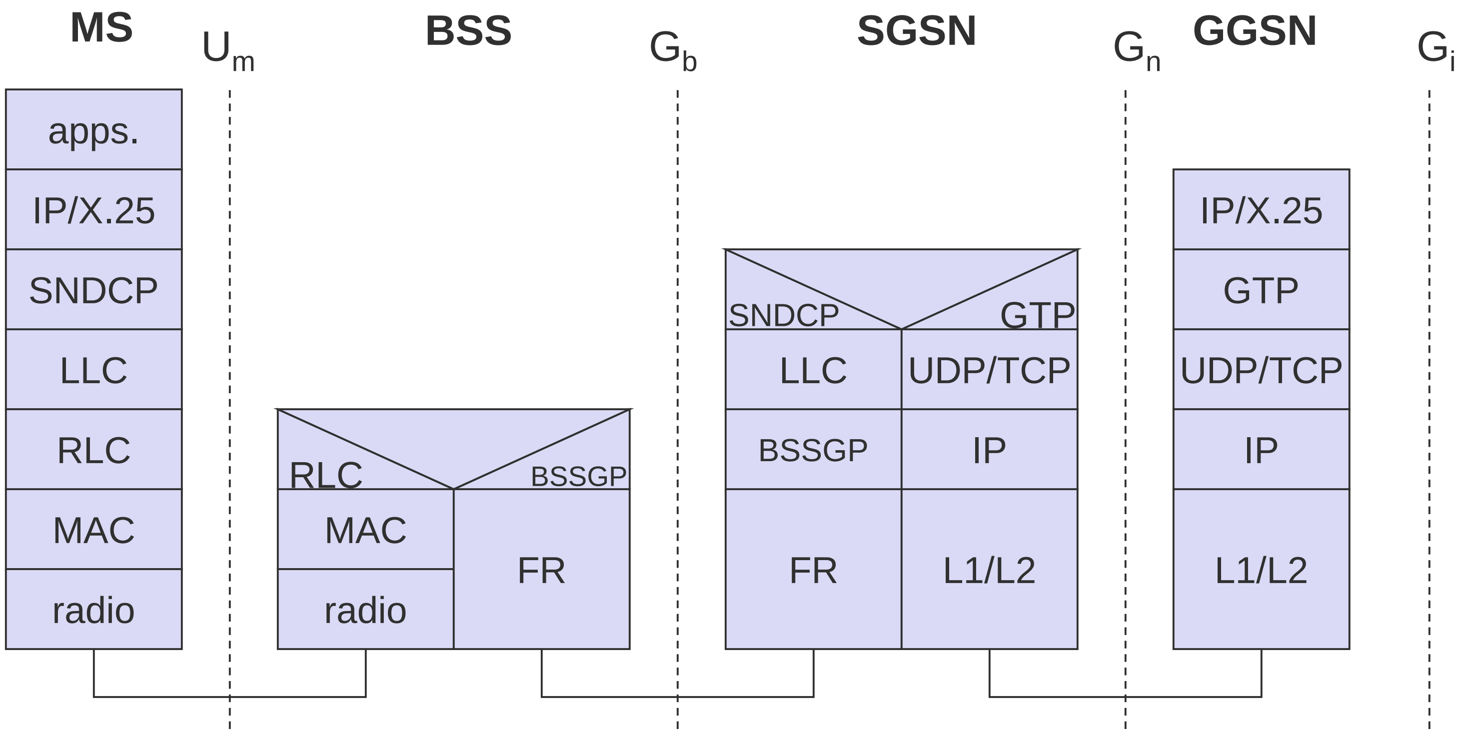
GPRS user data rates in kbit/s

Coding scheme	1 slot	2 slots	3 slots	4 slots	5 slots	6 slots	7 slots	8 slots
CS-1	9.05	18.1	27.15	36.2	45.25	54.3	63.35	72.4
CS-2	13.4	26.8	40.2	53.6	67	80.4	93.8	107.2
CS-3	15.6	31.2	46.8	62.4	78	93.6	109.2	124.8
CS-4	21.4	42.8	64.2	85.6	107	128.4	149.8	171.2

GPRS architecture and interfaces



GPRS protocol architecture



Questions & Tasks

- What multiplexing schemes are used in GSM for what purposes? Think also of other layers apart from the physical layer.
- How is synchronisation achieved in GSM? Who is responsible for synchronisation and why is synchronisation very important?
- How is the shift from voice-only to Internet-style traffic reflected in the GSM system?
- Why is a new infrastructure needed for GPRS, but not for HSCSD? Which components are new and what is their purpose?
- Only few operators offered HSCSD – why?
- What are the reasons for the delays in a GSM system for packet data traffic? Distinguish between circuit-switched and packet-switched transmission.
- Relatively high delay, low reliability – why was GPRS yet a break-through in the GSM world?
- What are the limitations of a GSM cell in terms of diameter and capacity (voice, data) for the traditional GSM, HSCSD, GPRS? How can the capacity be increased?
- What determines the coding scheme?
- Give reasons for a handover in GSM and the problems associated with it. Which are the typical steps for handover, what types of handover can occur? Which resources need to be allocated during handover for data transmission using HSCSD or GPRS respectively? What about QoS guarantees?

TETRA - Terrestrial Trunked Radio

Trunked radio systems
- many different radio carriers
- assign single carrier for a short period to one user/group of users
- taxi service, fleet management, rescue teams
- interfaces to public networks, voice and data services
- very reliable, fast call setup, local operation

TETRA - ETSI standard, 2G system, EN 300 392
- formerly: Trans European Trunked Radio
  - https://www.etsi.org/technologies/tetra
- point-to-point and point-to-multipoint
- encryption (end-to-end, air interface), authentication of devices, users and networks
- group call, broadcast, sub-second group-call setup
- ad-hoc (“direct mode”), relay and infrastructure networks
- call queuing with pre-emptive priorities
- Push-To-Talk (PTT)

TETRA
TRUSTED · ALWAYS · EVERYWHERE

Source: tcca.info

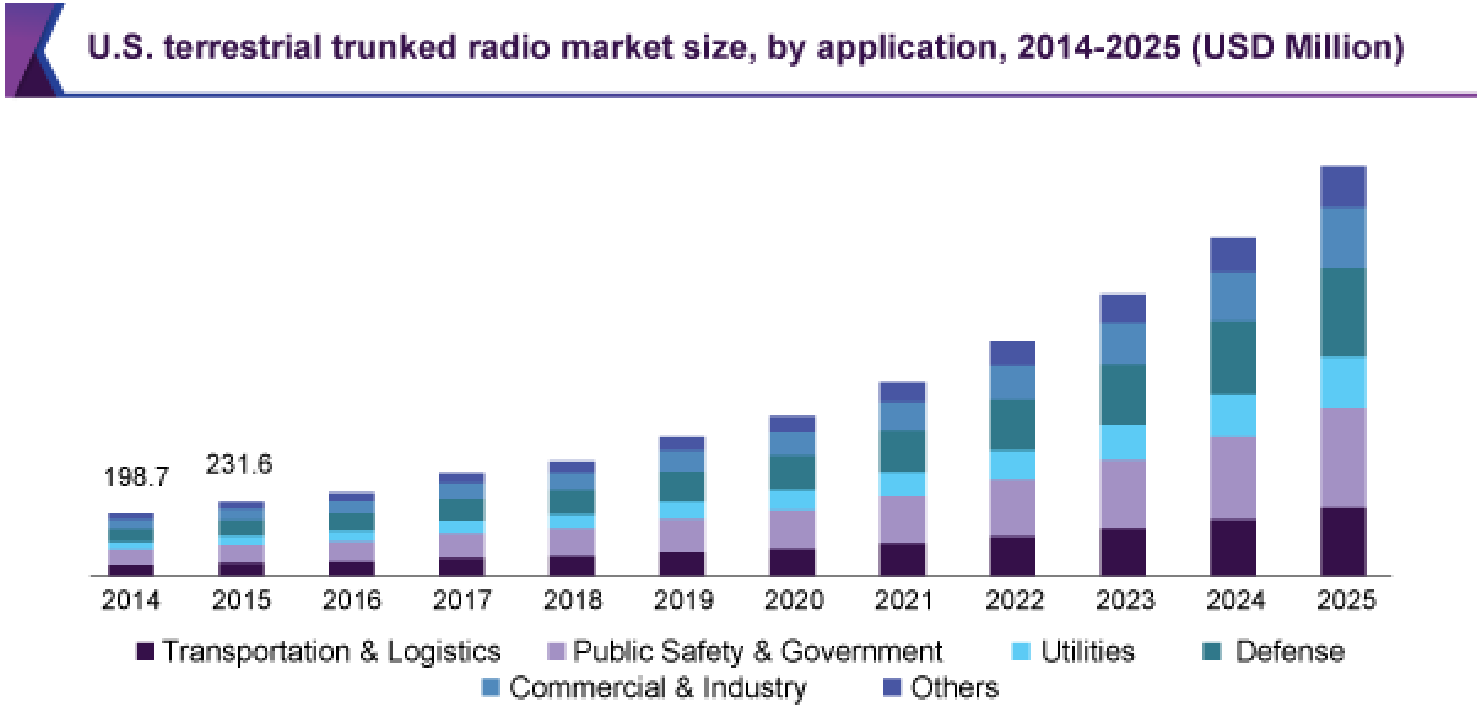
Source: www.motorolasolutions.com

Source: www.sepura.com

TETRA – Markets by sector

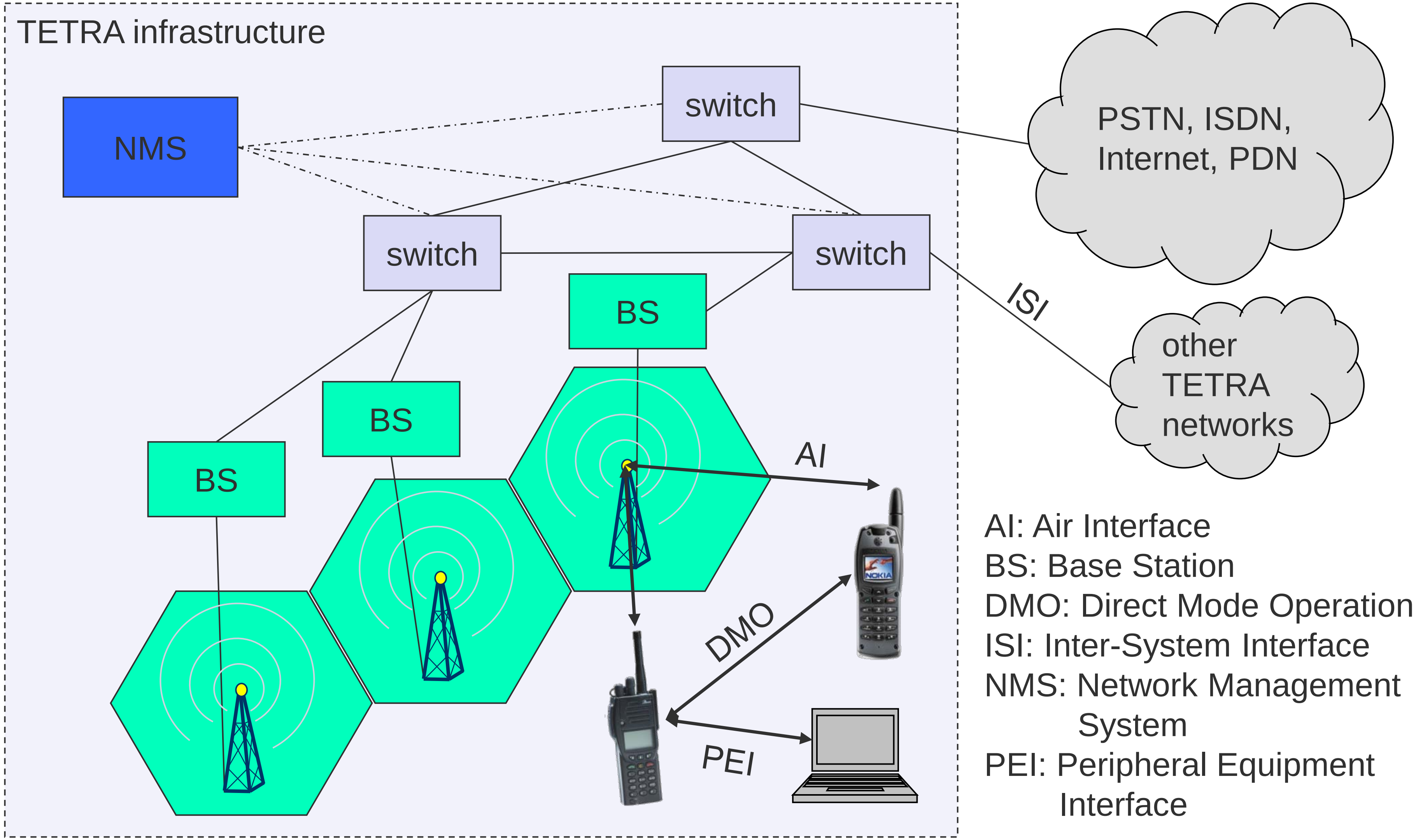
Estimated 5 mio. terminals in 2020

Used in over 120 countries



Source: www.grandviewresearch.com

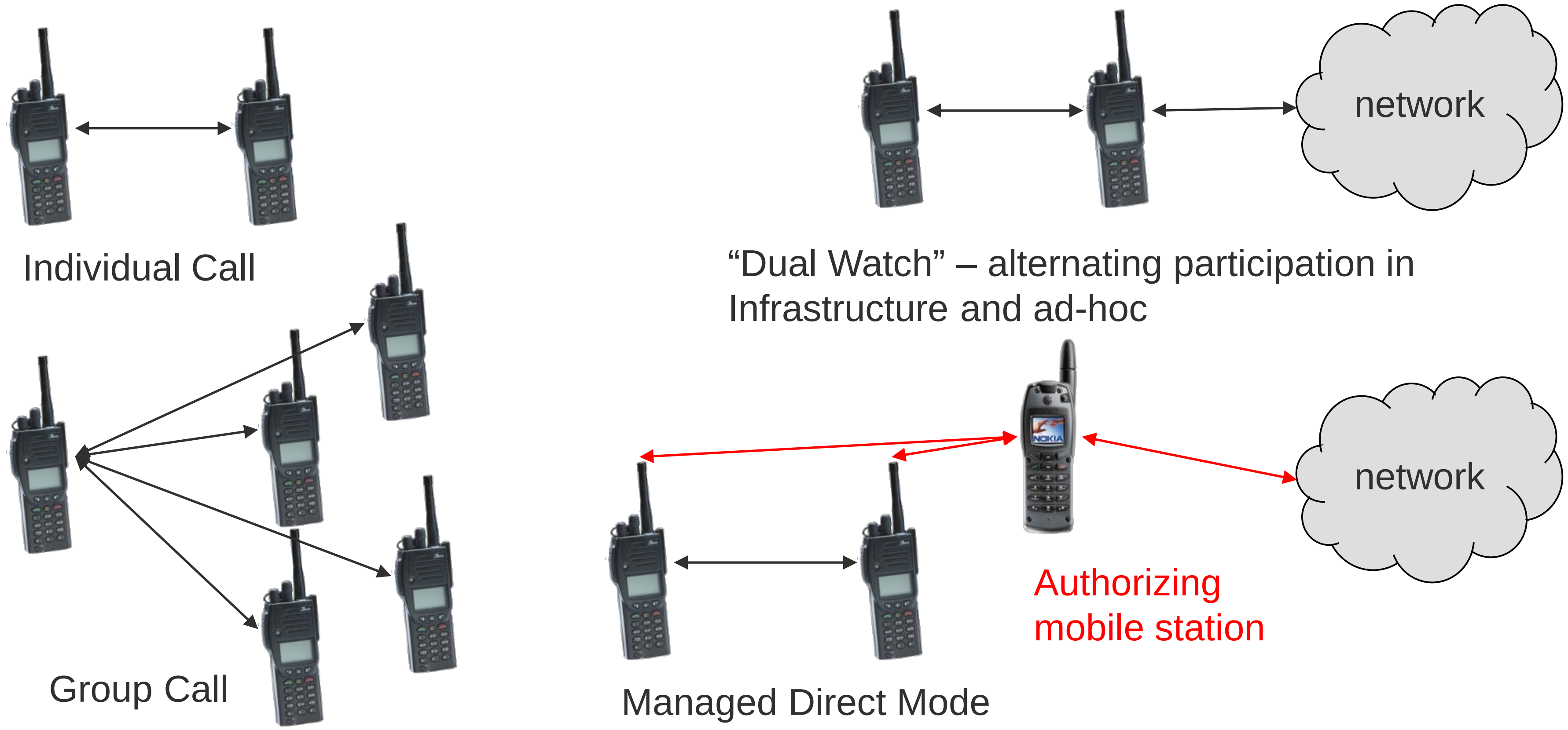
TETRA – Network Architecture



AI: Air Interface
BS: Base Station
DMO: Direct Mode Operation
ISI: Inter-System Interface
NMS: Network Management System
PEI: Peripheral Equipment Interface

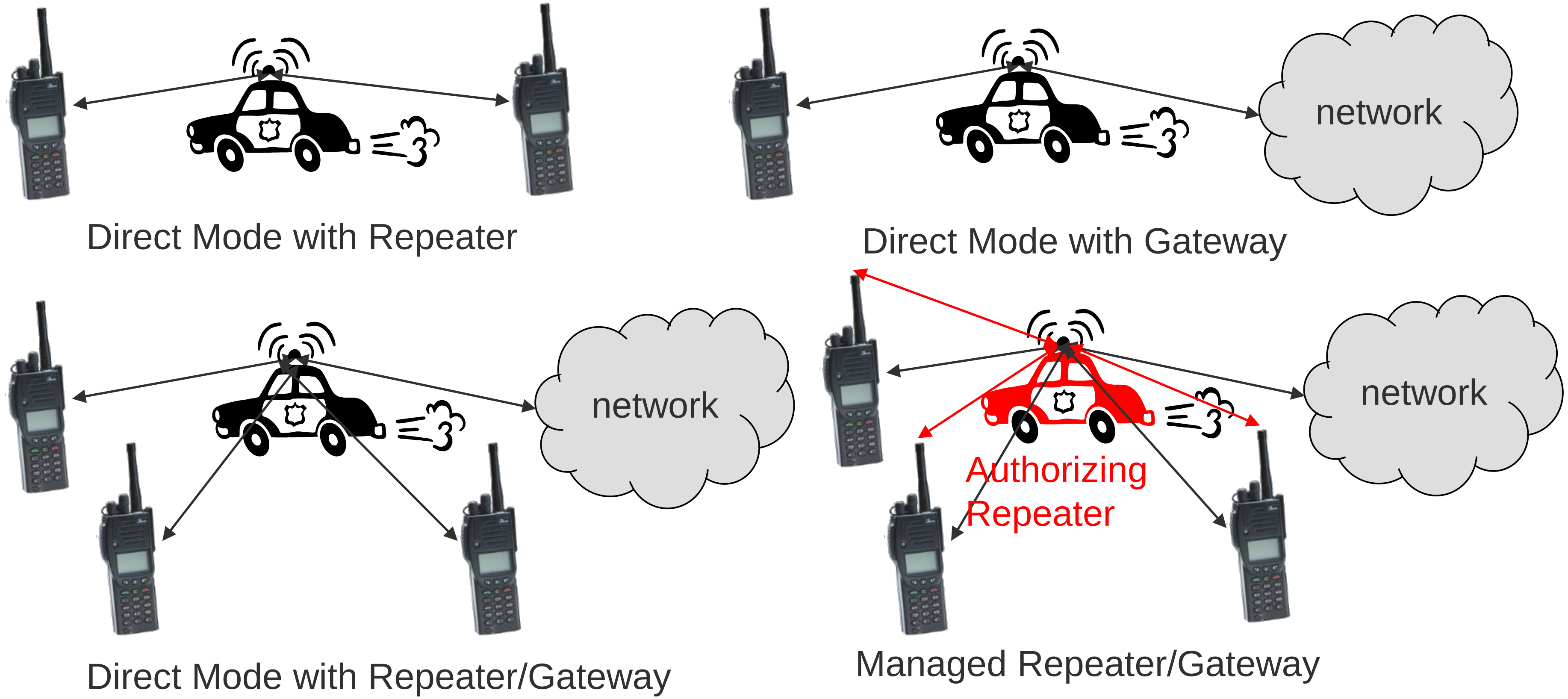
TETRA – Direct Mode I

Direct Mode enables ad-hoc operation and is one of the most important differences to pure infrastructure-based networks such as GSM, cdma2000 or UMTS.



TETRA – Direct Mode II

An additional repeater may increase the transmission range (e.g. police car)



TETRA – Technology

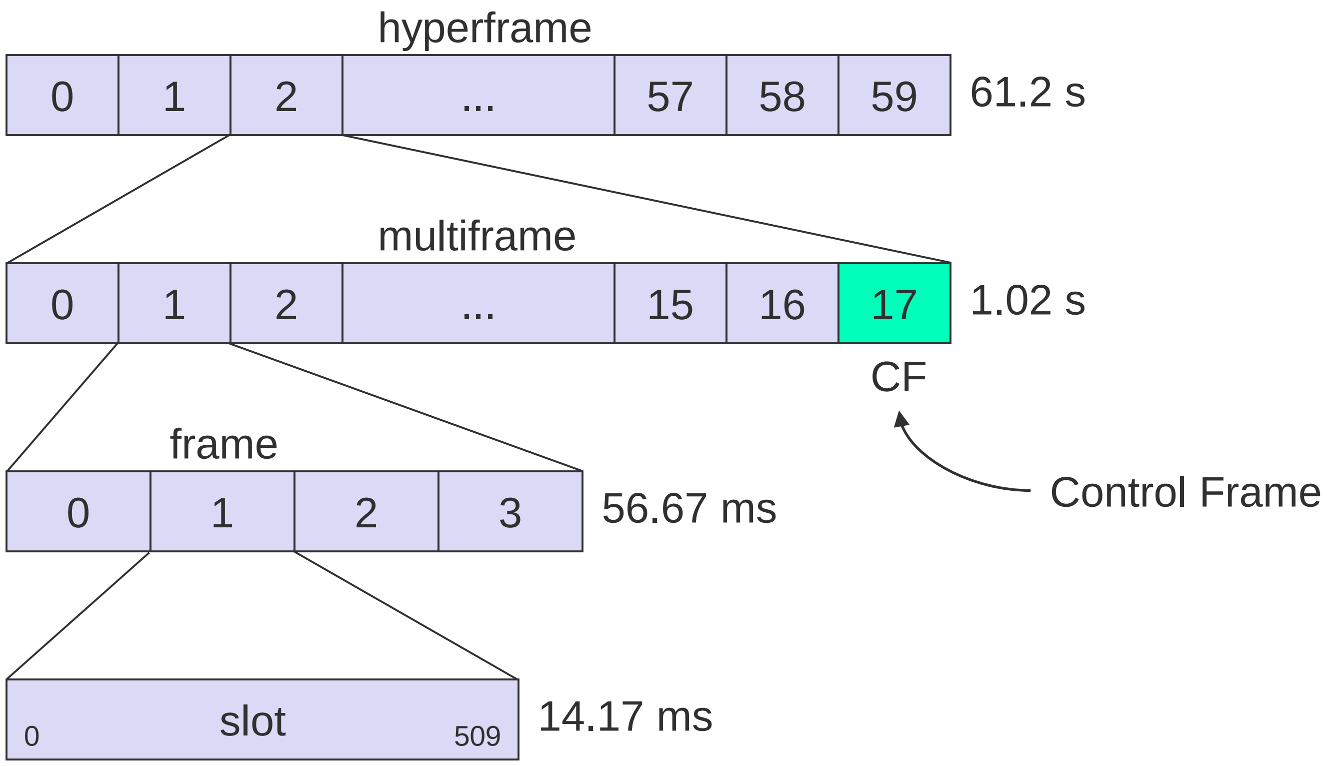
Services

- Voice+Data (V+D) and Packet Data Optimized (PDO)
- Short data service (SDS)

Frequencies

- Duplex: FDD, Modulation: DQPSK
- Europe (in MHz, not all available yet)
  - 380-390 UL / 390-400 DL; 410-420 UL / 420-430 DL, 450-460 UL / 460-470 DL; 870-876 UL / 915-921 DL
- Other countries
  - 380-390 UL / 390-400 DL; 410-420 UL / 420-430 DL, 806-821 UL / 851-866 DL

TDMA structure of the voice+data system



TETRA – Data Rates

Infrastructure mode, V+D in kbit/s

No. of time slots	1	2	3	4
No protection	7.2	14.4	21.6	28.8
Low protection	4.8	9.6	14.4	19.2
High protection	2.4	4.8	7.2	9.6

TETRA Release 2 – Supporting higher data rates
- -TEDS (TETRA Enhanced Data Service)
- -up to 100-500 kbit/s
  - -depends on modulation (DQPSK, D8PSK, 4/16/64QAM) and channel width (25/50/100/150 kHz)
- -backward compatibility

Future of TETRA?
- Data rates to low compared to e.g. LTE
- Specialized devices very expensive (no COTS)
- LTE Public Safety Broadband

Questions & Tasks

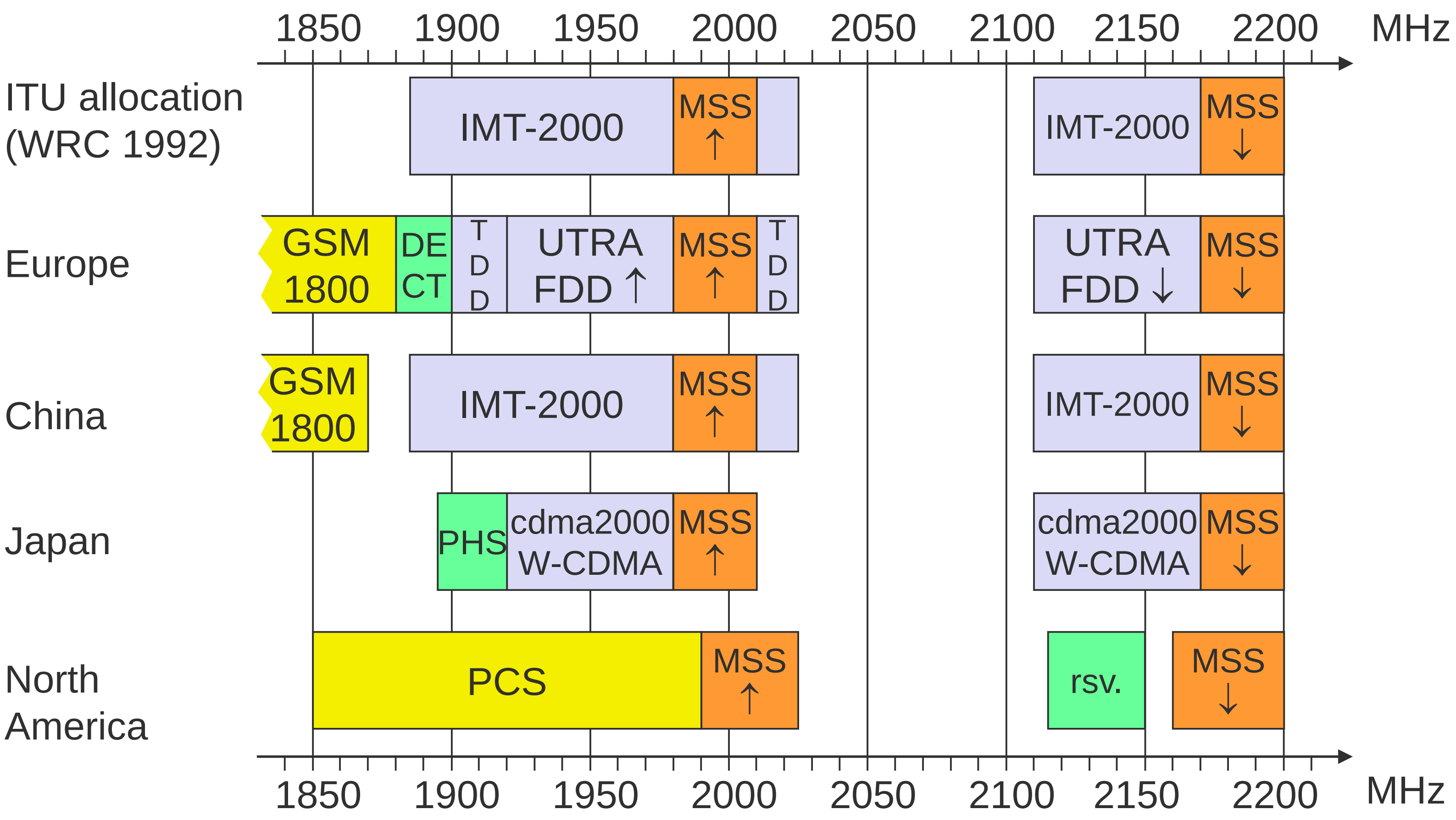
- Why using a separated, specialized system like TETRA? Why not using the “normal” cellular phone network with some “extras”? There are reasons for and against such an approach!
- What else could be problematic using e.g. current LTE/UMTS/GSM systems?
- Check the current approaches of 3GPP towards a public safety mobile network! What is a general trend?

UMTS and IMT-2000 – The 3rd Generation

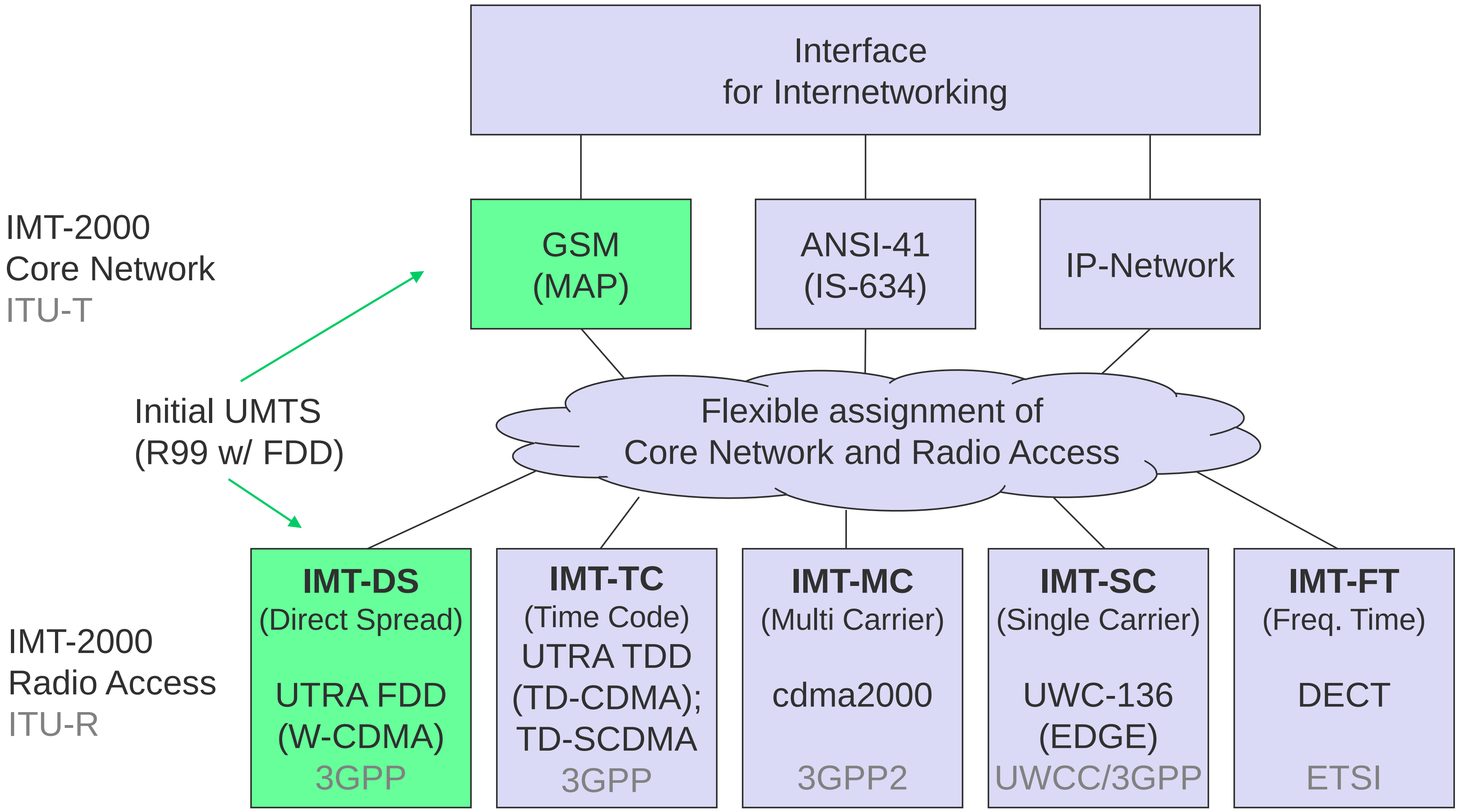
Proposals for IMT-2000 (International Mobile Telecommunications)
- UWC-136, cdma2000, WP-CDMA
- UMTS (Universal Mobile Telecommunications System) from ETSI

UMTS
- UTRA (was: UMTS, now: Universal Terrestrial Radio Access)
- enhancements of GSM
  - EDGE (Enhanced Data rates for GSM Evolution): GSM up to 384 kbit/s
  - CAMEL (Customized Application for Mobile Enhanced Logic)
  - VHE (virtual Home Environment)
- fits into GMM (Global Multimedia Mobility) initiative from ETSI
- requirements
  - min. 144 kbit/s rural (goal: 384 kbit/s)
  - min. 384 kbit/s suburban (goal: 512 kbit/s)
  - up to 2 Mbit/s urban

Frequencies for IMT-2000



IMT-2000 family



GSM, UMTS, and LTE Releases

Stages
- (0: feasibility study)
- 1: service description from a service-user’s point of view
- 2: logical analysis, breaking the problem down into functional elements and the information flows amongst them
- 3: concrete implementation of the protocols between physical elements onto which the functional elements have been mapped
- (4: test specifications)

Note
- "Release 2000" was used only temporarily and was eventually replaced by "Release 4" and "Release 5"

Additional information:
- www.3gpp.org/releases

Rel	Spec version no.	Functional freeze date, indicative only
Rel-12	12.x.y	Stage 1 freeze March 2013
		Stage 2 freeze December 2013
		Stage 3 freeze June 2014, RAN: Sept. 2014
Rel-11	11.x.y	Stage 1 freeze September 2011
		Stage 2 freeze March 2012
		Stage 3 freeze September 2012
Rel-10	10.x.y	Stage 1 freeze March 2010
		Stage 2 freeze September 2010
		Stage 3 freeze March 2011
Rel-9	9.x.y	Stage 1 freeze December 2008
		Stage 2 freeze June 2009
		Stage 3 freeze December 2009
Rel-8	8.x.y	Stage 1 freeze March 2008
		Stage 2 freeze June 2008
		Stage 3 freeze December 2008
Rel-7	7.x.y	Stage 1 freeze September 2005
		Stage 2 freeze September 2006
		Stage 3 freeze December 2007
Rel-6	6.x.y	December 2004 - March 2005
Rel-5	5.x.y	March - June 2002
Rel-4	4.x.y	March 2001
R00	4.x.y	see note 1 below
	9.x.y	
R99	3.x.y	March 2000
	8.x.y	
R98	7.x.y	early 1999
R97	6.x.y	early 1998
R96	5.x.y	early 1997
Ph2	4.x.y	1995
Ph1	3.x.y	1992

Licensing Example: UMTS in Germany, 18. August 2000

UTRA-FDD:

- Uplink 1920-1980 MHz
- Downlink 2110-2170 MHz
- duplex spacing 190 MHz
- 12 channels, each 5 MHz

UTRA-TDD:

- 1900-1920 MHz,
- 2010-2025 MHz;
- 5 MHz channels

Coverage of the population

- 25% until 12/2003
- 50% until 12/2005

STAND DER LIZENZVERGABE

Versteigerung UMTS/IMT-2000-Lizenzen

Runde 173 Datum 17.08.00 Uhrzeit 15:51:26

Höchstgebote für Frequenzblöcke (mind. 2 Blöcke erforderlich für Lizenz)

Bieter	Anzahl der Frequenzblöcke 1	2	3	Lizenzgebot (TDM)	(€ in Tsd)
E-Plus Hutchison	2 x 5 MHz	2 x 5 MHz		16.418.200	8.394.492
Group 3G	2 x 5 MHz	2 x 5 MHz		16.446.000	8.408.706
Mannesmann Mobilfunk	2 x 5 MHz	2 x 5 MHz		16.473.800	8.422.920
MobilCom Multimedia	2 x 5 MHz	2 x 5 MHz		16.370.000	8.369.848
T-Mobil	2 x 5 MHz	2 x 5 MHz		16.582.200	8.478.344
VIAG Interkom	2 x 5 MHz	2 x 5 MHz		16.517.000	8.445.008
debitel Multimedia	ausgeschieden				
Lizenzsumme				98.807.200	50.519.319

RUNDENERGEBNIS

Versteigerung UMTS/IMT-2000-Frequenzen

Runde: 9

Lfd. Nr.	Umfang	Höchstbieter	Höchstgebot (TDM)	Höchstgebot* (€ in Tsd)
13	1 x 5 MHz konkret	E-Plus Hutchison	73.600	37.631
14	1 x 5 MHz	MobilCom Multimedia	121.000	61.866
15	1 x 5 MHz	T-Mobil	122.700	62.736
16	1 x 5 MHz	Mannesmann Mobilfunk	121.000	61.866
17	1 x 5 MHz	Group 3G	122.700	62.736
		Summe Höchstgebote	561.000	286.835

* Eurowerte gerundet

VIAG Interkom ausgeschieden

Sum: 50.81 billion €

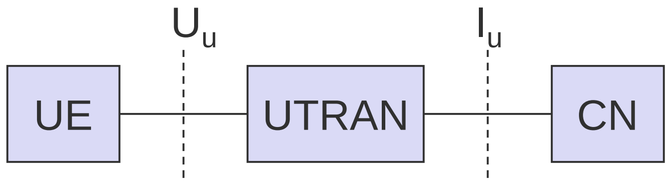
UMTS architecture

Release 99 used here as starting point
- Shows the key differences
- Newer releases explained in the context of LTE

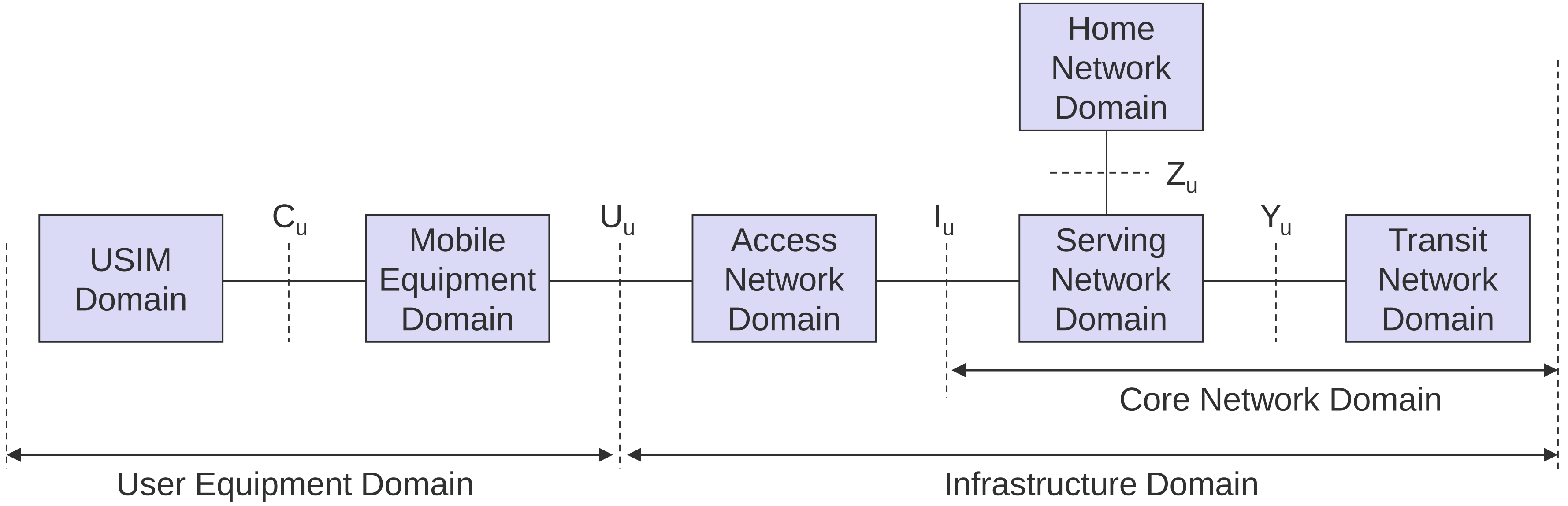
UTRAN (UTRA Network)
- Cell level mobility
- Radio Network Subsystem (RNS)
- Encapsulation of all radio specific tasks

UE (User Equipment)

CN (Core Network)
- Inter system handover
- Location management if there is no dedicated connection between UE and UTRAN



UMTS domains and interfaces I



User Equipment Domain
- Assigned to a single user in order to access UMTS services

Infrastructure Domain
- Shared among all users
- Offers UMTS services to all accepted users

UMTS domains and interfaces II

Universal Subscriber Identity Module (USIM)
- Functions for encryption and authentication of users
- Located on a SIM inserted into a mobile device

Mobile Equipment Domain
- Functions for radio transmission
- User interface for establishing/maintaining end-to-end connections

Access Network Domain
- Access network dependent functions

Core Network Domain
- Access network independent functions
- Serving Network Domain
  - Network currently responsible for communication
- Home Network Domain
  - Location and access network independent functions

Freie Universität Berlin

Questions & Tasks

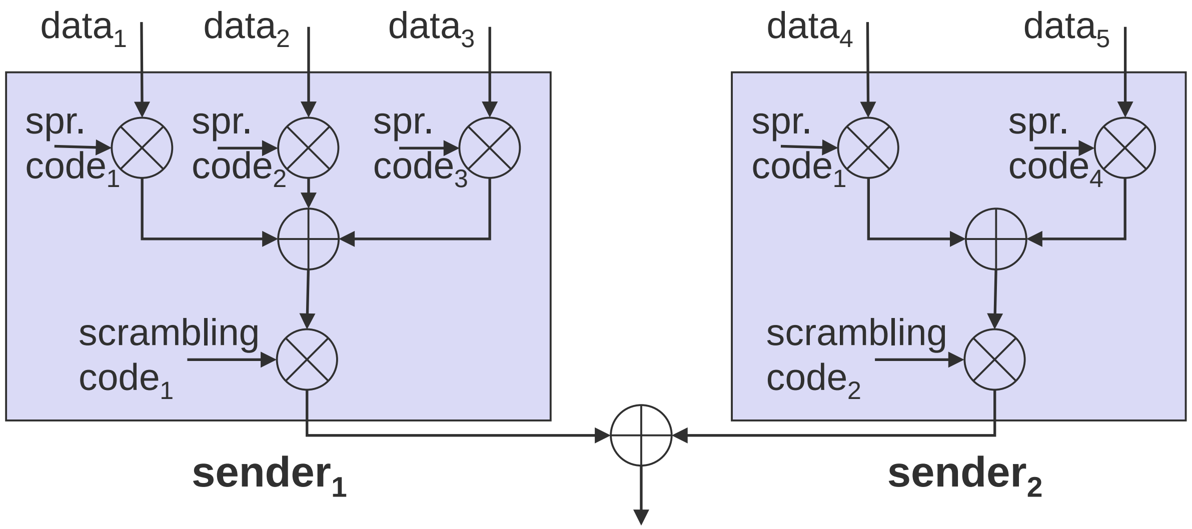
- -What defines the 3rd generation? What was the initial idea?
- -What led to the different developments? – There are many reasons!
- -Check www.3gpp.org/releases and understand the ideas of stages and releases!
- -What was the focus of early UMTS on? How is this reflected in the spectrum?
- -What is the problem of the condition “coverage of the population in %”?
- -Why did most operators already using GSM pick UMTS as 3rd generation and cdmaOne operators cdma2000?

Spreading and scrambling of user data

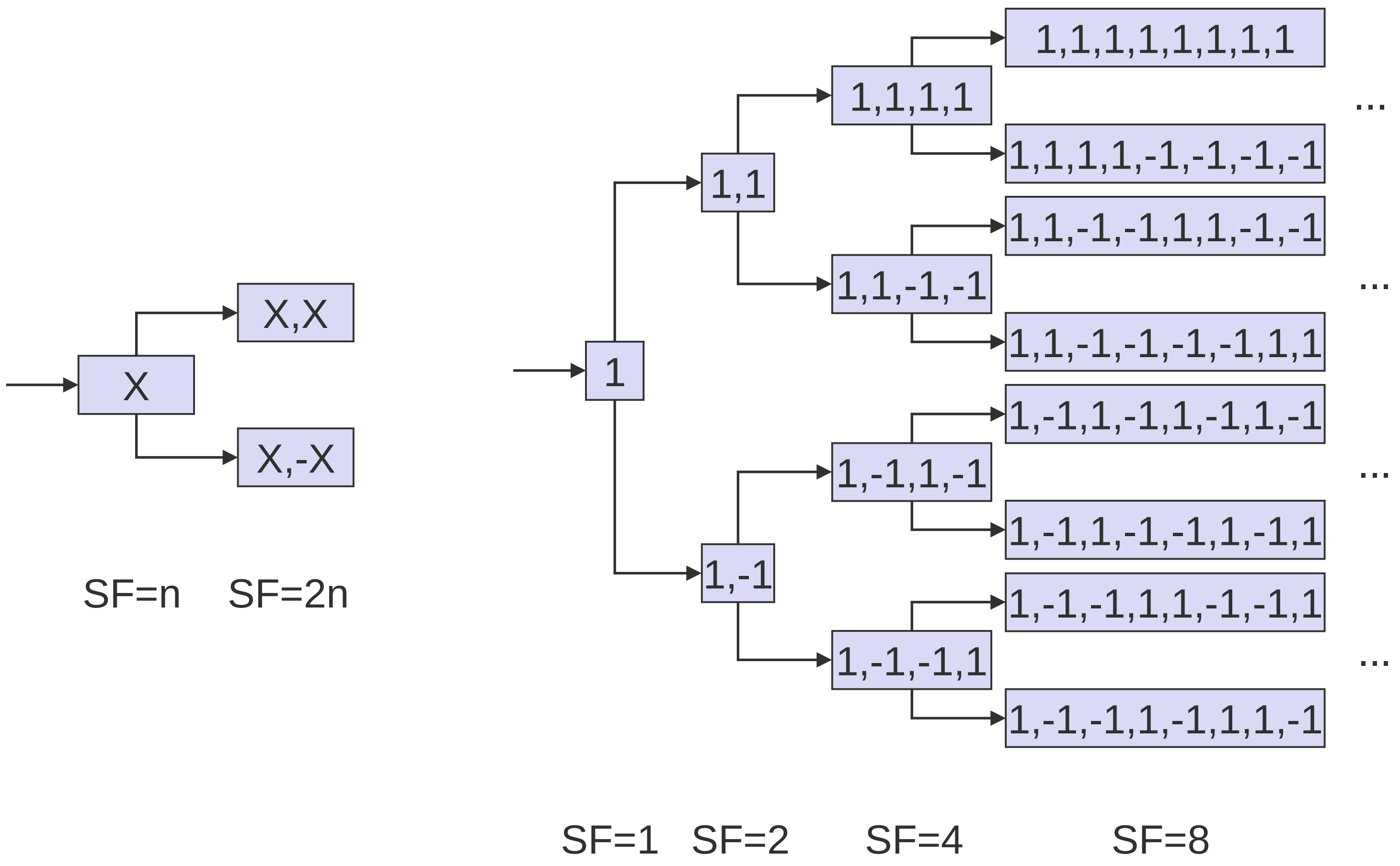
Constant chipping rate of 3.84 Mchip/s

Different user data rates supported via different spreading factors
- higher data rate: less chips per bit and vice versa

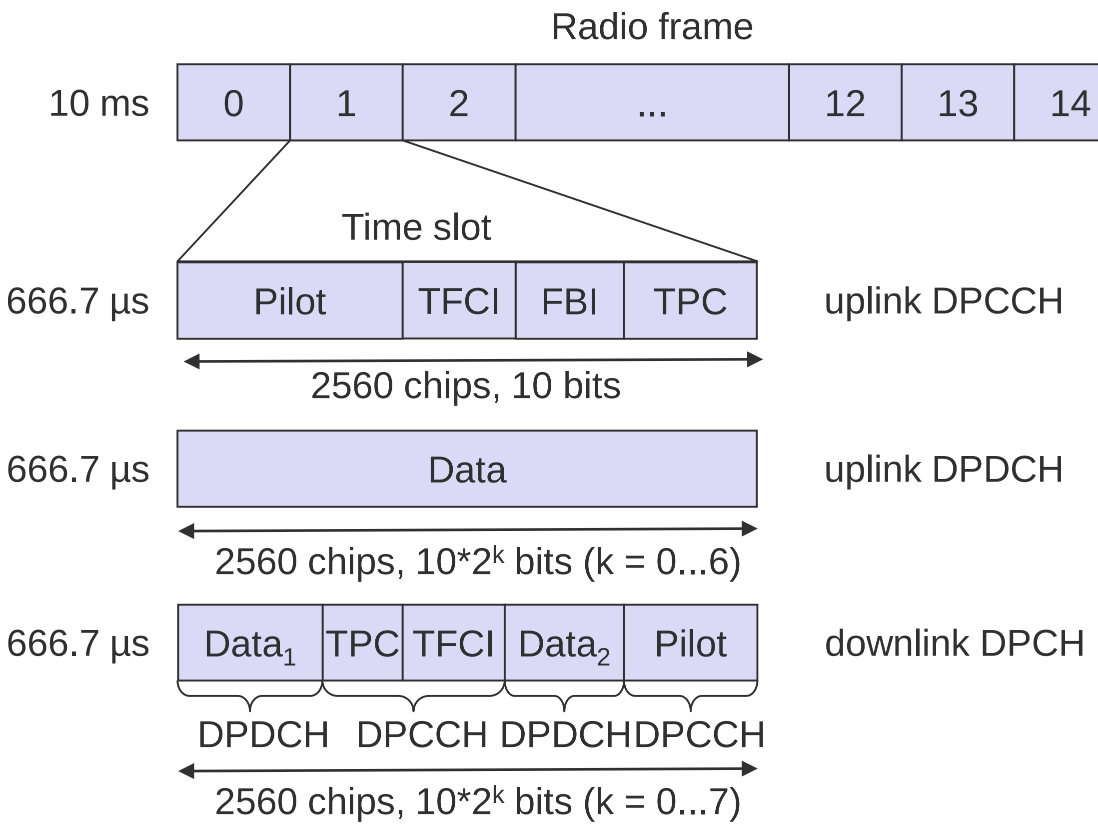
User separation via unique, quasi orthogonal scrambling codes
- users are not separated via orthogonal spreading codes
- much simpler management of codes: each station can use the same orthogonal spreading codes
- precise synchronization not necessary as the scrambling codes stay quasi-orthogonal



OVSF (Orthogonal Variable Spreading Factor) coding



UMTS FDD frame structure



Slot structure NOT for user separation but synchronization for periodic functions!

W-CDMA

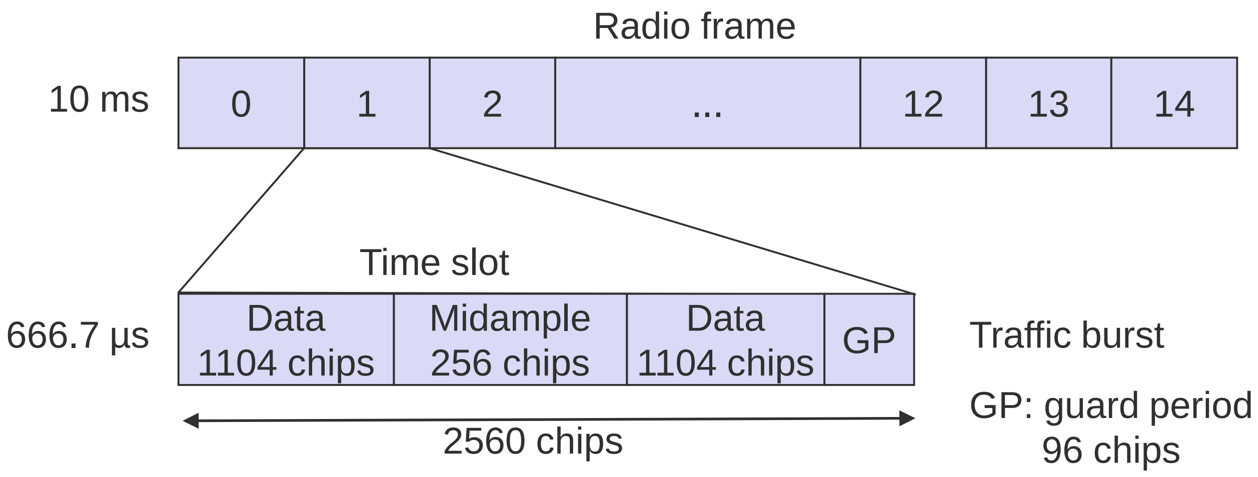
- 1920-1980 MHz uplink
- 2110-2170 MHz downlink
- chipping rate: 3.840 Mchip/s
- soft handover
- QPSK
- complex power control (1500 power control cycles/s)
- spreading: UL: 4-256; DL:4-512

FBI: Feedback Information
TPC: Transmit Power Control
TFCI: Transport Format Combination Indicator
DPCCH: Dedicated Physical Control Channel
DPDCH: Dedicated Physical Data Channel
DPCH: Dedicated Physical Channel

Typical UTRA-FDD uplink data rates

User data rate [kbit/s]	12.2 (voice)	64	144	384
DPDCH [kbit/s]	60	240	480	960
DPCCH [kbit/s]	15	15	15	15
Spreading	64	16	8	4

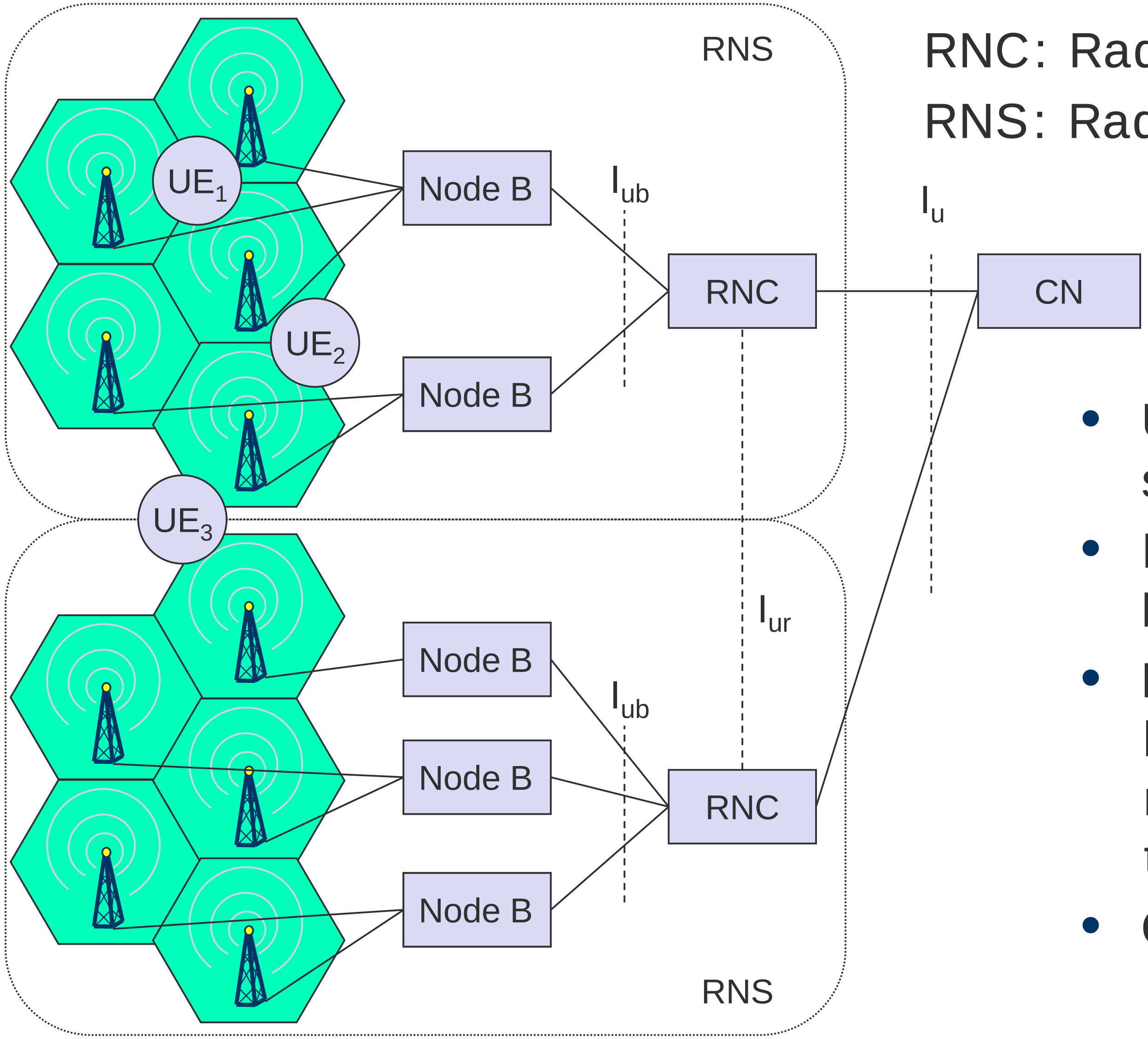
UMTS TDD frame structure (burst type 2)



TD-CDMA

- 2560 chips per slot
- spreading: 1-16
- symmetric or asymmetric slot assignment to UL/DL (min. 1 per direction)
- tight synchronization needed
- simpler power control (100-800 power control cycles/s)

UTRAN architecture



RNC: Radio Network Controller

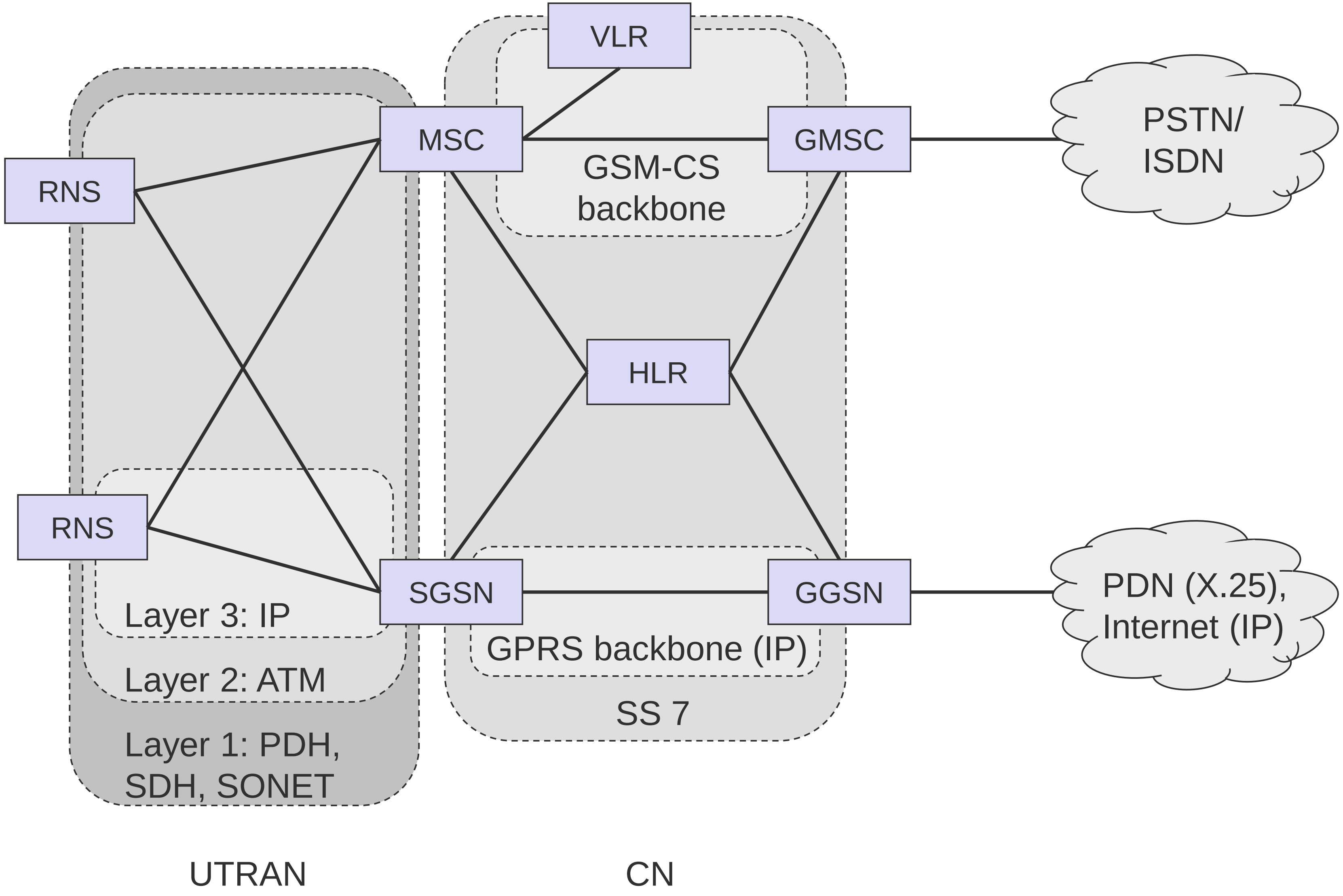
RNS: Radio Network Subsystem

- UTRAN comprises several RNSs
- Node B can support FDD or TDD or both
- RNC is responsible for handover decisions requiring signaling to the UE
- Cell offers FDD or TDD

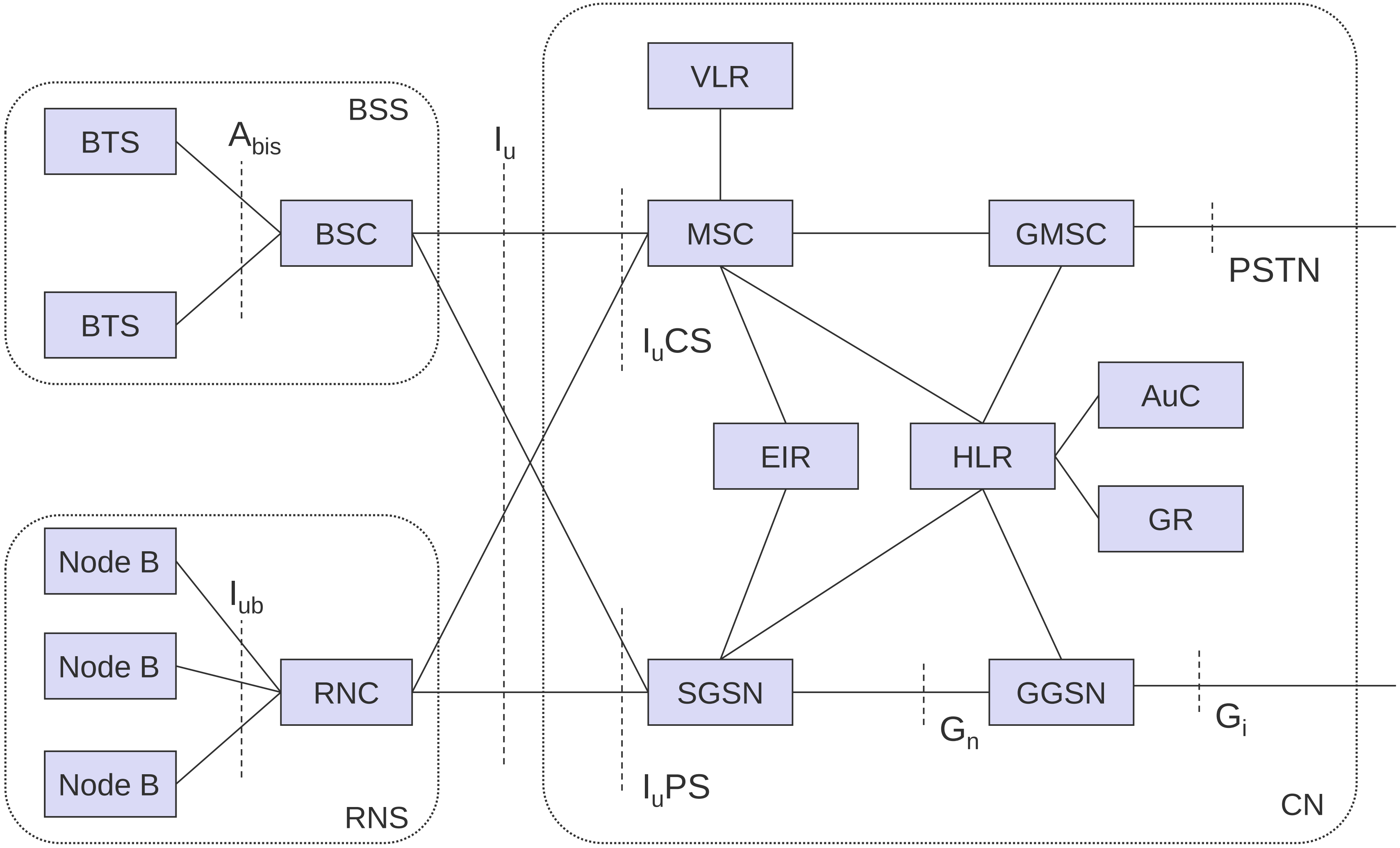
UTRAN functions

Admission control
Congestion control
System information broadcasting
Radio channel encryption
Handover
SRNS moving
Radio network configuration
Channel quality measurements
Macro diversity
Radio carrier control
Radio resource control
Data transmission over the radio interface
Outer loop power control (FDD and TDD)
Channel coding
Access control

Core network: protocols



Core network: architecture



Core network

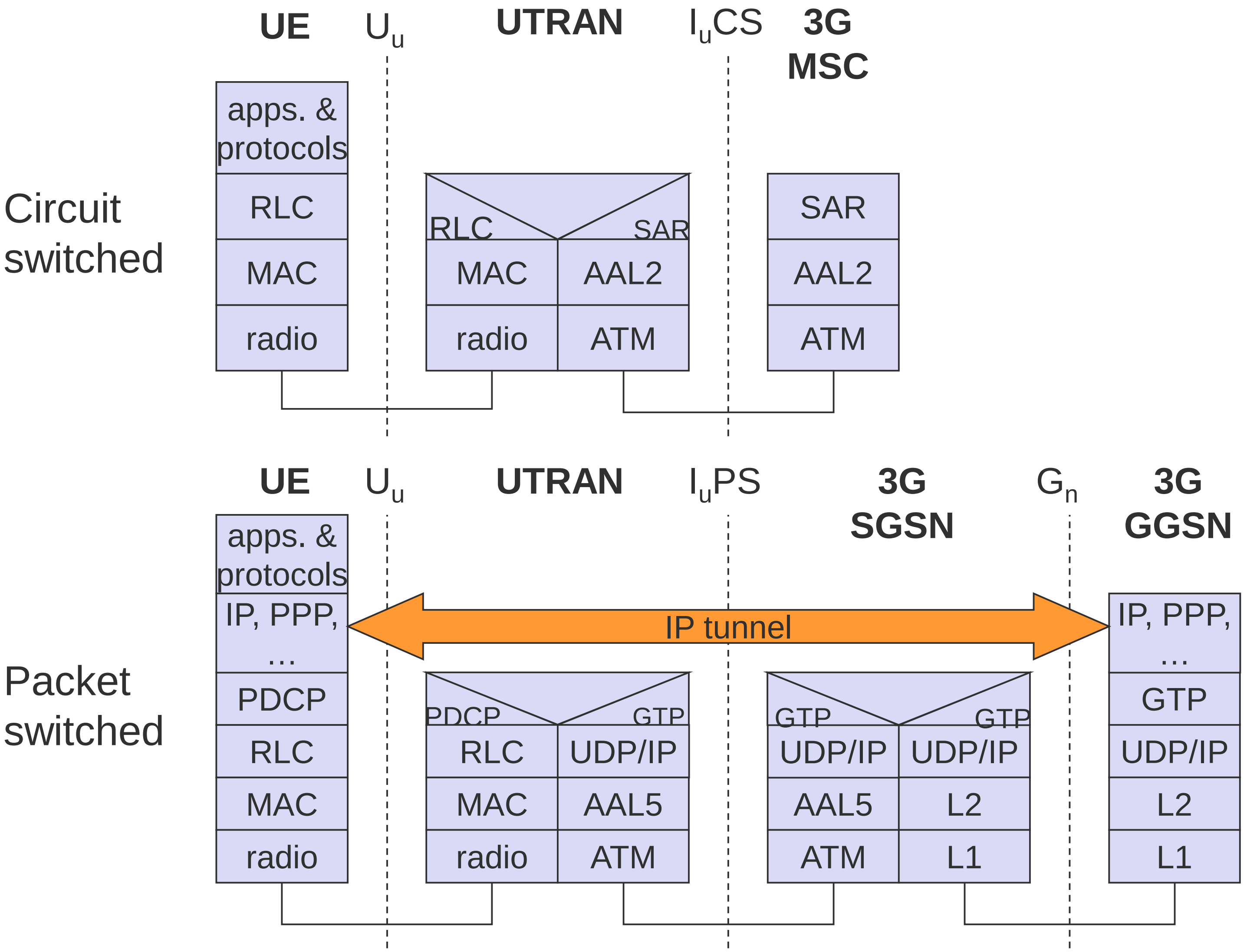
The Core Network (CN) and thus the Interface I_u, too, are separated into two logical domains:

Circuit Switched Domain (CSD)
- Circuit switched service incl. signaling
- Resource reservation at connection setup
- GSM components (MSC, GMSC, VLR)
- I_uCS

Packet Switched Domain (PSD)
- GPRS components (SGSN, GGSN)
- I_uPS

Release 99 uses the GSM/GPRS network and adds a new radio access!
- Helps to save a lot of money …
- Much faster deployment
- Not as flexible as newer releases (5, 6, … 12, 13, 14, …)

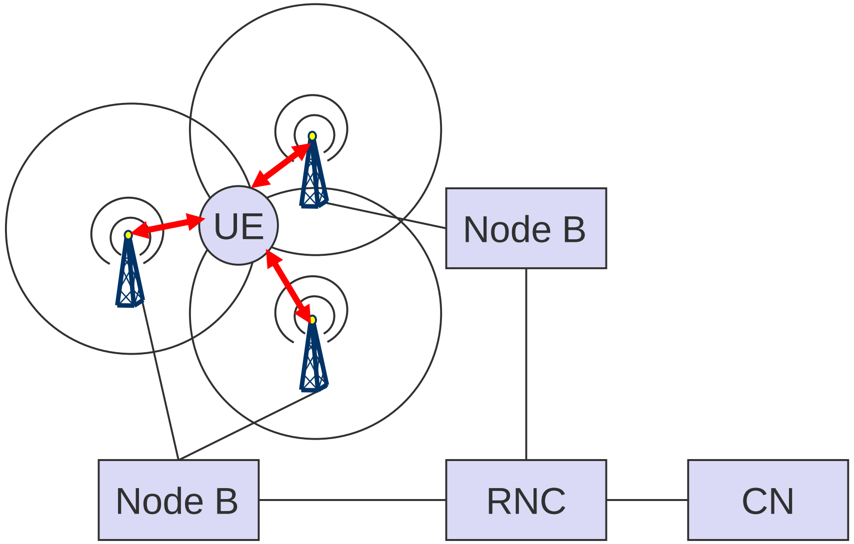
UMTS protocol stacks (user plane)



Questions & Tasks

- How do higher/lower data rates influence the robustness of the transmission in UMTS? How do typical applications fit to these effects?
- How does UTRA-FDD counteract the near-far effect?
- What is a drawback of OVSF? How is it compensated?
- How are different data streams from different users separated?
- Compare the UTRAN architecture with that of GSM. What is a major difference in the radio subsystem (BSS/RNS)? What is it used for?

Support of mobility: macro diversity



Multicasting of data via several physical channels

- Enables soft handover
- FDD mode only

Uplink

- simultaneous reception of UE data at several Node Bs
- Reconstruction of data at Node B, SRNC or DRNC

Downlink

- Simultaneous transmission of data via different cells
- Different spreading codes in different cells

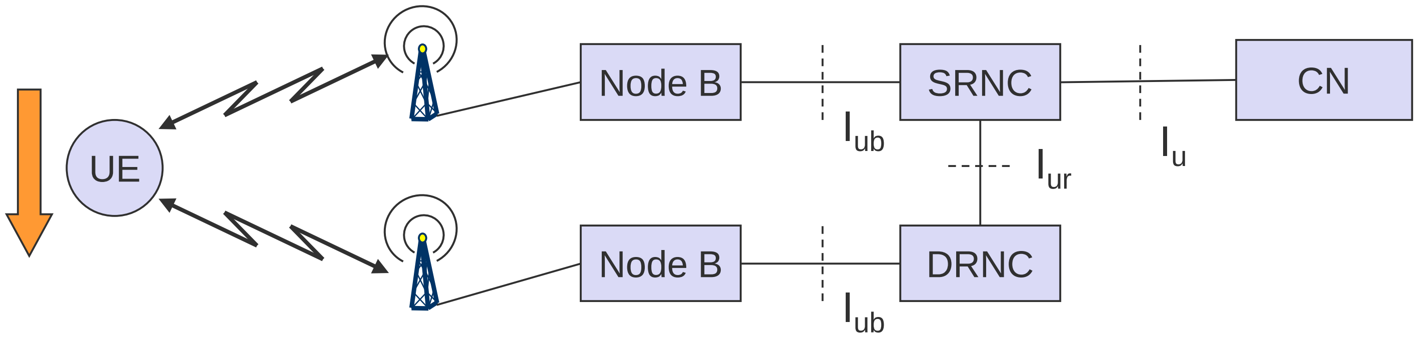
Support of mobility: handover

From and to other systems (e.g., UMTS to GSM)
- This is a must as UMTS coverage is/was poor in the beginning

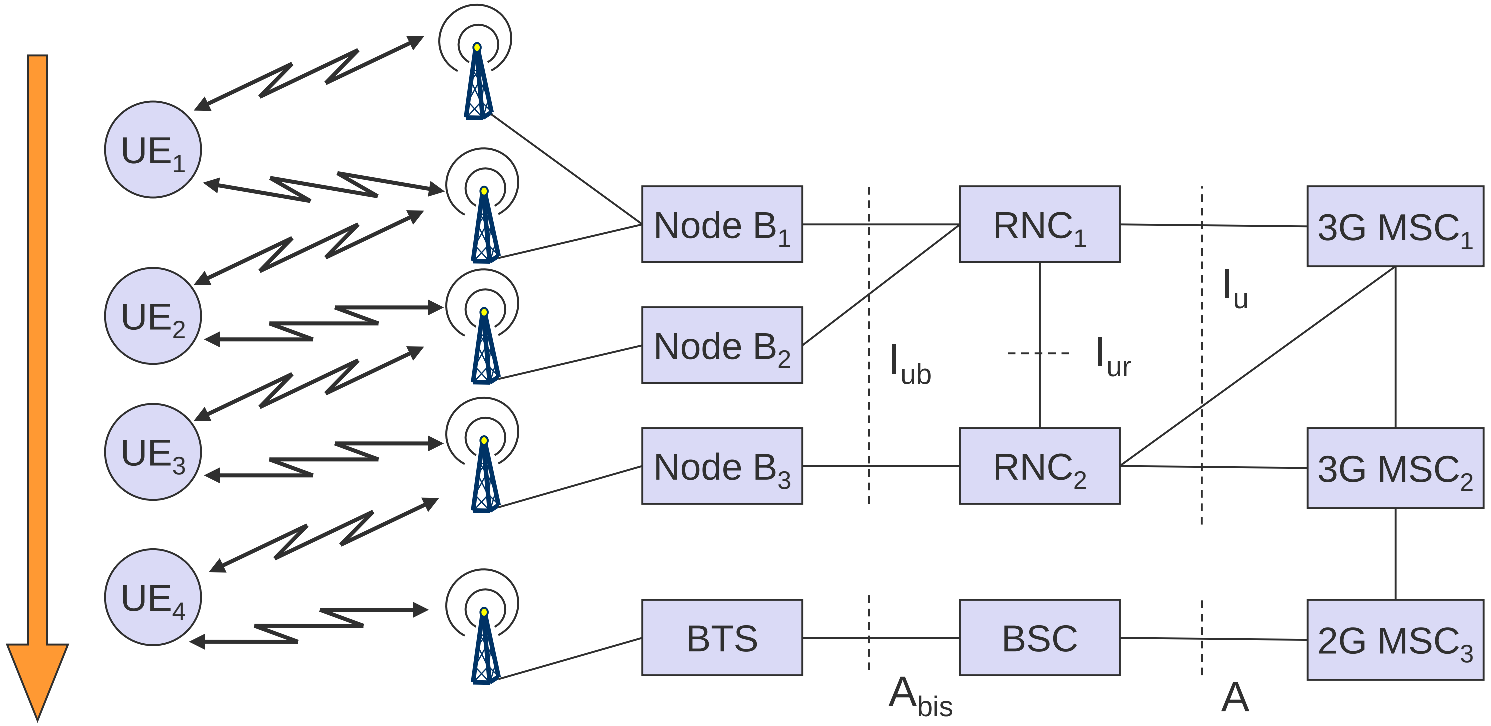
RNS controlling the connection is called SRNS (Serving RNS)

RNS offering additional resources (e.g., for soft handover) is called Drift RNS (DRNS)

End-to-end connections between UE and CN only via I_u at the SRNS
- Change of SRNS requires change of I_u
- Initiated by the SRNS
- Controlled by the RNC and CN



Example handover types in UMTS/GSM



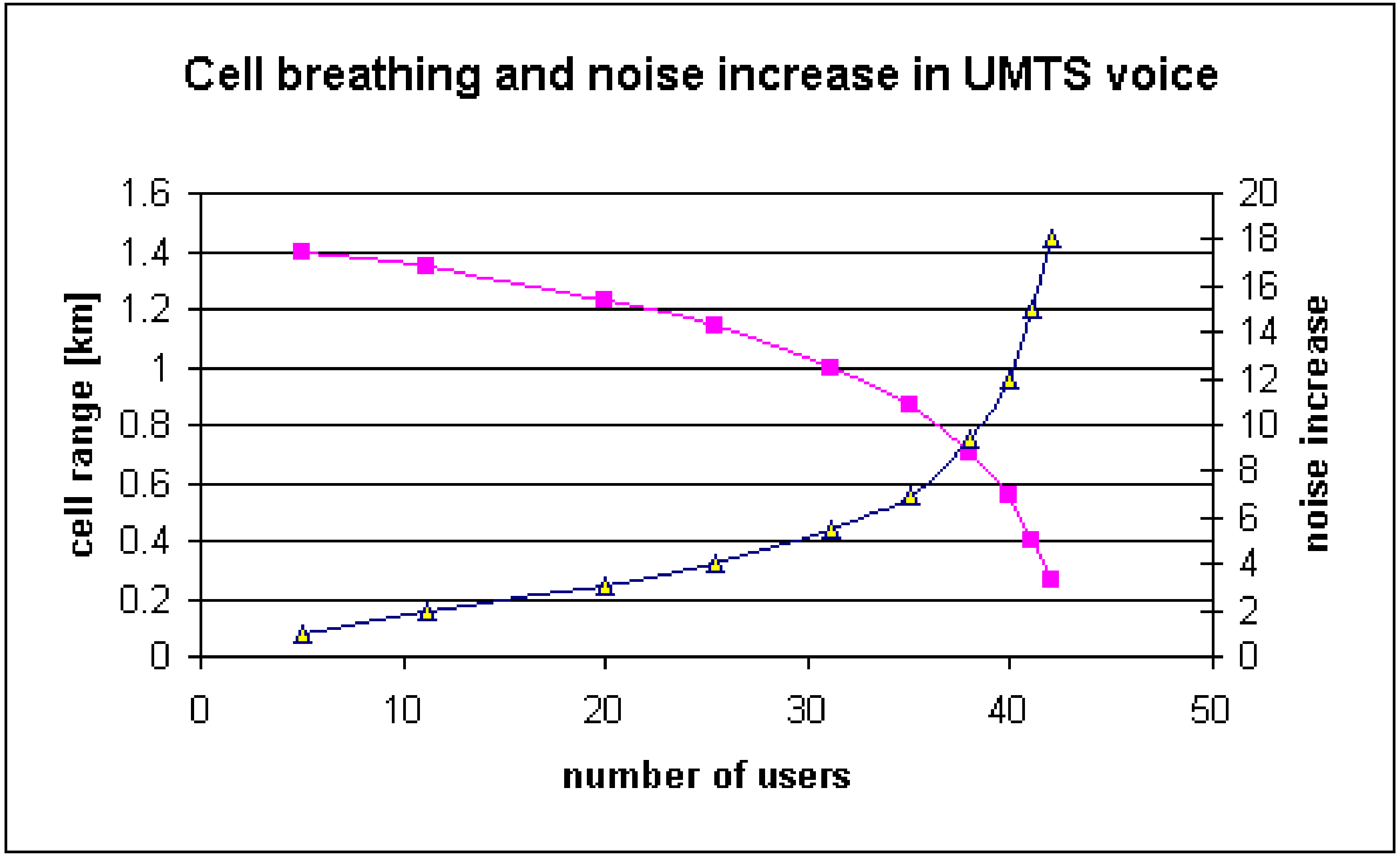
Breathing Cells

GSM
- Mobile device gets exclusive signal from the base station
- Number of devices in a cell does not influence cell size

UMTS
- Cell size is closely correlated to the cell capacity
- Signal-to-nose ratio determines cell capacity
- Noise is generated by interference from
  - other cells
  - other users of the same cell
- Interference increases noise level
- Devices at the edge of a cell cannot further increase their output power (max. power limit) and thus drop out of the cell
  ⇨ no more communication possible
- Limitation of the max. number of users within a cell required

- Cell breathing complicates network planning

Breathing Cells: Example



UMTS services (originally)

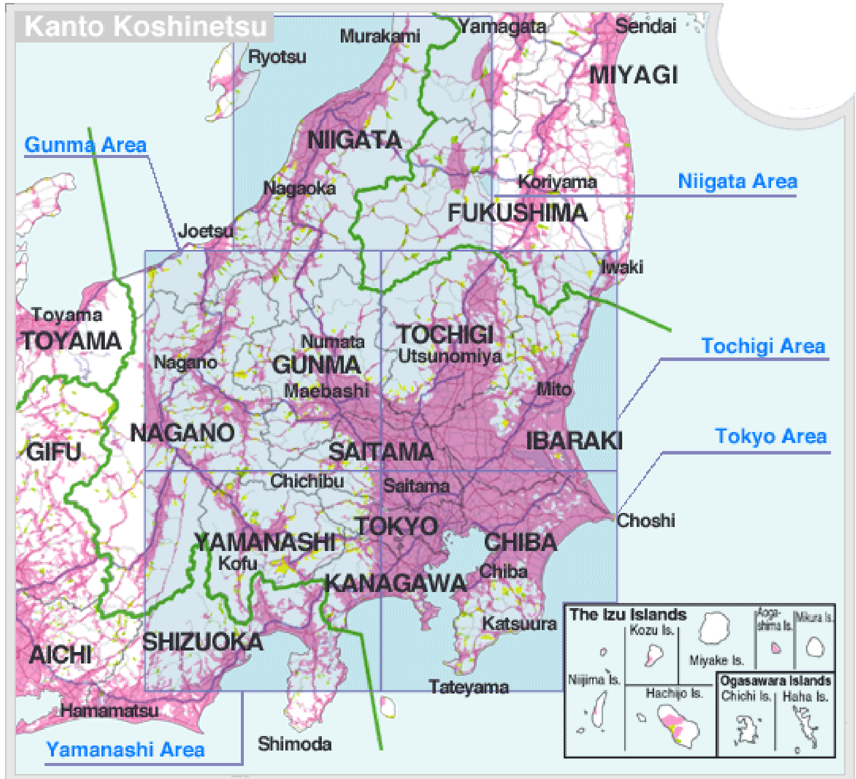
Data transmission service profiles

Service Profile	Bandwidth	Transport mode	
High Interactive MM	128 kbit/s	Circuit switched	Bidirectional, video telephone
High MM	2 Mbit/s	Packet switched	Low coverage, max. 6 km/h
Medium MM	384 kbit/s	Circuit switched	asymmetrical, MM, downloads
Switched Data	14.4 kbit/s	Circuit switched	
Simple Messaging	14.4 kbit/s	Packet switched	SMS successor, E-Mail
Voice	16 kbit/s	Circuit switched	

Virtual Home Environment (VHE)

- Enables access to personalized data independent of location, access network, and device
- Network operators may offer new services without changing the network
- Service providers may offer services based on components which allow the automatic adaptation to new networks and devices
- Integration of existing IN services

Early 3G Networks: Japan



FOMA (Freedom Of Mobile multimedia Access) in Japan

FOMA
らくらくホン

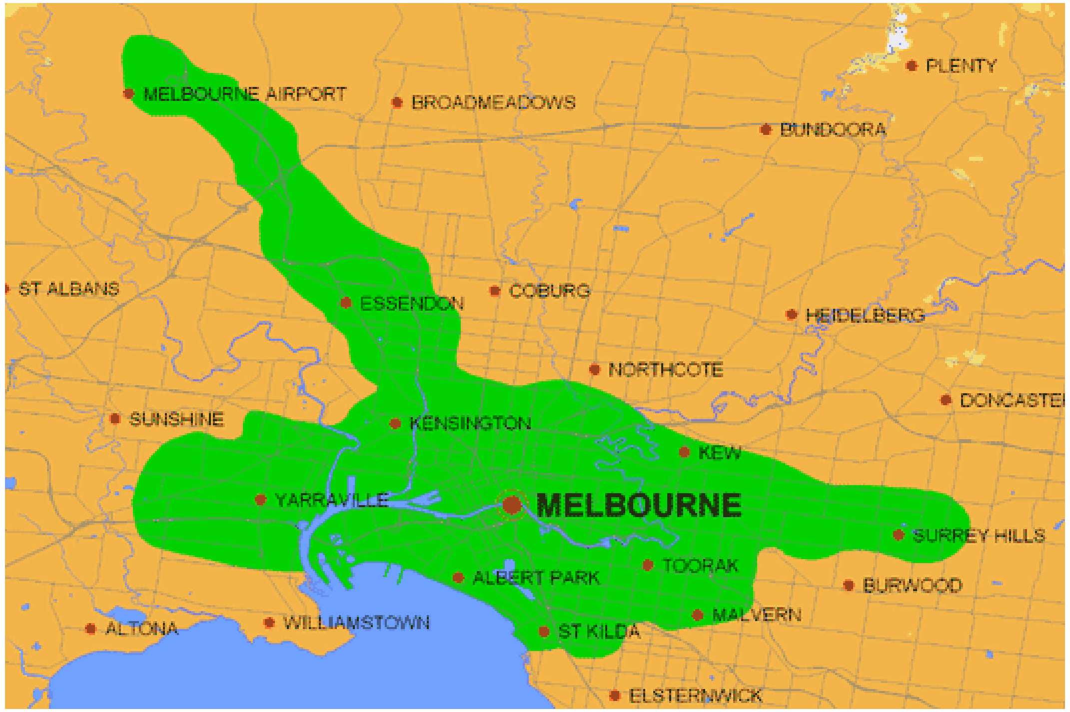
Silver

BlackSilver×DarkSilver

With Videophone you can enjoy conversations while facing each other.

Examples for FOMA phones

Early 3G networks: Australia

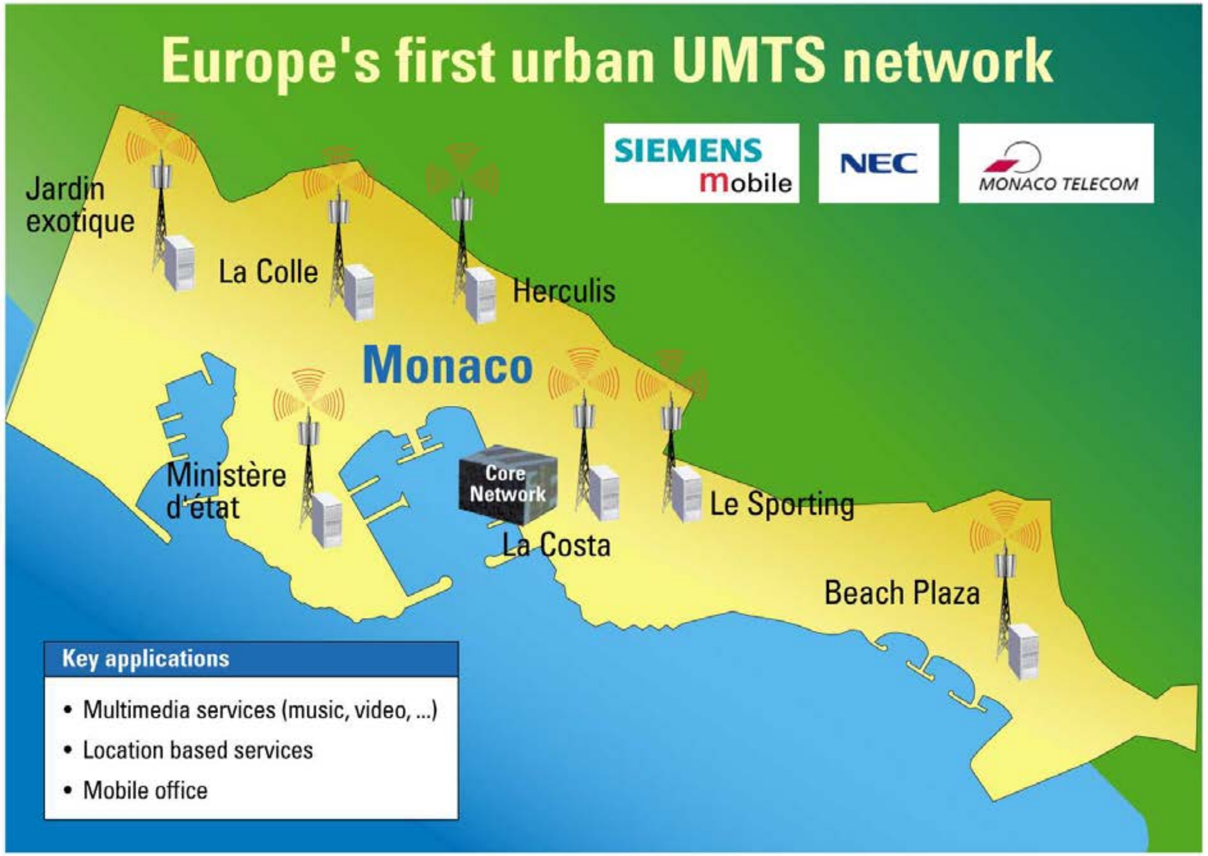


cdma2000 1xEV-DO in Melbourne/Australia

Examples for 1xEV-DO devices

Isle of Man – Start of UMTS in Europe as Test

UMTS in Monaco



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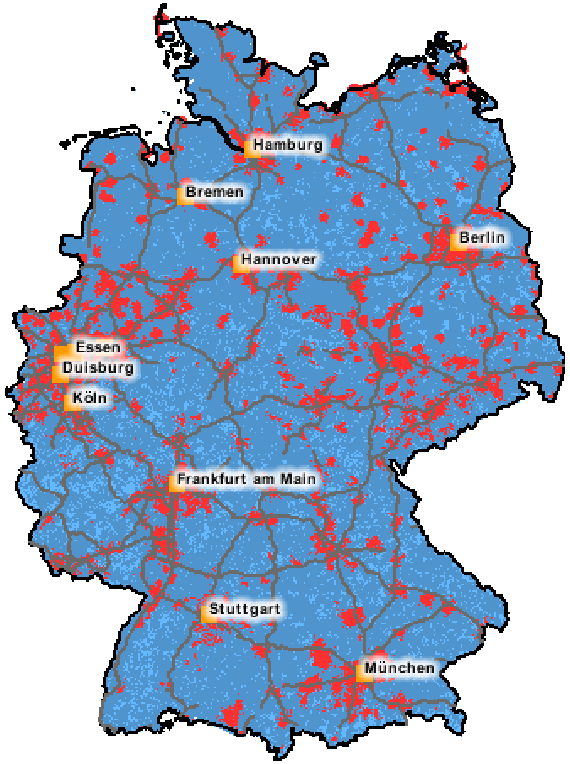
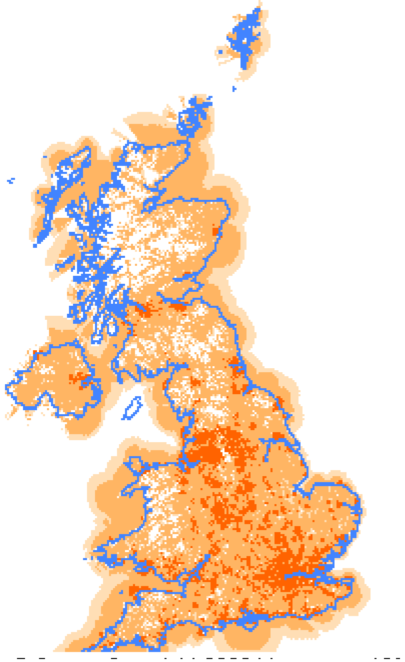
Early UMTS in Europe



Vodafone/Germany



Orange/UK

Some current GSM enhancements

EMS/MMS

- EMS: 760 characters possible by chaining SMS, animated icons, ring tones, was soon replaced by MMS (or simply skipped)
- MMS: transmission of images, video clips, audio
  - see WAP 2.0 – not really successful, typically substituted by email with attached multimedia content
- Today, more and more IP-based messaging used, less specialized services offered by the network

EDGE (Enhanced Data Rates for Global [was: GSM] Evolution)

- 8-PSK instead of GMSK, up to 384 kbit/s
- new modulation and coding schemes for GPRS ➔ EGPRS
  - MCS-1 to MCS-4 uses GMSK at rates 8.8/11.2/14.8/17.6 kbit/s
  - MCS-5 to MCS-9 uses 8-PSK at rates 22.4/29.6/44.8/54.4/59.2 kbit/s

Some current UMTS enhancements

HSDPA (High-Speed Downlink Packet Access)

- initially up to 10 Mbit/s for the downlink, later > 20 Mbit/s using MIMO- (Multiple Input Multiple Output-) antennas
- can use 16-QAM instead of QPSK (ideally > 13 Mbit/s)
- user rates e.g. 3.6 or 7.2 Mbit/s

HSUPA (High-Speed Uplink Packet Access)

- initially up to 5 Mbit/s for the uplink
- user rates e.g. 1.45 Mbit/s

HSPA+ (Evolved HSPA)

- Rel-7/Rel-8/Rel-9/…
- Downlink 28/42/84/> 100 Mbit/s
- Uplink 11/23/>23 Mbit/s
- 2x2 MIMO, 64 QAM

Dual-/Multi-Carrier HSPA (DC-/MC-HSPA)

- Connect 2 (Rel-8/9) or more carriers (Rel-11) e.g. of two cells offering up to 672 Mbit/s (4x4 MIMO)

Questions & Tasks

- Compare the handovers in GSM with the ones in UMTS. Why are they called hard or soft, respectively?
- How much is the core network aware of the type of handover?
- What are the consequences of introducing IP-based packet transmission?
- What is the key to higher data rates in UMTS?
- While the data rates increased over time, the delay remained more or less constant at about 100-150 ms from a mobile device to the base station. What problem arises if e.g. downloading content using TCP via these fast connections? Think of congestion avoidance/RTT!

Long Term Evolution (LTE)

Initiated in 2004 by NTT DoCoMo,
focus on enhancing the Universal
Terrestrial Radio Access (UTRA) and
optimizing 3GPP’s radio access architecture

Targets: Downlink 100 Mbit/s, uplink 50 Mbit/s, RTT<10ms

2007: E UTRA progressed from the feasibility study stage to the first issue of approved Technical Specifications

2008: stable for commercial implementation

2009: first public LTE service available (Stockholm and Oslo)

2010: LTE starts in Germany

LTE is not 4G – sometimes called 3.9G

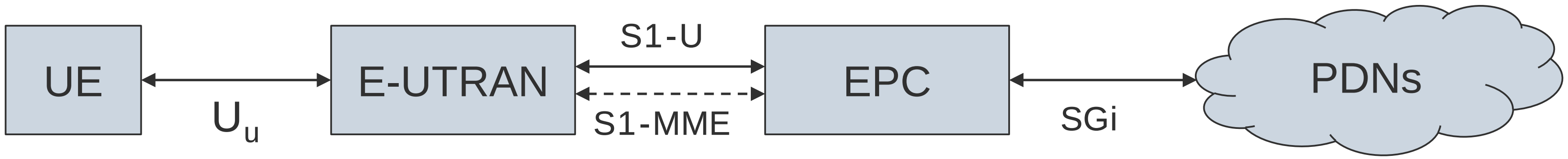
- Does not fulfill all requirements for IMT advanced

LTE High-level Architecture

User Equipment (UE)
- Mobile Termination (MT) handles wireless/mobile communication
- Terminal Equipment (TE) handles data streams
- Universal Integrated Circuit Card (UICC): the SIM for LTE, runs the USIM

Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)
- comprises the eNodeBs (i.e. the base stations including controllers)
- interfaces to the EPC via a user interface (S1-U) and signaling interface (S1-MME)

Evolved Packet Core (EPC)
- comprises the central database for subscribers, equipment identity
- routes data to/from other Packet Data Networks (PDN)
- functions for policing, charging, authentication



Initial typical data rates (Release 8)

UE Category	Max. data rate downlink	Max downlink MIMO	Max data rate uplink
1	10.3	1	5.2
2	51.0	2	25.5
3	102.0	2	51.0
4	150.8	2	51.0
5	299.6	4	75.4

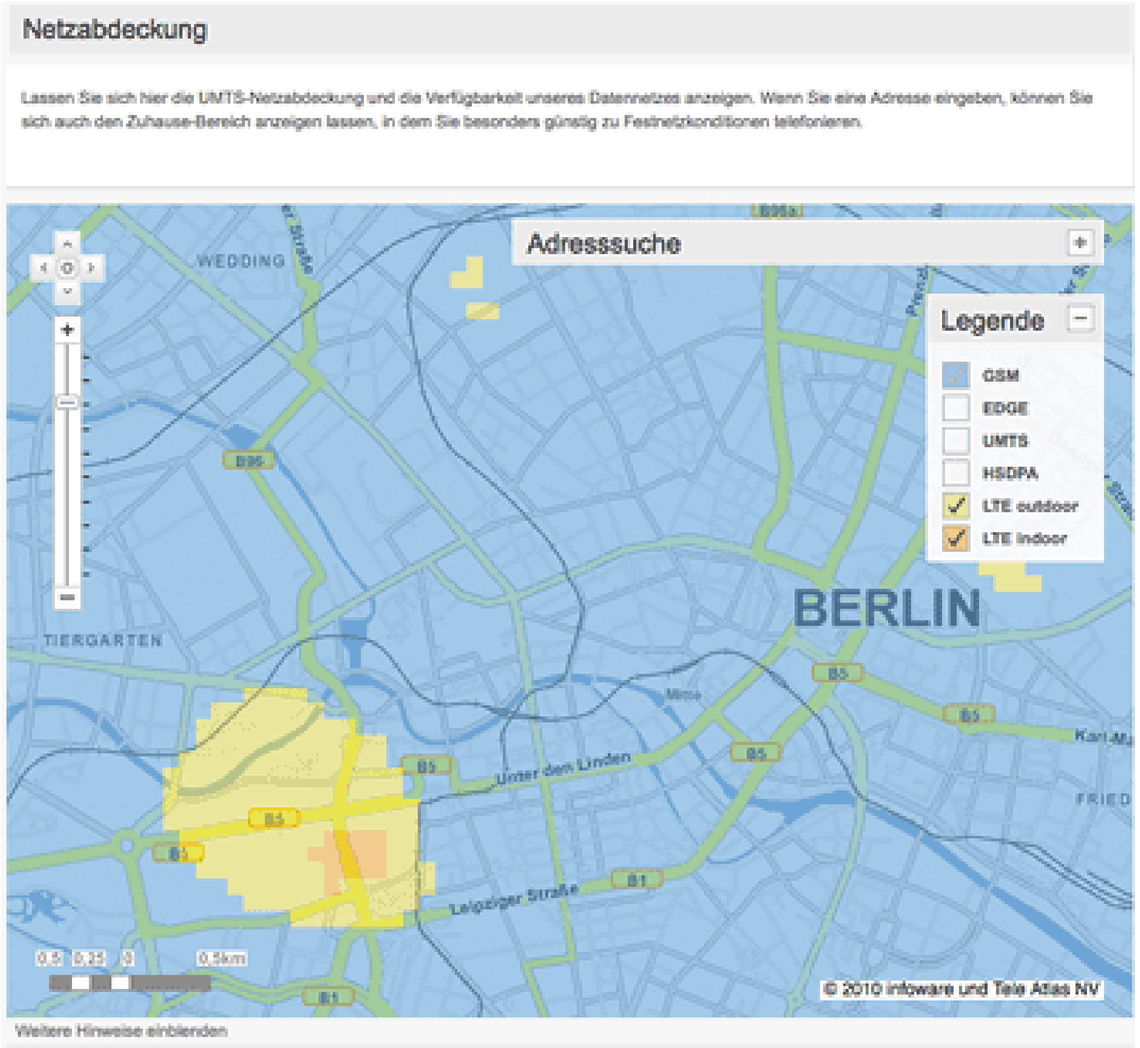
Higher (and lower) data rates with LTE advanced!

QoS Classes

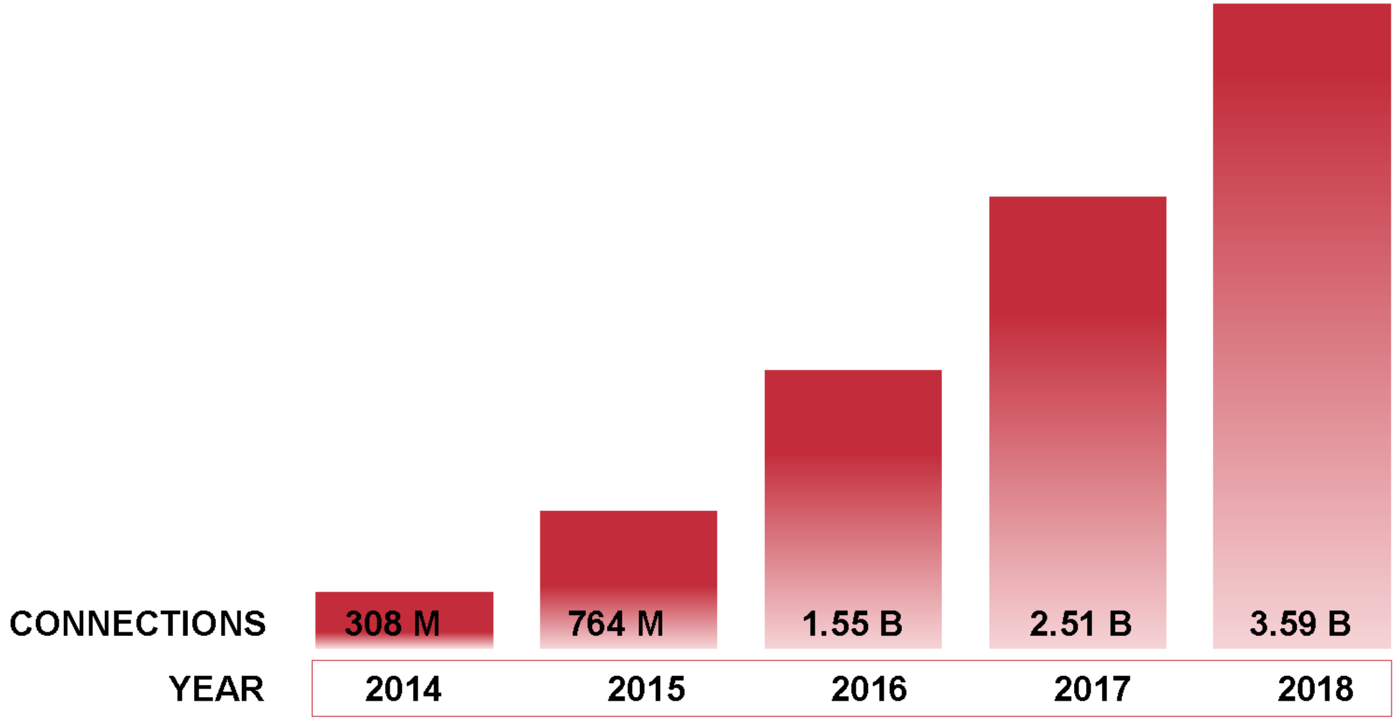
3GPP TS 23.203
(only part shown here)

QCI	Resource Type	Priority Level	Packet Delay Budget	Packet Error Loss Rate (NOTE 2)	Example Services
1 (NOTE 3)	GBR	2	100 ms (NOTE 1)	10^{-2}	Conversational Voice
2 (NOTE 3)		4	150 ms (NOTE 1)	10^{-3}	Conversational Video (Live Streaming)
3 (NOTE 3)		3	50 ms (NOTE 1)	10^{-3}	Real Time Gaming
4 (NOTE 3)		5	300 ms (NOTE 1)	10^{-6}	Non-Conversational Video (Buffered Streaming)
65 (NOTE 9)		0.7	75ms (NOTE 7, NOTE 8)	10^{-2}	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		2	100 ms (NOTE 1, NOTE 8)	10^{-2}	Non-Mission-Critical user plane Push To Talk voice
5 (NOTE 3)	Non-GBR	1	100 ms (NOTE 1)	10^{-6}	IMS Signalling
6 (NOTE 4)		6	300 ms (NOTE 1)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7 (NOTE 3)		7	100 ms (NOTE 1)	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
8 (NOTE 5)		8	300 ms (NOTE 1)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9 (NOTE 6)		9			
69 (NOTE 9)		0.5	60 ms (NOTE 7)	10^{-6}	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70		5.5	200 ms (NOTE 7)	10^{-6}	Mission Critical Data (e.g. example services are the same as QCI 6/8/9)

May 2011, Berlin gets LTE

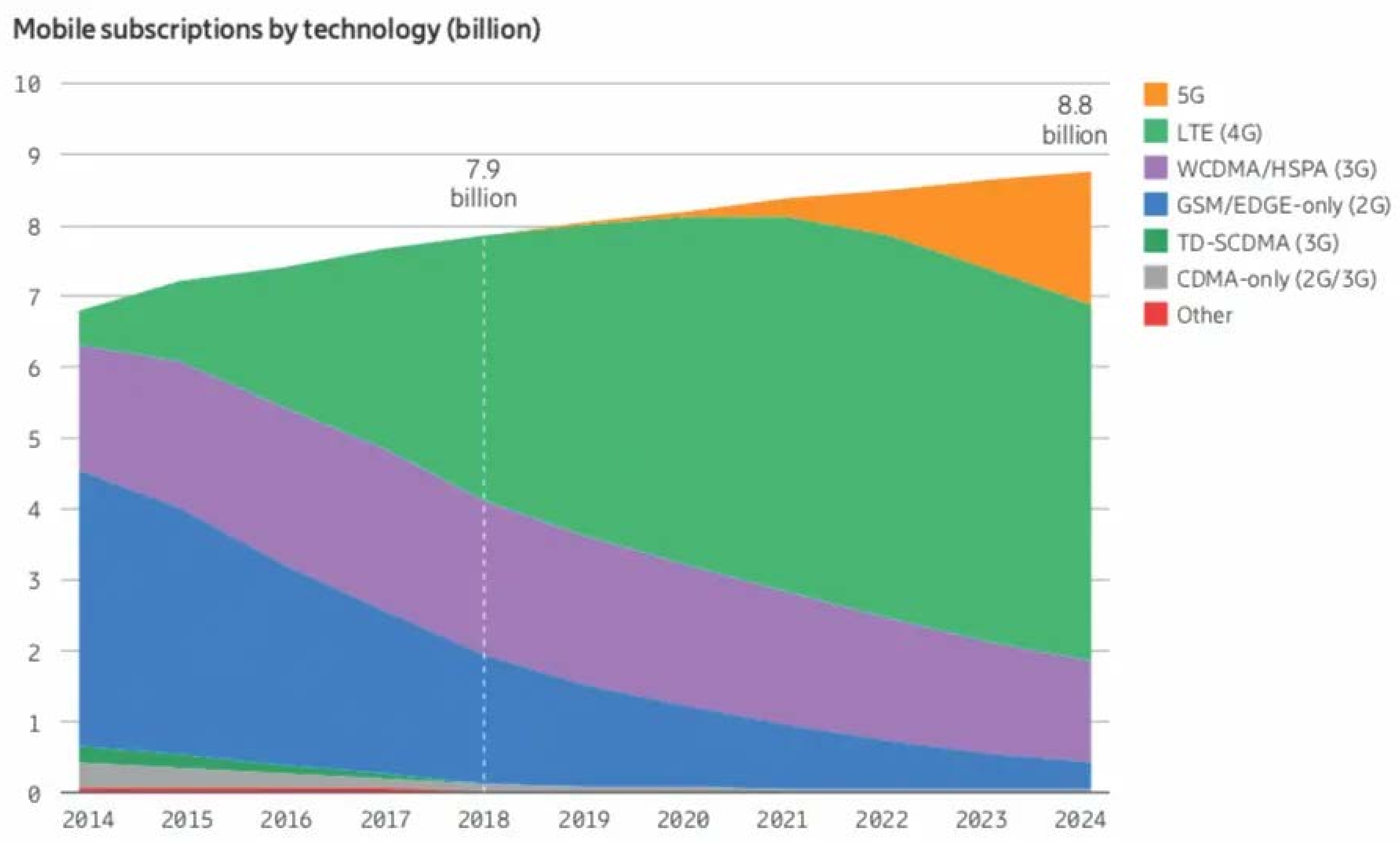


Fast growth rates of LTE



Source: Ovum June 2018

LTE will stay for a while



source: Heise-Verlag, c’t 15/2019

LTE today – THE global standard (only 9 countries *without* LTE in 2019)

May 2020

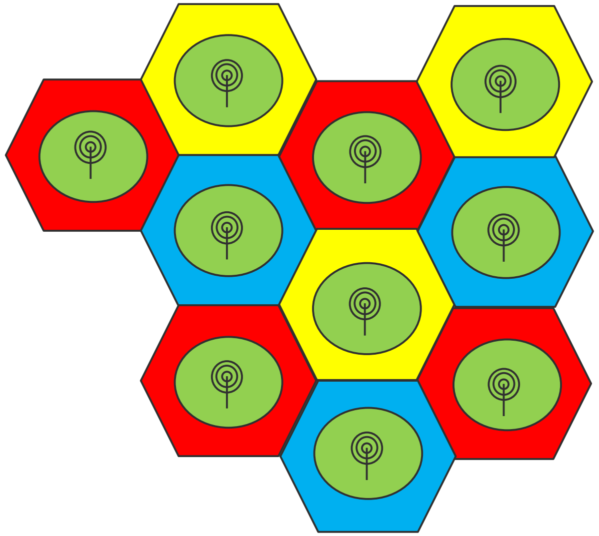
- 797 operators
- 325 LTE advanced/pro
- 210 VoLTE networks
- 106 NB-IoT networks
- 80 operators offering 5G
- https://gsacom.com/technology/5g/

"LTE-Not-Spots" (source: GSA/Heise-Verlag, c't 15/2019)

Key LTE features

Simplified network architecture compared to GSM/UMTS
- Flat IP-based network replacing the GPRS core, optimized for the IP-Multimedia Subsystem (IMS), no more circuit switching

Network should be in parts self-organizing



Scheme for soft frequency reuse between cells
- Inner part uses all subbands with less power
- Outer part uses pre-served subbands with higher power

Much higher data throughput supported by multiple antennas
Much higher flexibility in terms of spectrum, bandwidth, data rates
Much lower RTT – good for interactive traffic and gaming
Smooth transition from W-CDMA/HSPA, TD-SCDMA and cdma2000 1x EV-DO – but completely different radio!
Large step towards 4G – IMT advanced

See www.3gpp.org for all specs, tables, figures etc.!

High flexibility

E-UTRA (Evolved UMTS Terrestrial Radio Access)
- Operating bands 700-2700MHz
- Channel bandwidth 1.4, 3, 5, 10, 15, or 20 MHz
- TDD and FDD

Modulation
- QPSK, 16QAM, 64QAM

Multiple Access
- OFDMA (DL), SC-FDMA (UL)

Peak data rates (cat 5 UE)
- 300 Mbit/s DL (4x4 MIMO, 20 MHz)
- 75 Mbit/s UL
- Depends on UE category

Cell radius
- From <1km to 100km

Mobility
- up to 350km/h

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			FDD
16	Reserved			Reserved			FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
Note 1: Band 6 is not applicable							

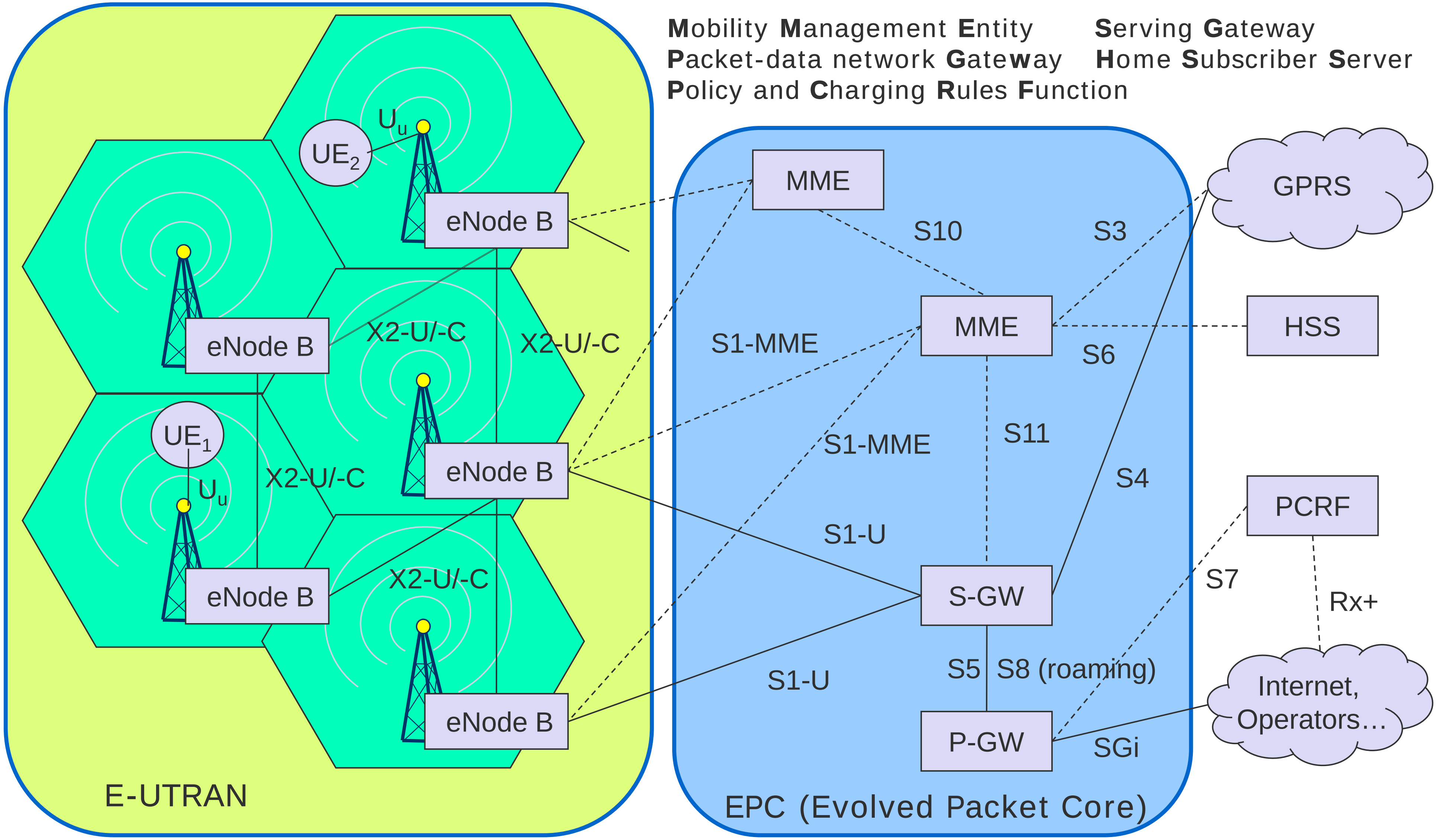
source: 3GPP TS 36.101

Questions & Tasks

- Why is LTE such a world-wide success? Think of parameters, architecture …
- Name high-level differences between LTE and GSM/GPRS/UMTS! What do they have in common?
- What is the idea of soft frequency reuse?

LTE architecture

Mobility **M**anagement **E**ntity
Packet-data network **G**ateway
Policy and **C**harging **R**ules **F**unction
Serving **G**ateway
Home **S**ubscriber **S**erver

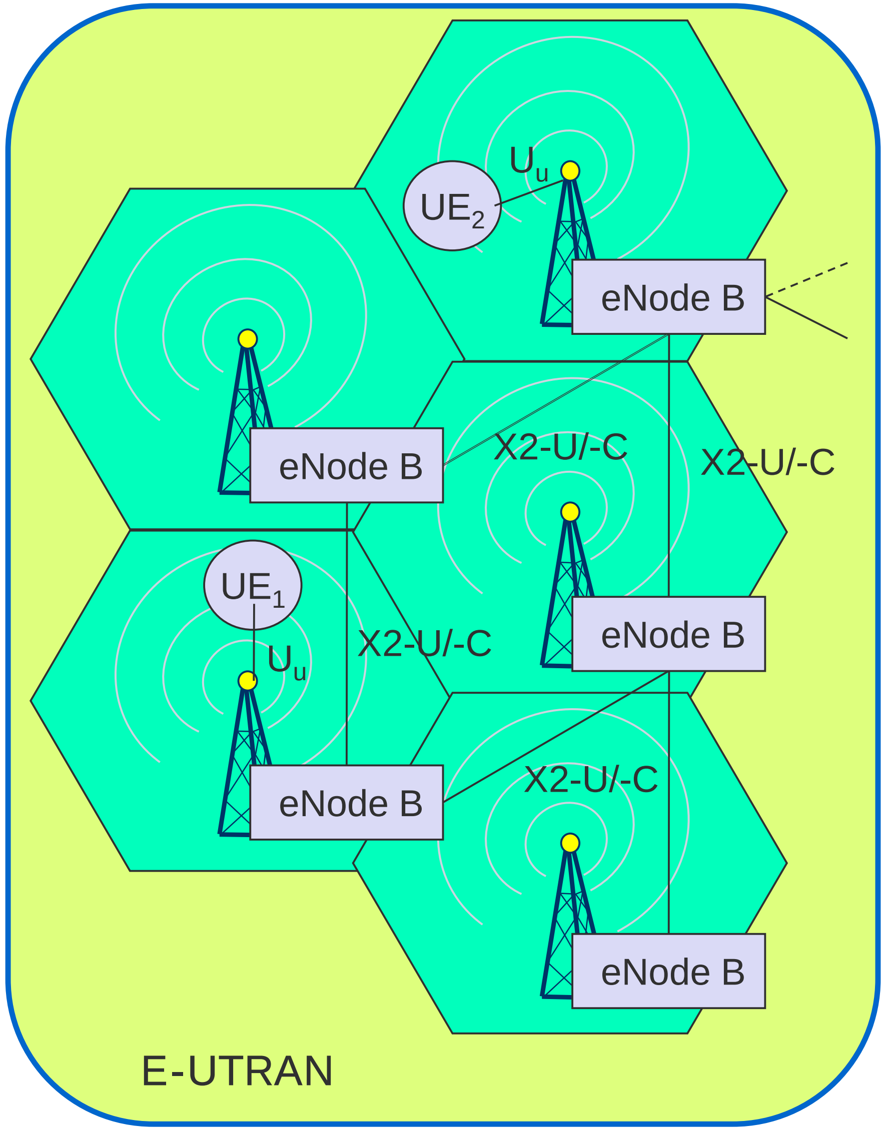


Components of the LTE architecture I – Evolved-UTRAN

eNode B

- Radio resource management
- QoS management
- Interference management
- Admission control
- Signal measurements
- Scheduling/resource allocation
- IP header compression
- Encryption

- Comprises former NodeB plus RNC functionality, now for LTE to reduce latency
- UE communicates only with one eNodeB, the serving eNodeB
- Connection to EPC (via S1-U and S1-MME) and to other eNodeBs (via X2-U and X2-C)
- Home eNodeBs possible (e.g. to create a femtocell at home)



Components of the LTE architecture II - EPC (Evolved Packet Core)

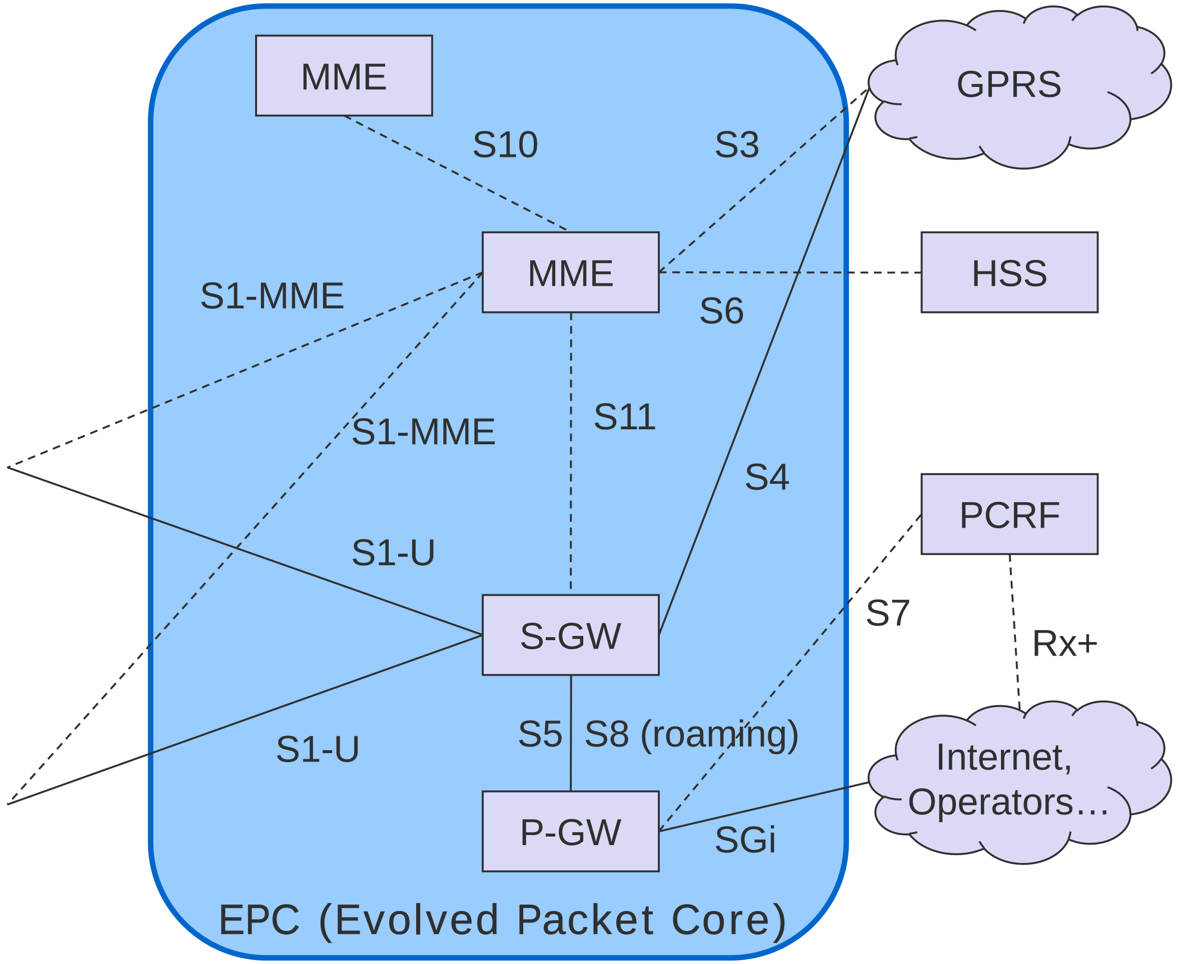
MME (Mobility Management Entity)
- Signaling between UE and EPC
- Security, Mobility Handling
- Bearer Control

S-GW (Serving Gateway)
- Mobility Anchor for all user IP packets
- Buffering during UE paging
- Charging, lawful interception

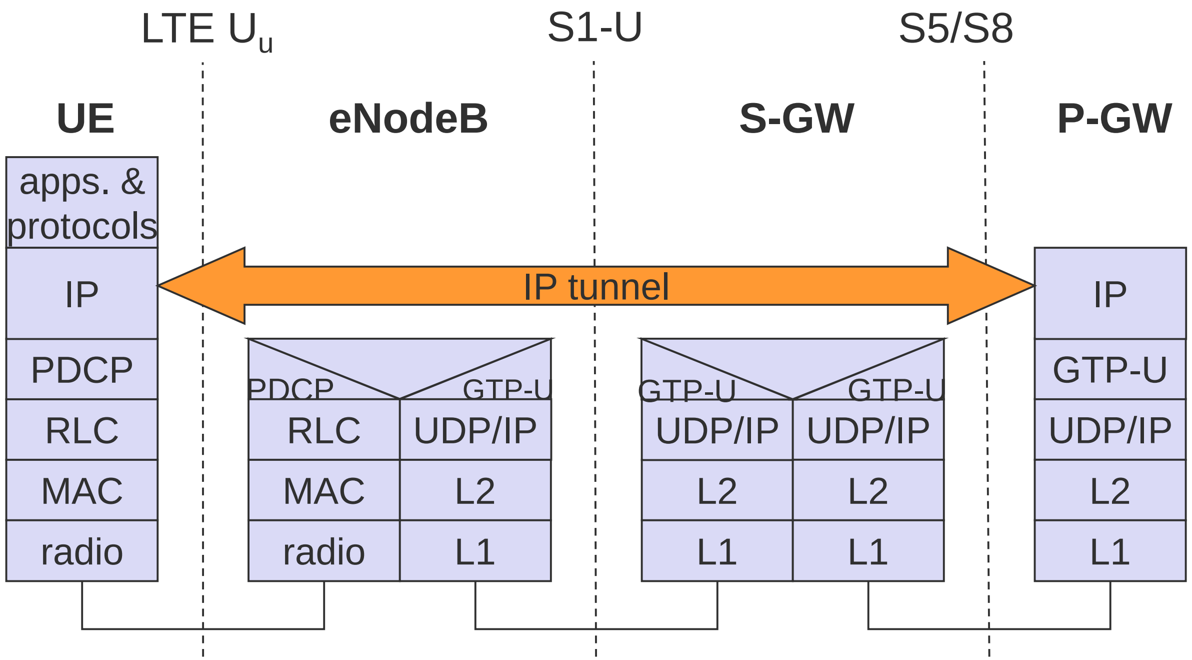
P-GW (PDN Gateway)
- IP address allocation for the UE
- Packet filtering, QoS enforcement

HSS (Home Subscriber Server)
- Subscriber information (allowed PDNs, QoS profile, roaming restrictions)
- MME identity of current location
- Includes authentication center

PCRF (Policy and Charging Rules Function)
- QoS authorization, policy control, controls flow-based charging

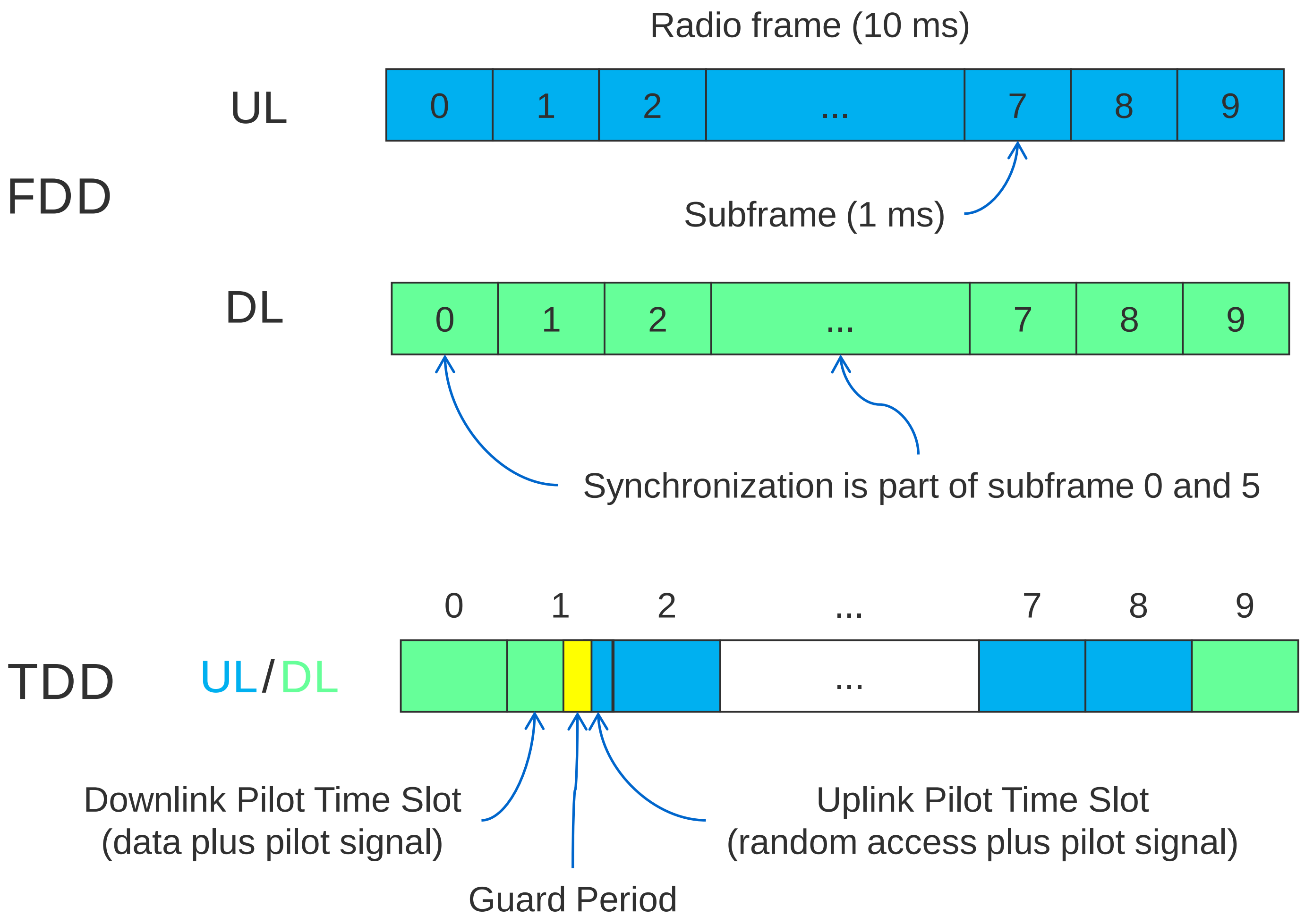


LTE protocol stack (user plane)



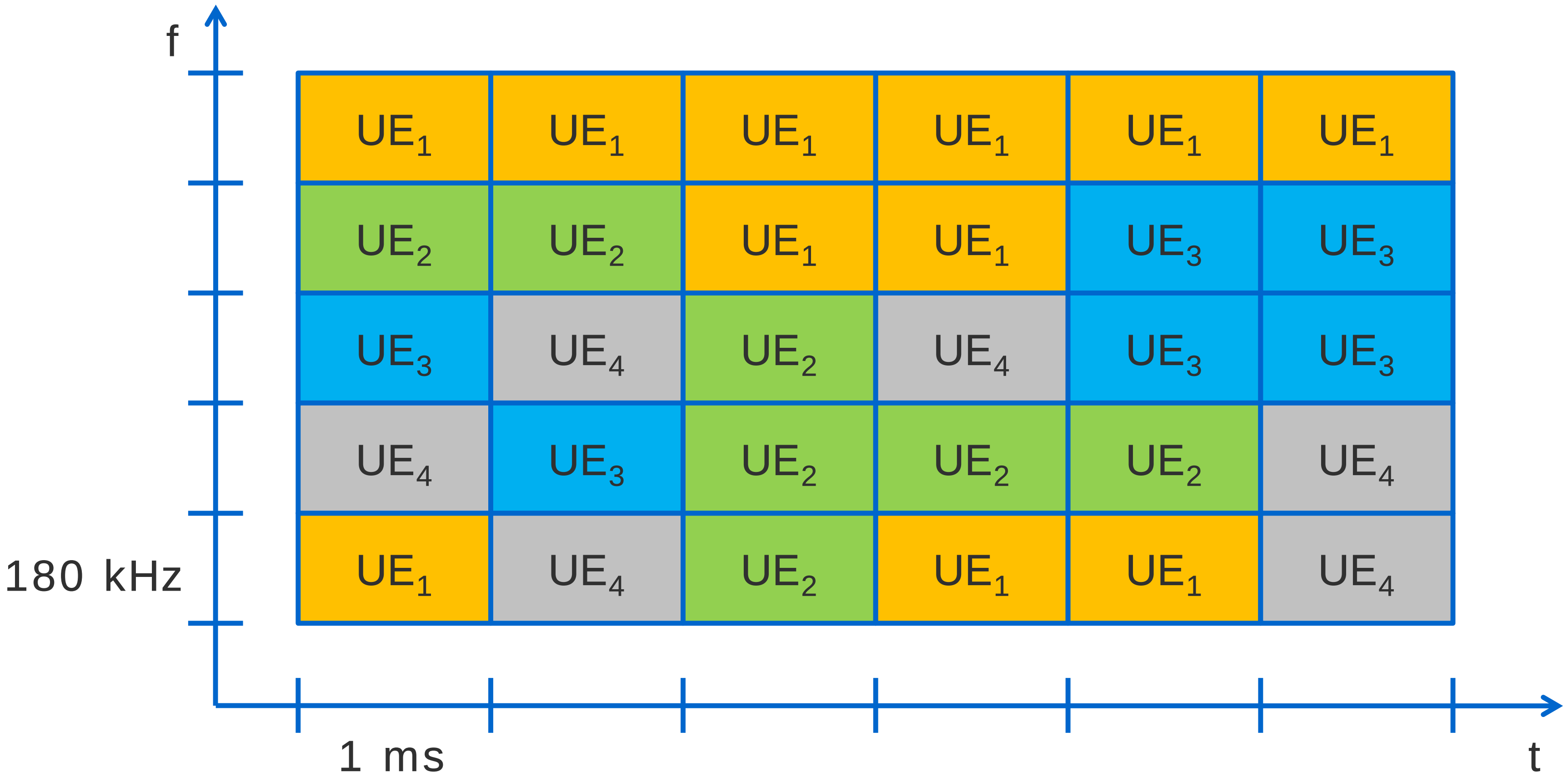
Packet switched only!

LTE frame structure



LTE multiple access

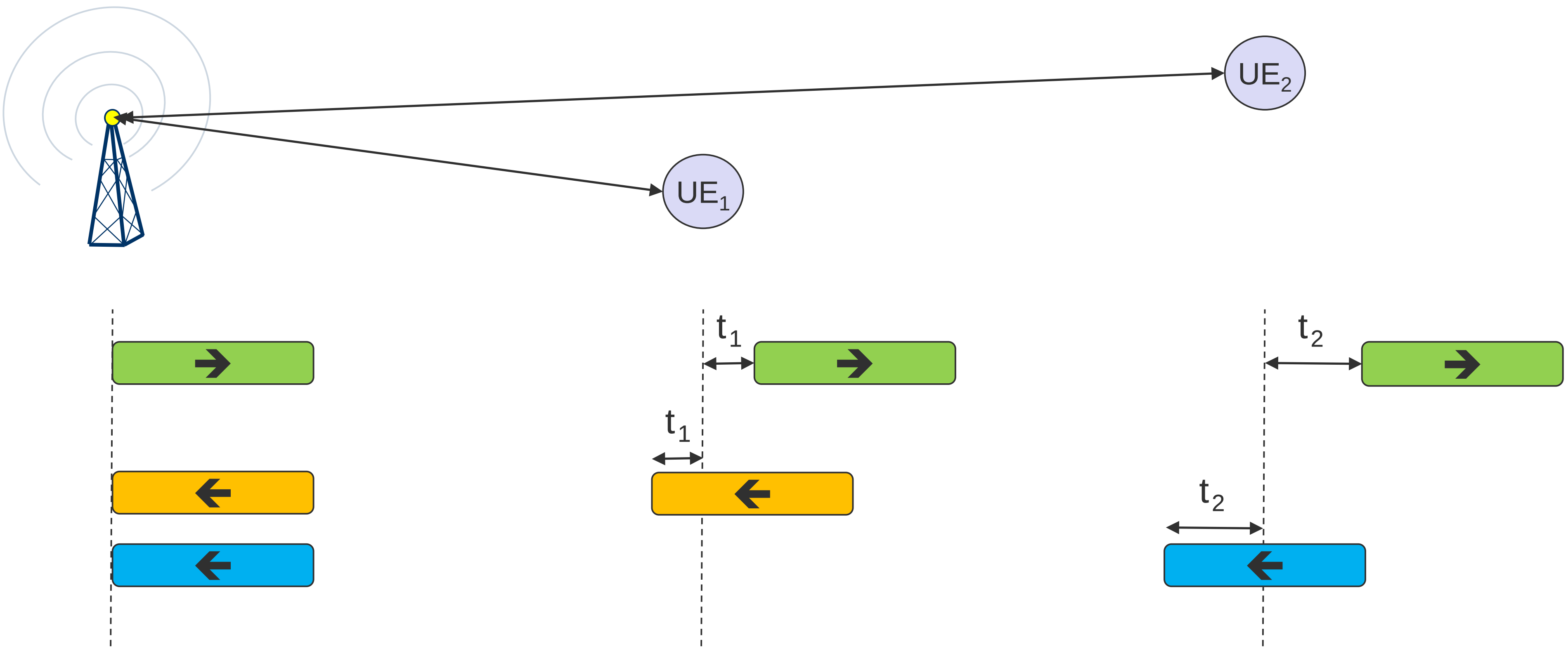
Scheduling of UEs in time and frequency (very simplified) using resource blocks (180kHz in 1 ms)



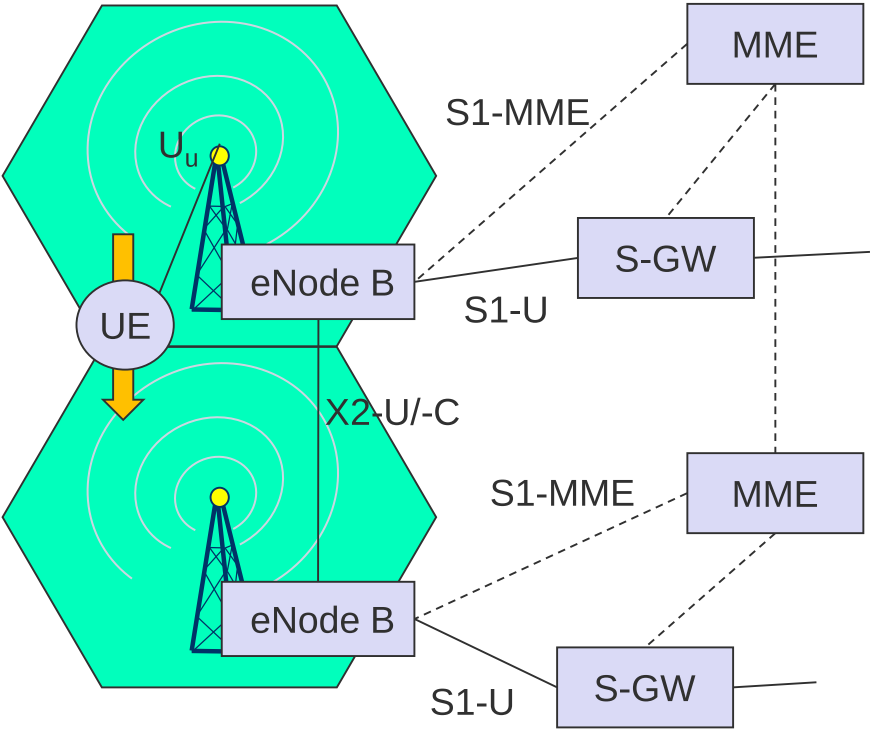
TDM requires Timing Alignment

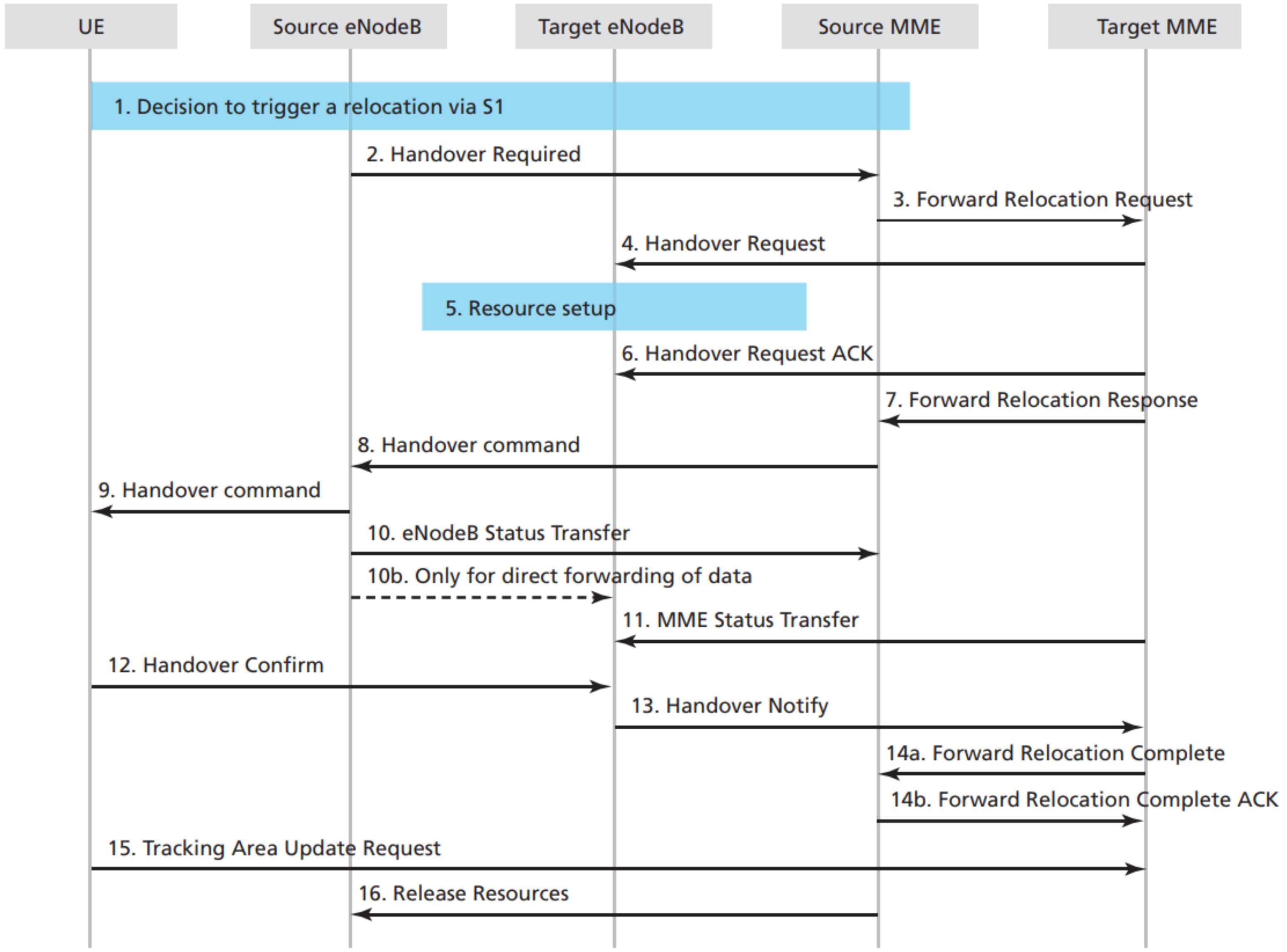
Similar to GSM – the further away a UE from the eNodeB is, the earlier it transmits

Configurable at a granularity of 0.52µs from 0 to 0.67 ms (corresponding to a max. cell radius of 100 km)



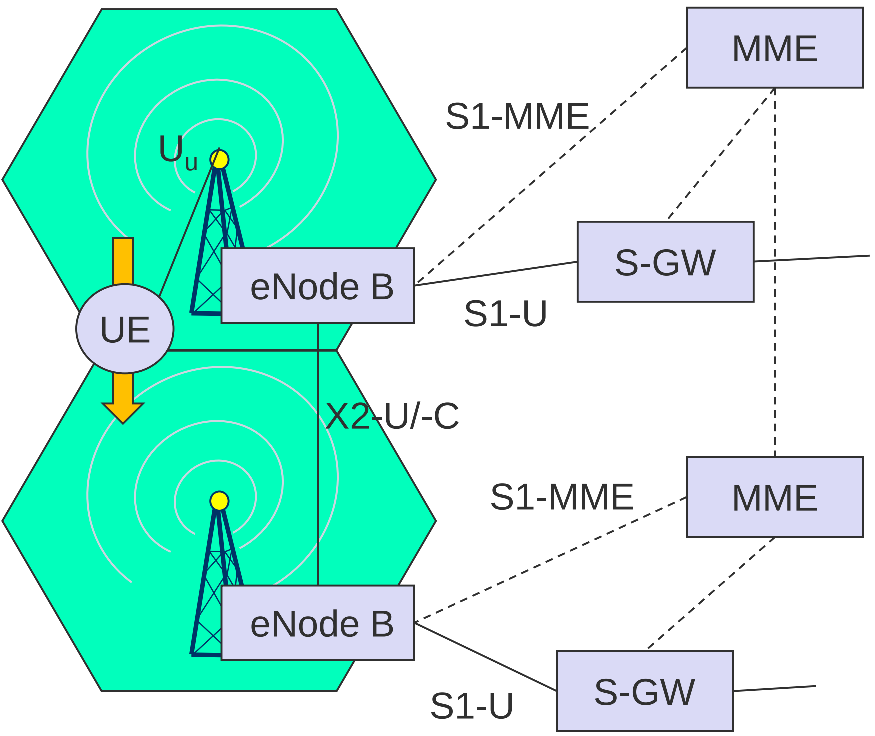
LTE handover via S1

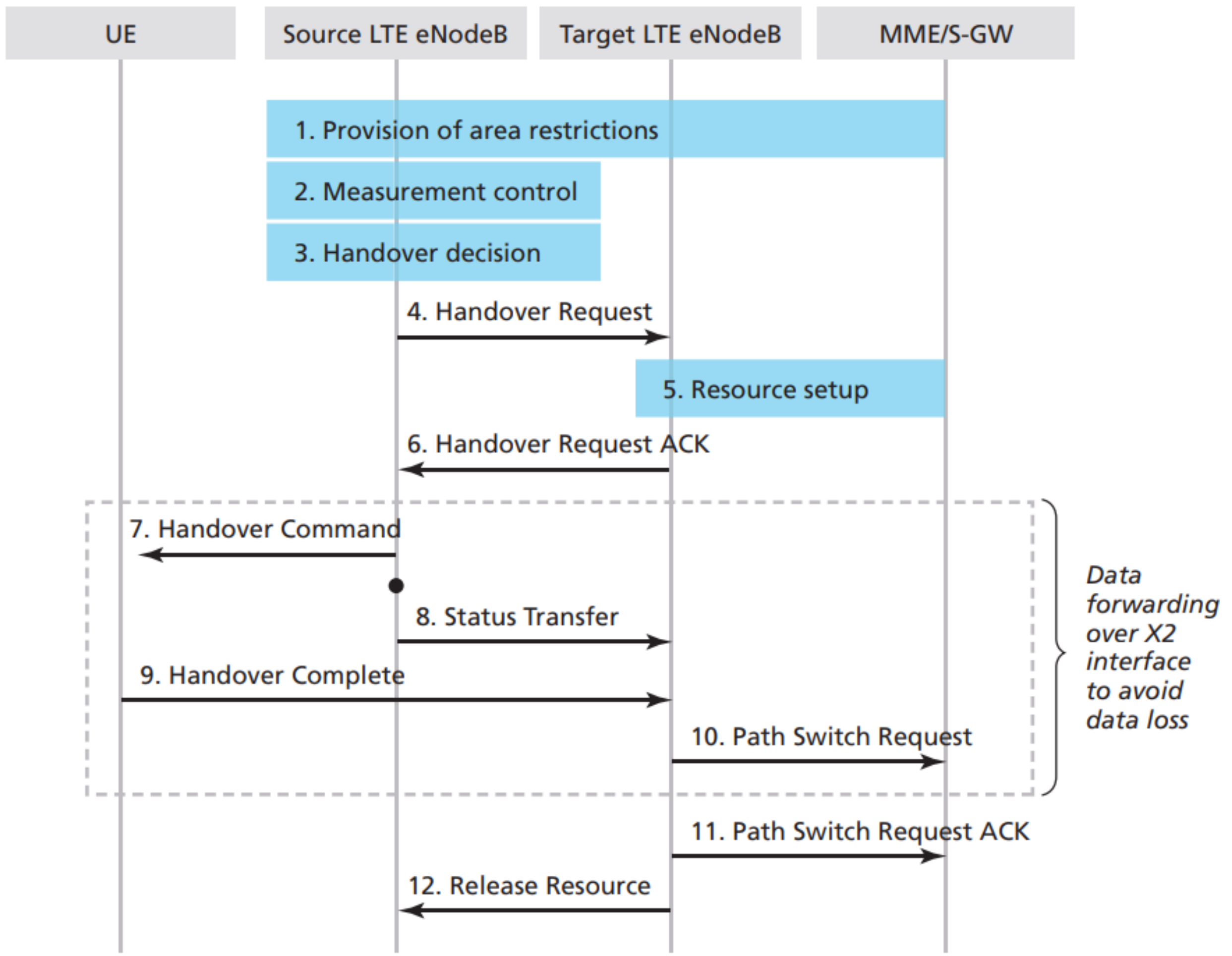




Source: The LTE Network Architecture, Strategic White Paper, Alcatel Lucent 2009

LTE handover via X2 interface





Seamless or lossless handovers possible as well as multiple target eNodeBs

Source: The LTE Network Architecture, Strategic White Paper, Alcatel Lucent 2009

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Questions & Tasks

- Compare the architecture of LTE/UMTS/GSM – what is new, what is basically the same?
- What is the purpose of the X2 connections between eNodeBs? How can LTE support seamless / lossless handover?
- How can LTE guarantee data rates, delays?
- Compare the multiplexing/multiple access in LTE with UMTS/GSM – differences/similarities?

IMT Advanced – from www.itu.int

Key features of ´IMT-Advanced´:

- a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
- compatibility of services within IMT and with fixed networks;
- capability of interworking with other radio access systems;
- high quality mobile services;
- user equipment suitable for worldwide use;
- user-friendly applications, services and equipment;
- worldwide roaming capability; and,
- enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research).

These features enable IMT-Advanced to address evolving user needs and the capabilities of IMT-Advanced systems are being continuously enhanced in line with user trends and technology developments.

LTE Advanced (Pro)

GSM – UMTS - LTE
- LTE advanced as candidate for IMT-advanced, 3GPP Rel 10/11/12
- LTE-A Pro: 4.5G/Pre 5G…, 3GPP Rel 13/14 – steps towards 5G

Worldwide functionality & roaming, compatibility of services

Interworking with other radio access systems (e.g. WiFi), use of unlicensed spectrum

Enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1/3 Gbit/s for low mobility)

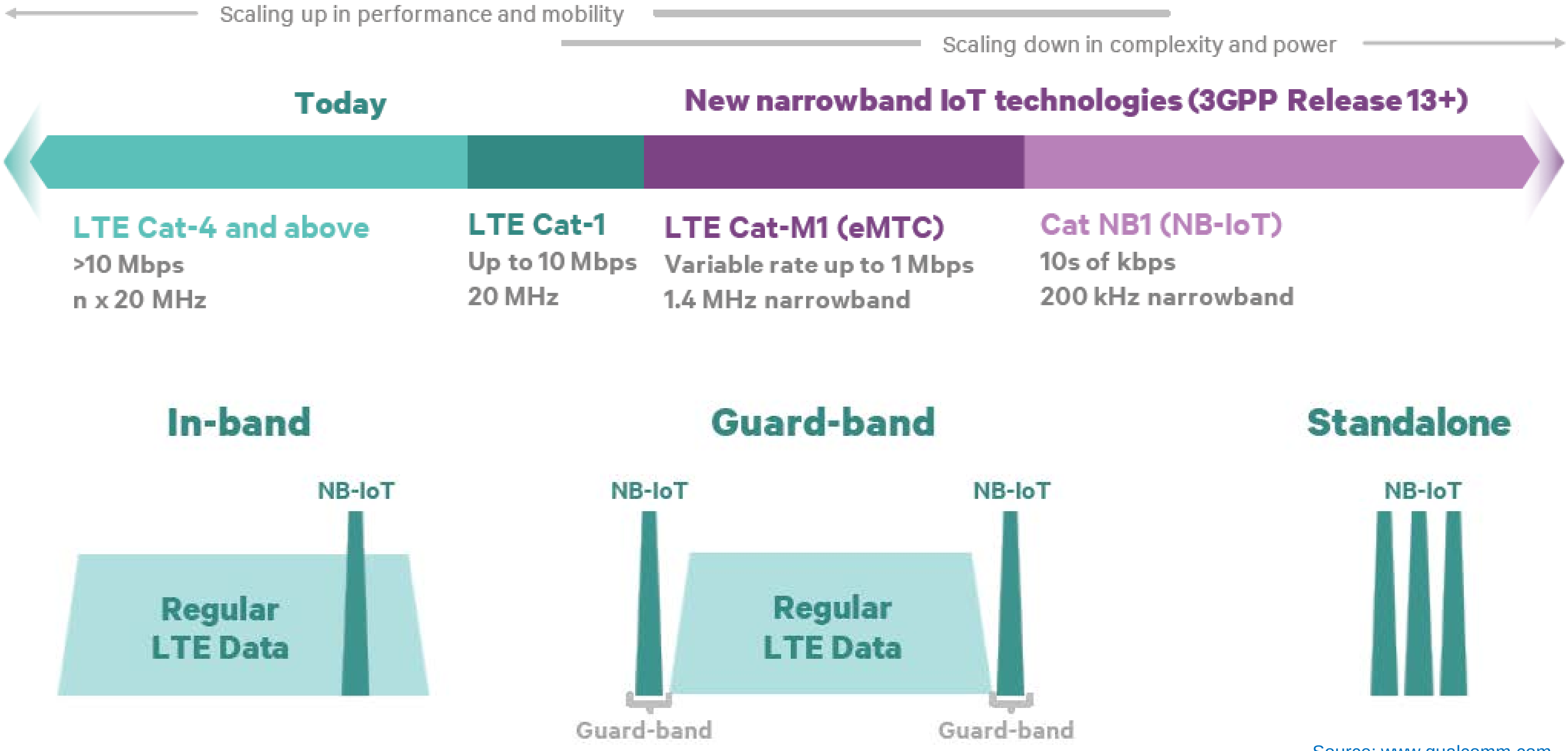
3GPP will be contributing to the ITU-R towards the development of IMT-Advanced via its proposal for LTE-Advanced.

Relay Nodes to increase coverage, Machine-Type-Communications, Public Safety Features (e.g. D2D)

100 MHz bandwidth (5x LTE with 20 MHz), carrier aggregation, increased battery life …

LTE for the Internet of Things I

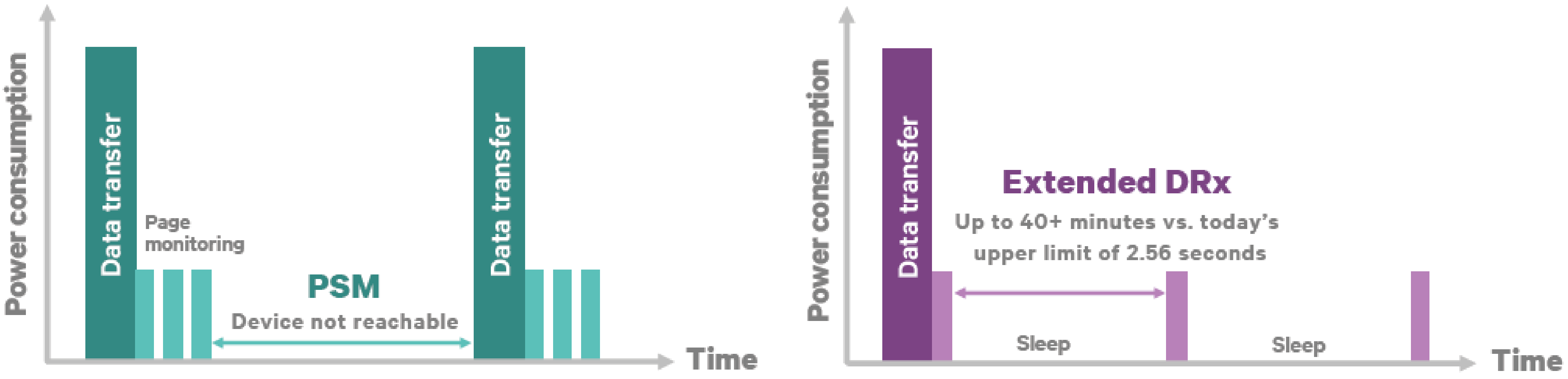
LTE as scaleable platform



Source: www.qualcomm.com

LTE for the Internet of Things II

Low power LTE – run-times > 10 years based on battery



Source: www.qualcomm.com

Questions & Tasks

-What is “evolutionary” in LTE?

-How does LTE reflect the variety of different demands?

-Check out the current status of LTE and the smooth transition towards 5G e.g. on 3GPP!