Cellular networks
GSM and WCDMA

EP2950

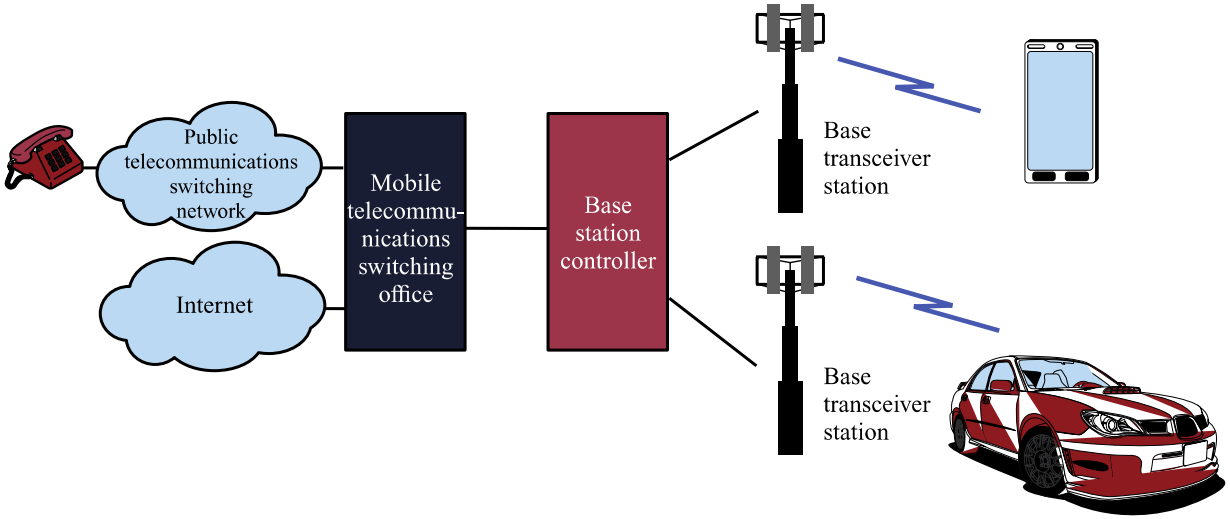
KTH Technology
and Health

Outline

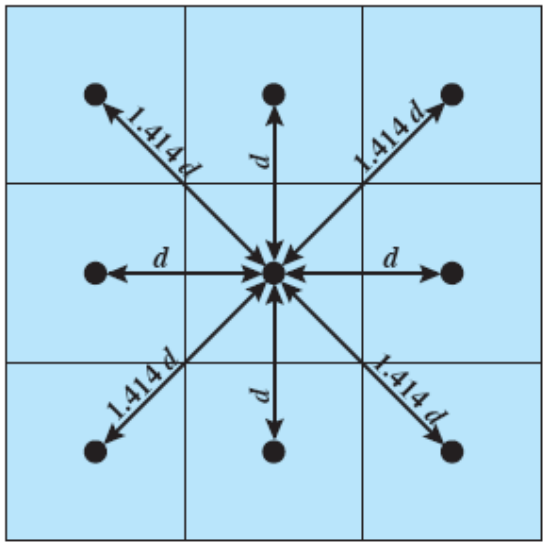
- ✓ Cellular networks
- ✓ Traffic engineering
- ✓ Wireless cellular systems
  - Second generation: GSM system
  - Third generation: UMTS/W-CDMA

Wireless cellular networks

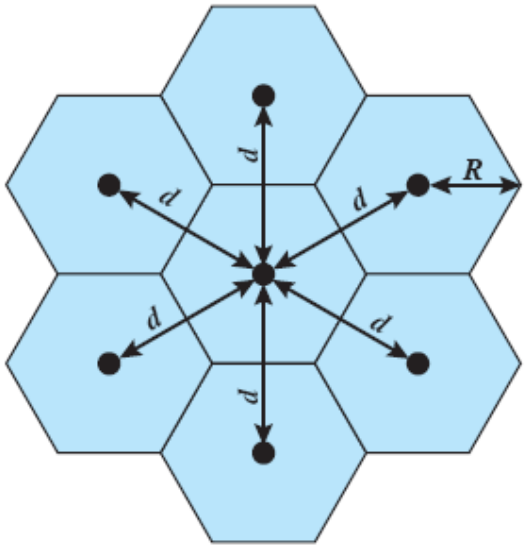
- ✓ Base transceiver stations (BTS)
- ✓ Base station controllers (BSC)
- ✓ Mobile switching centers (MSC)



- ✓ Networks organized in cells
  - A base station is assigned a set of frequencies
  - Reuse of frequencies
    - Low power transceivers and limited spectrum
  - Hexagonal pattern gives equidistant antennas
  - $d = \sqrt{3} \times R$



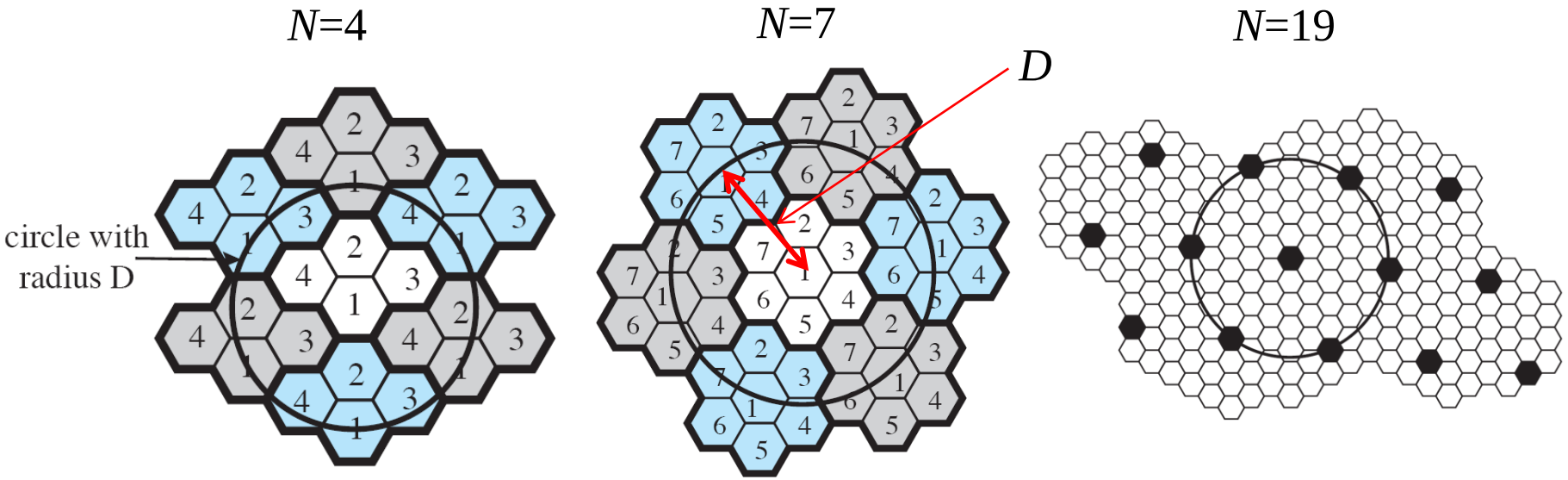
(a) Square pattern



(b) Hexagonal pattern

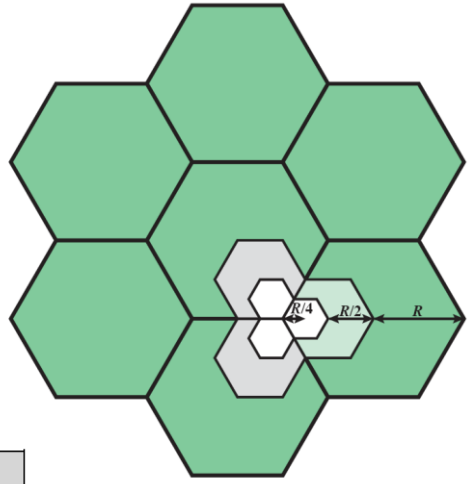
✓ Reuse factor *N*

- A grouped pattern of *N* cells is repeated
  - *N* is the number of cells that cannot use the same frequencies
- *K* is the total number of frequencies in the system
- *D* is the minimum distance between centers of cells with the same frequency band
- In a hexagonal cell pattern *N*=1,3,4,7,9,12,13,16,19,21, …



- ✓ Reuse factor N
  - N large means few frequencies per cell and larger distance between reused frequencies
  - N small means many frequencies per cell and smaller distance between reused frequencies
- ✓ C channels in a cellular system with reuse factor N
  - Number of channels per cell, $\eta = C/N$
- ✓ Example
  - 32 cells with radius 1.6 km, all frequencies in the system support 336 channels, N=7.
  - How many channels per cell?
    - η=(number of channels)/N = 336/7= 48
  - How many channels in the entire system?
    - Number of channels per cell × number of cells = 48×32=1536

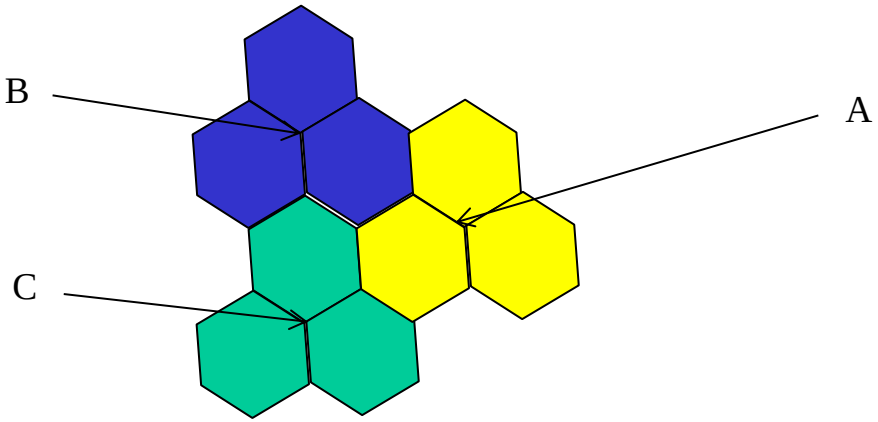
- ✓ Increasing capacity
  - Add channels
  - Borrow channels from less congested adjacent cells
  - Split cells
  - Cell sectoring
  - Network densification
    - Microcells, femtocells

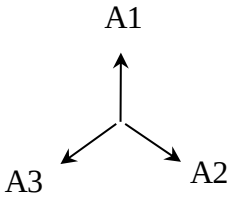


	Macrocell	Microcell
Cell radius	1 to 20 km	0.1 to 1 km
Transmission power	1 to 10 W	0.1 to 1 W
Average delay spread	0.1 to 10 μs	10 to 100 ns
Maximum bit rate	0.3 Mbps	1 Mbps

✓ Example

- 24 frequencies in a 3/9 pattern
- One site serves three cells



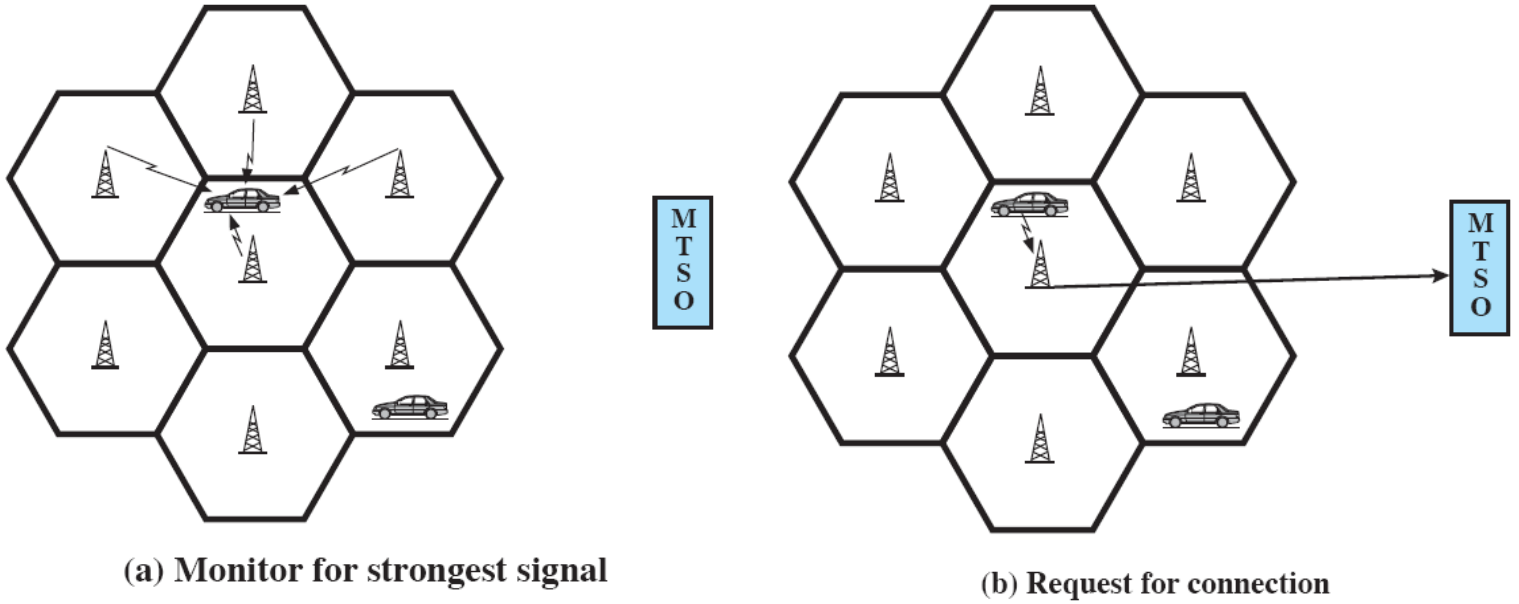


Freq. groups	A1	A2	A3	B1	B2	B3	C1	C2	C3
Channels	1	2	3	4	5	6	7	8	9
	10	11	12	13	14	15	16	17	18
	19	20	21	22	23	24			

- ✓ Traffic case: a call between mobile users
  - Control channels for signaling (xxCH)
    - Broadcast, common, dedicated and associated
  - Traffic channels (TCH)

a) Mobile phone is switched on (Broadcast, BCCH)

b) Mobile originated call (Random access, RACH)



(a) Monitor for strongest signal

(b) Request for connection

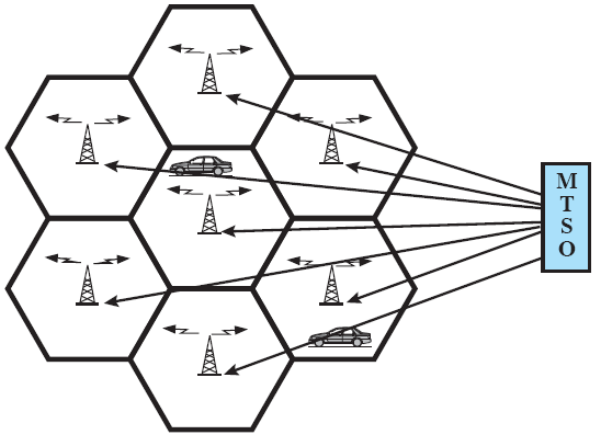
MTSO is MSC in GSM. More detailed : MS → BTS → BSC→MSC/VLR → HLR/AUC)

c) Paging (PCH)

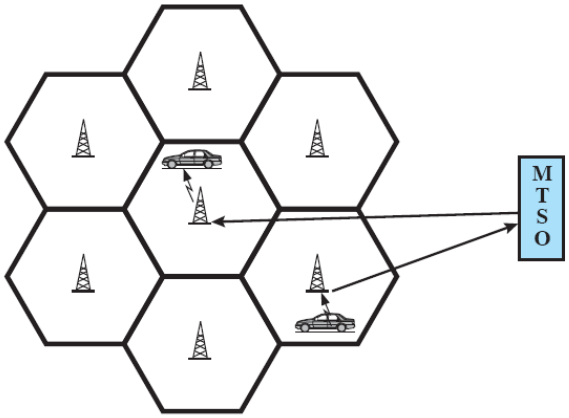
d) Call accepted

e) On-going call (TCH)

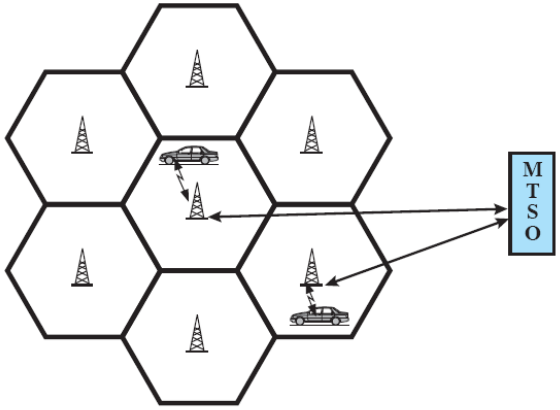
f) Handoff/handover (Fast associate CCH)



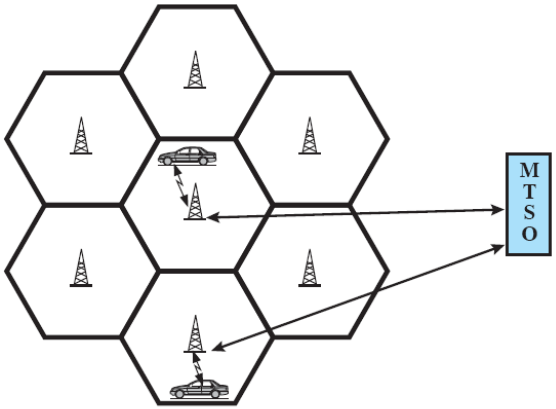
(c) Paging



(d) Call accepted



(e) Ongoing call

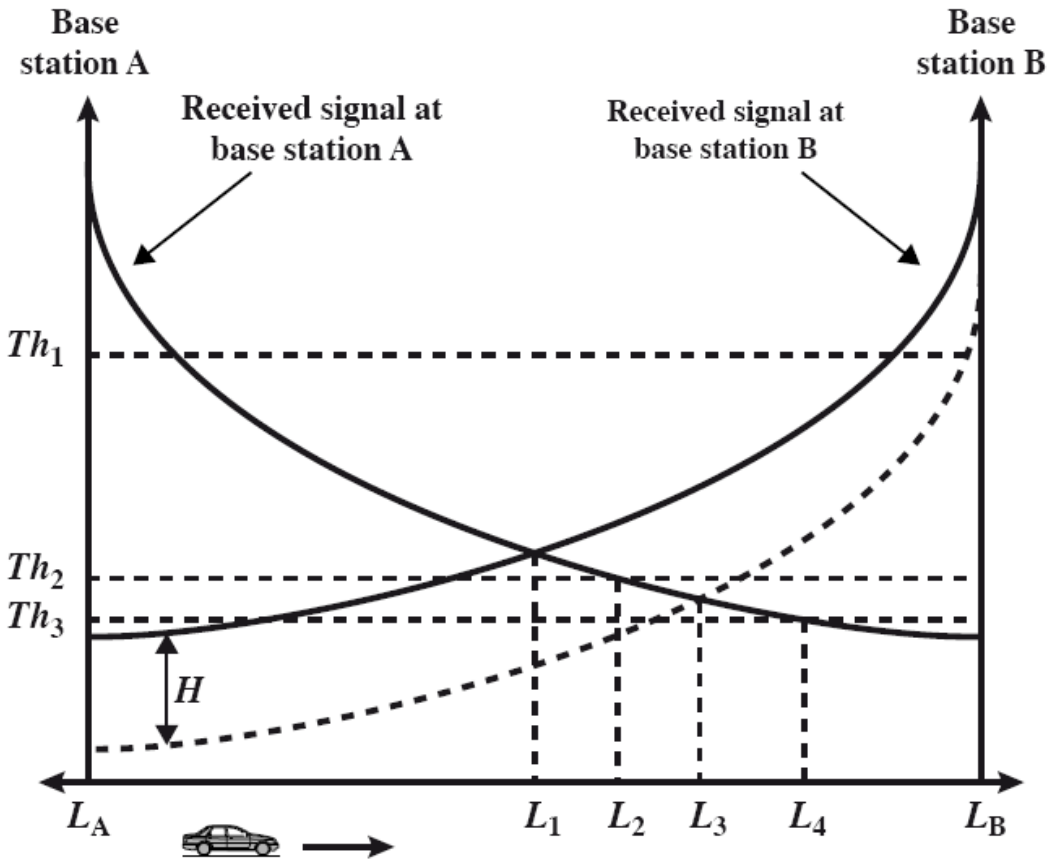


(f) Handoff

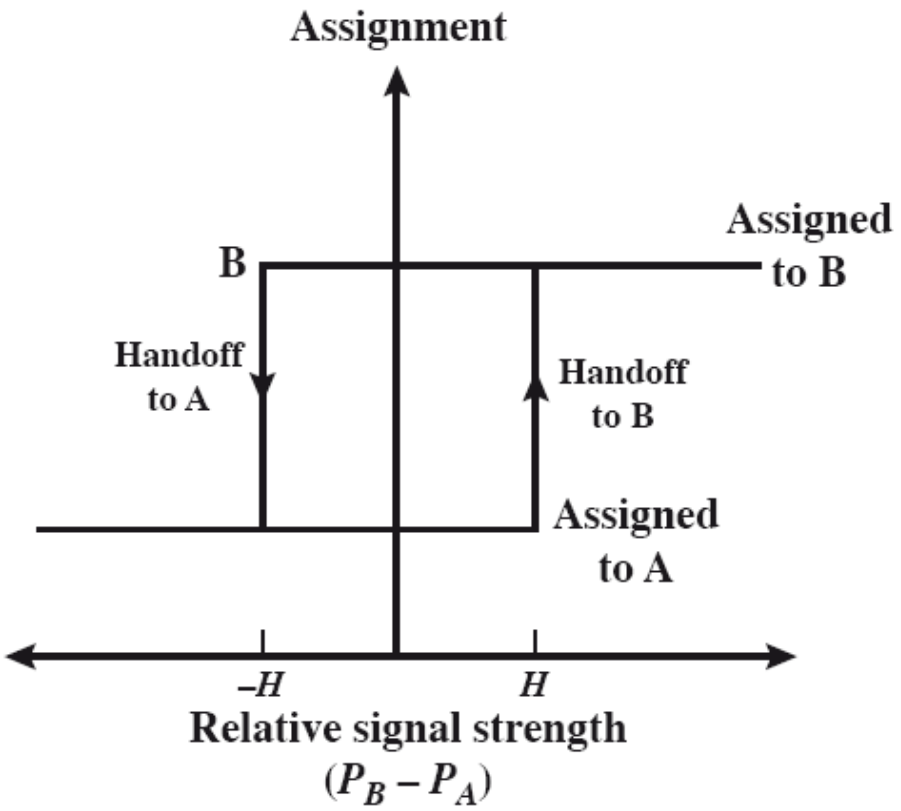
✓ Handover

✓ Measurement of signal strength

- Handover based on relative signal strength (at L_1) or threshold Th_2 (at L_2)



- ✓ Handover based on hysteresis
  - Margin H, handover at L_3
- ✓ Handover based on hysteresis and threshold

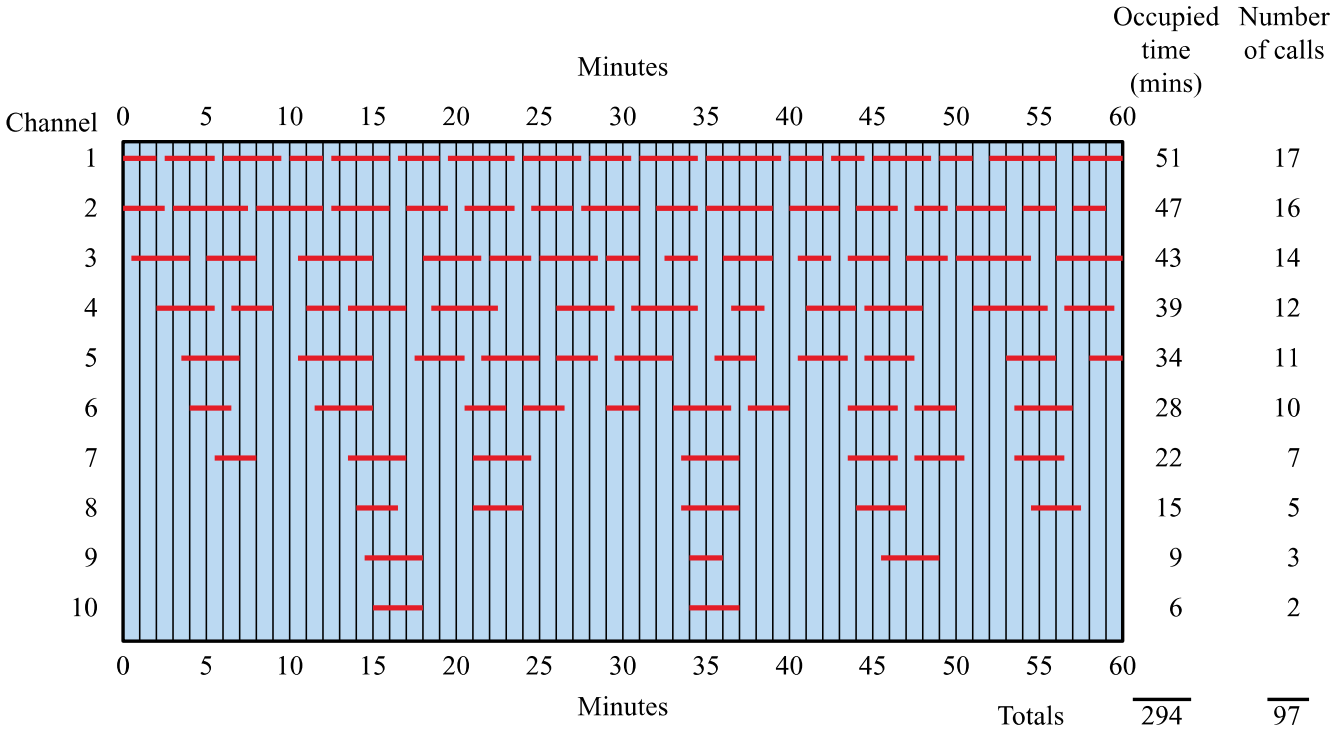


- ✓ Power control
  - ✓ Sufficient SNR or E_b/N_0
  - ✓ Minimize transmission power
  - ✓ Save battery power, health issues etc
  - ✓ Equalize received power from all mobile stations in WCDMA
    - Near-far problem
  - ✓ Open-loop
    - No feedback from base station
    - Mobile station monitors signal strength in pilot channel sent from base station and adjusts transmission power
  - ✓ Closed-loop
    - Base station sets the mobile's transmission power based on measurements

Traffic engineering

- L mobile units and N channels
  - If $L > N$ the system is blocking
  - If $L < N$ the system is non-blocking
- Dimensioning and performance issues
  - Carried traffic and grade of service (blocking probability)
- Offered traffic load to a system
  - $A = \rho = \lambda \times h$ (Erlang)
    - λ = average arrival rate of calls
    - $h = 1/\mu$ = mean service (holding) time (duration of calls)
    - μ = average number of calls per second being served
  - Measured during peak load – busy period

- ✓ Traffic in 10 channels during one hour
  - ✓ Rate of calls per minute, $\lambda = 97/60$
  - ✓ Mean service (holding) time, $h = 1/\mu = 294/97$
  - ✓ The amount of traffic, $A = \rho = \lambda \times h = 97/60 \times 294/97 = 4.9$ Erlang



Note: horizontal lines indicate occupied periods to the nearest 1/2 minute

- ✓ Carried traffic = $\rho \times (1-P)$
  - ρ = offered load, P = blocking probability
- ✓ Erlang loss formula (Erlang-B)
  - Blocked calls are cleared and not queued

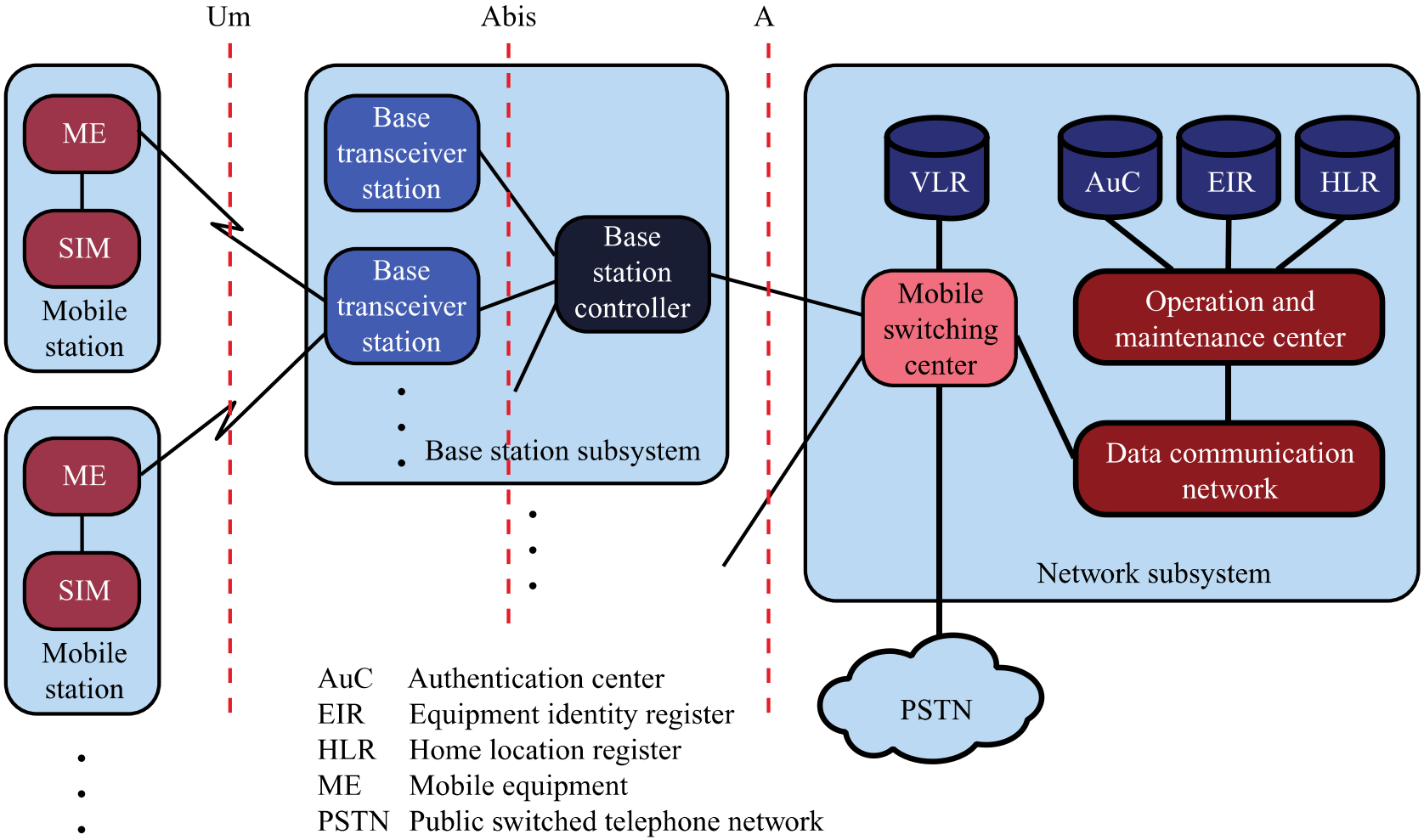
✓ Second generation systems

- Introduced around 1990

	GSM	IS-136	IS-95
Year introduced	1990	1991	1993
Access method	TDMA	TDMA	CDMA
Base station transmission band	935 to 960 MHz	869 to 894 MHz	869 to 894 MHz
Mobile station transmission band	890 to 915 MHz	824 to 849 MHz	824 to 849 MHz
Spacing between forward and reverse channels	45 MHz	45 MHz	45 MHz
Channel bandwidth	200 kHz	30 kHz	1250 kHz
Number of duplex channels	125	832	20
Mobile unit maximum power	20 W	3 W	0.2 W
Users per channel	8	3	35
Modulation	GMSK	$\pi/4$ DQPSK	QPSK
Carrier bit rate	270.8 kbps	48.6 kbps	9.6 kbps
Speech coder	RPE-LTP	VSELP	QCELP
Speech coding bit rate	13 kbps	8 kbps	8, 4, 2, 1 kbps
Frame size	4.6 ms	40 ms	20 ms
Error control coding	Convolutional 1/2 rate	Convolutional 1/2 rate	Convolutional 1/2 rate forward; 1/3 rate reverse

✓ TDMA design guidelines

- Number timeslots in TDMA frame: 8
- Frequency: around 900 MHz + 1800/1900 MHz
- Maximum vehicle speed (V_m): 250 km/h
- Maximum cell radius (R): 35 km
- Maximum coding delay: approx. 20 ms
- Maximum delay spread (Δ_m): 10 μs
- Bandwidth: Not to exceed 200 kHz


Um
Abis
A
ME
SIM
Mobile station
ME
SIM
Mobile station
Base transceiver station
Base transceiver station
Base station controller
Base station subsystem
VLR
AuC
EIR
HLR
Mobile switching center
Operation and maintenance center
Data communication network
Network subsystem
PSTN
AuC Authentication center
EIR Equipment identity register
HLR Home location register
ME Mobile equipment
PSTN Public switched telephone network
SIM Subscriber identity module
VLR Visitor location register

- GSM subsystems
  - Mobile station (MS)
    - Communicates over the U_m interface with the base station
    - Mobile equipment + SIM (subscriber identity module)
  - Base station subsystem (BSS)
    - Includes the Base station controller (BSC) and one or more Base transceivers (BTS). A BTS has a radio antenna, a radio transceiver and a link to a BSC. It reserves radio frequencies, manages handovers of mobile units from one cell to another within a BSS, and controls paging.
  - Network subsystem (NSS)
    - The link between cellular network and public switched networks
    - Controls handovers between cells in different BSSs
    - Authenticates users and validates accounting
    - Enables worldwide roaming of mobile users

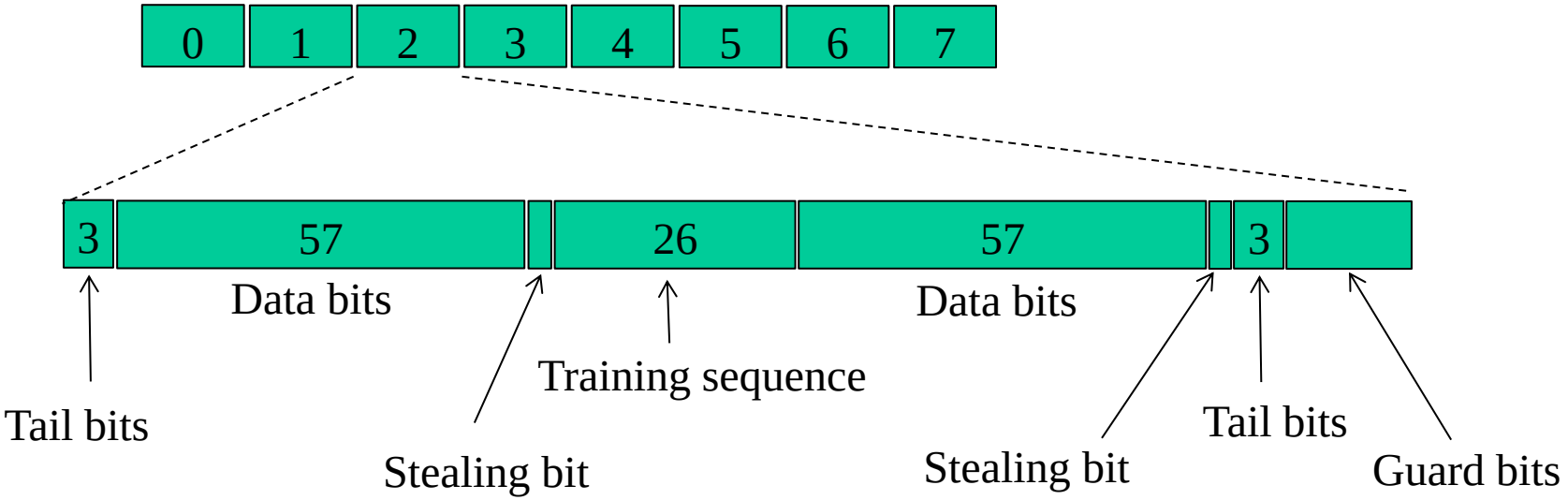
- ✓ Network subsystem (NSS) cont.
  - Mobile switching centre (MSC)
  - Visitor location register (VLR) database
    - Maintains information about subscribers currently physically in the region. Collocated with MSC.
  - Home location register (HLR) database
    - Stores information about subscribers
  - Authentication centre (AUC)
    - Collocated with HLR. Used for authentication activities, holds encryption keys.
  - Equipment identification register (EIR)
    - Keeps track of the type of equipment that exists at the mobile station.

- ✓ Cellular network systems
- ✓ GSM Global system for mobile communications
  - Mobile station (equipment + SIM (subscriber identity module))
  - Base station transceiver (BTS)
  - Base station controller (BSC)
  - Mobile switching centre (MSC) and G-MSC to fixed public networks
  - Visitor location register (VLR) – collocated with MSC
  - Home location register (HLR)
  - Authentication centre (AUC) – collocated with HLR
  - Equipment identification register (EIR)

- ✓ GPRS - General packet radio service
  - Allocate several timeslots – increased bit rate
    - Different channel coding schemes (block and convolutional)
    - EDGE/Enhanced GPRS - max 384kb/s (higher-order modulation)
  - Gateway GPRS support node (GGSN) for packet data communication with the public network
  - Service GPRS support node (SGSN) corresponds to MSC/VLR
- ✓ UMTS/3G
  - W-CDMA
  - Increased data rates
  - User equipment domain (UE)
  - UTRA – Universal terrestrial radio access
    - Radio network controller (RNC) (as a BSC in GSM)
    - Controls Node B connected to one or more antennas
  - Core network
    - MSC/VLR, HLR/AUC, EIR, SGSN, GGSN … etc

- GSM (900 MHz) uses FDD, FDM and TDMA
  - Frequency division duplex (FDD)
    - Uplink 890.2 – 915 MHz
    - Downlink 935.2 – 960 MHz
  - Frequency division multiplexing (FDM)
    - 124 channels of 200 kHz each
  - Time division multiplexing access (TDMA)
    - Each channel has frames of 4.615 ms repeated continuously
    - A frame consists of 8 timeslots
    - Each timeslot is 0.577 ms

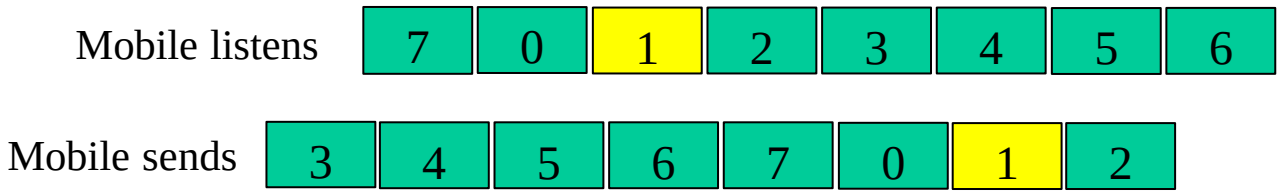
- TDMA format and timeslots
  - TDMA frame
    - 4.615 ms (26 frames in 120 ms)
  - 8 timeslots per frame
    - 0.577 ms per timeslot
    - Information sent in a timeslot is called a burst
    - 148 bits takes 546.25 µs – leaves 8.25 bits (≈ 30.5 µs) as guard bits



- ✓ Channel encoder provides 456 bits every 20 ms of speech. They are interleaved and sent in bursts of 57 bits (divided into 8 frames).
- ✓ The symbol rate in a frame is 270.833…ksymbols/s.
- ✓ Modulation - Gaussian minimum shift key (GMSK). One bit per symbol (baud rate = bit rate).
- ✓ One timeslot can carry 0.577 ms×270.833 kb/s = 156.25 bits. 148 bits in the timeslot leaves 8.25 bits as a guard period.

- ✓ Training sequence
  - A predefined bit sequence used as input to the equalizer. It is a digital filter that creates an impulse response of the received bit sequences and creates an inverse filter that can be used to compensate for the effect of delay spread caused by multi-path fading.
- ✓ Tail bits are used for synchronization
- ✓ Stealing bits indicate if the burst carries signaling or user data
- ✓ Guard bits - avoid overlap with other bursts

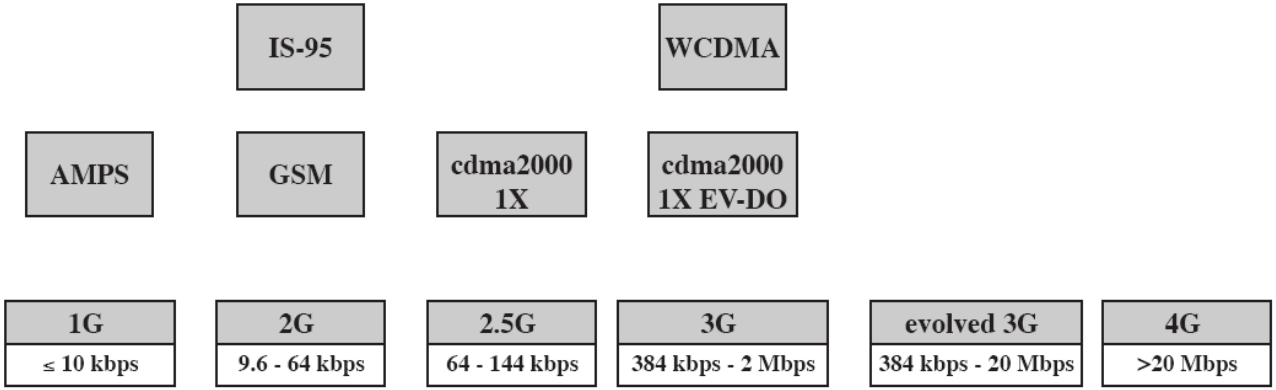
- Timeslots for sending and receiving
  - The mobile does not send and receive at the same time
    - Time separation delays between listening and sending



  - Slow frequency hopping
    - Each successive TDMA frame in a given channel is carried on a different carrier frequency (not always)
    - Compensates for multipath fading (as it is dependent on carrier frequency)
    - Reduces co-channel interference

✓ Third generation systems

- Evolution of cellular wireless systems



✓ Some acronyms

- ETSI - European Telecommunications Standard Institute
- IMT2000 - International Mobile Telecommunications 2000
- UMTS- Universal Mobile Telecommunication System (IMT2000 in ETSI)
- UTRA- Universal (UMTS) Terrestrial Radio Access
- UTRAN - UTRA Network
- 3GPP – 3rd Generation Partnership Project

✓ UMTS network elements

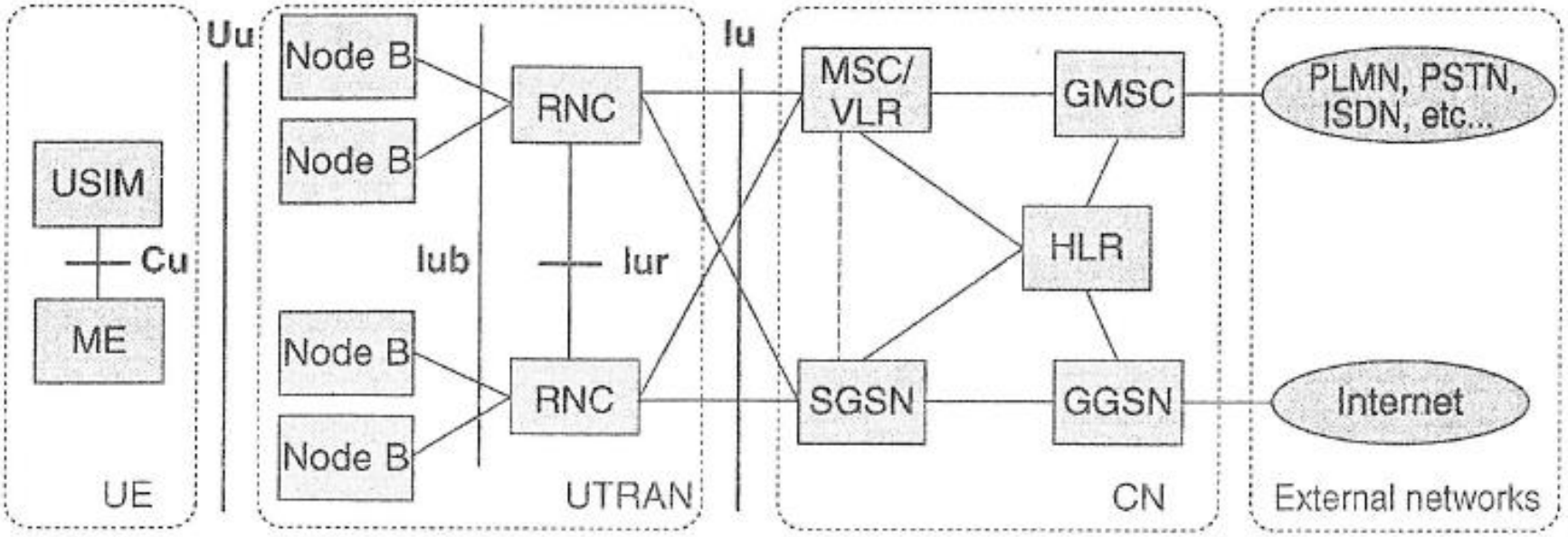


Figure 5.2. Network elements in a PLMN

- W-CDMA parameters
  - Channel bandwidth 5 MHz
  - Chip rate 3.84 Mchip/s
  - Frames of 10ms – 15 slots per frame
  - Modulation
    - QPSK and BPSK
  - Spreading factors 4-256
  - Power control
    - Open and closed loop control
  - Soft handover

✓ Comparison GSM and UMTS air interfaces

	GSM	W-CDMA
Duplexing	FDD	FDD
Muliple access	TDMA	CDMA
Handover	Hard	Hard and soft
Frequency reuse	4-18	1
RF carrier	200 kHz	5 MHz
Maximum bit rates	GSM 9.6 kbps HSCSD 43.2 kbps GPRS 62.4 kbps EGPRS 179.2 kbps	DPCH 403.2 kbps HSDPA 7.2 Mbps HSUPA 1.44 Mbps
Max uplink transmit power	33 dBm	24 dBm
Min uplink transmit power	5 dBm	-50 dBm

Source: Radio access networks for UMTS, C. Johnsson, 2008

- ✓ Advantage of CDMA systems
  - ✓ Frequency diversity
    - Transmission spread over large bandwidth
    - Reduce effect of frequency dependant impairment
      - e.g. selective fading
  - ✓ Multipath resistance
    - Low chipping code auto-correlation
    - Reduce interference of delayed signals
  - ✓ Privacy
    - Noise-like signals, unique codes
  - ✓ Graceful degradation
    - Allows more users with reduced performance

Drawbacks of CDMA

- Self-jamming – arriving transmissions from multiple users not aligned on chip boundaries unless users are perfectly synchronized
- Near-far problem – signals closer to the receiver are received with less attenuation than signals farther away

✓ Soft handover

✓ A UE can be connected to more than one base station

- Smooth handover
- Macro diversity
- Robust transmission

✓ Softer handover

- Softer handover is a special case of soft handover where the radio links that are added and removed belong to the same Node B.
- A site of co-located base stations from which several sector cells are served.

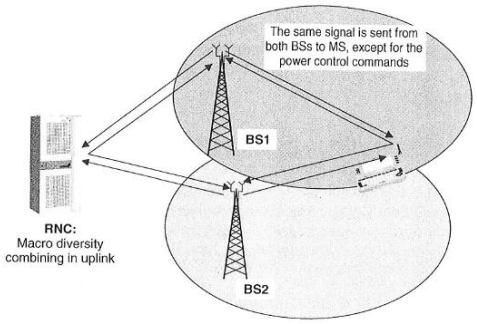


Figure 3.12. Soft handover

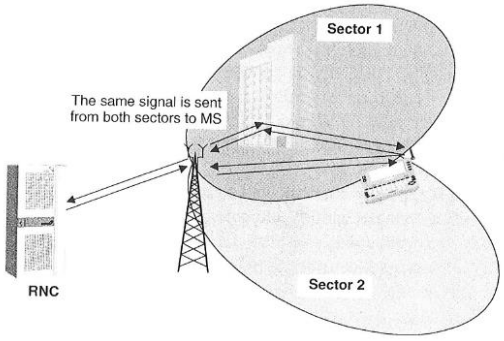


Figure 3.11. Softer handover

- Spreading factors (SF)
  - Orthogonal variable spreading factor codes (OVSF)
  - Chipping rate constant in W-CDMA (3.84 Mchip/s)
  - Spreading factors enables different data rates
    - SF=4 means 960 kbps, SF=8 means 480 kbps

WCDMA and UMTS

- 144 kbps to 2 Mbps, depending on mobility
- High Speed Downlink Packet Access (HSDPA)
  - Release 5
  - 1.8 to 14.4 Mbps downlink
  - Adaptive modulation and coding, hybrid ARQ, and fast scheduling
- High Speed Uplink Packet Access (HSUPA)
  - Release 6
  - Uplink rates up to 5.76 Mbps
- High Speed Packet Access Plus (HSPA+)
  - Release 7 and successively improved in releases through Release 11
  - Maximum data rates increased from 21 Mbps up to 336 Mbps
  - 64 QAM, 2×2 and 4×4 MIMO, and dual or multi-carrier combinations
- 3GPP Release 8 onwards introduced Long Term Evolution (LTE)
  - Pathway to 4G, Chapter 14