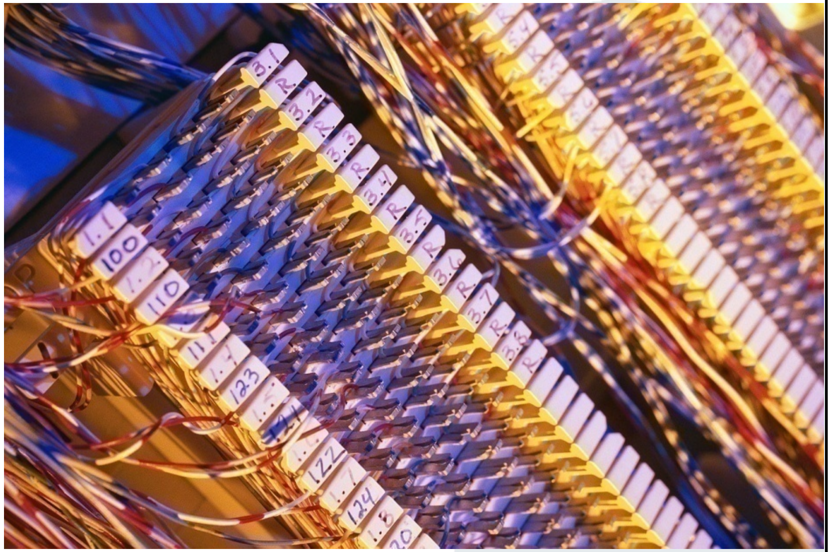
mobile business

Lecture 2

Basic Communication Paradigms and Mobile Telecommunications Infrastructures



Mobile Business I (WS 2023/24)

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Chair of Mobile Business & Multilateral Security
Johann Wolfgang Goethe University Frankfurt a. M.

- 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

Mobile Data Services
Data Transmission Paradigms

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.

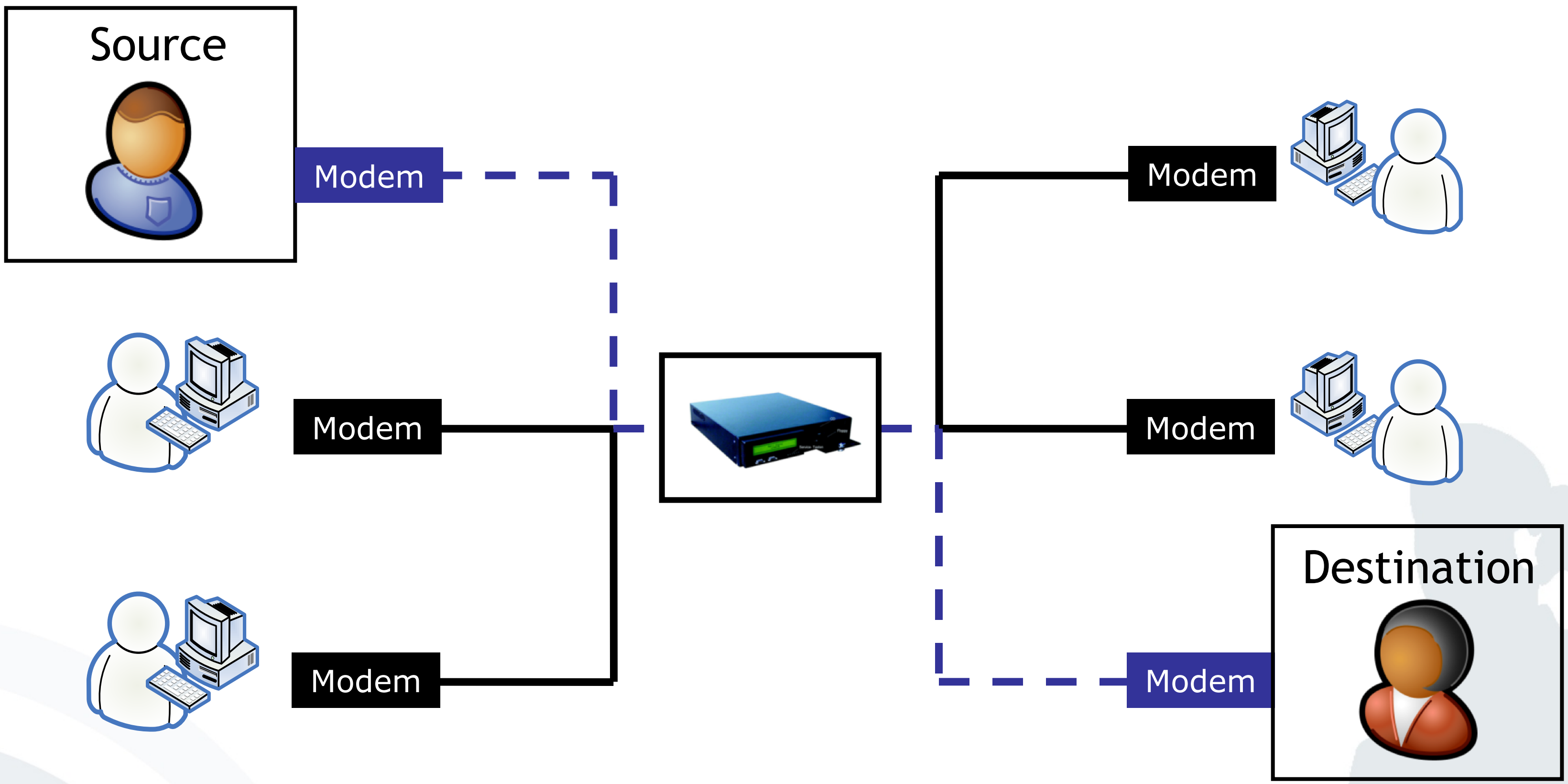
- Connections are **exclusive** ➲ even if no data is transferred, the network resources are used.
- In reality, the typical usage for voice connections is 30% of the network's capacity - for data transmission it is less than 10%.
- The ***duration of a connection*** is used for billing purposes
- Example: *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

[Schiller2003]

Mobile Data Services
Circuit-Switched Networks

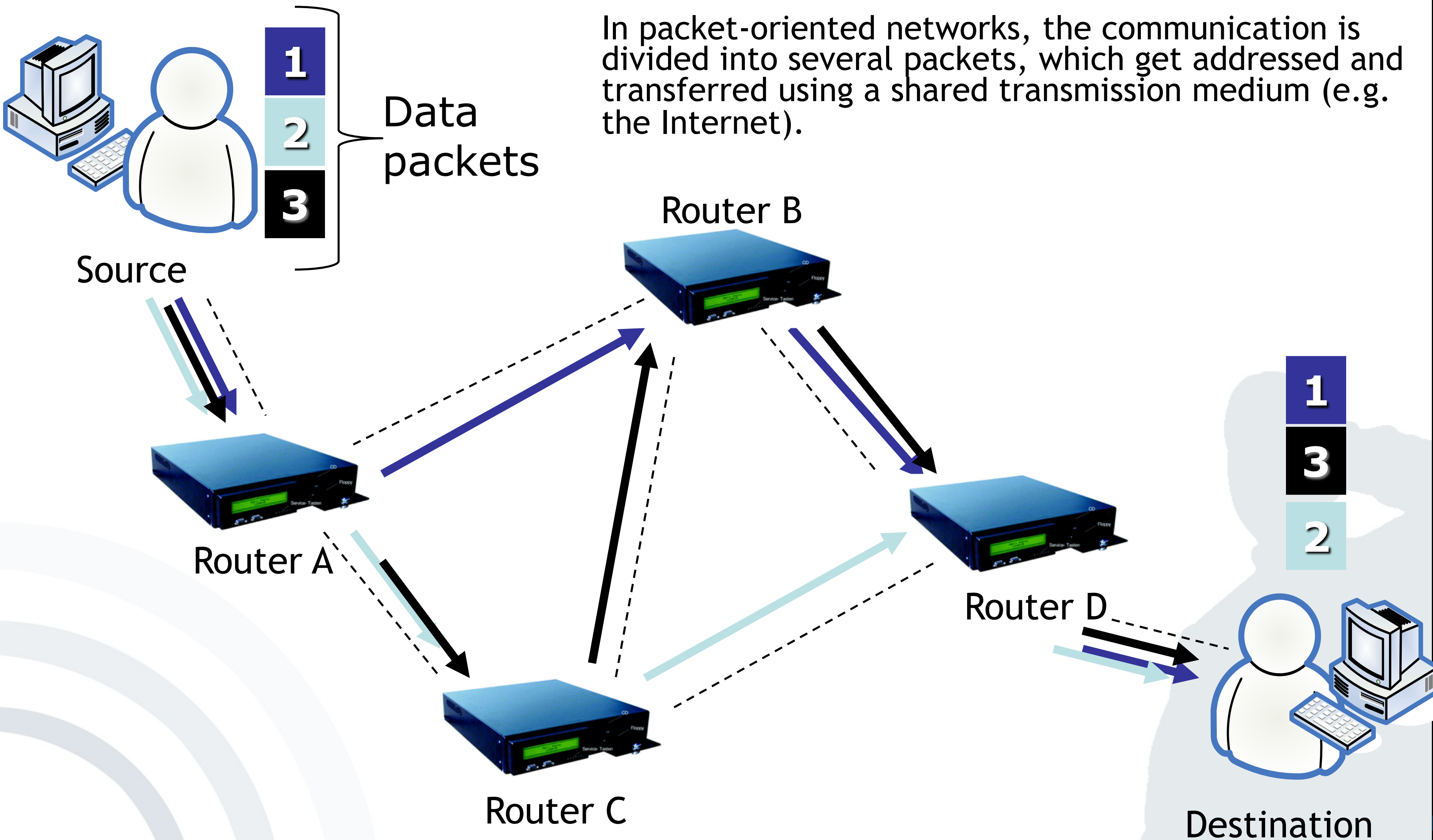


In circuit-switched networks, the communication line is used exclusively for the communicating parties (similar to the phone system, CSD and HSCSD).

[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).



[M-Chair]

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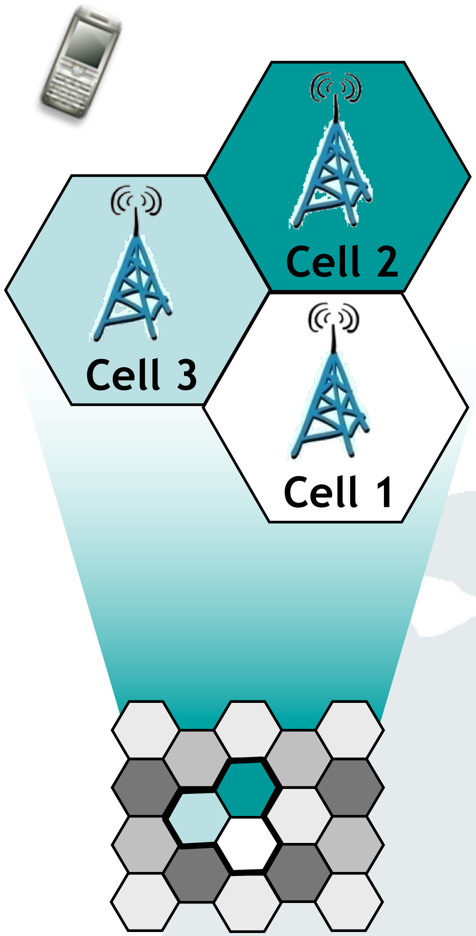
Cell Based Communication (CBC)

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.



[Schiller2003]

[M-Lehrstuhl]

Cell Based Communication (CBC)

Advantages of CBC (1)

- 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

[Schiller2003]

Cell Based Communication (CBC)

Advantages of CBC (2)

- 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

[Schiller2003]

Cell Based Communication (CBC)

Disadvantages of CBC

- 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.

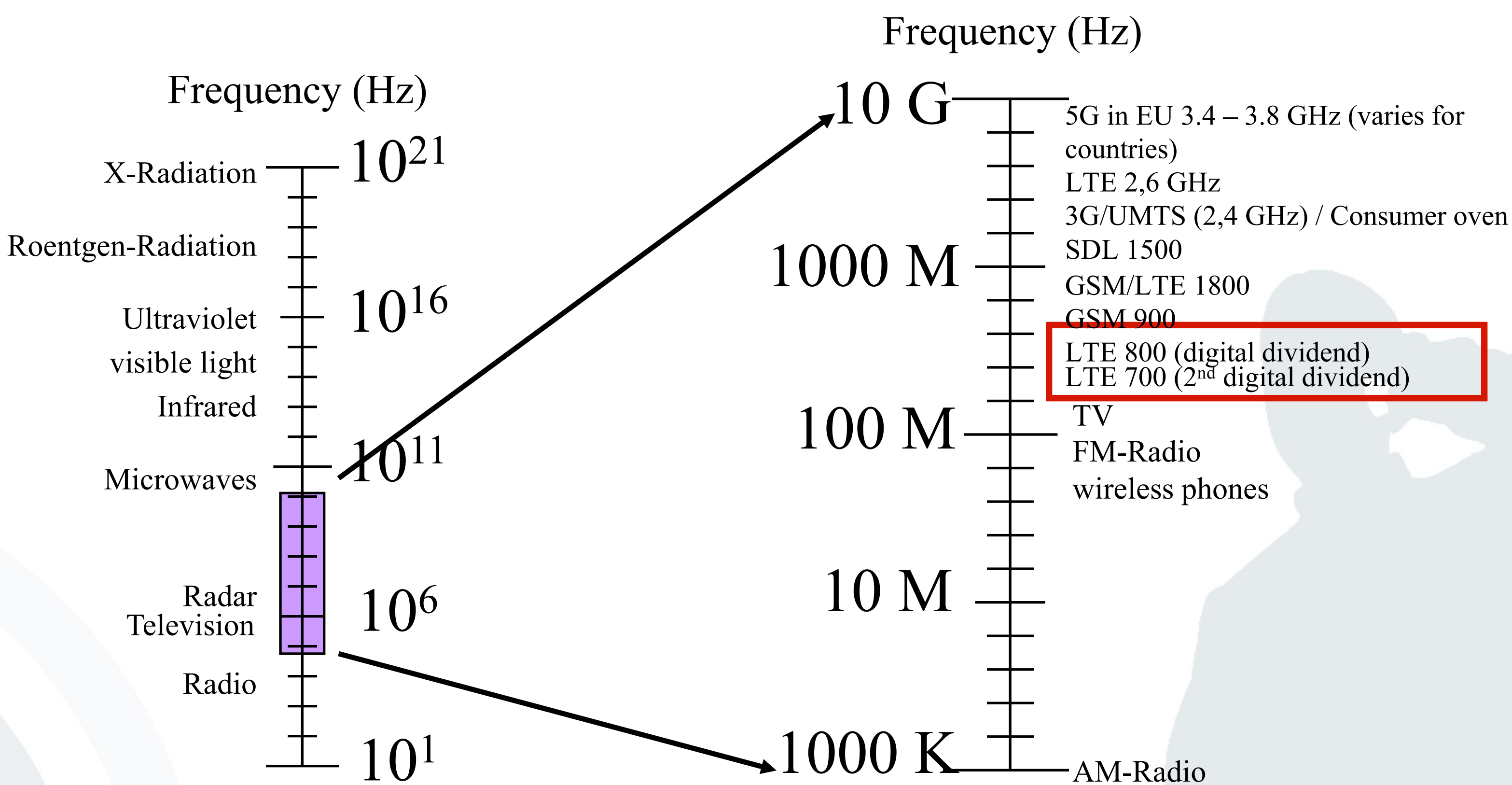
[Schiller2003]

Cell Based Communication (CBC)

Multiplexing

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

Frequency range of instruments of entertainment and communication electronics



Cf. [Heise2014] for more information on discussion related to the digital dividend.

Overview

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Mobile Telecommunication Infrastructures

- ***1st Generation (1G) - Analogue networks***
- ***2nd Generation (2G) - GSM networks***
  Global System for Mobile Communications
- ***3rd 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
- ***4th Generation (4G) - LTE Advanced***
- ***5th Generation (5G) - Mobile broadband***
- ***6th Generation (6G) - Ubiquitous wireless intelligence [Latva19]***

Evolution of mobile telecommunication infrastructures

2G – GSM | **3.9G/4G – LTE** | **5G**

1G | **3G – UMTS** | **4G – LTE Advanced** | **6G**

Mobile Telecommunication Infrastructures – Early history

- ***1st mobile radio network in Germany: "A-Netz"***
  - Started in 1958 – decommissioned in 1977
  - Analogue transmission
  - Manual switching of calls
  - For a call to a mobile callee the caller or operator (switchboard clerk) needed to know the location area of the callee (range from 30 to 50 km radius).
  - Frequency range 150 MHz
  - Price of terminal: 8.000 - 15.000 DM
- ***2nd mobile radio network in Germany: "B-Netz"***
  - Started in 1972 – decommissioned 1994-12-31
  - Analogue transmission
  - Automatic dial switching by area code
  - Caller needed to know the area and the area code of the mobile callee.
  - Terminal prices comparable to those of the "A-Netz"

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Mobile Telecommunication Infrastructures – Early history

- ***3rd mobile radio network in Germany: “C-Netz”***
  - Started in 1985 – decommissioned 2000-12-31
  - Analogue transmission
  - First ***cell based*** mobile radio system in Germany
  - The change of cells happens automatically by distance measuring to the nearest base station.
  - The network 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 a magnet stripe card and later a chip card (predecessor of the GSM SIM)
  - Customer peak 1993: 850.000 participants

Mobile Telecommunication Infrastructures 1990-2008

- 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.

Mobile Telecommunication Infrastructures 2009-2018

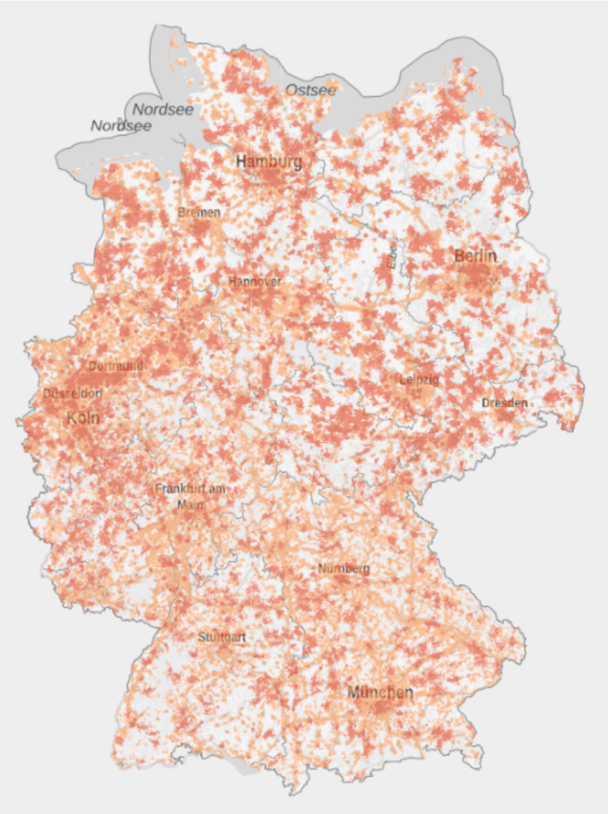
- First **Long Term Evolution** Networks (3.9G/4G) became **commercially available** in Stockholm and Oslo in 2009.
- On April and May 2010, the **digital dividend** frequency spectrum auctioned in Germany (4.4 bn €) for
  - use in Long Term Evolution Networks (3.9G/4G)
  - improving broadband coverage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

Mobile Telecommunication Infrastructures 2019/2022

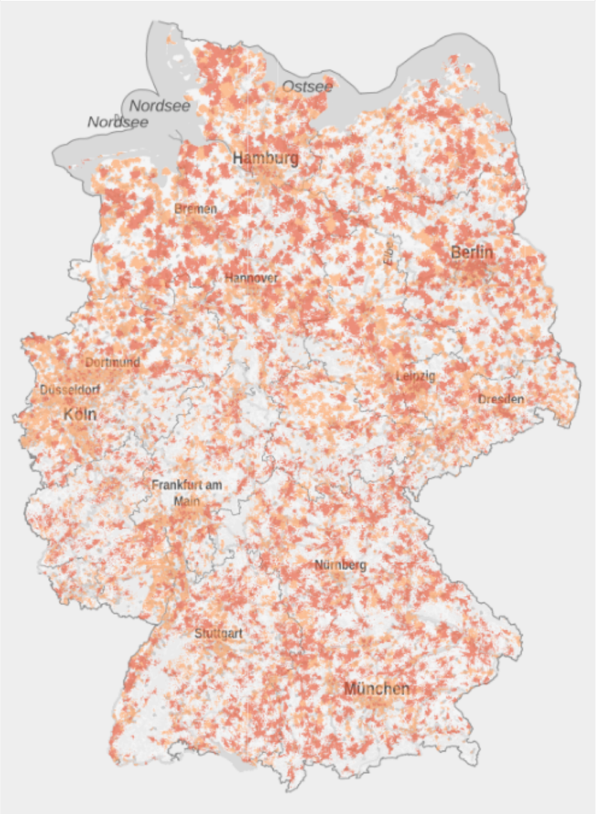
- 5G Auction finished on June 12, 2019
- 497 auctioning rounds led to 6,55 billion Euro in bidding[1]
  - Telekom: 13 frequency blocks, i.e. largest share among the bidding parties for 2,175 bn Euro
  - Vodafone: eleven frequency blocks for 1,880 bn euro
  - Telefónica: nine frequency blocks for 1,425 bn Euro
  - 1&1 Drillisch: seven frequency blocks for 1,070 bn Euro
- High bandwidth, low latency (especially important for real-time communication between devices like cars), high number of devices can be connected (IoT), availability and implementation (possible to build individual 5G networks for one company → examples include BASF and Hamburg Port)
- 3G networks went out of service in 2021/2022 in Germany.

Mobile Telecommunication 5G – Status of Rollout

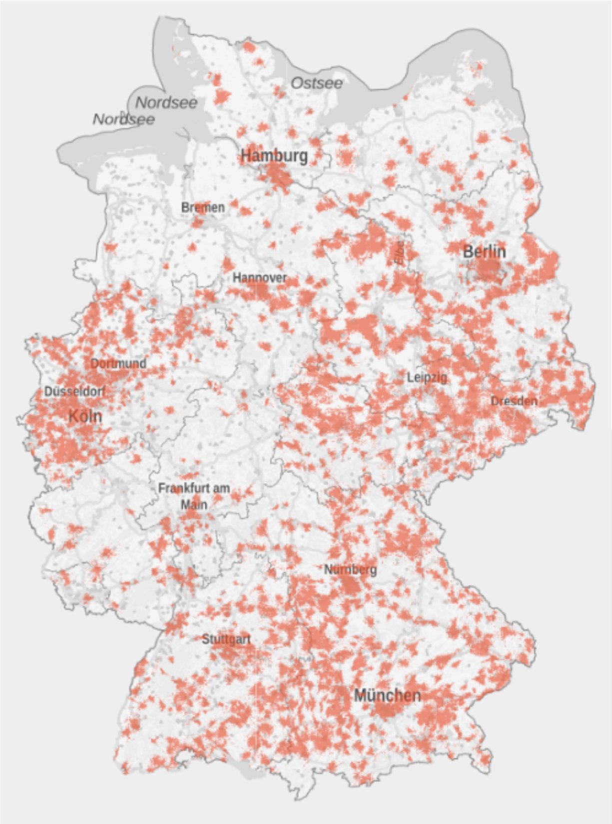
Telekom



Vodafone



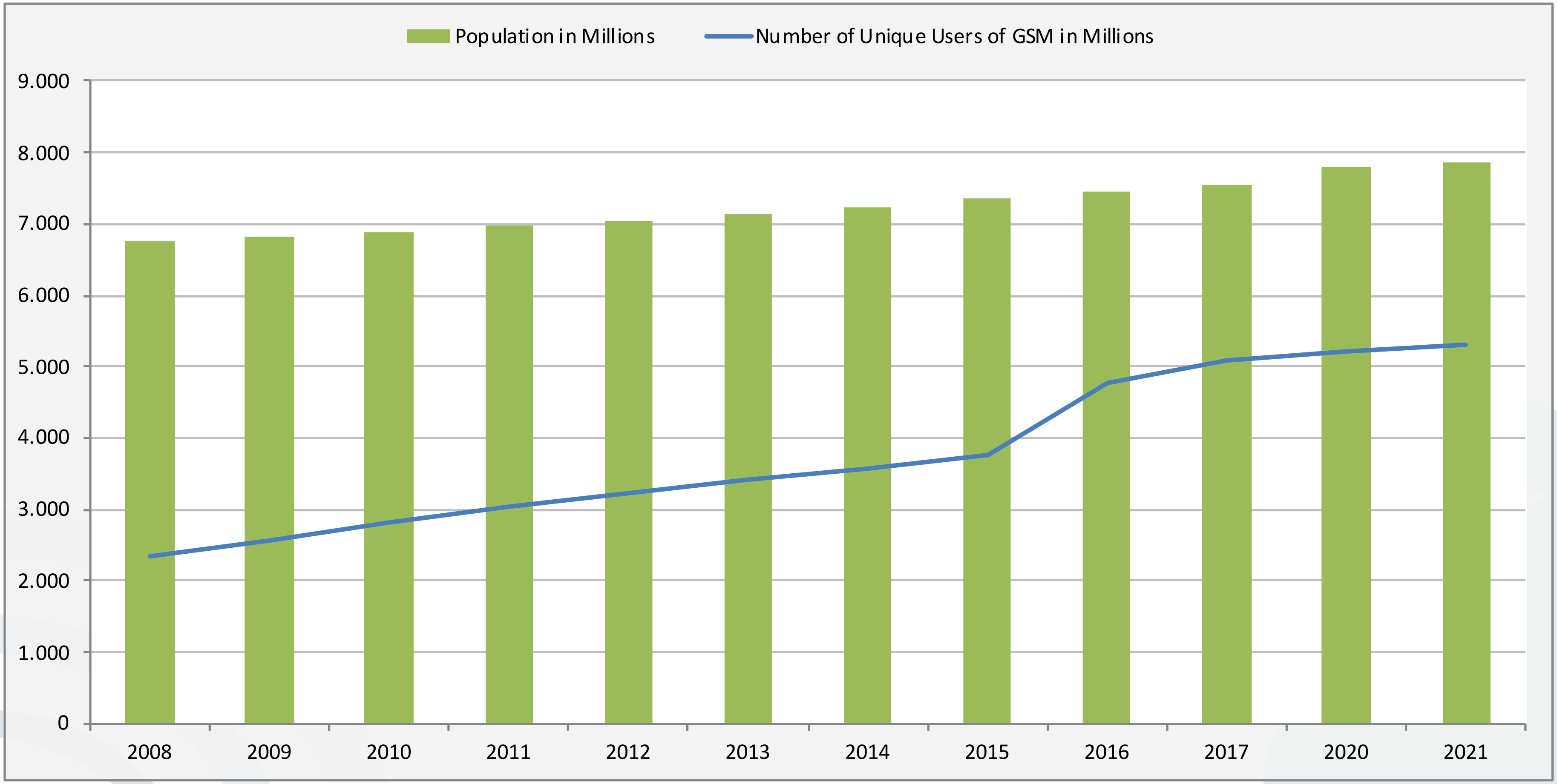
Telefonica



→ No similar representation of the current network coverage across Telcos

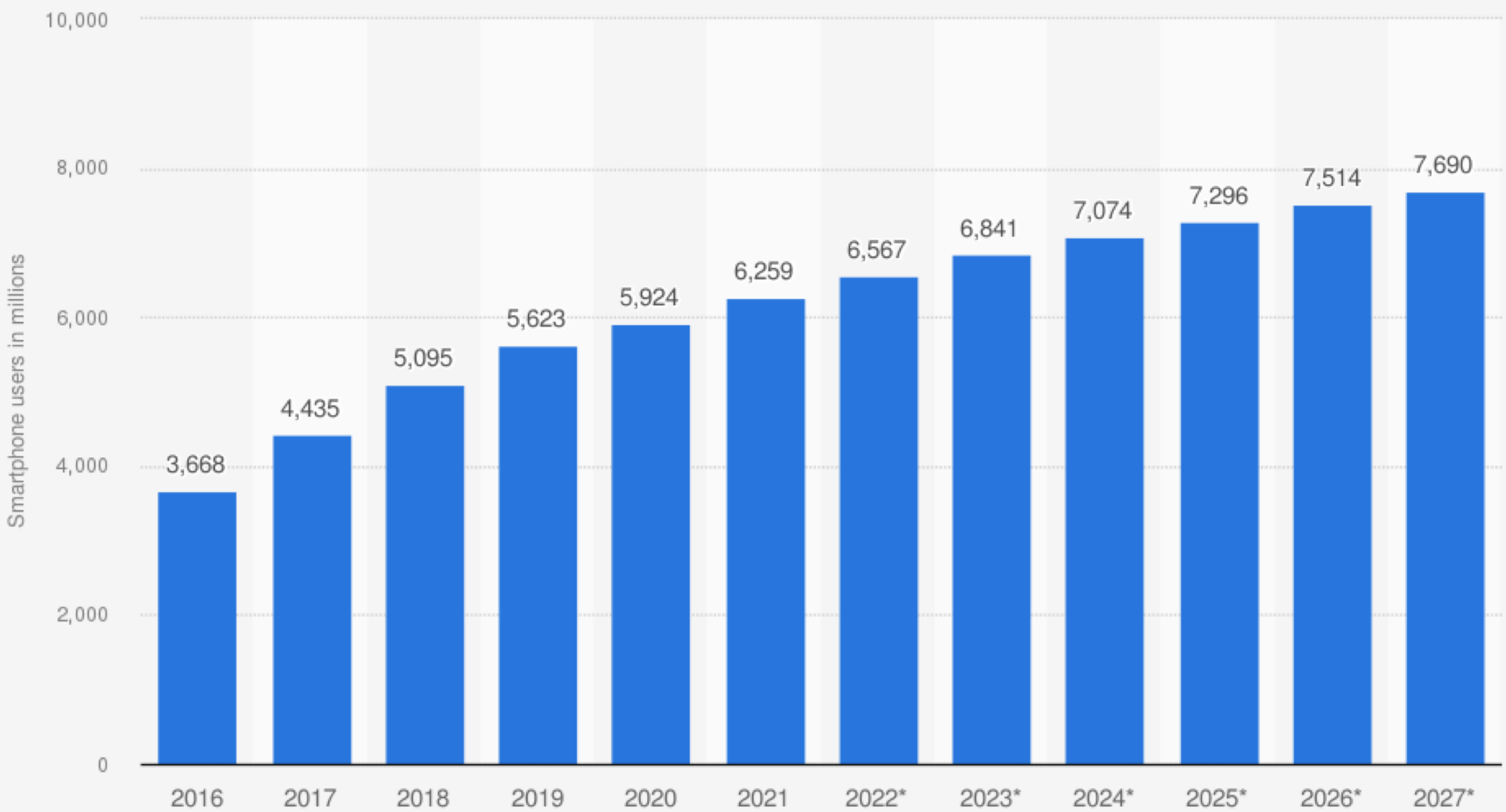
[Breitband2022]

Unique users of GSM and related networks Recent development



[Stat2013], [Stat2014], [StiftWelt2013], [StiftWelt2014], [GSMA2014][GSMA2015][Stat2015] [Stat2017] [GSMA2017] [GSMA2020] [Stat 2022] [GSMA2022]

Number of smartphone subscriptions worldwide from 2016 to 2021,
with forecasts from 2022 to 2027



Source
Ericsson
© Statista 2022

Additional Information:
Worldwide; Ericsson; 2016 to 2021

[Stat2022]

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GSM (2G)

Overview

- 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

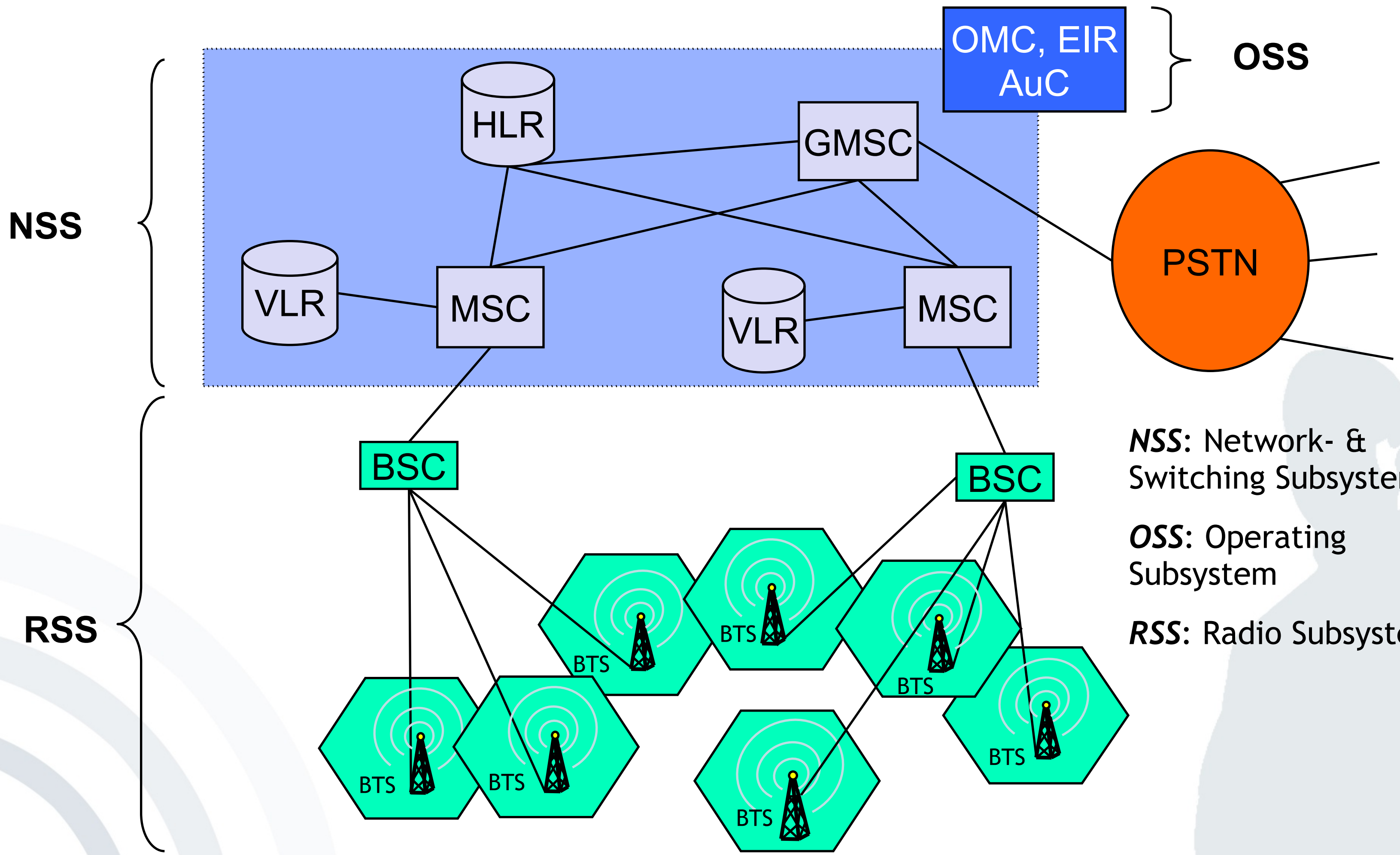
    →The focus of GSM standardization was on voice services
  - Telecommunications services
    - Telecommunication services (mainly voice) support the mobile communications among users

    →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).

Cf. Lecture 4 "Mobile Communication Services"

GSM (2G)

System Architecture



NSS: Network- & Switching Subsystem

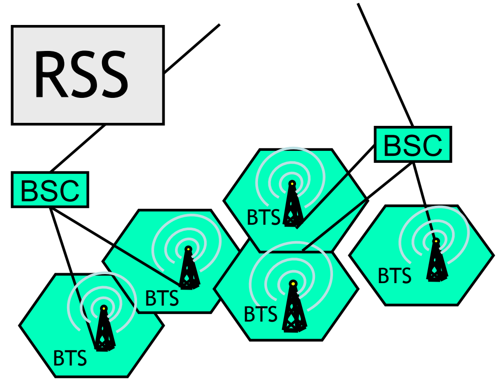
OSS: Operating Subsystem

RSS: Radio Subsystem

Based on [Schiller2003]

GSM (2G)

System Architecture – RSS



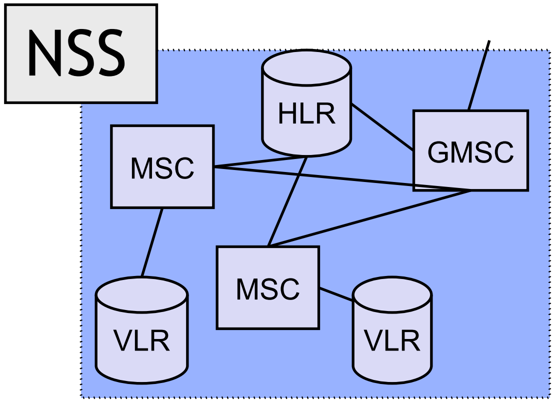
- **Radio Subsystem (RSS)**
  - System consisting of radio
  - Specific components
- Components:
  - **Mobile Station (MS):** System of mobile terminal & SIM
  - **Base Transceiver Station (BTS):** Radio facility for signal transfer. A BTS serves one GSM cell (~100m to ~30km radius).
  - **Base Station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

[Schiller2003]

GSM (2G)

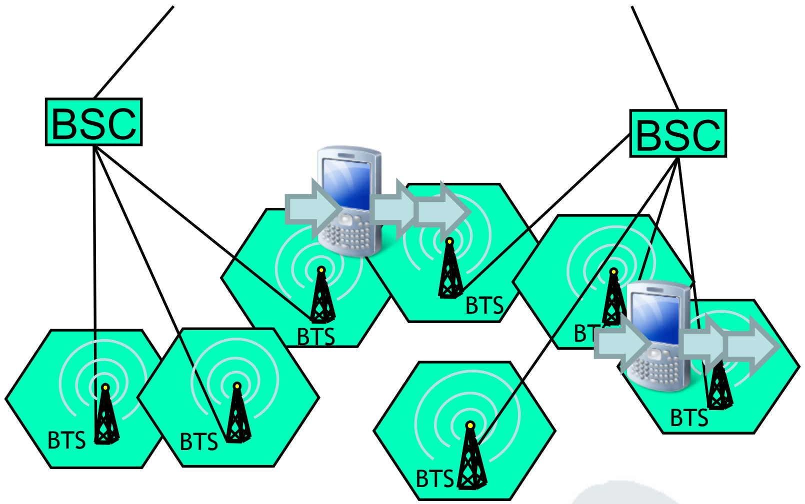
System Architecture – NSS

- **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
  - **Visitor Location Register (VLR):** Data base assigned to every MSC with data of active subscribers in the MSC's range (HLR fraction copy).
  - **Home Location Register (HLR):** Central data base with subscribers' data (International Mobile Subscriber Identity (IMSI), telephone numbers, keys, locations)

[Schiller2003]

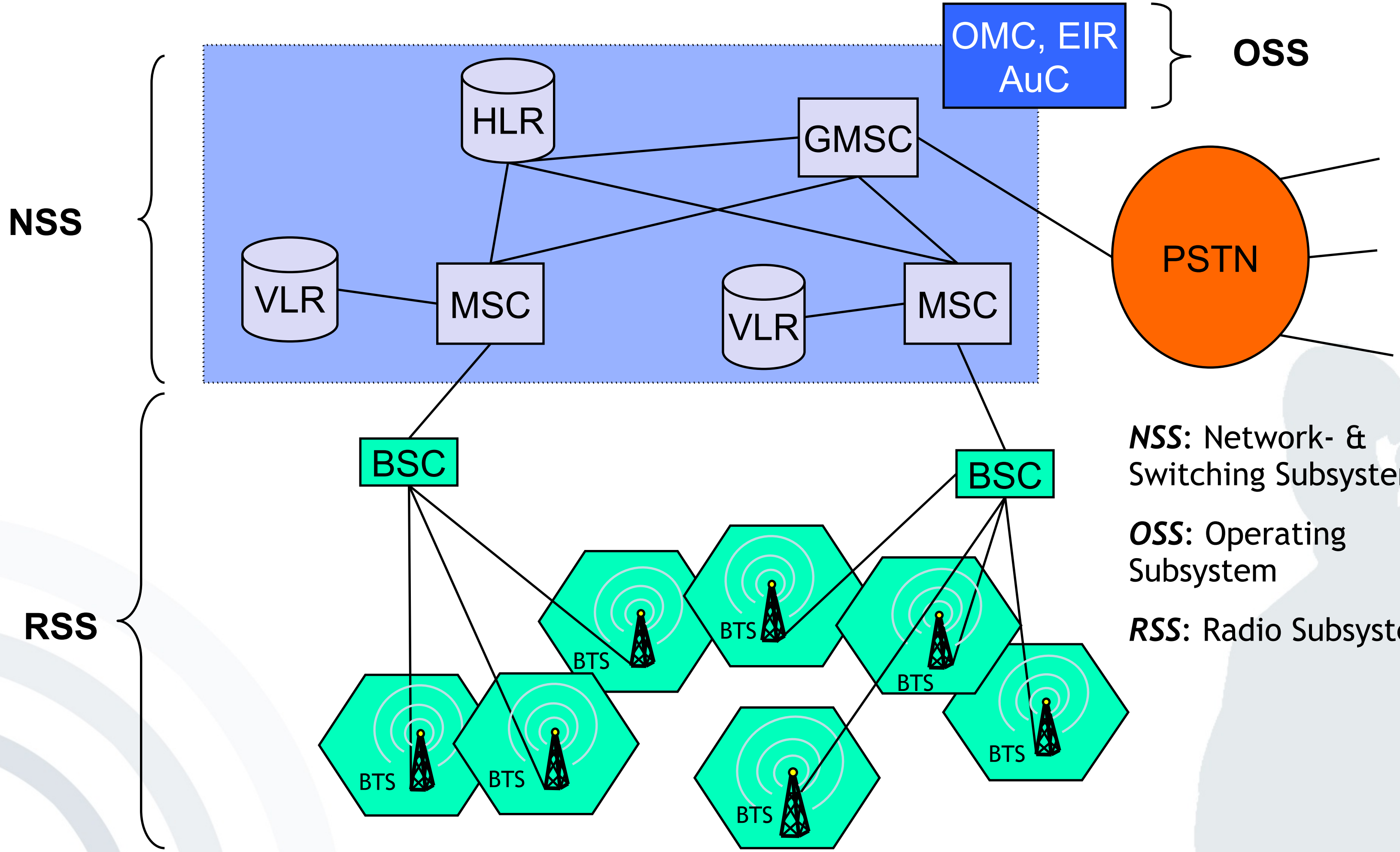


- Transfer of calls or data sessions from one trans-mitting station (in GSM: Base Transceiver Station, BTS) to another.

- 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

GSM (2G)

System Architecture – Handover



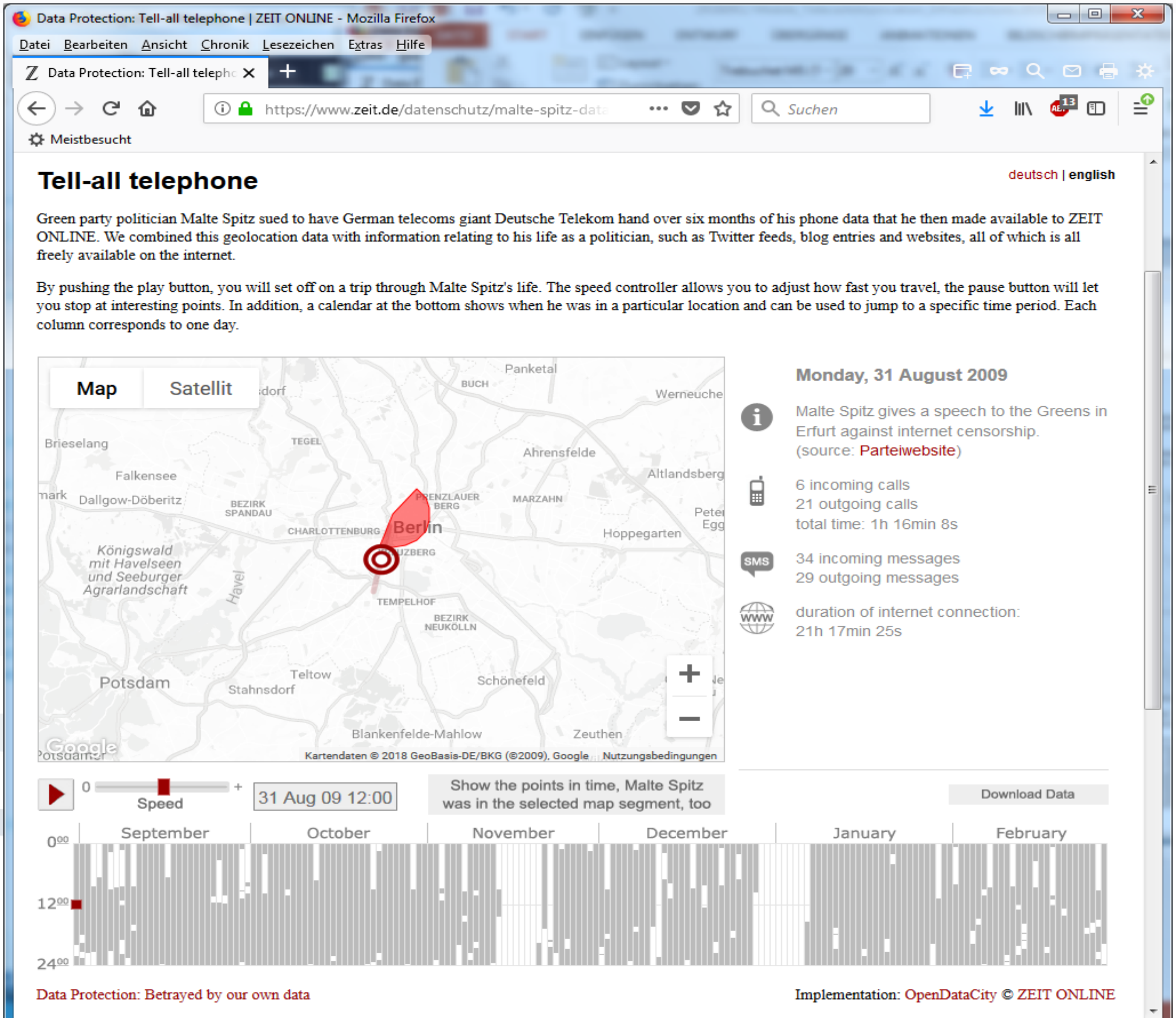
NSS: Network- & Switching Subsystem

OSS: Operating Subsystem

RSS: Radio Subsystem

Based on [Schiller2003]

Data retention of cell-based location data



[https://www.zeit.de/datenschutz/malte-spitz-vorratsdaten]

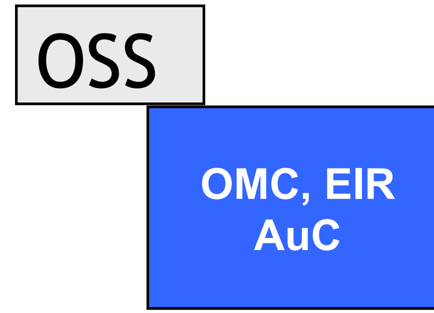
Handover

Roaming within GSM

- 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.

GSM (2G)

System Architecture – OSS



- **Operation Subsystem (OSS)**
  - Supervises operation and maintenance of the whole GSM network

- 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)

[Schiller2003]

GSM (2G)
Security Model

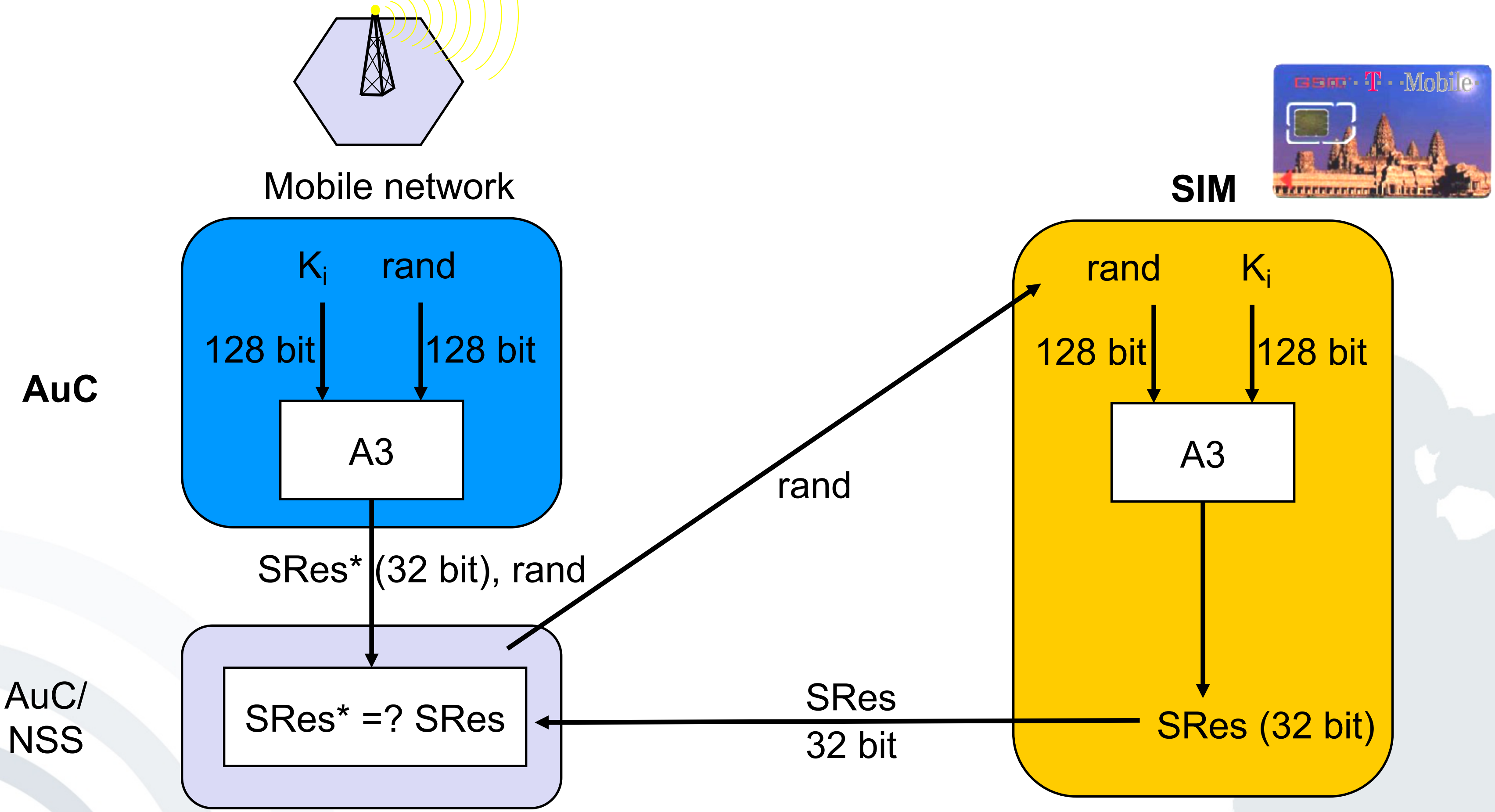
The GSM system offers several “security services“:

- **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)

GSM (2G)

SIM based subscriber authentication

- Challenge-response procedure



K_i: individual subscriber authentication key

A3: („secret") authentication algorithm

SRes: signed response

[Schiller2003]

GSM (2G)

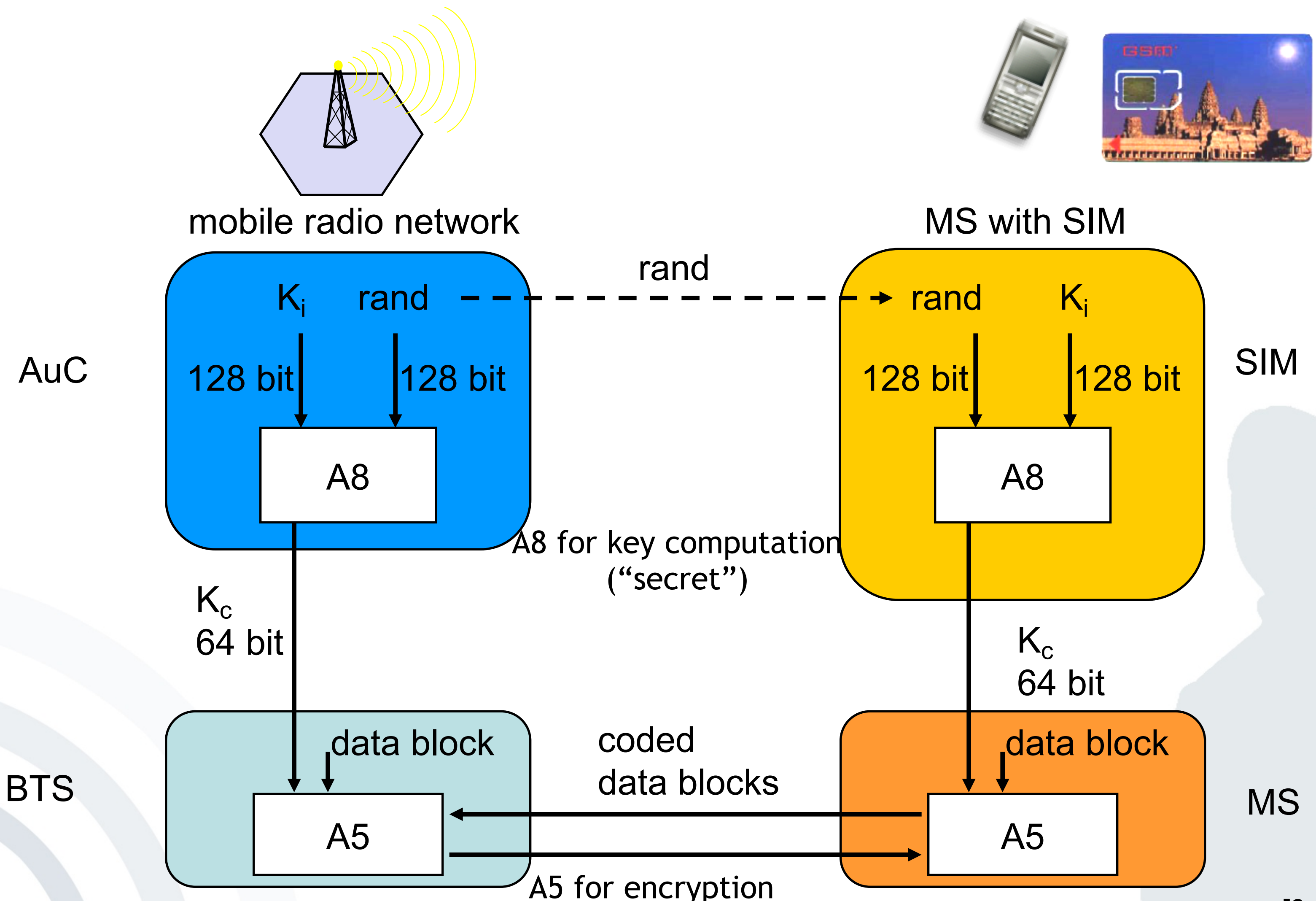
Security Model

- 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 (2G)

Security Model – Encryption



[Schiller2003]

GSM (2G)

Security Model – Encryption

- **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.

GSM (2G)

Security Model – Shortcomings

- 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.

GSM (2G)

Security Model – Shortcomings

- 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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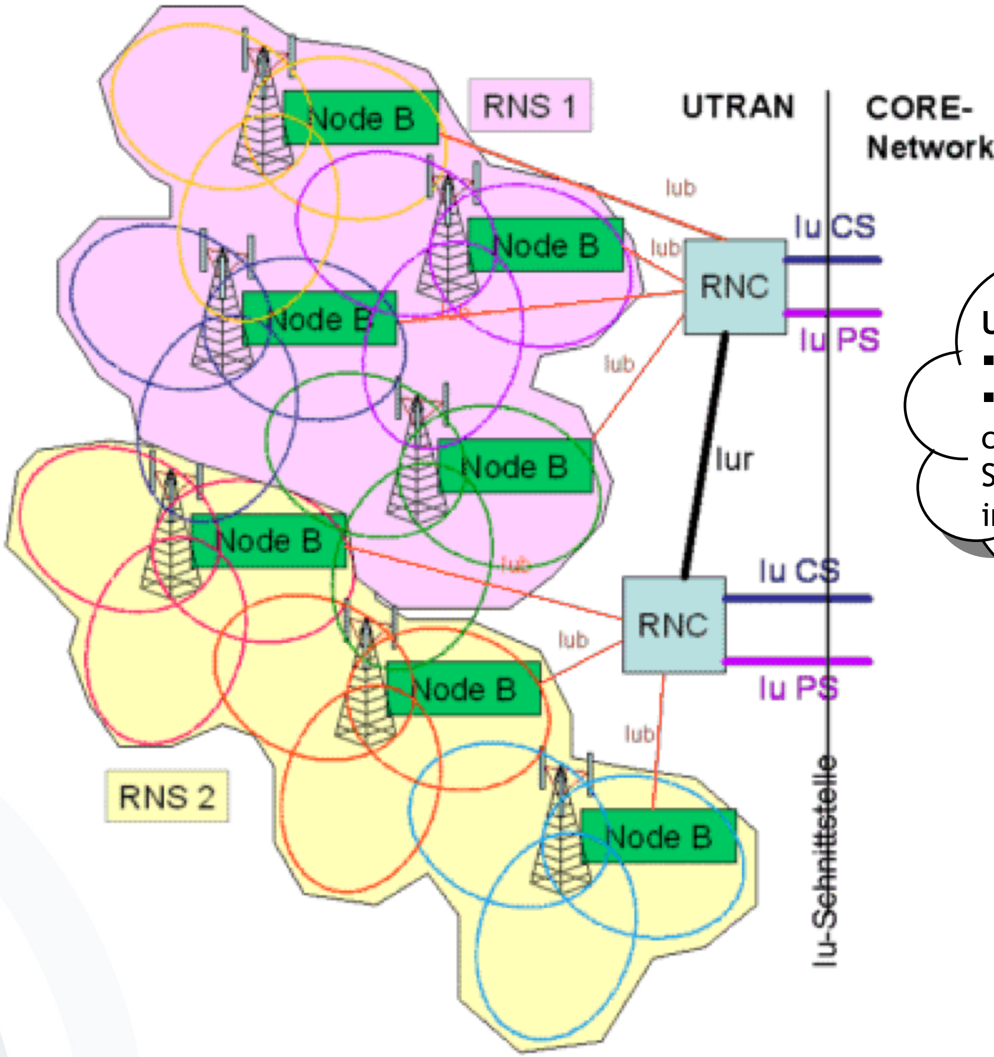
UMTS (3G)

- 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 regulation offices (e.g. ETSI, ARIB, ANSI) via the International Telecommunication Union (ITU)

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

Source: UMTSlink.at (2011)

UMTS (3G)
Bandwidths

- 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

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

UMTS (3G)

Standard vs. Implementation

- 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 the features that have been standardised are actually implemented in existing networks, as they are optional and can be added on demand.

[UMTSLink2013]

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Long Term Evolution (3.9G, 4G)

- **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].

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5th Generation (5G) The Concept

Two views of 5G:

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

5G technology promises

- 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]

Potential 5G use cases

- 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

[GSMA5G]

- 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

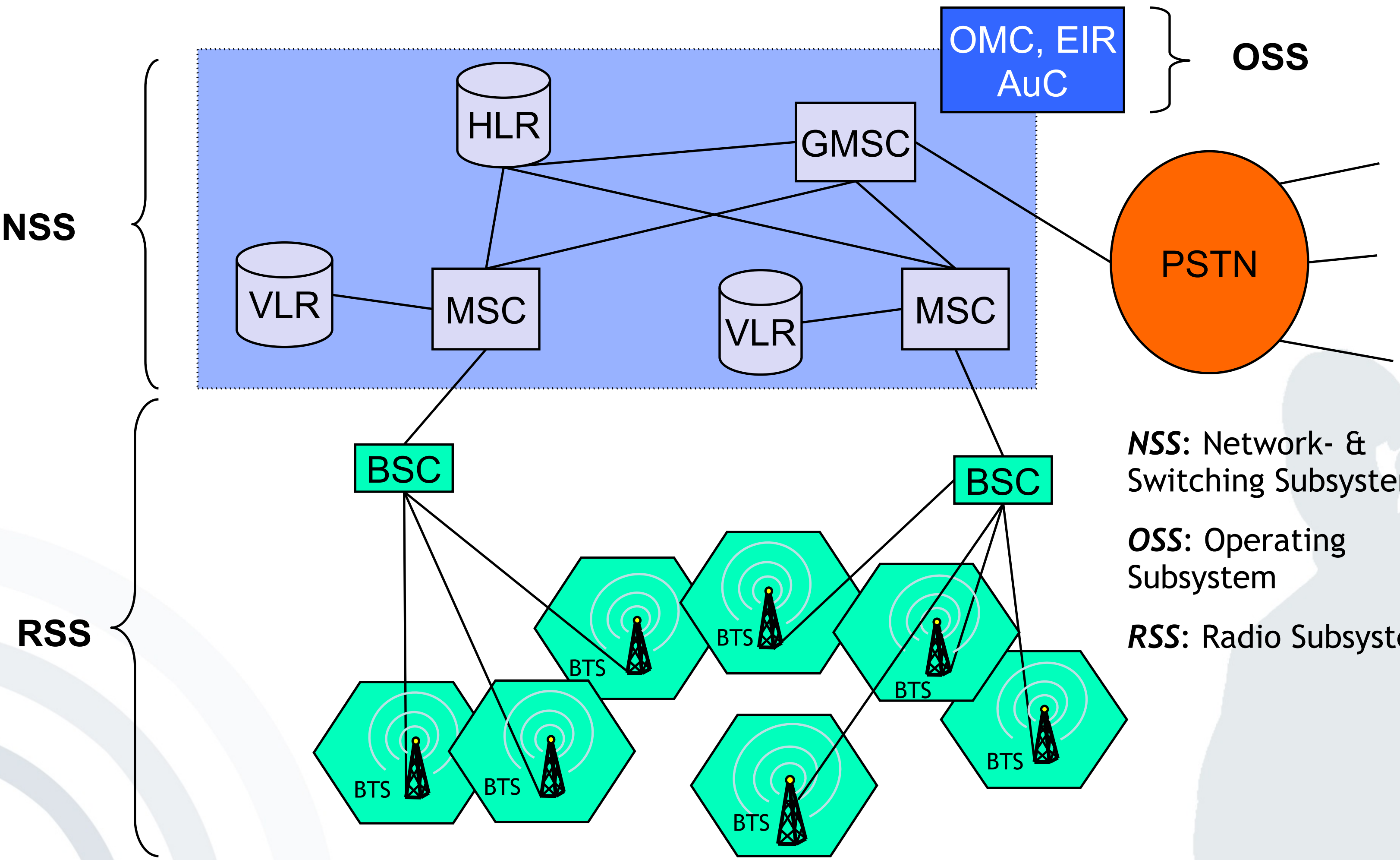
Overview

- 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).

Roaming

GSM System Architecture



NSS: Network- & Switching Subsystem

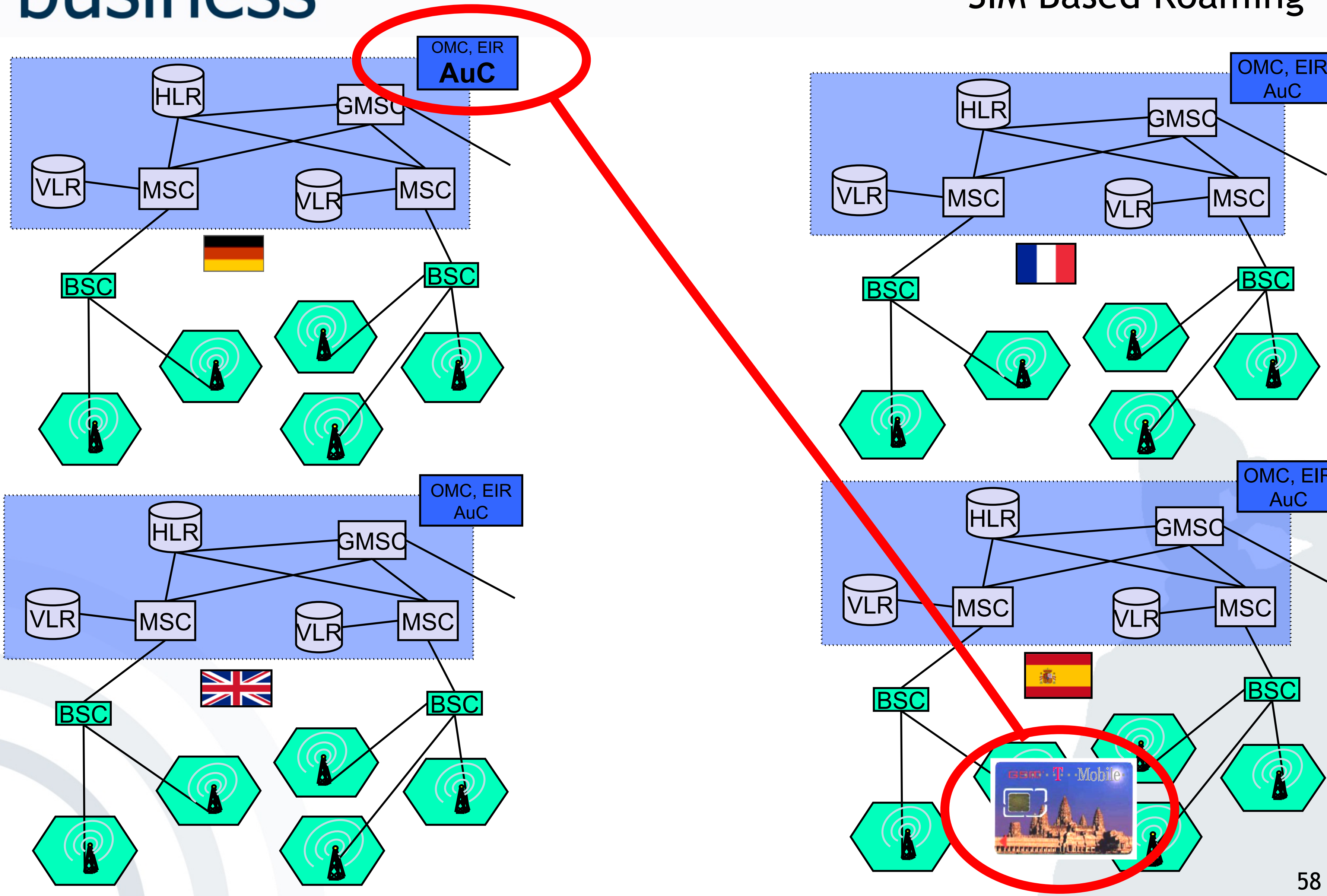
OSS: Operating Subsystem

RSS: Radio Subsystem

Based on [Schiller2003]

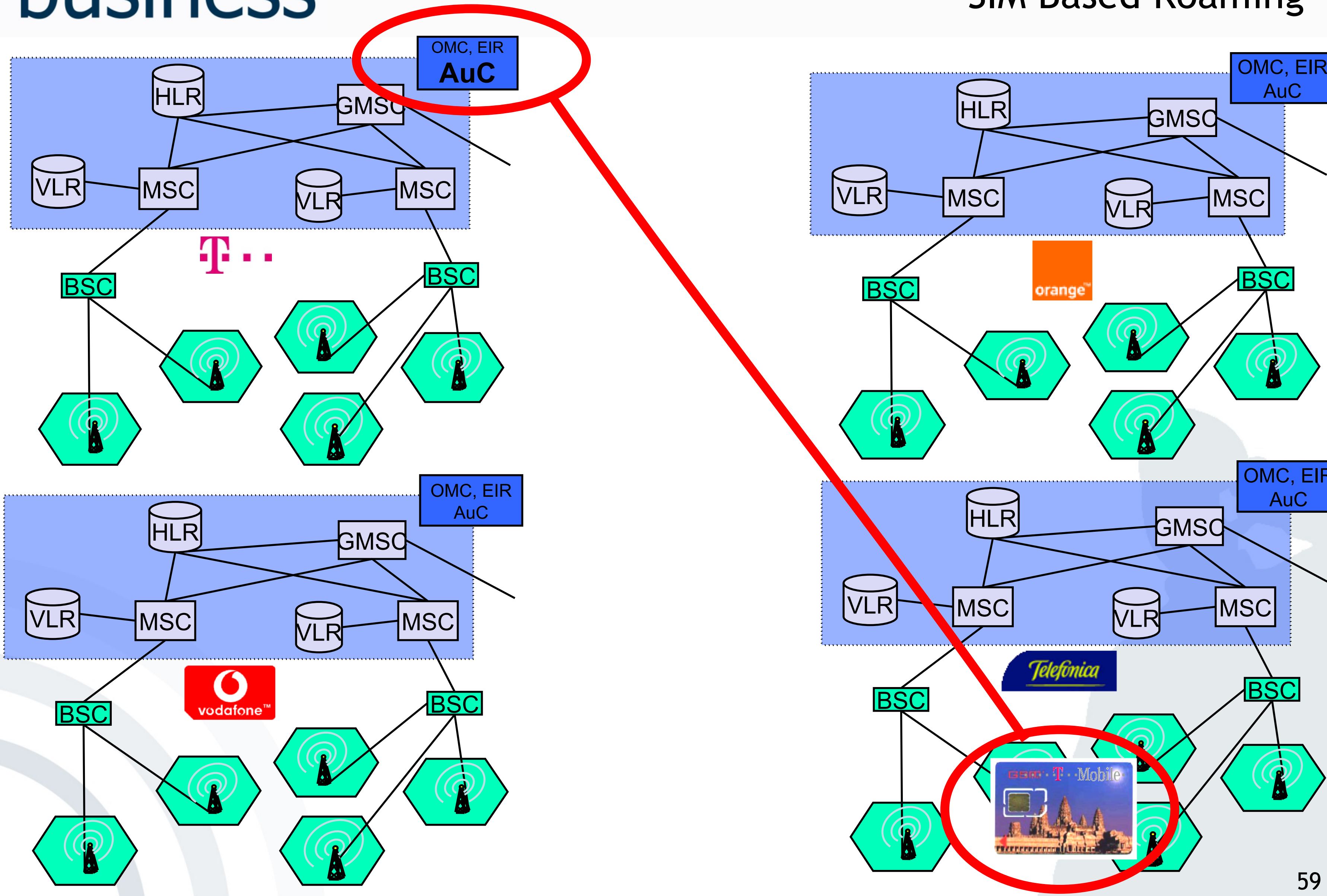
Roaming

SIM Based Roaming



Roaming

SIM Based Roaming



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