Mobile Computing

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Introduction

- Mobile devices accessing the internet Vs human beings living on the earth.
- There are 7.9 billion mobile devices compared to 7.4 billion world population (2015).
- On an average 3.2 billion users accessing internet any day.
- 90% of accessing internet will be mobile devices by 2020.
- Personal computer OS sales is in down trend. Microsoft OS license down by 14% in 2014.
- Personal computing (using desktop computers) slowly converging to Mobile computing. Windows 10 OS aims to develop universal applications. (ie. can run in cross platform environments).
- Mobile applications makeup of 47% of internet traffic.

Mobile devices

- Smart Phones
- Tablets
- E-Readers
- Scanners
- Personal Digital Assistant(PDA)
- Notebook
- ..many more

Mobile devices components

- Case
- RAM
- Keyboard
- Network Connection
- Operating System
- CPU
- Video card
- Screen
- Applications

Mobile devices features

- Size
- OS
- Access to mobile broadband network
- Battery life
- GPS capability
- Accelerometer
- Gyroscope
- Silicon
- Camera
- Touch Screen

Mobile Computing - Definition

- Mobile computing is a technology which enable people to access network service any place any time.
- It uses portable and wireless communication devices.

Mobility

- User Mobility
- Device Mobility

Classification of Communication devices

- Fixed and Wired
- Mobile and Wired
- Fixed and Wireless
- Mobile and Wireless

Wireless Communication – Short History

- Light, flag, smoke signals
- Optical Telegraph, Telephone
- Electro magnetic waves (Maxwell, Michael Faraday, Hertz)
- Radio –short wave , AM and FM
- Television (John Baird)

Wireless network standards

- NMT (Nordic Mobile Telephone System) – European Standard, Analog
- GSM – Initially Group Speciale for Mobile (analog)

  Now Global System for Mobile Communication (digital 900 Mhz)
- AMPS – Advanced Mobile Phone System
- Cordless system – CT0,CT1, CT2
- DECT – Digital European Cordless Telephone
- Wireless LAN Standard – IEEE 802.11, HIPERLAN
- Mobile communication using satellites – Global Satellite System
- Current standards – UMTS (universal Mobile Telecommunications Service, 3G standard for GSM) , IMT 2000 (International mobile Telephone)- standards for 3G cellular system)

Wireless Network - Definition

- Wireless network is a technology that enables two or more entities to communicate using electromagnetic waves in open space.

Wireless Network - Advantages

- Reduces cost
- Access computing/communication services on the move
- Shrinks the world
- Always connected
- Scalable

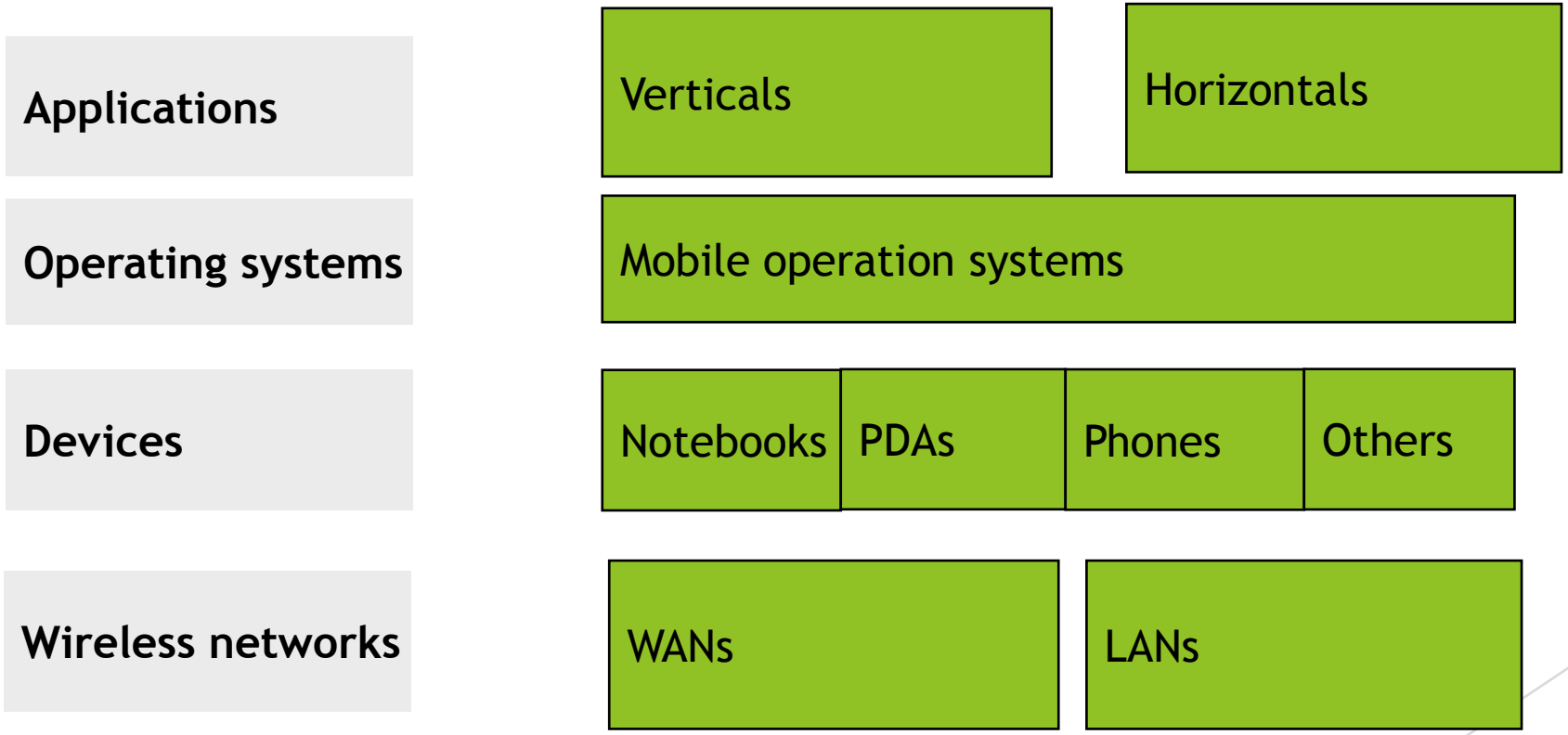
Wireless Network Vs Wired (Limitations)

Feature	Wired	Wirelss
Noise (unwanted signal which degrades the quality of original data)	Can be shielded	Better techniques are in developing stage
Attenuation (Reduction of signal strength due to long travel)	Repeaters are used	It is difficult
Data speed	Can be increased using coaxial or fibre optic cables	Re-engineering can’t be done. We can improve transmission and reception techniques.

Wireless Network Vs Wired (Limitations)

Feature	Wired	Wirelss
Access capacity	Any number of users can be added by increasing new wire circuits. Unlimited	Limited Access media is air and to be shared by all users
Interference	Minimal	Multi user interference (radio signal of different users interfere with each other) Self interference (created by itself, multipath effect) Interference Management - Share Channel , Multiple Access Problem – FDMA, CDMA, TDMA - Media Access control – Aloha, CSMA

Layers of Mobile Computing



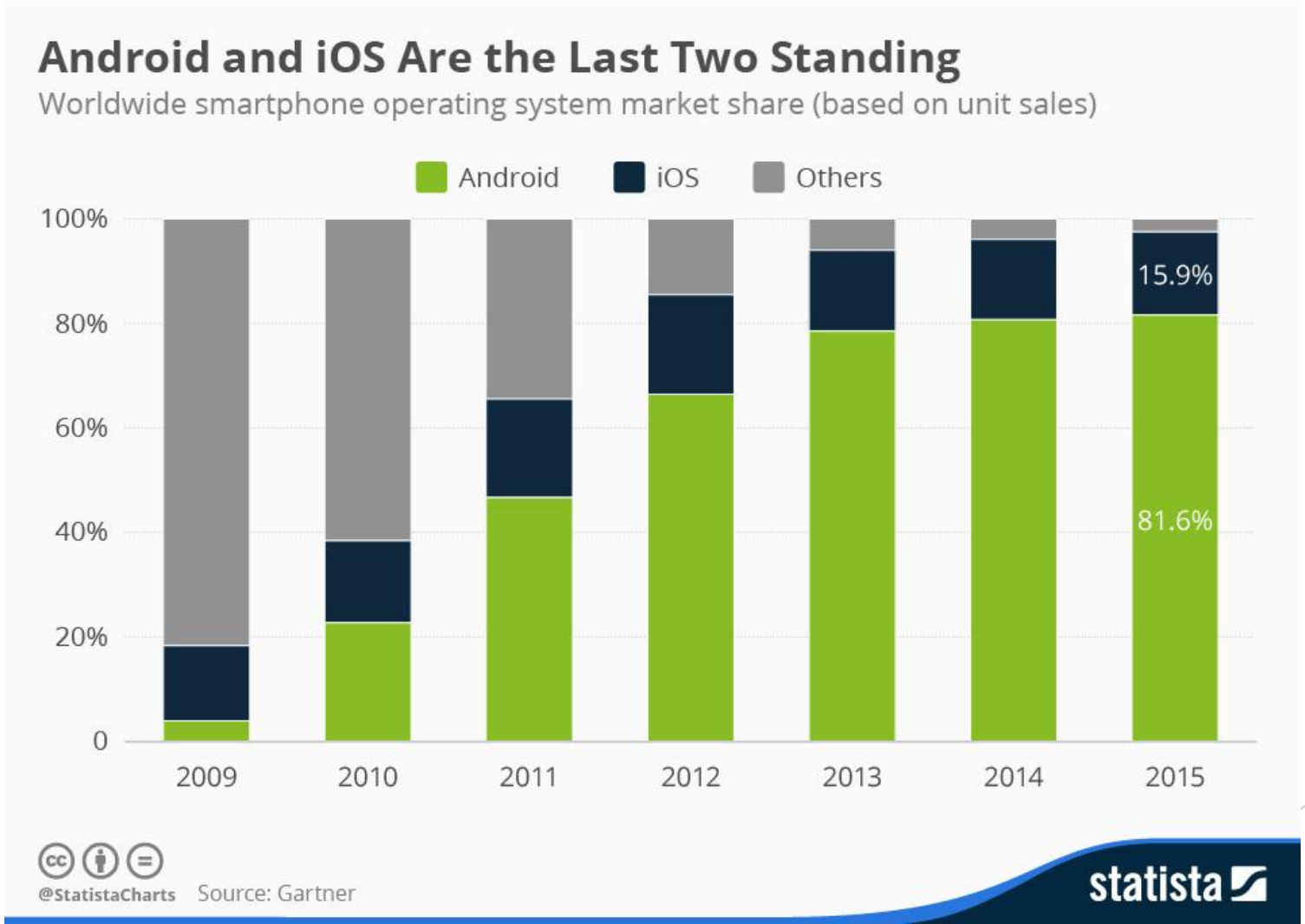
Mobile Applications

- Vertical applications: those apply to a function part of an industry such as field sales and field service, or to specific market segment such as banking or health care
- Horizontal applications: apply to many people across most market segments

Mobile Operating Systems

- Mobile Operating System provides tools for application programmers to access different mobile devices and different wireless networks.
- A key layer to rapid growth of wireless networking and proliferation of applications.

Mobile operating systems – Market Share



Mobile devices

- All the mobile devices we carry with us:
  - Notebook computers
  - Personal Digital Assistants (PDAs)
  - Cellular phones
  - Combination devices

Wireless Wide Area Network (WWAN)

- The Wireless Wide Area Network (WAN) is also called "Mobile Data" including:
  - Packet networks: RAM/Mobitex, ARDIS/Modacom
  - Paging networks
  - Data over cellular: CDPD (over AMPS), GPRS (over GSM)
  - Data over satellite

Wireless LAN (WLAN)

- A **wireless local area network** (**WLAN**) is a wireless computer network that links two or more devices using a wireless distribution method (often spread-spectrum or OFDM radio) within a limited area.
- Most modern WLANs are based on IEEE 802.11 standards and are marketed under the Wi-Fi brand name.

Challenges in Mobile Computing

- Signal Strength fluctuates significantly
- High error rate
- Shared Channel, Access capacity is limited
- User Location Management problem
- Device Limitation
  - Limited Memory
  - Limited Computational Power
  - Small Display
  - Limited Battery life

Evolution of Mobile Communications
First Generation(1 G)

- Standards - AMPS (Advanced Mobile Phone System, US), TACS(Total Access Communication System, Europe, NIT(Nippon Telephone Telegraph),Japan)
- Services – Only Voice
- Technology – Analog
- Speed - 1kbps to 2.4 kbps
- Sharing of resources – FDMA
- Circuit Switching

Second Generation (2G)

- Standard – GSM
- Services - Digital Voice, SMS, International Roaming, Conferencing, Call Waiting, Call Hold, Call Forwarding, Call Barring, Caller Number Identification, Closed User Groups (CUGs) , USSD(Unstructured Supplementary Service data) Services, Authentication , billing based on the services provided to their customers
- Technology – Digital
- Speed – 14kbps to 64 kbps
- Frequency 900 MHz, 1800 MHz
- Shared Resource – TDMA, CDMA
- Circuit switching

2.5 Generation

- Standards - General Packet Radio Service (GPRS) & EDGE (Enhanced Data rates in GSM)
- Frequency: 850 -1900 MHz
- Speed – 115kbps (GPRS)/384kbps(EDGE)
- Switching – packet switching for data transfer
- Services – push to talk, multimedia, web based info entertainment, support WAP, MMS, SMS, mobile games, and search and directory, email access, video conferencing.

Third Generation (3G)

- Standards -
  - UMTS-Universal Mobile telecommunicating System (Wideband-CDMA)– Based on GSM (Global Systems for Mobile).
- The data are sent through the technology called **Packet Switching.**
- Services - Wireless voice telephony, high speed internet access, fixed wireless Internet access, video calls, chatting & conferencing, mobile TV, Video on demand, Location-based services
- Speed : 384Kbps to 2Mbps
- Frequency : about 8 to 2.5GHz
- Bandwidth – 5 to 20 MHz

Fourth Generation (4G)

- The fourth Generation mobile system is all **IP based network system**. The main goal of 4G technology is **to provide high speed, high quality, high capacity, security and low cost services for voice and data services, multimedia and internet over IP.**
- 4G introduced new physical radio interface known as Evolved UMTS Terrestrial Radio Access (E-UTRA) and new packet –switching based core network called as Evolved Packet Core (EPC).
- Standards - **Long-Term Evolution Time-Division Duplex** (LTE-TDD and LTE-FDD) Mobile, WiMAX standard (**802.16m standardized by the IEEE)**
- Speed - 100Mbps while moving and 1Gbps while stationary ,with the help of following features
  - IP telephony
  - WiMAX- Worldwide Interoperability Microwave Access

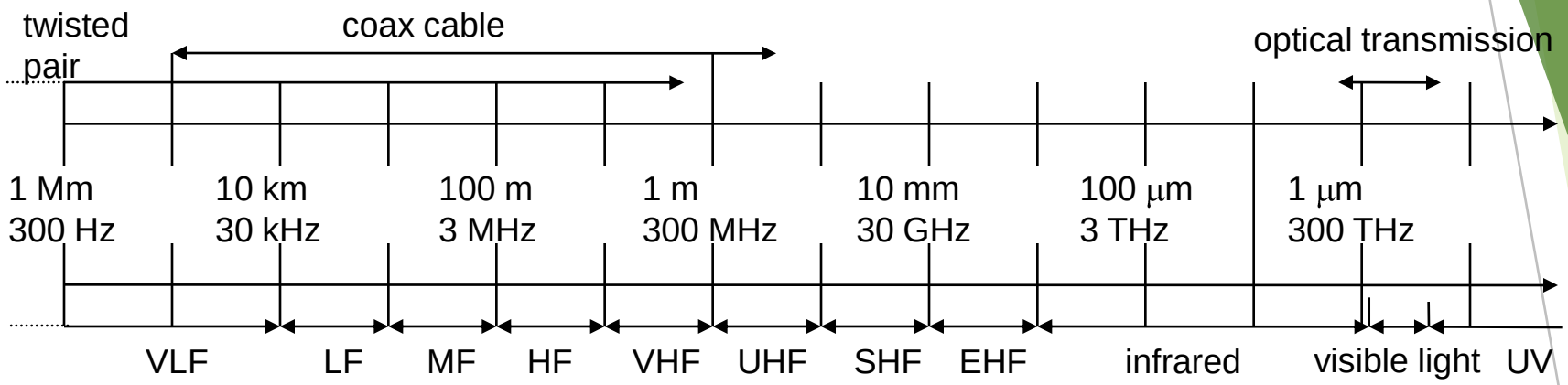
Fifth Generation (5G)

- Initiation year-2015. It will make Unified global standard.
- The Physical and Data Link layer defines the 5G wireless technology indicating it as an Open Wireless Architecture(OWA).
- In 5G technology the higher bit rate loss is overcome by using Open Transport Protocol (OTP).
- The application layer is for quality of service management over various types of networks. 5G brings forward a real wireless world-Wireless World Wide Web (WWWW)
- Speed - 1 to 10 Gbps.
- Bandwidth - 1,000x bandwidth per unit area.
- Frequency - 3 to 300 GHz

Sixth and Seventh Generation (6G & 7G)

- 6G is proposed to integrate 5G with satellite networks for global coverage.
- The satellite communication network may consist of telecommunication satellite networks, earth imaging satellite networks and navigation satellite networks.
- The goal of 6G is to integrate these kinds of satellite networks to provide network position identifier, multimedia and internet connectivity, and weather information services to the mobile users.
- Specially designed Nano Antennas will be implemented at different geographical locations or positions along roadsides, villages, malls, airports, hospitals etc to broadcast such high speed electromagnetic signals.
- The 7G of mobile wireless networks which aims to acquire space roaming. The world is trying to become completely wireless, demanding uninterrupted access to information anytime and anywhere with better quality, high speed, increased bandwidth and reduction in cost.

Frequencies for communication



- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency
- UHF = Ultra High Frequency
- SHF = Super High Frequency
- EHF = Extra High Frequency
- UV = Ultraviolet Light

- Frequency and wave length: $\lambda = c/f$
- wave length λ, speed of light $c \cong 3x10^8 m/s$, frequency f

Wireless frequency allocation

- Radio frequencies range from 9KHz to 400GHZ (ITU)

- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Infrared frequency range
  - Roughly, $3x10^{11}$ to $2x10^{14}$ Hz
  - Useful in local point-to-point multipoint applications within confined areas

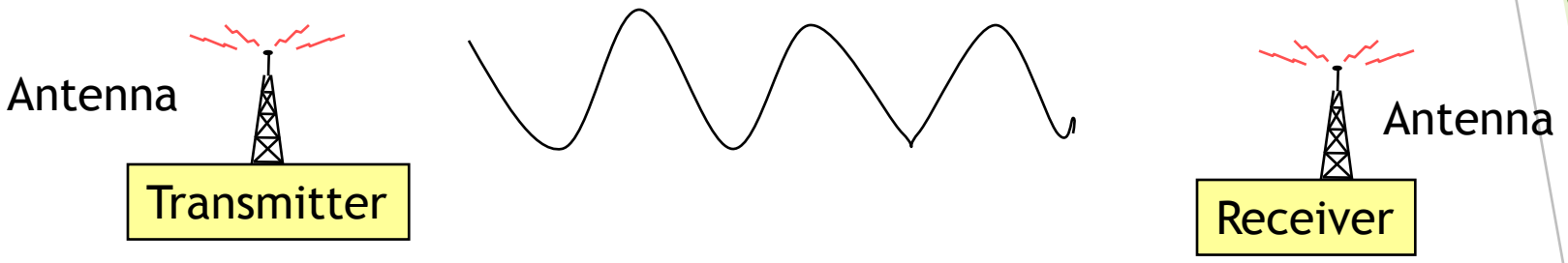
Frequencies for mobile communication

- VHF-/UHF-ranges for mobile radio
  - simple, small antenna for cars
  - deterministic propagation characteristics, reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antenna, focusing
  - large bandwidth available
- Wireless LANs use frequencies in UHF to SHF spectrum
  - some systems planned up to EHF
  - limitations due to absorption by water and oxygen molecules (resonance frequencies)
    - weather dependent fading, signal loss caused by heavy rainfall etc.

Frequency regulations

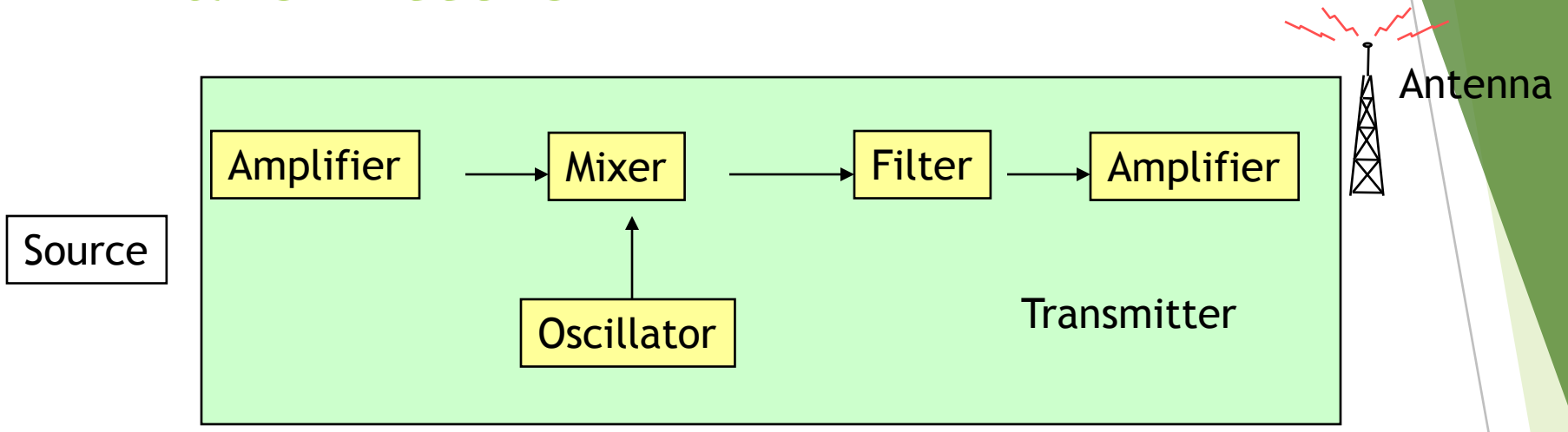
- Frequencies from 9KHz to 300 MHZ in high demand (especially VHF: 30-300MHZ)
- Two unlicensed bands
  - Industrial, Science, and Medicine (ISM): 2.4 GHz
  - Unlicensed National Information Infrastructure (UNII): 5.2 GHz
- Different agencies license and regulate
  - www.fcc.gov - US
  - www.etsi.org - Europe
  - www.wpc.dot.gov.in - India
  - www.itu.org - International co-ordination
- Regional, national, and international issues
- Procedures for military, emergency, air traffic control, etc

Wireless transmission



- Wireless communication systems consist of:
  - Transmitters
  - Antennas: radiates electromagnetic energy into air
  - Receivers
- In some cases, transmitters and receivers are on same device, called transceivers.

Transmitters



Suppose you want to generate a signal that is sent at 900 MHz and the original source generates a signal at 300 MHz.

- Amplifier - strengthens the initial signal
- Oscillator - creates a carrier wave of 600 MHz
- Mixer - combines signal with oscillator and produces 900 MHz (also does modulation, etc)
- Filter - selects correct frequency
- Amplifier - Strengthens the signal before sending it

Antenna

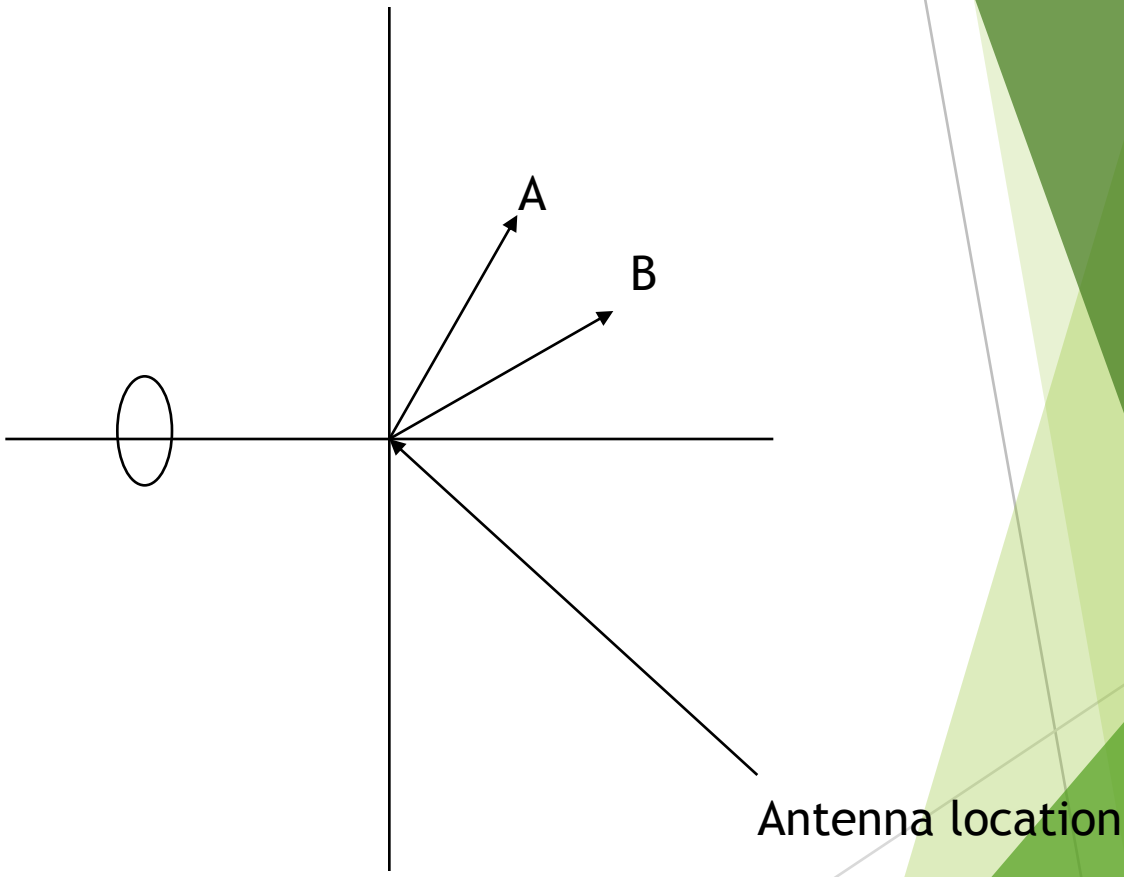
- An electrical conductor or system of conductors used for radiating electromagnetic energy into space or for collecting electromagnetic energy from the space
  - An integral part of a wireless system

Radiation Patterns

- Antenna radiates power in all directions
  - but typically does not radiate equally in all directions
- Ideal antenna is one that radiates equal power in all direction
  - called an isotropic antenna
  - all points with equal power are located on a sphere with the antenna as its center

Omnidirectional Antenna

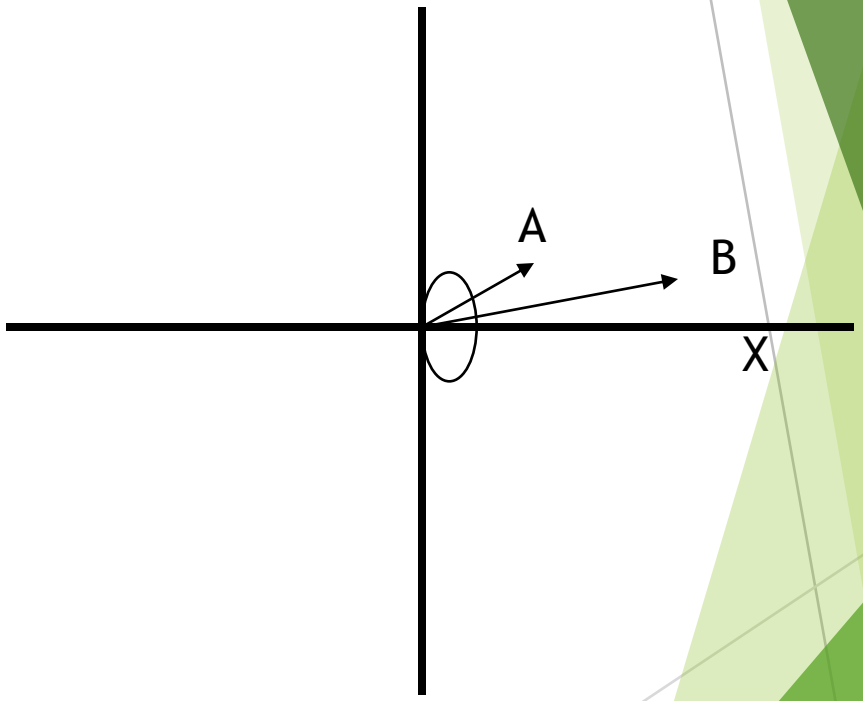
- Produces omnidirectional radiation pattern of equal strength in all directions
- Vector A and B are of equal length



Omnidirectional Antenna

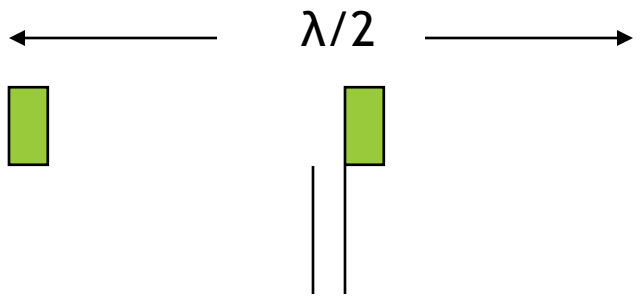
Directional Antenna

- Radiates most power in one axis (direction)
  - radiates less in other direction
  - vector B is longer than vector A : more power radiated along B than A
  - directional along X



Dipole Antenna

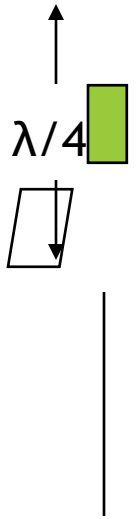
- Half-wave dipole or Hertz antenna consists of two straight collinear conductor of equal length
- Length of the antenna is half the wavelength of the signal.



Half-wave dipole

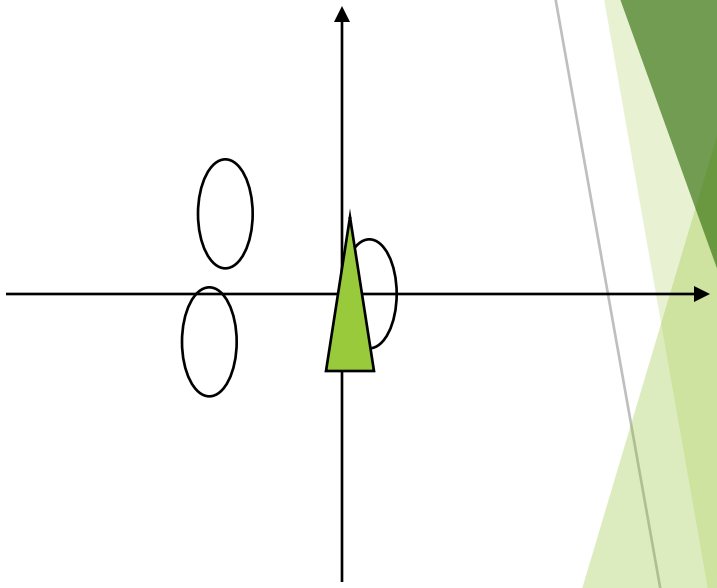
Quarter-wave antenna

- Quarter-wave or marconi antenna has a veritcal conductor of length quarter of the wavelength of the signal



Sectorized Antenna

- Several directional antenna combined on a single pole to provide sectorized antenna
- each sector serves receivers listening it its direction



3 sector antenna

Comparison of omni and directional

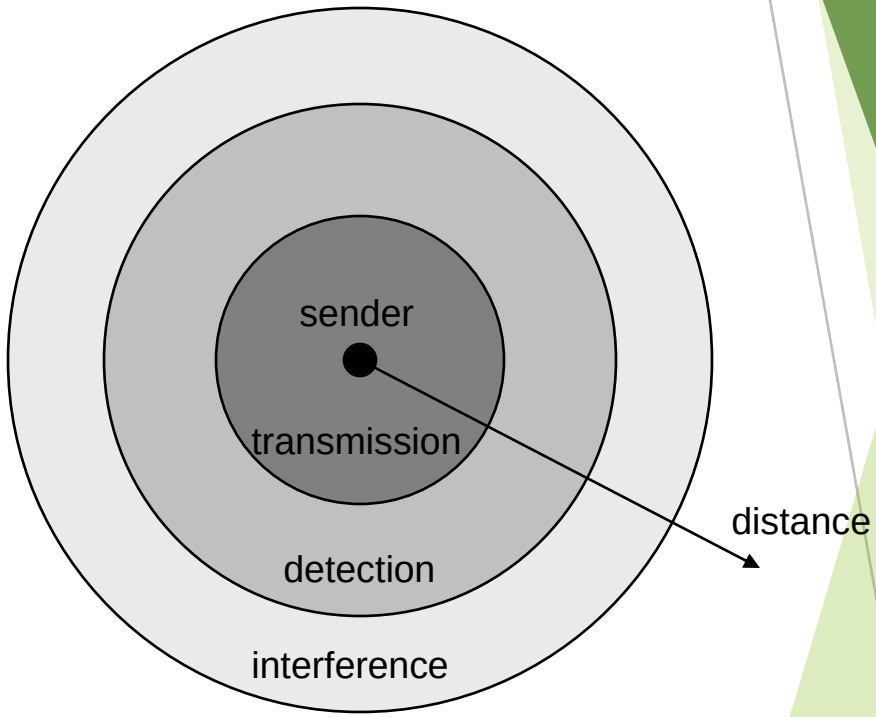
Issues	Omni	Directional
Spatial Reuse	Low	High
Connectivity	Low	High
Interference	High	Low
Cost & Complexity	Low	High

Signals

- physical representation of data
- function of time and location
- signal parameters: parameters representing the value of data
- classification
  - continuous time/discrete time
  - continuous values/discrete values
  - analog signal = continuous time and continuous values
  - digital signal = discrete time and discrete values
- signal parameters of periodic signals:
  period T, frequency f=1/T, amplitude A, phase shift φ
  - sine wave as special periodic signal for a carrier

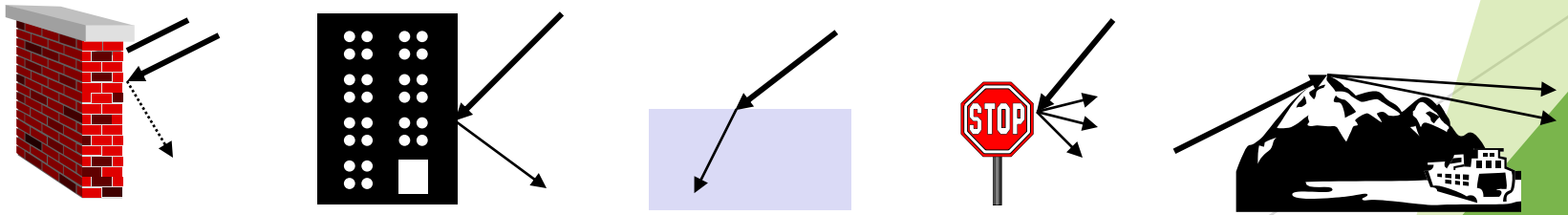
Signal propagation ranges

- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise



Signal propagation

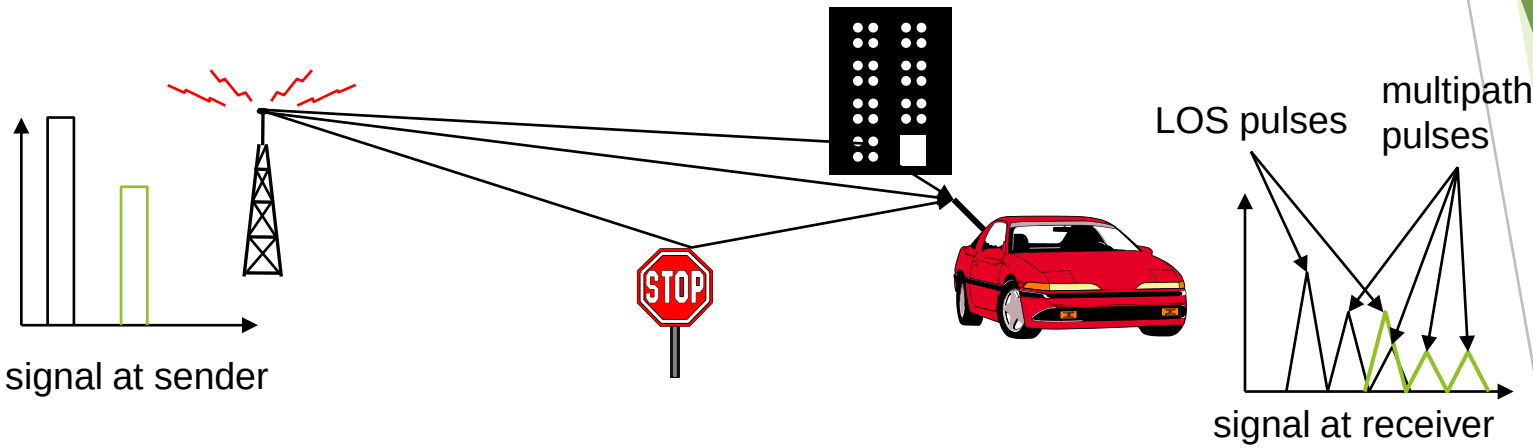
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$
  (d = distance between sender and receiver)
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges



shadowing reflection refraction scattering diffraction

Multipath propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction

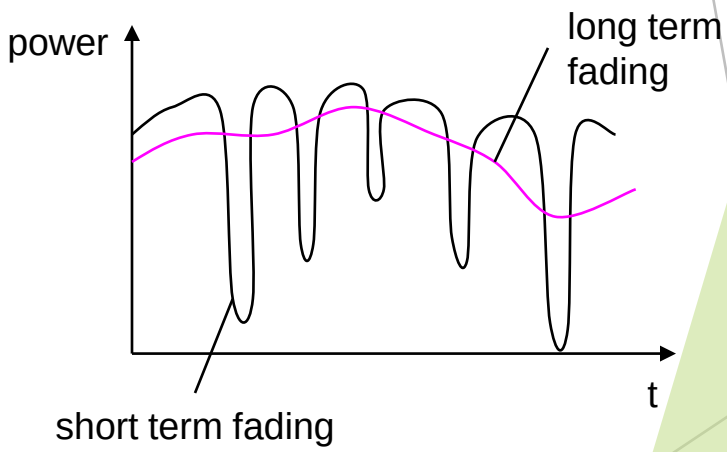


- Time dispersion: signal is dispersed over time
- ➔ interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
- ➔ distorted signal depending on the phases of the different parts

Effects of mobility

- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
- ➔ quick changes in the power received

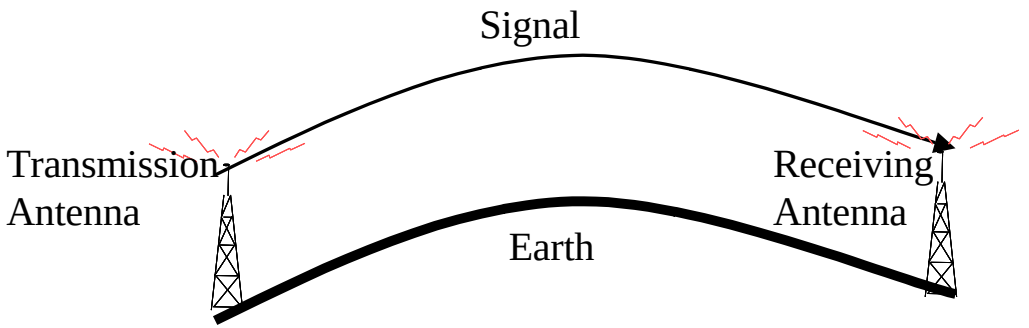
(short term fading)



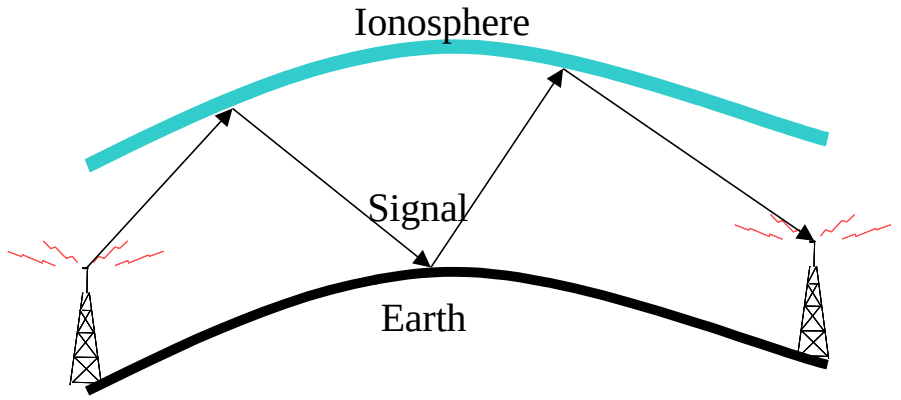
- Additional changes in
  - distance to sender
  - obstacles further away
- ➔ slow changes in the average power received (long term fading)

Propagation modes

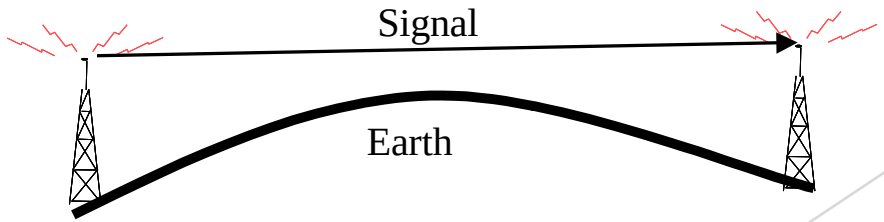
a) Ground Wave Propagation



b) Sky Wave Propagation



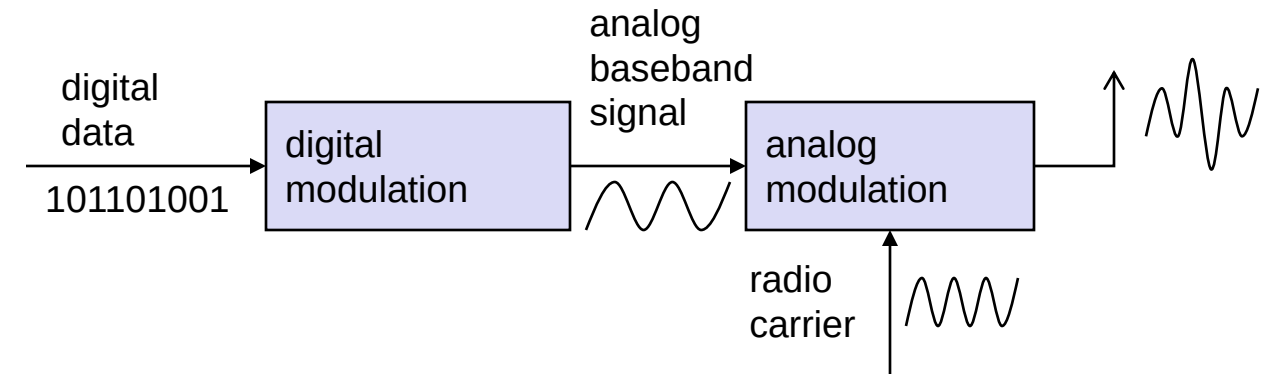
c) Line-of-Sight Propagation



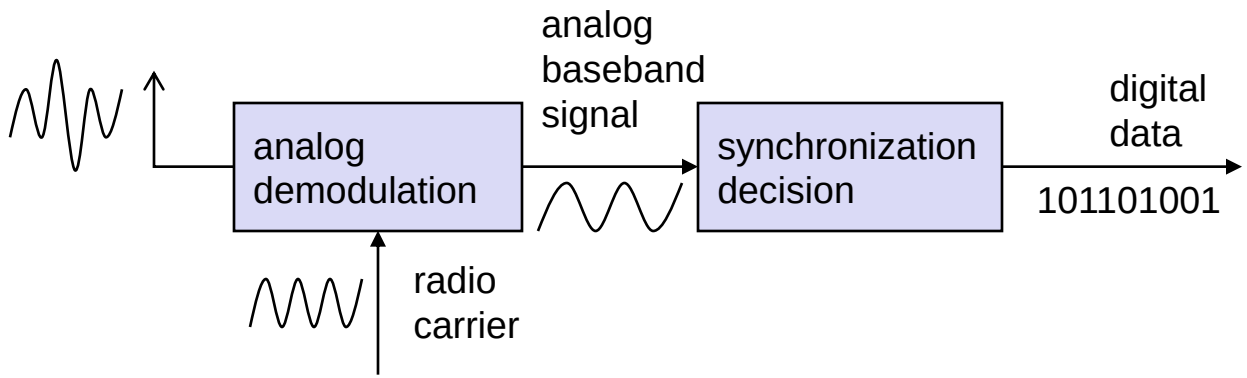
Modulation

- Digital modulation
  - digital data is translated into an analog signal (baseband)
  - ASK, FSK, PSK
  - differences in spectral efficiency, power efficiency, robustness
- Analog modulation
  - shifts center frequency of baseband signal up to the radio carrier
- Motivation
  - smaller antennas (e.g., $\lambda/4$)
  - Frequency Division Multiplexing
  - medium characteristics
- Basic schemes
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)

Modulation and demodulation



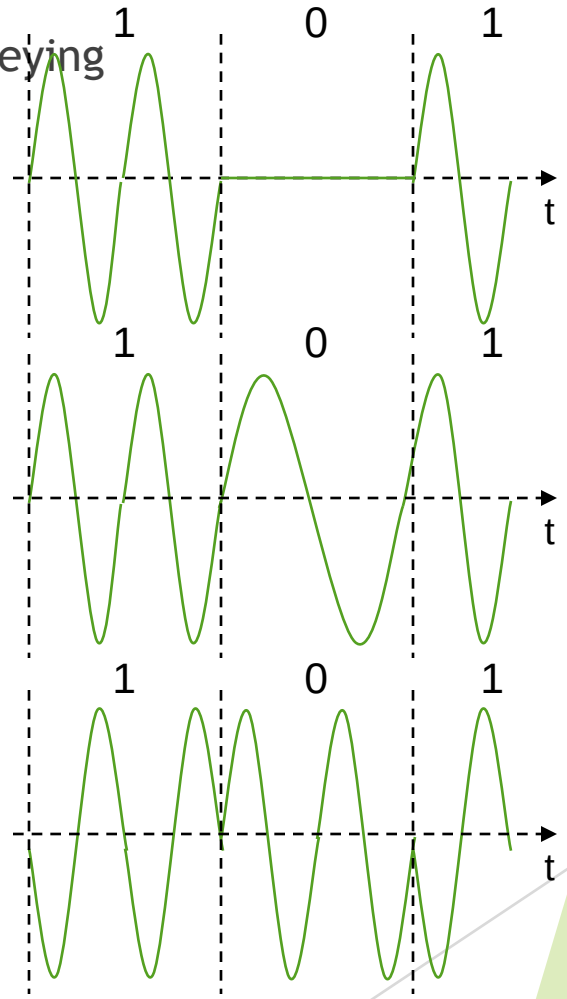
radio transmitter



radio receiver

Digital modulation

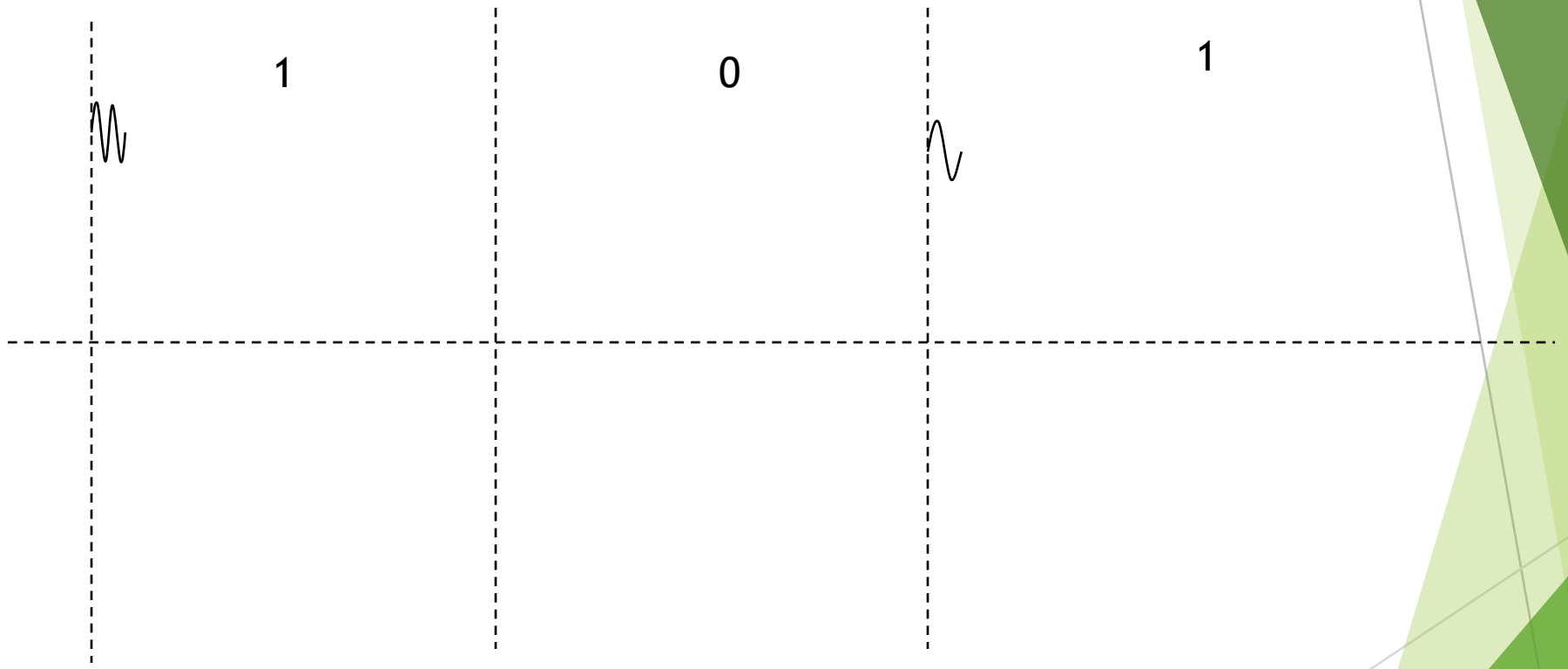
- Modulation of digital signals known as Shift Keying
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference
- Frequency Shift Keying (FSK):
  - needs larger bandwidth
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference
- Many advanced variants



Amplitude Shift Keying (ASK)

- ASK is the most simple digital modulation scheme
- Two binary values, 0 and 1, are represented by two different amplitude
- In wireless, a constant amplitude cannot be guaranteed, so ASK is typically not used

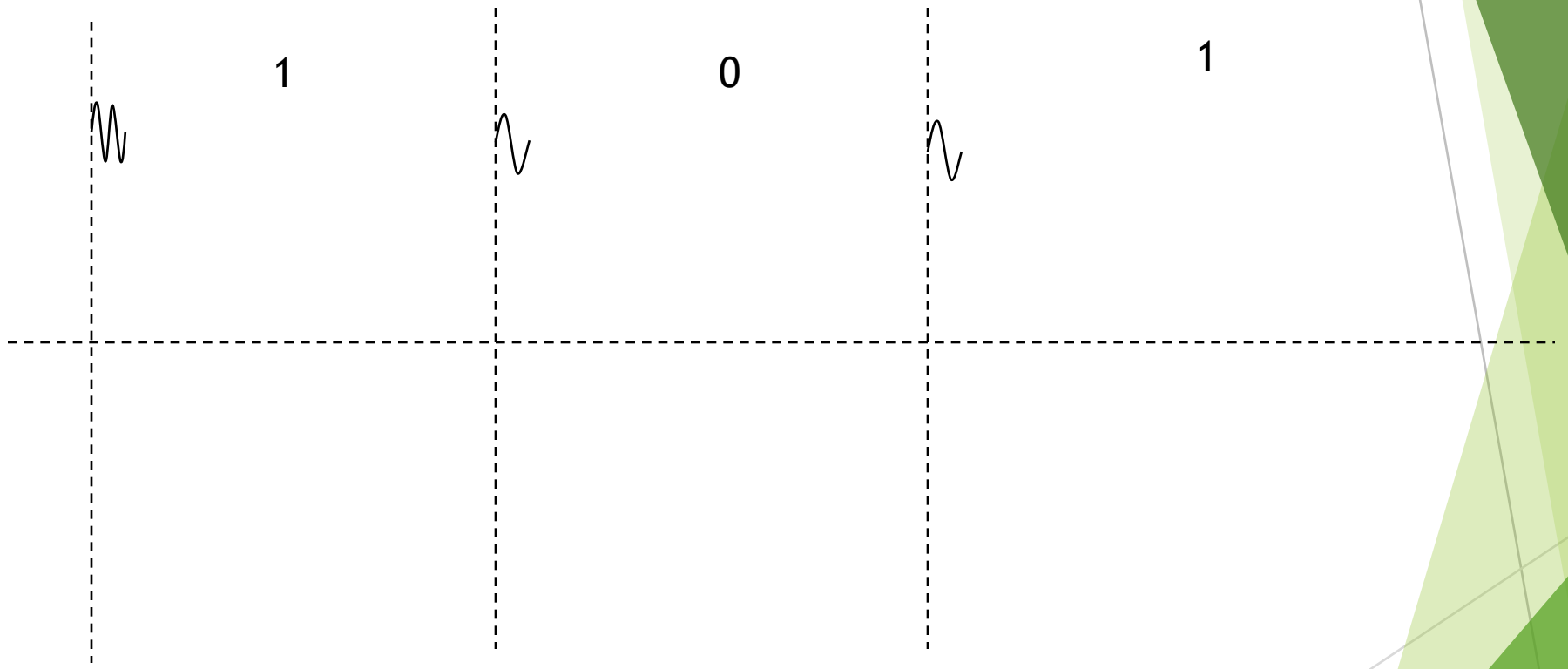
Amplitude Shift Keying (ASK)



Frequency Shift Keying (FSK)

- The simplest form of FSK is binary FSK
  - assigns one frequency f_1 to binary 1 and another frequency f_2 binary 0
- Simple way to implement is to switch between two oscillators one with f_1 and the other with f_2
- The receiver can demodulate by having two bandpass filter

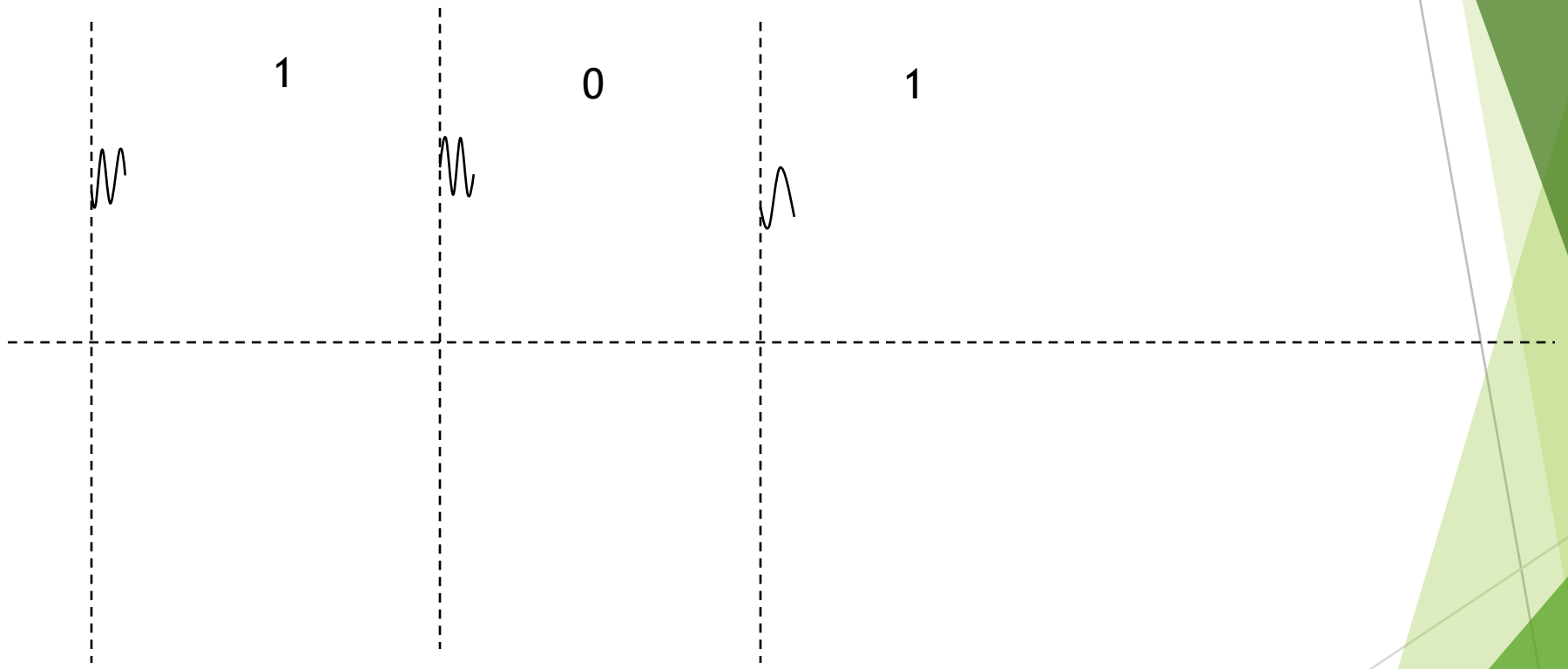
Frequency Shift Keying (FSK)



Phase Shift Keying (PSK)

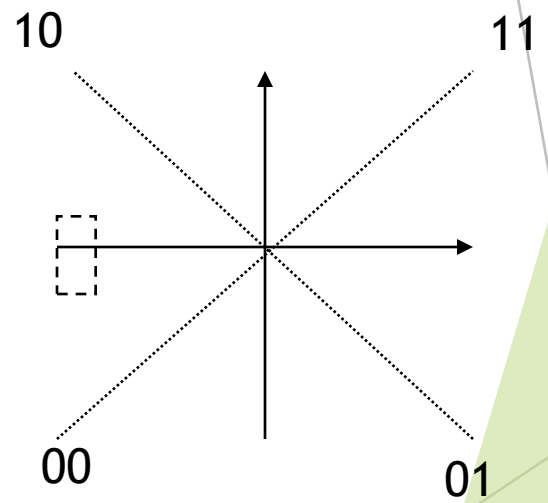
- Uses shifts in the phase of a signal to represent data
- Shifting the phase by 180^0 each time data changes: called binary PSK
- The receiver must synchronize in frequency and phase with the transmitter

Phase Shift Keying (PSK)



Quadrature Phase Shift Keying (Q-PSK)

- Higher bit rate can be achieved for the same bandwidth by coding two bits into one phase shift.
- 45^0 for data 11
- 135^0 for data 10
- 225^0 for data 00
- 315^0 for data 01



Multiplexing

- A fundamental mechanism in communication system and networks
- Enables multiple users to share a medium
- For wireless communication, multiplexing can be carried out in four dimensions: space, time, frequency and code

Space division multiplexing

- Channels are assigned on the basis of “space” (but operate on same frequency)
- The assignment makes sure that the transmission do not interfere with each (with a guard band in between)

Space division multiplexing

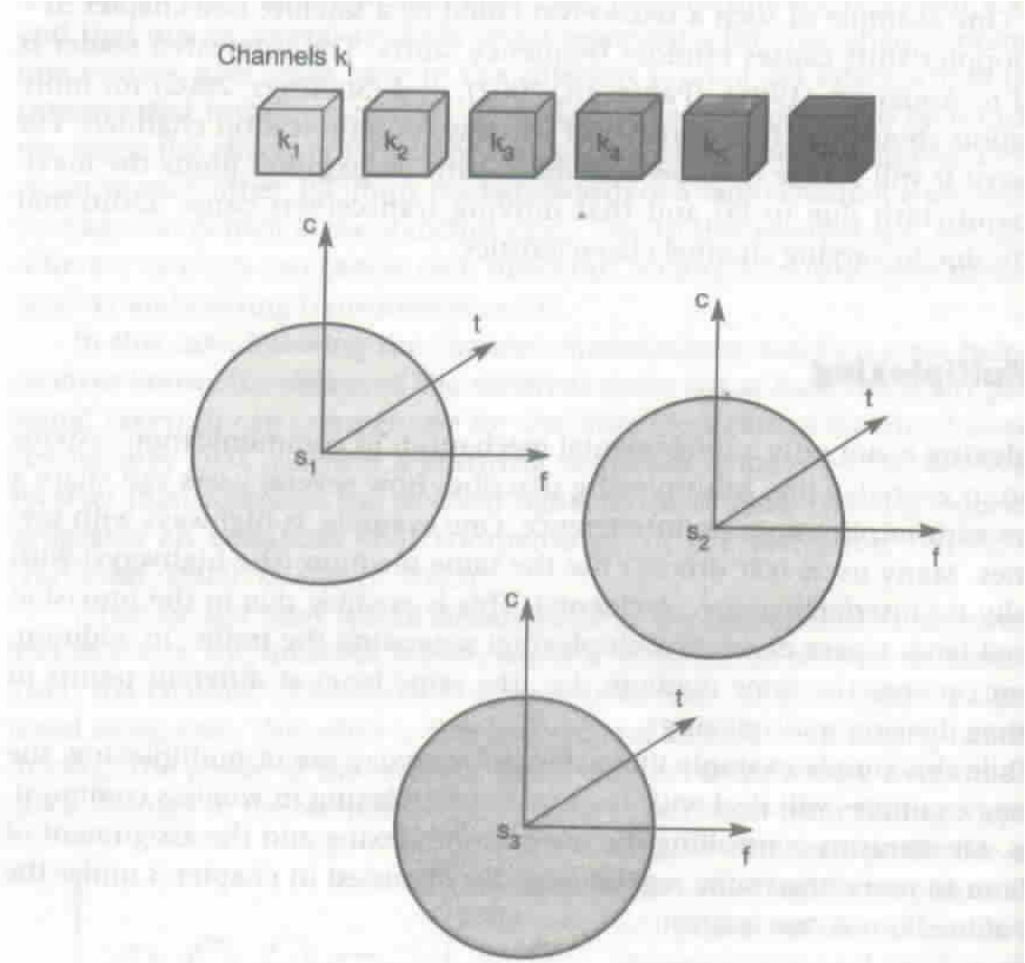


Figure 2.16
Space division multiplexing (SDM)

Frequency Division Multiplexing

- Frequency domain is subdivided into several non-overlapping frequency bands
- Each channel is assigned its own frequency band (with guard spaces in between)

Frequency Division Multiplexing

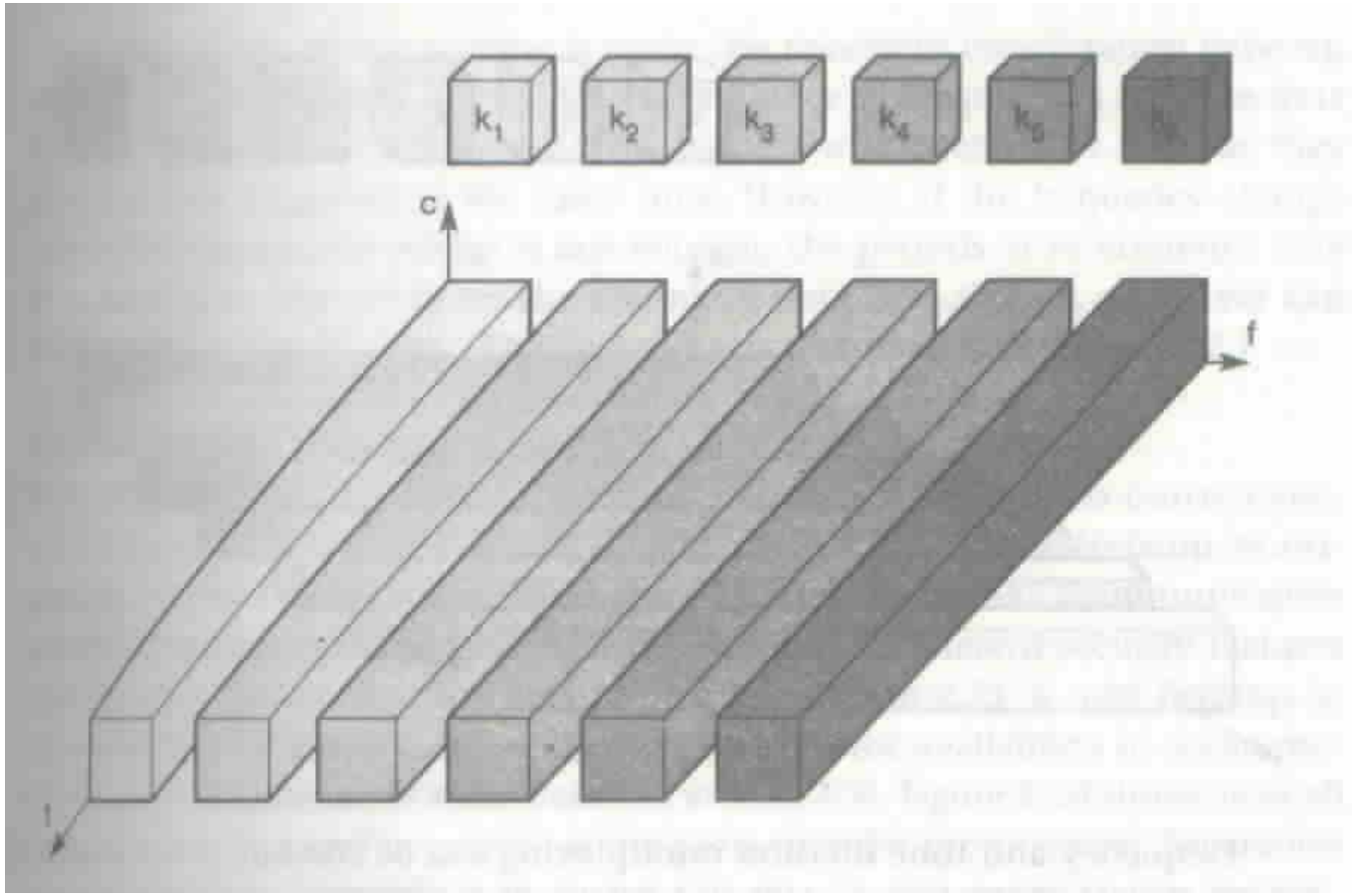


Figure 2.17
Frequency division multiplexing (FDM)

Time Division Multiplexing

- A channel is given the whole bandwidth for a certain amount of time
  - All senders use the same frequency, but at different point of time

Time Division Multiplexing

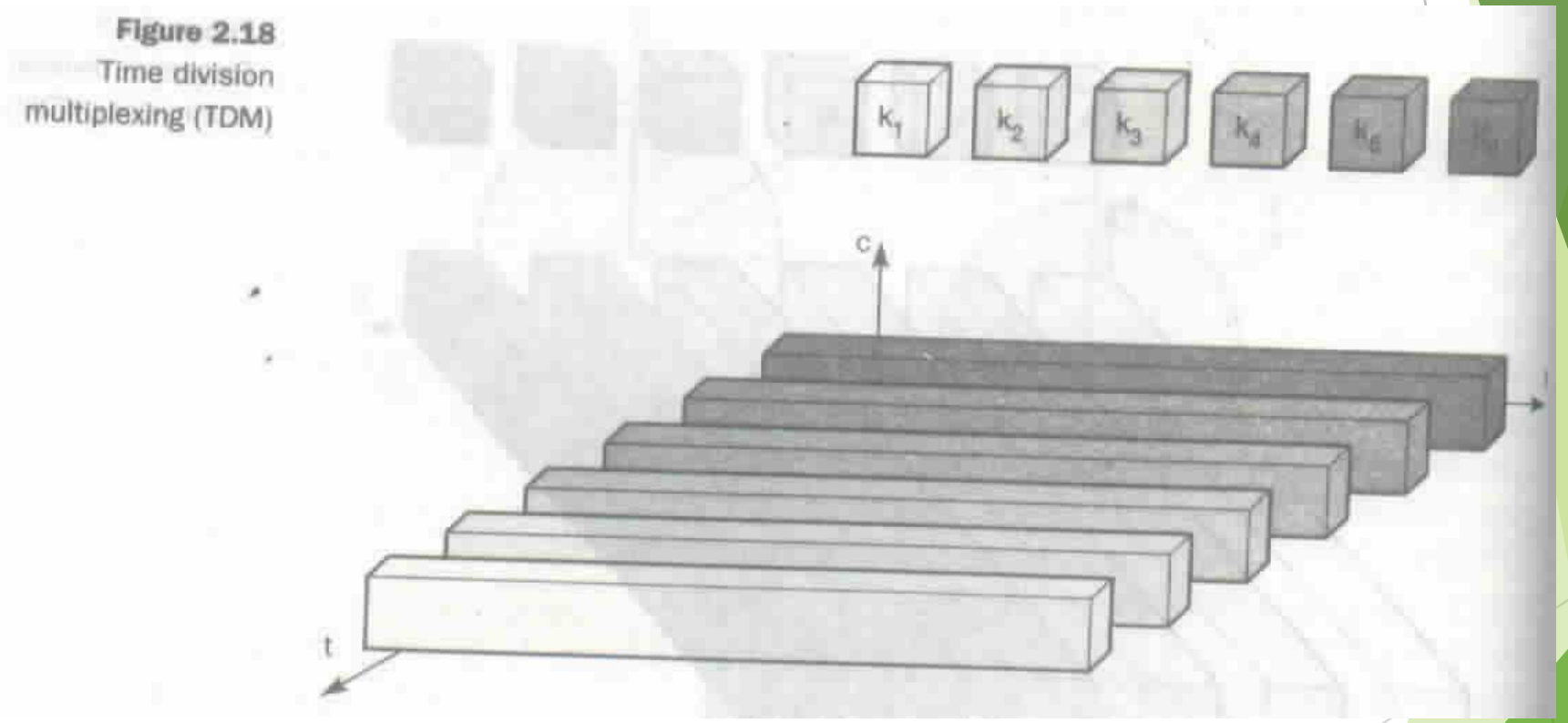


Figure 2.18
Time division multiplexing (TDM)

Frequency and time division multiplexing

- A channel use a certain frequency for a certain amount of time and then uses a different frequency at some other time
  - Used in GSM systems

Frequency and time division multiplexing

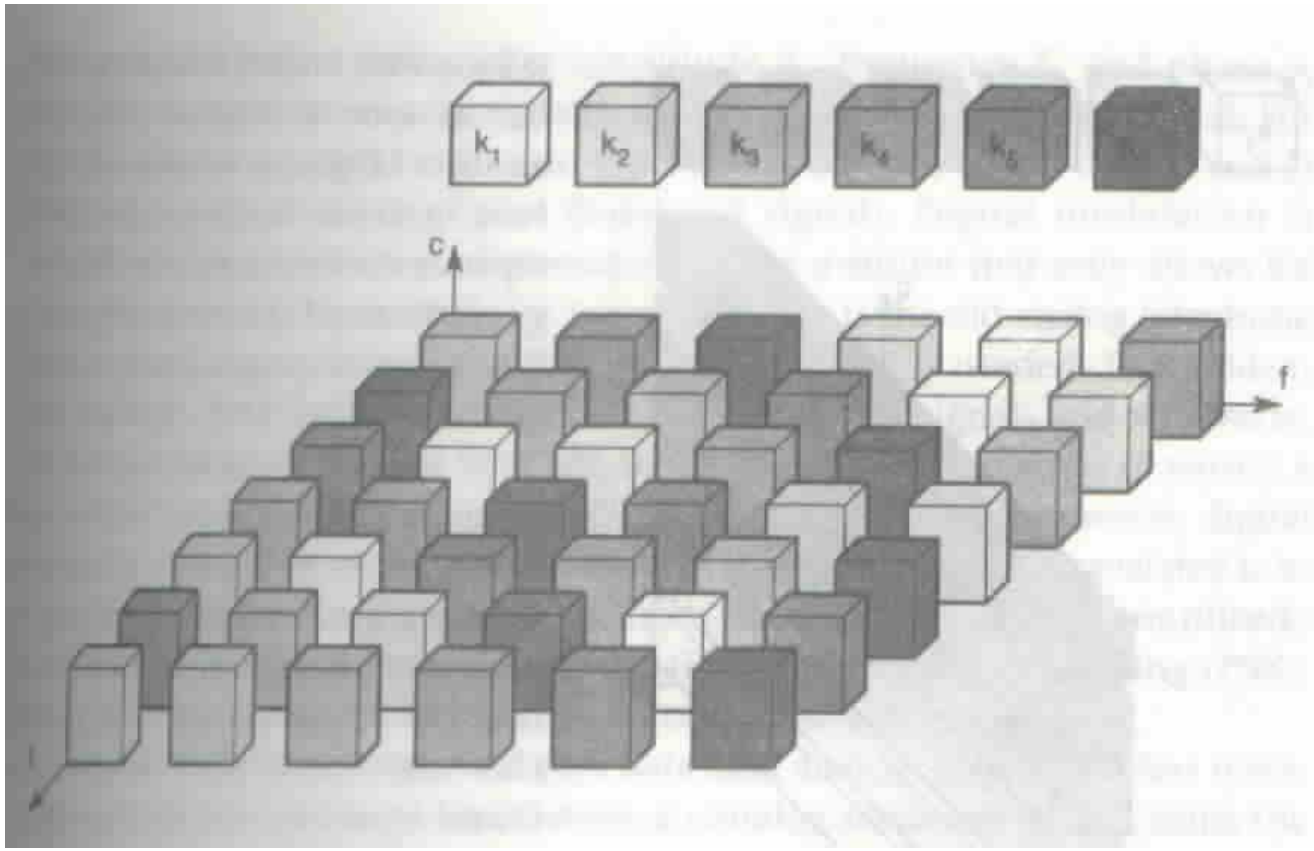


Figure 2.19
Frequency and time division multiplexing combined

Code division multiplexing

- separation of channels achieved by assigning each channel its own *code*
- guard spaces are realized by having *distance* in code space (e.g. orthogonal codes)
- transmitter can transmit in the same frequency band at the same time, but have to use different code
- Provides good protection against interference and tapping
- but the receivers have relatively high complexity
  - has to know the code and must separate the channel with user data from the noise composed of other transmission
  - has to be synchronized with the transmitter

Code division multiplexing

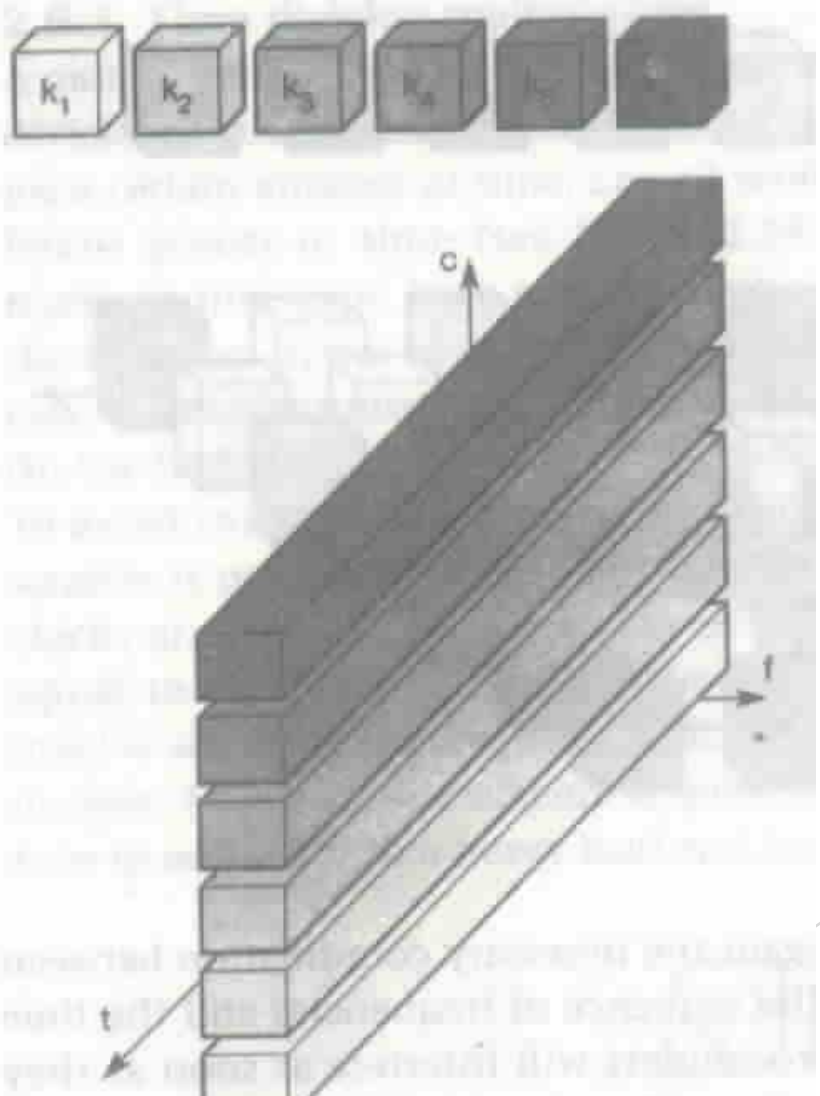
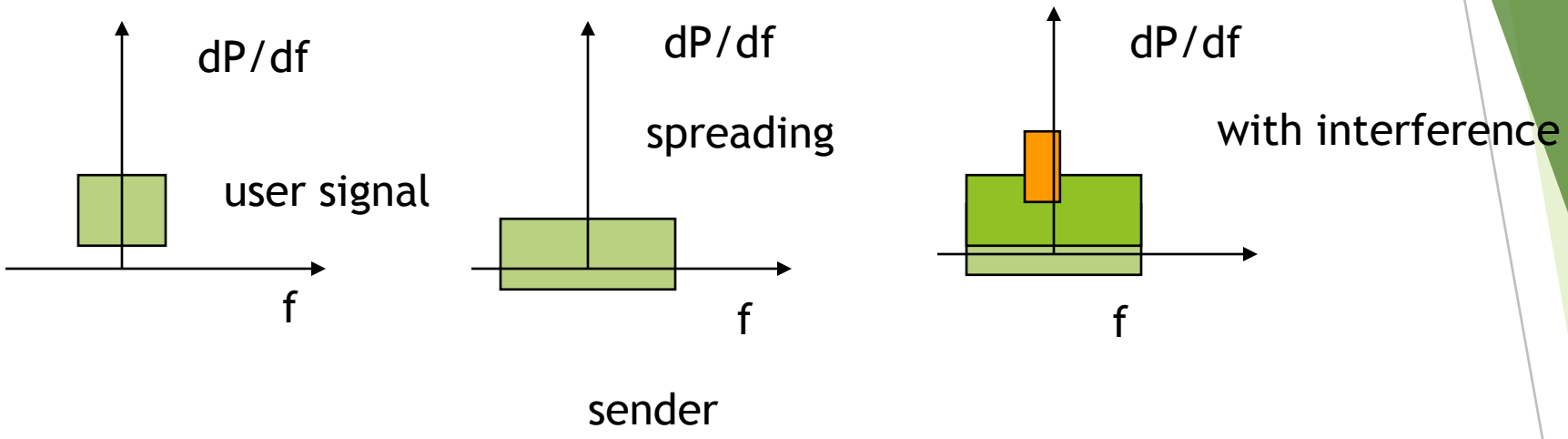


Figure 2.20
Code division multiplexing (CDM)

Spread Spectrum

- Spreading the bandwidth needed to transmit data
  - Spread signal has the same energy as the original signal, but is spread over a larger frequency range
  - provides resistance to narrowband interference

Spread Spectrum

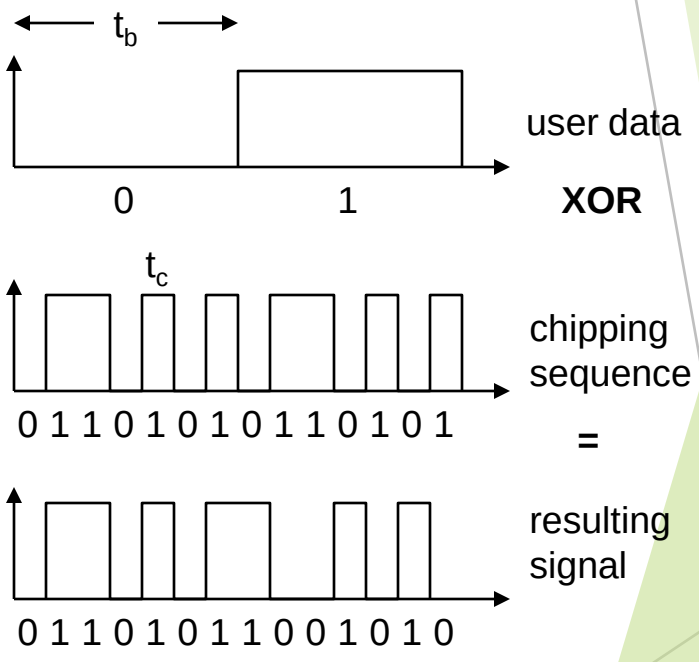


Direct Sequence Spread Spectrum

- Takes a user bit sequence and performs an XOR with, what is known as, *chipping sequence*
- Each user bit duration t_b
- chipping sequence has smaller pulses t_c
- If chipping sequence is generated properly it may appear as random noise
  - sometimes called pseudo-noise (PN)
- t_b/t_c is known as the *spreading factor*
  - determines the bandwidth of the resultant signal
- Used by 802.11b

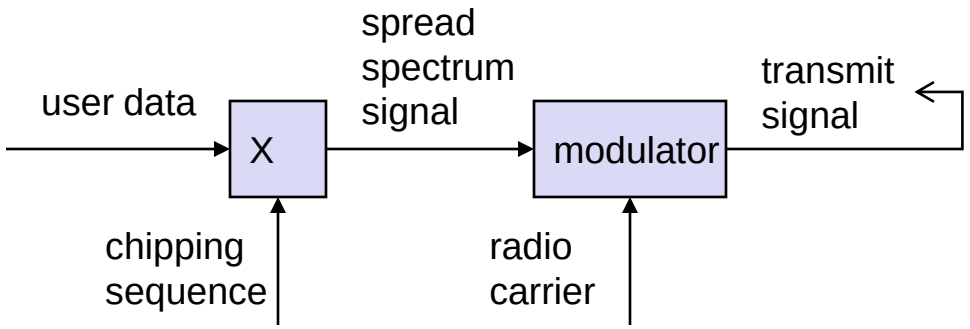
DSSS (Direct Sequence)

- XOR of the signal with pseudo-random number (chipping sequence)
  - many chips per bit (e.g., 128) result in higher bandwidth of the signal
- Advantages
  - reduces frequency selective fading
  - in cellular networks
    - base stations can use the same frequency range
    - several base stations can detect and recover the signal
    - soft handover
- Disadvantages
  - precise power control necessary

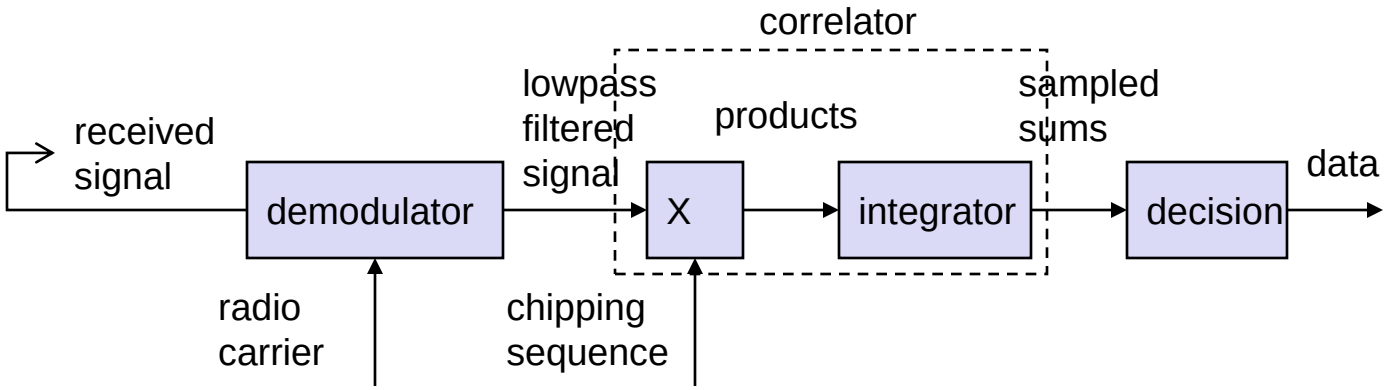


t_b: bit period
t_c: chip period

DSSS Transmit/Receive



transmitter



receiver

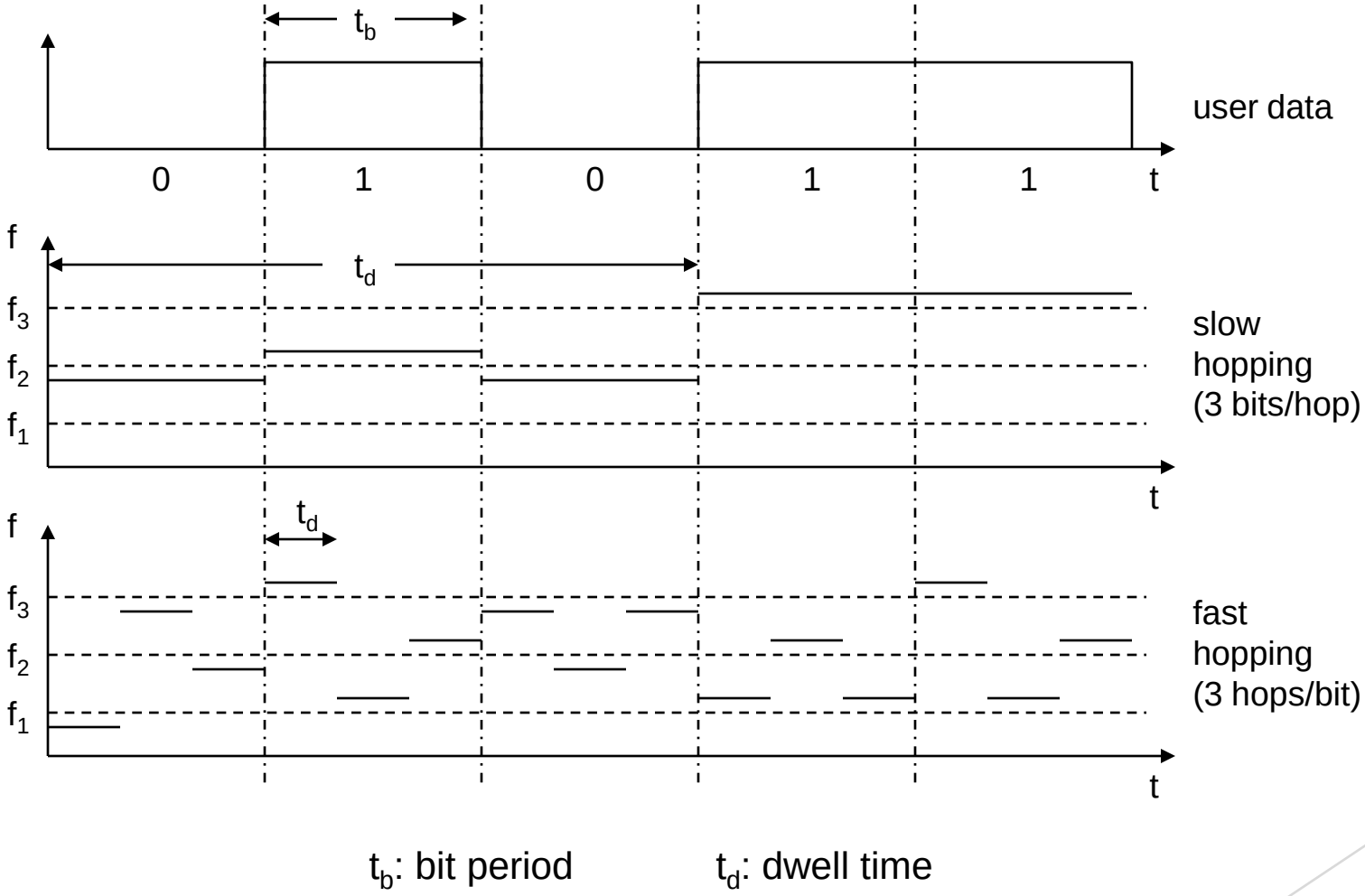
Frequency Hopping Spread Spectrum (FHSS)

- Signal is broadcast over seemingly random series of radio frequencies
- Signal hops from frequency to frequency at fixed intervals
- Channel sequence dictated by spreading code
- Receiver, hopping between frequencies in synchronization with transmitter, picks up message
- Advantages
  - Eavesdroppers hear only unintelligible blips
  - Attempts to jam signal on one frequency succeed only at knocking out a few bits

FHSS (Frequency Hopping)

- Discrete changes of carrier frequency
  - sequence of frequency changes determined via pseudo random number sequence
- Two versions
  - Fast Hopping: several frequencies per user bit
  - Slow Hopping: several user bits per frequency
- Advantages
  - frequency selective fading and interference limited to short period
  - simple implementation
  - uses only small portion of spectrum at any time
- Disadvantages
  - not as robust as DSSS
  - simpler to detect

Slow and Fast FHSS



t_b: bit period t_d: dwell time

CDMA Example

- *D* = rate of data signal
- Break each bit into *k chips*
  - Chips are a user-specific fixed pattern
- Chip data rate of new channel = *kD*

- If *k*=6 and code is a sequence of 1s and -1s
  - For a '1' bit, A sends code as chip pattern
    - <c1, c2, c3, c4, c5, c6>
  - For a '0' bit, A sends complement of code
    - <-c1, -c2, -c3, -c4, -c5, -c6>
- Receiver knows sender's code and performs electronic decode function
    - <d1, d2, d3, d4, d5, d6> = received chip pattern
    - <c1, c2, c3, c4, c5, c6> = sender's code

$$S_u(d) = d1 \times c1 + d2 \times c2 + d3 \times c3 + d4 \times c4 + d5 \times c5 + d6 \times c6$$

CDMA Example

- User A code = <1, –1, –1, 1, –1, 1>
  - To send a 1 bit = <1, –1, –1, 1, –1, 1>
  - To send a 0 bit = <–1, 1, 1, –1, 1, –1>
- User B code = <1, 1, –1, – 1, 1, 1>
  - To send a 1 bit = <1, 1, –1, –1, 1, 1>
- Receiver receiving with A's code
  - (A's code) x (received chip pattern)
    - User A '1' bit: 6 -> 1
    - User A '0' bit: -6 -> 0
    - User B '1' bit: 0 -> unwanted signal ignored

Mobile Computing
Vol II

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Goals of cellular architecture

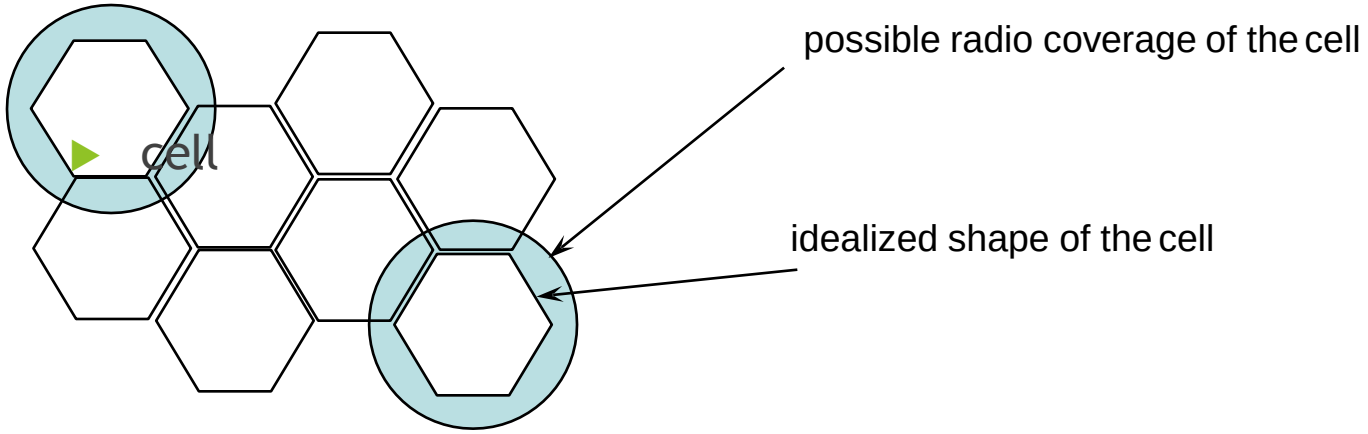
- Low power transmitter system
- Increase network capacity
- Frequency reuse
- Reduced interference

Idea!

- Partition the region into smaller regions called cells.
- Each cell gets at least one base station or tower
- Users within a cell talks to the tower
- How can we divide the region into cells?

GSM: cellular network

segmentation of the area into cells; each cell serving a number of customers



Properties of Cell structure

- Typical Cell sizes
  - some cites few hundred meters
  - country side few tens of kilometers
- Advantages of cell structures:
  - more capacity due to frequency reusage
  - less transmission power needed
  - more robust, tolerate failures
  - deals interference, transmission area locally
  - Hexagonal shape of cells is idealized (cell overlap, shapes depend on geography)
- Problems:
  - fixed network needed for the base stations
  - handover (changing from one cell to another) necessary
  - interference with other cells

Inside a cell

- Center-excited cell where the tower is placed somewhat near the center with a omni-directional antenna
- Edge-excited cell where the towers are placed on three of the six corners with sectored directional antennas.

Advantages of small cell

- Higher capacity

Implementing SDM allows frequency reuse. If one transmitter is far away from another, i.e., outside the interference range, it can reuse the same frequencies. As most mobile phone systems assign frequencies to certain users (or certain hopping patterns), this frequency is blocked for other users. But frequencies are a scarce resource and, the number of concurrent users per cell is very limited. Huge cells do not allow for more users. On the contrary, they are limited to less possible users per square km.. This is also the reason for using very small cells in cities where many more people use mobile phones.

Advantages of small cell

- Less transmission power

While power aspects are not a big problem for base stations, they are indeed problematic for mobile stations. A receiver far

- away from a base station would need much more transmit power than the current few Watts. But energy is a serious problem for mobile handheld devices.

- Local interference only
- Having long distances between sender and receiver results in even more interference problems. With small cells, mobile stations and base stations only have to deal with ‘local’ interference.

- Robustness

Cellular systems are decentralized and so, more robust against the failure of single components. If one antenna fails, this only influences communication within a small area.

Disadvantages of small cell

- Infrastructure needed

Cellular systems need a complex infrastructure to connect all base stations. This includes many antennas, switches for call forwarding, location registers to find a mobile station etc, which makes the whole system quite expensive.

- Handover needed

The mobile station has to perform a handover when changing from one cell to another. Depending on the cell size and the speed of movement, this can happen quite often.

- Frequency planning

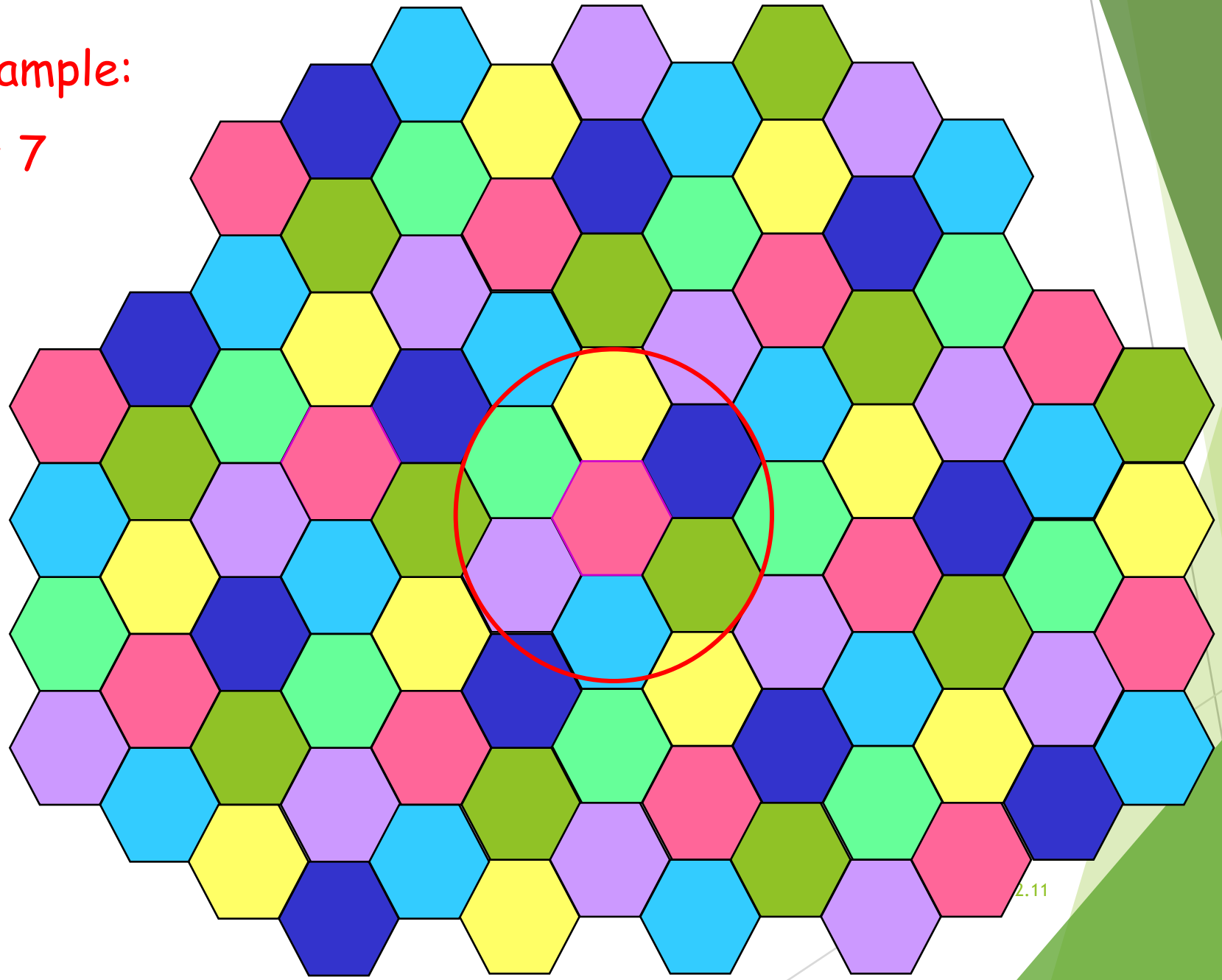
To avoid interference between transmitters using the same frequencies, frequencies have to be distributed carefully. On the one hand, interference should be avoided, on the other, only a limited numberof frequencies is available.

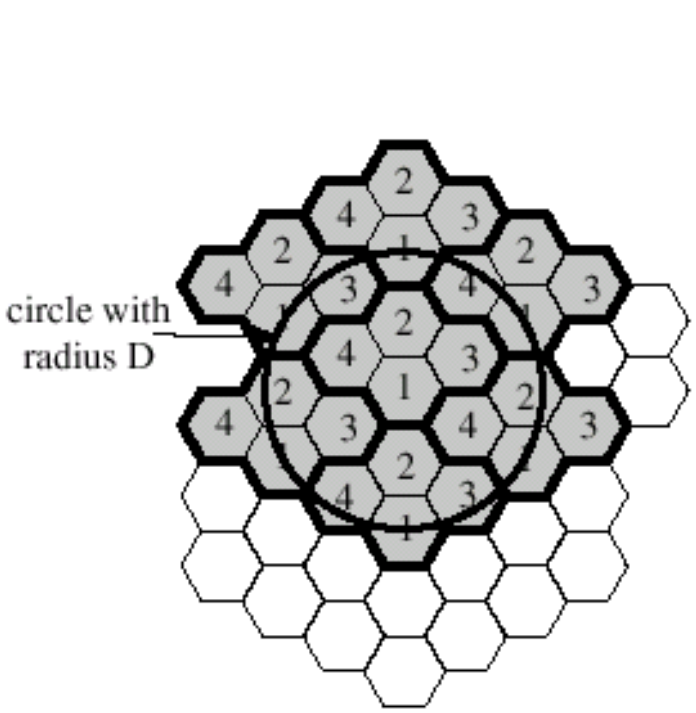
Channel Reuse

- The total number of channels are divided into *K* groups.
  - *K* is called reuse factor or cluster size.
- Each cell is assigned one of the groups.
- The same group can be reused by two different cells provided that they are sufficiently far apart.

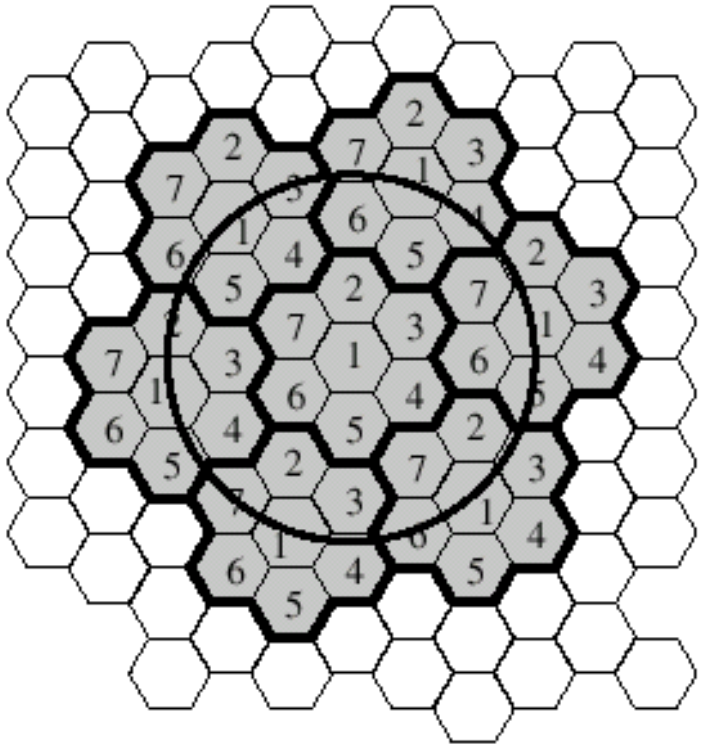
Example:

K = 7



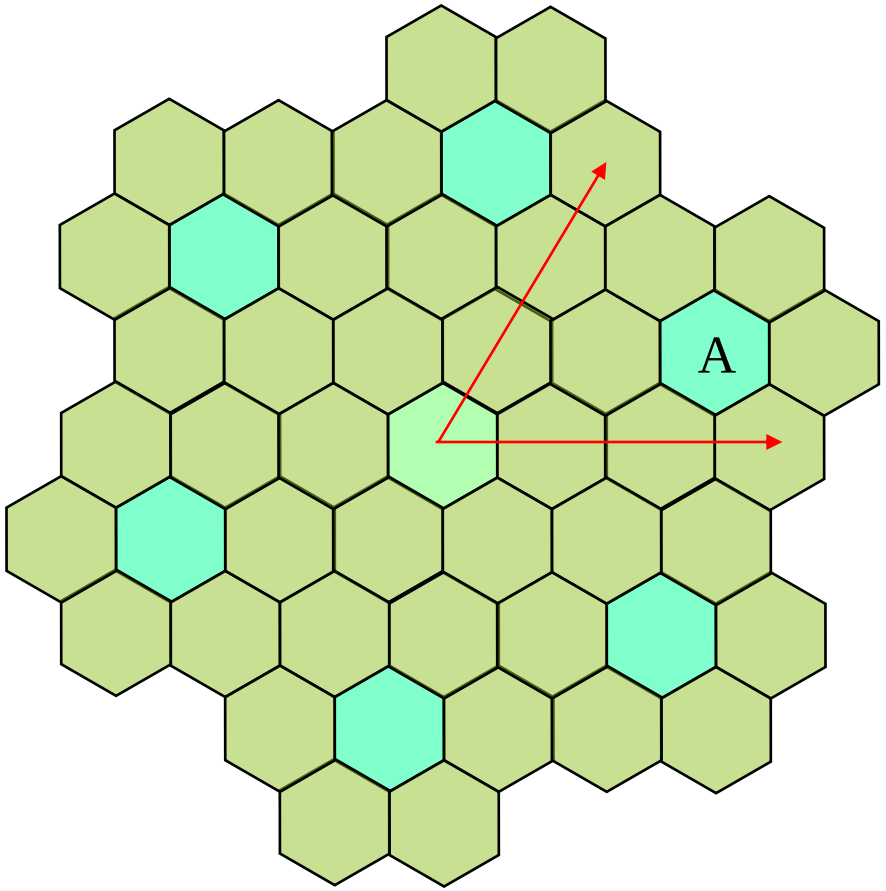


(a) Frequency reuse pattern for $N = 4$



(b) Frequency reuse pattern for $N = 7$

Coordinate System

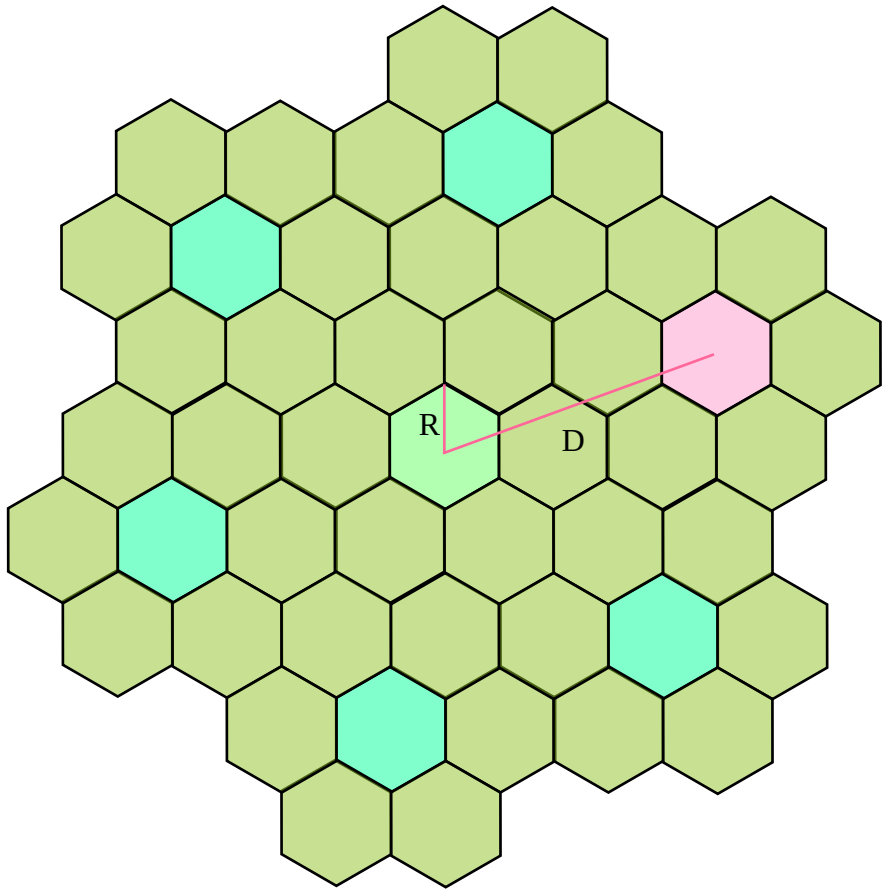


Use (*i*,*j*) to denote a particular cell.

Example:

Cell A is represented by (2,1).

Distance Formula



$$D = \sqrt{3(i^2 + ij + j^2)}R$$

$$= \sqrt{3K}R$$

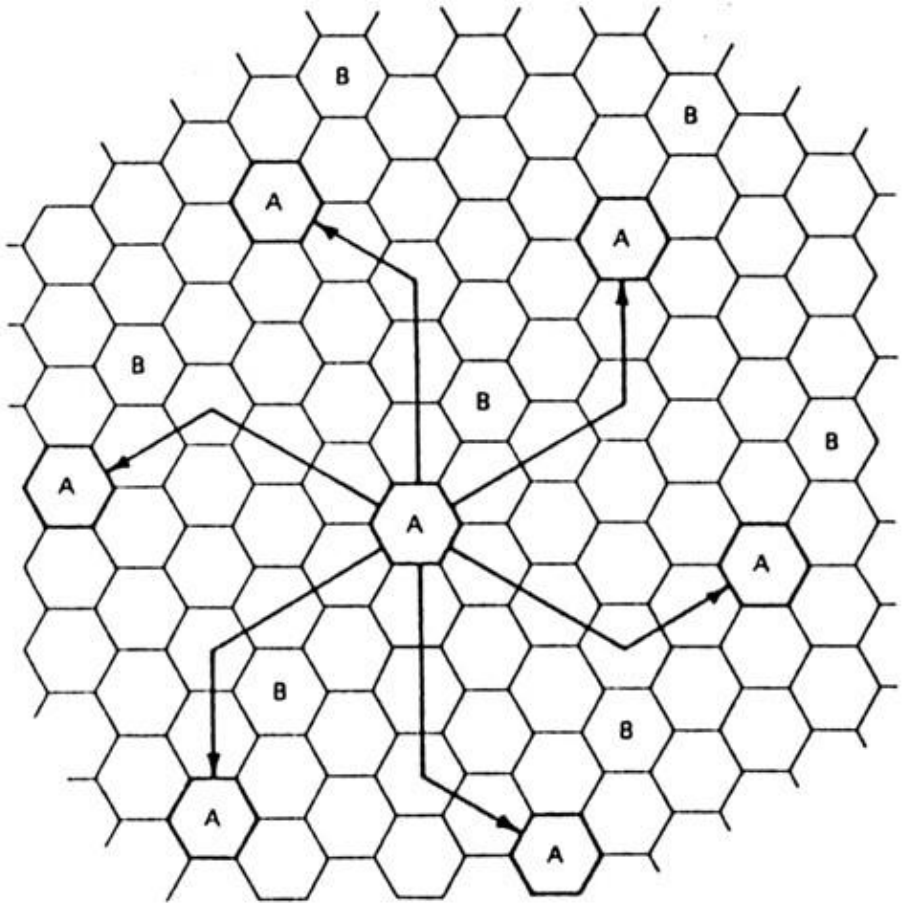
where

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

Reuse factor

Note: *i* and *j* are integers

The Cellular Concept: Co-Channel Cells



SHIFT PARAMETERS: i = 3, j = 2

Using “Shift parameters”(i,j) to lay out a cellular system.

-Move i cells along any chain of hexagons ;
-turn counterclockwise 60 degree
-move j cells along the chain that lies on this new heading.

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

Smaller N is more capacity, but also **more interference**

Table 3.1 Co-channel Reuse Ratio for Some Values of N

	Cluster Size (N)	Co-channel Reuse Ratio (Q)
$i = 1, j = 1$	3	3
$i = 1, j = 2$	7	4.58
$i = 2, j = 2$	12	6
$i = 1, j = 3$	13	6.24

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

$$Q = \frac{D}{R} = \sqrt{3N}$$

R: radius of the cell
D: the distance to the center of the nearest co-channel cell
N: cluster size

1/N is the frequency re-use factor

Example 3.1

If a total of 33 MHz of bandwidth is allocated to a particular FDD cellular telephone system which uses two 25 kHz simplex channels to provide full duplex voice and control channels, compute the number of channels available per cell if a system uses (a) four-cell reuse, (b) seven-cell reuse, and (c) 12-cell reuse. If 1 MHz of the allocated spectrum is dedicated to control channels, determine an equitable distribution of control channels and voice channels in each cell for each of the three systems.

Solution

Given:

Total bandwidth = 33 MHz

Channel bandwidth = 25 kHz × 2 simplex channels = 50 kHz/duplex channel

Total available channels = 33,000/50 = 660 channels

(a) For $N = 4$,
total number of channels available per cell = 660/4 ≈ 165 channels.

(b) For $N = 7$,
total number of channels available per cell = 660/7 ≈ 95 channels.

(c) For $N = 12$,
total number of channels available per cell = 660/12 ≈ 55 channels.

A 1 MHz spectrum for control channels implies that there are 1000/50 = 20 control channels out of the 660 channels available. To evenly distribute the control and voice channels, simply allocate the same number of voice channels in each cell wherever possible. Here, the 660 channels must be evenly distributed to each cell within the cluster. In practice, only the 640 voice channels would be allocated, since the control channels are allocated separately as 1 per cell.

(a) For $N = 4$, we can have five control channels and 160 voice channels per cell. In practice, however, each cell only needs a single control channel (the control channels have a greater reuse distance than the voice channels). Thus, one control channel and 160 voice channels would be assigned to each cell.

(b) For $N = 7$, four cells with three control channels and 92 voice channels, two cells with three control channels and 90 voice channels, and one cell with two control channels and 92 voice channels could be allocated. In practice, however, each cell would have one control channel, four cells would have 91 voice channels, and three cells would have 92 voice channels.

(c) For $N = 12$, we can have eight cells with two control channels and 53 voice channels, and four cells with one control channel and 54 voice channels each. In an actual system, each cell would have one control channel, eight cells would have 53 voice channels, and four cells would have 54 voice channels.

GSM: Overview

- GSM
  - formerly: Groupe Spéciale Mobile (founded 1982)
  - now: Global System for Mobile Communication
  - Pan-European standard (ETSI, European Telecommunications Standardisation Institute)
  - simultaneous introduction of essential digital cellular services in three phases (1991, 1994, 1996) by the European telecommunication administrations, seamless roaming within Europe possible
  - today many providers all over the world use GSM (more than 130 countries in Asia, Africa, Europe, Australia, America)
  - more than 100 million subscribers

Performance characteristics of GSM

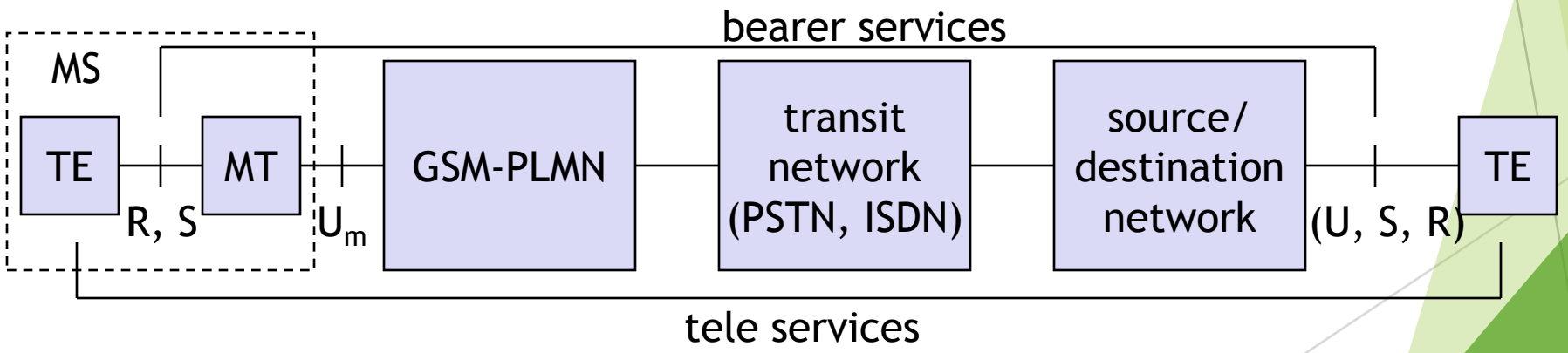
- Communication
  - mobile, wireless digital communication; support for voice and data services
- Total mobility
  - international access, chip-card enables use of access points of different providers
- Worldwide connectivity
  - one number, the network handles localization
- High capacity
  - better frequency efficiency, smaller cells, more customers per cell
- High transmission quality
  - high audio quality
  - uninterrupted phone calls at higher speeds (e.g., from cars, trains) – better handoffs and
- Security functions
  - access control, authentication via chip-card and PIN

Disadvantages of GSM

- There is no perfect system!!
  - no end-to-end encryption of user data
  - no full ISDN bandwidth of 64 kbit/s to the user, no transparent B-channel
  - abuse of private data possible
    - roaming profiles accessible
  - high complexity of the system
  - several incompatibilities within the GSM standards

GSM: Mobile Services

- GSM offers
  - several types of connections
    - voice connections, data connections, short message service
  - multi-service options (combination of basic services)
- Three service domains
  - Bearer Services – interface to the physical medium (transparent for example in the case of voice or non transparent for data services)
  - Telematic Services – services provided by the system to the end user (e.g., voice, SMS, fax, etc.)
  - Supplementary Services – associated with the tele services: call forwarding, redirection, etc.



Bearer Services

- Telecommunication services to transfer data between access points
  - R and S interfaces – interfaces that provide network independent data transmission from end device to mobile termination point.
  - U interface – provides the interface to the network (TDMS, FDMA, etc.)
- Specification of services up to the terminal interface (OSI layers 1-3)
  - Transparent – no error control of flow control, only FEC
  - Non transparent – error control, flow control
- Different data rates for voice and data (original standard)
  - voice service (circuit switched)
    - synchronous: 2.4, 4.8 or 9.6 Kbps.
  - data service (circuit switched)
    - synchronous: 2.4, 4.8 or 9.6 kbit/s
    - asynchronous: 300 - 1200 bit/s
  - data service (packet switched)
    - synchronous: 2.4, 4.8 or 9.6 kbit/s
    - asynchronous: 300 - 9600 bit/s

Tele Services I

- Telecommunication services that enable voice communication via mobile phones
- All these basic services have to obey cellular functions, security measures etc.
- Offered voice related services
  - mobile telephony
    primary goal of GSM was to enable mobile telephony offering the traditional bandwidth of 3.1 kHz
  - Emergency number
    common number throughout Europe (112); mandatory for all service providers; free of charge; connection with the highest priority (preemption of other connections possible)
  - Multinumbering
    several ISDN phone numbers per user possible

Tele Services II

- Additional services: Non-Voice-Teleservices
  - group 3 fax
  - voice mailbox (implemented in the fixed network supporting the mobile terminals)
  - electronic mail (MHS, Message Handling System, implemented in the fixed network)
  - ...
  - Short Message Service (SMS)
    alphanumeric data transmission to/from the mobile terminal using the signaling channel, thus allowing simultaneous use of basic services and SMS (160 characters)

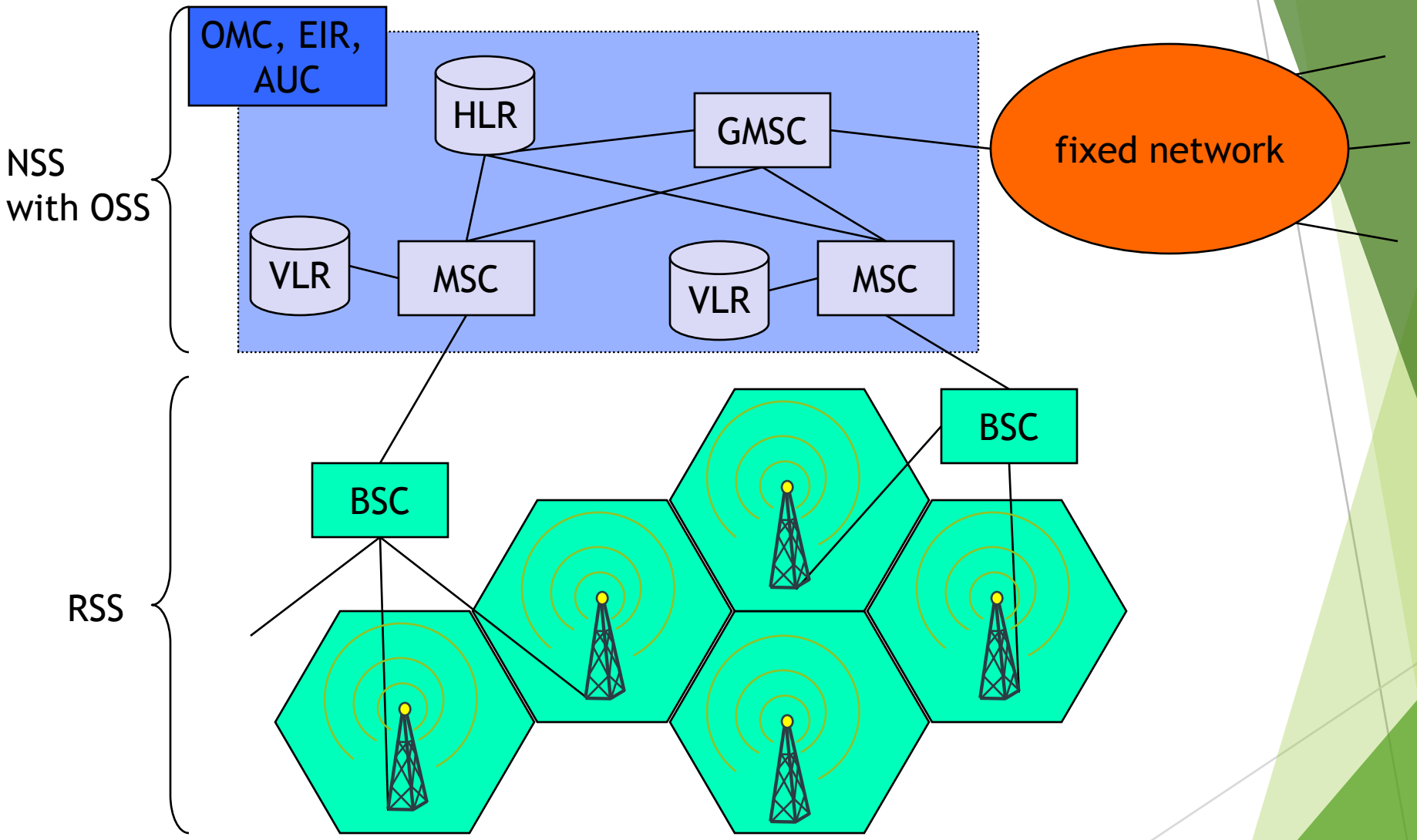
Supplementary services

- Services in addition to the basic services, cannot be offered stand-alone
- May differ between different service providers, countries and protocol versions
- Important services
  - identification: forwarding of caller number
  - suppression of number forwarding
  - automatic call-back
  - conferencing with up to 7 participants
  - locking of the mobile terminal (incoming or outgoing calls)
  - ...

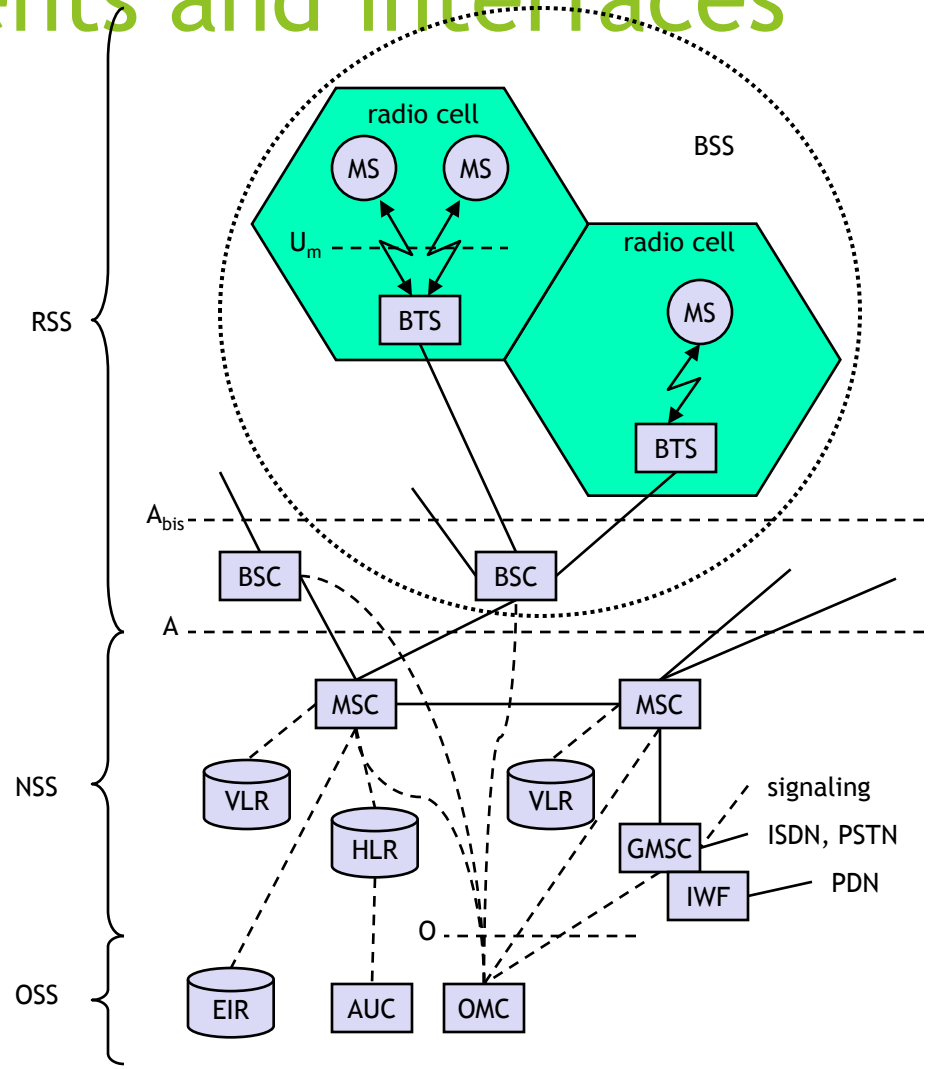
Architecture of the GSM system

- GSM is a PLMN (Public Land Mobile Network)
  - 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
    - NSS (network and switching subsystem): call forwarding, handover, switching
    - OSS (operation subsystem): management of the network

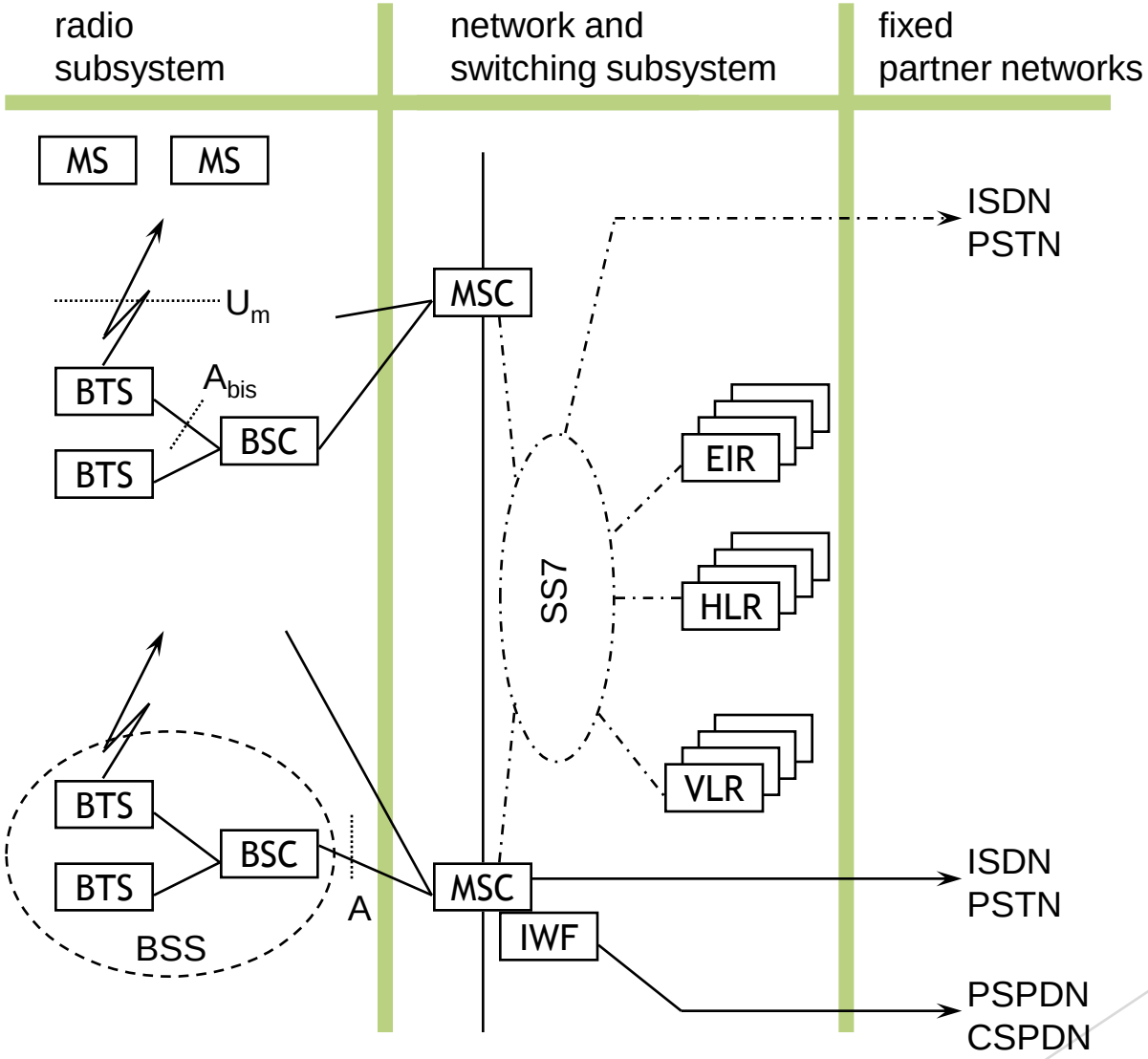
GSM: overview



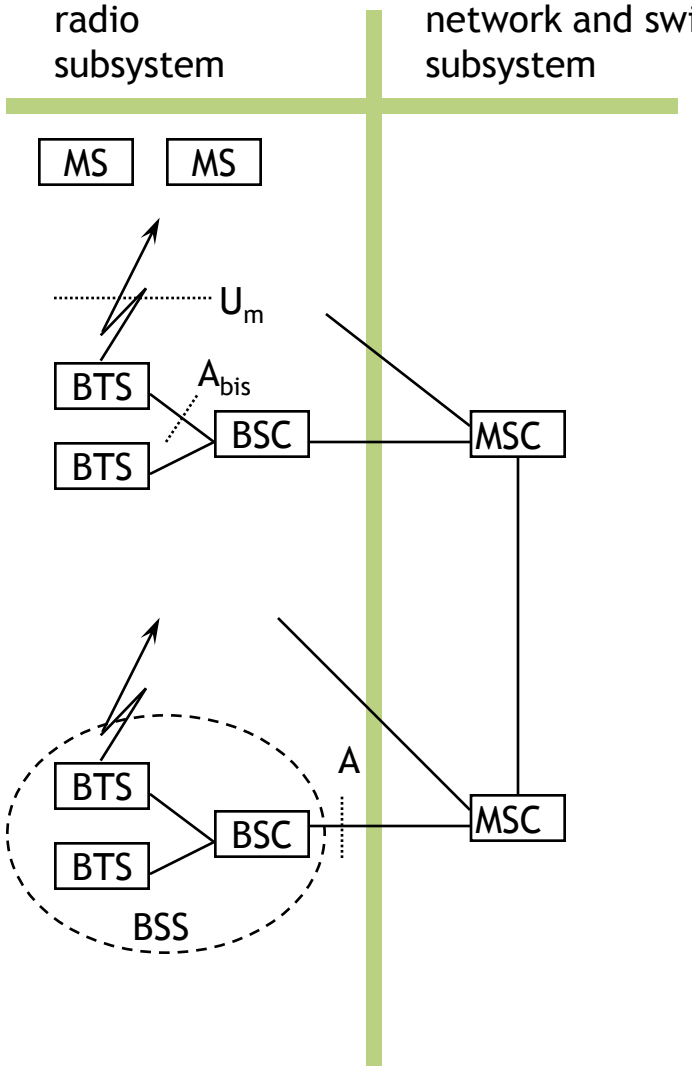
GSM: elements and interfaces



GSM: system architecture

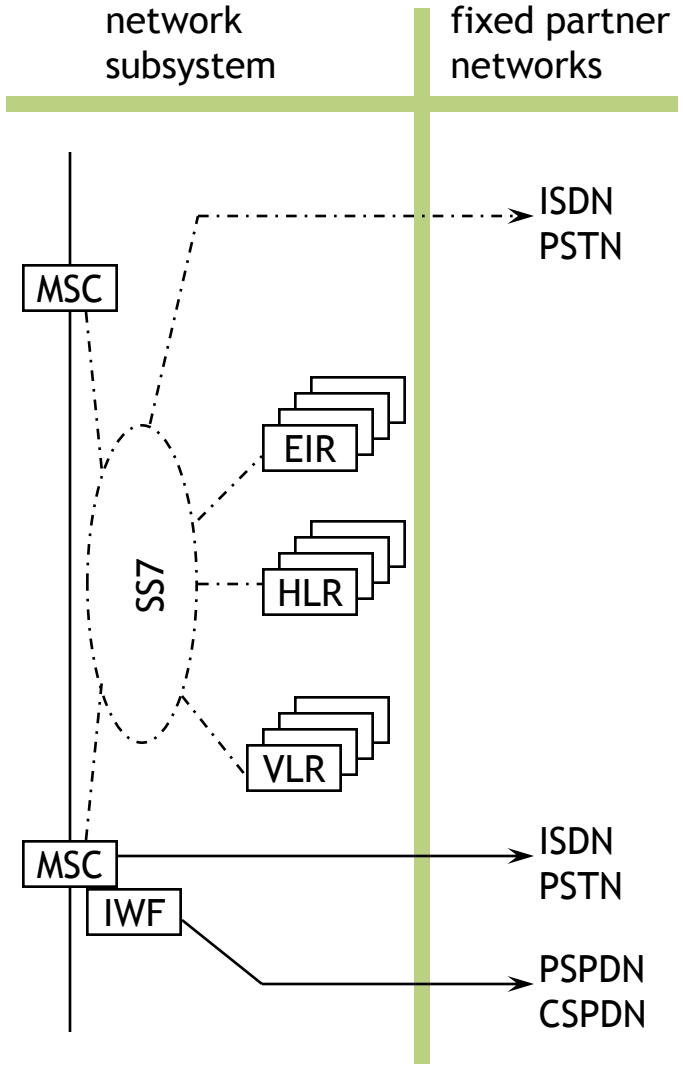


System architecture: radio subsystem



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

System architecture: 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)

Radio subsystem

- The Radio Subsystem (RSS) comprises the cellular mobile network up to the switching centers
- Components
  - Base Station Subsystem (BSS):
    - Base Transceiver Station (BTS): radio components including sender, receiver, antenna - if directed antennas are used one BTS can cover several cells
    - Base Station Controller (BSC): switching between BTSs, controlling BTSs, managing of network resources, mapping of radio channels (U_m) onto terrestrial channels (A interface)
    - BSS = BSC + sum(BTS) + interconnection
  - Mobile Stations (MS)

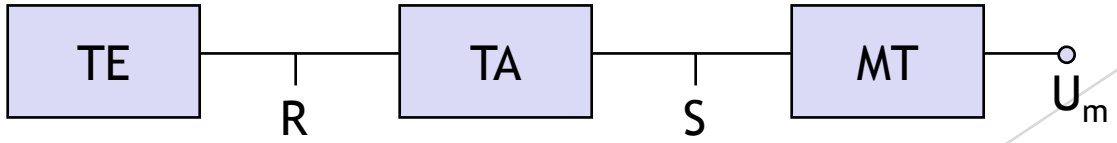
Base Transceiver Station and Base Station Controller

- Tasks of a BSS are distributed over BSC and BTS
- BTS comprises radio specific functions
- BSC is the switching center for radio channels

Functions	BTS	BSC
Management of radio channels		X
Frequency hopping (FH)	X	X
Management of terrestrial channels		X
Mapping of terrestrial onto radio channels		X
Channel coding and decoding	X	
Rate adaptation	X	
Encryption and decryption	X	X
Paging	X	X
Uplink signal measurements	X	
Traffic measurement		X
Authentication		X
Location registry, location update		X
Handover management		X

Mobile station

- Terminal for the use of GSM services
- A mobile station (MS) comprises several functional groups
  - MT (Mobile Terminal):
    - offers common functions used by all services the MS offers
    - corresponds to the network termination (NT) of an ISDN access
    - end-point of the radio interface (U_m)
  - TA (Terminal Adapter):
    - terminal adaptation, hides radio specific characteristics (TE connects via modem, Bluetooth, IrDA etc. to MT)
  - TE (Terminal Equipment):
    - peripheral device of the MS, offers services to a user
    - Can be a headset, microphone, etc.
    - does not contain GSM specific functions
  - SIM (Subscriber Identity Module):
    - personalization of the mobile terminal, stores user parameters



Network and switching subsystem

- NSS is the main component of the public mobile network GSM
  - switching, mobility management, interconnection to other networks, system control
- Components
  - Mobile Services Switching Center (MSC)
    controls all connections via a separated network to/from a mobile terminal within the domain of the MSC - several BSC can belong to a MSC
  - Databases (important: scalability, high capacity, low delay)
    - Home Location Register (HLR)
      central master database containing user data, permanent and semi-permanent data of all subscribers assigned to the HLR (one provider can have several HLRs)
    - Visitor Location Register (VLR)
      local database for a subset of user data - data about all users currently visiting in the domain of the VLR

Mobile Services Switching Center

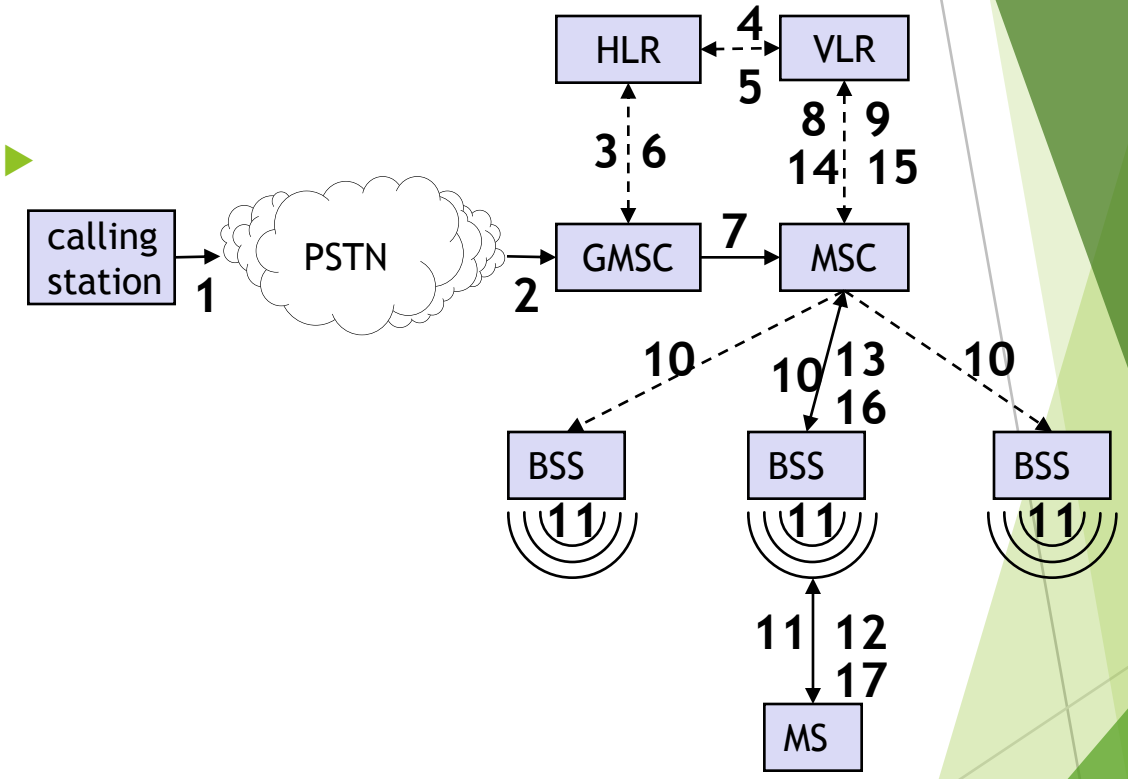
- The MSC (mobile switching center) plays a central role in GSM
  - switching functions
  - additional functions for mobility support
  - management of network resources
  - interworking functions via Gateway MSC (GMSC)
  - integration of several databases
- Functions of a MSC
  - specific functions for paging and call forwarding
  - termination of SS7 (signaling system no. 7)
  - mobility specific signaling
  - location registration and forwarding of location information
  - provision of new services (fax, data calls)
  - support of short message service (SMS)
  - generation and forwarding of accounting and billing information

Operation subsystem

- The OSS (Operation Subsystem) enables centralized operation, management, and maintenance of all GSM subsystems
- Components
  - Authentication Center (AUC)
    - generates user specific authentication parameters on request of a VLR
    - authentication parameters used for authentication of mobile terminals and encryption of user data on the air interface within the GSM system
  - Equipment Identity Register (EIR)
    - registers GSM mobile stations and user rights
    - stolen or malfunctioning mobile stations can be locked and sometimes even localized
  - Operation and Maintenance Center (OMC)
    - different control capabilities for the radio subsystem and the network subsystem

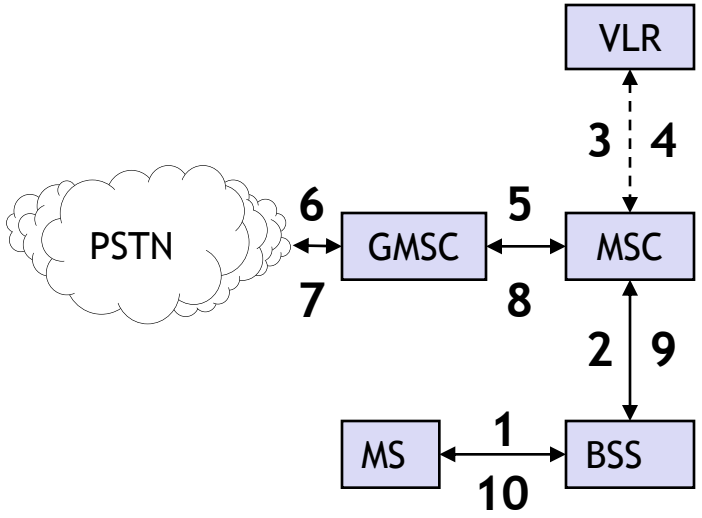
Mobile Terminated Call

- 1: calling a GSM subscriber
- 2: forwarding call to GMSC
- 3: signal call setup to HLR
- 4, 5: request MSRN from 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

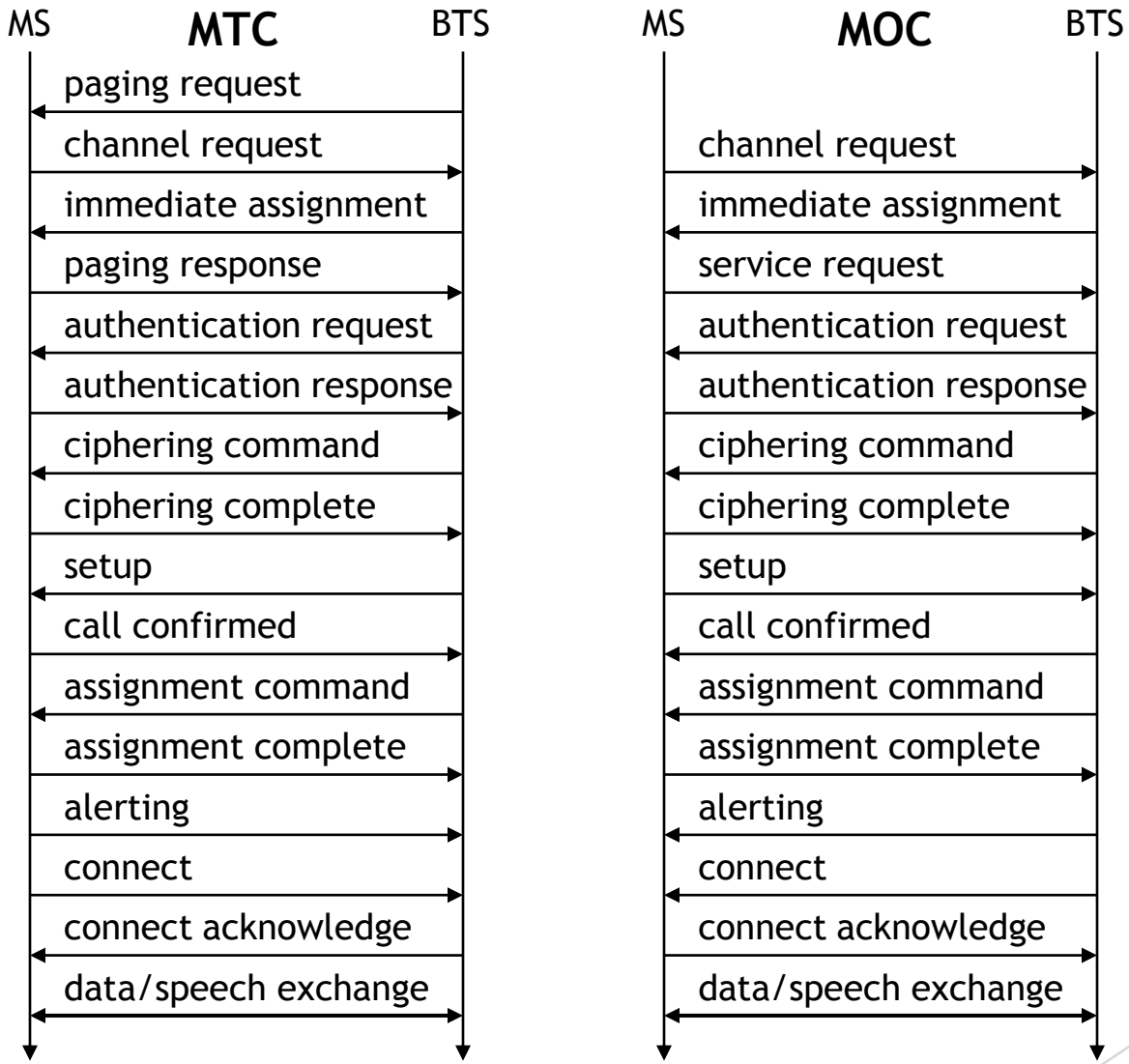


Mobile Originated Call

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



MTC/MOC


MS
MTC
BTS
paging request
channel request
immediate assignment
paging response
authentication request
authentication response
ciphering command
ciphering complete
setup
call confirmed
assignment command
assignment complete
alerting
connect
connect acknowledge
data/speech exchange
MS
MOC
BTS
channel request
immediate assignment
service request
authentication request
authentication response
ciphering command
ciphering complete
setup
call confirmed
assignment command
assignment complete
alerting
connect
connect acknowledge
data/speech exchange

Handoffs

- Cellular systems require handover procedures, as single cells do not cover the

whole service area, but, e.g., only up to 35 km around each antenna on the countryside and some hundred meters in cities (Tripathi, 1998). The smaller the cell size and the faster the movement of a mobile station through the cells (up to 250 km/h for GSM), the more handovers of ongoing calls are required. However, a handover should not cause a cut-off, also called call drop. GSM aims at maximum handover duration of 60 ms.

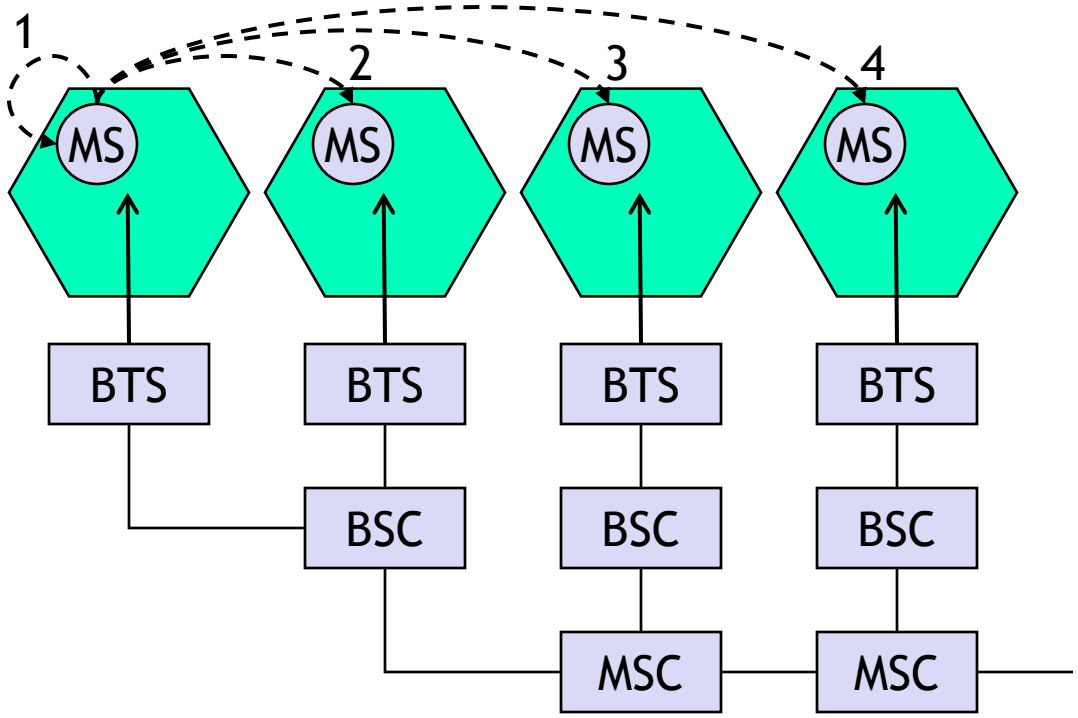
Handoffs Reasons

- The mobile station moves out of the range of a BTS or a certain antenna of a BTS respectively. The received signal level decreases continuously until it falls below the minimal requirements for communication. The error rate may grow due to interference, the distance to the BTS may be too high (max. 35 km) etc. – all these effects may diminish the quality of the radio linkand make radio transmission impossible in the near future.

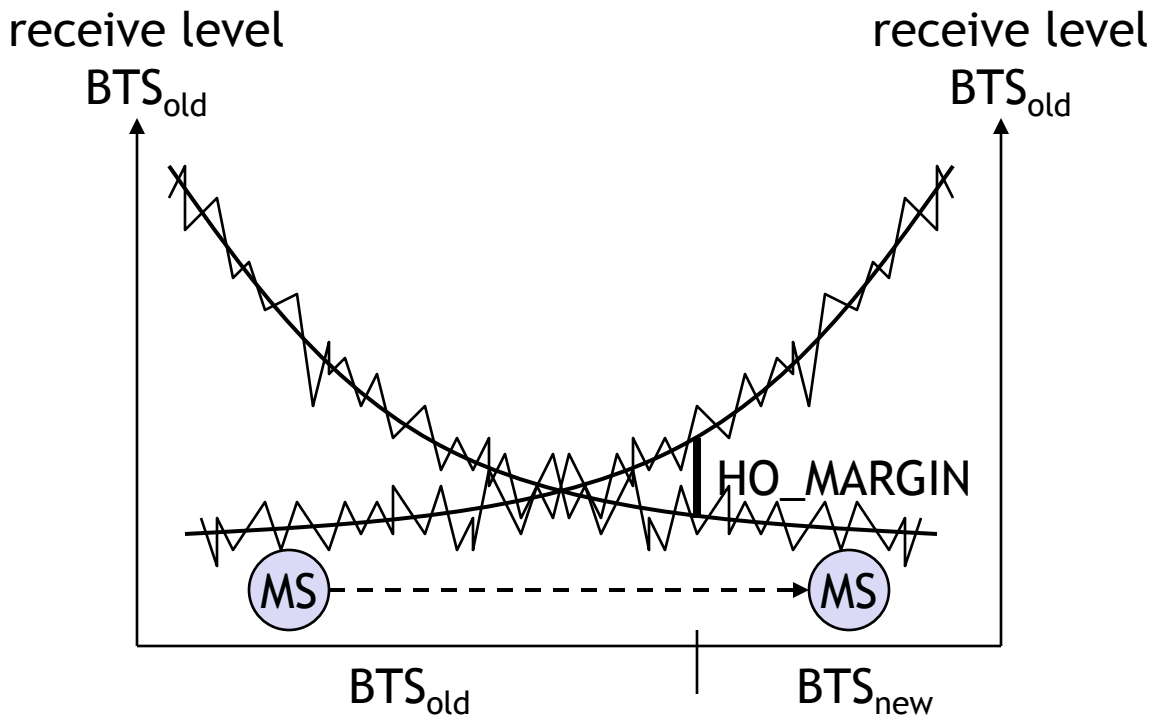
- The wired infrastructure (MSC, BSC) may decide that the traffic in one cell is too high

and shift some MS to other cells with a lower load (if possible). Handover may be due to load balancing.

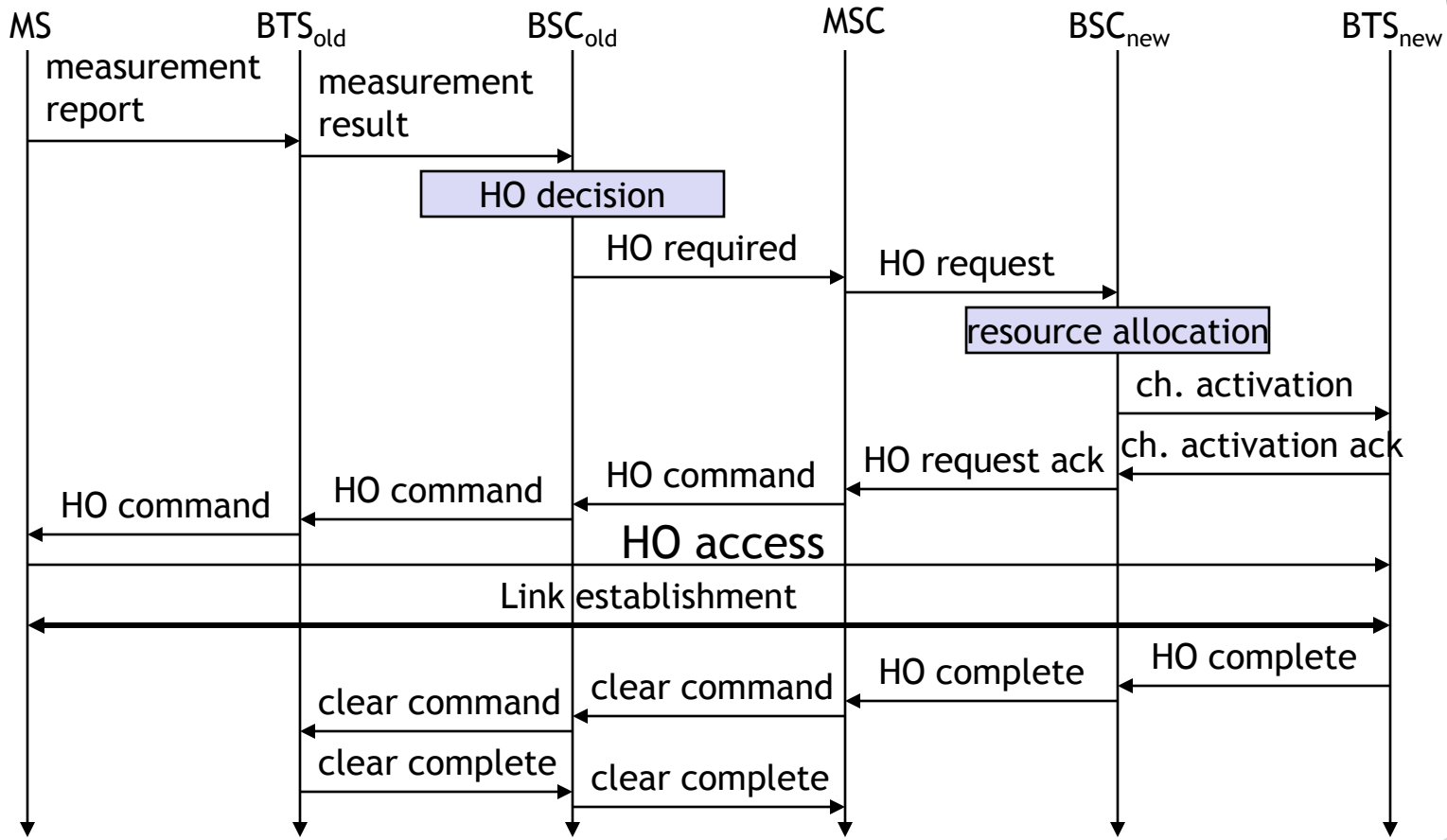
4 types of handover



Handover decision



Handover procedure

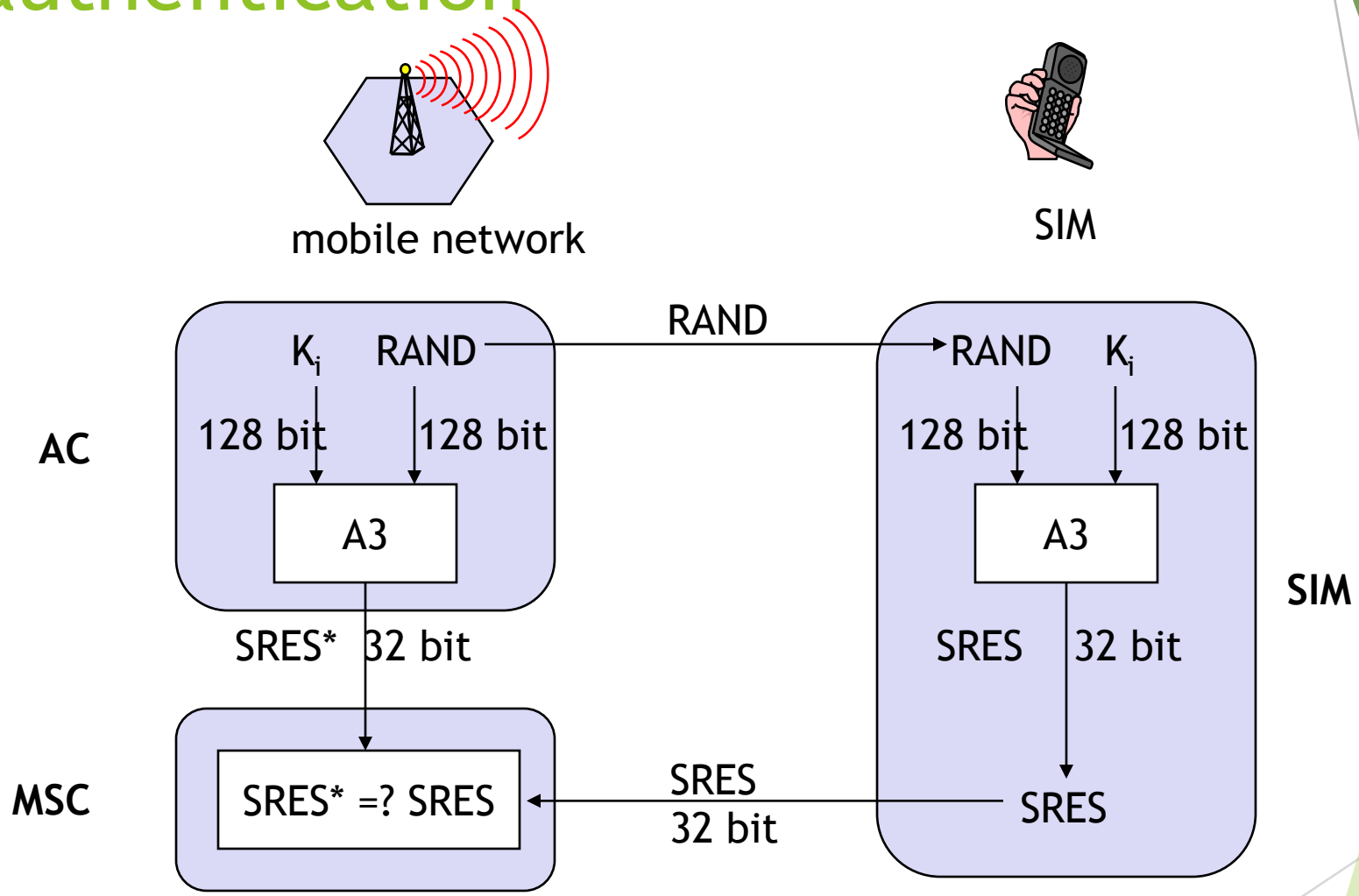


Security in GSM

- 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)

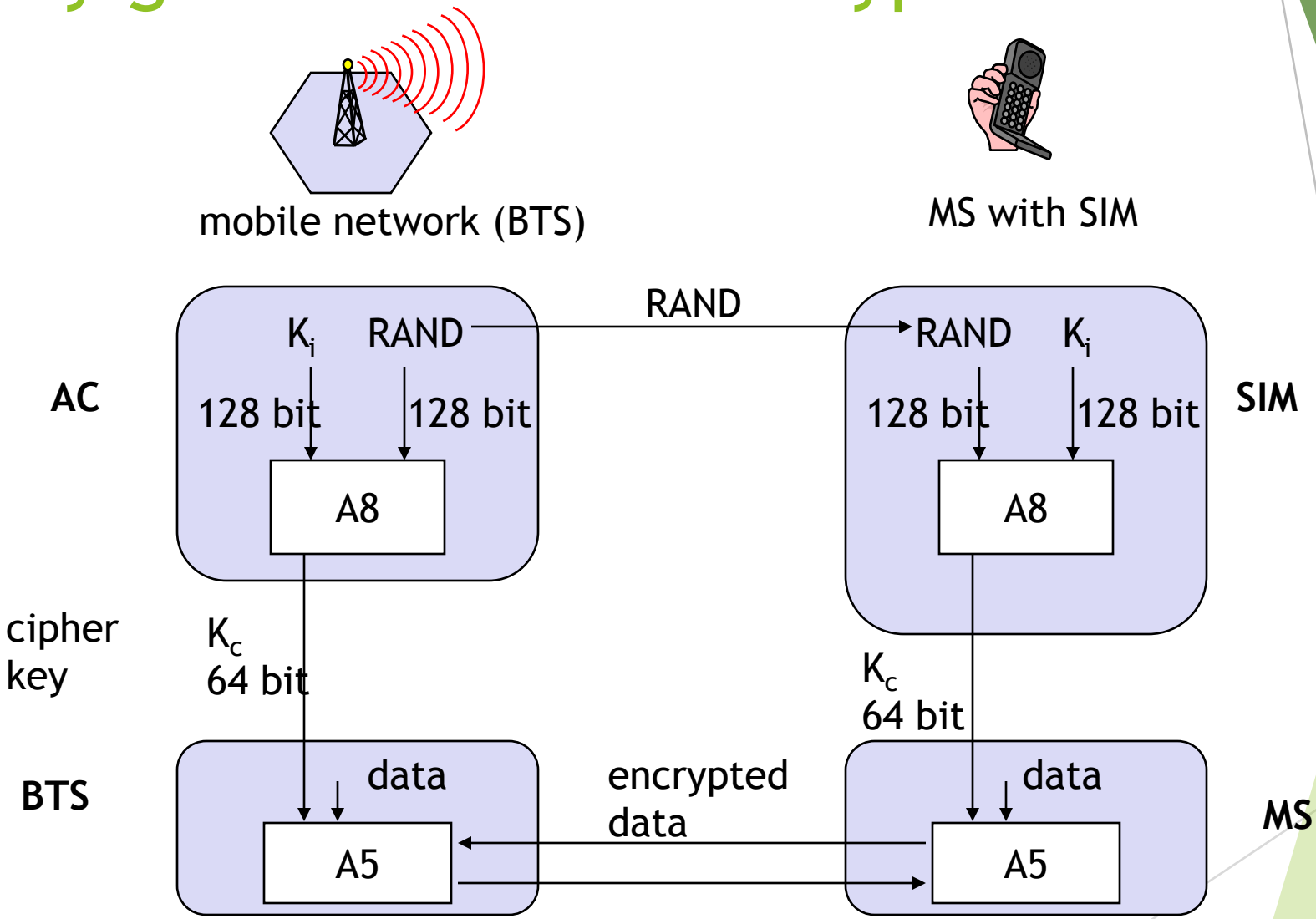
“secret”:
• A3 and A8 available via the Internet
• network providers can use stronger mechanisms

GSM - authentication



K_i: individual subscriber authentication key SRES: signed response

GSM - key generation and encryption



Data services in GSM I

- Data transmission standardized with only 9.6 kbit/s
  - advanced coding allows 14.4 kbit/s
  - not enough for Internet and multimedia applications
- HSCSD (High-Speed Circuit Switched Data)
  - already standardized
  - bundling of several time-slots to get higher AIUR (Air Interface User Rate) (e.g., 57.6 kbit/s using 4 slots, 14.4 each)
  - advantage: ready to use, constant quality, simple
  - disadvantage: channels blocked for voice transmission

AIUR [kbit/s]	TCH/F4.8	TCH/F9.6	TCH/F14.4
4.8	1		
9.6	2	1	
14.4	3		1
19.2	4	2	
28.8		3	2
38.4		4	
43.2			3
57.6			4

Data services in GSM II

- GPRS (General Packet Radio Service)
  - packet switching
  - using free slots only if data packets ready to send (e.g., 115 kbit/s using 8 slots temporarily)
  - standardization 1998
  - advantage: one step towards UMTS, more flexible
  - disadvantage: more investment needed
- GPRS network elements
  - GSN (GPRS Support Nodes): GGSN and SGSN
  - GGSN (Gateway GSN)
    - interworking unit between GPRS and PDN (Packet Data Network)
  - SGSN (Serving GSN)
    - supports the MS (location, billing, security)
  - GR (GPRS Register)
    - user addresses