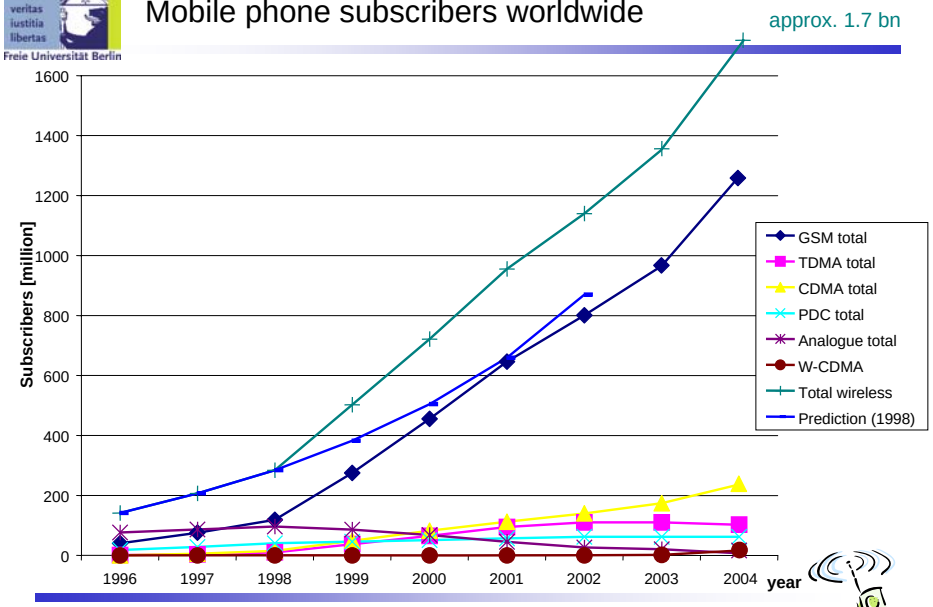
# Mobile Communications Chapter 4: Wireless Telecommunication Systems

- Market
- GSM
  - Overview
  - Services
  - Sub-systems
  - Components
- UMTS/IMT-2000



## Mobile phone subscribers worldwide






## First Generation

Advanced Mobile Phone Service (AMPS)
- US trials 1978; deployed in Japan ('79) & US ('83)
- 800 MHz band — two 20 MHz bands
- TIA-553
- Still widely used in US and many parts of the world

Nordic Mobile Telephony (NMT)
- Sweden, Norway, Demark & Finland
- Launched 1981; now largely retired
- 450 MHz; later at 900 MHz (NMT900)

Total Access Communications System (TACS)
- British design; similar to AMPS; deployed 1985
- Some TACS-900 systems still in use in Europe



## Second Generation — 2G

Digital systems

Leverage technology to increase capacity
- Speech compression; digital signal processing

Utilize/extend "Intelligent Network" concepts

Improve fraud prevention

Add new services

There are a wide diversity of 2G systems
- IS-54/ IS-136 North American TDMA; PDC (Japan)
- iDEN
- DECT and PHS
- IS-95 CDMA (cdmaOne)
- GSM

## D-AMPS/ TDMA & PDC

- Speech coded as digital bit stream
  - Compression plus error protection bits
  - Aggressive compression limits voice quality
- Time division multiple access (TDMA)
  - 3 calls per radio channel using repeating time slices
- Deployed 1993 (PDC 1994)
  - Development through 1980s; bakeoff 1987
- IS-54 / IS-136 standards in US TIA
- ATT Wireless & Cingular use IS-136 today
  - Plan to migrate to GSM and then to W-CDMA
- PDC dominant cellular system in Japan today
  - NTT DoCoMo has largest PDC network



## iDEN

- Used by Nextel
- Motorola proprietary system
  - Time division multiple access technology
  - Based on GSM architecture
- 800 MHz private mobile radio (PMR) spectrum
  - Just below 800 MHz cellular band
- Special protocol supports fast “Push-to-Talk”
  - Digital replacement for old PMR services
- Nextel has highest APRU in US market due to “Direct Connect” push-to-talk service



## DECT and PHS

- Also based on time division multiple access
- Digital European Cordless Telephony
  - Focus on business use, i.e. wireless PBX
  - Very small cells; In building propagation issues
  - Wide bandwidth (32 kbps channels)
  - High-quality voice and/or ISDN data
- Personal Handiphone Service
  - Similar performance (32 kbps channels)
  - Deployed across Japanese cities (high pop. density)
  - 4 channel base station uses one ISDN BRI line
  - Base stations on top of phone booths
  - Legacy in Japan; new deployments in China today



## North American CDMA (cdmaOne)

- Code Division Multiple Access
  - All users share same frequency band
  - Discussed in detail later as CDMA is basis for 3G
- Qualcomm demo in 1989
  - Claimed improved capacity & simplified planning
- First deployment in Hong Kong late 1994
- Major success in Korea (1M subs by 1996)
- Used by Verizon and Sprint in US
- Simplest 3G migration story today



## cdmaOne — IS-95

TIA standard IS-95 (ANSI-95) in 1993

IS-95 deployed in the 800 MHz cellular band

- J-STD-08 variant deployed in 1900 MHz US “PCS” band

Evolution fixes bugs and adds data

- IS-95A provides data rates up to 14.4 kbps
- IS-95B provides rates up to 64 kbps (2.5G)
- Both A and B are compatible with J-STD-08

All variants designed for TIA IS-41 core networks (ANSI 41)



## GSM

« Groupe Special Mobile », later changed to « Global System for Mobile »

- Joint European effort beginning in 1982
- Focus on seamless roaming across Europe

Services launched 1991

- Time division multiple access (8 users per 200KHz)
- 900 MHz band; later extended to 1800MHz
- Added 1900 MHz (US PCS bands)

GSM is dominant world standard today

- Well defined interfaces; many competitors
- Network effect (Metcalfe’s law) took hold in late 1990s
- Tri-band GSM phone can roam the world today



## Distribution of GSM Subscribers

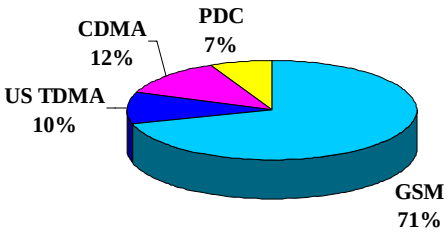
GSM is used by 70% of subscribers worldwide

- 564 M subs / 800 M subs in July 2001

Most GSM deployments in Europe (59%) and Asia (33%)

- ATT & Cingular deploying GSM in US today

**Number of subscribers in the world (Jul 2001)**

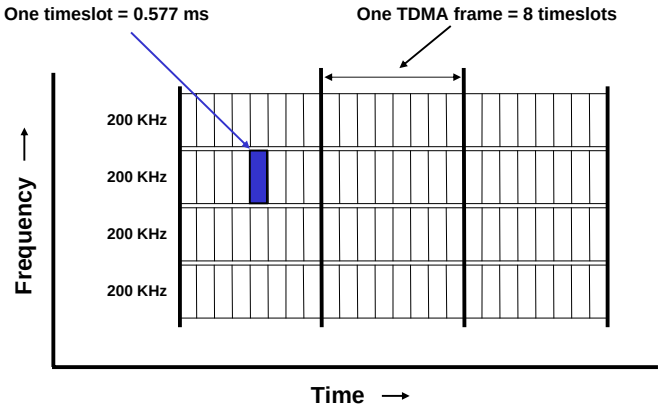



Source: EMC World Cellular / GSM Association



## 2G — TDMA

*Time Division Multiple Access*




## 2G & 3G — CDMA

*Code Division Multiple Access*

Spread spectrum modulation

- Originally developed for the military
- Resists jamming and many kinds of interference
- Coded modulation hidden from those w/o the code

All users share same (large) block of spectrum

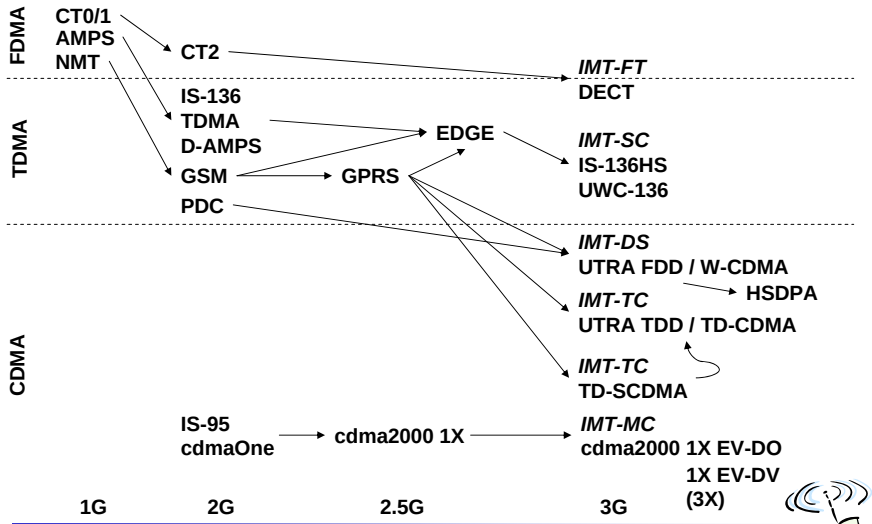
- One for one frequency reuse
- Soft handoffs possible

Almost all accepted 3G radio standards are based on CDMA

- CDMA2000, W-CDMA and TD-SCDMA



## Development of mobile telecommunication systems






## GSM: 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
- today many providers all over the world use GSM (more than 200 countries in Asia, Africa, Europe, Australia, America)
- more than 1.2 billion subscribers in more than 630 networks
- more than 75% of all digital mobile phones use GSM (74% total)
- over 200 million SMS per month in Germany, > 550 billion/year worldwide (> 10% of the revenues for many operators)
  [be aware: these are only rough numbers…]



## 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

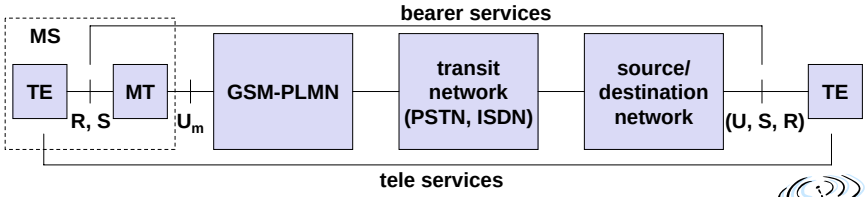
- abuse of private data possible
- roaming profiles accessible

- high complexity of the system
- several incompatibilities within the GSM standards

## 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: data rates of approx. 50 kbit/s possible – will be covered later!



## 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)
  - 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 (160 characters) using the signaling channel, thus allowing simultaneous use of basic services and SMS
    (almost ignored in the beginning now the most successful add-on!)

## 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

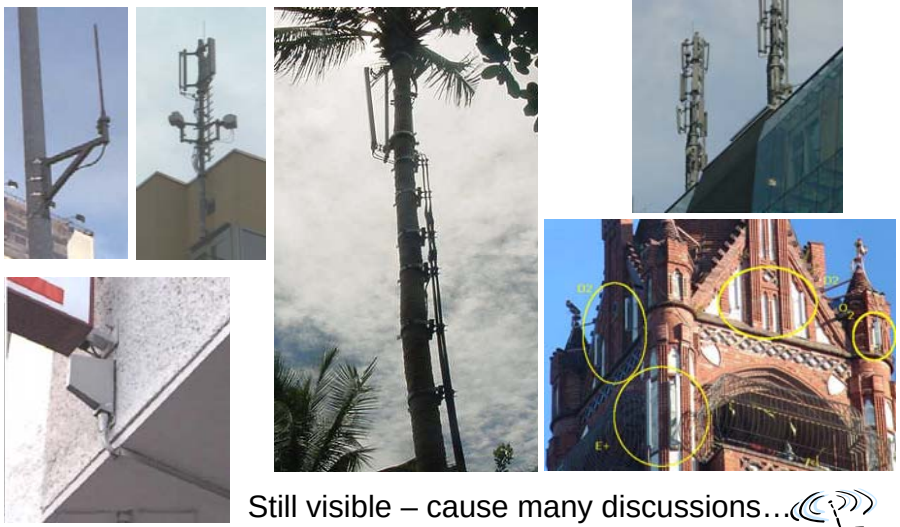


## Ingredients 1: Mobile Phones, PDAs & Co.

The visible but smallest part of the network!



## Ingredients 2: Antennas

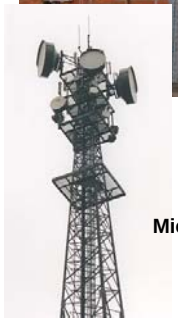


Still visible – cause many discussions…

## Ingredients 3: Infrastructure 1

Base Stations

Cabling



Microwave links



## Ingredients 3: Infrastructure 2

Switching units

Management

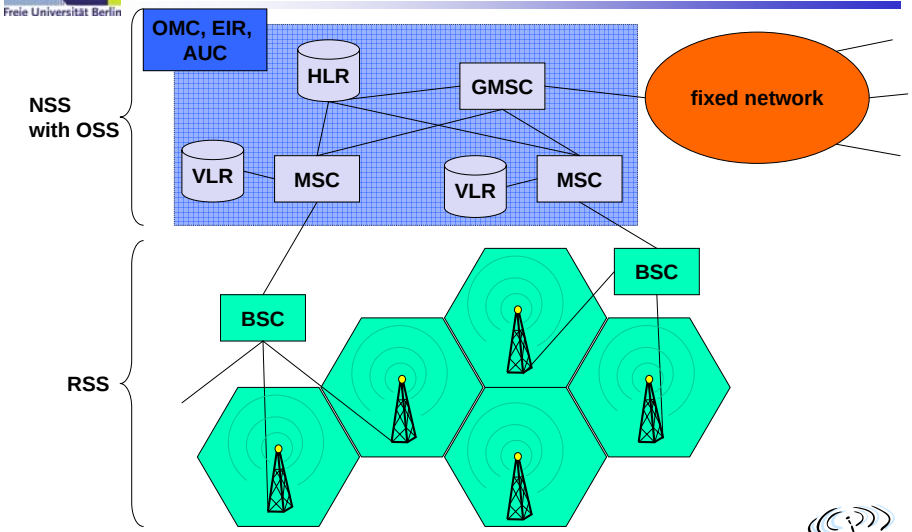
Data bases

Monitoring

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

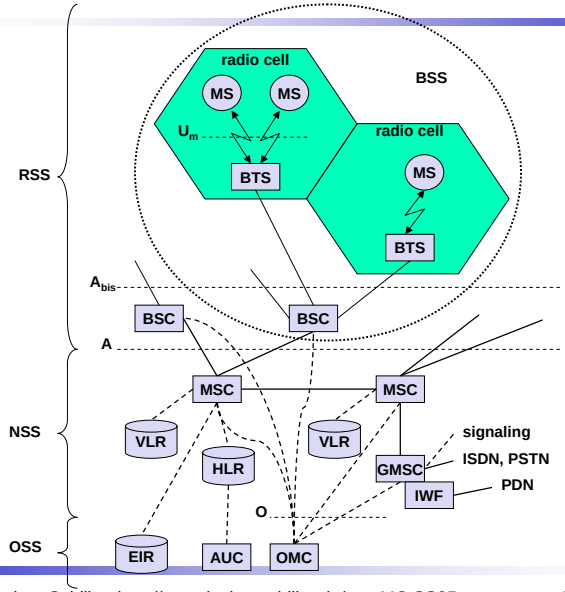


## GSM: overview

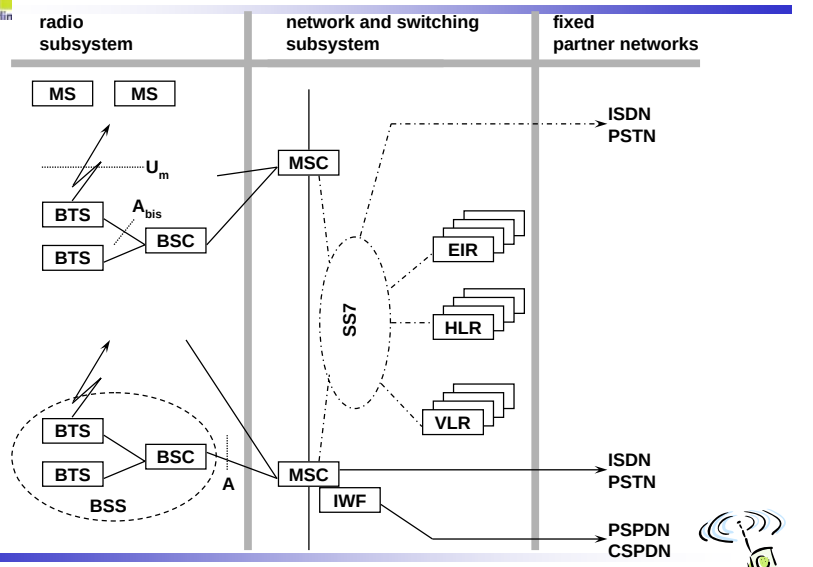





## GSM: elements and interfaces

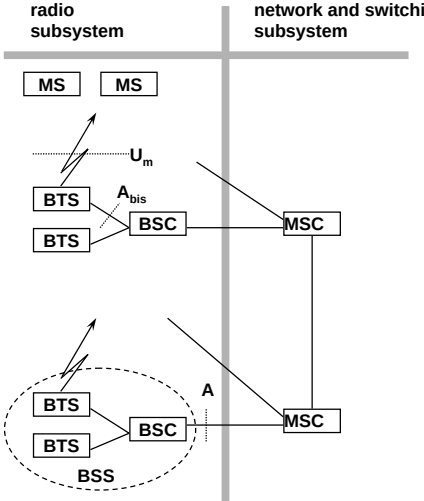


## GSM: system architecture






## 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



## Radio subsystem

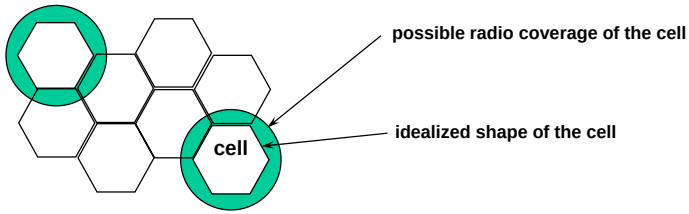
The Radio Subsystem (RSS) comprises the cellular mobile network up to the switching centers

- 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

## GSM frequency bands

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



## 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

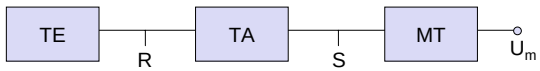
| Functions | BTS | BSC |
|---|---|---|
| Management of radio channels | | X |
| Frequency hopping (FH) | X | X |
| Management of terrestrial channels | | X |
| Mapping of terrestrial onto radio channels | | X |
| Channel coding and decoding | X | |
| Rate adaptation | X | |
| Encryption and decryption | 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

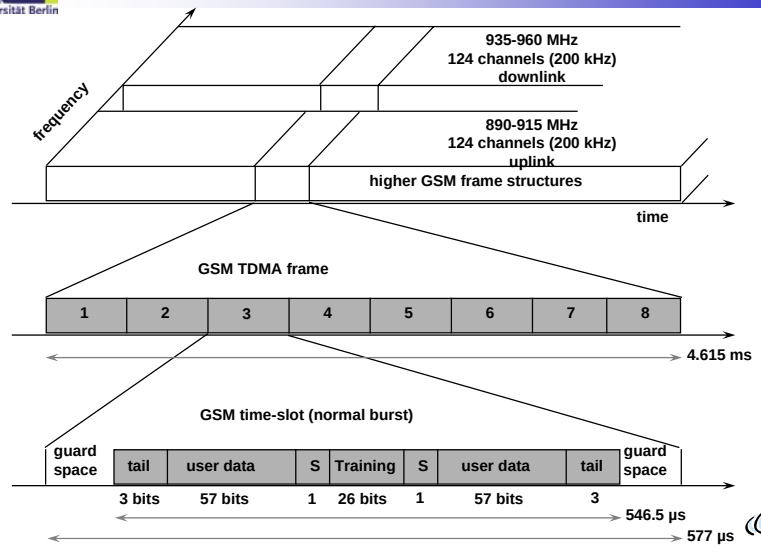
The MSC (mobile switching center) plays a central role in GSM

- 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

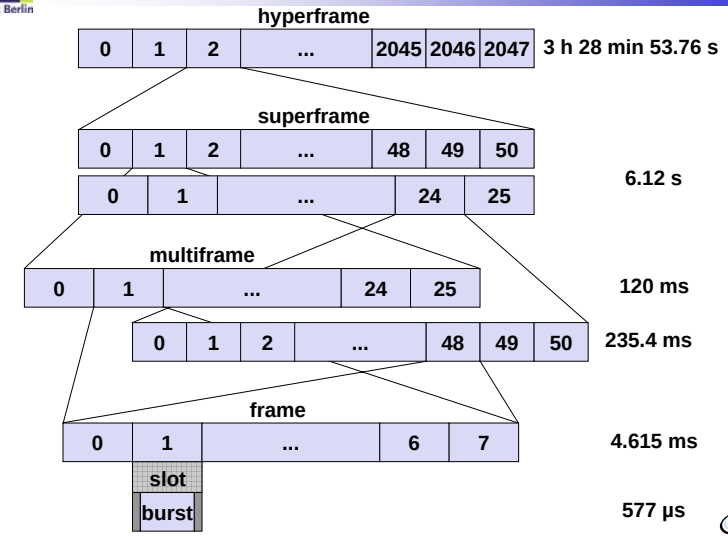


## GSM - TDMA/FDMA



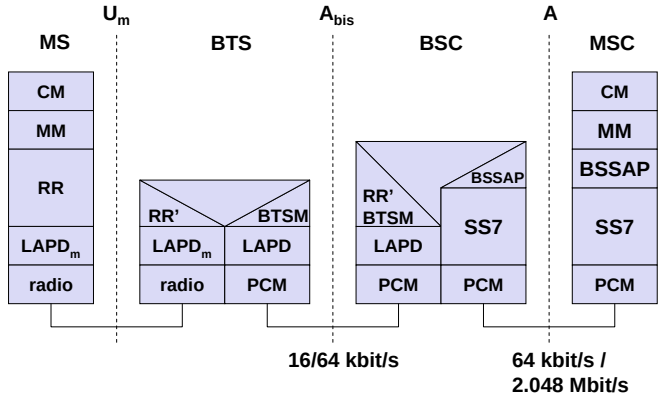



## GSM hierarchy of frames



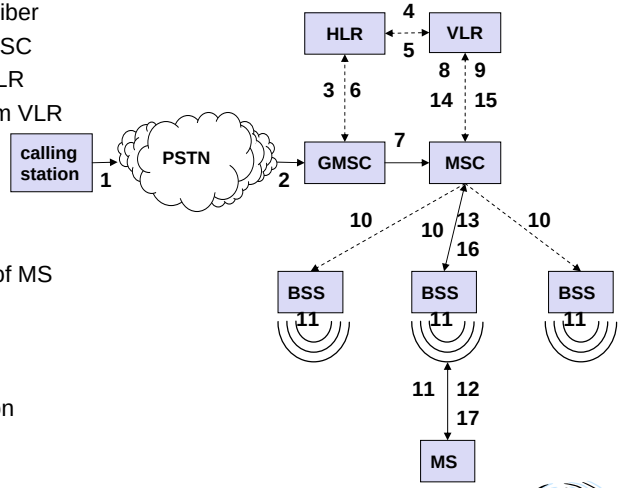



## GSM protocol layers for signaling




## Mobile Terminated Call

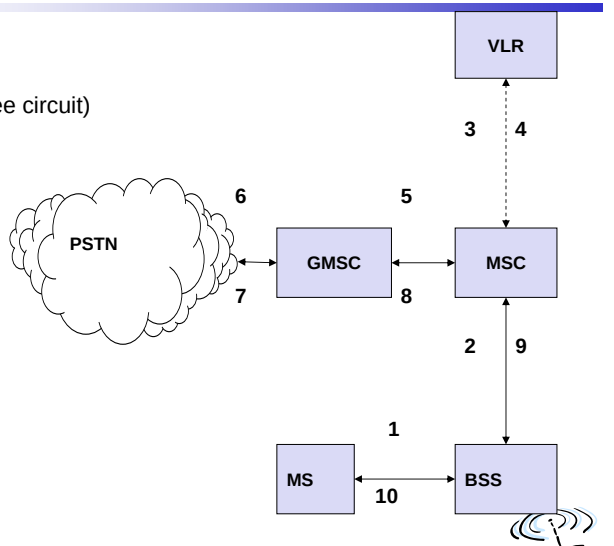
1: calling a GSM subscriber
2: forwarding call to GMSC
3: signal call setup to HLR
4, 5: request MSRN from VLR
6: forward responsible MSC to GMSC
7: forward call to current MSC
8, 9: get current status of MS
10, 11: paging of MS
12, 13: MS answers
14, 15: security checks
16, 17: set up connection





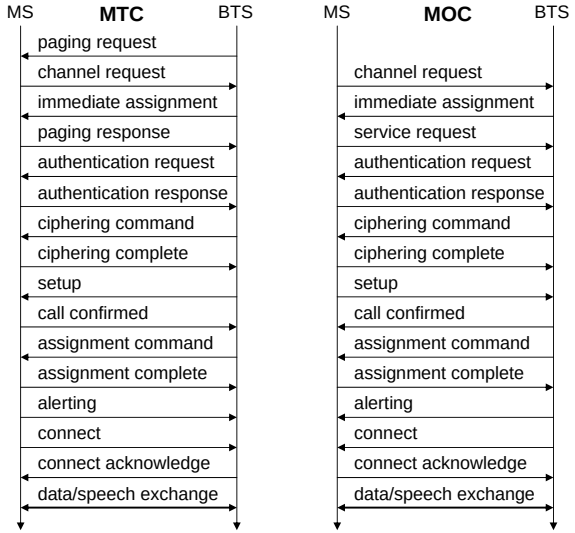

## Mobile Originated Call

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



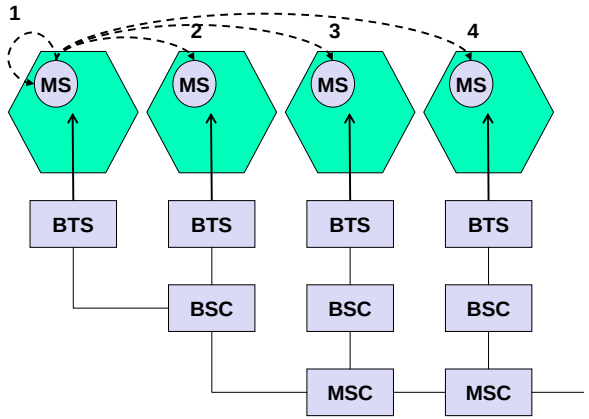



## MTC/MOC

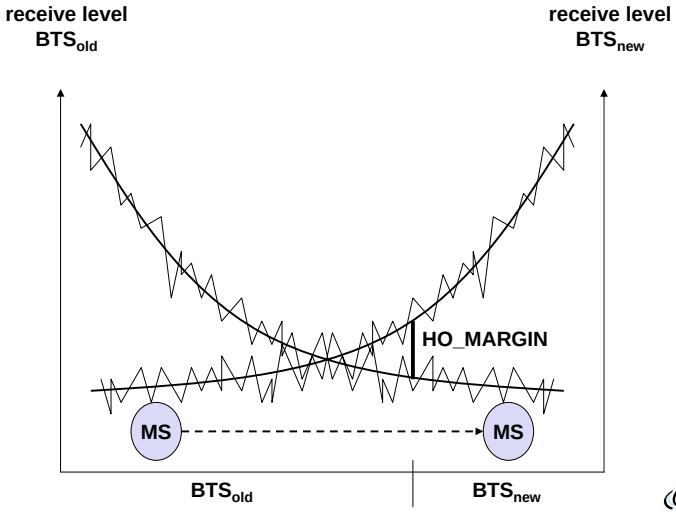





## 4 types of handover

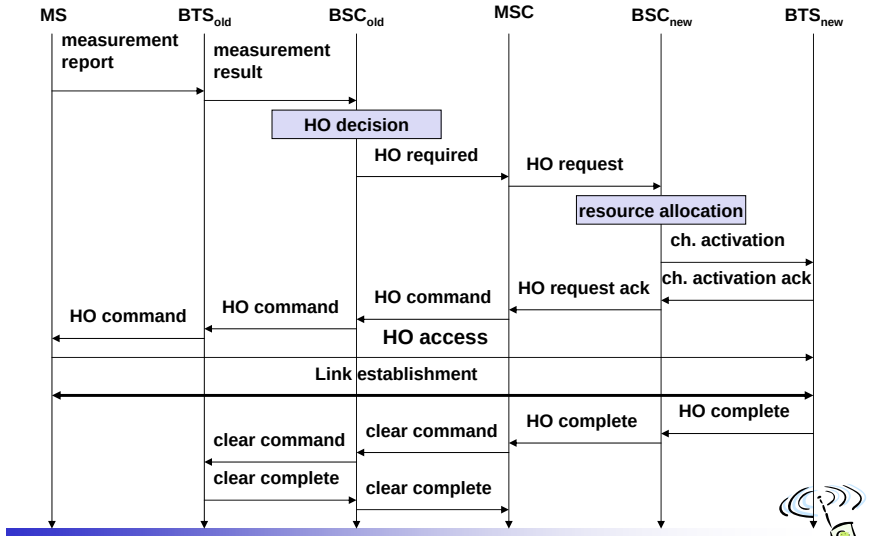


## Handover decision






## 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

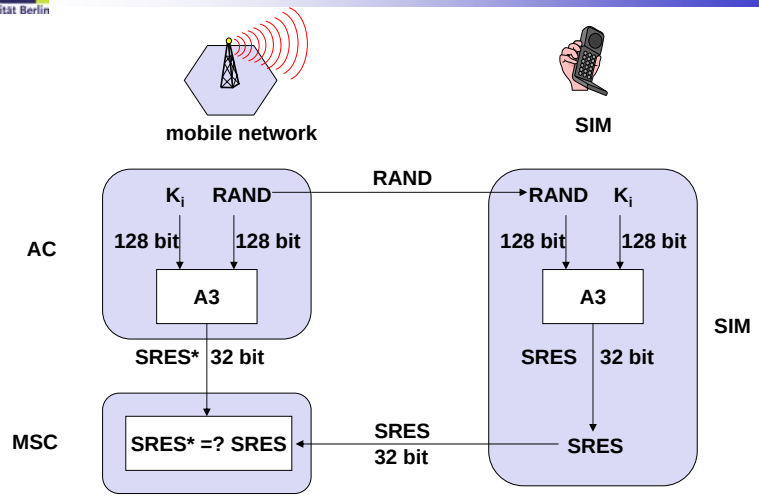
"secret":
• A3 and A8 available via the Internet
• network providers can use stronger mechanisms

3 algorithms specified in GSM

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

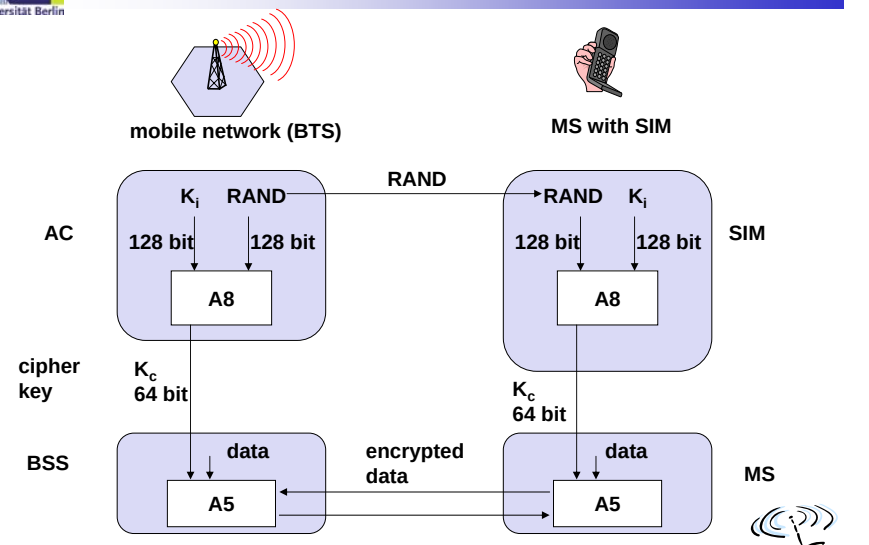


## GSM - authentication




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)

- 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 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., 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 |

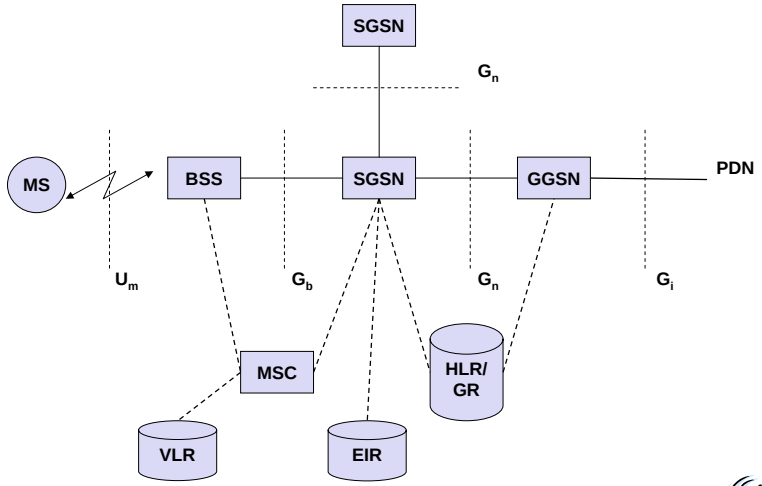


## GPRS user data rates in kbit/s

| 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 |

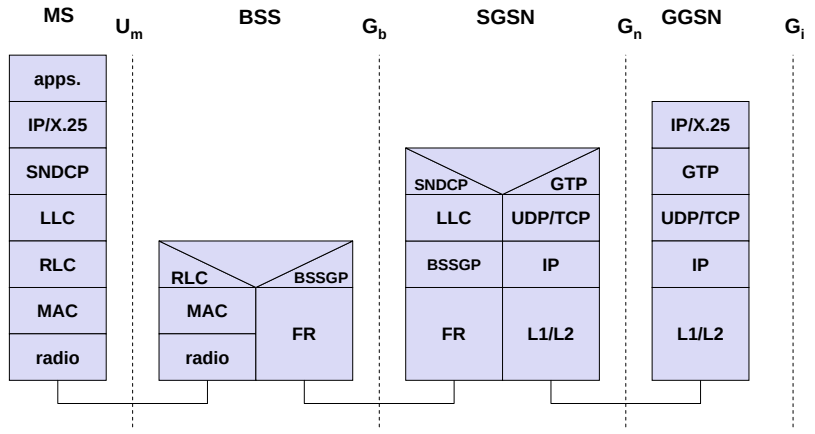


## GPRS architecture and interfaces






## GPRS protocol architecture






## UMTS and IMT-2000

Proposals for IMT-2000 (International Mobile Telecommunications)

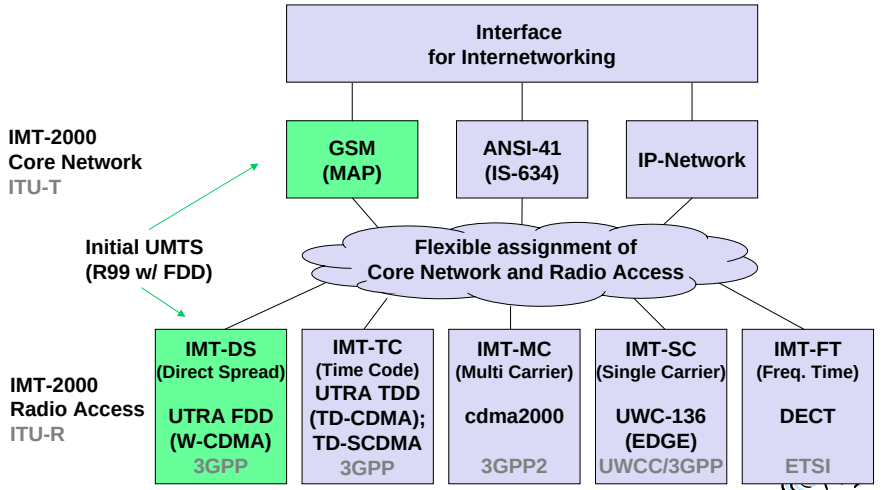
- UWC-136, cdma2000, WP-CDMA
- UMTS (Universal Mobile Telecommunications System) from ETSI

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



## IMT-2000 family






## GSM and UMTS Releases

| GSM/EDGE Release | 3G Release | Abbreviated name | Spec version number | Freeze date (indicative only) |
|---|---|---|---|---|
| Phase 2+ Release 6 | Release 6 | Rel-6 | 6.x.y | December 2004 - March 2005 |
| Phase 2+ Release 5 | Release 5 | Rel-5 | 5.x.y | March - June 2002 |
| Phase 2+ Release 4 | Release 4 | Rel-4 | 4.x.y | March 2001 |
| - | Release 2000 | R00 | 4.x.y | Renaming… |
| Phase 2+ Release 2000 | - | | 9.x.y | |
| - | Release 1999 | R99 | 3.x.y | March 2000 |
| Phase 2+ Release 1999 | - | | 8.x.y | |
| Phase 2+ Release 1998 | - | R98 | 7.x.y | early 1999 |
| Phase 2+ Release 1997 | - | R97 | 6.x.y | early 1998 |
| Phase 2+ Release 1996 | - | R96 | 5.x.y | early 1997 |
| Phase 2 | - | Ph2 | 4.x.y | 1995 |
| Phase 1 | - | Ph1 | 3.x.y | 1992 |



## UMTS architecture (Release 99 used here!)

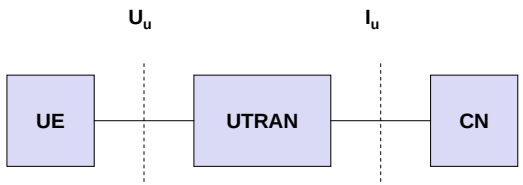
UTRAN (UTRA Network)

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

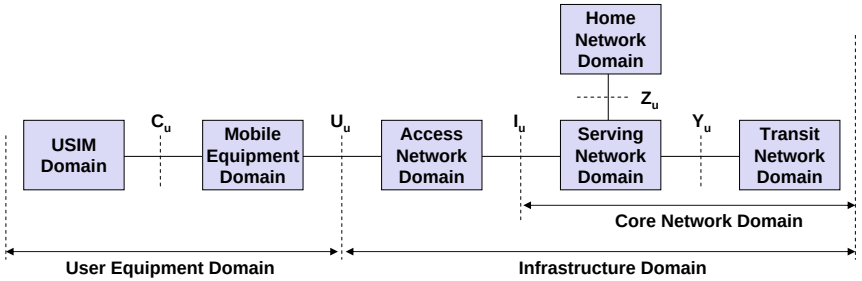
UE (User Equipment)

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

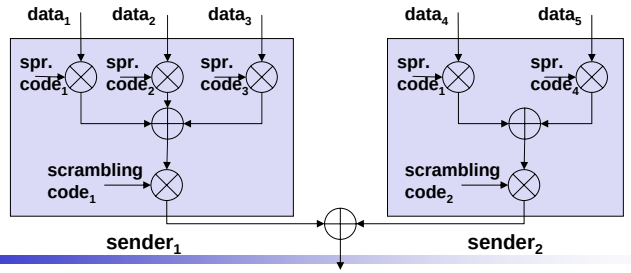


# Spreading and scrambling of user data

Constant chipping rate of 3.84 Mchip/s

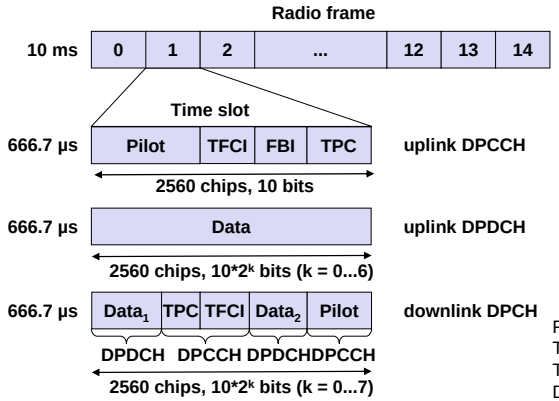
Different user data rates supported via different spreading factors
- higher data rate: less chips per bit and vice versa

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 synchronisation not necessary as the scrambling codes stay quasi-orthogonal






# 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

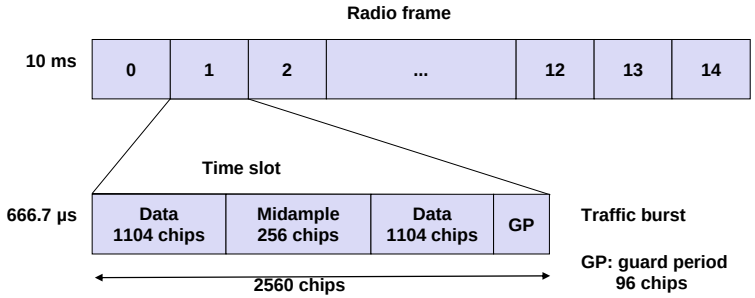
**Slot structure NOT for user separation but synchronisation for periodic functions!**

## 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 |



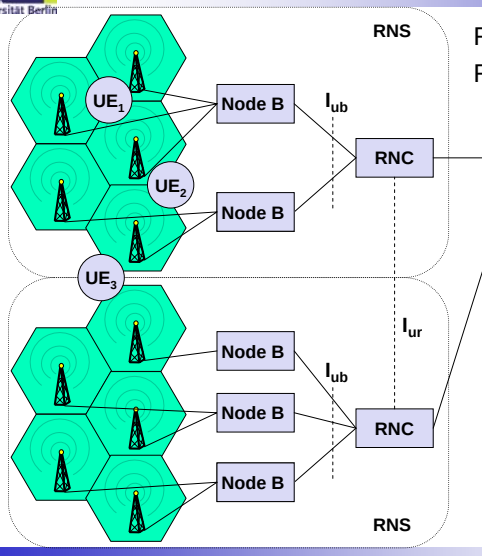
## UMTS TDD frame structure (burst type 2)




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



## UTRAN architecture




RNC: Radio Network Controller

RNS: Radio Network Subsystem

UTRAN comprises several RNSs

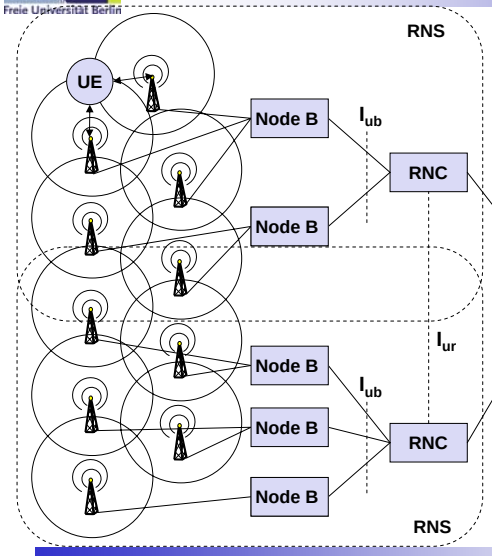
Node B can support FDD or TDD or both

RNC is responsible for handover decisions requiring signalingto the UE

Cell offers FDD or TDD



## 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

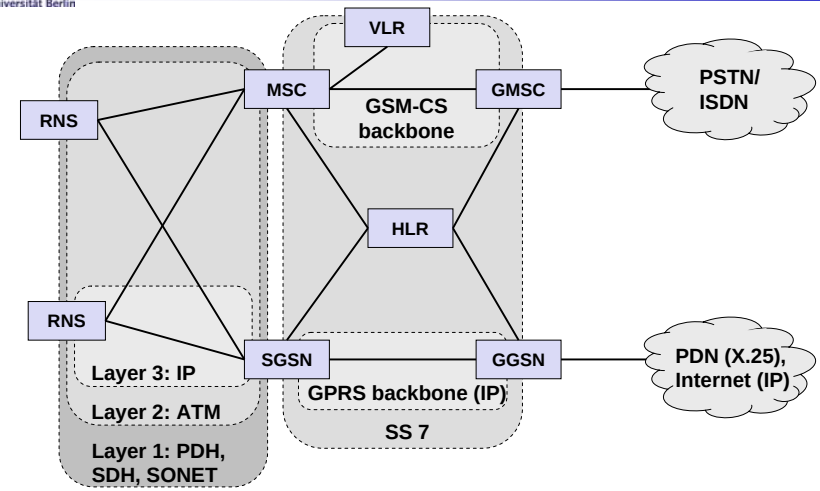
Cell offers FDD or TDD

## 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

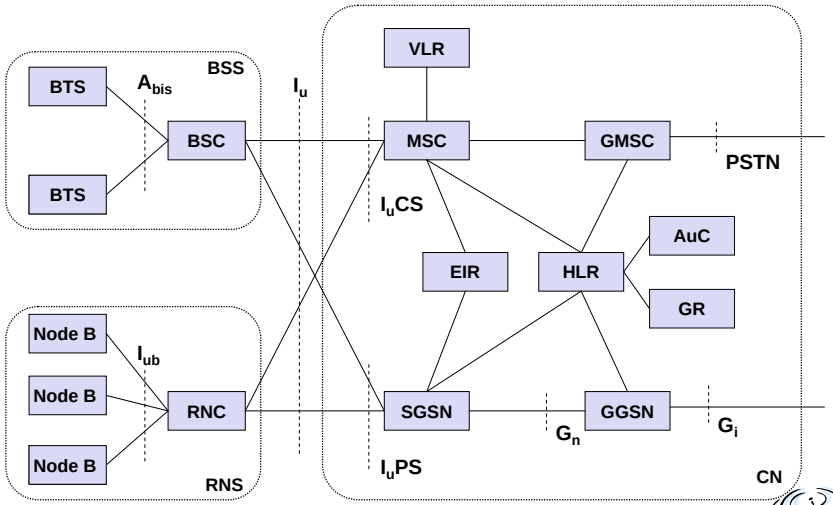


## Core network: protocols






## Core network: architecture






## Core network

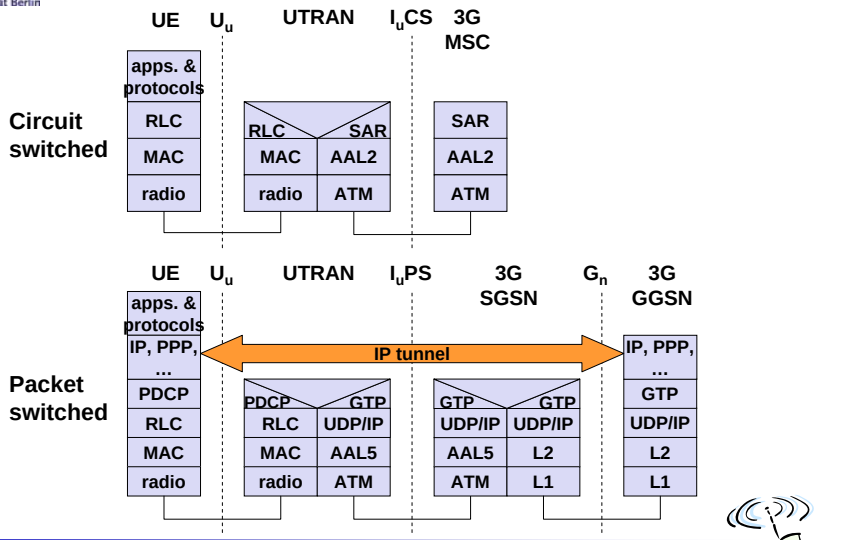
The Core Network (CN) and thus the Interface $I_u$, too, are separated into two logical domains:

- Circuit Switched Domain (CSD)
  - Circuit switched service incl. signaling
  - Resource reservation at connection setup
  - GSM components (MSC, GMSC, VLR)
  - $I_u$CS
- Packet Switched Domain (PSD)
  - GPRS components (SGSN, GGSN)
  - $I_u$PS

Release 99 uses the GSM/GPRS network and adds a new radio access!

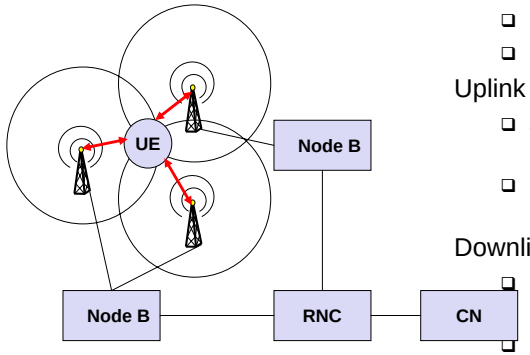
- Helps to save a lot of money …
- Much faster deployment
- Not as flexible as newer releases (5, 6)

## UMTS protocol stacks (user plane)






## Support of mobility: macro diversity

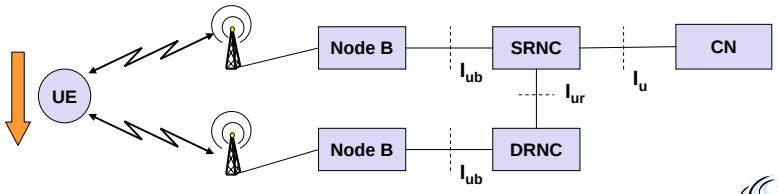



- Multicasting of data via several physical channels
  - Enables soft handover
  - FDD mode only
- Uplink
  - simultaneous reception of UE data at several Node Bs
  - Reconstruction of data at Node B, SRNC or DRNC
- Downlink
  - Simultaneous transmission of data via different cells
  - Different spreading codes in different cells



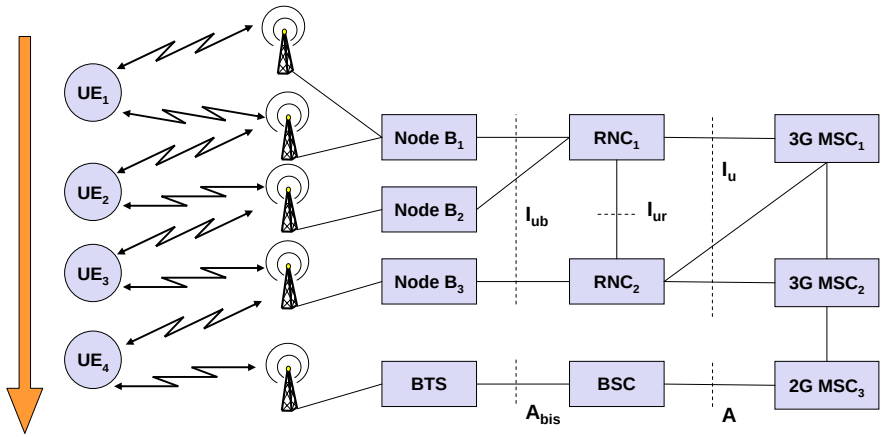
## Support of mobility: handover

- From and to other systems (e.g., UMTS to GSM)
  - This is a must as UMTS coverage will be 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

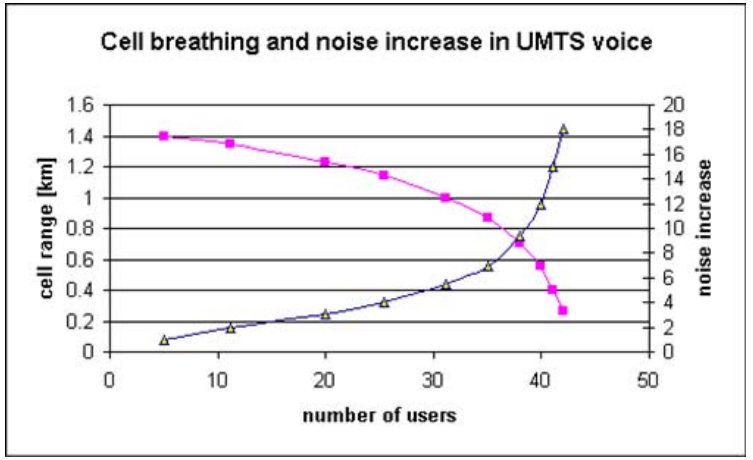
GSM
- Mobile device gets exclusive signal from the base station
- Number of devices in a cell does not influence cell size

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



## Some current enhancements

GSM
- 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 / chapter 10
- 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

UMTS
- HSDPA (High-Speed Downlink Packet Access)
  - initially up to 10 Mbit/s for the downlink, later on 20 Mbit/s using MIMO- (Multiple Input Multiple Output-) antennas
  - uses 16-QAM instead of QPSK