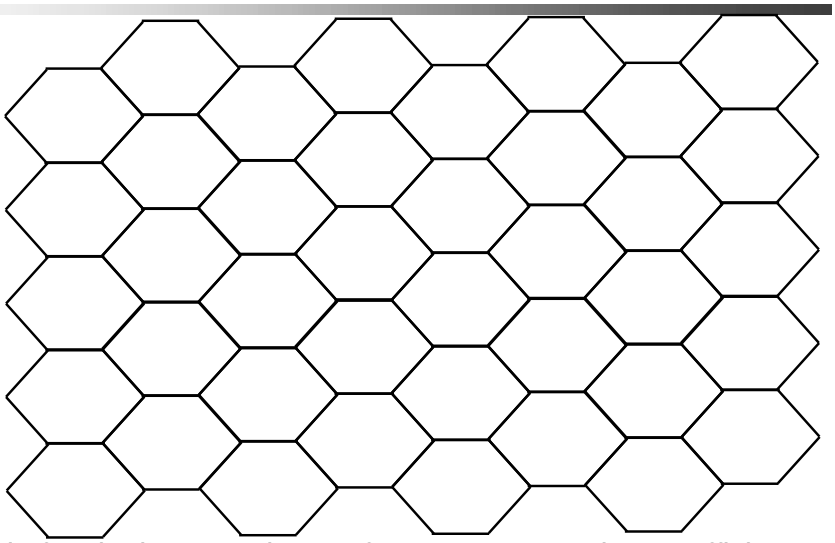
Cellular Systems

- Concept
- GSM
- IS-95

Adapted from J. Schiller, "Mobile Communications", Chapter 4

Cellular Concept



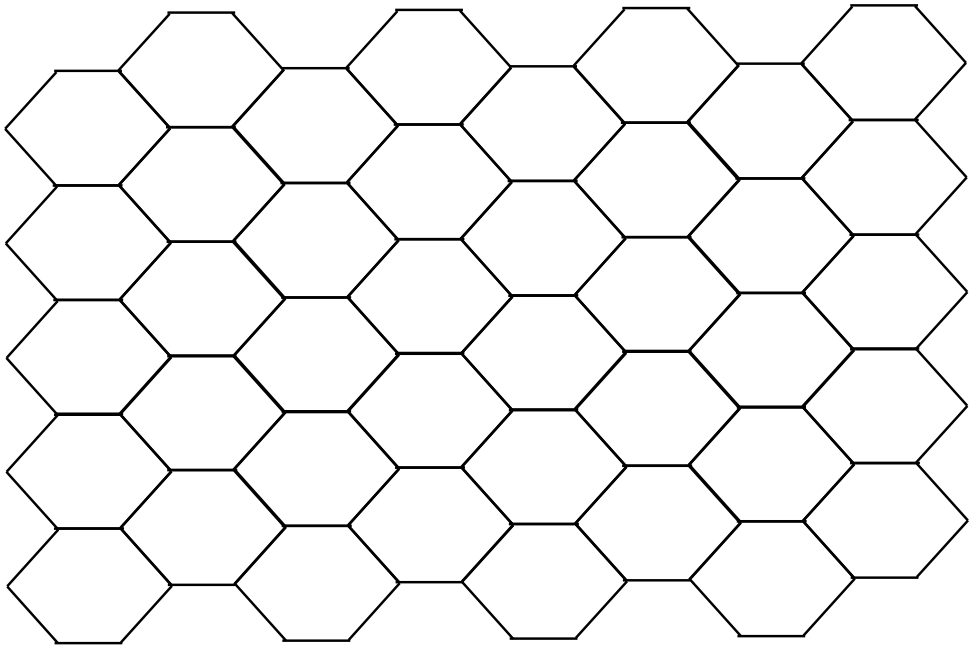
Several small cells instead of a single transmitter=> frequency reuse: better efficiency
Fixed Channel Allocation:

Cluster of size $N = i^2+ij+j^2$; and $D = \text{sqrt}(3N)R$

R cell radius and

D distance at which a frequency can be reused with acceptable interference

Examples



Capacity in Cellular Systems

Blocking Probability (Grade Of Service): *Erlang B* formula

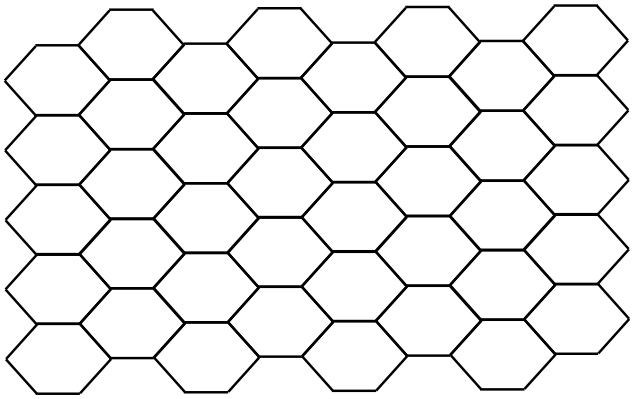
$$GOS = \frac{(\lambda T)^C / C!}{\sum_{n=0}^{C} (\lambda T)^n / n!}$$

λ: calls arrival rate; T: calls average duration (service time: $1/\mu$)

Increasing Capacity

Cells splitting

Sectoring: 3 sectoring (120^0) or 6 sectoring



GSM: Overview

GSM

- formerly: Groupe Spéciale Mobile (founded 1982)
- now: Global System for Mobile Communication
- today many providers all over the world use GSM (more than 130 countries in America, Asia, Africa, Europe, Australia)
- 500 million subscribers

Performance characteristics of GSM

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

- electromagnetic radiation

- abuse of private data possible
- roaming profiles accessible

- high complexity of the system (over 5000 pages)

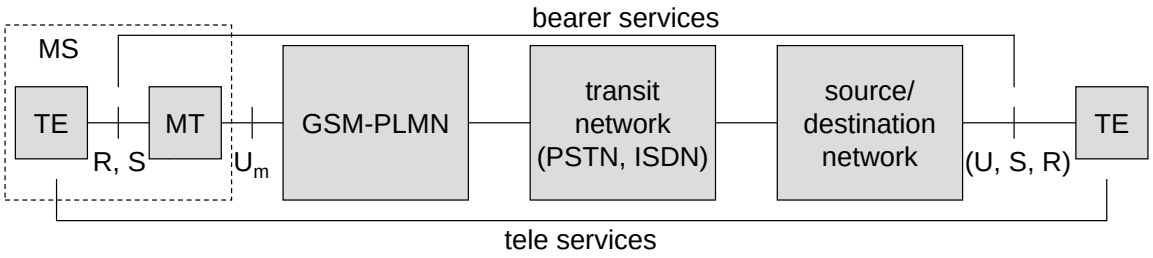
GSM: Mobile Services

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

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 (911); mandatory for all service providers; free of charge; connection with the highest priority (preemption of other connections possible)
  - Multinumbering
    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 using the signaling channel, thus allowing simultaneous use of basic services and SMS

Supplementary services

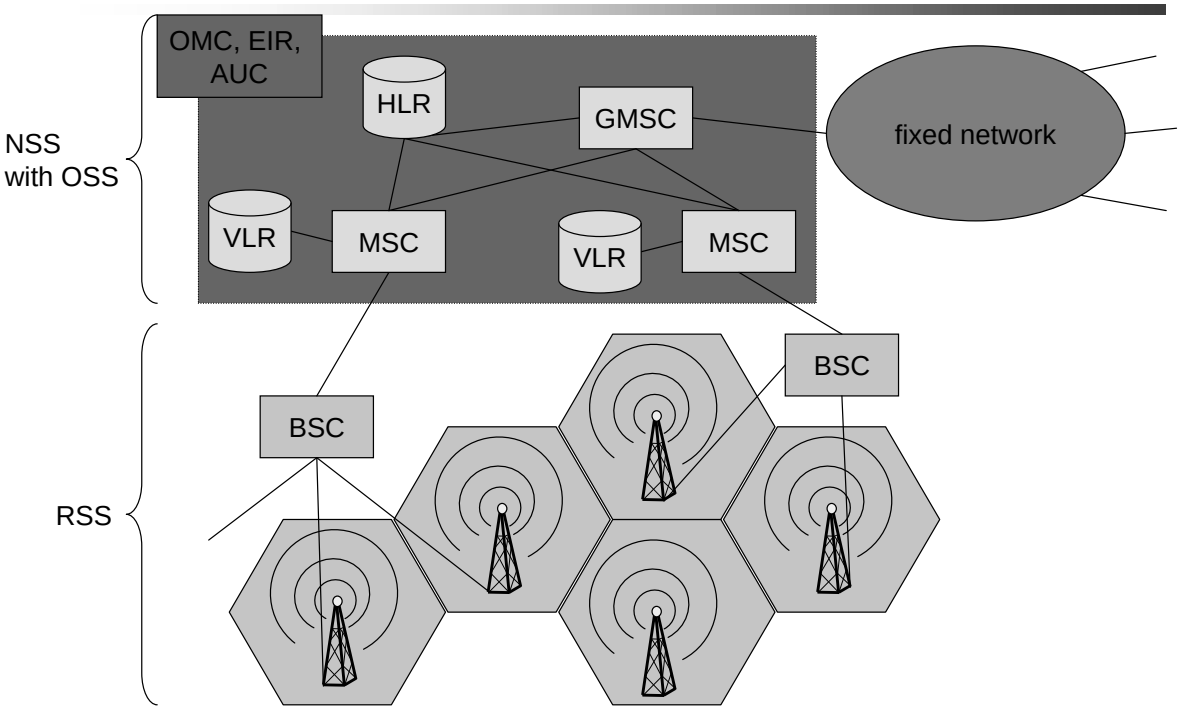
- Services in addition to the basic services, cannot be offered stand-alone
- Similar to ISDN services besides lower bandwidth due to the radio link
- May differ between different service providers, countries and protocol versions
- Important services
  - identification: forwarding of caller number
  - suppression of number forwarding
  - automatic call-back
  - conferencing with up to 7 participants
  - locking of the mobile terminal (incoming or outgoing calls)
  - ...

Architecture of the GSM system

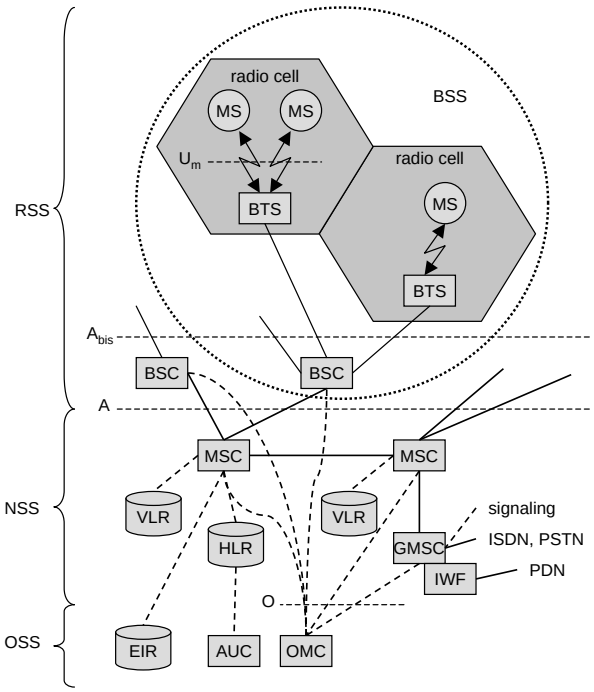
GSM is a PLMN (Public Land Mobile Network)

- 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

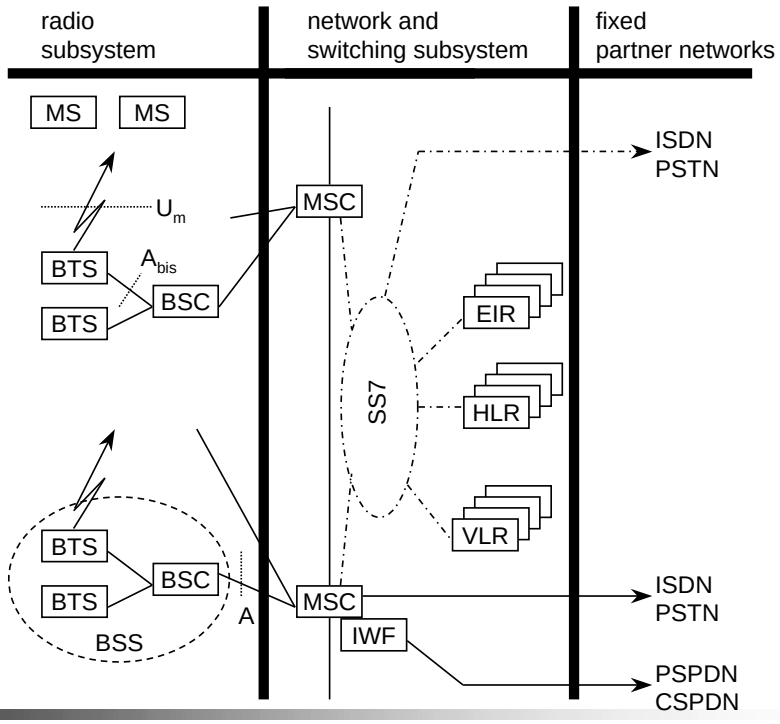
GSM: overview



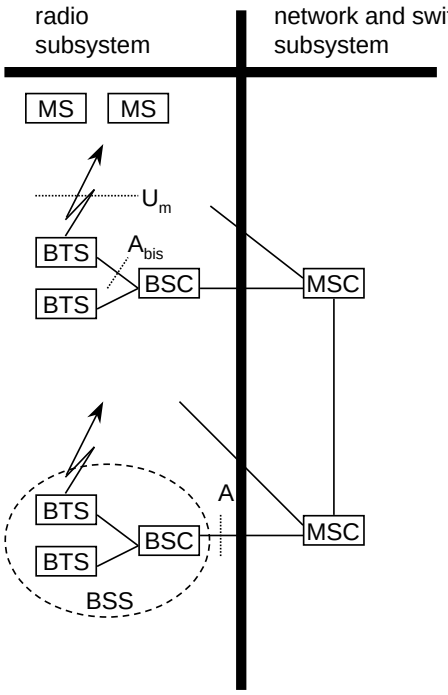
GSM: elements and interfaces



GSM: system architecture



System architecture: radio subsystem



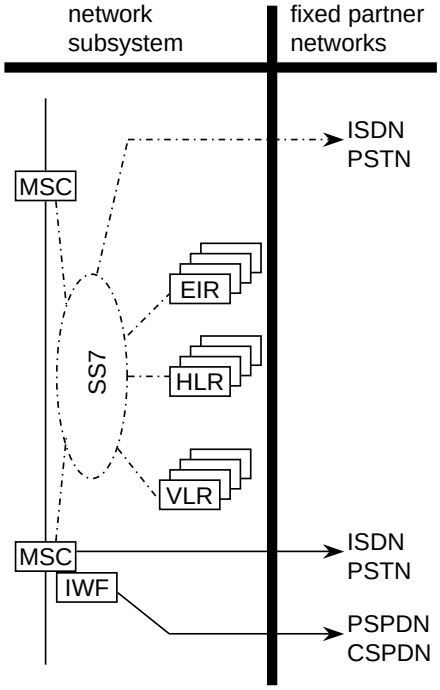
Components

- *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 *R*egister)
- *VLR* (Visitor Location *R*egister)
- *EIR* (Equipment Identity Register)

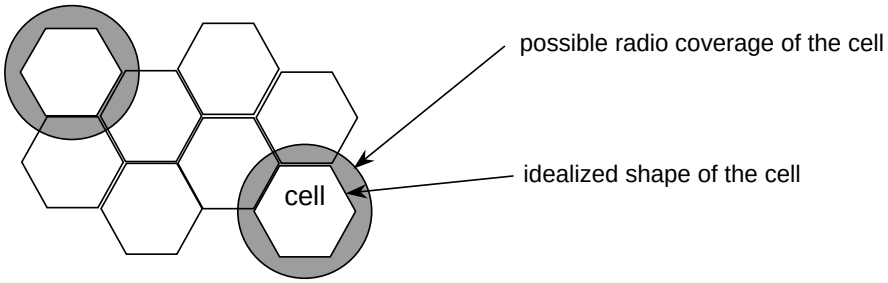
Radio subsystem

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 300 feet up to 20 miles 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

Base Transceiver Station and Base Station Controller

Tasks of a BSS are distributed over BSC and BTS

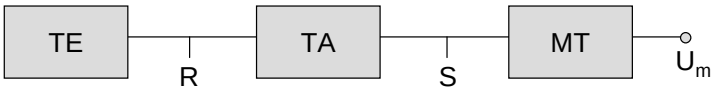
- BTS comprises radio specific functions
- BSC is the switching center for radio channels

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 (U_m)
  - 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



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 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

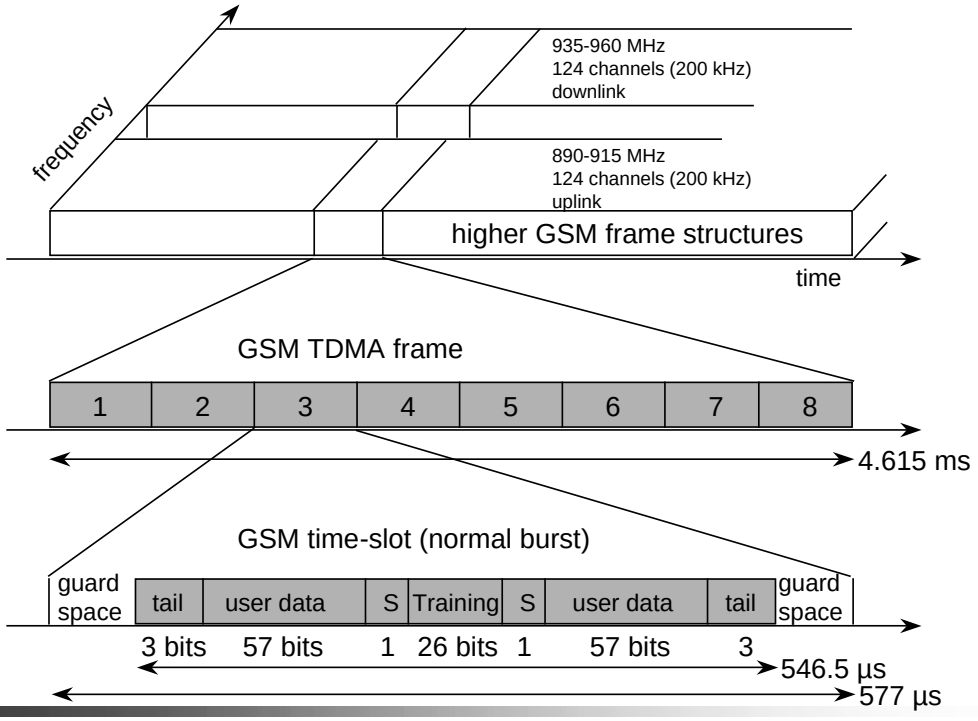
- Functions of a MSC
  - specific functions for paging and call forwarding
  - termination of SS7 (signaling system no. 7)
  - mobility specific signaling
  - location registration and forwarding of location information
  - provision of new services (fax, data calls)
  - support of short message service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

Operation subsystem

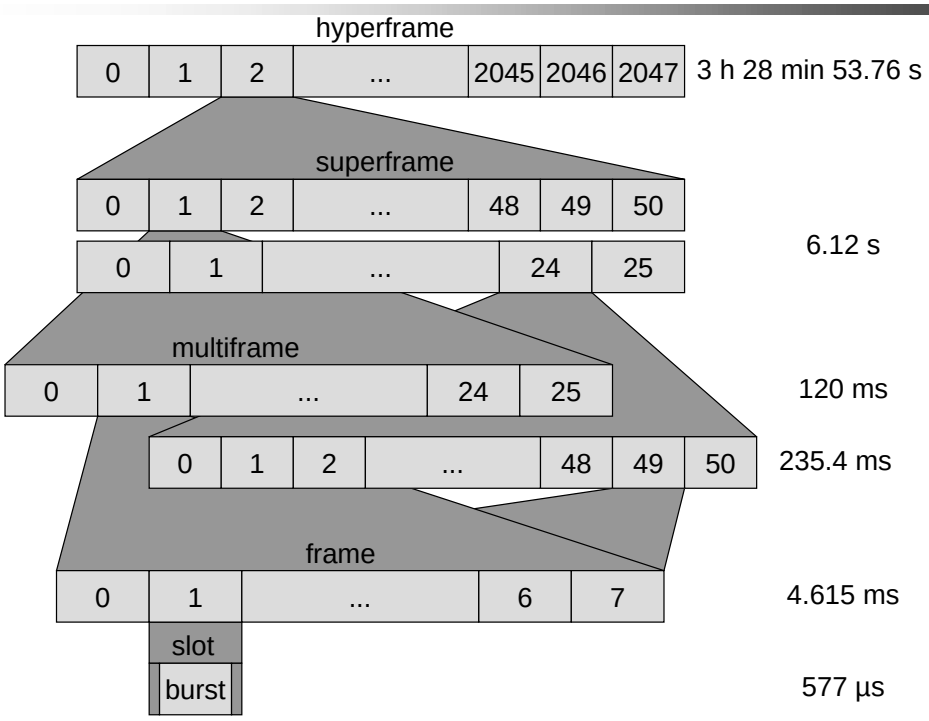
The OSS (Operation Subsystem) enables centralized operation, management, and maintenance of all GSM subsystems

- 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

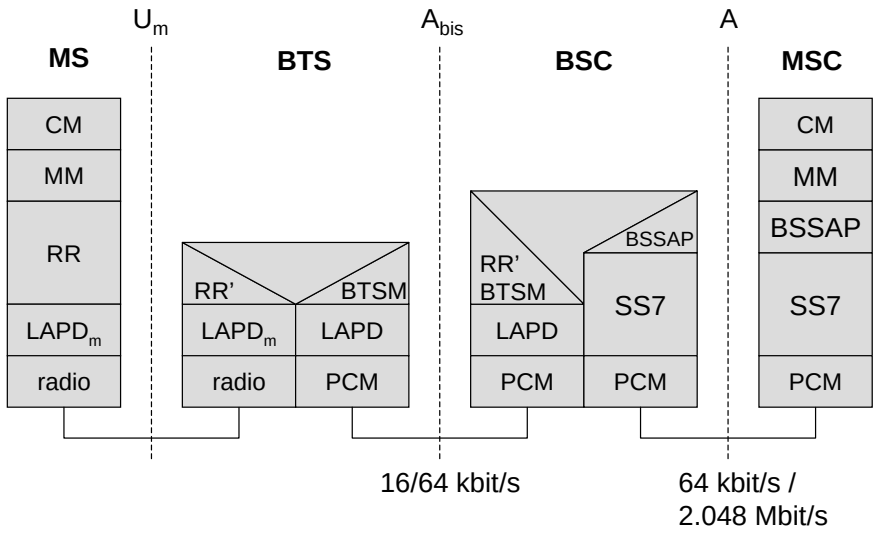
GSM - TDMA/FDMA



GSM hierarchy of frames

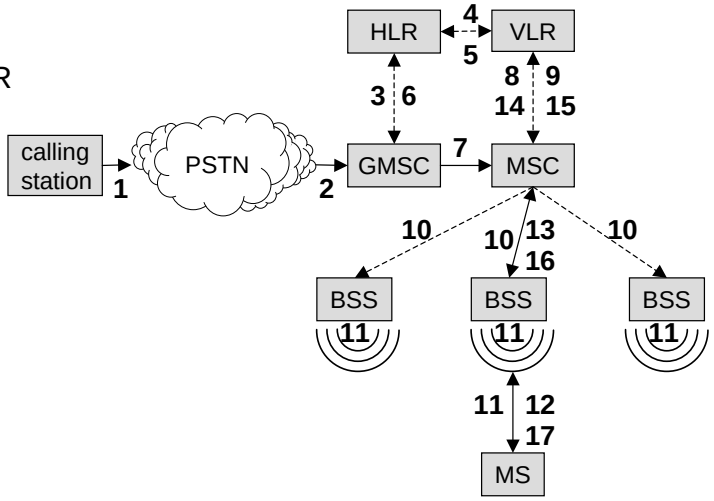


GSM protocol layers for signaling



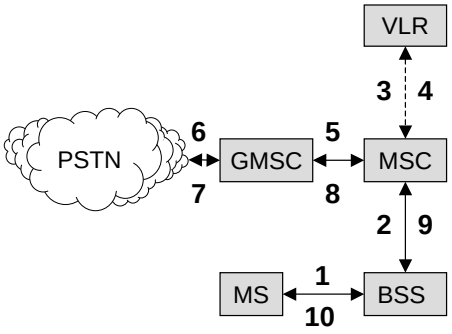
Mobile Terminated Call

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

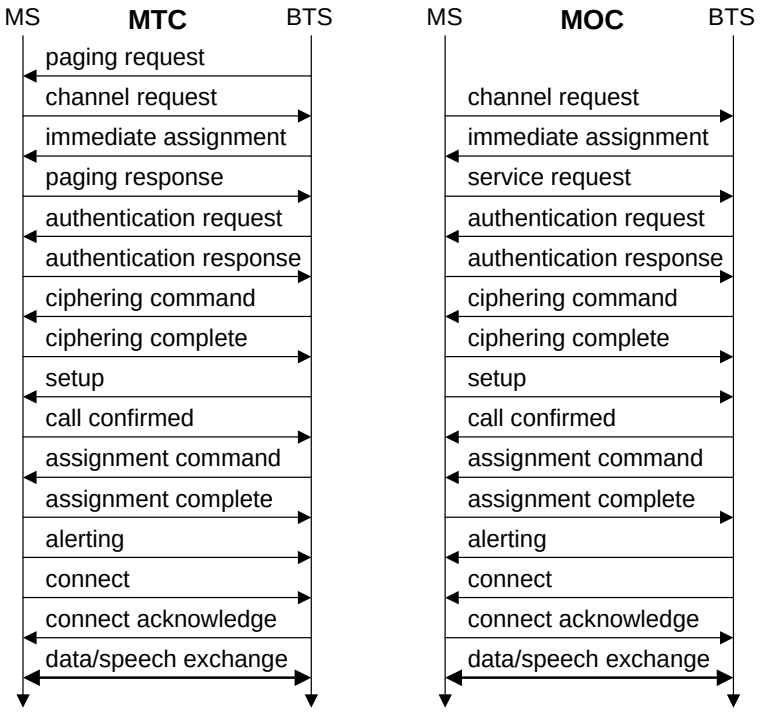


Mobile Originated Call

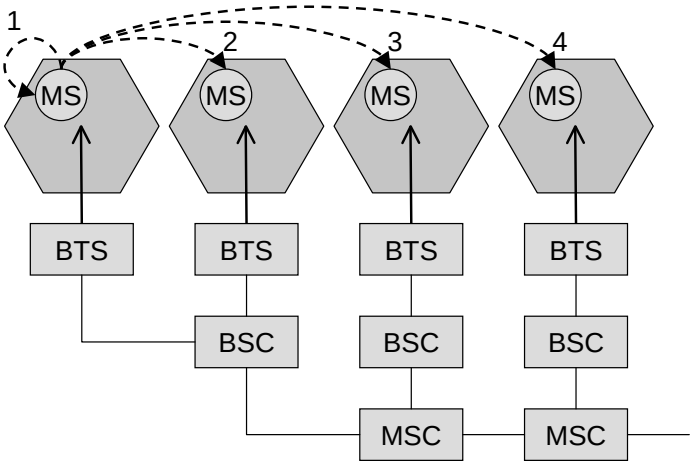
1, 2: connection request
3, 4: security check
5-8: check resources (free circuit)
9-10: set up call



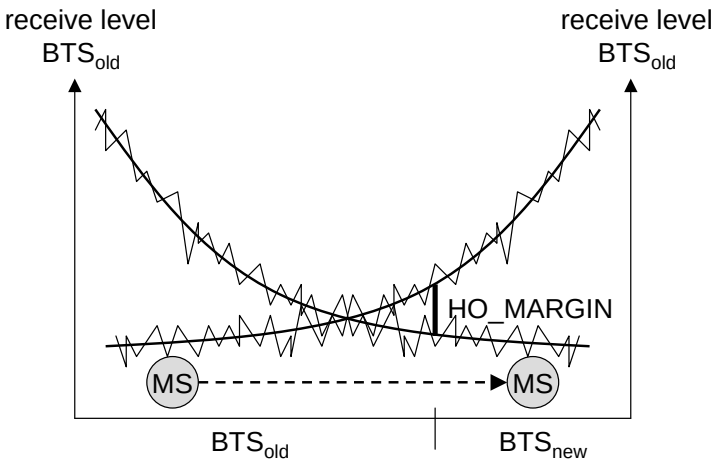
MTC/MOC



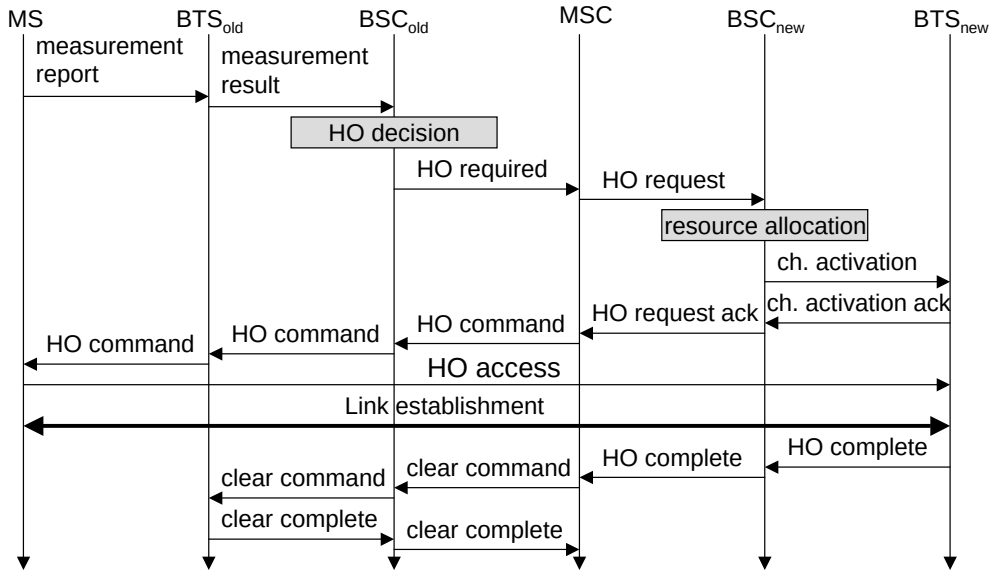
4 types of handover



Handover decision



Handover procedure



Security in GSM

Security services

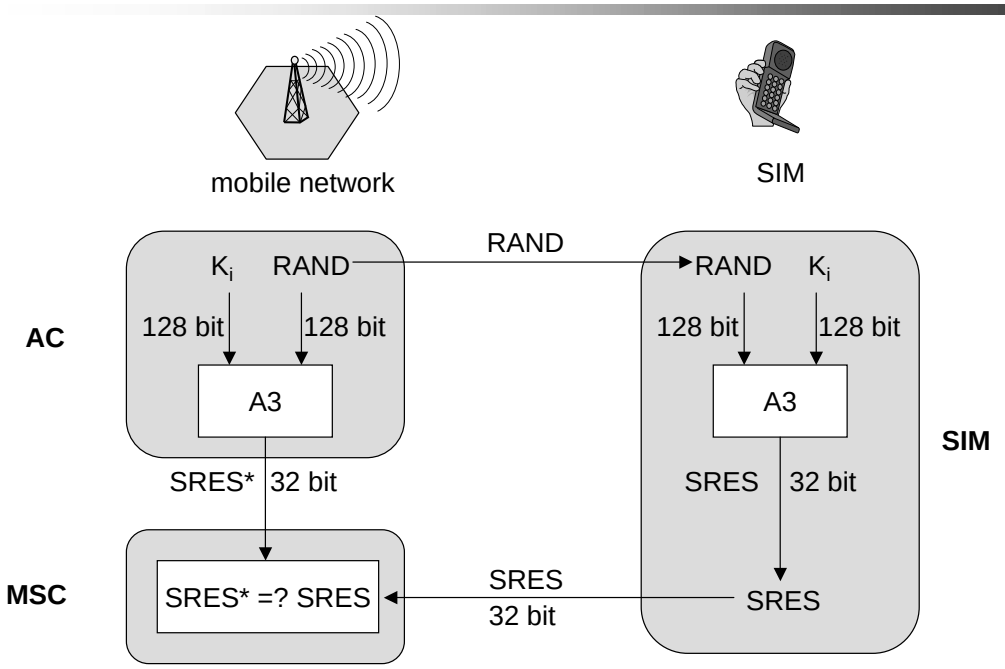
- access control/authentication
  - user ⌫ SIM (Subscriber Identity Module): secret PIN (personal identification number)
  - SIM ⌫ network: challenge response method
- confidentiality
  - voice and signaling encrypted on the wireless link (after successful authentication)
- anonymity
  - temporary identity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

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

3 algorithms specified in GSM

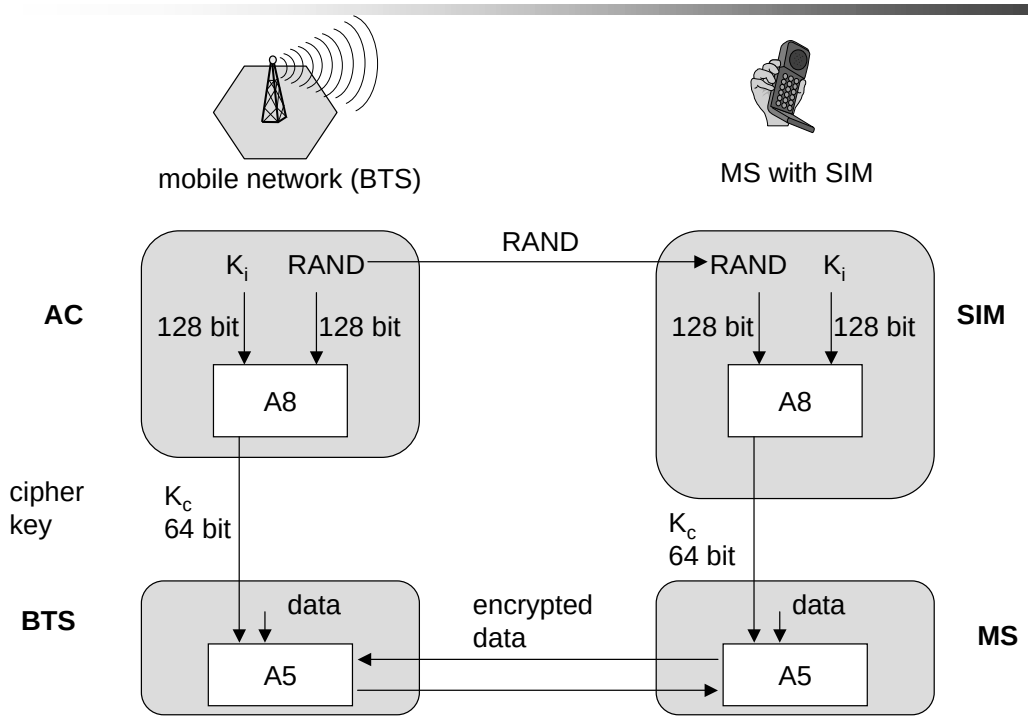
- A3 for authentication ("secret", open interface)
- A5 for encryption (standardized)
- A8 for key generation ("secret", open interface)

GSM - authentication



K_i: individual subscriber authentication key SRES: signed response

GSM - key generation and encryption



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)

- already standardized
- bundling of several time-slots to get higher AIUR (Air Interface User Rate) (e.g., 57.6 kbit/s using 4 slots, 14.4 each)
- 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., 115 kbit/s using 8 slots temporarily)
- standardization 1998, introduced 2000
- advantage: one step towards 3G, more flexible
- disadvantage: more investment needed

GPRS network elements

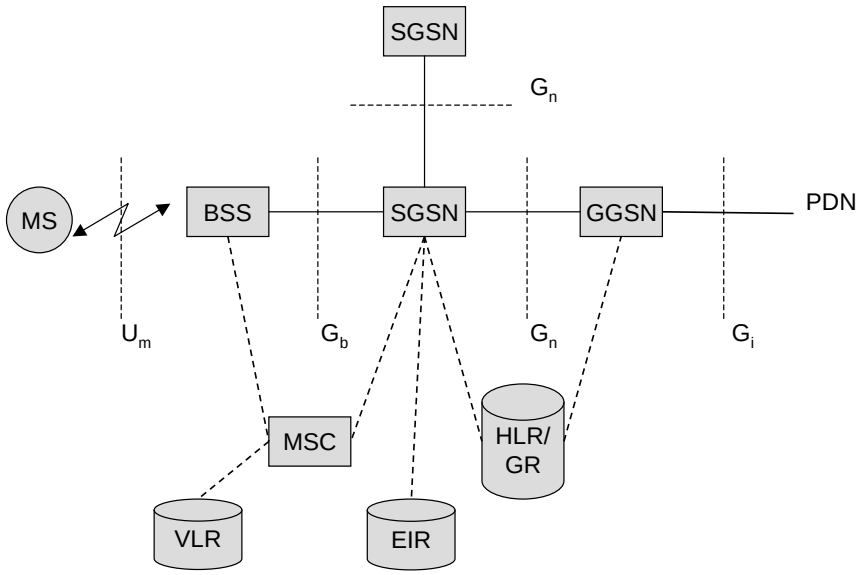
- GSN (GPRS Support Nodes): GGSN and SGSN
- GGSN (Gateway GSN)
  - interworking unit between GPRS and PDN (Packet Data Network)
- SGSN (Serving GSN)
  - supports the MS (location, billing, security)
- GR (GPRS Register)
  - user addresses

GPRS quality of service

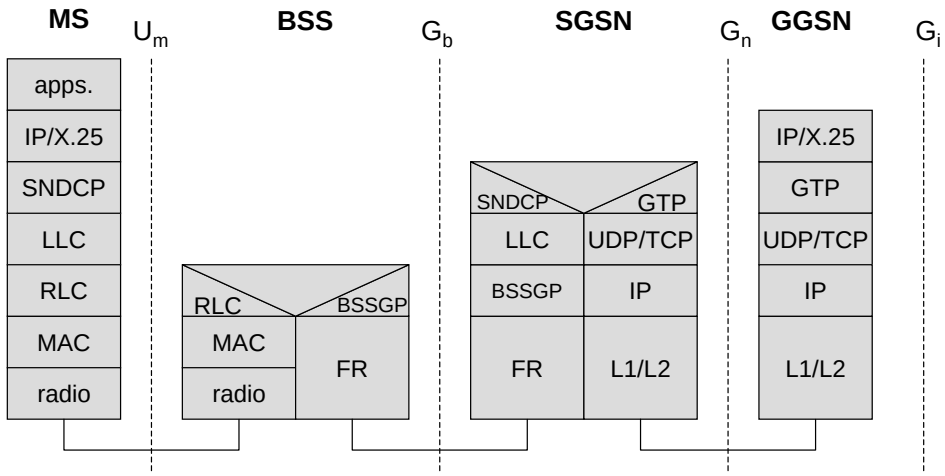
Reliability class	Lost SDU probability	Duplicate SDU probability	Out of sequence SDU probability	Corrupt SDU probability
1	10^{-9}	10^{-9}	10^{-9}	10^{-9}
2	10^{-4}	10^{-5}	10^{-5}	10^{-6}
3	10^{-2}	10^{-5}	10^{-5}	10^{-2}

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			

GPRS architecture and interfaces



GPRS protocol architecture



IS-95 (CdmaOne): [TIA/EIA IS-95]

IS-95: standard for the radio interface
IS-41: standard for the network part

Operates of 800MHz and 1900MHz bands

Uses DS-CDMA technology (1.2288 Mchips/s)

Forward link (downlink): ½ convolutional code, interleaved, 64 chips spreading sequence (Walsh-Hadamard functions)
pilot channel (code 0), synchronization channel (code 32), 7 paging channels, upto 63 traffic channels

Reverse link (uplink): 1/3 convolutional code, interleaved, 6 bits are mapped into a Walsh-Hadamard sequence, spreading using a User-BaseStation specific code (with period 2^{42}-1/2^{15})

Tight power control (open-loop, fast closed loop)