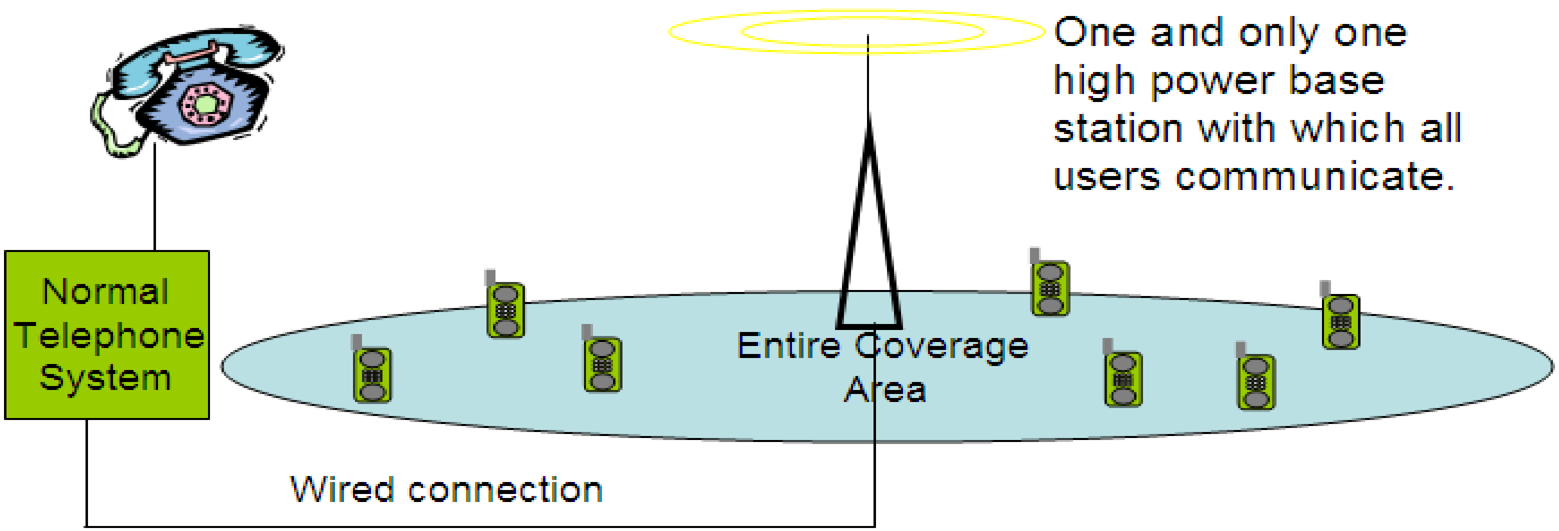
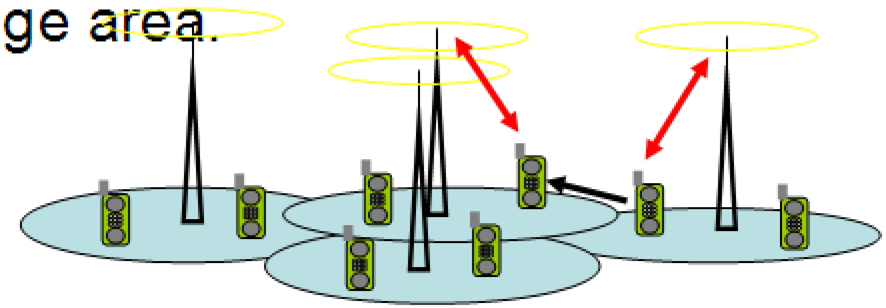
Cellular Networks

First Mobile Telephone System



The Core Idea: Cellular Concept

- The core idea that led to today's system was the cellular concept.
- **The cellular concept**: multiple lower-power base stations that service mobile users within their coverage area and **handoff** users to neighboring base stations as users move. Together base stations **tessellate** the system coverage area.



Cellular Network Organization

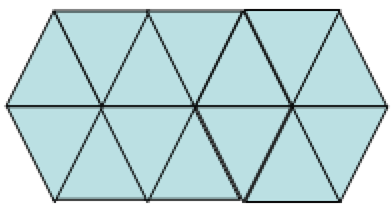
- Use multiple low-power transmitters (100 W or less)

- Areas divided into cells
  - Each served by its own antenna
  - Served by base station consisting of transmitter, receiver, and control unit
  - Band of frequencies allocated
  - Cells set up such that antennas of all neighbors are equidistant (hexagonal pattern)

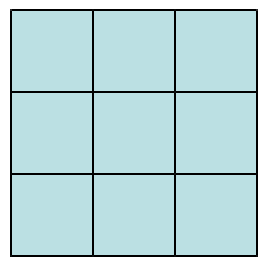
3 Core Principles

- Small cells tessellate overall coverage area.
- Users handoff as they move from one cell to another.
- Frequency reuse.

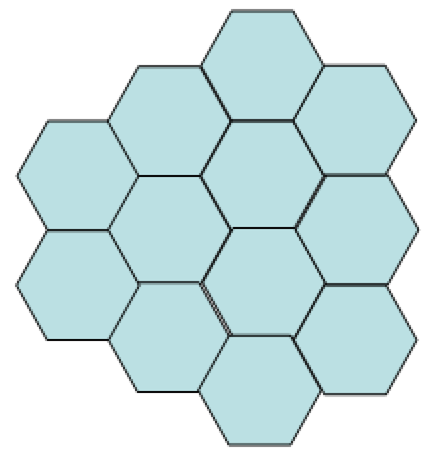
- Three regular polygons that always tessellate:
  - Equilateral triangle
  - Square
  - Regular Hexagon



Triangles

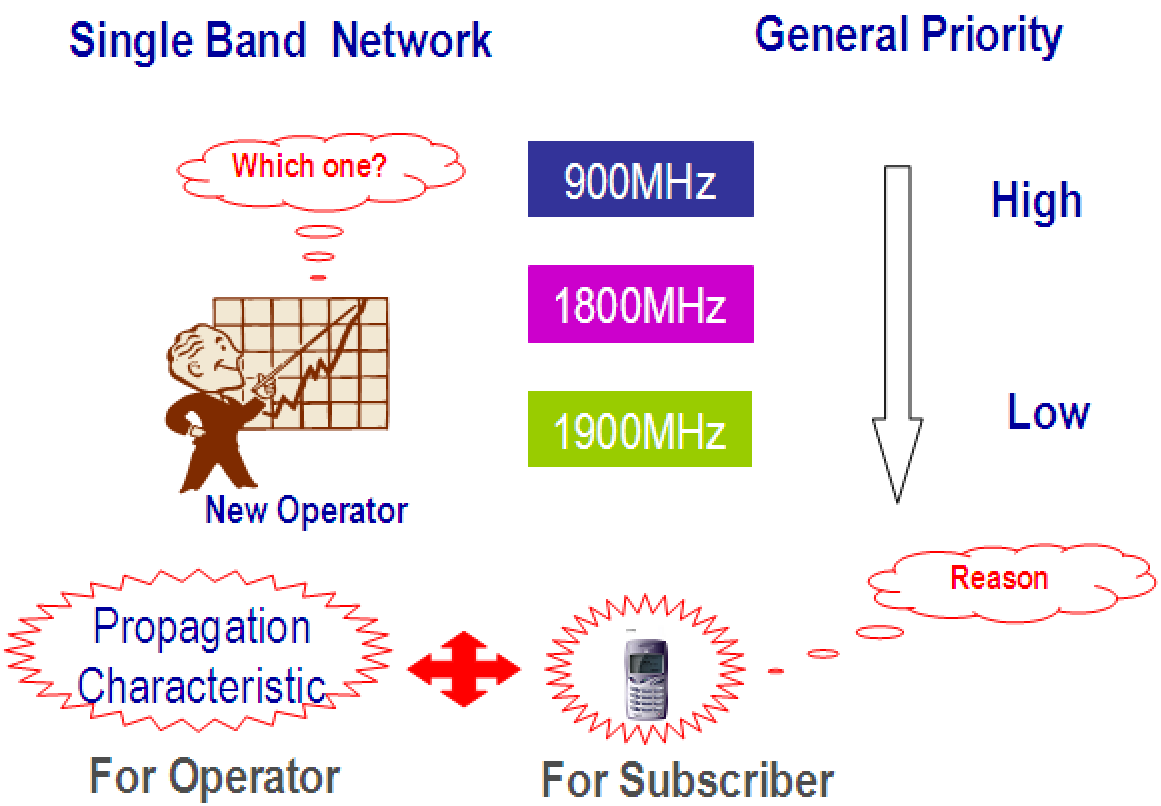


Squares

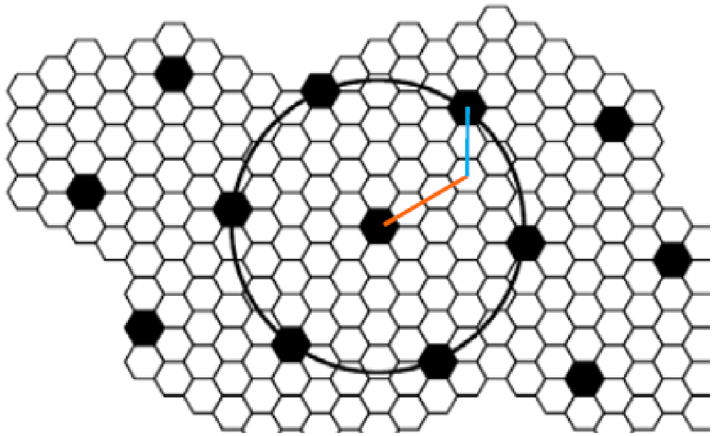


Hexagons

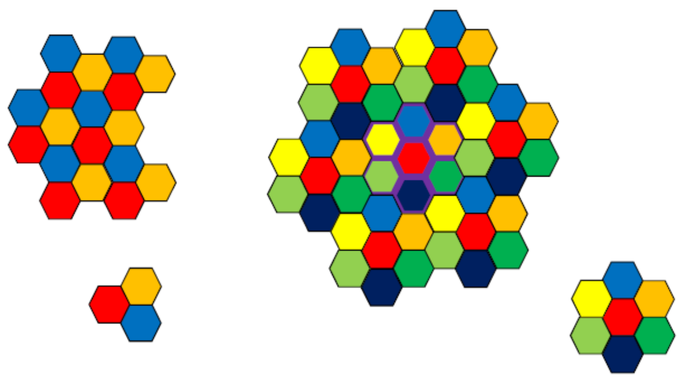
Frequency Resource



Example of Frequency Reuse



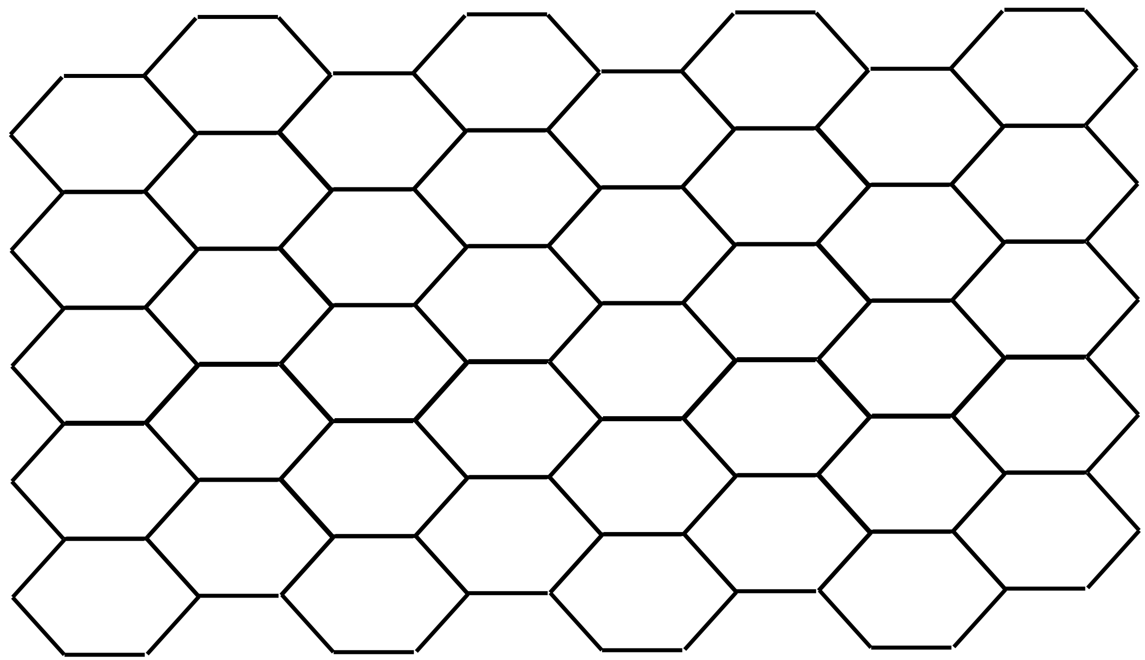
Cluster Size and Frequency Reuse Factor



Frequency Reuse

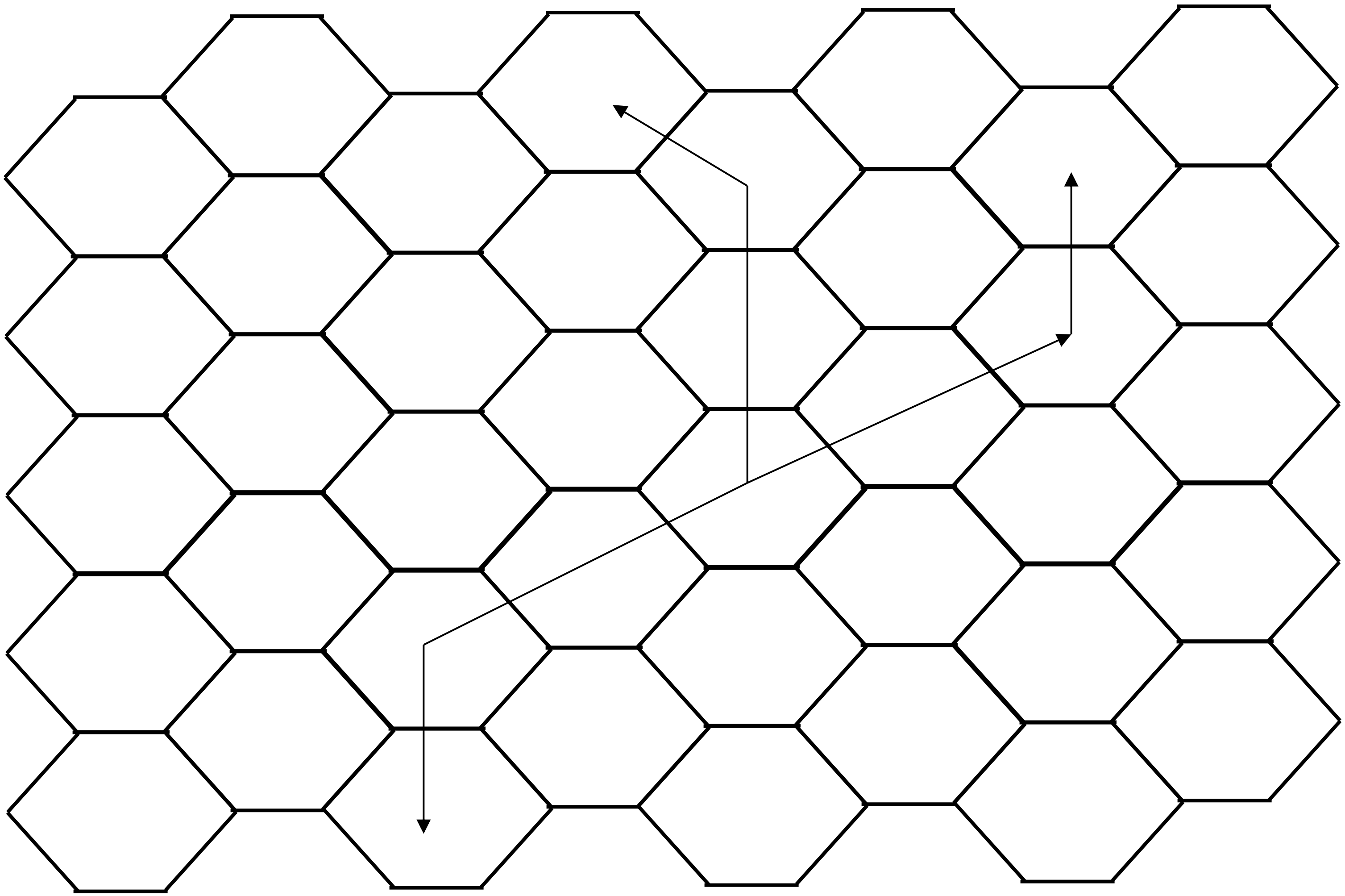
- Adjacent cells assigned different frequencies to avoid interference or crosstalk
- Objective is to reuse frequency in nearby cells
  - 10 to 50 frequencies assigned to each cell
  - Transmission power controlled to limit power at that frequency escaping to adjacent cells
  - The issue is to determine how many cells must intervene between two cells using the same frequency

Cellular Concept

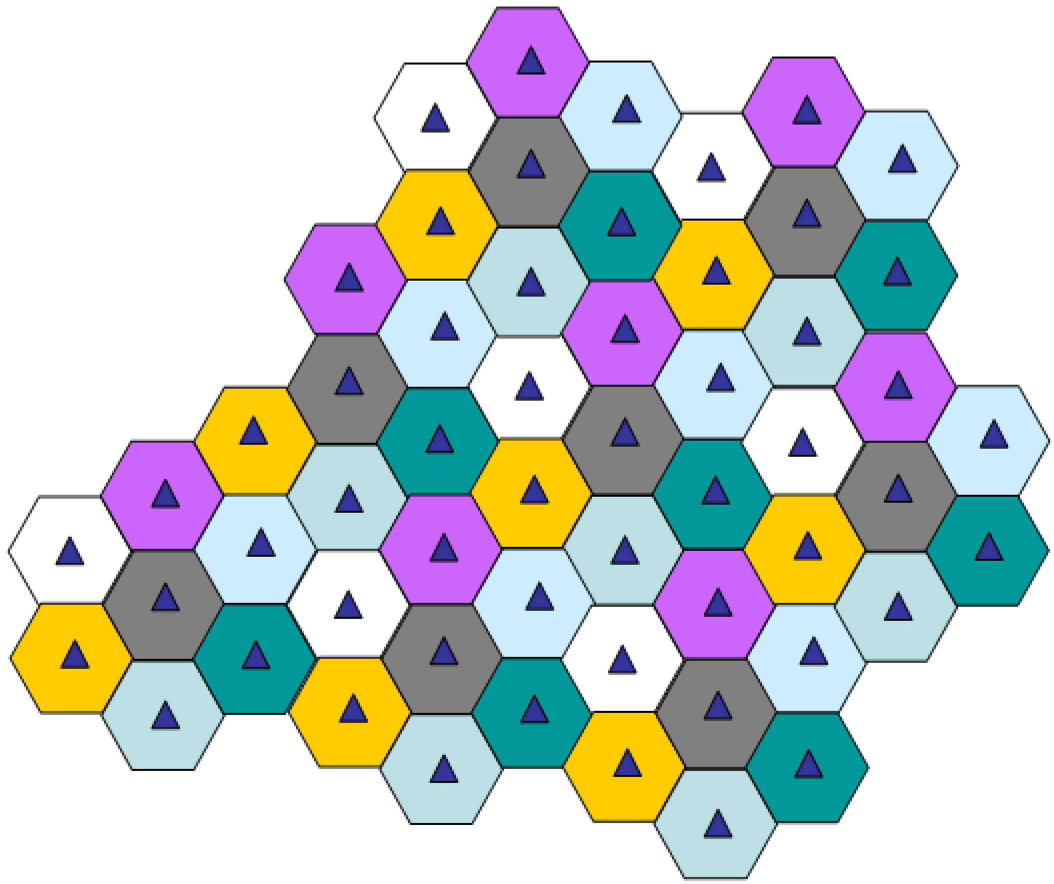


- Several small cells instead of a single transmitter=> frequency reuse: better efficiency
- Fixed Channel Allocation:
- Cluster of size $N = i^2+ij+j^2$; and D = sqrt($3N$)R
- R cell radius and
- D distance at which a frequency can be reused with acceptable interference

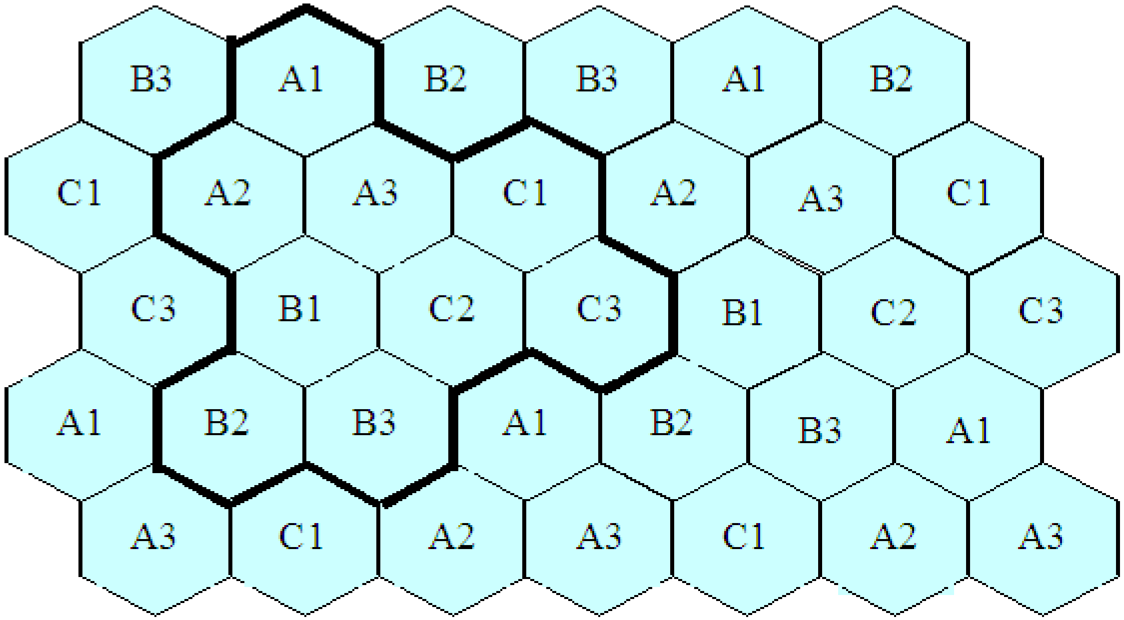
Examples



Clustersize of 7, Reuse Pattern



Frequency Reuse



“3 ´ 3” reuse mode:

one group includes 3 sectors /site ,9 frequency which are distributed to 3 sites. Every site owns 3 frequency.

Approaches to Cope with Increasing Capacity

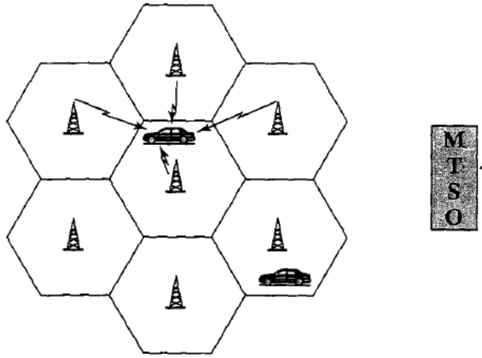
- Adding new channels
- Frequency borrowing – frequencies are taken from adjacent cells by congested cells
- Cell splitting – cells in areas of high usage can be split into smaller cells
- Cell sectoring – cells are divided into a number of wedge-shaped sectors, each with their own set of channels
- Microcells – antennas move to buildings, hills, and lamp posts

Cellular Systems Terms

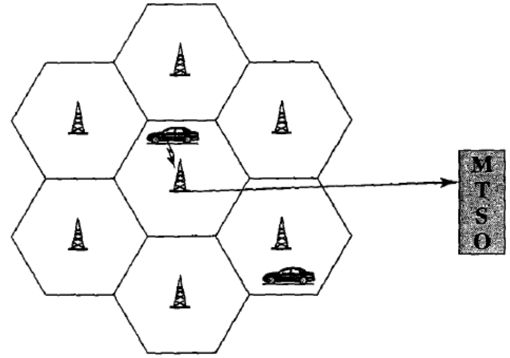
- Base Station (BS) – includes an antenna, a controller, and a number of receivers
- Mobile telecommunications switching office (MTSO) – connects calls between mobile units
- Two types of channels available between mobile unit and BS
  - Control channels – used to exchange information having to do with setting up and maintaining calls
  - Traffic channels – carry voice or data connection between users

Steps in an MTSO Controlled Call between Mobile Users

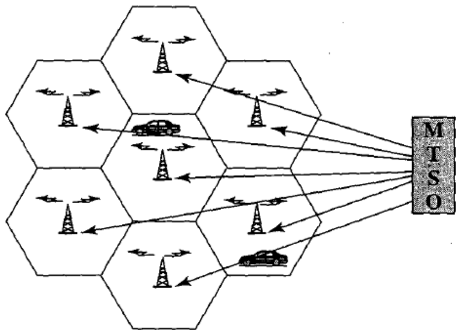
- Mobile unit initialization
- Mobile-originated call
- Paging
- Call accepted
- Ongoing call
- Handoff



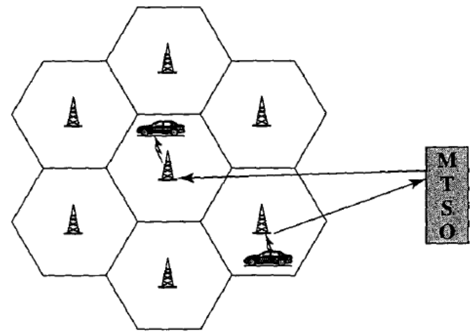
(a) Monitor for strongest signal



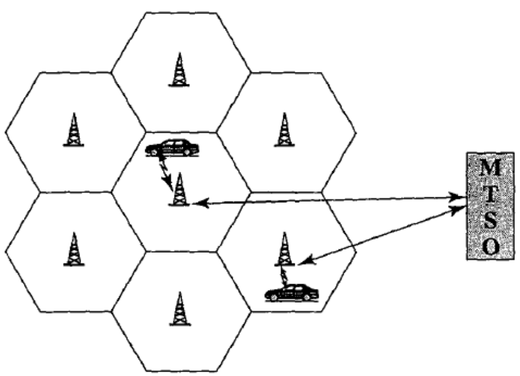
(b) Request for connection



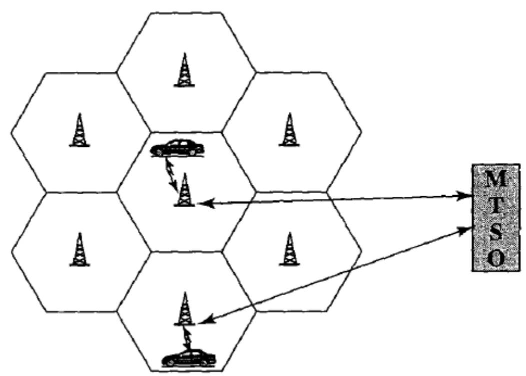
(c) Paging



(d) Call accepted



(e) Ongoing call



(f) Handoff

Additional Functions in an MTSO Controlled Call

- Call blocking
- Call termination
- Call drop
- Calls to/from fixed and remote mobile subscriber

Handoff Performance Metrics

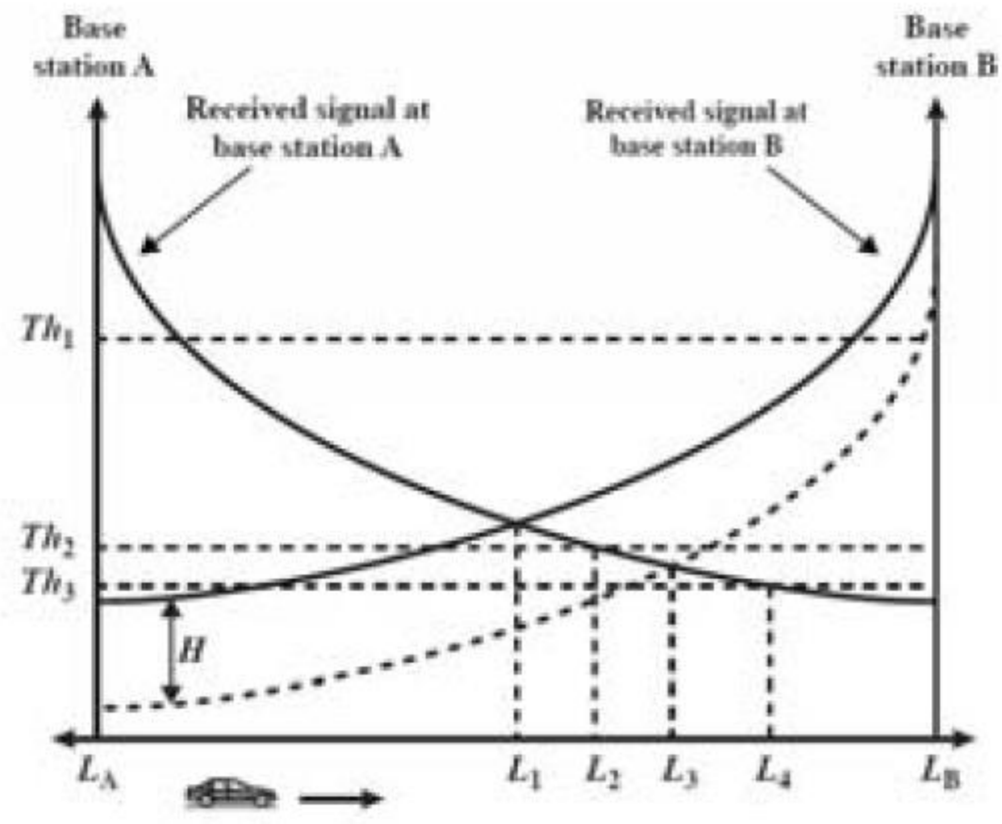
- Cell blocking probability – probability of a new call being blocked
- Call dropping probability – probability that a call is terminated due to a handoff
- Call completion probability – probability that an admitted call is not dropped before it terminates
- Probability of unsuccessful handoff – probability that a handoff is executed while the reception conditions are inadequate

Handoff Strategies Used to Determine Instant of Handoff

- Relative signal strength
- Relative signal strength with threshold
- Relative signal strength with hysteresis
- Relative signal strength with hysteresis and threshold
- Prediction techniques

Handover Strategies Used to Determine Instant of Handover

- Relative signal strength
  - With or without hysteresis and/or threshold
- Prediction techniques



First-Generation Analog

- Advanced Mobile Phone Service (AMPS)
  - In North America, two 25-MHz bands allocated to AMPS
    - One for transmission from base to mobile unit
    - One for transmission from mobile unit to base
  - Each band split in two to encourage competition (12.5MHz per operator)
  - Channels of 30 KHz SPACING
  - TOTAL 416 channels. 21 control channels (FSK), 395 traffic channels (FM voice) per operator
  - Operates at 10kbps (data)
  - Frequency reuse (N = 7)

Differences Between First and Second Generation Systems

- Digital traffic channels – first-generation systems are almost purely analog; second-generation systems are digital
- Encryption – all second generation systems provide encryption to prevent eavesdropping
- Error detection and correction – second-generation digital traffic allows for detection and correction, giving clear voice reception
- Channel access – second-generation systems allow channels to be dynamically shared by a number of users

TDMA Design Considerations

- Number of logical channels per physical channel (number of time slots in TDMA frame): 8
- Maximum cell radius (R): 35 km
- Frequency: region around 900 MHz
- Maximum vehicle speed (V_m):250 km/hr
- Maximum coding delay: approx. 20 ms
- Maximum delay spread (Δ_m): 10 μs
- Bandwidth: Not to exceed 200 kHz (25 kHz per channel)

GSM Network Architecture

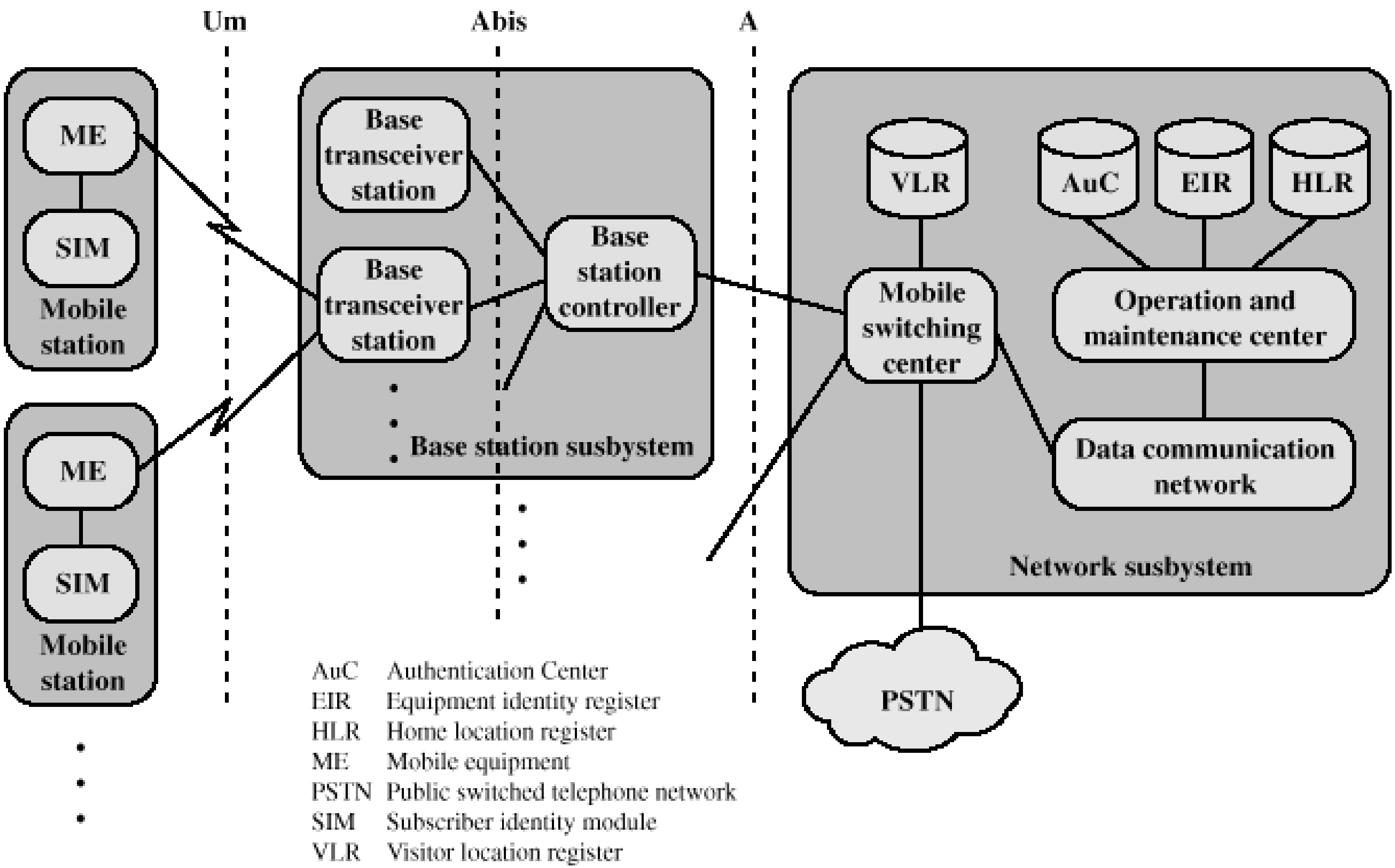
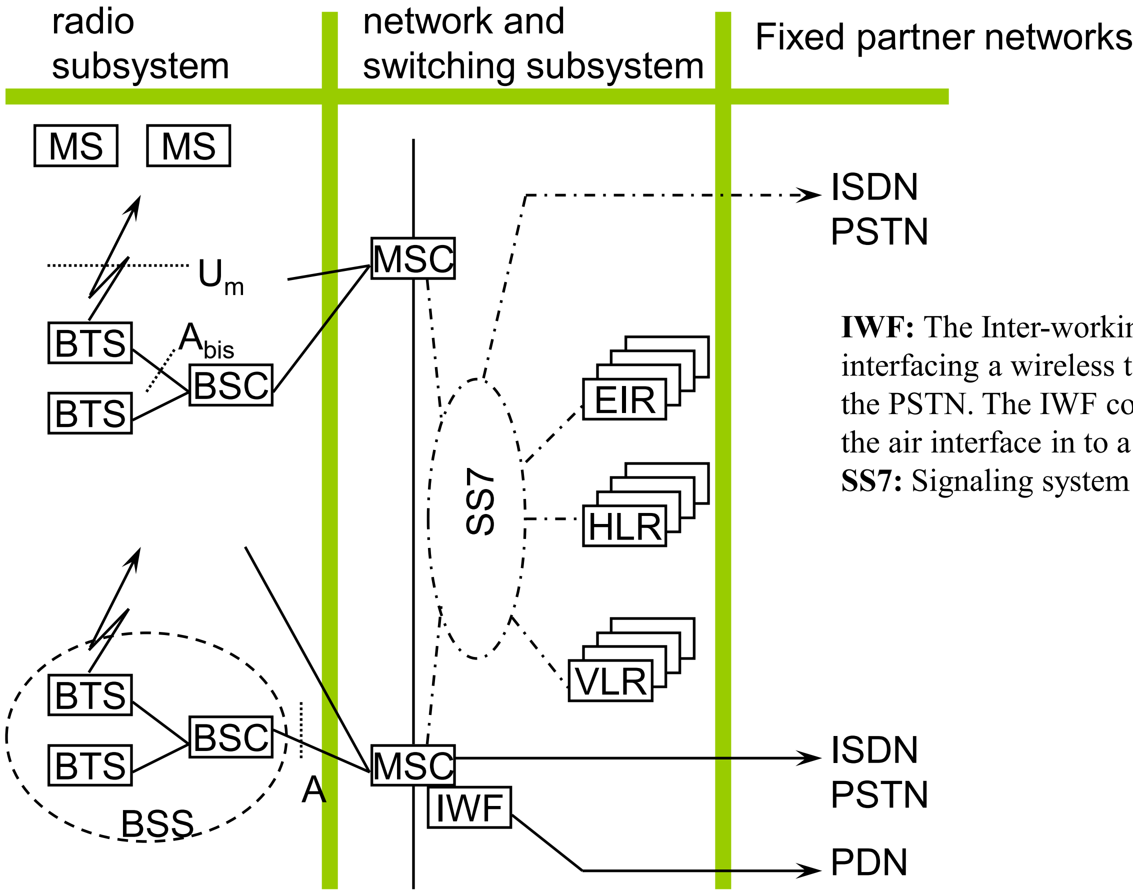


Figure 10.14 Overall GSM Architecture

Architecture of the GSM system

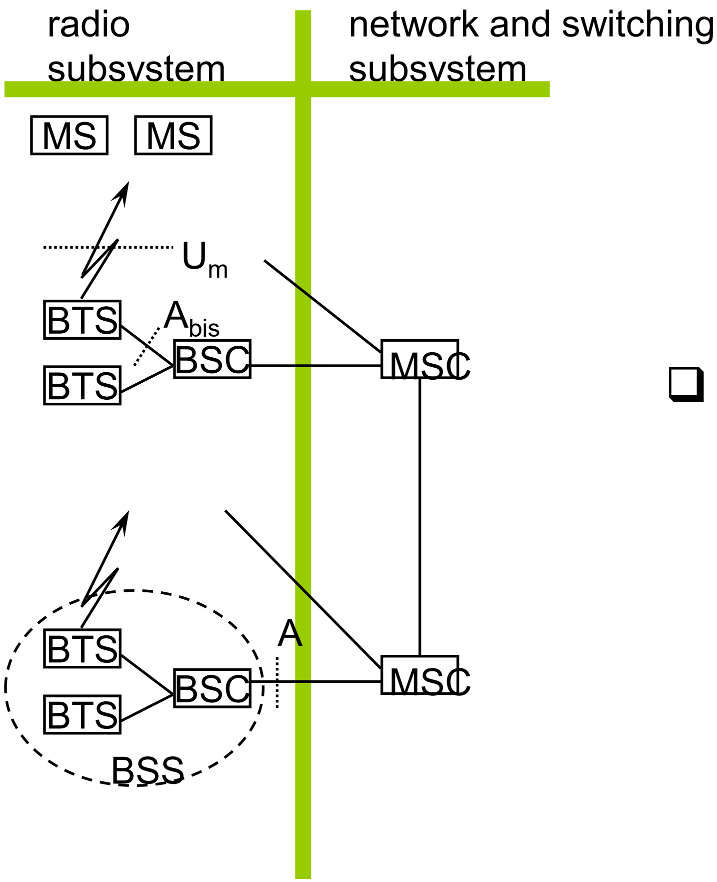
- Several providers setup mobile networks following the GSM standard within each country
- Components
  - MS (mobile station)
  - BS (base station)
  - MSC (mobile switching center)
  - LR (location register)
- Subsystems
  - RSS (radio subsystem): covers all radio aspects
    - Base station subsystem
  - NSS (network and switching subsystem): call forwarding, handover, switching
  - OSS (operation subsystem): management of the network

GSM: system architecture



IWF: The Inter-working Function (IWF) is a method for interfacing a wireless telecommunication network with the PSTN. The IWF converts the data transmitted over the air interface in to a format suitable for the PSTN
SS7: Signaling system protocol in communication

Radio subsystem



- Components
  - o *MS* (Mobile Station)
  - o *BSS* (Base Station Subsystem): consisting of
    - *BTS* (Base Transceiver Station): sender and receiver
    - *BSC* (Base Station Controller): controlling several transceivers
- Interfaces
  - o U_m : radio interface
  - o A_{bis} : standardized, open interface with
    16 kbit/s user channels
  - o *A*: standardized, open interface with
    64 kbit/s user channels

Mobile Station

- Mobile station communicates across Um interface (air interface) with base station transceiver in same cell as mobile unit

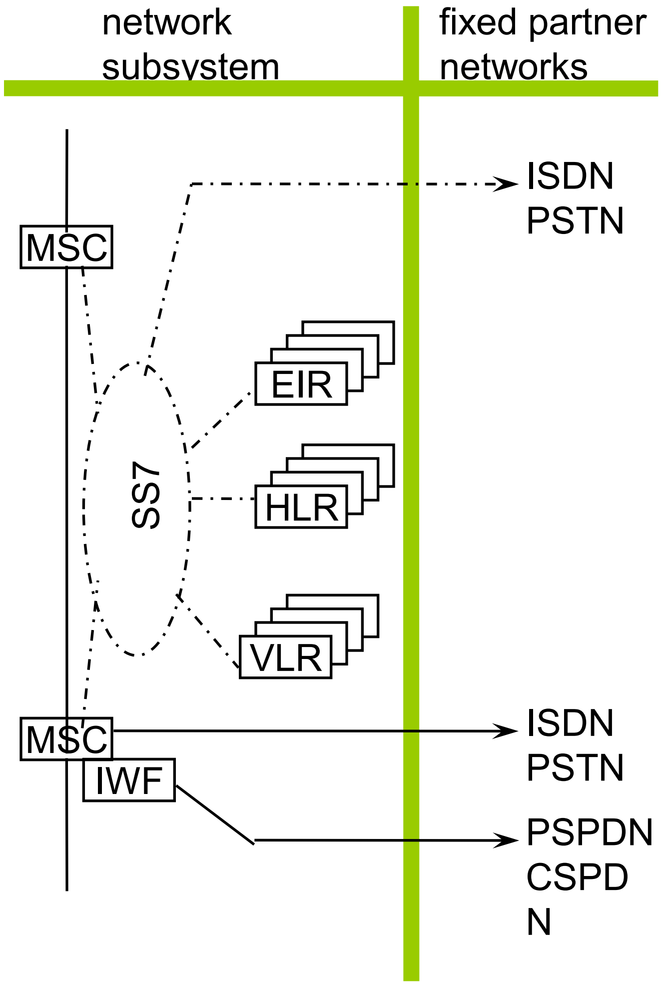
- Mobile equipment (ME) – physical terminal, such as a telephone or PDA
  - ME includes radio transceiver, digital signal processors and subscriber identity module (SIM)

- GSM subscriber units are generic until SIM is inserted
  - SIMs roam, not necessarily the subscriber devices

Base Station Subsystem (BSS)

- BSS consists of base station controller and one or more base transceiver stations (BTS)
- Each BTS defines a single cell
  - Includes radio antenna, radio transceiver and a link to a base station controller (BSC)
- BSC reserves radio frequencies, manages handoff of mobile unit from one cell to another within BSS, and controls paging

Network and switching subsystem



- Components
  - *MSC* (Mobile Services Switching Center):
  - *IWF* (Interworking Functions)

  - *ISDN* (Integrated Services Digital Network)
  - *PSTN* (Public Switched Telephone Network)
  - *PSPDN* (Packet Switched Public Data Net.)
  - *CSPDN* (Circuit Switched Public Data Net.)

- Databases
  - *HLR* (Home Location *R*egister)
  - *VLR* (Visitor Location *R*egister)
  - *EIR* (Equipment Identity Register)

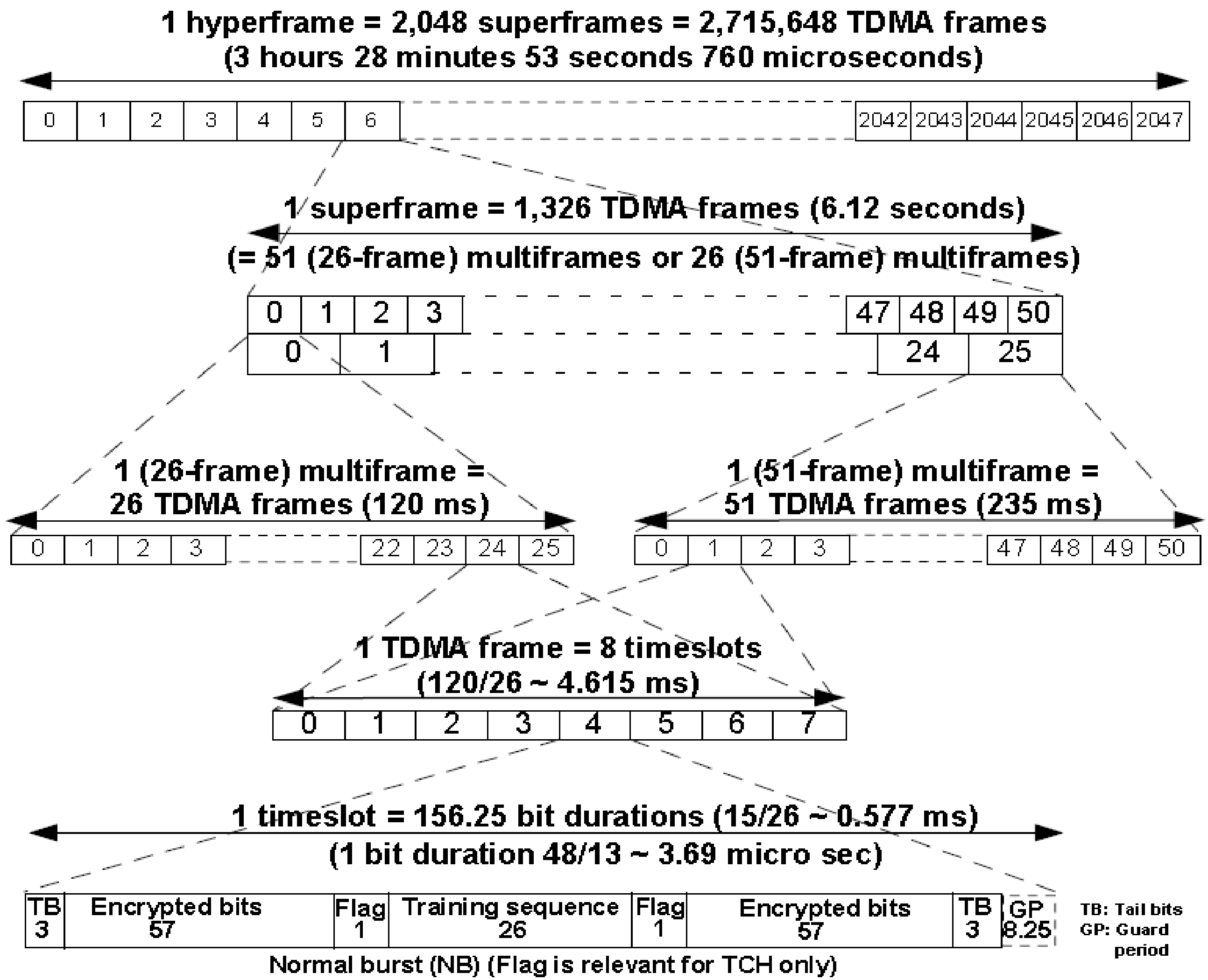
Mobile Switching Center (MSC) Databases

- Home location register (HLR) database – stores information about each subscriber that belongs to it
- Visitor location register (VLR) database – maintains information about subscribers currently physically in the region
- Authentication center database (AuC) – used for authentication activities, holds encryption keys
- Equipment identity register database (EIR) – keeps track of the type of equipment that exists at the mobile station

TDMA Format – Time Slot Fields

- GSM uses a complex TDMA frames to define logical channels. Each 200 kHz frequency band is divided into 8 logical channels.
- With a bitrate of 270.84kbps, each time slot has a length of 156.25 bits with duration of 0.5777 ms.

- Trail bits – allow synchronization of transmissions from mobile units located at different distances
- Encrypted bits – encrypted data
- Stealing bit - indicates whether block contains data or is "stolen"
- Training sequence – used to adapt parameters of receiver to the current path propagation characteristics
    - Strongest signal selected in case of multipath propagation
- Guard bits – used to avoid overlapping with other bursts


1 hyperframe = 2,048 superframes = 2,715,648 TDMA frames
(3 hours 28 minutes 53 seconds 760 microseconds)
0 1 2 3 4 5 6 2042 2043 2044 2045 2046 2047
1 superframe = 1,326 TDMA frames (6.12 seconds)
(= 51 (26-frame) multiframes or 26 (51-frame) multiframes)
0 1 2 3 47 48 49 50
0 1 24 25
1 (26-frame) multiframe =
26 TDMA frames (120 ms)
0 1 2 3 22 23 24 25
1 (51-frame) multiframe =
51 TDMA frames (235 ms)
0 1 2 3 47 48 49 50
1 TDMA frame = 8 timeslots
(120/26 ~ 4.615 ms)
0 1 2 3 4 5 6 7
1 timeslot = 156.25 bit durations (15/26 ~ 0.577 ms)
(1 bit duration 48/13 ~ 3.69 micro sec)
TB 3
Encrypted bits 57
Flag 1
Training sequence 26
Flag 1
Encrypted bits 57
TB 3
GP 8.25
TB: Tail bits
GP: Guard period
Normal burst (NB) (Flag is relevant for TCH only)

GSM Speech Processing

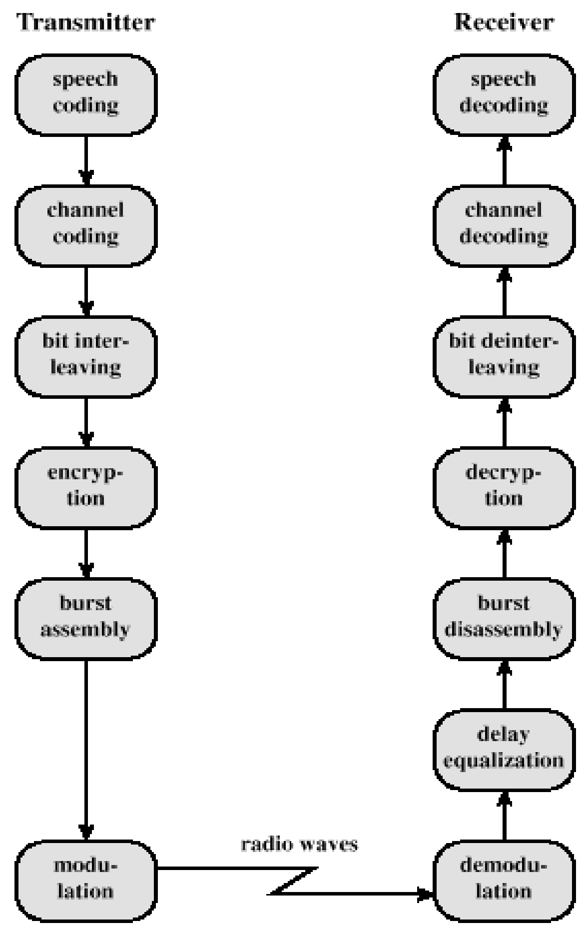


Figure 10.16 GSM Speech Signal Processing

Speech coding:

- The speech signal is compressed using an algorithm Regular Pulse Excited-Linear Predictive Coder (RPE-LPC)
- 260 bits in every 20 ms (13kbps)
- 260 bit divided into three classes

  Class 1a: 50 bits, most sensitive to bit errors

  Class2b: 132 bits: moderately sensitive to bit errors

  Class3c: 78 bits: least sensitive to bit errors.

- 50 bits are protected by 3 bit CRC, if error detected then discard (53)
- 53+132=185 bits +4 bit trail sequence=189 bits.
- 2 convolution error correcting code 189*2= 378 bits
- 378+78=456 bits / 20 ms = 22.8 kbps (GSM traffic data rate)

- To add protection againt burst errors, each 456 bits are divided into 8 57bit blocks. Carries data from dirrent speech samples.
- Data encripted 114 bits at a time. Assembled into time slot (burst assembly)

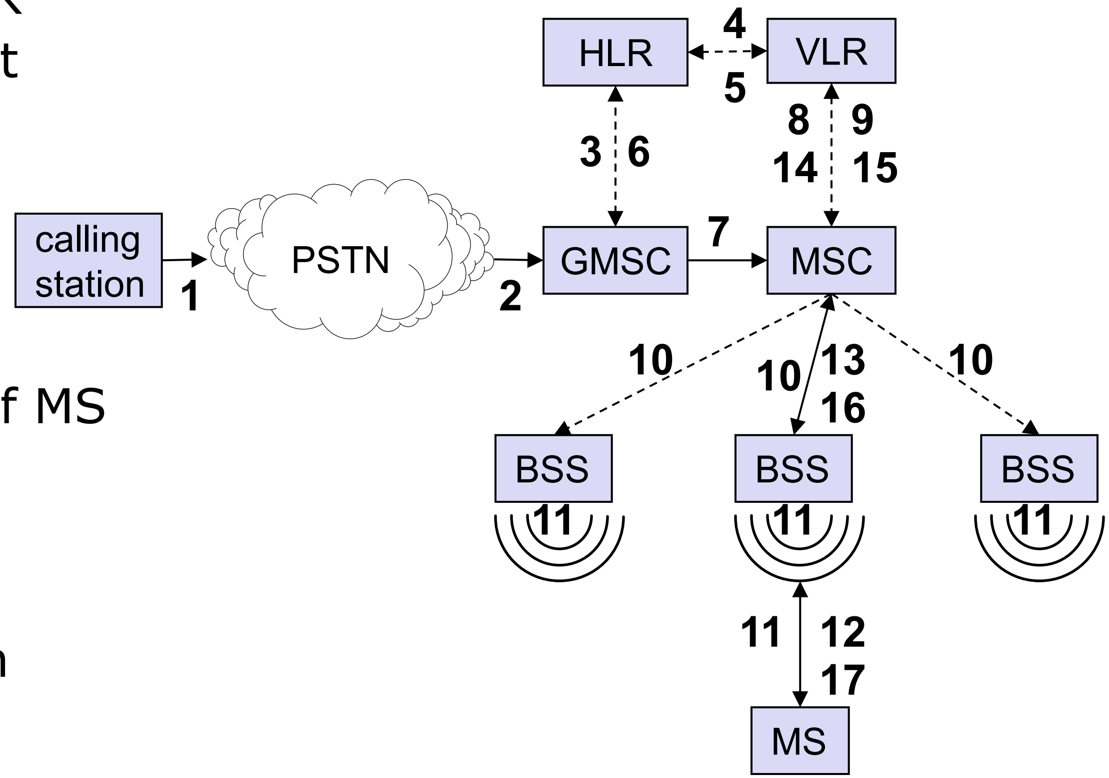
  Modulation (GMSK)

GSM Speech Processing Steps

- Speech compressed using a predictive coding scheme
- Divided into blocks, each of which is protected partly by CRC and partly by a convolutional code
- Interleaving to protect against burst errors
- Encryption for providing privacy
- Assembled into time slots
- Modulated for analog transmission using FSK

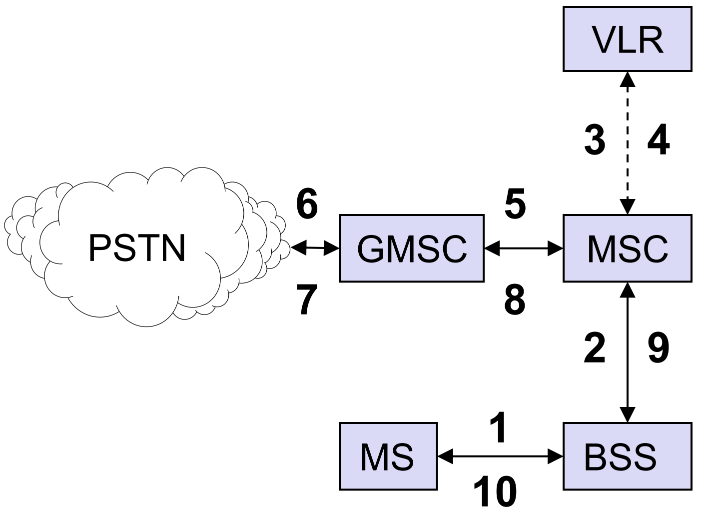
Mobile Terminated Call

- 1: calling a GSM subscriber
- 2: forwarding call to GMSC
- 3: signal call setup to HLR
- 4, 5: connect with current 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

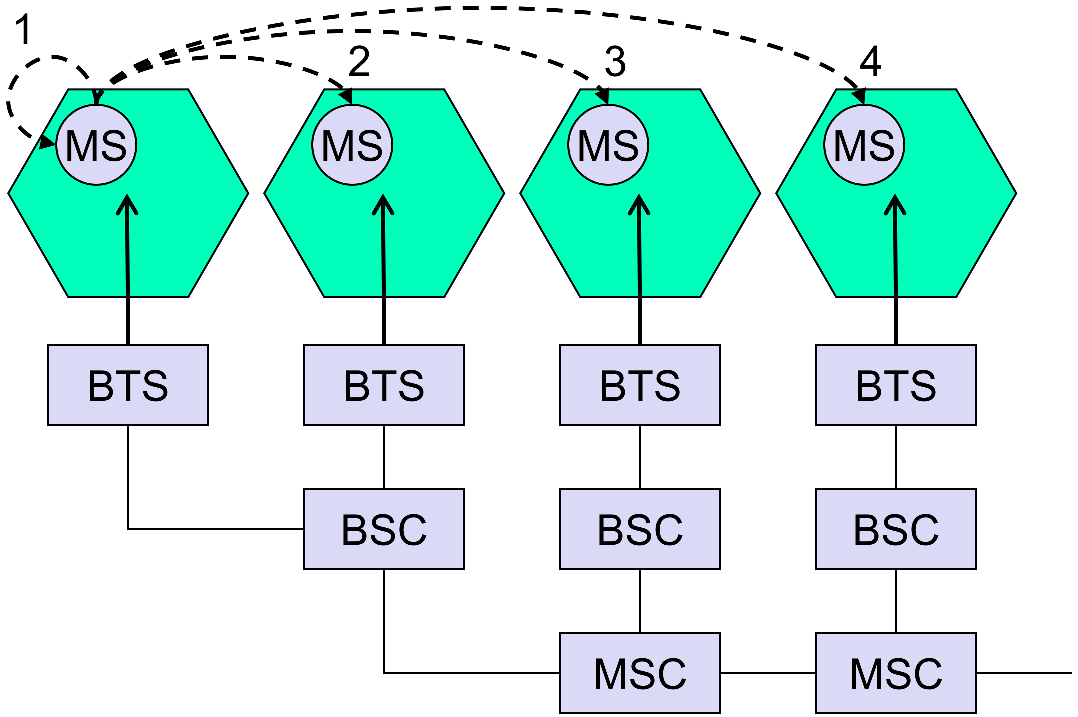


Mobile Originated Call

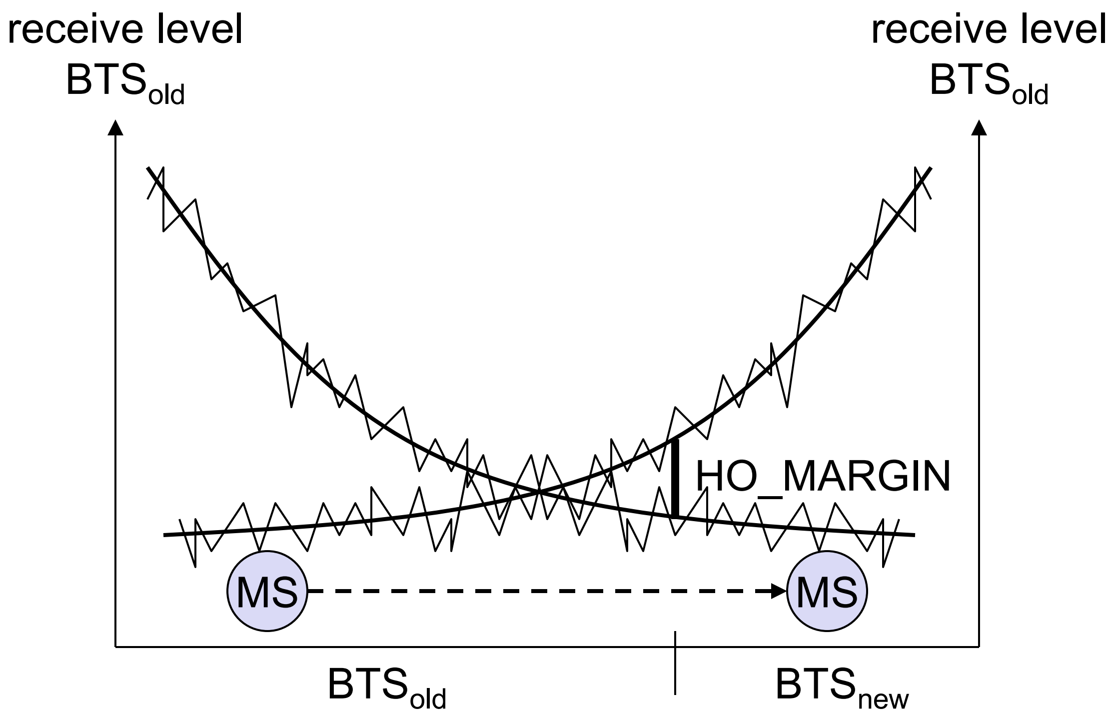
- 1, 2: connection request
- 3, 4: security check
- 5-8: check resources (free circuit)
- 9-10: set up call



4 types of handover



Handover decision

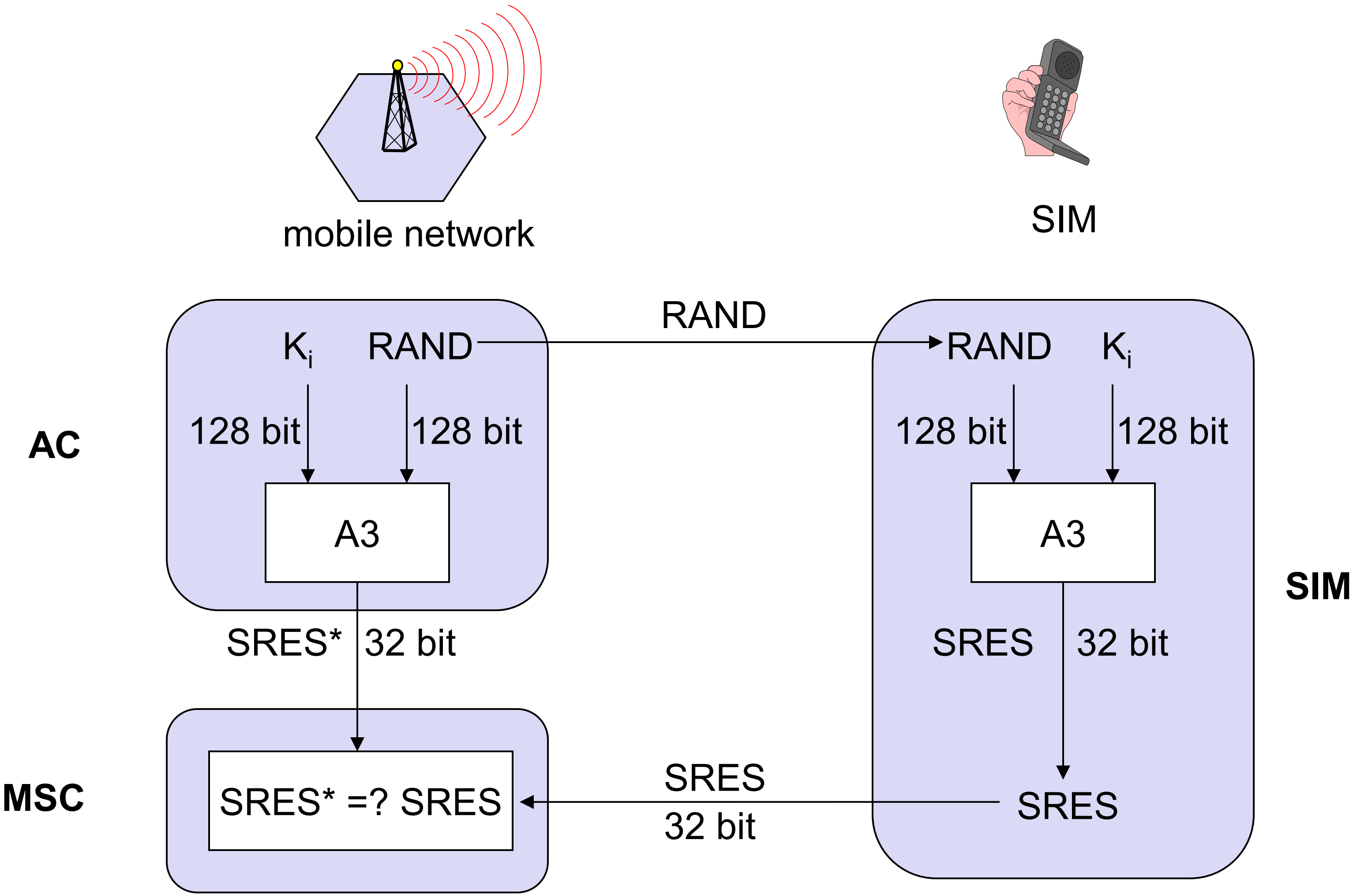


Security in GSM

- 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
- 3 algorithms specified in GSM
  - A3 for authentication (“secret”, open interface)
  - A5 for encryption (standardized)
  - A8 for key generation (“secret”, open interface)

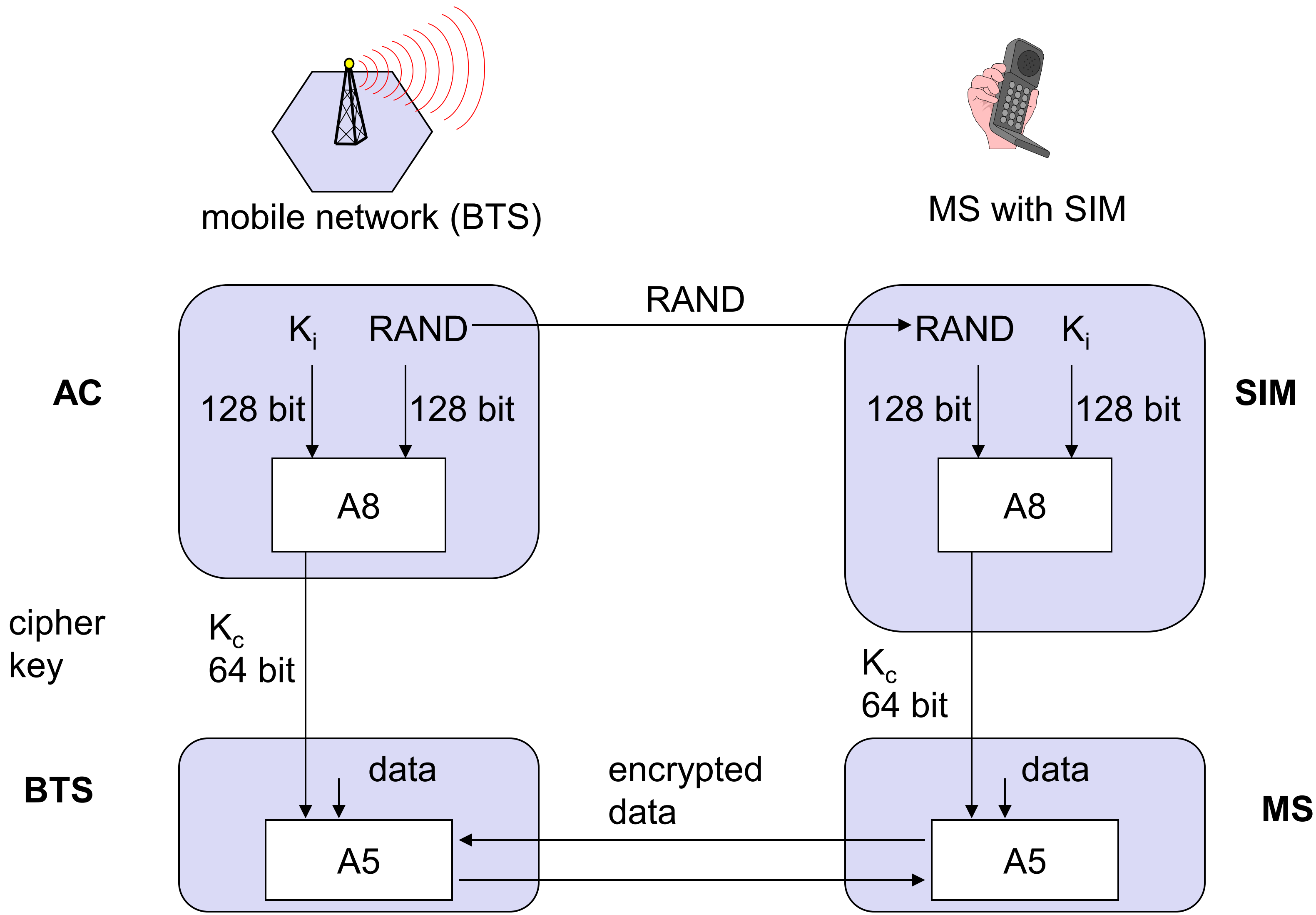
“secret”:
• A3 and A8 available via the Internet
• network providers can use stronger mechanisms

GSM - authentication



K_i: individual subscriber authentication key   SRES: signed response

GSM - key generation and encryption



CDMA Technology

CDMA Technology

- ***Code division multiple access (CDMA)*** *is a communication channel access principle.*
- *It uses* ***Spread-spectrum*** *technology and a special coding scheme.*
- ***CDMA*** *also refers to digital cellular telephony systems that use this multiple access scheme, as pioneered by* ***QUALCOMM****, and* ***W-CDMA*** *by the International Telecommunication Union (ITU).*

Working of CDMA

- ***CDMA*** *is a "**spread spectrum**" technology, allowing many users to occupy the same time and frequency allocations in a given band/space.*
- *As its name implies, **CDMA** (Code Division Multiple Access) assigns **unique codes** to each communication to differentiate it from others in the same spectrum.*
- *CDMA works by converting speech signals into digital signals, which are then transmitted over a wireless network and then decoded at the receiver's end. The receiver's equipment, is tuned to identify the particular code.*

IS-95 (CdmaOne)

- IS-95: standard for the radio interface
- IS-41: standard for the network part
- Operates in 800MHz and 1900MHz bands
- Uses DS-CDMA technology (1.2288 Mchips/s)
- Forward link (downlink): (2,1,9)-convolutional code, interleaved, 64 chips spreading sequence (Walsh-Hadamard functions)
- Pilot channel, synchronization channel, 7 paging channels, up to 63 traffic channels
- Reverse link (uplink): (3,1,9)-convolutional code, interleaved, 6 bits are mapped into a Walsh-Hadamard sequence, spreading using a user-specific code
- Tight power control (open-loop, fast closed loop)

Advantages of CDMA Cellular

Frequency diversity – frequency-dependent transmission impairments have less effect on signal

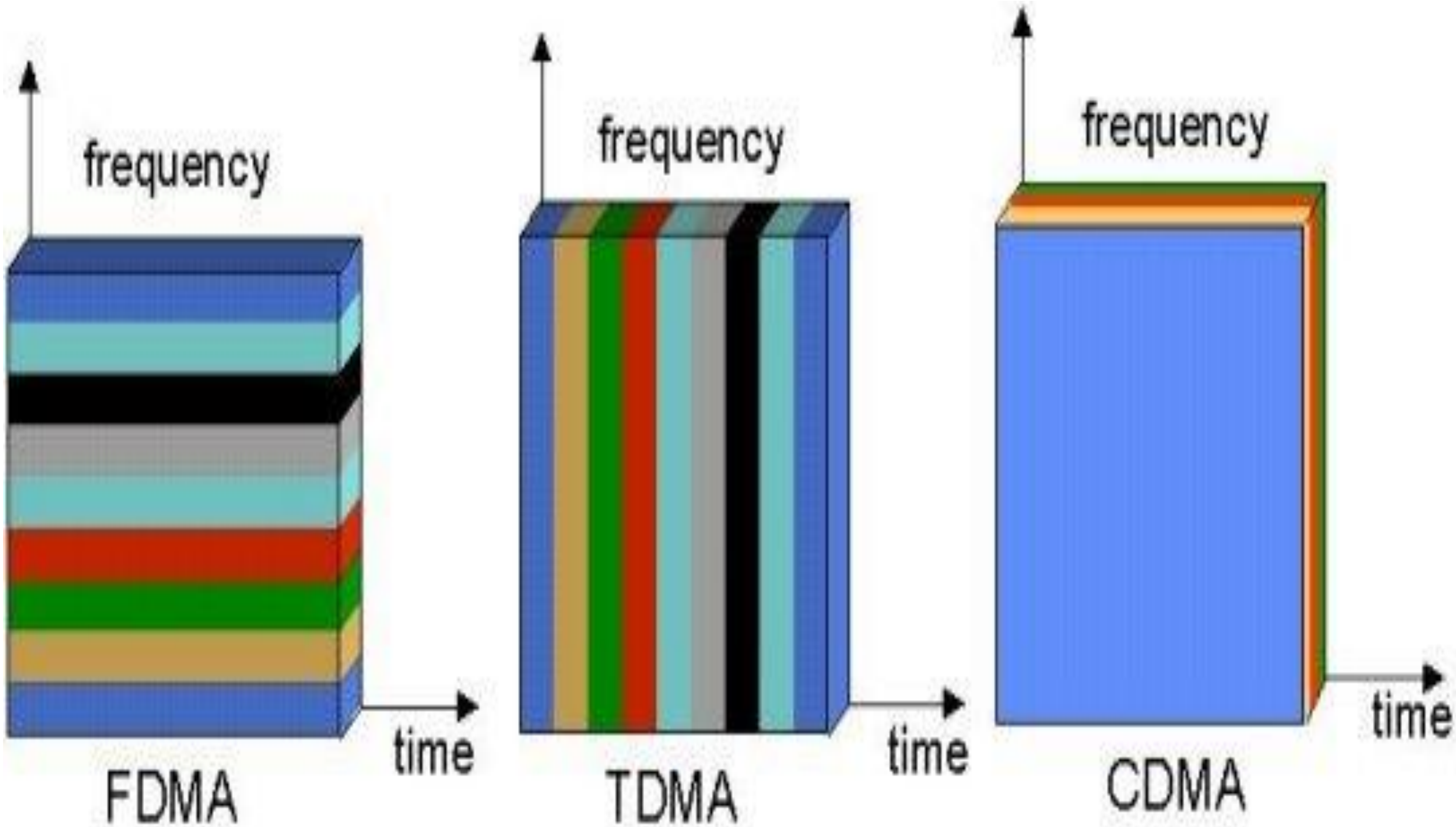
Multipath resistance – chipping codes used for CDMA exhibit low cross correlation and low autocorrelation

Privacy – privacy is inherent since spread spectrum is obtained by use of noise-like signals

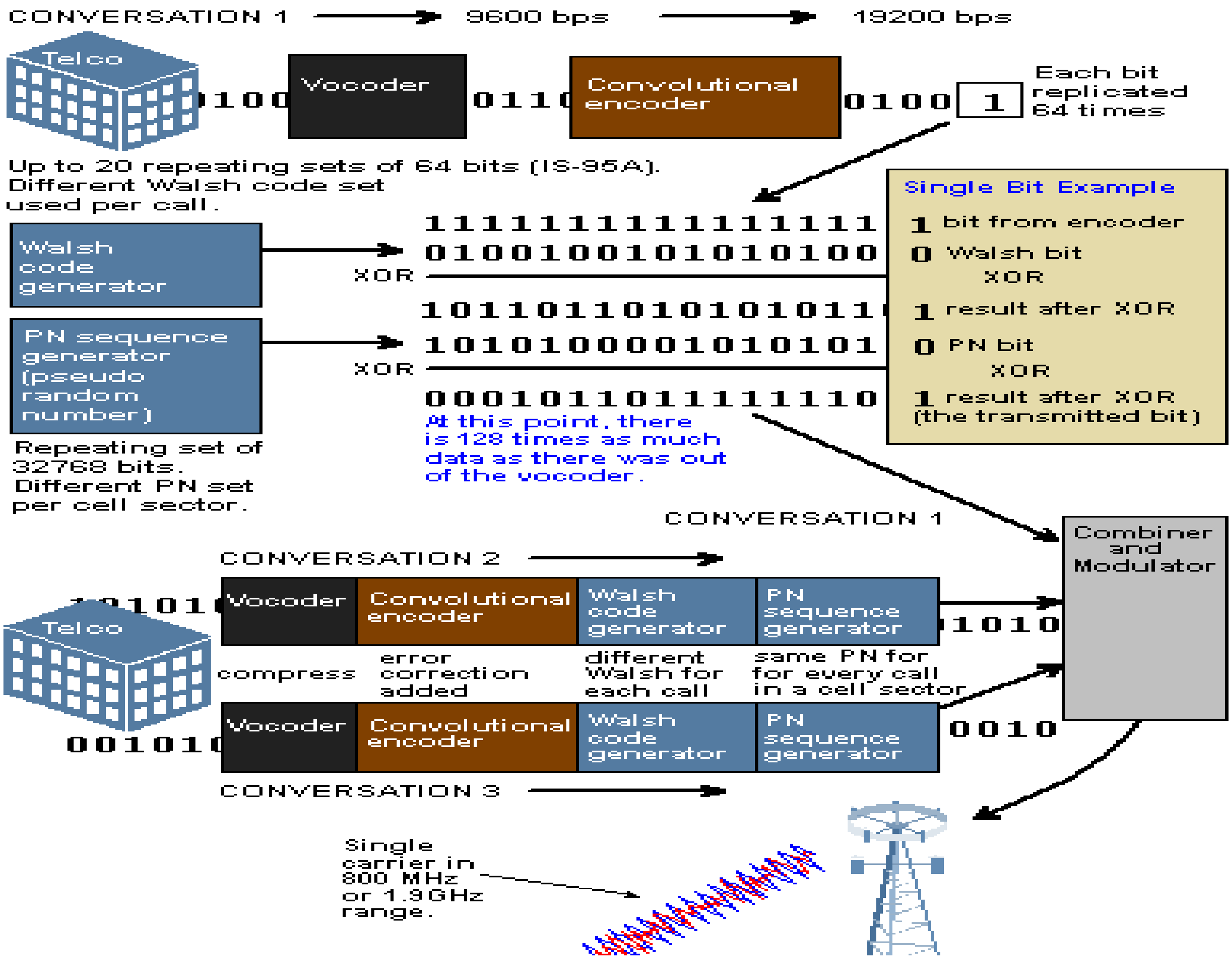
Graceful degradation – system only gradually degrades as more users access the system

Drawbacks of CDMA Cellular

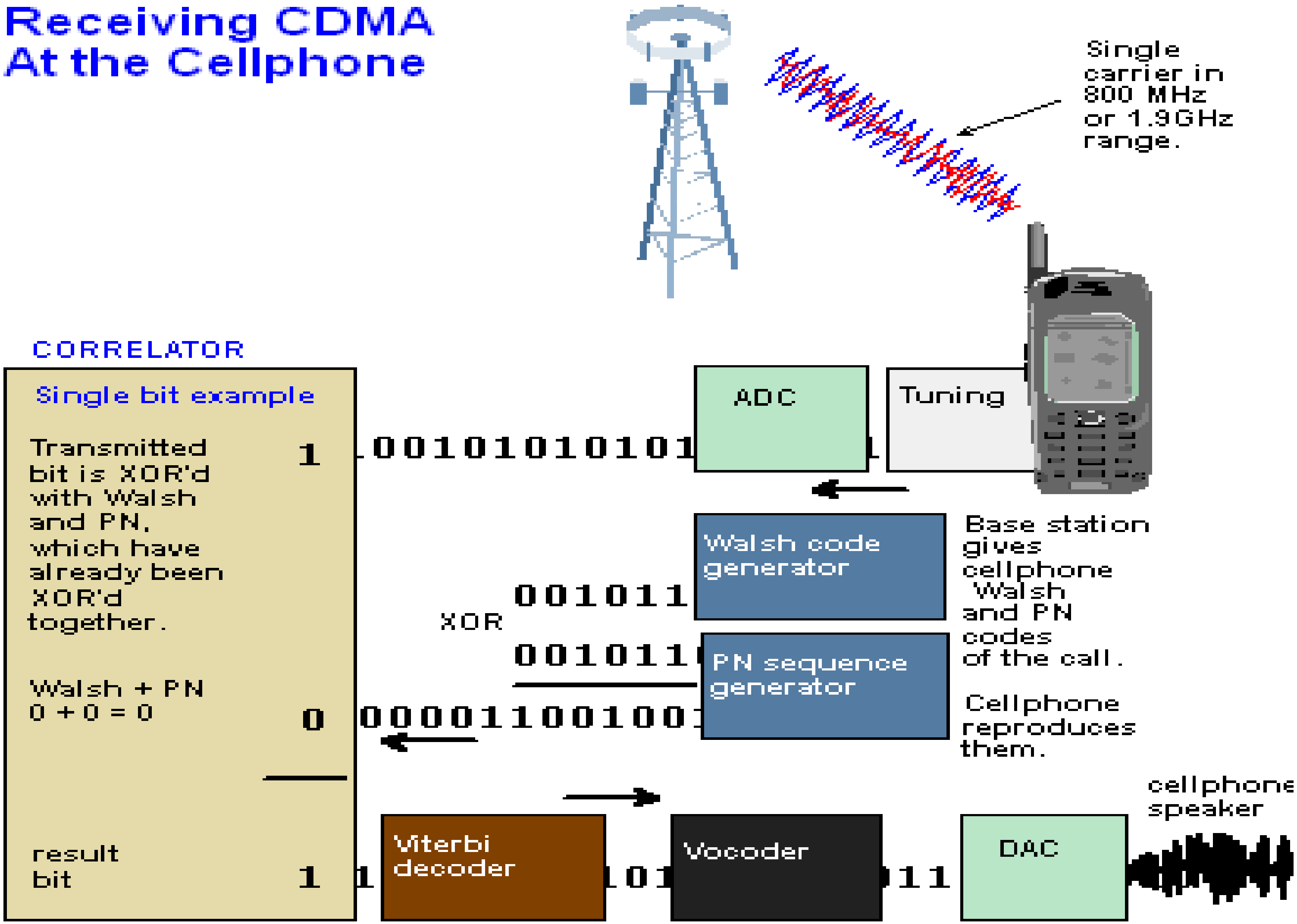
- Self-jamming – arriving transmissions from multiple users not aligned on chip boundaries unless users are perfectly synchronized
- Near-far problem – signals closer to the receiver are received with less attenuation than signals farther away
- Soft handoff – requires that the mobile acquires the new cell before it relinquishes the old; this is more complex than hard handoff used in FDMA and TDMA schemes


frequency
time
FDMA
frequency
time
TDMA
frequency
time
CDMA

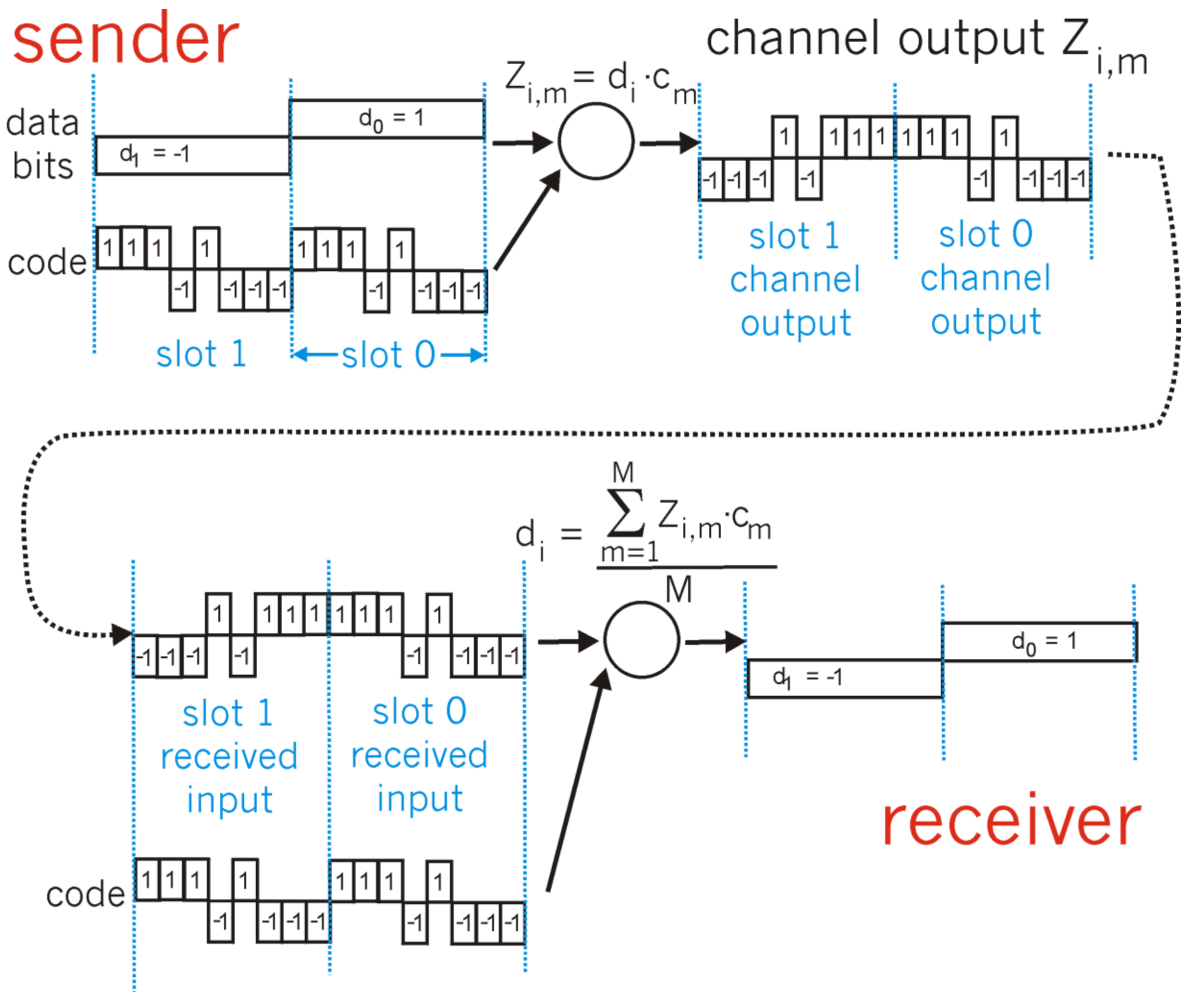
Transmitting CDMA Conversations From the Base Station



Receiving CDMA At the Cellphone



CDMA Encode/Decode



CDMA: two-sender interference

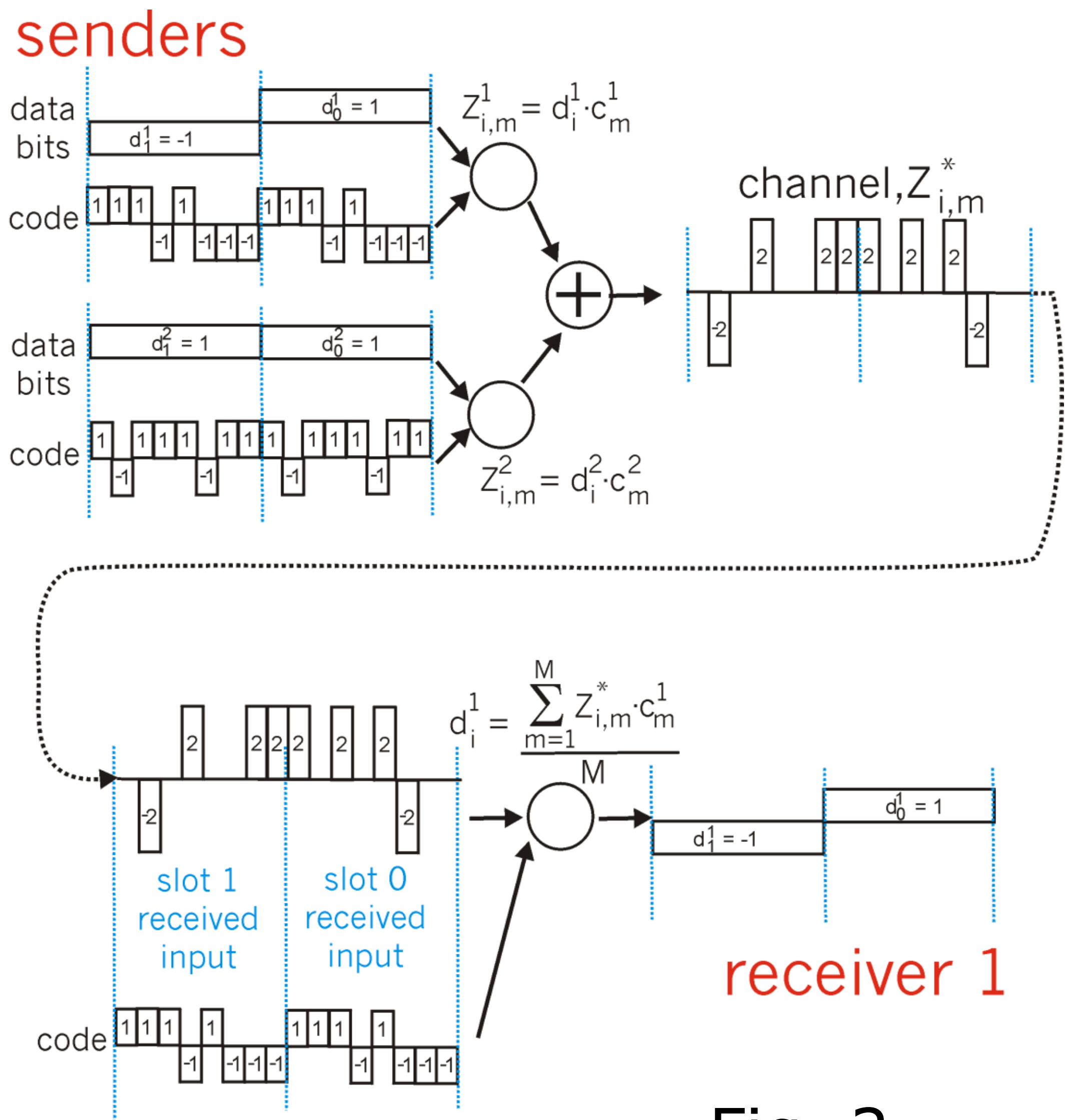


Fig. 2

DUSECHES MUSEUM CDMA CELL SITE ANTENNA

Handoff in CDMA System

In GSM hard handoff occurs at the cell boundary

Soft Handoff

- Mobile commences Communication with a new BS without interrupting communication with old BS
- same frequency assignment between old and new BS
- provides different site selection diversity

Softer Handoff

- Handoff between sectors in a cell

CDMA to CDMA hard handoff

- Mobile transmits between two base stations with different frequency assignment

Soft Handoff- A unique feature of CDMA Mobile

Advantages

Contact with new base station is made before the call is switched

Diversity combining is used between multiple cell sites

- Diversity combining is the process of combining information from multiple transmitted packets to increase the effective SNR of received packets
- additional resistance to fading

If the new cell is loaded to capacity, handoff can still be performed for a small increase in BER

Neither the mobile nor the base station is required to change frequency

Principle of RAKE Receiver

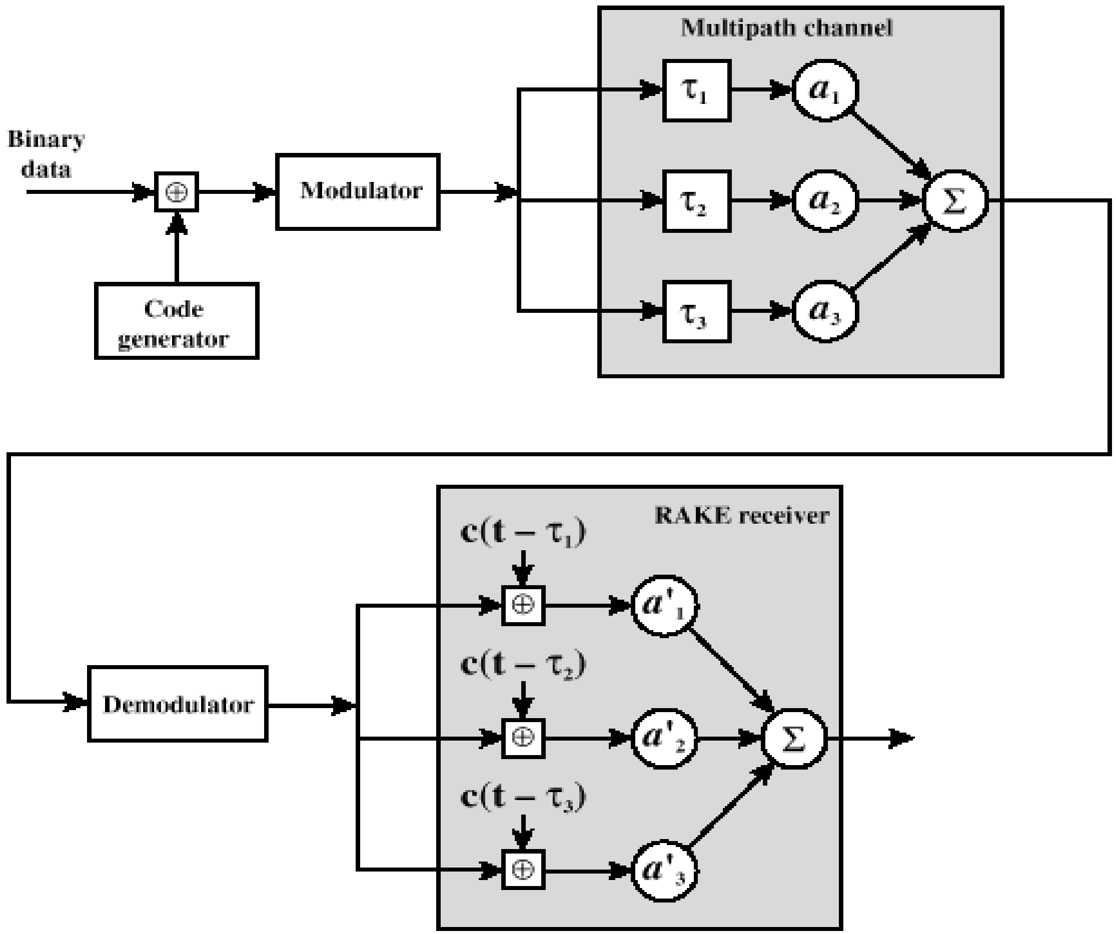


Figure 10.18 Principle of RAKE Receiver [PRAS98]

Forward Traffic Processing Steps

Speech is encoded at a rate of 8550 bps

Additional bits added for error detection

Data transmitted in 2-ms blocks with forward error correction provided by a convolutional encoder

Data interleaved in blocks to reduce effects of errors

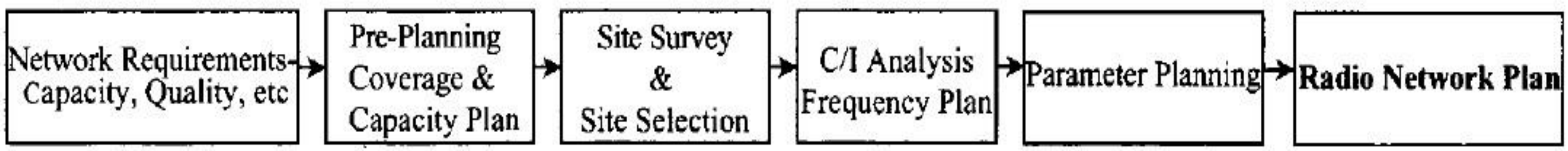
Data bits are scrambled, serving as a privacy mask

- Using a long code based on user’s electronic serial number

Forward Traffic Processing Steps

- Power control information inserted into traffic channel
- DS-SS function spreads the 19.2 kbps to a rate of 1.2288 Mbps using one row of 64 x 64 Walsh matrix
- Digital bit stream modulated onto the carrier using QPSK modulation scheme

NETWORK PLANNING PROCESS



The pre-planning process results in theoretical coverage and capacity plans.

- The average cell capacity requirement per service area is estimated for each phase of network design.
- Coverage-driven to a capacity-driven process.
- To find the minimum number of sites for producing the required coverage, radio planners often have to experiment with both coverage and capacity, as the capacity requirements may have to increase the number of sites, resulting in a more effective frequency usage and minimal interference.

Sites are then searched for, and one of these is selected based on the inputs from the transmission planning and installation engineers. Civil engineers are also needed to do a feasibility study of constructing the base station at that site.

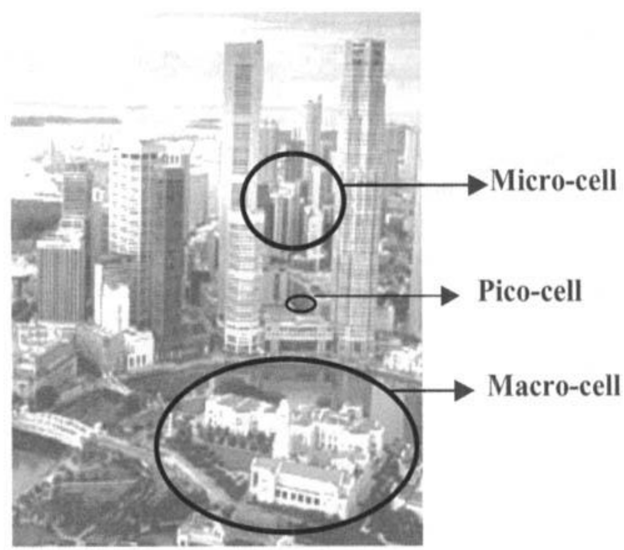
Frequency allocation is based on the cell-to-cell channel to interference (C/I) ratio. The frequency plans need to be fine-tuned based on drive test results and network management statistics.

Parameter plans are drawn up for each of the cell sites. This may include cell service area definitions, channel configurations, handover and power control.

The radio plan consists of the coverage plans, capacity estimations, interference plans, power budget calculations, parameter set plans, frequency plans, etc.

Radio Cell and Wave Propagation

- The requirement from the radio planners is generally a network design that covers 100% of the area.
- The whole land area is divided into three major classes - urban, suburban and rural - based on human-made structures and natural terrains. The cells (sites) that are constructed in these areas can be classified as outdoor and indoor cells. Outdoor cells can be further classified as macro-cellular, micro-cellular or pico cellular.



Dimensioning

- The dimensioning exercise is to identify the equipment and the network type (i.e. technology employed) required in order to cater for the coverage and quality requirements, apart from seeing that capacity needs are fulfilled for the next few years (generally 3-5 years).

The inputs that are required for the dimensioning include:

- The geographical area to be covered
- The estimated traffic in each region
- Minimum requirements of power in each region and blocking criteria
- Path loss
- The frequency band to be used and frequency re-use.

RADIO NETWORK DETAILED PLANNING

The detailed radio network plan can be sub-divided into three sub-plans:

- Link budget calculation,
- Coverage, capacity planning and spectrum efficiency,
- Parameter planning.

Important Components of Link Budget Calculations

- MS sensitivity: This factor is dependent upon the receiver noise and minimum level of *Eb/No* (i.e. output signal to noise ratio) needed. This is calculated by using the GSM specifications (ETSI GSM recommendation 05.05). The recommended values of MS sensitivity in GSM 900 and 1800 are -102 dBm and -100 dBm respectively.

- BTS sensitivity: The sensitivity of the base station is again specified by the ETSI's GSM recommendations 05.05 and is calculated in the same manner as the MS sensitivity. The recommended value of BTS sensitivity is -106 dBm. However, when doing power budget calculations, the value given by the manufacturer (or measured value) should be used.

- Fade margin: This is the difference between the received signal and receiver threshold. Usually a fast fade margin is of importance in power budget calculations. Different values are used for different types of regions, such as 2 dB for dense urban or 1 dB for urban.

- Connector and cable losses: As cables and connectors are used in power transmission, the losses incurred therein should be taken into account. Cable attenuation figures are usually quoted in loss (dB) per 100 m.

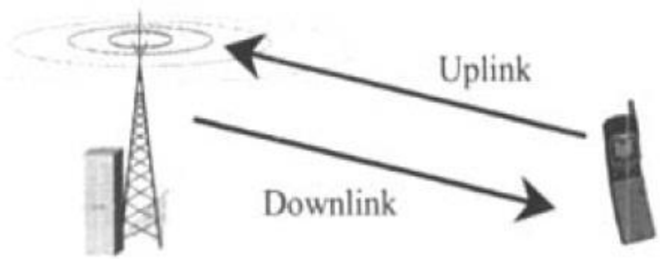
- MS and BTS antenna gain: The antennas used for MS and BTS have significantly different gain levels.

Link Budget & Power Budget

Power budget calculation

Consider a BTS and MS along with the parameters as shown in Figure 2.9.

- RF Power of BST (UL): 42 dBm
- Antenna Gain (Gb): 18 dbm
- Cable Loss (UL/DL): 2 dB
- BTS Sensitivity:- 108 dBm
- Combiner Loss; 2 dB



- RF Power of MS : 32 dBm
- Antenna Gain (Gm): 0 dbm
- Cable Loss (UL/DL): 0 dB
- MS Sensitivity:- 106 dBm

Example of a power budget

Link Budget

- Link budget calculations give the loss in the signal strength on the path between the mobile station antenna and base station antenna.
- Link budget calculations are done for both the uplink and downlink.
- Effective Isotropic Effective power

Uplink calculations

PLu (Path Loss in uplink) = EIRPm (Peak EIRP of Mobile) − Prb (Power Received by the base station)

$$
\begin{aligned}
EIRPm &= \text{Ptm (Power transmitted from the MS)} - \text{Losses} + \text{Gm} \\
Losses &= \text{Lcm (cable loss at mobile)} + \text{Lom (any other loss)} \\
Prb &= -\text{Gb (antenna gain)} - \text{Losses} + \text{Bs (BTS sensitivity)} \\
Losses &= \text{Lcb (cable loss at BTS)} + \text{Lob (any other loss)} \\
PLu &= \text{EIRPm} - \text{Prb} \\
&= [Ptm - Lcm - Lom + Gm] - [-Gb + Lcb + Lob + Bs] \\
&= [32 - 0 + 0 + 0] - [-18 + 2 + 0 + (-108)] \\
&= 32 + 124 = 156\,dB
\end{aligned}
$$

Downlink calculations

PLd (Path Loss in downlink) = EIRPb (peak EIRP of BTS) − Prm (Power received by the MS)

$$EIRPb = Ptb\ (\text{Power transmitted by BTS}) + Gtb\ (\text{antenna gain}) - Losses$$

$$Losses = Lcb\ (\text{cable loss at BTS}) + Lccb\ (\text{combiner loss at BTS})$$

$$Prm = Ms\ (\text{Mobile sensitivity}) + Losses - Gm\ (\text{mobile antenna Gain})$$

$$Losses = Lcm\ (\text{cable loss}) + Lom\ (\text{any other loss})$$

$$\begin{aligned} PLd &= EIRPb - Prm \\ &= [Ptb + Gtb - Lcb - Lccb] - [Ms - Lcm - Lom - Gm] \\ &= [42 + 18 - 2 - 2] - [-106 - 0 - 0 - 0] \\ &= 56 + 106 = 162\ dB \end{aligned}$$

There is an obvious difference in the results of the uplink and downlink power budget calculations, where the downlink path loss exceeds the uplink power loss. This is an indication that the area covered by the base station antenna radiation is more than the area covered by the mobile station antenna, thereby giving more coverage in the downlink direction. Reducing the power in the downlink direction can reduce this difference but results in a loss of coverage.

The link budget is the table recording the power loss in the uplink or downlink of the network. Below is an example of the link budget from GSM 900 MHz. The link budget results can be improved by adopting some techniques like frequency hopping or using receiver diversity. (Ref. ETSI)

TRANSMITTING END		**MS**	**BS**	
TX RF-output peak power	W	2.00	6.00	
(mean power over RF cycle)	dBm	33.00	38.00	K
Isolator + combiner + filter	dB	0.00	3.00	L
RF-peak power, combiner output	dBm	33.00	26.00	M=K-L
Cable loss + connector	dB	0.00	4.00	N
TX-antenna gain	dBi	0.00	12.00	O
Peak EIRP	W	2.00	20.00	
(EIRP = ERP + 2dB)	dBm	33.00	34.00	P=M-N+O
Path loss due to ant./body loss	dBi	9.00	9.00	Q
Isotropic path loss	dB	133.00	133.00	R=P-F-Q

RECEIVED END		BS	MS	
RX RF-input sensitivity	dBm	-104.00	-102.00	A
Interference degrading margin	dB	3.00	3.00	B
Cable loss + connector	dB	4.00	0.00	C
Rx antenna gain	dBi	12.00	0.00	D
Isotropic power	dBm	-109.00	-99.00	E=A+B+C+D
Field strength	dBV/m	20.24	30.24	F=E+Z
				Z=77.2+20*log(freq/MHz)

The output and effects of link budget calculations:

- Path loss and Rx Power: Main output of the link budget. The better the Input data accuracy the more accurate the results.
- Cell range: If the path loss is lessened, the signal from the transmitter (BTS) antenna will cover more distance, so increasing the area covered by one BTS. Thus, the power budget calculations play a direct role in determining the covered area, and so deciding on the number of base stations that will be required in a network.
- Coverage threshold: The downlink signal strength at the cell border for a given location probability is known the coverage threshold. Although slow fade margin and MS isotropic power can be used to calculate this value, power budget calculations are used for this purpose. Propagation models are used for more accurate calculation of the cell range and coverage area (Cost-hata, Ericsson, SUI).

Example: Capacity requirements on the Ater interface

Assume, that radio planners have decided that there are five sites of 2 + 2 configuration under a single BSC. Air interface blocking is 2% and Ater 0.1%

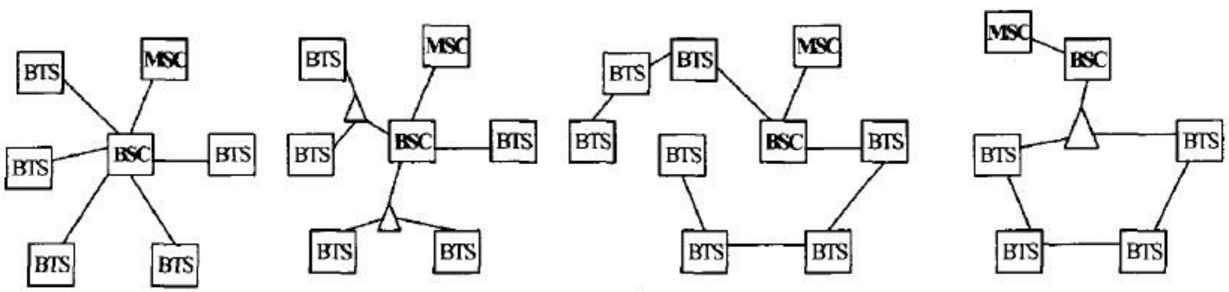
5 sites of 2 + 2 configuration = 10 cells, each having 15 TCH

- ❑ Air interface blocking = 2%
- ❑ Using Erlang B tables, 15 TCH support = 9.07 Erl of traffic.
- ❑ Traffic offered to the BSC = 10 x 9.01 = 90.1 Erl.
- ❑ If Ater blocking probability is 0.1%, then the number of traffic channels supported =117(approx.)
- ❑ If the number of traffic channels that can be multiplexed on the Ater = 120
- ❑ Then Ater interface capacity would be = 117/120=0.975 ~ 1 El

Equipment Location

The base station and TCSM locations need to be decided during the nominal planning phase itself. For Example :If the TCSMs were placed physically near the MSC, it would save transmission costs.

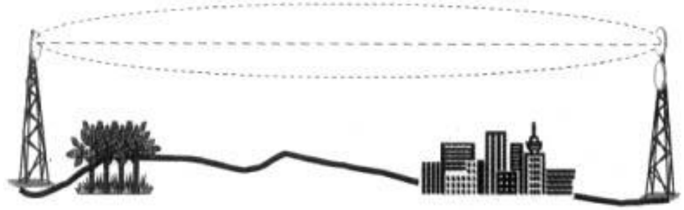
Network Topology

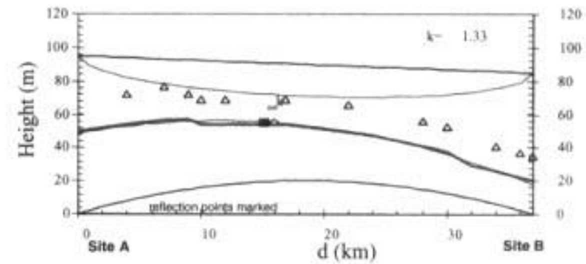


Point-to-Point topology   Star topology   Chain topology   Loop topology

Site Selection and Line-of-Sight Survey

- Transmission planning engineers prefer sites that are very high, so that connectivity to a large number of other sites is possible.

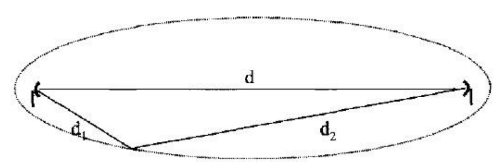




Line-of Sight Survey

- Area that is covered by an imaginary ellipsoid drawn between the transmitting and receiving antennas in such as way that the distance covered by the ray being reflected from the surface of the ellipsoid and reaching the receiving antenna is half a wavelength longer than the distance covered by the direct ray travelling from the transmitting to the receiving antennas, i.e.

$$d_1 + d_2 = d + \lambda/2.$$

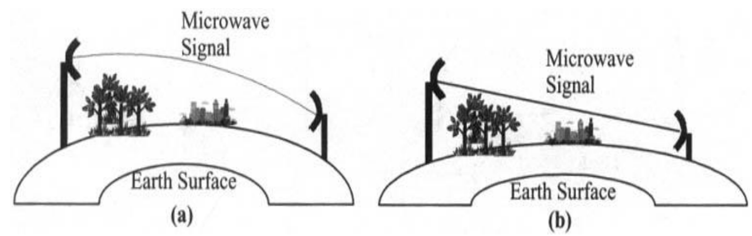


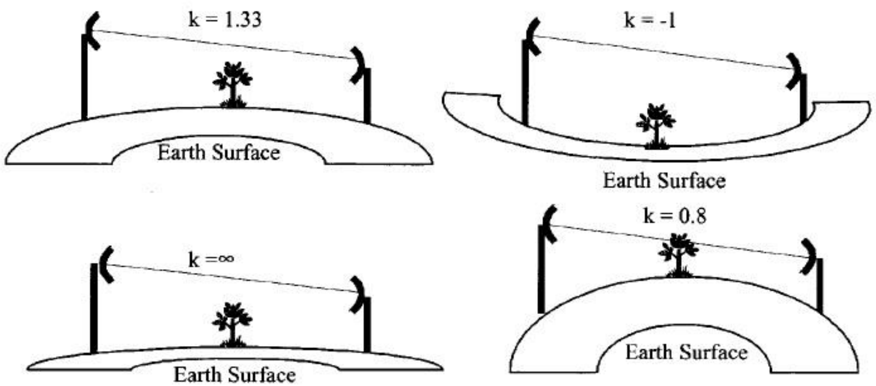
The Fresnel zone is dependent upon two factors: frequency of transmission and the distance covered. Mathematically, the radius of the Fresnel zone can be calculated as:

$$F_1 = 12.75(d_1^* d_2 / f^* D)^{1/2}$$

Propagation Phenomena

- Microwave signal trajectory
- Refractivity
- Antenna Height
- K Factor





Variation of the *k*-factor

$$\eta = V_{fs} / V_m$$

radio refractivity, N, which is defined as:

$$N = (\eta - 1)^* 10^6$$

$$3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

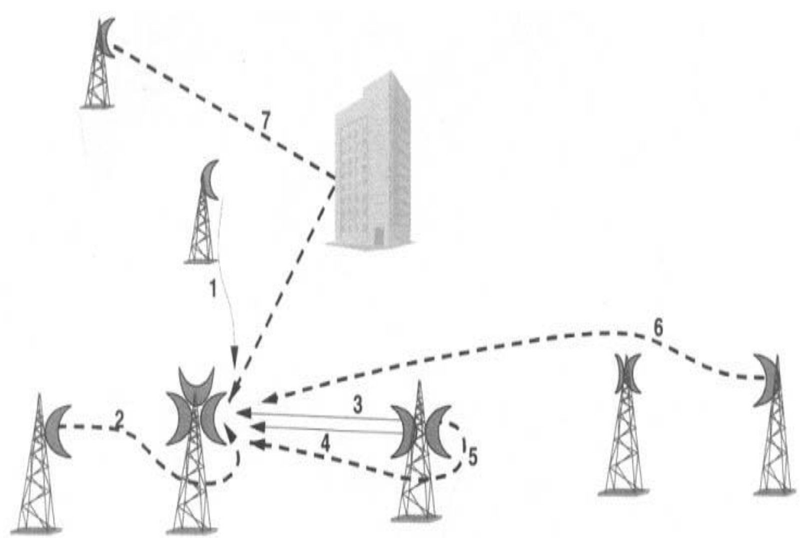
- h_1 = height of antenna one
- h_2 = height of antenna two

DETAILED TRANSMISSION NETWORK PLANNING

Frequency plan

- A microwave link is rarely situated in an isolated environment. There are usually many microwave links in a given region, of the same and/or different network operators. So it is very important to construct correct frequency plans for one's own network.

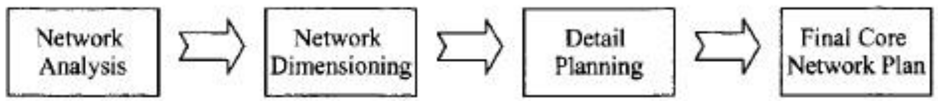
- **intra-system interference (noise, imperfections, etc.)**
- **inter-channel interference (adjacent/co-channel, etc.)**
- **inter-hop interference (front-to-back, over-reach)**
- **external interference (other systems, radar, etc.).**



Capacity Planning

- Traffic Estimation
- Frequency re-use
- Avg. Antenna Height

CORE NETWORK PLANNING PROCESS



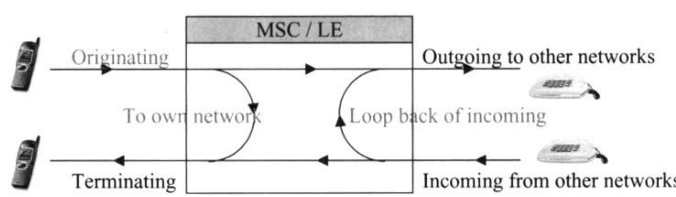
- It consists of two parts: switch network planning and signaling network planning

Network analysis

- Traffic distribution
- Apart from voice, this generally includes value-added services such as SMS, MMS, Internet, etc.

Network Dimensioning

- Number of switches required to handle subscribers and traffic (both present and forecast)
- The most efficient location of the switches in the network
- How the switches will be connected to each other (i.e. transmission plan for the switches)
- The most efficient way to route the traffic.



Basics of a Traffic Calculation

Consider a simple core network with one switch.

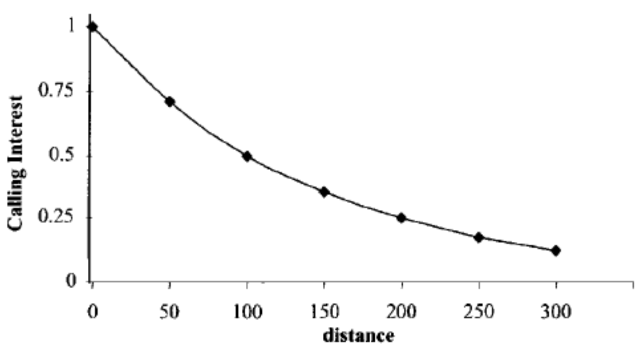
- Subscribers originating (SO): This is the traffic originated by subscribers of the network.
- Generally, this input comes from the network (or network operator). Typical values can
- be 65% for the switch and/or 50% for the LE.
- Subscribers terminating (ST): This is the traffic that is being terminated in the same mobile network. This value can be calculated as ST = 100% - SO.
- Own network (terminating) traffic: This is the traffic that is originated in the network and terminated there also. It is usually a product of subscribers in the network and SO.
- Loop back of incoming traffic: This is the traffic originating from the external networks and routed back to them.
- Outgoing and incoming traffic: Traffic going outside the mobile network to an external network is outgoing traffic, while traffic coming from external networks is incoming traffic.
- These can be calculated as follows:
- **Incoming** = (ST- own network traffic)/(I - loop back of incoming traffic)
- **Outgoing** = SO - own network traffic + loop back of incoming traffic.

Calling and moving interest

Calling interest indicates the distance to which calls are made

- Moving interest is another parameter that defines the subscriber behavior of moving within the network.
- When the number of subscribers has been determined, the number of switches can be calculated. Thus:

Number of switches = number of subscribers/VLR (or



- The transit switch has great importance in this arrangement; it is often advised to have a second redundant transit switch.
- If the cellular network is spread over a very large region

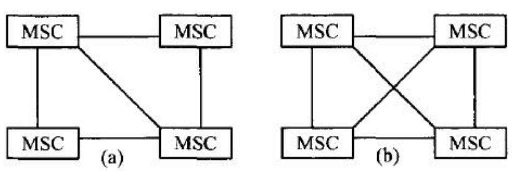


Figure 4.4 Interswitch connection

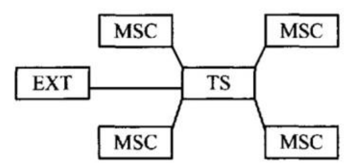


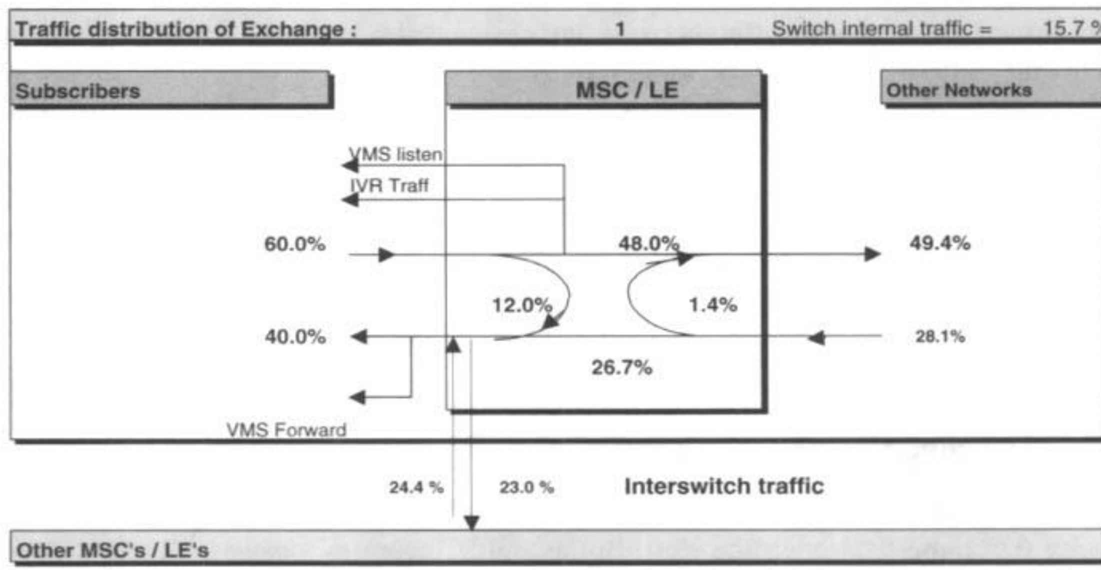
Figure 4.5 Switch network with transit switch

Traffic Dimensioning

There are four MSCs and an external network.
The number of subscribers handled by each MSC is 50,000.
With the traffic generated by each subscriber being 27 mErl (milli-Erlangs), the total traffic generated by each MSC is 1350 Erl.
The percentage of calls originating within their own switch is 60%, of which 40% terminate in the same network.
Calling interest and moving interest are 215 km and 50 km respectively.

Input	MSC1	MSC2	MSC3	MSC4
X	0	0	200	100
Y	0	0	0	100
subscribers	50000	50000	50000	50000
tr/subs (mErl)	27	27	27	27
total traffic	1350	1350	1350	1350
subs originating	60%	60%	60%	70%
subs terminating	40%	40%	40%	30%
to own network	20%	20%	20%	20%
to own NW of total	12%	12%	12%	14%
to own NW of total	162	162	162	189
loopback	5%	5%	5%	5%
initial outg ISW	110	110	93	136
initial outg ISW%	8%	8%	7%	10%

call int	215
move int	50



Traffic Theory...

- **Traffic Intensity, $E = \lambda t_h$ Erlangs** (Danish Mathematician)
  - λ = call arrival rate (calls/hour)
  - t_h = mean holding time (hours/call)

$\Rightarrow$ **1 Erlang = 1 channel occupied continuously**

Example: Assume 100 subscribers with the following traffic profile:

Subscribers	Traffic
20 make 1 call/hour for 6 min.	20x1x(6/60) = **2 E**
20 make 3 calls/hour for ½ min.	20x3x(½/60) = **½ E**
60 make 1 call/hour for 1 min	60x1x(1/60) = **1 E**
100	**3.5 E**

$\Rightarrow$ **100 subscribers use 3.5 E... = 35 mE per subscriber**

$$B_c = \mathrm{Erl}(n,a) = \frac{\frac{a^n}{n!}}{\sum_{i=0}^{n} \frac{a^i}{i!}}$$

Assume that,

- on the average, there are 1800 new calls in an hour, and
- the mean holding time is 3 minutes

- It follows that the traffic intensity is

$$a = 1800 * 3/60 = 90 \text{ erlang}$$

- If the mean holding time increases from 3 minutes to 10 minutes, then

$$a = 1800 * 10/60 = 300 \text{ erlang}$$

- Assume that there are n = 4 channels on a link and the offered traffic is a = 2.0 erlang. Then the call blocking probability B_c is

$$B_c = \mathrm{Erl}(4,2) = \frac{\frac{2^4}{4!}}{1+2+\frac{2^2}{2!}+\frac{2^3}{3!}+\frac{2^4}{4!}} = \frac{\frac{16}{24}}{1+2+\frac{4}{2}+\frac{8}{6}+\frac{16}{24}} = \frac{2}{21} \approx 9.5\%$$

- If the link capacity is raised to n = 6 channels, B_c reduces to

$$B_c = \mathrm{Erl}(6,2) = \frac{\frac{2^6}{6!}}{1+2+\frac{2^2}{2!}+\frac{2^3}{3!}+\frac{2^4}{4!}+\frac{2^5}{5!}+\frac{2^6}{6!}} \approx 1.2\%$$

- Consider a single analog cell tower with 56 traffic channels, when all channels are busy calls are blocked. Calls arrive according to a Poisson process at a rate of 1 call per active user an hour. During the busy hour 3/4 the users are active. The call holding time is exponentially distributed with a mean of 120 seconds.
- (a) What is the maximum load the cell can support while providing 2% call blocking?

  From the Erlang B table with c= 56 channels and 2% call blocking the maximum load = 45.9 Erlangs
- (b) What is the maximum number of users supported by the cell during the busy hour?

  Load per active user = 1 call x 120 sec/call x 1/3600 sec = 33.3 mErlangs

  Number active users = 45.9/(0.0333) = 1377

  Total number users = 4/3 number active users = 1836
- Determine the utilization of the cell tower ρ

  $\rho = \alpha/c = 45.9/56 = 81.96\%$

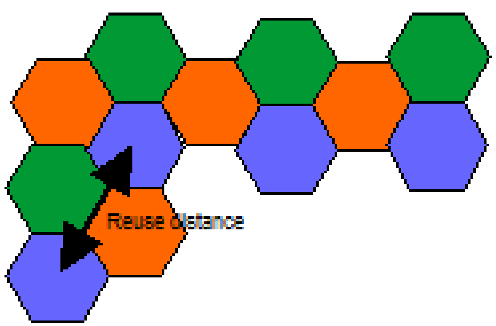
Traffic Estimation

- The amount of traffic is expressed in Erlangs, which is the magnitude of telecommunications traffic. An Erlang describes the amount of traffic in one hour :

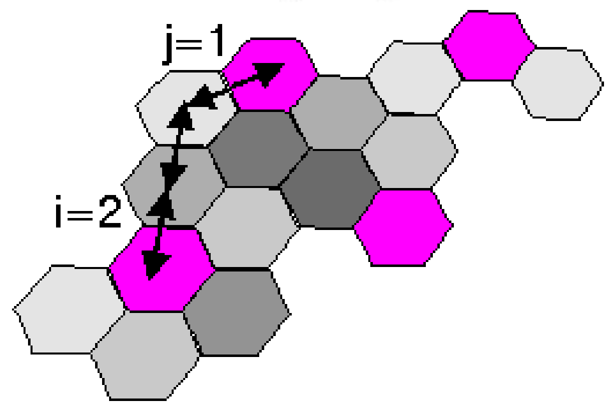
  Erlang=(number of calls in hour)(average call length)/3600 s

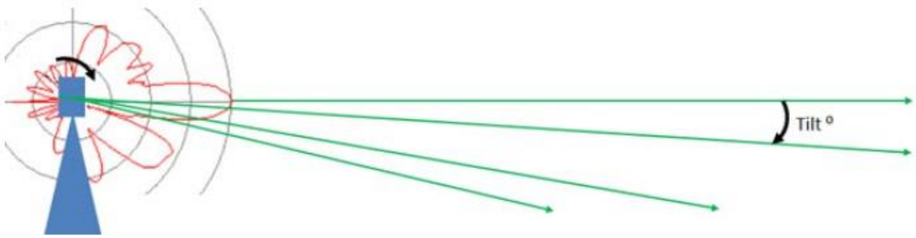
Frequency Reuse

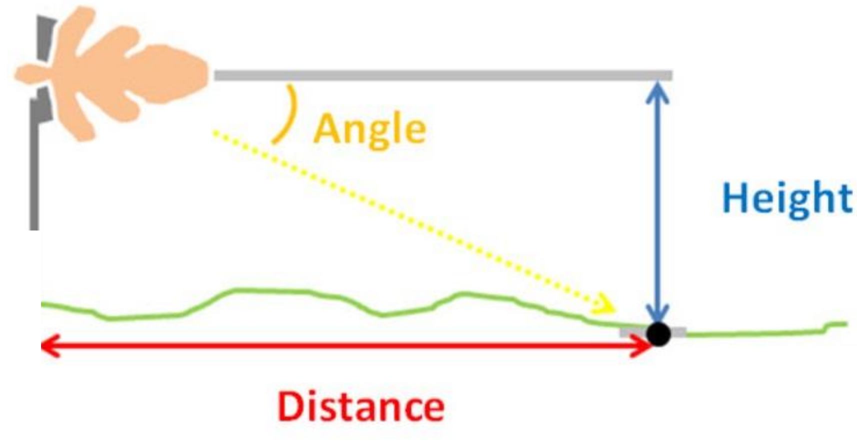
$$D = \sqrt{3N}\,R$$



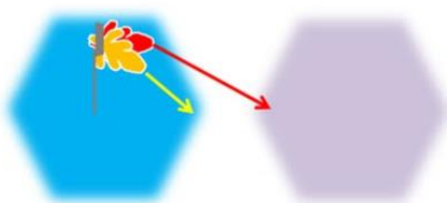
$$N = i^2 + ij + j^2$$







Angle = ArcTAN (Height / Distance)



- ❑ Optical line of sight

$$d = 3.57\sqrt{h}$$

- ❑ Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

KPIs are more important for GSM radio network optimization & benchmarking to achieve remarkable QoS:

- Accessibly
- Paging Success Rate
- CSSR (Call Set up Success Rate).
- CDR (Call Drop Rate).
- HSR (Handover Success Rate).
- TCH (Traffic Channel) Congestion Rate.