



TEKNILLINEN KORKEAKOULU

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# Telephone Network





# The Telephone Network

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- Telephone network is a huge machine
  - Aware of connections through it
  - Operated by specialized organizations
  - The intelligence is in the network, not at the terminal
  - A complete service production platform, including features like customer management and billing
- Telephone technologies are based on circuit switching
  - The network connects endpoints
  - Capacity is reserved from the network (64 kb/s for a voice call)





# Structure of the Telephone Network

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- Links are created between points using wiring or fiberoptics
- Transmission layer provides fixed capacity virtual circuits between points
- The circuits are created from different links using switching
- The circuits can be used for voice calls or other digital data transmission (current telephone systems are digital except the customer's connection part)
- The switching is controlled by a signaling network





- Early telephone networks basically connected a microphone to a speaker
  - Galvanic connection, i.e. direct electrical connection
  - Only one call per one wire pair
- Multiplexing was invented to allow several calls to share a wire pair
- Digitizing the voice calls makes multiplexing easier and provides better transmission quality
  - All modern telephone networks digitize the voice at the (cellular) telephone or at the point of presence closest to the customer





# Digital Multiplexing Methods

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- Frequency division multiplexing (FDM)
  - Data is transmitted by modulating carrier waves or sending signals on different frequencies
  - Currently used mostly for radio transmissions
- Wavelength division multiplexing (WDM)
  - Same as FDM, but refers to the use of light
  - Currently used on fiber optics
- Time division multiplexing (TDM)
  - Signals are sent one after each other
  - Currently used on electrical data transmission (wires)
- Code division multiplexing (CDM)
  - Energy (radio signals) is sent on different frequencies at different times, receiver can pick the transmission out based on a shared code





# Voice transmission

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- Voice is digitized 8000 times a second,
- Each sample is one byte, thus a data stream of 64 kb/s is created
- The samples are placed in frames using technologies called PDH or SDH (both use TDM)
  - Plesiochronous Digital Hierarchy
  - Synchronous Digital Hierarchy
  - In all systems 8000 frames are sent per second, but the amount of data differs
- A PDH E1 frame contains 32 bytes
  - Each byte is a time slot
  - Two are needed for synchronization and signaling
  - An E1 connection can thus support 30 telephone calls (or 2 Mb/s data)
- A SDH STM-1 frame contains 2430 bytes, equivalent to 155 Mb/s
- PDH and SDH are used as flexible low level protocols to build connections of different capacities





# User Equipment

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- The user has an analog telephone
  - Speaker, microphone
  - Touch tone generator for dialing
  - A hook for indicating when the user is at the phone
- The user is connected to a telephone switch that
  - Digitizes the user's speech (A/D transformation)
  - Synthesizes the voice from digital data received (D/A)
  - Recognizes the position of the hook
  - Recognizes the dialing tones





- At the beginning of a telephone call a free route is found through the network and a (virtual, not electrical) circuit is created
  - An analogue to the routing functionality in IP networks, but done only once per call, not for each data packet
- The route is created by ordering telephone switches to transfer the data in the time slots of the incoming frames to other time slots in the outgoing frames
- The Switching Network is controlled using SS7
  - Signaling System 7
  - An overlay network that transmits messages in data packets between the switches





# Signaling System 7

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- A router based packet network inside the telephone network
- Does not carry user data (voice traffic)
- Is specialized for telephony signaling
- A switch can send messages to configure the route of the telephone call
- The status of the call is transmitted (set up complete, ringing, talking, release connection)





# Mobile telephony

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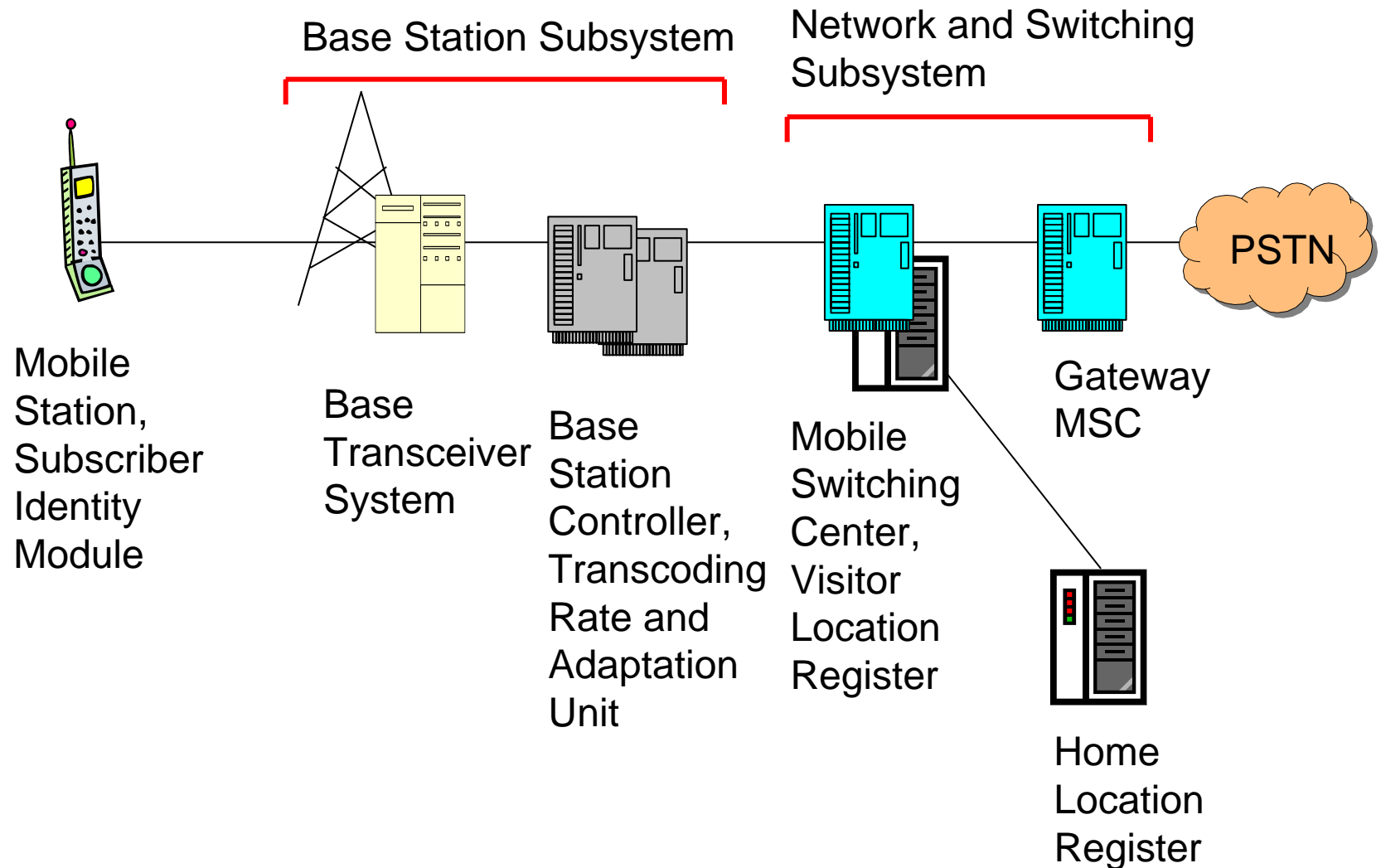
- The successful analog 1:st generation mobile telephone systems proved that there is a market for mobile telephones
  - ARP (AutoRadioPuhelin) in Finland
  - NMT (Nordic Mobile Telephone) in Nordic countries
- Concurrent development happened in the United States and Europe in the 1980's
- The European system was called GSM and deployed in the early 1990's
  - Global System for Mobile Communications
  - The main services are
    - Voice, 3.1 kHz
    - Data, 9.6 kbps with and w/o error correction
    - SMS-messages





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# The GSM Architecture







# Base Station Subsystem

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- Transcoding Rate and Adaptation Unit (TRAU)
  - Performs coding between the 64 kbps PCM coding used in the backbone network and the 13 kbps coding used for the Mobile Station
- Base Station Controller (BSC)
  - Controls the channel (time slot) allocation implemented by the BTSes
  - Manages the handovers within the BSS area
  - Knows which mobile stations are within the cell and informs the MSC/VLR about this
  - Does not know the exact location of a MS before a call is made
- Base Transceiver System (BTS)
  - Controls several transmitters
  - Each transmitter has 8 time slots, some used for signaling, on a specific frequency
  - Maximum amount of frequencies and transmitters in a cell is 6, thus maximum capacity of a cell is 48 calls (+ 3 time slots for signaling)





# Network and Switching Subsystem

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- The backbone of a GSM network is an ordinary telephone network with some added capabilities
- Mobile Switching Center (MSC)
  - An ISDN exchange with additional capabilities to support mobile communications
  - Visitor Location Register (VLR)
    - A database, part of the MSC
    - Contains the location of the active Mobile Stations
- Gateway Mobile Switching Center (GMSC)
  - Links the system to PSTN and other operators
- Home Location Register (HLR)
  - Contains subscriber information, including authentication information in Authentication Center (AuC)
- Equipment Identity Register (EIR)
  - International Mobile Station Equipment Identity (IMEI) codes for e.g. blacklisting stolen phones





# Home Location Register

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- One database per operator
- Contains all the permanent subscriber information
  - MSISDN (Mobile Subscriber ISDN number) is the telephone number of the subscriber
  - IMSI code is used to link the MSISDN number to the subscriber's SIM (Subscriber Identity Module)
  - International Mobile Subscriber Identity (IMSI) is the 15 digit code used to identify the subscriber
    - It incorporates a country and operator code
  - Charging information
  - Services available to the customer
- Also the subscriber's present Location Area Code, which refers to the MSC, which can connect to the MS





- MS is the user's handset and has two parts
- Mobile Equipment
  - Radio equipment
  - User interface
  - Processing capability and memory required for various tasks
    - Call signaling
    - Encryption
    - SMS messages
  - Equipment IMEI number
- Subscriber Identity Module





# Subscriber Identity Module

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- A small smart card
- Encryption codes needed to identify the subscriber
- Subscriber IMSI number
- Subscriber's own information (telephone directory)
- Third party applications (banking etc.)
- Can also be used in other systems besides GSM, e.g. some WLAN access points accept SIM based user authentication





# Other systems

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- Operations Support System
  - The management network for the whole GSM system
  - Usually vendor dependent
  - Very loosely specified in the GSM standards
- Value added services
  - Voice mail
  - Call forwarding
  - Group calls
- Short Message Service Center
  - Stores and forwards the SMS messages
  - Like an e-mail server
  - Required to operate the SMS service
  - The SMS service was initially used to notify the subscriber about new voicemail





# Location Update when Inactive

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- The cells overlap and usually a mobile station can "see" several transceivers (BTSes)
- The MS monitors the identifier for the BSC controlling the cells
- When the mobile station reaches a new BSC's area, it requests an location update
- The update is forwarded to the MSC, entered to the VLR, the old BSC is notified and an acknowledgement is passed back





- When a call is in process the changes in location require more processing
- Within a BSS the BSC, which knows the current radio link configuration, prepares an available channel in the new BTS
- The MS is told to switch over to the new BTS
- This is called a hard handover
  - In a soft handover the MS is connected to two BTSes simultaneously





# Types of Handover

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- Within a BSS's cells the BSC handles the handover
- Between BSSes the MSC/VLR can control the handover
- Between MSCs (Location Areas) the HLR can control the handover, this is not always implemented
- A handover between operators is not currently implemented, so the call is interrupted and a new call must be made





- When a MS enters another operators network, it can be allowed to use the services of this operator
  - Operator to operator agreements and contracts
  - Higher billing
- The MS is identified by the information in the SIM card and the identification request is forwarded to the home operator
  - The home HLR is updated to reflect the MS's location





# How to Call a Mobile Phone

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- A call is made from the PSTN to a mobile subscriber's number
- The call enters the GMSC
- The GMSC queries the HLR for information about which MSC serves the MS
- The call is forwarded to the MSC in charge
- The MSC queries the VLR about which BSC is currently in charge of the MS
- BSC sends a paging call to all cells to find the exact location of the mobile
- The mobile signals that it answers
- The call is completed





# Radio Link Coding Methods

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- FDMA, Frequency Division Multiple Access
  - One frequency per user
  - E.g. NMT
- TDMA, Time Division Multiple Access
  - Timeslots on the same frequency
  - E.g. GSM
- CDMA, Code Division Multiple Access
  - Sender and receiver use a code to identify the radio transmission from the background noise
  - Multiple senders on same frequency and timeslot
  - E.g. UMTS





# GSM Frequency Bands

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- The initial design used the 900 MHz range
- Uplink to BTS 890 - 915 MHz
- Downlink to MS 935 - 960 MHz
- There are 124 channels of 200 kHz and 100 kHz of guard spectrum at the edges of the band
  - And each channel can carry 8 TDMA users
- Usually an operator does not have access to the full range
- GSM technology is also used on other frequencies
- 450, 800, 1800, 1900 MHz
- Maximum range is 35 kilometers due to timing requirements
- MS power is max 2 W for the handheld devices





# Radio Access Network Design

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- An operator wants usually to make most efficient use of their frequency range
  - Full coverage in all places
  - Sufficient capacity for all customers
- The basic solution is to make the neighboring cells to use different frequencies
  - Frequencies can be re-used in cells further away
- The cells can be shaped using directional antennas
- Transmitter power can be used to regulate the size of a cell
  - Pico cells inside buildings
  - Micro cells for streets
  - Macro cells for larger areas





# Wireless challenges

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- Path loss and fading
  - Buildings, trees etc. block or weaken signals
- Reflected signals
  - Multiple copies of a signal with small timing differences
  - Even fading due to interference
- Flash crowds
  - The customer's traffic patterns are difficult to predict





# GSM data services

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- The basic GSM data service transmits data instead of voice, using a time slot like a voice call
  - 9.6 or 14.4 kbps rate
  - Time based billing
- The data connection from the MS is usually connected to an traditional analog modem, which is connected to the PSTN
  - The operator can also provide direct data connections
  - Long setup time 5-30 seconds
- High Speed Circuit Switched Data (HSCSD) uses multiple time slots to increase the data rate
  - Up to 57.6 kbps
- GSM data appears to be an evolutionary dead end and packet based data transmission is going to overtake it





# Global Packet Radio Service

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- GPRS uses the time slots not used for circuit switched services
- Data rate depends on the availability of free time slots
  - GPRS uses the multislot technique, but within one frequency
  - It also can change the coding schema used for error correction
  - Theoretical maximum rate is 171.2 kbps
    - 10-40 kbps more realistic
- Enhanced Data rates for Global Evolution (EDGE) provides higher data rates

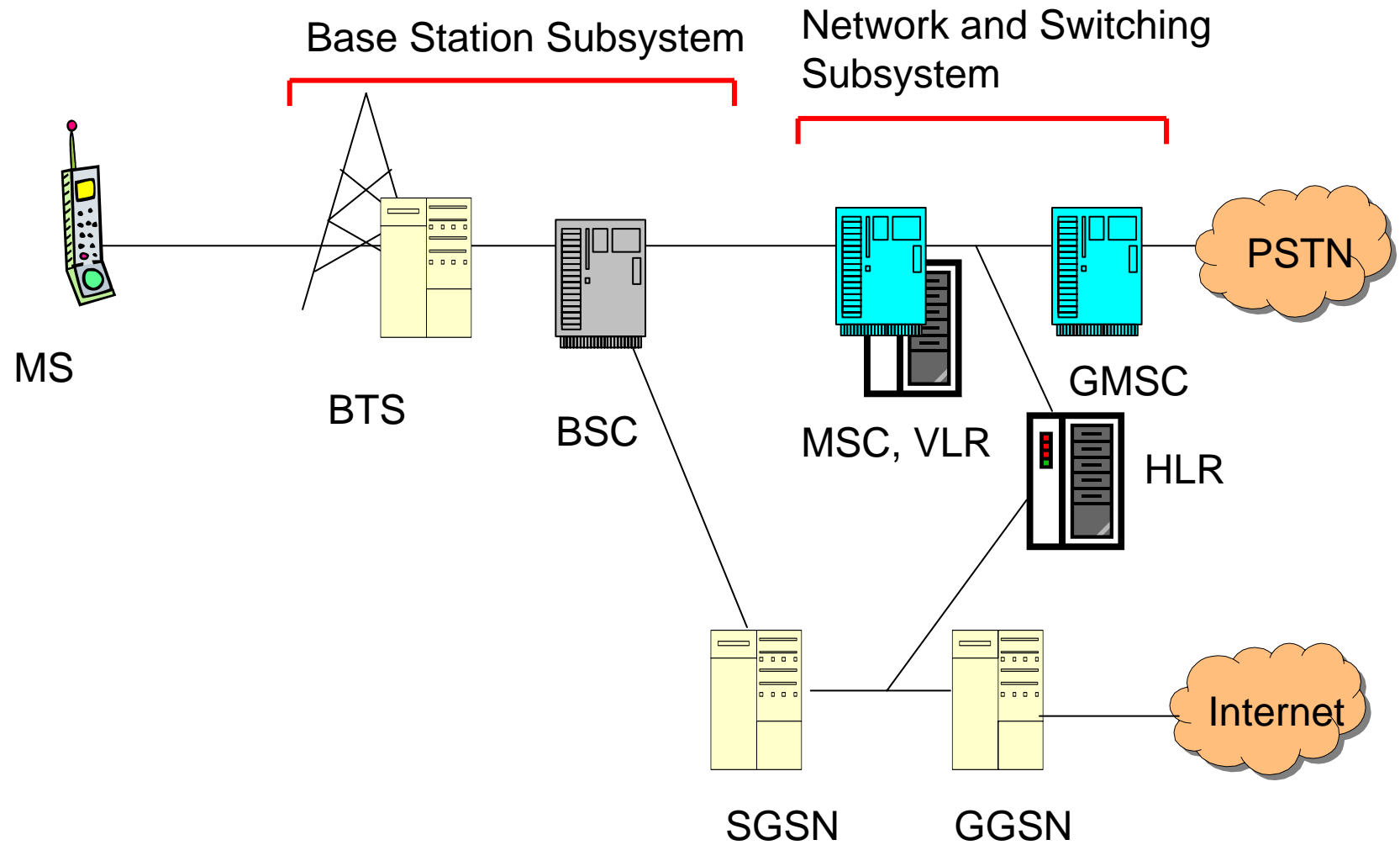




# GPRS Network

- GPRS uses the same Radio Access Network (RAN) as GSM
  - A Packet Control Unit is added to the BSS
- Form the BSS the data packets are tunneled over the GSM backbone network
- Important new elements are
  - Serving GPRS Support Node (SGSN)
    - Tracks the location of the MS
    - Provides routing and mobility management
    - Authenticates the MS
    - Manages the session
    - Collects billing data
    - IP packets from the MS are treated as IP packets first time here
  - Gateway GPRS Support Node (GGSN)
    - Connects the GPRS network to other networks, e.g. the Internet
  - GSM VLR and HLR are used









# GPRS Handovers

- There are no GPRS handovers as such
  - Since there is no circuit to hand over
- The MS requests a cell reselection and the packets are routed to the new cell
- Requires dynamic routing





# GPRS Mobility Management

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- A GPRS node may be in three states
  - Idle - no MS location information is kept by the network, no active PDP (Packet Data Protocol) context
  - Busy - The location is known at cell level, an active PDP context to an access point name is established
  - Standby - The location is known at the Routing Area Identifier (RAI) level, the PDP context is active
  - A timeout moves the MS from Busy to Standby state, helps to reduce battery consumption
- GPRS attachment
  - The MS request a PDP context from the SGSN
  - The SGSN selects the GGSN to be used based on the Access Point Name
    - Internet, WAP gateway, a corporate network
  - The SGSN queries the HLR to authenticate the MS and verify the request





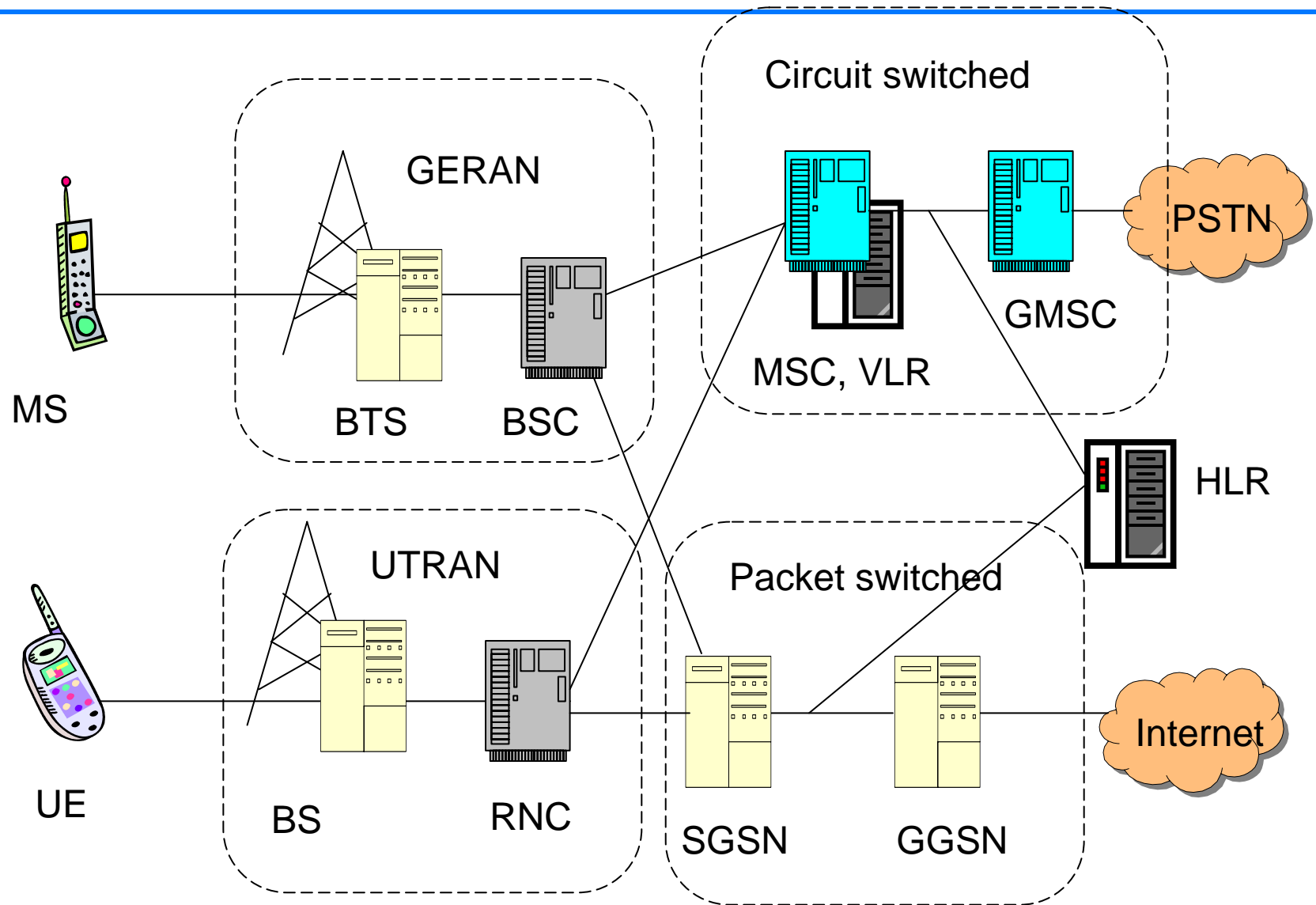
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- Enhanced Data rates for Global Evolution
  - Up to 348 kbps
  - Initially developed for operators who failed to get UMTS spectrum
  - Uses different modulation to squeeze more data into same timeslot as GPRS
  - Requires hardware support in both the handset and the BTS and software in the BSC





- Universal Mobile Telecommunications System
  - A.k.a. 3G
- Provides:
  - More of the same as GSM/GPRS/EDGE
    - Up to 2 Mbps promised data rate
    - 144 kbps a more realistic bit rate
  - VoIP instead of PSTN calls?
  - Video phone, other multimedia services
  - Global roaming (almost)
  - Convergence for the operators
  - More effective radio spectrum usage









- UMTS requires a new Radio Access Network
  - The Wideband CDMA-based UTRAN (Universal Terrestrial RAN) provides the higher data rates
    - 1885-2025 MHz (uplink)
    - 2110-2200 MHz (downlink)
  - The GSM/EDGE GERAN can be used with UMTS
    - Might stay for a long time in the less populated areas
- New names for new components
  - Radio Network Controller
  - Base Station
  - User Equipment
- New functions
  - Soft handover





# Soft Handover

- As the UE is promised a certain Quality of Service in the beginning of an active service connection the handover issue is more complex than in 2G services, where the only service is the basic voice call
  - Multimedia calls have variable QoS requirements
- In a soft handover the UE has multiple radio connections to base stations
  - Due to CDMA technology all the base stations are using the same frequencies (wideband transmission)
- A more complex procedure than hard handover, intended to provide seamless service quality





# 4G - after UMTS

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- A combination of UMTS, WLAN, Bluetooth and other similar technologies is often interpreted as 4G
- No formal definition yet
- Data rates of 20 - 100 Mbps?
- WLAN is already coming to the new high end terminals, enabling e.g. VoIP
- 4G is more about the services than the actual networking technologies