Mobile Communication: Telecommunications

Dominic Duggan

Based on materials by Jochen Schiller

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INTRODUCTION TO GSM

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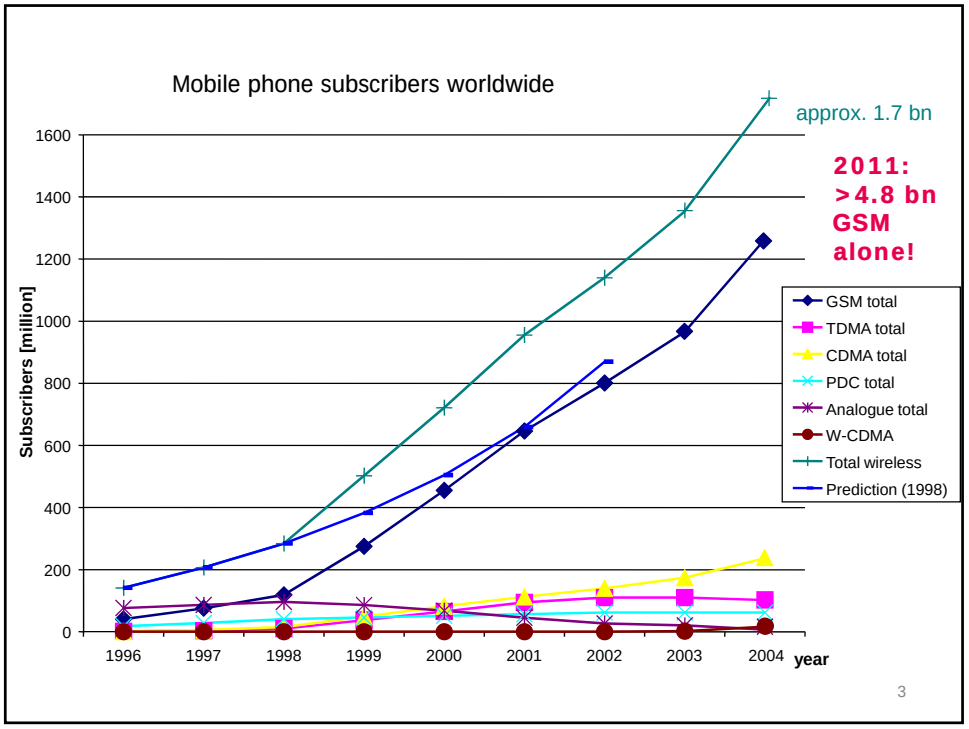
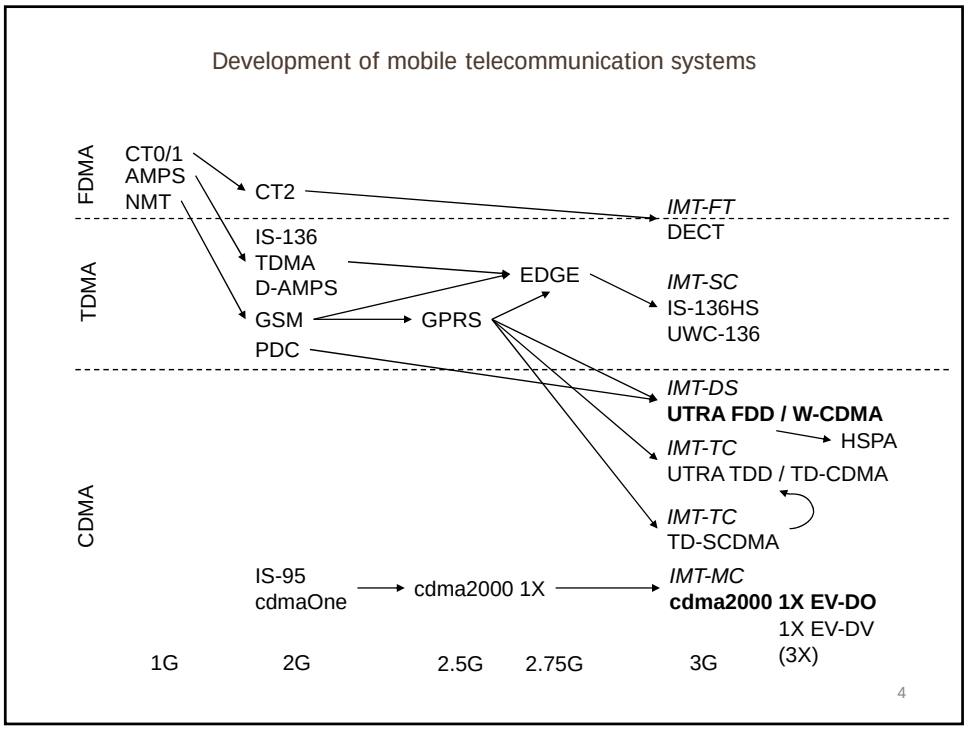

Mobile phone subscribers worldwide
approx. 1.7 bn
2011:
>4.8 bn
GSM
alone!
Subscribers [million]
1600
1400
1200
1000
800
600
400
200
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
year
GSM total
TDMA total
CDMA total
PDC total
Analogue total
W-CDMA
Total wireless
Prediction (1998)
3


Development of mobile telecommunication systems
FDMA
TDMA
CDMA
CT0/1
AMPS
NMT
CT2
IS-136
TDMA
D-AMPS
GSM
PDC
GPRS
EDGE
IS-95
cdmaOne
cdma2000 1X
IMT-FT
DECT
IMT-SC
IS-136HS
UWC-136
IMT-DS
UTRA FDD / W-CDMA
IMT-TC
UTRA TDD / TD-CDMA
HSPA
IMT-TC
TD-SCDMA
IMT-MC
cdma2000 1X EV-DO
1X EV-DV
(3X)
1G
2G
2.5G
2.75G
3G
4

Market Data Summary (Q2 2009)

Connections by Bearer Technology

Total	4,310,295,611
cdmaOne	2,449,937
CDMA2000 1X	309,907,068
CDMA2000 1xEV-DO	118,688,849
CDMA2000 1xEV-DO Rev. A	12,644,062
GSM	3,450,410,548
WCDMA	255,630,141
WCDMA HSPA	133,286,097
TD-SCDMA	825,044
TDMA	1,480,766
PDC	2,740,320
iDEN	22,172,858
Analog	9,593

Connections by World Region

World	4,310,295,611
Africa	416,303,821
Americas	475,193,998
Asia Pacific	1,906,764,743
Europe: Eastern	462,040,510
Europe: Western	506,982,364
Middle East	243,953,091
USA/Canada	299,057,084

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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?

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GSM Performance wrt analog system

- 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

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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 incompatibilities within the GSM standards

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GSM SERVICES

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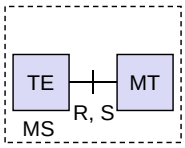
GSM mobile services

TE=terminal
MS=mobile station
MT=mobile terminal

- 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



S = interface for data transmission between TE and MT
R = interface for ISDN

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GSM mobile services

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PLMN=public land mobile network

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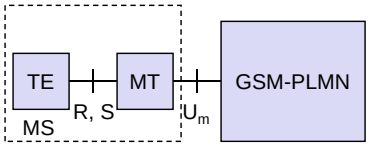

U = radio interface with mobile phone network

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GSM mobile services

TE=terminal
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PLMN=public land mobile network
PSTN=public switched telephone network
ISDN=integrated services data network

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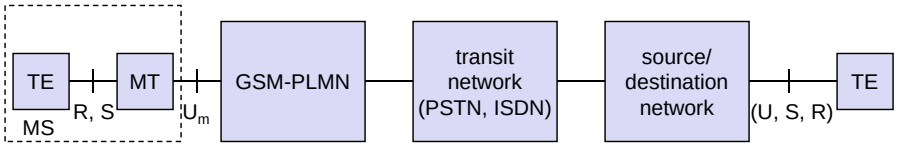

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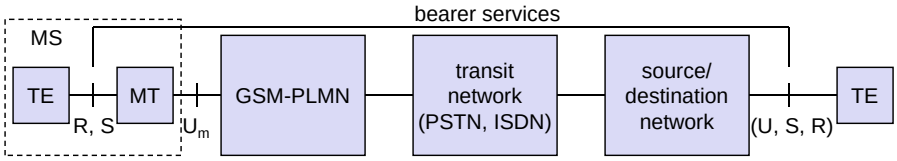

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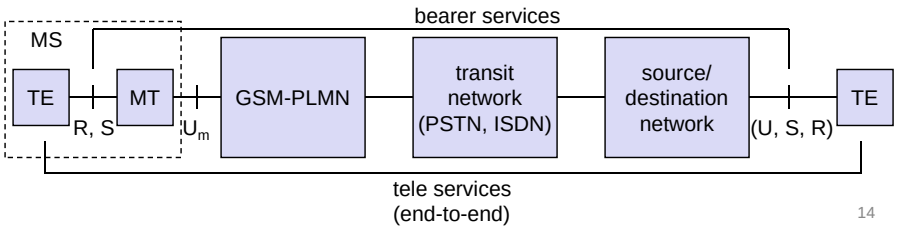

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Services

- Bearer Services
  - transfer data between access points
  - different data rates for voice and data
- Tele Services
  - enable voice communication via mobile phones
  - mobile telephony
  - emergency number multinumbering
  - group 3 fax
  - voice mailbox (implemented in the fixed network)
  - electronic mail (implemented in the fixed network)
  - ...
  - Short Message Service (SMS)

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Supplementary Services

- 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)
  - ...

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GSM ARCHITECTURE

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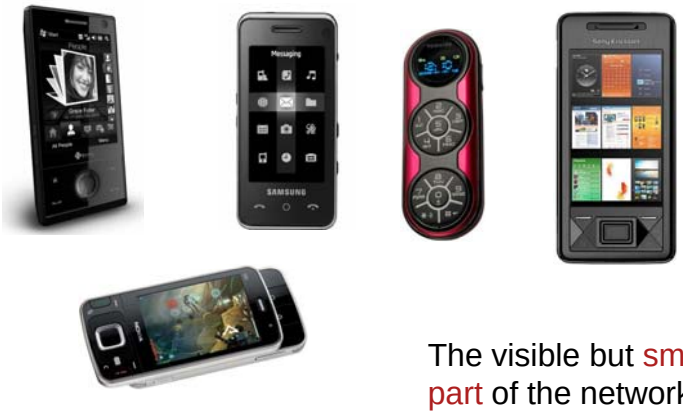
Ingredients I: Mobile phones, PDAs, etc



The visible but smallest part of the network!

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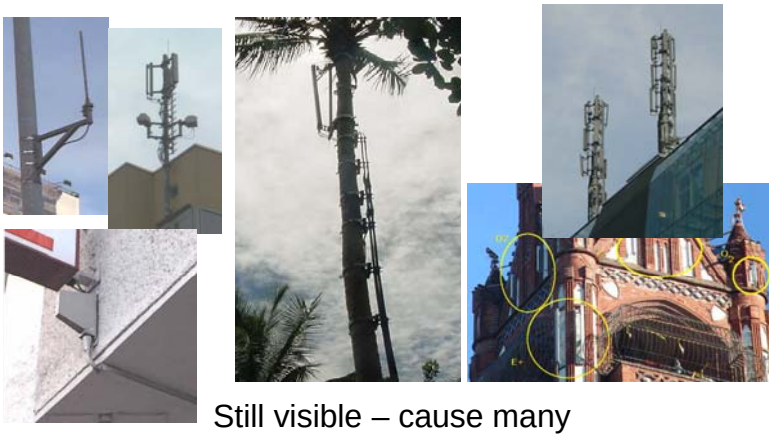
Ingredients 2: Antennas



Still visible – cause many discussions…

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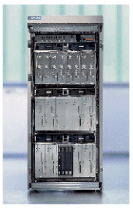
Ingredients 3: Infrastructure 1

Base Stations



Cabling

Microwave links

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Ingredients 3: Infrastructure 2

Switching units

Management

Data bases

Monitoring

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

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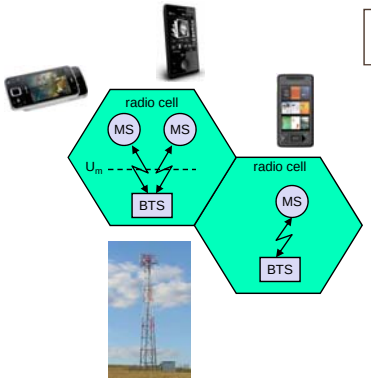
GSM: Elements and interfaces



MS=mobile station
BTS=base transceiver station

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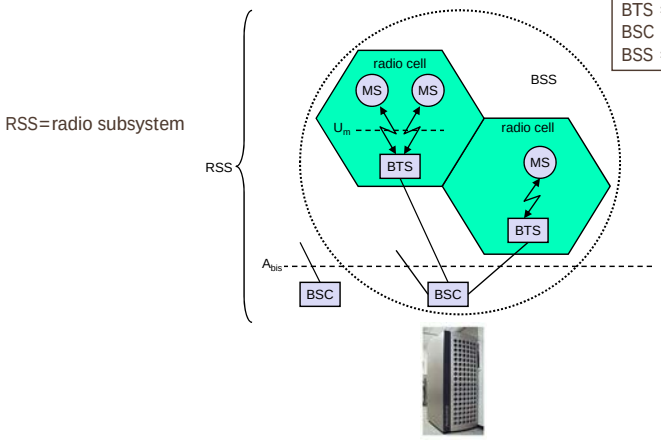
GSM: Elements and interfaces

MS = mobile station
BTS = base transceiver station
BSC = base station controller
BSS = base station subsystem



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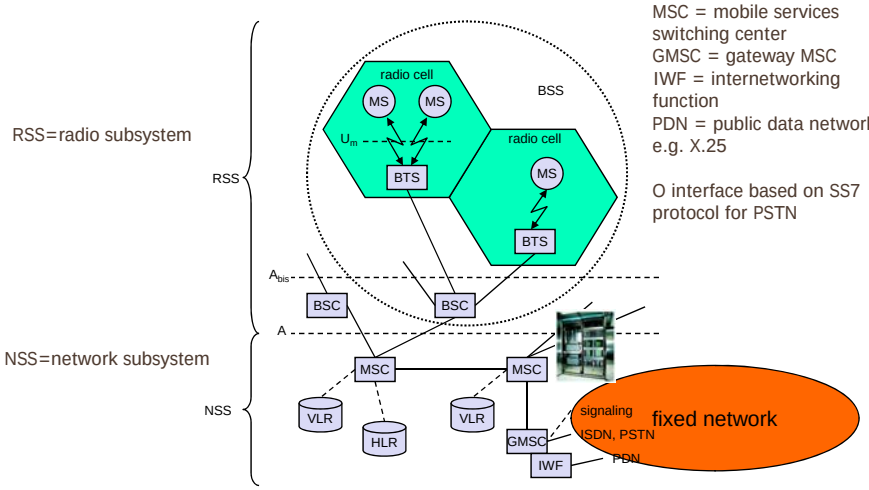
GSM: Elements and interfaces

HLR = home location registry
VLR = visitor location registry
MSC = mobile services switching center
GMSC = gateway MSC
IWF = internetworking function
PDN = public data network e.g. X.25

O interface based on SS7 protocol for PSTN



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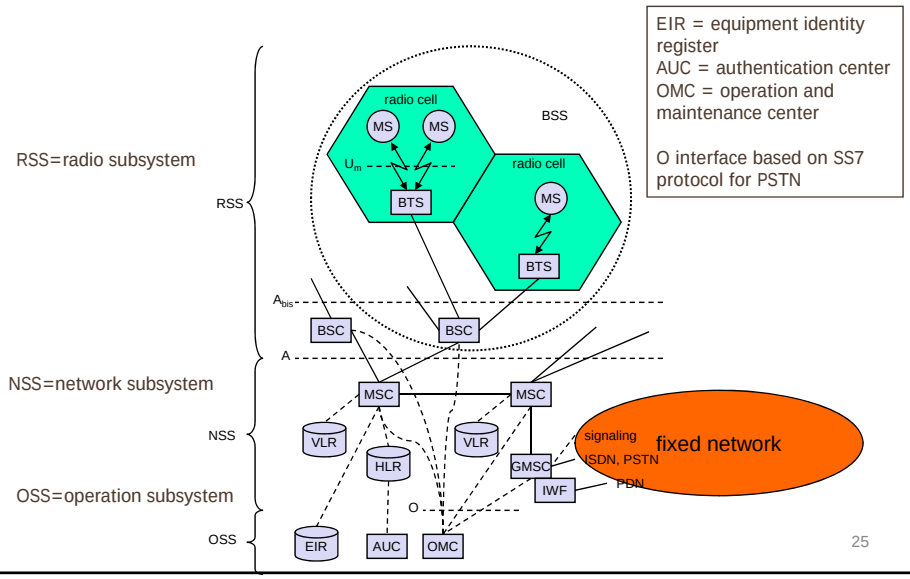
GSM: Elements and interfaces



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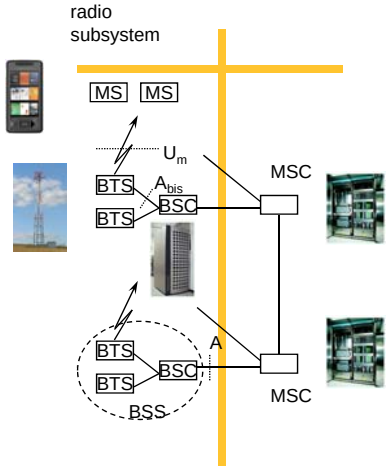
System architecture: radio subsystem



- 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

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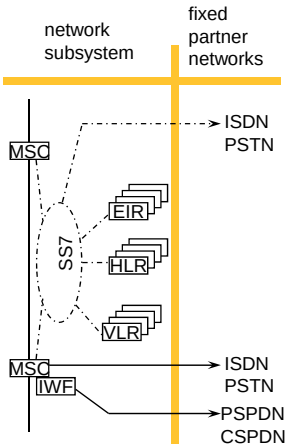
System architecture: network and switching subsystem



- 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)

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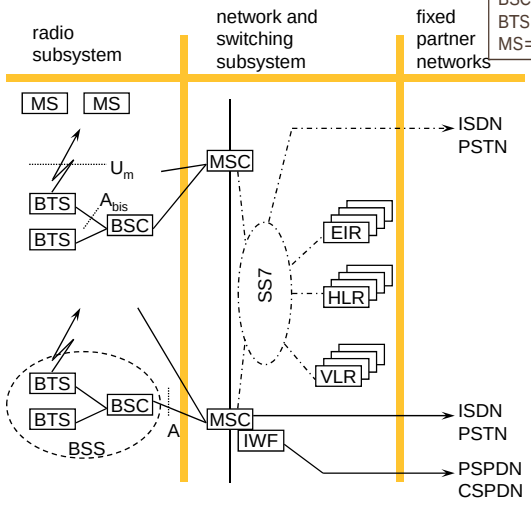
GSM: System architecture

BSS=base station subsystem
BSC=base station controller
BTS=base transceiver station
MS=mobile station



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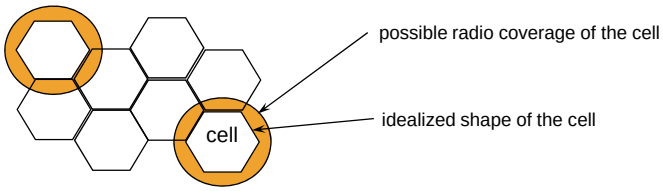
GSM: cellular network

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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Example coverage of GSM networks

T-Mobile (GSM-900/1800) Germany

O_2 (GSM-1800) Germany

AT&T (GSM-850/1900) USA

Vodacom (GSM-900) South Africa

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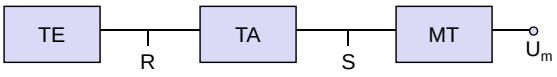
Mobile Station

- 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



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Mobile Services Switching Center

- The MSC (mobile 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 a 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

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GSM PROTOCOLS

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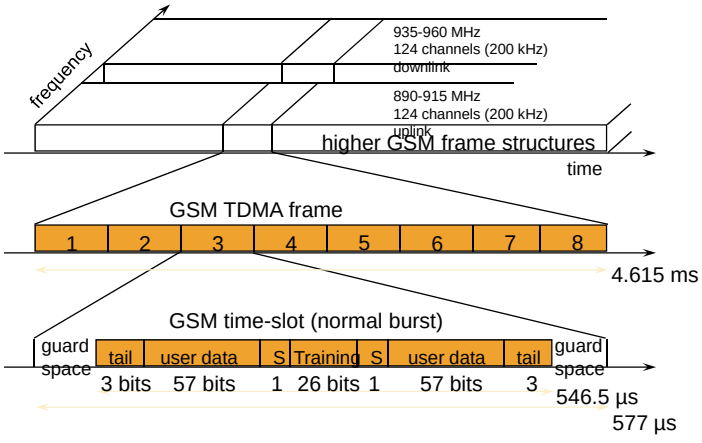
GSM: TDMA/FDMA



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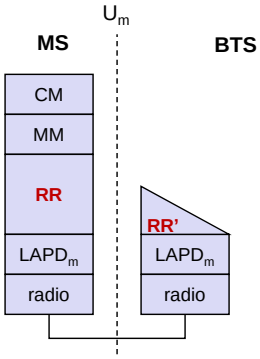
GSM Protocol layers for signaling



CM = call management
- Call control, SMS, supplementary service
- In-band tone

MM = mobility management

RR = radio resource management

LAPD = link access for D-channel (ISDN)
- Reliable data transfer over connections

Physical layer
- Error detection/correction
- Channel coding (incl voice activity detection, comfort noise)

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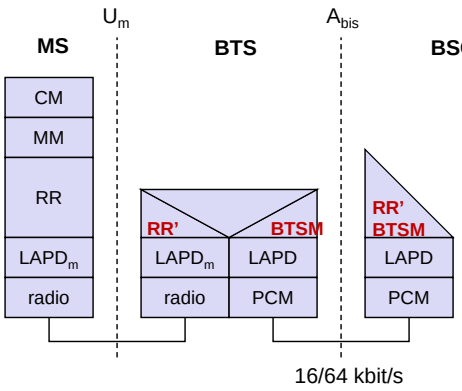
GSM Protocol layers for signaling

BTSM = base transceiver station management

PCM = pulse code modulation



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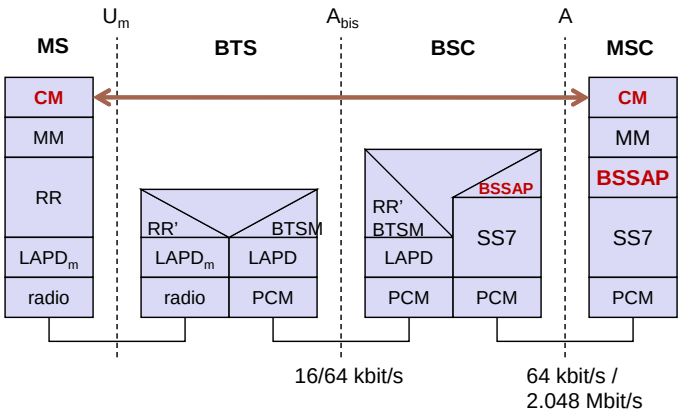
GSM Protocol layers for signaling

CM = call management

BSSAP = base station subsystem application part



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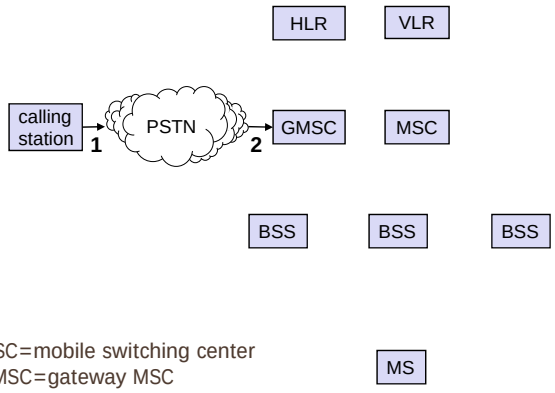
Mobile Terminated Call

- 1: calling a GSM subscriber
- 2: forwarding call to GMSC



MSC=mobile switching center
GMSC=gateway MSC
MSRN=mobile station request number

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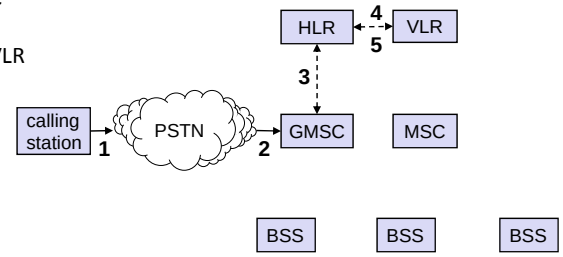
Mobile Terminated Call

- 1: calling a GSM subscriber
- 2: forwarding call to GMSC
- 3: signal call setup to HLR
- 4, 5: request MSRN from VLR



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MS

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Mobile Terminated Call

- 1: calling a GSM subscriber
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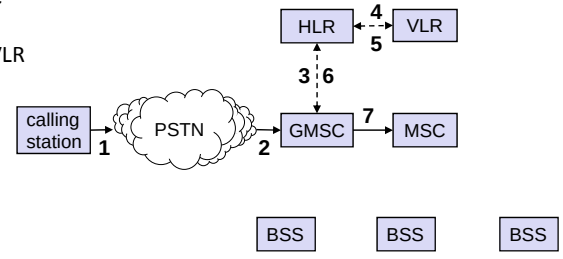
- 4, 5: request MSRN from VLR
- 6: forward responsible MSC to GMSC
- 7: forward call to current MSC



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MS

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Mobile Terminated Call

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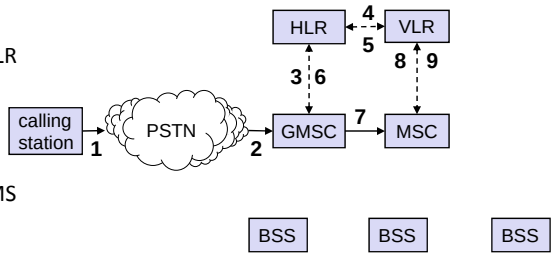
- 6: forward responsible MSC to GMSC
- 7: forward call to
- current MSC
- 8, 9: get current status of MS



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MS

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Mobile Terminated Call

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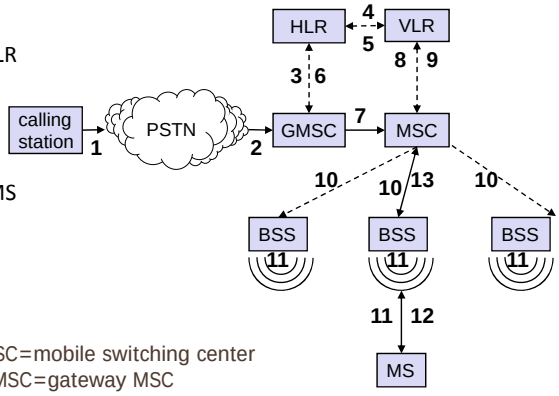
- 6: forward responsible MSC to GMSC
- 7: forward call to
- current MSC
- 8, 9: get current status of MS
- 10, 11: paging of MS
- 12, 13: MS answers



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MS

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Mobile Terminated Call

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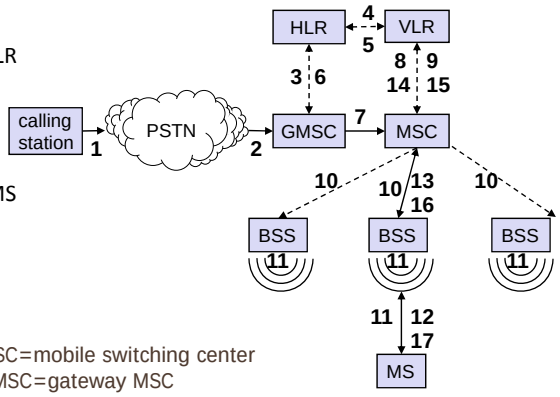
- 7: forward call to
- current MSC
- 8, 9: get current status of MS
- 10, 11: paging of MS
- 12, 13: MS answers
- 14, 15: security checks
- 16, 17: set up connection



MSC=mobile switching center
GMSC=gateway MSC
MSRN=mobile station request number

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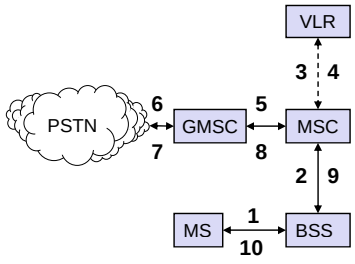
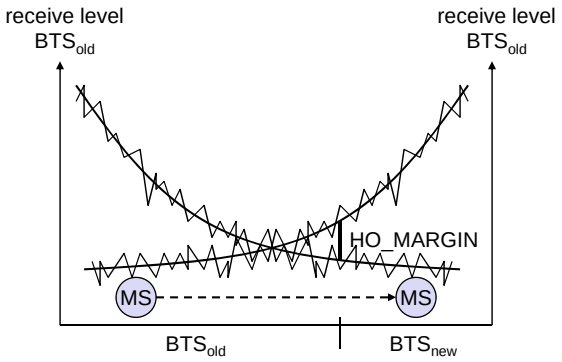
Mobile Originated Call

- 1, 2: connection request
- 3, 4: security check
- 5-8: check resources (free circuit)
- 9-10: set up call



44

Handover decision



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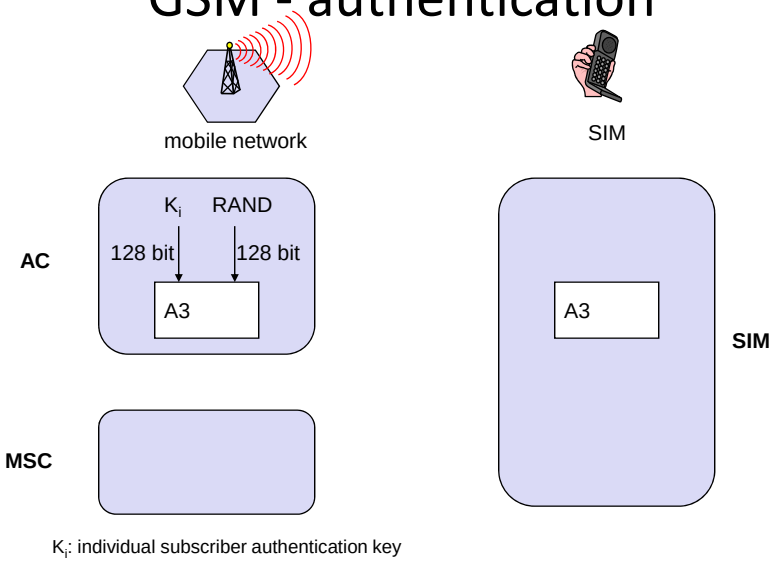
Security in GSM

- Security services
  - access control/authentication
    - user ⇔ SIM (Subscriber Identity Module): secret PIN
    - SIM ⇔ network: challenge response
  - 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)

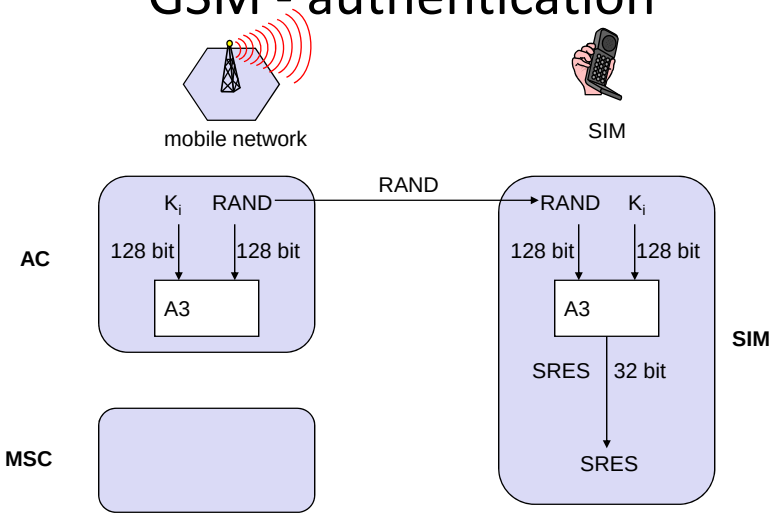
“secret”:
• A3 and A8 available via the Internet
• network providers can use stronger mechanisms

GSM - authentication



K_i: individual subscriber authentication key

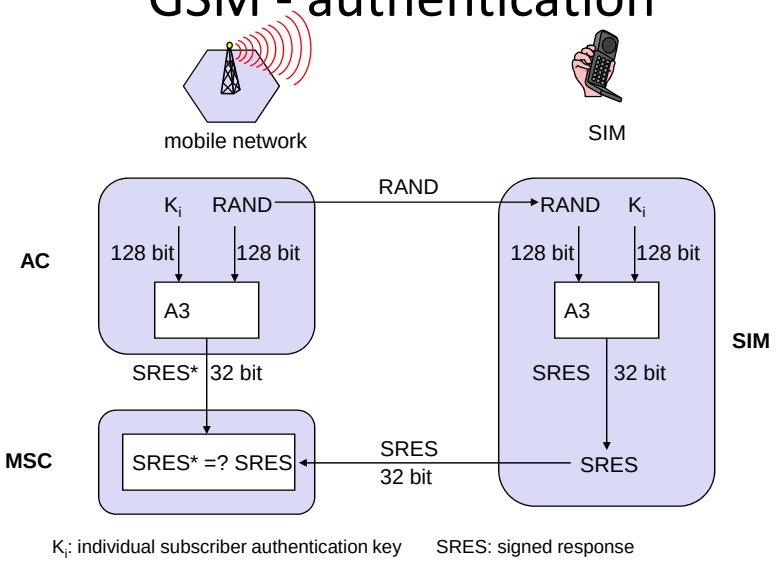
GSM - authentication



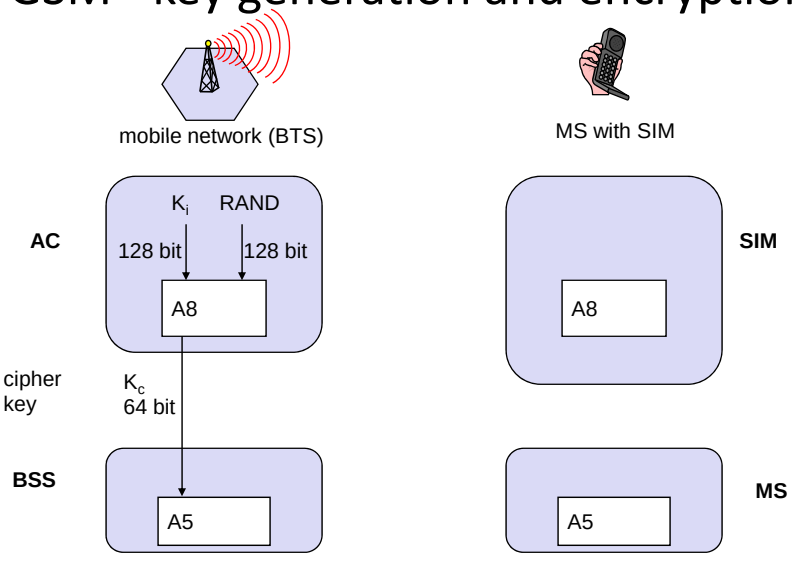
K_i: individual subscriber authentication key

SRES: signed response

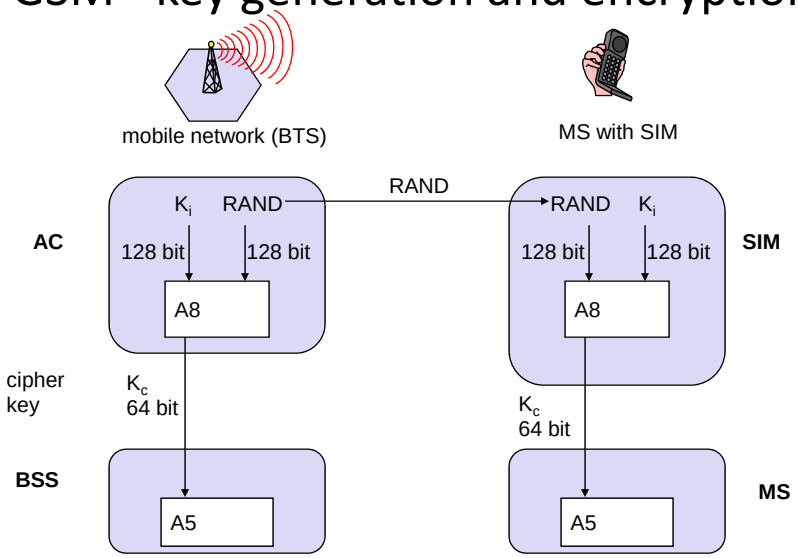
GSM - authentication



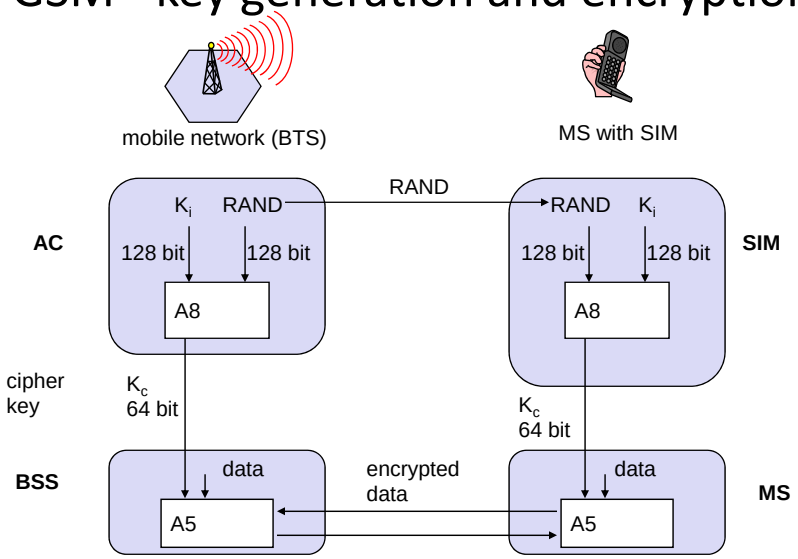
GSM - key generation and encryption



GSM - key generation and encryption



GSM - key generation and encryption



GPRS: GENERAL PACKET RADIO SERVICE

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General Packet Radio Service (GPRS)

- GSM Data transmission standardized with only 9.6 kb/s
  - Circuit-switched
  - not enough for Internet and multimedia applications
  - High-speed circuit-switched data (HSCSD): combine time slots
- GPRS supports rate up to ~170kb/s
  - packet switching
  - using free slots only if data packets ready to send (e.g., 50 kbit/s using 4 slots temporarily)
  - Transition to UMTS

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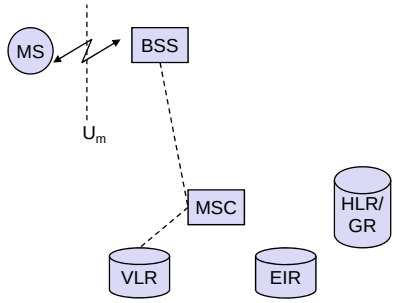
GPRS Architecture and Interfaces

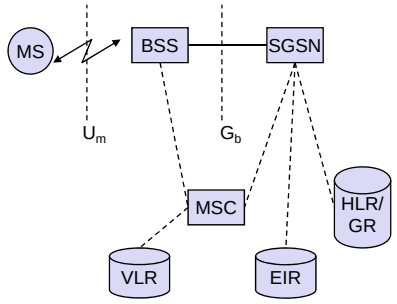
GR = GPRS Register



55

GPRS Architecture and Interfaces

GSN = GPRS Support Nodes
SGSN = Serving GSN (serving MS)
GR = GPRS Register



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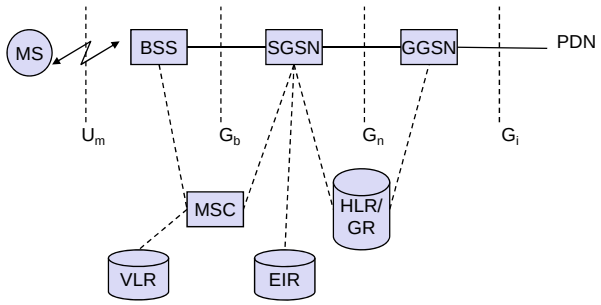
GPRS Architecture and Interfaces

GSN = GPRS Support Nodes
GGSN = Gateway GSN
SGSN = Serving GSN (serving MS)
GR = GPRS Register



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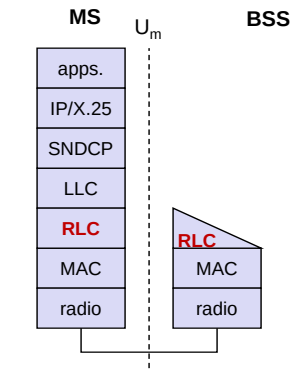
GPRS protocol architecture



RLC = radio link control

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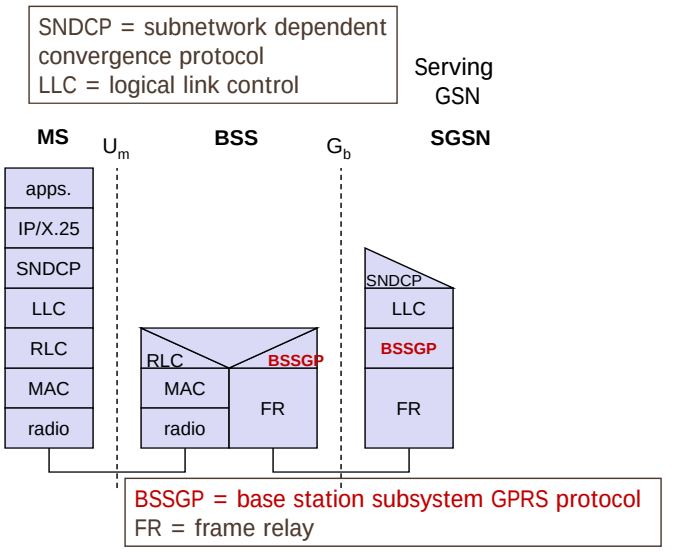
GPRS protocol architecture



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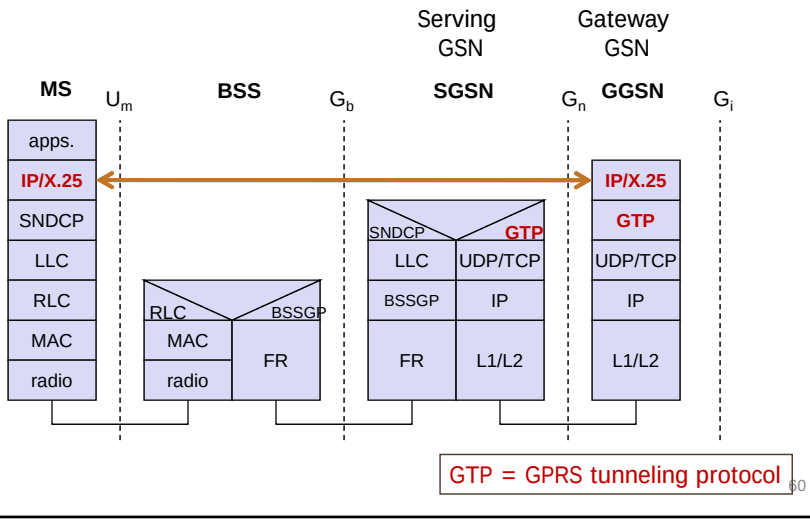
GPRS protocol architecture



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UMTS: UNIVERSAL MOBILE TELECOMM SYSTEM

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Universal Mobile Telecomm System (UMTS)

- Proposals for IMT-2000 (International Mobile Telecommunications)
  - UWC-136, cdma2000, WP-CDMA
  - UMTS from ETSI
- UMTS
  - UTRA: UMTS/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)
  - 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

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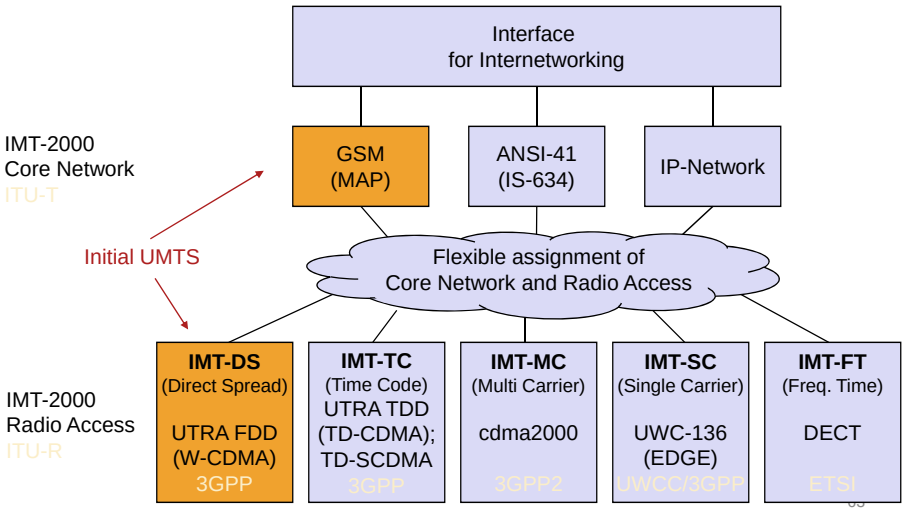
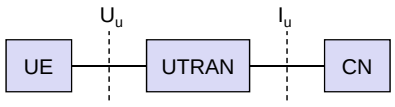
IMT-2000 Family



UMTS Architecture

- 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



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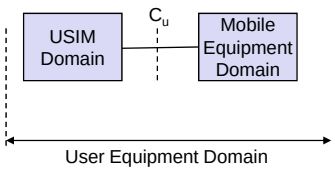
UMTS Domains and Interfaces I



Universal Subscriber Identity Module (USIM)
• Functions for encryption and authentication of users

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

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

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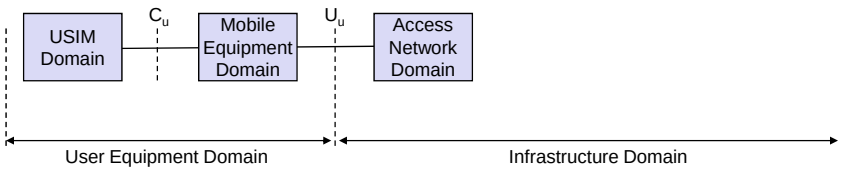
UMTS Domains and Interfaces II

Access Network Domain
• Access network dependent functions



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

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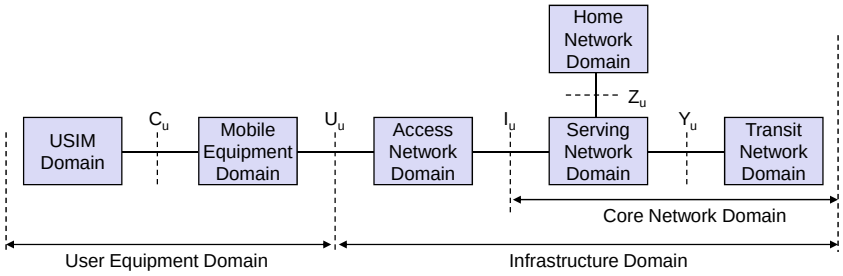
UMTS Domains and Interfaces III



- Access Network Domain
  - Access network dependent functions
- Core Network Domain
  - Access network independent functions

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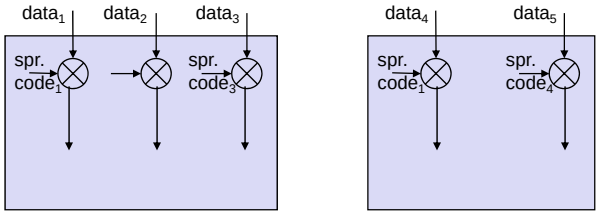
Spreading and scrambling of user data I

- 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



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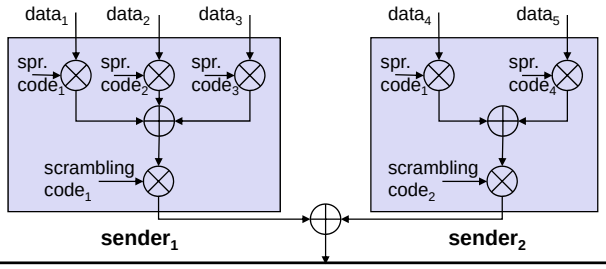
Spreading and scrambling of user data II

- 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



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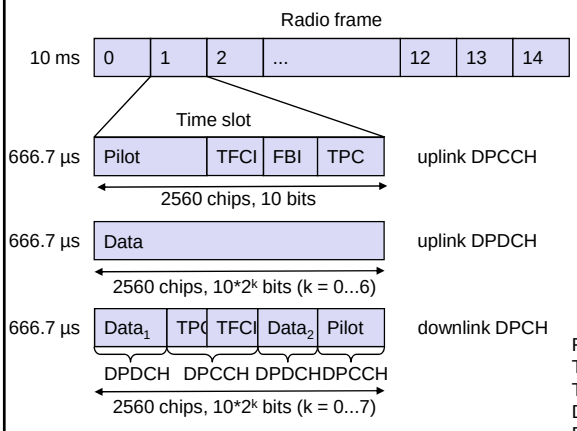
UMTS FDD frame structure

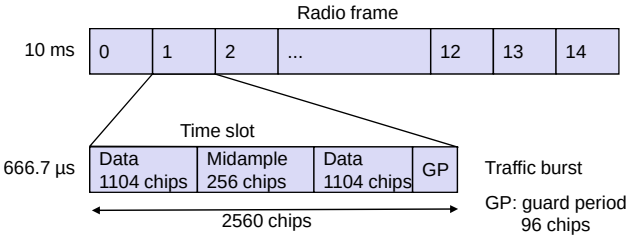


W-CDMA
- 1920-1980 MHz uplink
- 2110-2170 MHz downlink
- chipping rate: 3.840 Mchip/s
- soft handover
- QPSK
- complex power control (1500 power control cycles/s)
- spreading: UL: 4-256; DL:4-512

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

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

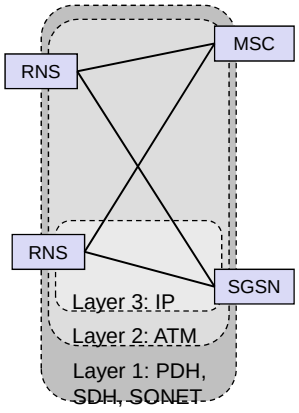
UMTS TDD frame structure (burst type 2)



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)

Core network: protocols

RNS = radio network subsystem
UTRAN = universal/UMTS terrestrial radio access network
CN = core network



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Core network: protocols

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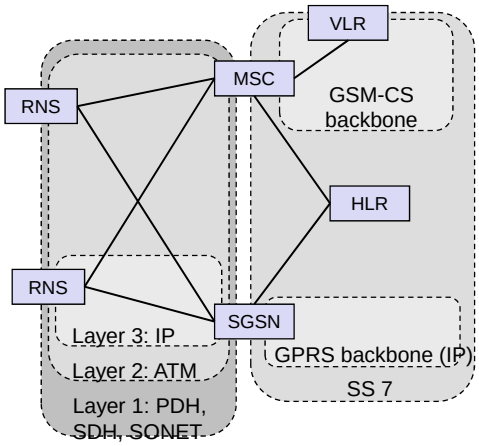

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Core network: protocols

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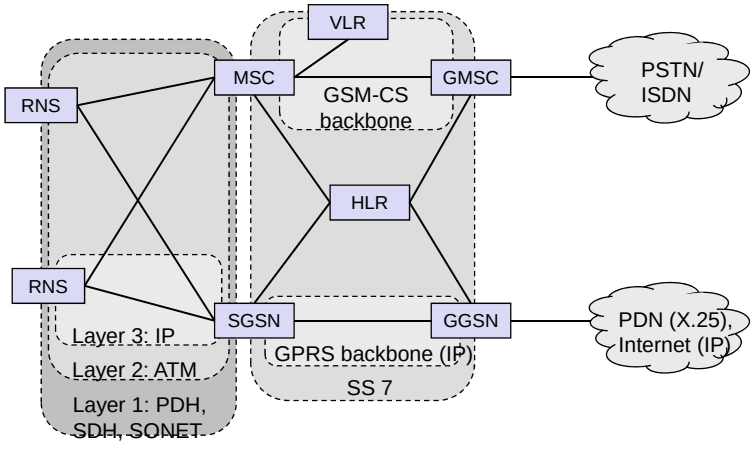

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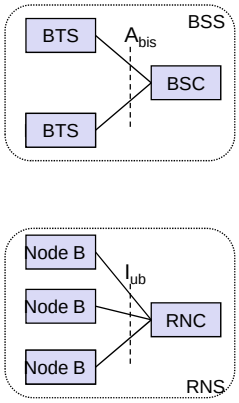
Core network: architecture

BSS = base station subsystem



RNS = radio network subsystem

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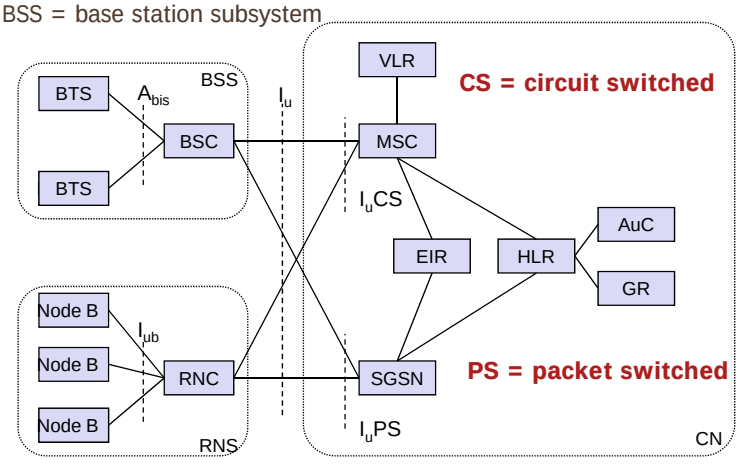
Core network: architecture

BSS = base station subsystem



RNS = radio network subsystem

CN = core network

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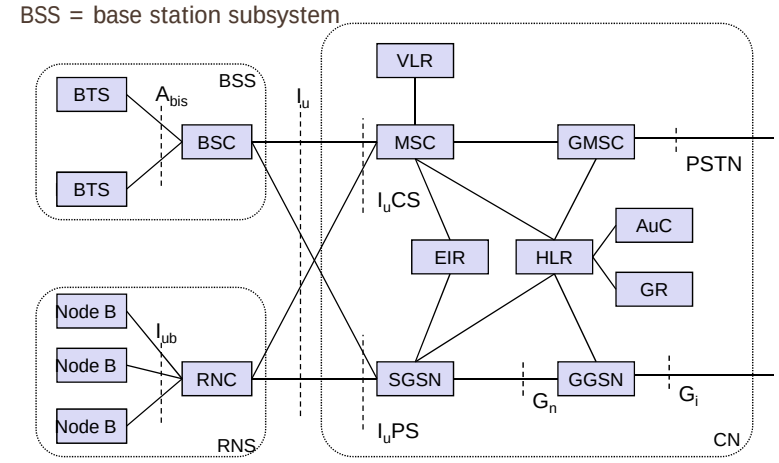
Core network: architecture



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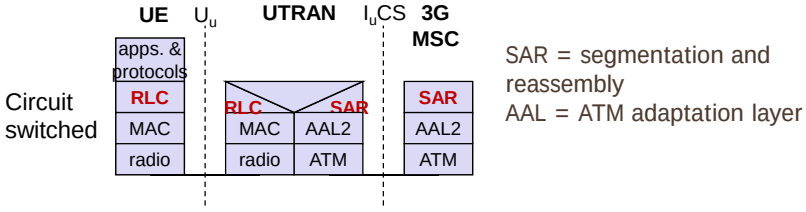
UMTS protocol stacks (user plane)



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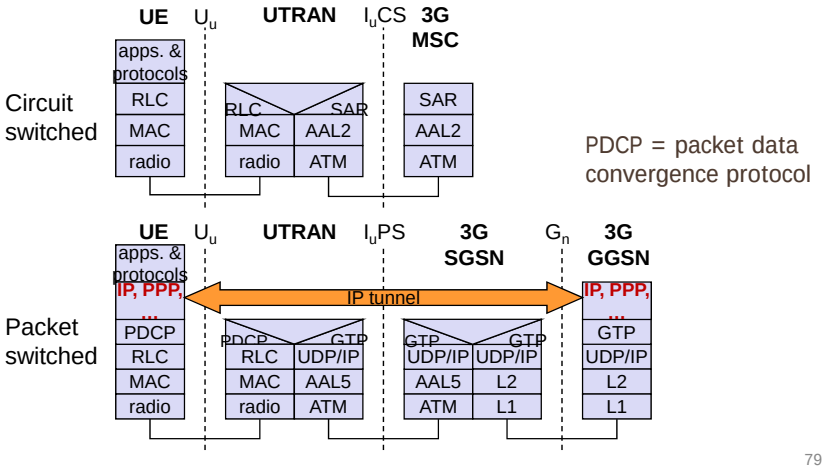
UMTS protocol stacks (user plane)



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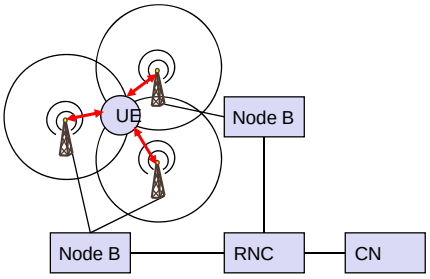
Support of mobility: macro diversity



- 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

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

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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

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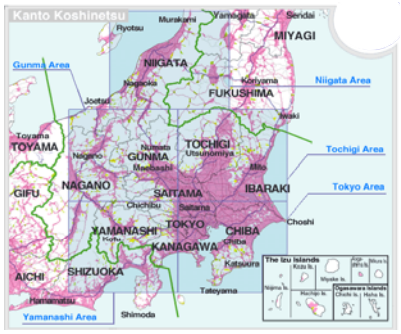
Example 3G Network: Japan



FOMA (Freedom Of Mobile multimedia Access) in Japan

Examples for FOMA phones

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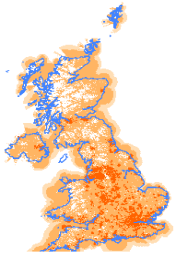
UMTS in Europe

Vodafone/Germany



Orange/UK

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Other enhancements

- GSM
  - MMS: transmission of images, video clips, audio (WAP 2.0)
  - EDGE (Enhanced Data Rates for Global Evolution)
    - 8-PSK instead of GMSK, up to 384 kbit/s
    - new modulation and coding schemes for GPRS ➔ EGPRS
- UMTS
  - 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
    - 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

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US Cell Phones

- IS-54: TDMA system
  - Based on analog AMPS
  - Incorporated ideas from GSM
- IS-136: NA-TDMA, D-AMPS
  - Digital control channels, more efficient
- IS-95: cdmaOne
  - Originally a 2G improvement over TDMA
  - Ideas of CDMA integrated into all 3G systems
  - Cdma2000 EV-DO competing with W-CDMA/UMTS

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Evolutionary Paths

- Europe:
  - GSM ⇒ GPRS ⇒ UMTS
- USA
  - TDMA ⇒ EDGE ⇒ UMTS
  - CMDA2000 EVDO
- Japan
  - W-CDMA (UMTS, FOMA), CDMA2000
- China
  - W-CDMA, CDMA2000, TD-CDMA/SCDMA

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LTE: LONG TERM EVOLUTION (AND BEYOND)

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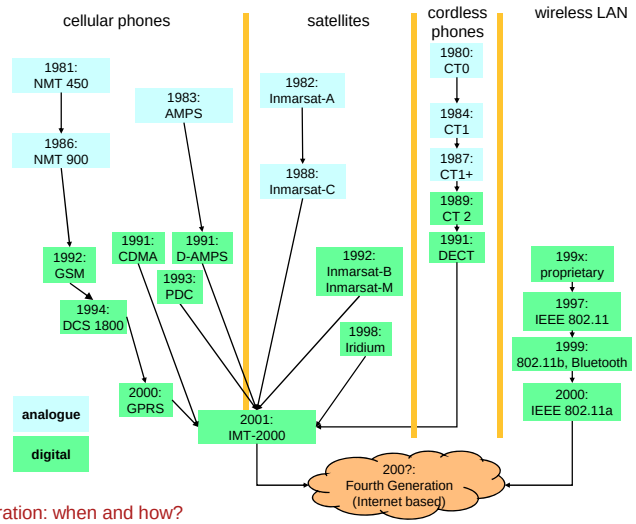
Evolution of networks



4G – fourth generation: when and how?

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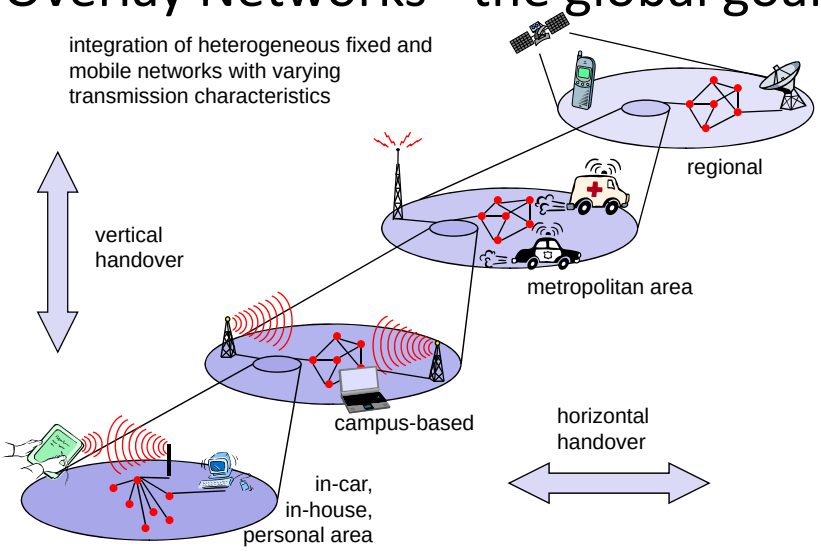
Overlay Networks - the global goal

integration of heterogeneous fixed and mobile networks with varying transmission characteristics



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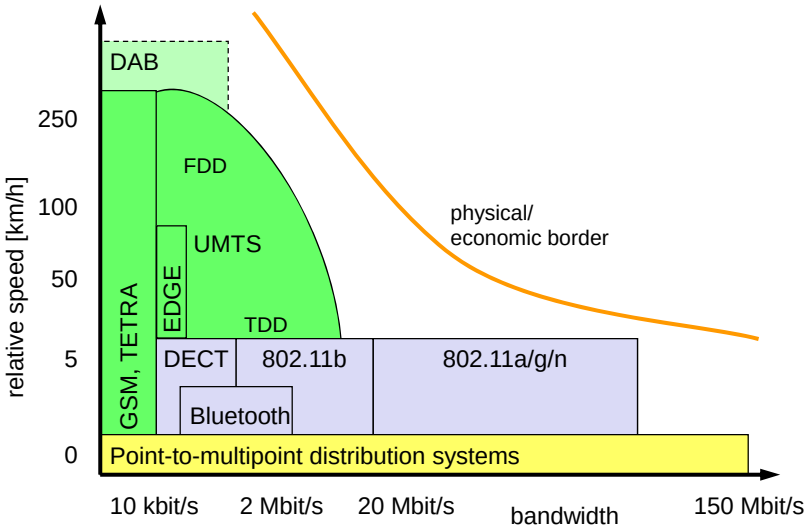
Wireless access technologies



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Key features of future mobile and wireless networks

- Improved radio technology and antennas
  - smart antennas, beam forming, multiple-input multiple-output (MIMO)
    - space division multiplex to increase capacity, benefit from multipath
  - software defined radios (SDR)
    - use of different air interfaces, download new modulation/coding/...
    - requires a lot of processing power (UMTS RF 10000 GIPS)
  - dynamic spectrum allocation
    - spectrum on demand results in higher overall capacity
- Core network convergence
  - IP-based, quality of service, mobile IP
- Ad-hoc technologies
  - spontaneous communication, power saving, redundancy
- Simple and open service platform
  - intelligence at the edge, not in the network (as with IN)
  - more service providers, not network operators only

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Long Term Evolution (LTE)

- Initiated in 2004, 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
- Downlink: OFDM, QPSK, 16QAM, and 64QAM
- Uplink: SC-FDMA, BPSK, QPSK, 8PSK and 16QAM
- Channel bandwidths between 1.25 and 20 MHz
- 4 x Increased Spectral Efficiency, 10 x Users Per Cell (MIMO), reduced RTT
- FDD and TDD supported, co-existence with earlier 3GPP standards incl. handover
- Core network: System Architecture Evolution (SAE), optimizing it for packet mode and in particular for the IP-Multimedia Subsystem (IMS)

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LTE advanced

- GSM – UMTS - LTE
  - LTE advanced as candidate for IMT-advanced
- Worldwide functionality & roaming
- Compatibility of services
- Interworking with other radio access systems
- Enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 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.

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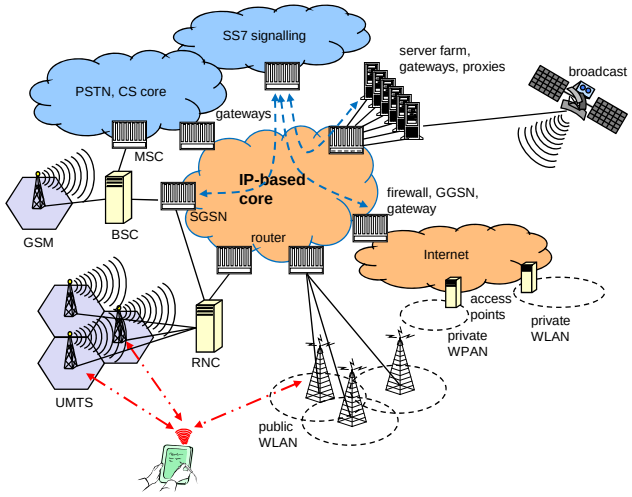
Example IP-based 4G/Next G/… network



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Potential problems

- Quality of service
  - Today's Internet is best-effort
  - Integrated services did not work out
  - Differentiated services have to prove scalability and manageability
  - What about the simplicity of the Internet? DoS attacks on QoS?
- Security of the network
- Reliability, maintenance
  - Is Internet technology really cheaper as soon as high reliability (99.9999%) is required plus all features are integrated
- Missing charging models
  - Charging by technical parameters (volume, time) is not reasonable
  - Pay-per-application may make much more sense

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