

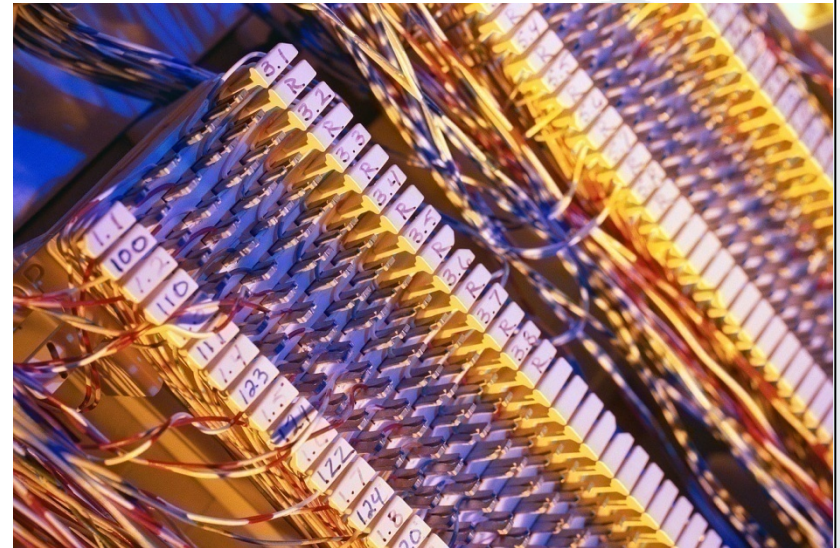
## ***Lecture 2***

Basic Communication Paradigms  
and Mobile Telecommunications  
Infrastructures

**Mobile Business I (WS 2015/16)**

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- Transmission Paradigms
- Cell Based Communication (CBC)
  - Introduction
  - Basic Technology (Cells, Multiplexing)
- Mobile Telecommunication Infrastructures
  - Introduction
  - GSM (Technology, Authentication, Location Management) (2G)
  - UMTS (3G)
  - Long Term Evolution (3.9G, 4G)
  - 5th Generation (5G): mobile broadband
- Roaming

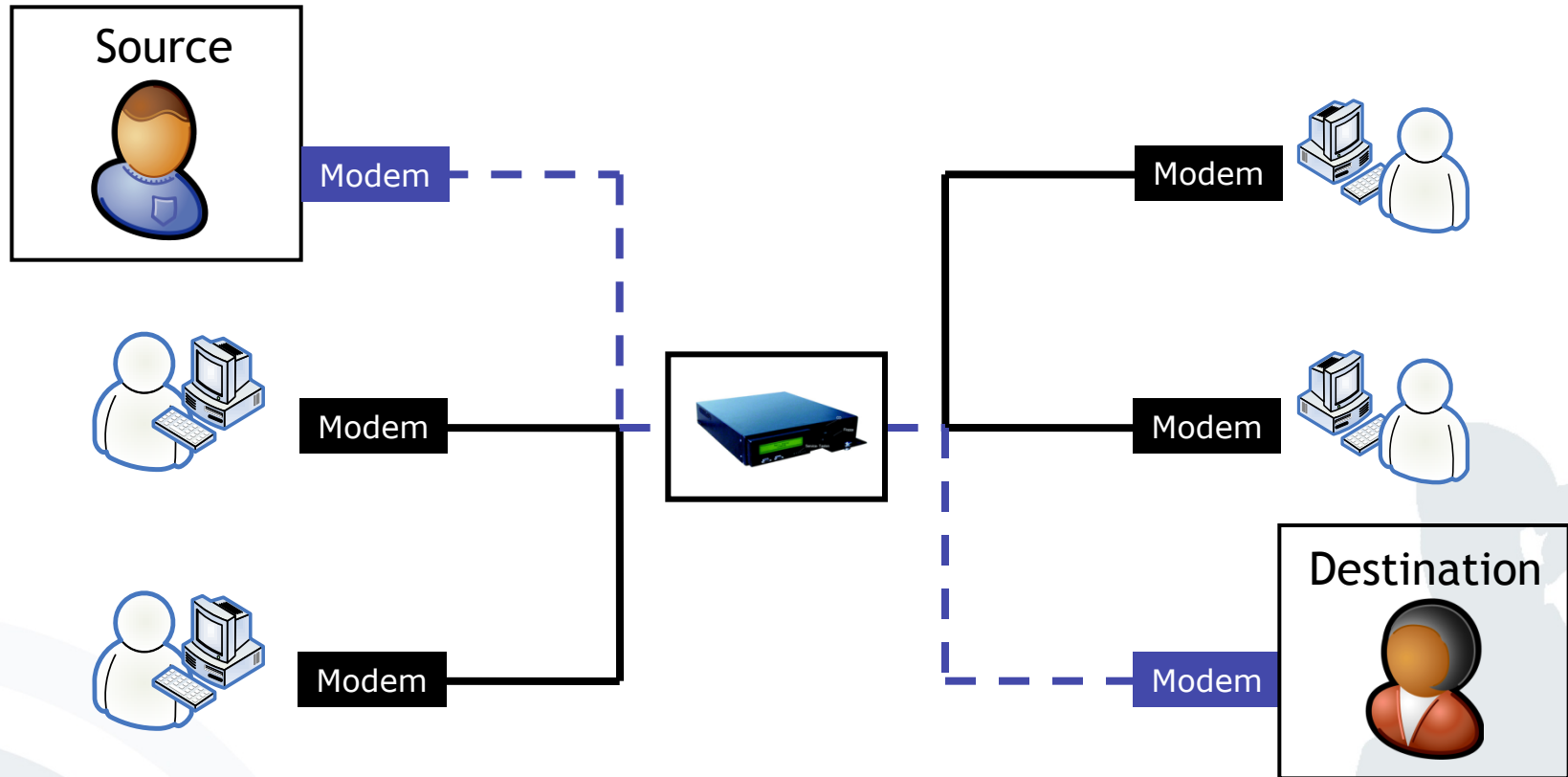
There are two major paradigms for data transmission in communication networks:

▪ **Circuit-Switched:** In circuit-switched networks, the communication line is used exclusively for the communicating parties.

- Connections are **exclusive** ➡ even if no data is transferred, the network resources are used.
- In reality, the typical usage for voice connections is 30% of the network's capacity - for data transmission it is less than 10%.
- The **duration of a connection** is used for billing purposes
- Example: *Circuit Switched Data (CSD)* and *High-Speed Circuit Switched Data (HSCSD)* for Mobile Data Services

▪ **Packet-Oriented:** In packet-oriented networks, the communication is divided into several packets, which get addressed and transferred using a **shared** transmission medium.

- The connection is kept all the time (always on). However, the network is only used when data is transmitted.
- The capacity of the communication network is allocated dynamically.
- For billing purposes, the **amount of transferred data** is used.
- Example: GPRS for Mobile Data Services

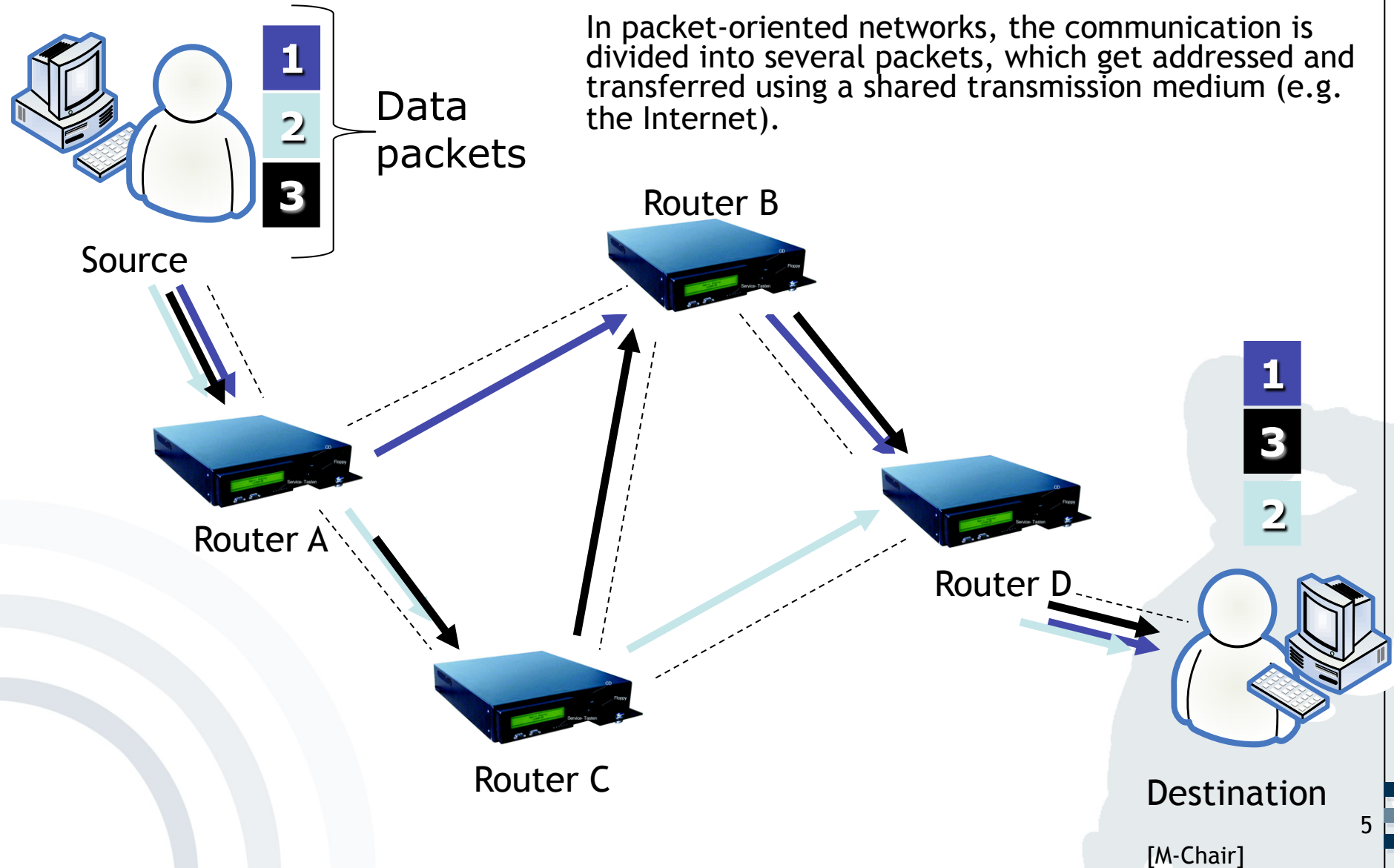


In circuit-switched networks, the communication line is used exclusively for the communicating parties (similar to the phone system, CSD and HSCSD).

[M-Chair]

## Mobile Data Services Packet-Oriented Networks

In packet-oriented networks, the communication is divided into several packets, which get addressed and transferred using a shared transmission medium (e.g. the Internet).

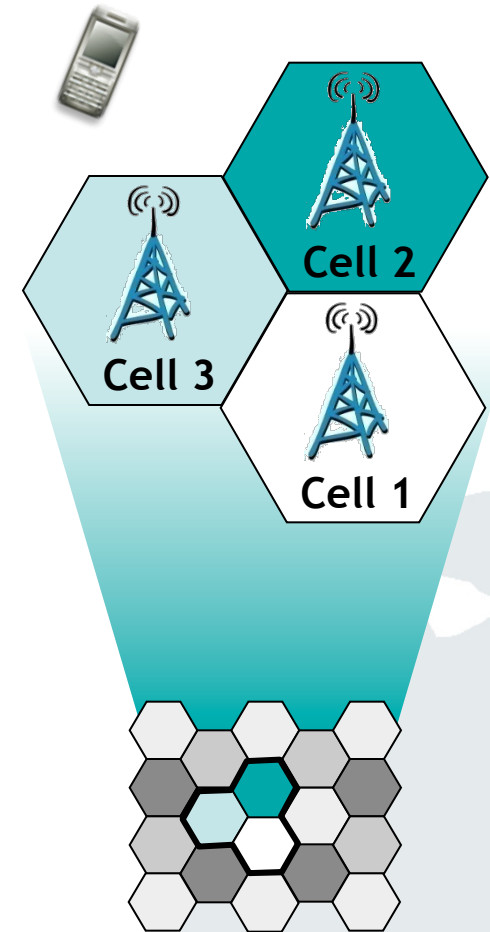


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# Cell Based Communication (CBC)

What is a Cellular Network?

- Cellular networks are radio networks consisting of several transmitters.
- Each transmitter or base station, covers a certain area ➔ **a cell**.
- Cell radii can vary from tens of meters to several kilometres.
- The shape of a cell is influenced by the environment (buildings, etc) and usually neither hexagonal nor a perfect circle, even though this is the usual way of drawing them.





- Cellular networks offer a number of advantages compared to centralised radio systems:
  - **Higher capacity:** Cells offer the possibility to “reuse” the transmission frequencies assigned to mobile devices (e.g. by multiplexing). In order to do so, the networks need a thorough planning of the position of base stations and their frequencies.
    - ➔ More users can use the infrastructure
  - **Reduced transmission power:** Reduced power usage for the mobile device, due to the fact that only a limited amount of transmission power is needed in a small cell, compared to a far away base station.
    - ➔ Reduced power consumption for mobile devices

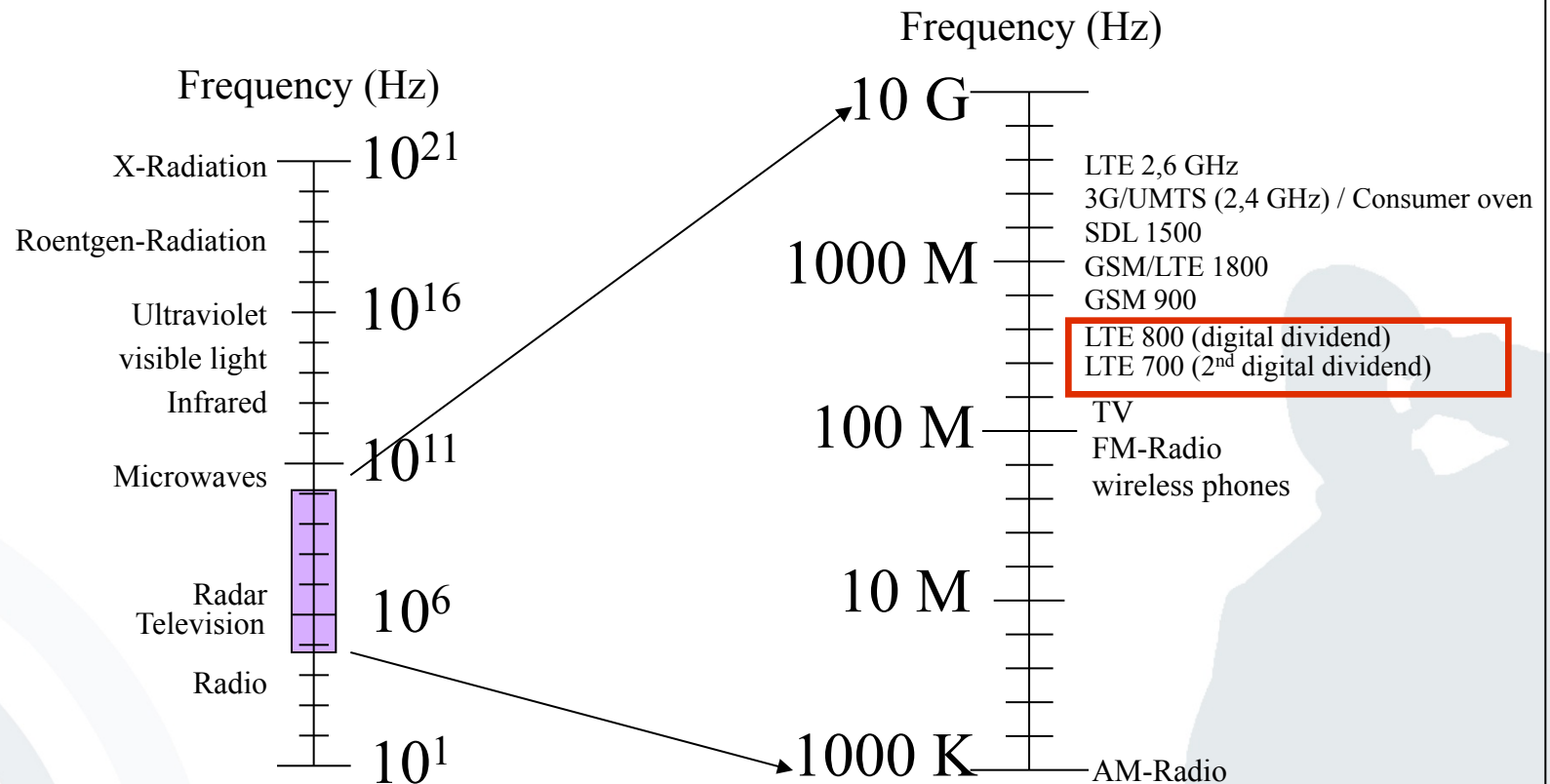


- Cellular networks offer a number of advantages compared to centralised radio systems:
  - **Robustness:** Cellular systems are decentralised with regard to their base stations. In the case that one antenna fails, only a small area gets affected.
    - ➡ Failure of one base station does not affect the complete infrastructure
  - **Better coverage:** Cells can be adapted to geographic conditions (mountains, buildings, etc.).
    - ➡ Better availability of the infrastructure

- However, there are also some drawbacks of cell based communication infrastructures:
  - ***Required infrastructure:*** A complex and costly infrastructure is required, in order to link all base stations. This includes switches, antennas, location registers, etc.
  - ***Handover needed:*** When changing from one cell to another, a handover mechanism is needed that allows a change of cells in real-time. These mechanisms are complex.
  - ***Frequency planning:*** The distribution of the frequencies being used for the base stations needs to be planned carefully, in order to minimise interferences, etc.

- Fundamental mechanism in communication system
- Describes how several users can share a medium (e.g. mobile network) with minimum or no interference.
- **Goal:** Most efficient usage of a medium
- **Abstract example:** Traffic (users) using a highway with several lanes (medium) without accidents (interference)

### Frequency range of instruments of entertainment and communication electronics



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- **1<sup>st</sup> Generation (1G) - Analogue networks**
- **2<sup>nd</sup> Generation (2G) - GSM networks**  
Global System for Mobile Communications
- **3<sup>rd</sup> Generation (3G/3.5G) - UMTS/HSPA/HSPA+**  
Universal Mobile Telecommunications System  
High Speed Packet Access / Evolved HSPA = HSPA+
- **3.9G or 4G - LTE**  
Long Term Evolution
- **4<sup>th</sup> Generation (4G) - LTE Advanced**
- **5<sup>th</sup> Generation (5G) - Mobile broadband**

Evolution of mobile telecommunication infrastructures

**2G – GSM**

**3.9G/4G – LTE**

**1G**

**3G – UMTS**

**4G – LTE Advanced**

**5G**

- ***1<sup>st</sup> mobile radio network in Germany: “A-Netz”***
  - Started in 1958 - decommissioned in 1977
  - Analogue network (Manual switching of calls, frequency range 150 MHz)
  - Price of terminal: 8.000-15.000 DM
  - For a call, the caller has to know the location of the callee (range from 30 to 50 km radius).
  
- ***2<sup>nd</sup> mobile radio network in Germany: “B-Netz”***
  - Started in 1972 – decommissioned in 1994
  - Analogue network (Automatic dial switching by area code)
  - Caller needs to know the area code of callee
  - Terminal prices comparable with those of the A-Network



- ***3rd mobile radio network in Germany: “C-Netz”***
  - Started in 1985 – decommissioned in 2000
  - Analogue network
  - First ***cell based*** mobile radio system in Germany
  - The change of cells happens automatically by distance measuring to the nearest base station
  - The net can automatically detect the place of the call partner by use of a Home Location Register (HLR)
  - Uniform (location independent) area code “0161” for all participants
  - Telephone number is not allocated to the terminal but to the smart card (later: SIM)
  - Peak in 1993 with 850.000 participants

- In 1991, the first GSM (2G) network (“D-Netze”) started in a test run in Germany.
- By introducing the worldwide GSM-standards and roaming agreements among mobile operators cross-border mobile communication became possible.
- In 2003 the first **UMTS** (3G) networks became available.

- First digital mobile radio network with high voice quality and reliability (roaming)
- Global diffusion in more than 212 countries with more than 1 billion users.
- In February 2004 the first commercial mobile radio network (based on GSM) was launched in Iraq.
- GSM is the basis of data services like GPRS and EGDE.



[Sauter2008]

- Third-generation (3G) mobile phone technology
- Provides high data transfer rates for multimedia communication services
- Germany's UMTS frequency licenses were sold by auction in 2000 for approx. 50bn €.
- Commercially available in Germany since 2004
- UMTS/3G is the underlying network and the basis of the data services HSPA and HSPA+.

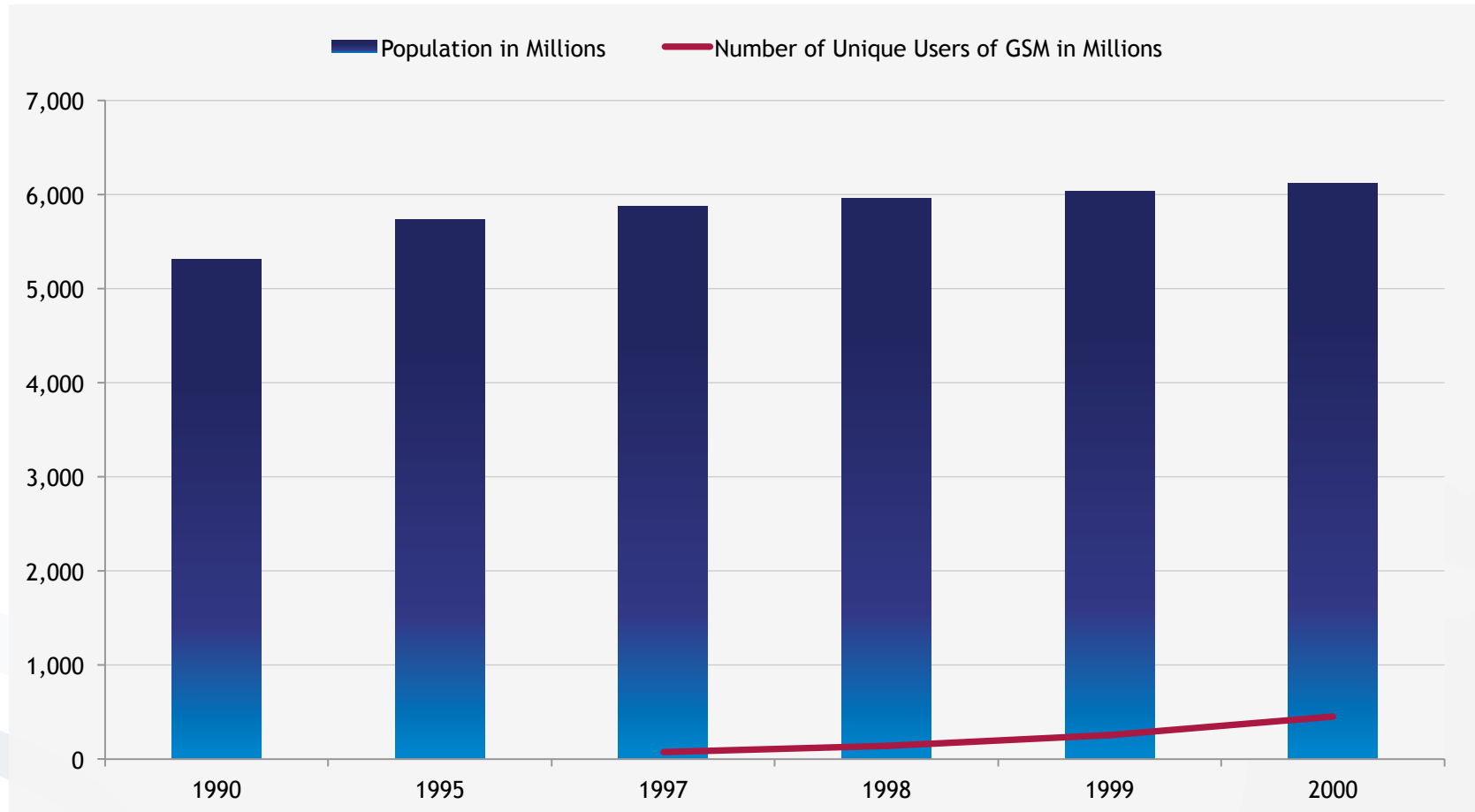


[Sauter 2008]



- The radio frequencies for mobile broadband connection were auctioned in Germany (5.08 bn €) in May/June 2015.
- In 2012, the European Commission committed 50 m € for research to deliver **5G in 2020**.
- First **Long Term Evolution Networks (3.9G/4G)** became **commercially available** in Stockholm and Oslo in 2009.
- On April and May 2010, the **digital dividend** frequency spectrum auctioned in Germany (4.4 bn €) for
  - use in Long Term Evolution Networks (3.9G/4G)
  - improving broadband coverage

# Unique users of GSM 1990-2000



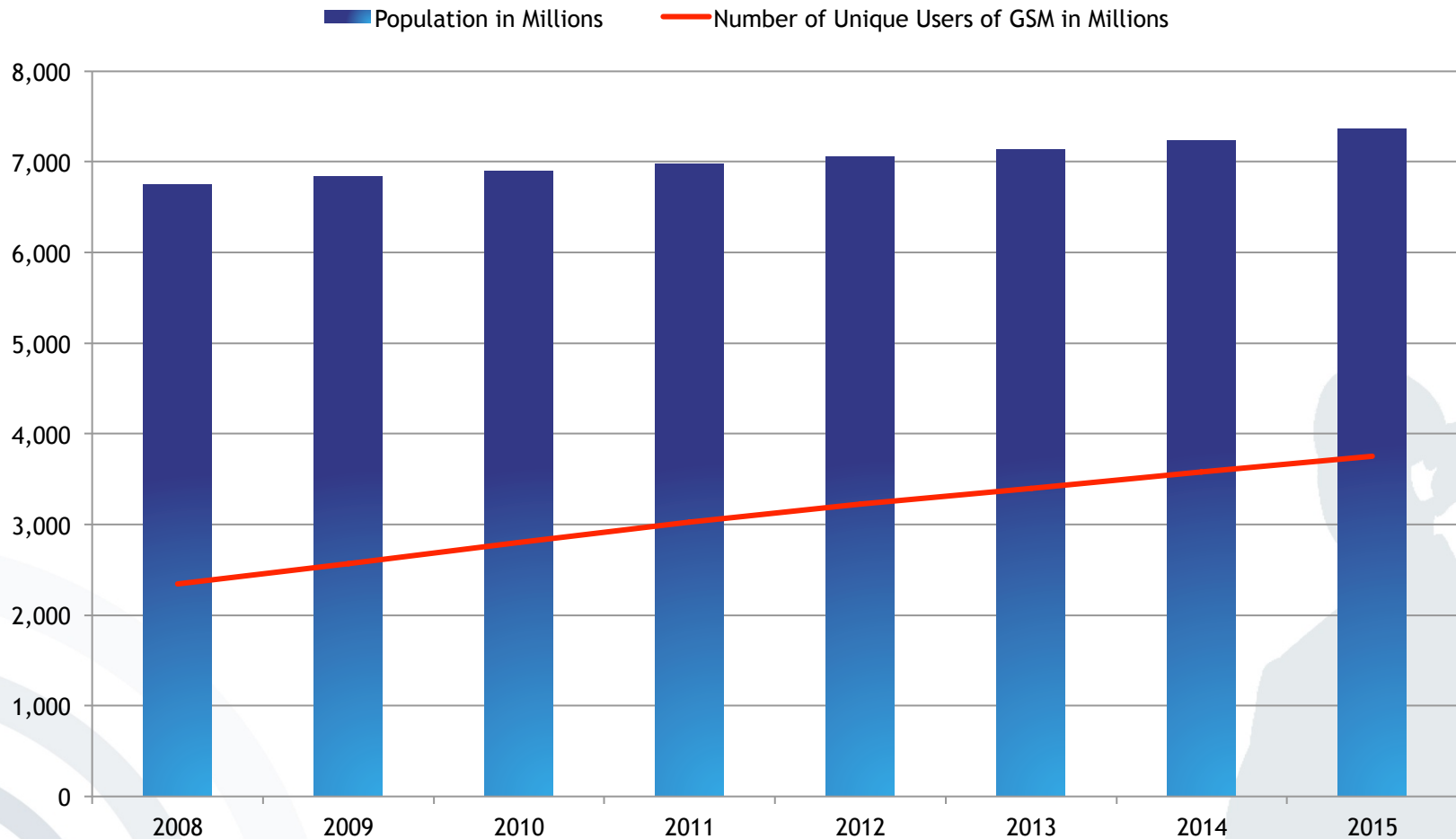
# Worldwide mobile communication penetration 1997-2007 by technology\*

	<b>GSM</b>	<b>UMTS (WCDMA)</b>	<b>CDMA</b>	<b>PDC</b>	<b>TDMA</b>
1997	<b>71,20</b>				
1998	<b>138,40</b>				
1999	<b>258,20</b>				
2000	<b>455,10</b>		<b>82,20</b>	<b>50,80</b>	<b>65,20</b>
2001	<b>636,40</b>		<b>110,00</b>	<b>52,90</b>	<b>90,00</b>
2002	<b>809,30</b>	<b>0,20</b>	<b>140,50</b>	<b>56,10</b>	<b>101,10</b>
2003	<b>1.012,00</b>	<b>2,80</b>	<b>183,60</b>	<b>58,10</b>	<b>100,10</b>
2004	<b>1.296,00</b>	<b>16,30</b>	<b>231,60</b>	<b>54,20</b>	<b>90,00</b>
2005	<b>1.709,20</b>	<b>50,00</b>	<b>296,70</b>	<b>46,30</b>	<b>48,50</b>
2006	<b>1.941,60</b>	<b>74,70</b>	<b>296,50</b>	<b>38,50</b>	<b>26,10</b>
2007	<b>2.278,10</b>	<b>114,70</b>	<b>290,00</b>	<b>27,90</b>	<b>16,20</b>

\* In Million subscribers [Source: Chair of Mobile Business 2007]



# Unique users of GSM Recent development



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- Abbreviation for **G**lobal **S**ystem for **M**obile Communications (GSM)



- Originally 1982 driven by “*Groupe Spéciale Mobile*” in order to create a cross national standard contrary to national analogue standards
- European standard by *ETSI* (European Telecommunications Standardisation Institute). ETSI is a partner in the 3rd Generation Partnership Project (3GPP).



- Worldwide adoption of the standard in more than *212 countries and territories* (most successful mobile radio system up to now)
- Thus, worldwide roaming among different mobile network operators became possible.

## ■ GSM-Services

### ■ Carrier services

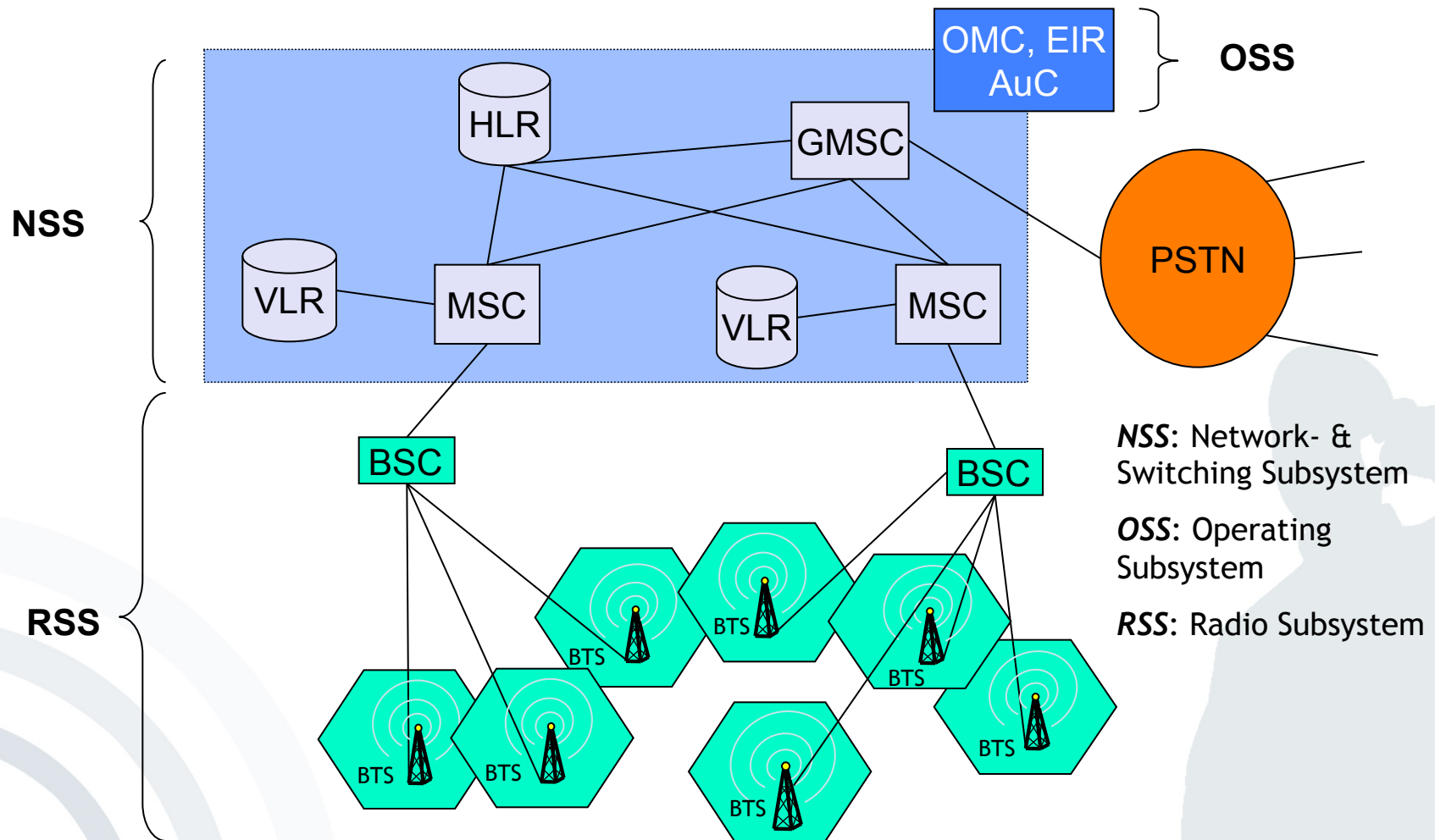
- Services to transfer signals over the GSM network  
→ The focus of GSM standardization was on voice services

### ■ Telecommunications services

- Telecommunication services (mainly voice) support the mobile communications among users  
→ Telecommunication services play a central role in the GSM standard

### ■ Supplementary services

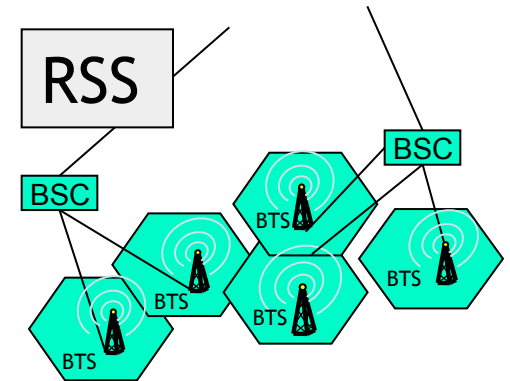
- GSM provides a number of supplementary services (specific to network operators), such as caller ID, call redirect, closed user groups (e.g. company-internal network or GSM-R), Teleconference (up to 7 participants).



- **Radio Subsystem (RSS)**
  - System consisting of radio
  - Specific components

- **Components:**

- **Mobile Station (MS):** System of mobile terminal & SIM
- **Base Transceiver Station (BTS):** Radio facility for signal transfer. A BTS serves one GSM cell (~100m to ~30km radius).
- **Base Station Controller (BSC):** Administrates affiliated BTS and supervises e.g. frequency allocation and connection handover between cells.

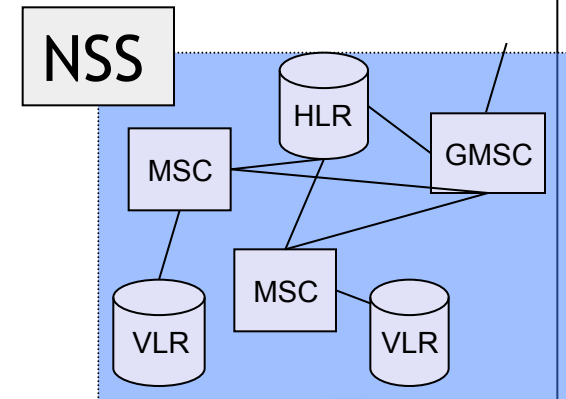


- **Network & Switching Subsystem (NSS)**

- Connects radio network with conventional networks
- Locates subscribers and monitors change of location

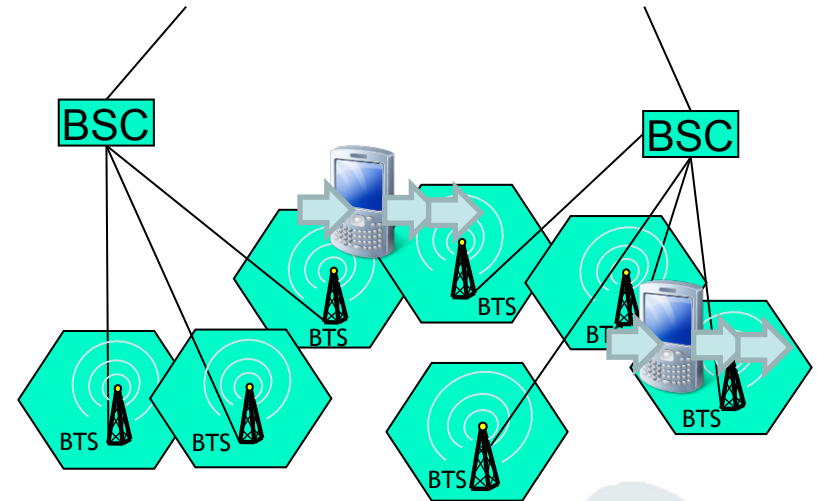
- **Components:**

- **Mobile Switching Centre (MSC):** Switching centre for initiation, termination and handover of connections
- **Home Location Register (HLR):** Central data base with subscribers' data (telephone numbers, keys, locations)
- **Visitor Location Register (VLR):** Data base assigned to every MSC with data of active subscribers in the MSC's range (HLR fraction copy).

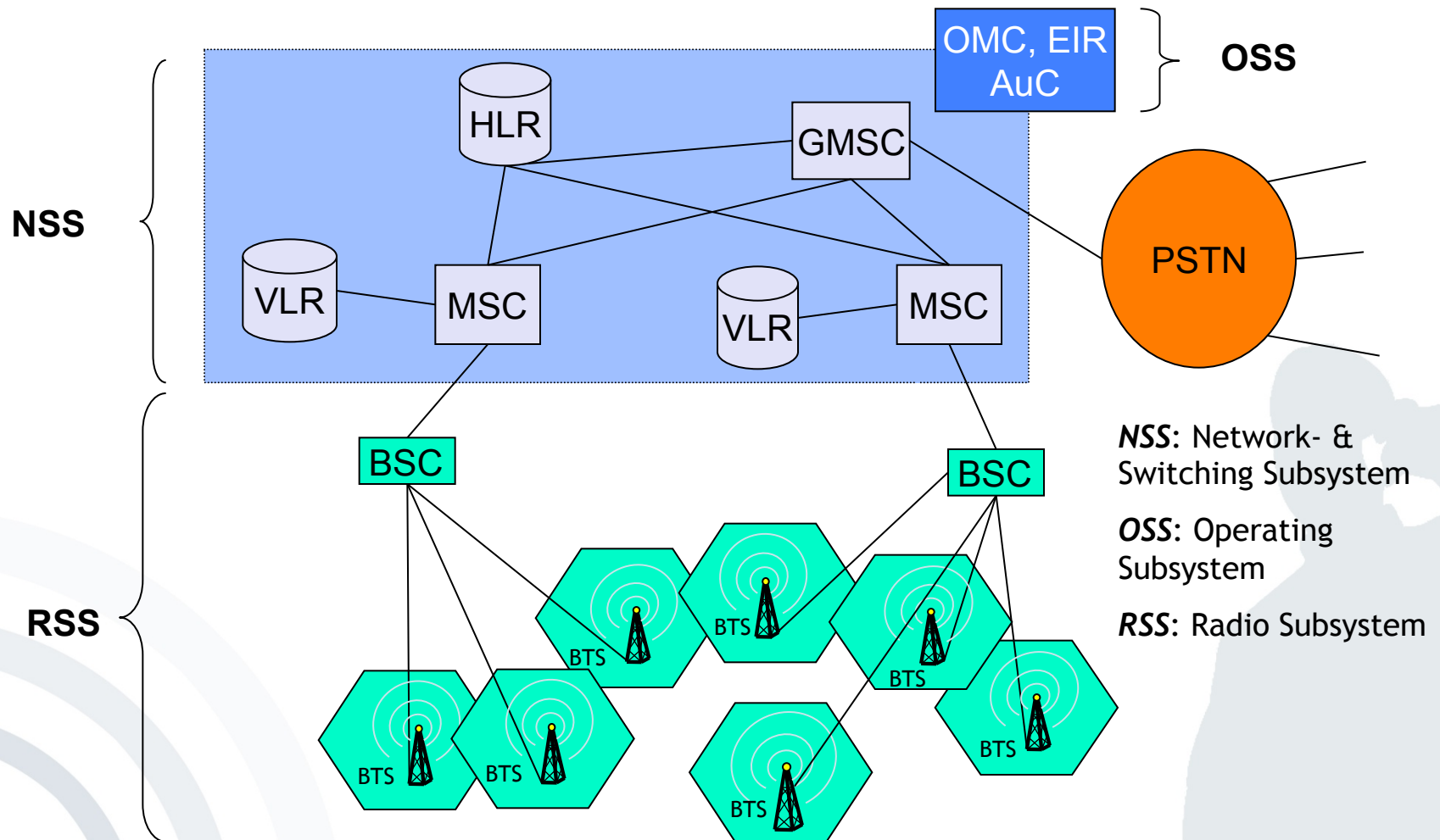


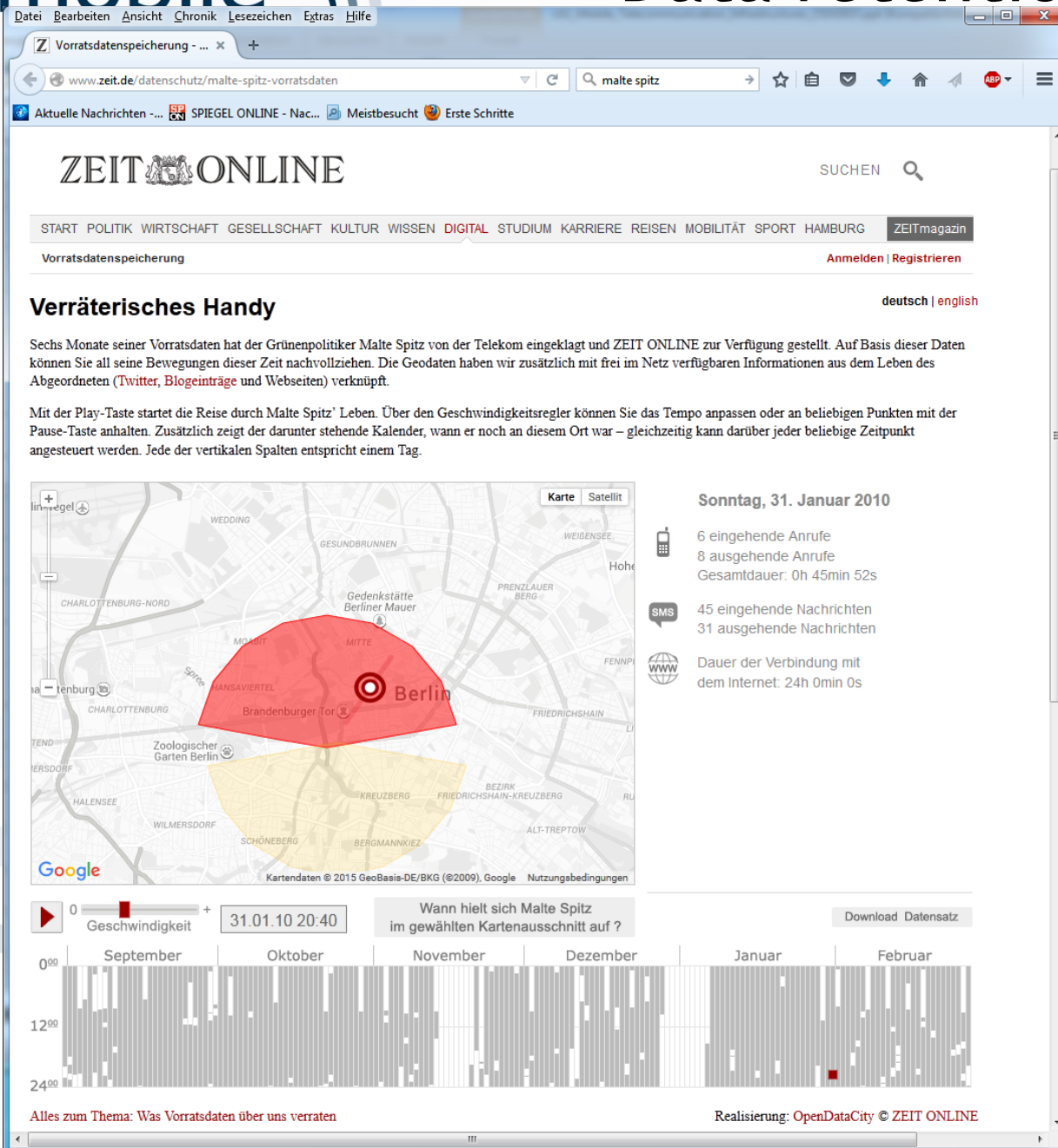


- Transferral of calls or data sessions from one transmitting station (in GSM: Base Transceiver Station, BTS) to another.
- Term **handover** common in British English
  - In international and Europe based organisations, e.g. ITU-T, IETF, ETSI and 3GPP
- Equivalent term **handoff** in American English
  - In IEEE and ANSI publications



- If a user of a mobile device moves from one cell to another cell, the connection handover should be as smooth as possible.
- GSM manages the handover between radio cells in the range of 100 ms; this implies a short connection interruption.
- The reason for the interruption is, among others, an update of the VLR.





[\[www.zeit.de/  
datenschutz/malte-  
spitz-vorratsdaten\]](http://www.zeit.de/datenschutz/malte-spitz-vorratsdaten)

- **Operation Subsystem (OSS)**

- Supervises operation and maintenance of the whole GSM network

OSS

OMC, EIR  
AuC

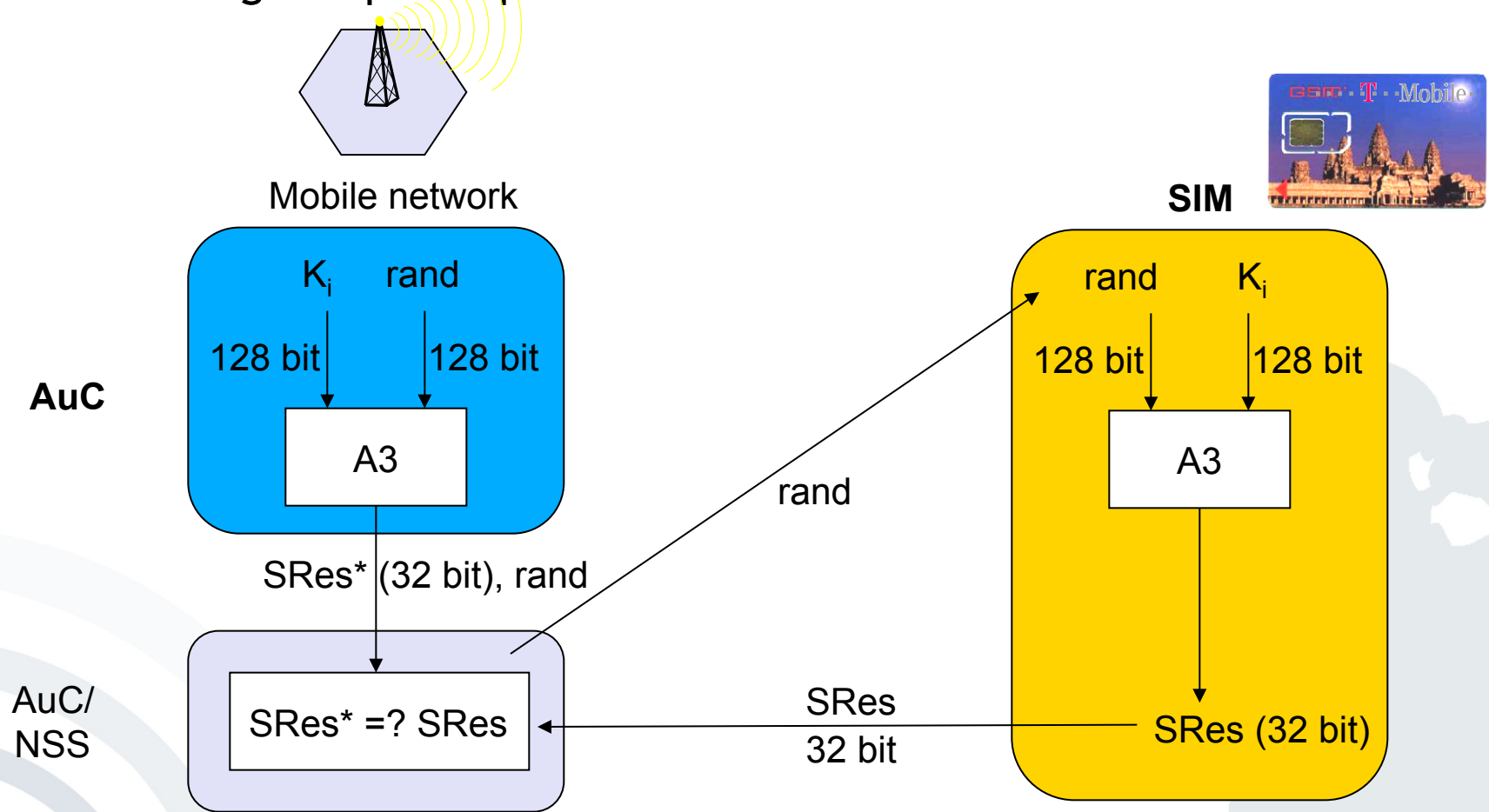
- **Components:**

- **Operation and Maintenance Centre (OMC):** Supervises each network component and creates status reports
- **Authentication Centre (AuC):** protects identity of participants & data transmission, administrates keys
- **Equipment Identity Register (EIR):** data base with identification list for devices, e.g. stolen terminals (whitelist, greylist, blacklist)

The GSM system offers different “security services”:

- **Access control and authentication:**
  - Authentication of the subscriber to the SIM by input of a PIN and to the GSM network by Challenge-Response-Procedure
- **Confidentiality:**
  - Data & voice transferred between mobile station and BTS are encrypted.
- **(Partial) Anonymity:**
  - No transfer of data which can identify the subscriber via radio, instead temporary identification
  - (Temporary Mobile Subscriber ID, TMSI)

- Challenge response protocol



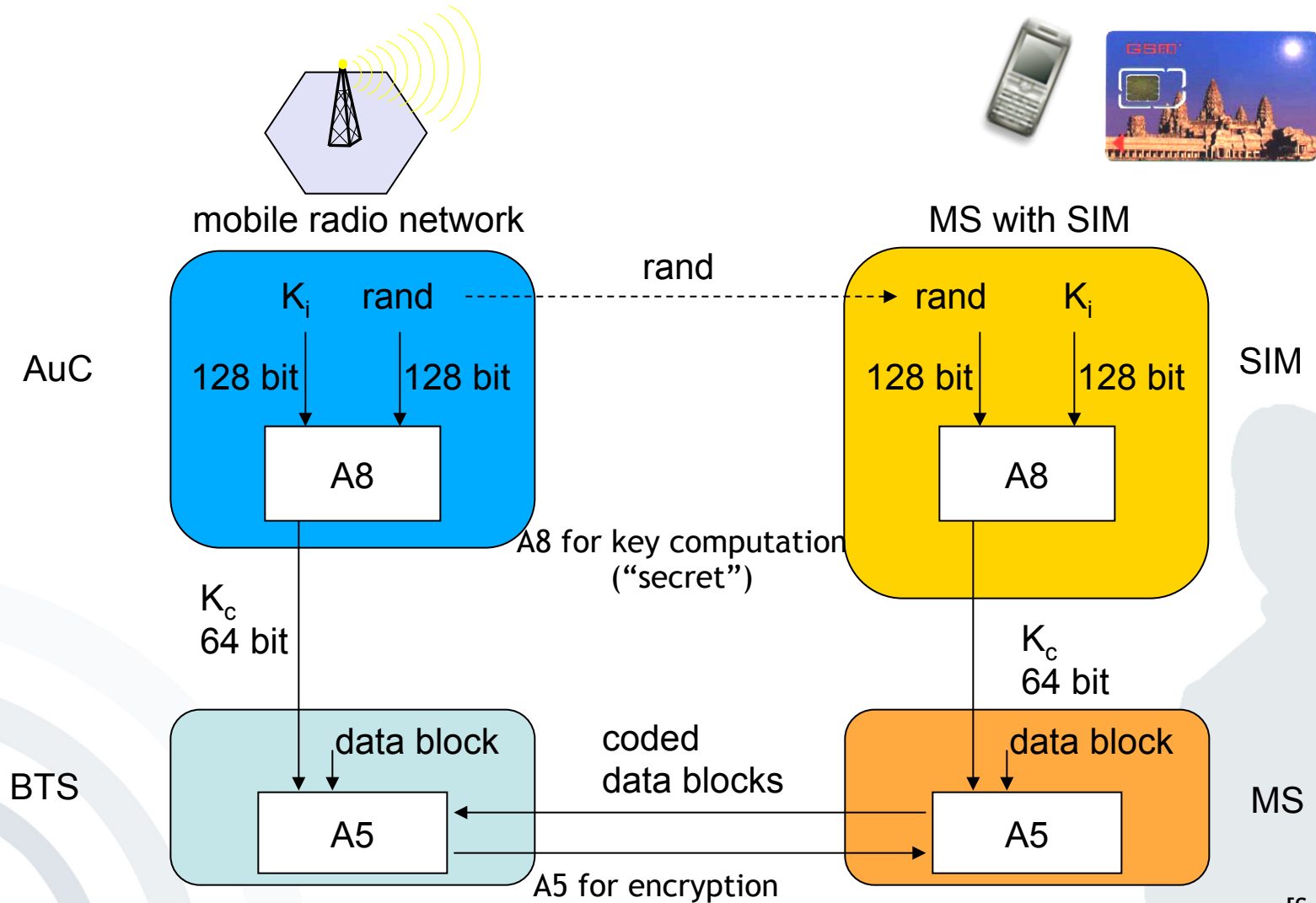
$K_i$ : individual subscriber authentication key

$A3$ : („secret“) authentication algorithm

$SRes$ : signed response



- Challenge-Response-Procedure (Subscriber Authentication)  
Authentication is based on the individual key  $K_i$ , the subscriber identification IMSI and a secret algorithm A3.
- $K_i$  and A3 are stored on the SIM and deposited in the AuC.
  1. AuC creates random number *rand*.
  2. AuC encrypts *rand* and  $K_i$  via A3 (-> SRes\*).
  3. AuC transfers *rand* and SRes\* to VLR.
  4. VLR transfers exclusively *rand* to SIM.
  5. SIM computes with “own”  $K_i$  and A3 Signed Response SRes.
  6. The SRES computed by the SIM is transmitted to the VLR and is compared with SRES\*.
  7. If SRES\* and SRES are equal the subscriber is authenticated successfully.



- **GSM provides encryption of voice and data transferred via the air interface:**
  1. AuC creates random number  $rand$ .
  2. AuC generates the key  $K_c$  for the encryption of the transferred data via  $rand$ ,  $K_i$  and A8.
  3. VLR transfers only  $rand$  to SIM.
  4. SIM computes the key  $K_c$  using A8, the  $rand$  received and the local  $K_i$ .
  5. Mobile station and mobile radio network use generated  $K_c$  and algorithm A5 for encryption and decryption of sent and received data.

- Partial Anonymity:
  - In order to guarantee the anonymity of the users temporary user identification (TMSI) is used.
  - Temporary user identification is updated automatically from time to time or on demand.
  - Data which identify users are not transferred.
  - **Example:** Anonymous charging is (technically) possible via prepaid card.

- Solely authentication of the terminal/subscriber toward the GSM network. The network does not authenticate itself.
  - Assumption that the network is trustworthy per se
  - Security model was developed at a time with a provider monopoly
- Subscriber localization is almost exclusively controlled by the network.
  - Centralized movement tracking is possible
  - In order to avoid localization the subscriber must switch off the terminal.

- Security model bases partly on secret encryption algorithms.
  - A3 and A8 were published without authorization.
  - Some operators use non-standardized algorithms.
- No encryption from terminal to terminal but solely over the air interface
  - Encryption deactivation by the network possible, without notification of the users
- Encryption comparatively “weak” because of key length (64 bit)
  - Sometimes the real key length is shorter.

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- Universal Mobile Telecommunications System (UMTS):
  - **Status of 2G-Networks:** Different standards in some different continents avoid worldwide roaming
  - **Demand for 3G-Networks:** Globally uniform standard

➔ Voting of regional & national standardisation bodies (e.g. ETSI, ARIB, ANSI) via the International Telecommunication Union (ITU)



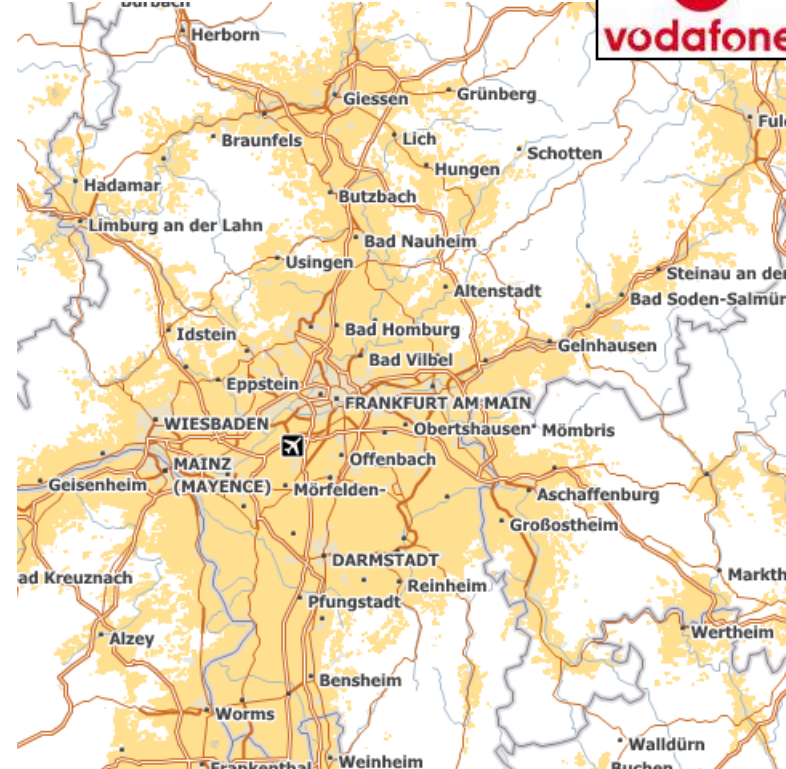




2010



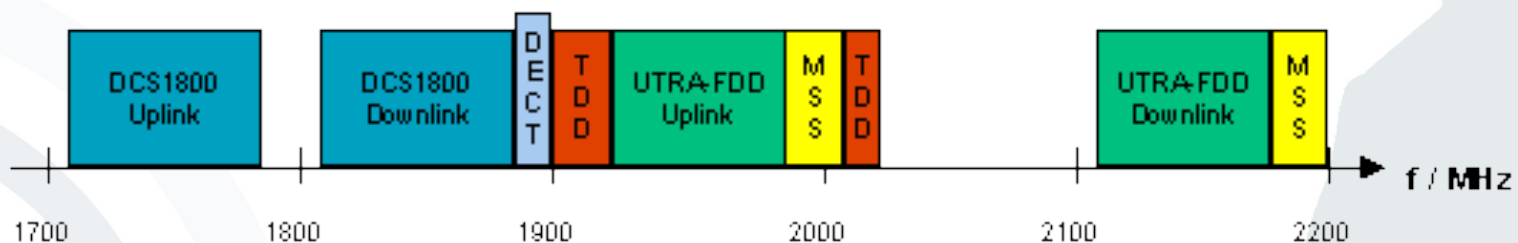
2010



- 3G coverage of Vodafone and Telefónica O<sub>2</sub> 2010-2015: Roughly unchanged.

[GSM2010]

- **Common approach:**  
Worldwide reservation of frequencies in the 2GHz range
- **Problem of competing targets:**
  - Existing national networks and installed network technique shall preferably be transferred into the new standard.
  - ➡ The specification of 3G-Networks, introduced by the ITU, leaves room for national, partly incompatible implementations.
- UMTS (UTRA-FDD/TDD) frequency allocation in Europe:



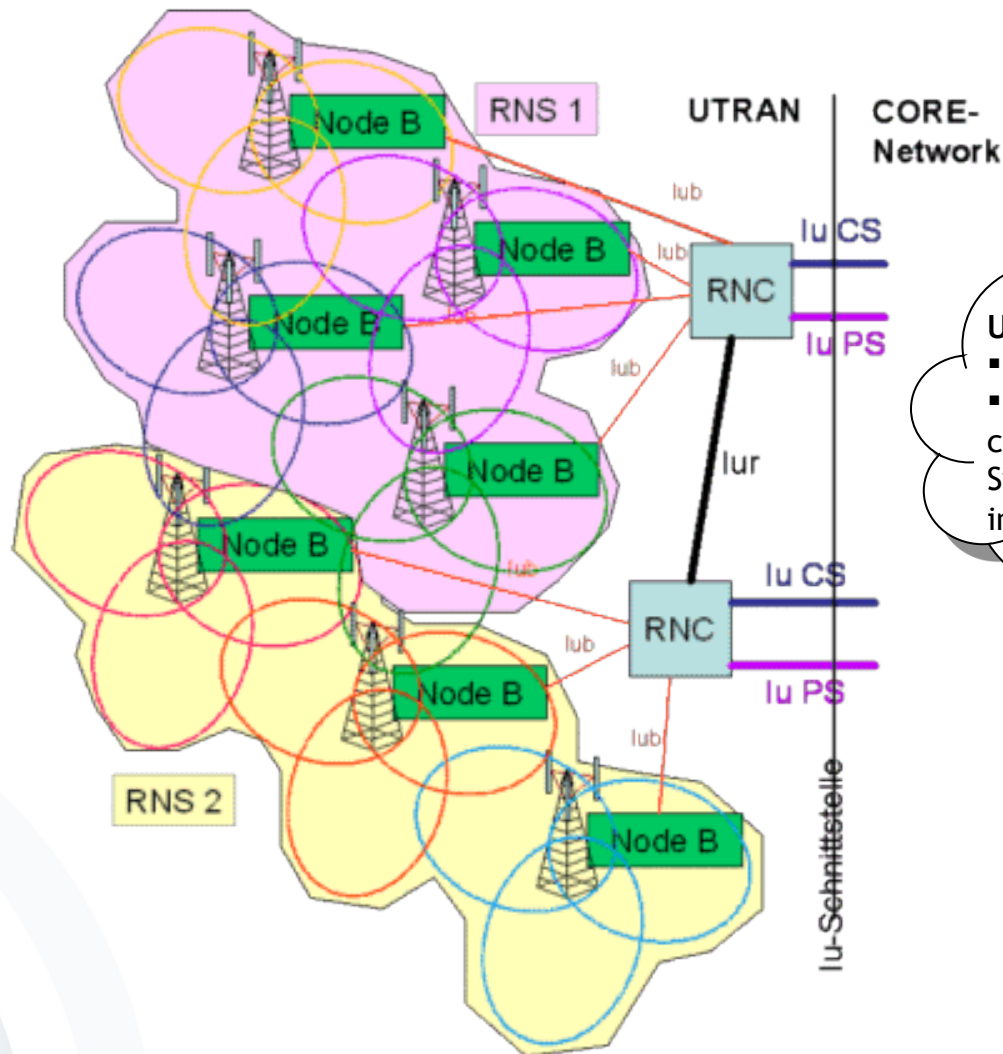
© 2001 UMTSlink.at

UTRA-FDD: UMTS Terrestrial Radio Access - Frequency Division Duplex

[UMTSlink2006]

# UMTS (3G) System Architecture

- **UTRAN:**  
UMTS  
Terrestrial  
Radio Access  
Network
- **RNS:** Radio  
Network  
Subsystem
- **RNC:** Radio  
Network  
Controller  
(controls the  
Node Bs)
- **Node B:**  
UMTS base  
stations  
(equivalent  
to base  
transceiver  
stations  
(BTS) in GSM)



## UMTS Core network

- is not shown here in detail
- UMTS Core network corresponds to Network- & Switching Subsystem (NSS) in GSM

- 3G UMTS/HSPA/HSPA+ bandwidths
    - UMTS: 384 kbit/s downlink/uplink
    - High Speed Packet Access (HSPA) provides higher data speeds for downlink and uplink, e.g.
      - 7.2 or 14.0 Mbit/s downlink speed (HSDPA)
      - 1.4 or 5.7 Mbit/s uplink speed (HSUPA).
    - Evolved HSPA (HSPA+) using either *Multiple Input Multiple Output (MIMO)* or *Dual-Cell* technology provides
      - downlink speeds of e.g. 21,1 or 42,2 Mbit/s and
      - a maximum uplink speed of 11.5 Mbit/s.
  - But: Available bandwidth per user decreases if terminal is moving or if there are many participants in one radio cell.
- ➔ Bandwidths enable multimedia services

- UMTS complements the security mechanisms known by GSM:
  - Enhanced participant authentication (EMSI)
  - Network authentication
  - Integrity protection of data traffic
  - Transferred security keys are also encrypted in the fixed network (e.g. HLR-VLR)
  - Increased key length
  - End-to-End encryption is possible.

- The UMTS standard includes the following features:
  - Quality of Service (QoS) for data services
  - Multilateral Security (with regard to authentication)
  - Virtual Home Environment (VHE)
  - High Speed Downlink Packet Access (HSDPA)
  - ...
- However, not **all** of these features that have been standardised are actually implemented in existing networks, as they are optional and can be added on demand.



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- **Long Term Evolution (3.9G, “4G”)** standard allows for 300 Mbit/s downlink and 75 Mbit/s uplink speeds
  - First commercial LTE network launched in Scandinavia in December 2009
  - LTE was originally not named a “4G network” due to stricter naming requirements \*)
  - The technology can be named either 3.9G or 4G network today.
- **LTE Advanced (4G)** makes use of the frequency spectrum more efficiently, resulting in higher data rates (towards 1 Gbit/s) and lower latency. It remains backward compatible with LTE, uses same frequency bands.



<http://www.3gpp.org/LTE>



<http://www.3gpp.org/LTE-Advanced>

\*) A 4G service was originally defined as meeting the *IMT-Advanced* requirements issued by the ITU-R. For more information see [Parkvall2008].



### LTE Speeds

▪ 3GPP Release 8 User Equipment **Category 3**: 100 Mbit/s downlink and 50 Mbit/s uplink.

▪ 3GPP Release 8 User Equipment **Category 4**: 150 Mbit/s downlink and 50 Mbit/s uplink.

▪ 3GPP Release 8 User Equipment **Category 5**: 300 Mbit/s downlink and 75 Mbit/s uplink.

### LTE Advanced Speeds

▪ 3GPP Release 10 User Equipment **Category 6**: 300 Mbit/s downlink and 50 Mbit/s uplink.

▪ 3GPP Release 10 User Equipment **Category 7**: 300 Mbit/s downlink and 150 Mbit/s uplink.

▪ 3GPP Release 10 User Equipment **Category 8**: 1200 Mbit/s downlink and 600 Mbit/s uplink.



## LTE Advanced Speeds

- 3GPP Release 11 User Equipment **Category 9**: 452.2 Mbit/s downlink and 51 Mbit/s uplink.
- 3GPP Release 11 User Equipment **Category 10**: 452.2 Mbit/s downlink and 102 Mbit/s uplink.
- 3GPP Release 12 User Equipment **Category 11**: 603 Mbit/s downlink and 51 Mbit/s uplink.
- 3GPP Release 12 User Equipment **Category 12**: 603 Mbit/s downlink and 102 Mbit/s uplink.
- 3GPP Release 12 User Equipment **Category 13**: 391.6 Mbit/s downlink and 153 Mbit/s uplink.
- 3GPP Release 12 User Equipment **Category 14**: 391.6 Mbit/s downlink and 102 Mbit/s uplink.
- 3GPP Release 12 User Equipment **Category 15**: 3,916.6 Mbit/s downlink and 1,497.8 Mbit/s uplink.



- LTE networks are **IP-based systems** (all-IP networks)
  - Voice calls in GSM and 3G (UMTS) are **circuit-switched**.
  - Only **packet-switched** communication is supported in LTE networks - no circuit-switched connections/calls/telephony!
- Four different approaches to provide telephony services in Long Term Evolution networks:
  - **CSFB** (Circuit Switched Fallback)
  - **VoLGA** (Voice over LTE via GAN - Generic Access Network)
  - **VoLTE (Voice Over LTE)** based on the IP Multimedia Subsystem (IMS) network.
  - **SVLTE** (Simultaneous Voice and LTE, handset-based approach)



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- Roaming

Two views of 5G:

- **View 1** - The hyper-connected vision
- **View 2** - Next-generation radio access technology

## 5G technology requirements

- 1 millisecond end-to-end round trip delay (latency)
- 1-10 Gbps connections to end points in the field (i.e. not theoretical maximum)
- 1000 x bandwidth per unit area
- 10-100 x number of connected devices
- 99.999 % availability
- 100 % geographical coverage
- 90 % reduction in network energy usage
- Up to ten year battery life for low power, machine-type devices

[GSMA5G]

- Autonomous driving/Connected cars
- Wireless cloud-based office/Multi-person videoconferencing
- Machine-to-machine connectivity (M2M)
  - vehicle telemetric systems (a field which overlaps with Connected cars above)
  - ‘connected home’ systems (e.g. smart meters, smart thermostats, smoke detectors)
  - consumer electronics and healthcare monitoring.
- Virtual Reality/Augmented Reality/Immersive or Tactile Internet

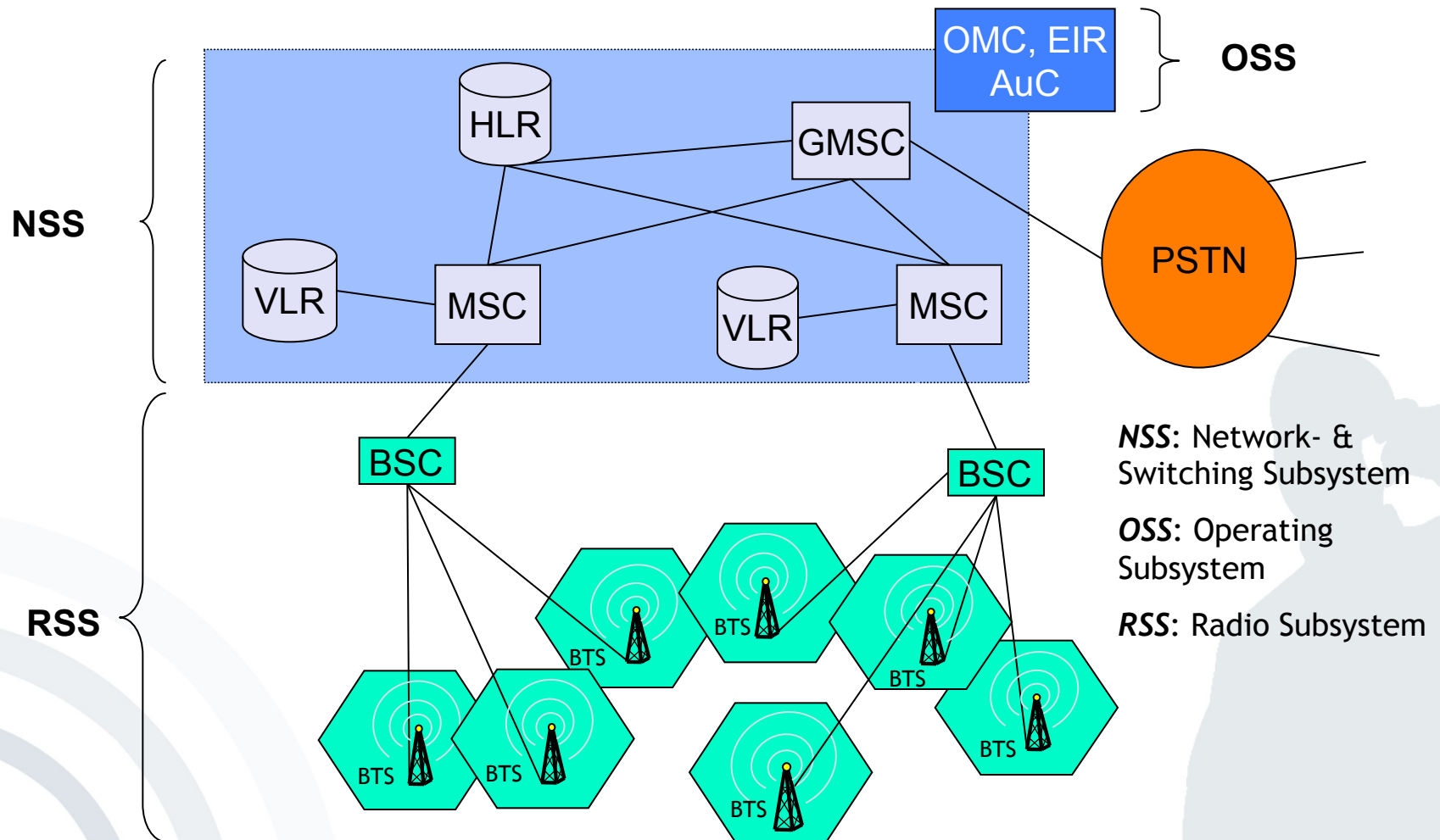
- Transmission Paradigms
- Cell Based Communication (CBC)
  - Introduction
  - Basic Technology (Cells, Multiplexing)
- Mobile Telecommunication Infrastructures
  - Introduction
  - GSM (Technology, Authentication, Location Management) (2G)
  - UMTS (3G)
  - Long Term Evolution (3.9G, 4G)
  - 5th Generation (5G): mobile broadband
- Roaming



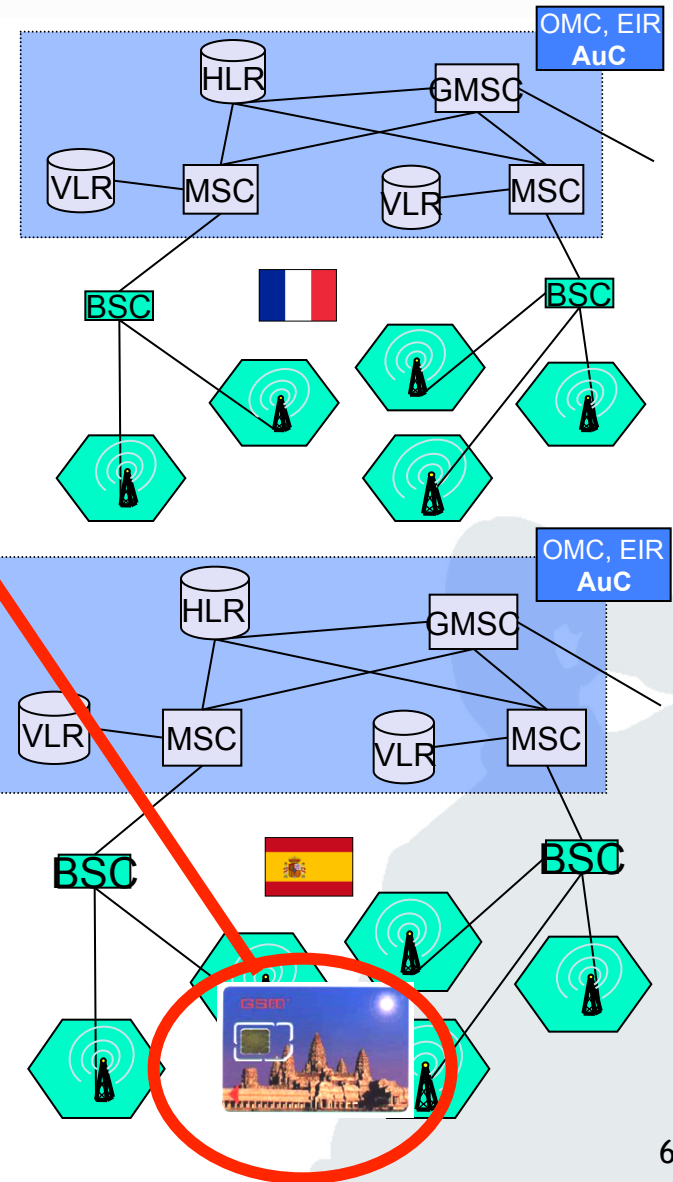
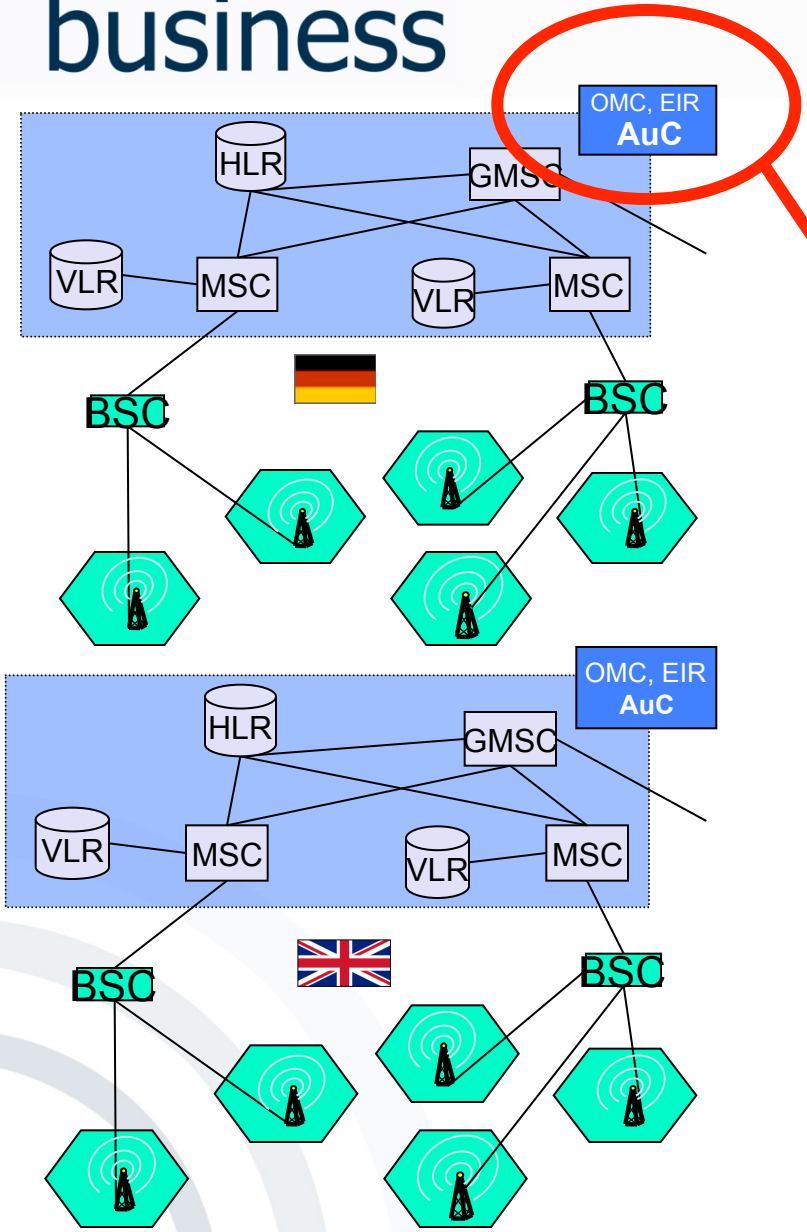
- Roaming denotes a change of network access, e.g.:
  - Change of the GSM network operator
  - Change between different network systems (UMTS, GSM, WLAN, CDMA, PDC)
  - Cell change within the GSM system (Handover)
- Roaming usually means extensive changes, e.g. of the network technique or the network operator, and with a new authentication:
  - **Example:** The mobile device automatically logs into an available WLAN when a hotspot is entered (e.g. airport, conferences).



- If a user of a mobile device moves from one cell to another cell, the connection handover should be as smooth as possible.
- GSM manages the handover between radio cells in the range of 100 ms; this implies a short connection interruption.
- The reason for the interruption is, among others, an update of the VLR.

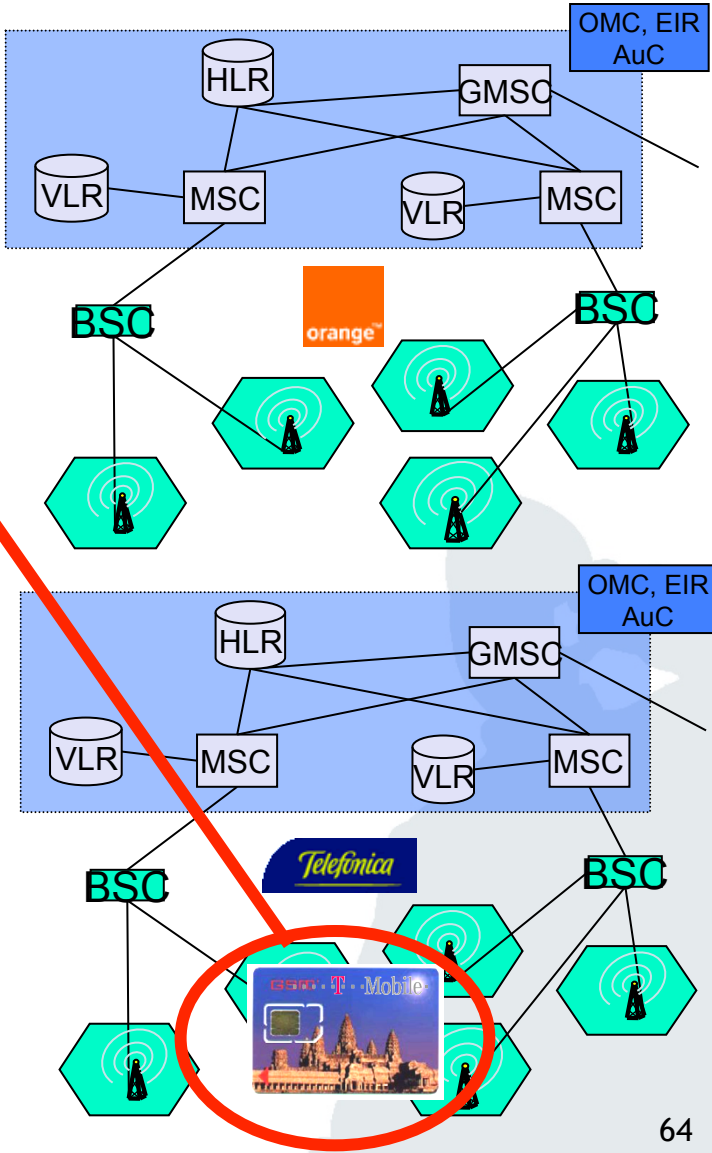
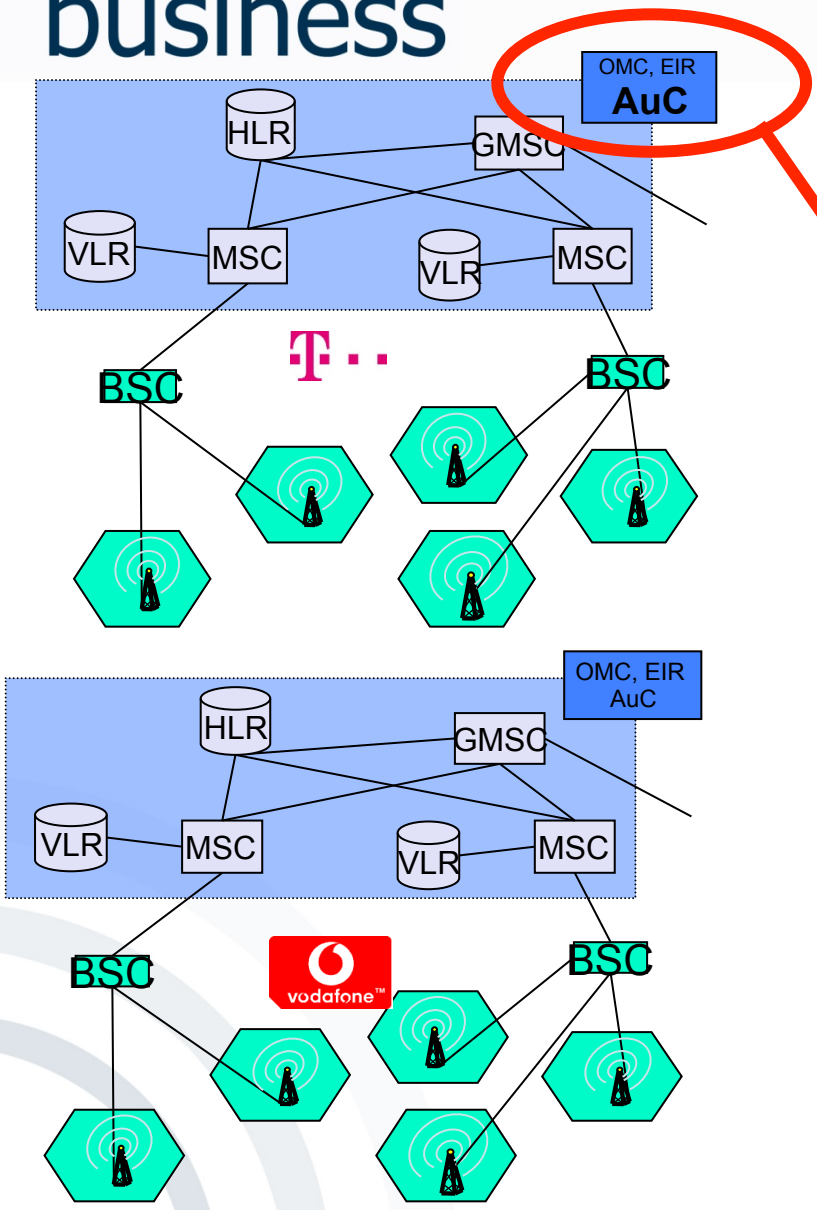


## Roaming SIM Based Roaming



# Roaming

## SIM Based Roaming



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