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MOBILE COMMUNICATION SYSTEMS

WIRELESS TRANSMISSION

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Wireless Transmission (overview)

- Component of communication systems
- Transmission direction
- Digital vs. Analog Communication
- Frequencies Spectrums
- Signals
- Antennas
- Signal propagation
- Multiplexing
- Spread spectrum
- Modulation
- Cellular systems

Component of Communication System….1

- Message dibangkitkan dari **sumber**. Message bisa berupa suara manusia, gambar televisi atau data. Sumber mengubah input dari *transducer* menjadi gelombang listrik dalam bentuk sinyal baseband atau sinyal data
- **Transmitter** : memodifikasi sinyal baseband untuk efisiensi proses pengiriman. Transmitter terdiri dari satu atau lebih subsitem ini: *pre-empasizer, sampler, quantizer, coder* dan *modulator*.
- **Kanal** : sebuah media untuk mengirim sinyal output transmitter. Kanal bisa berupa kabel: kabel koaksial, kabel tembaga, kabel optik, atau media udara. Berdsarkan tipe kanal ini, sistim komunikasi modern dibedakan dua macam: sistim komunikasi kabel dan sistim komunikasi nirkabel.

Component of Communication System….2

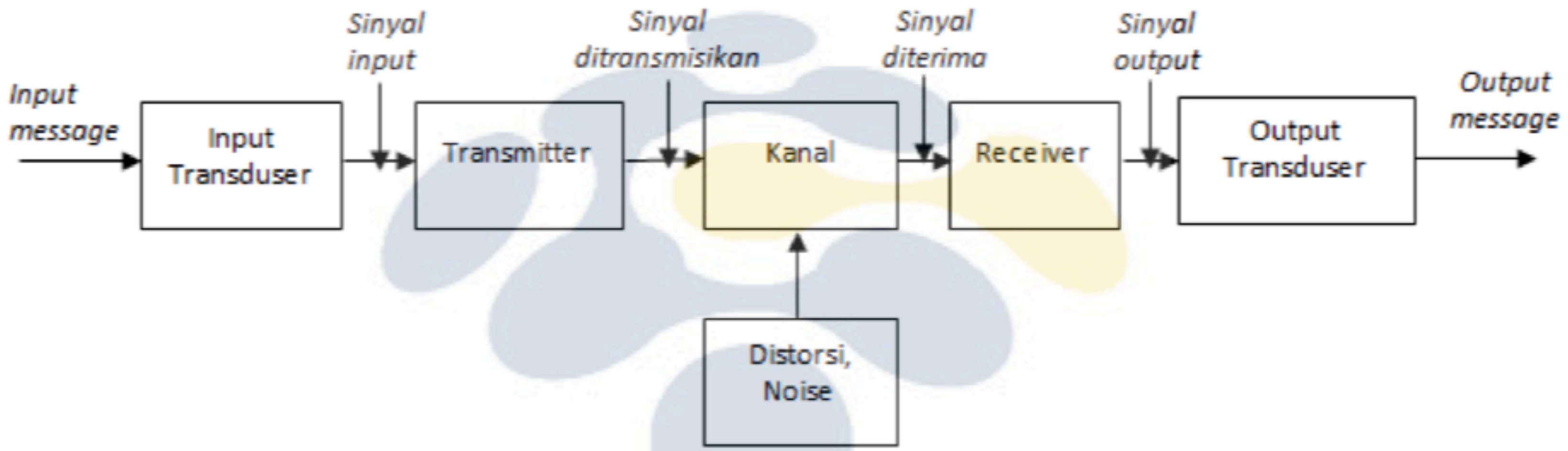
- **Receiver** menerima dan memproses kembali sinyal yang diterima dari kanal. Receiver memproses kebalikan dari modifikasi yang dilakukan di transmitter maupun pada kanal. Receiver bertugas meng-ekstrak sinyal yang diterima di output kanal yang telah terdistorsi ataupun mengandung noise. Receiver biasanya berisi *demodulator, decoder,* filter dan *de-emphasizer*.
- Output receiver diteruskan ke *output transducer* untuk mengubah sinyal listrik menjadi bentuk aslinya kembali.

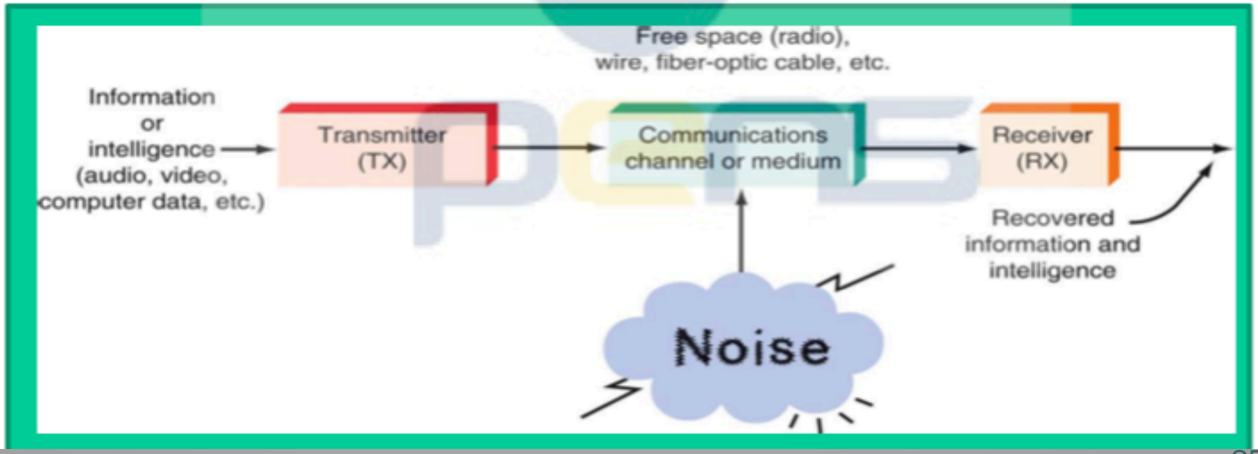
Component of Communication System….3

- **Distorsi:** disebut juga degradasi sinyal atau redaman sinyal selalu ada pada sistim transmisi nirkabel. Merupakan kondisi dimana sinyal mengalami perubahan bentuk terhadap sinyal aslinya.

- **Noise:** merupakan energi atau sinyal elektromagnetik yang random, dan tidak diharapkan, yang masuk ke dalam sistim komunikasi melalui media komunikasi, dan menginterferensi sinyal yang ditransmisikan.

Component of Communication System….4



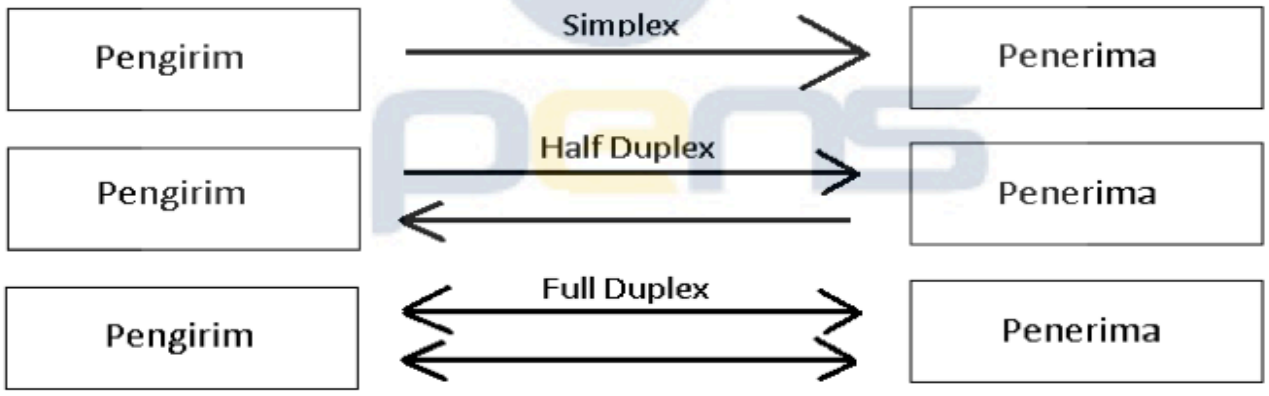


Arah Transmisi ….1

- Simpleks: Transmisi searah (one way) dari pengirim (transmitter) ke penerima (receiver)
- Contoh:
  - Komunikasi dari Pemancar radio ke penerima radio
  - TV Broadcasting
  - Pager
- Half-Duplex: Komunikasi dua arah (two-way) namun tidak serentak. Jika satu user sedang bicara, user yang lain mendengar. Begitu sebaliknya
  - Contoh:
    - Radio transmisi polisi
    - Citizen Band
    - Radio Amatir

Arah Transmisi

- Full-Duplex: Transmisi dua arah (two way) secara serentak (simultan). User dapat mendengar dan bicara dalam waktu yang sama
- Contoh:
  - Orang bertelepon (dengan suara)
  - Chatting (dengan text)



Komunikasi Digital vs Analog …1

Jenis informasi dalam sistim komunikasi:

- Informasi **Analog**: data-data yang nilainya bervariasi dalam range kontinyu.
  - Contoh: gelombang suara, gambar
- Informasi **Digital**: data informasi yang dibentuk dari bilangan atau simbol dalam ukuran diskrit.
  - Contoh: text, kode morse

Komunikasi Digital vs Analog …2

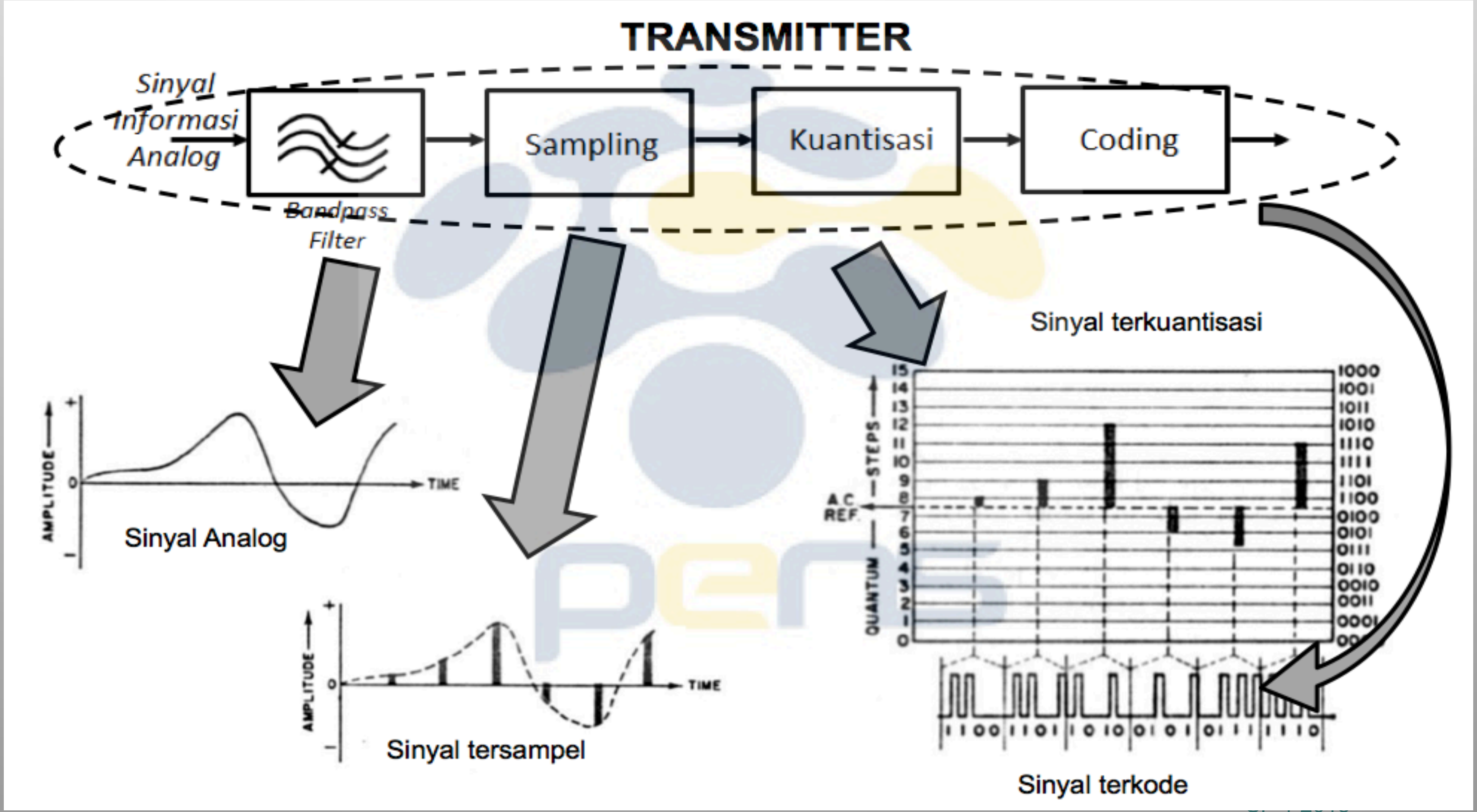
- Sinyal digital memiliki *imunitas noise*: data digital bisa direcovery tanpa noise sepanjang distorsi dan noise yang menyertainya berada dalam range tertentu. Namun pada sinyal analog, sedikit saja terkena distorsi atau noise, akan menyebabkan error pada sinyal yang diterima.
- Sinyal-sinyal analog dapat dikonversikan ke dalam bentuk digital terlebih dahulu sebelum ditransmisikan.
- Bentuk digital yang bisa dibawa dalam proses pengiriman sinyal adalah bentuk dua simbol (representasi biner)

Komunikasi Digital vs Analog …3

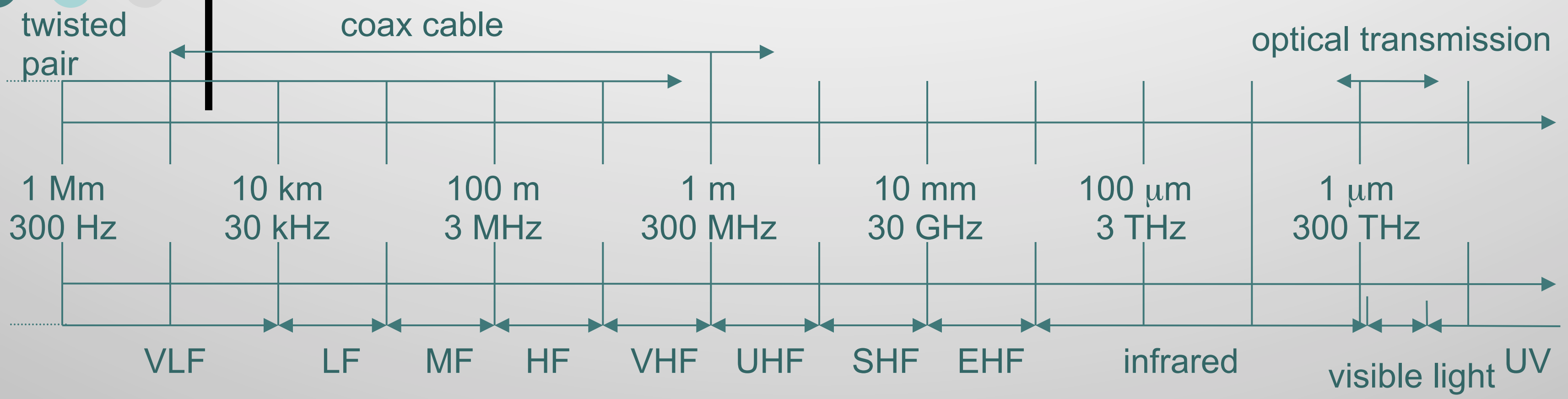
Konversi A/D dan D/A

- Teori Sampling: Mengambil sampel dari sinyall analog kontinyu untuk diberikan nilai tertentu.
  - Teori Sampling Shannon mengatakan bahwa frekuensi pengambilan sampel (sampling) sebuah sinyal tidak kurang dari 2 f_i (f_i=frekuensi dari sinyal informasi)
- Kuantisasi: Proses pemberian nilai kepada sampel sinyal dengan pendekatan kepada level-level tertentu.
- Coding:
  - **Source Coding**: Mengkonversikan bentuk kuantisasi sinyal menjadi urutan digital
  - **Channel Coding**: Mengatur redundansi sinyal dengan cara tertentu untuk menekan noise dan interferensi

Komunikasi Digital vs Analog …4



Spectrum Allocation



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

Relationship between frequency 'f' and wave length 'λ':

$$\lambda = c/f$$

where c is the speed of light $\cong 3 \times 10^8$ m/s

Frequencies Allocated for Mobile Communication

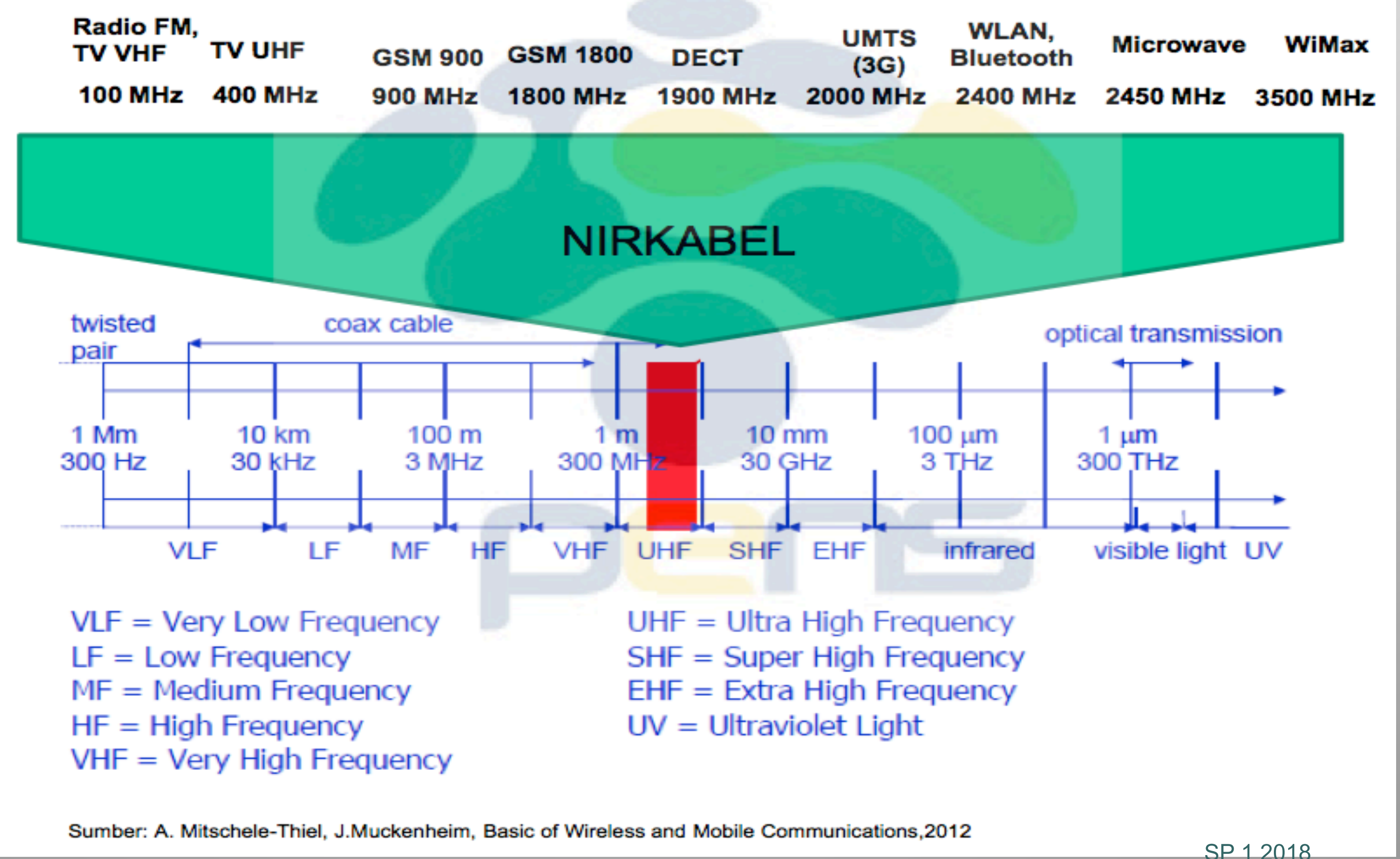
- VHF & UHF ranges for mobile radio
  - allows for simple, small antennas for cars
  - deterministic propagation characteristics
  - less subject to weather conditions –> more reliable connections
- SHF and higher for directed radio links, satellite communication
  - small antennas with directed transmission
  - large bandwidths 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
    - weather dependent fading, signal loss caused by heavy rainfall, etc.

Allocated Frequencies

- ITU-R holds auctions for new frequencies, manages frequency bands worldwide for harmonious usage (WRC - World Radio Conferences)

	Europe	USA	Japan
Mobile phones	**NMT** 453-457MHz, 463-467 MHz; **GSM** 890-915 MHz, 935-960 MHz; 1710-1785 MHz, 1805-1880 MHz	**AMPS**, **TDMA**, **CDMA** 824-849 MHz, 869-894 MHz; **TDMA**, **CDMA**, **GSM** 1850-1910 MHz, 1930-1990 MHz;	**PDC** 810-826 MHz, 940-956 MHz; 1429-1465 MHz, 1477-1513 MHz
Cordless telephones	**CT1+** 885-887 MHz, 930-932 MHz; **CT2** 864-868 MHz **DECT** 1880-1900 MHz	**PACS** 1850-1910 MHz, 1930-1990 MHz **PACS-UB** 1910-1930 MHz	**PHS** 1895-1918 MHz **JCT** 254-380 MHz
Wireless LANs	**IEEE 802.11** 2400-2483 MHz **HIPERLAN 1** 5176-5270 MHz	**IEEE 802.11** 2400-2483 MHz	**IEEE 802.11** 2471-2497 MHz

Spektrum Frekuensi Nirkabel



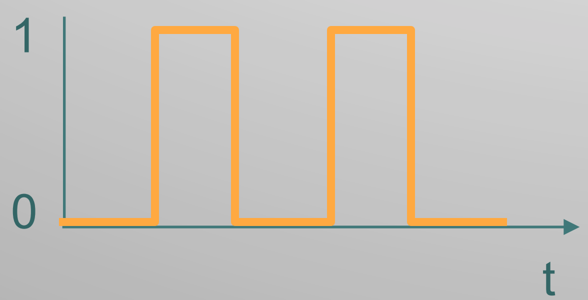
Signals

- 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:

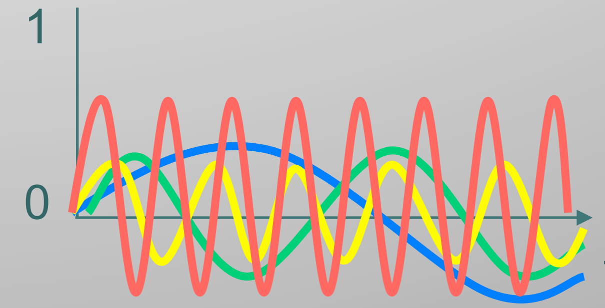
$$s(t) = A_t \sin(2 \pi f_t t + \varphi_t)$$

Fourier Representation of Periodic Signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$



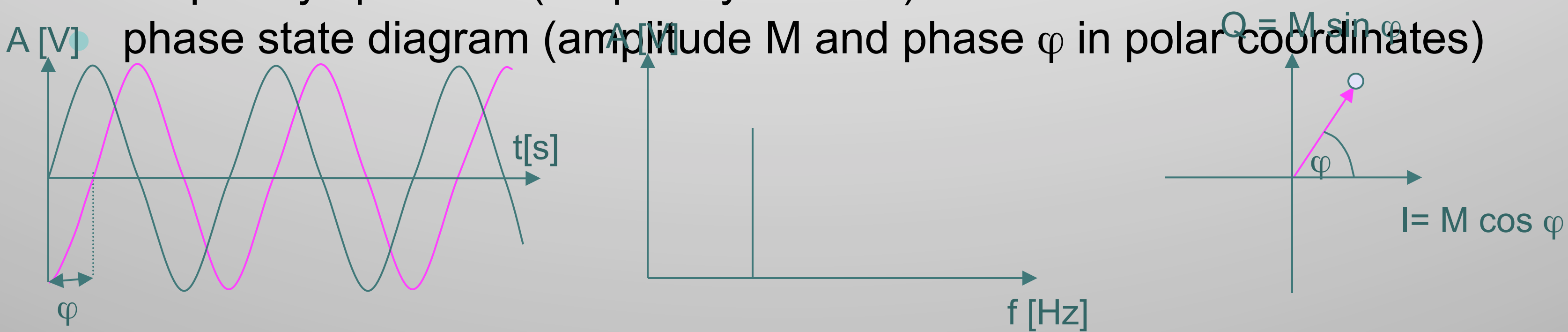
ideal periodic signal



real composition
(based on harmonics)

Signals

- Different representations of signals
  - amplitude (amplitude domain)
  - frequency spectrum (frequency domain)
  - phase state diagram (amplitude M and phase φ in polar coordinates)



- Composite signals mapped into frequency domain using Fourier transformation
- Digital signals need
  - infinite frequencies for perfect representation
  - modulation with a carrier frequency for transmission (->analog signal!)

Antennas

- Antennas are used to radiate and receive EM waves (energy)
- Antennas link this energy between the *ether* and a device such as a transmission line (e.g., coaxial cable)
- Antennas consist of one or several radiating elements through which an electric current circulates
- Types of antennas:
  - omnidirectional
  - directional
  - phased arrays
  - adaptive
  - optimal
- Principal characteristics used to characterize an antenna are:
  - radiation pattern
  - directivity
  - gain
  - efficiency

Antena

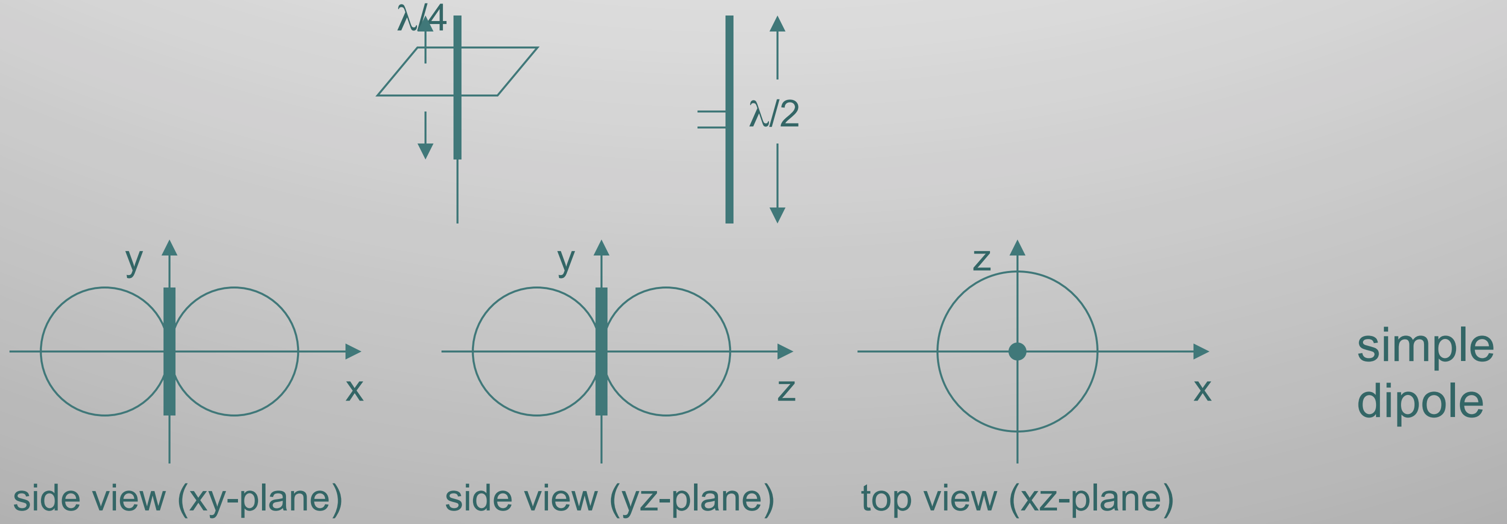
Antena tidak hanya untuk menambah penguatan pada sambungan wireless, antena juga mampu meningkatkan arah penangkapan sinyal dan menolak noise yang ada disekitar lintasan. Antena juga berfungsi untuk memindahkan energi gelombang elektromagnetik dari media kabel ke udara atau sebaliknya dari udara ke media kabel.

Antena RF

Antena RF adalah peralatan yang digunakan untuk menkonversikan sinyal frekuensi tinggi (RF) pada garis transmisi (kabel atau waveguide) ke gelombang siaran di udara. Medan elektrik dipancarkan dari antena yang disebut beams atau lobes.

Omnidirectional Antennas: simple dipoles

Real antennas are not isotropic radiators but, e.g., dipoles with lengths $\lambda/4$, or Hertzian dipole: $\lambda/2$ (2 dipoles)
➔ shape/size of antenna proportional to wavelength

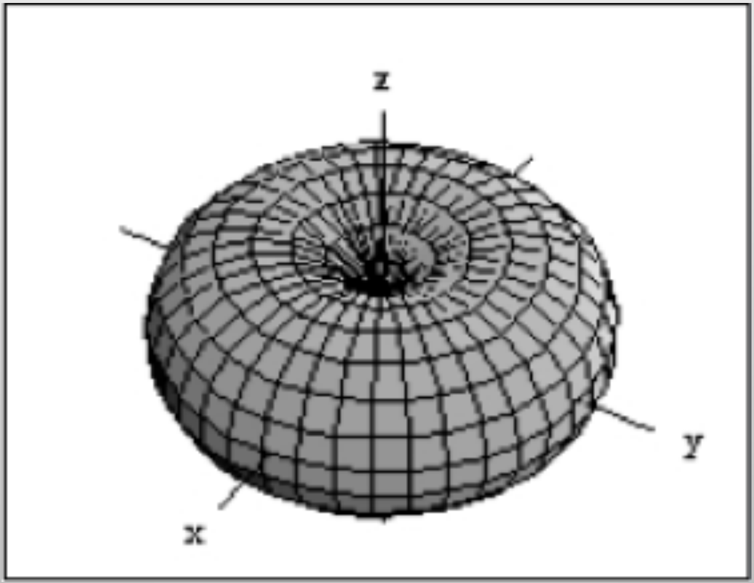


- Example: Radiation pattern of a simple Hertzian dipole
- Gain: ratio of the maximum power in the direction of the main lobe to the power of an isotropic radiator (with the same average power)

a. Antena Omni-Directional (Dipole)

Antena wireless LAN yang paling umum adalah antena dipole. Antena dipole merupakan peralatan standar pada kebanyakan access point dengan desain yang sederhana. Dipole adalah antena omni-directional, hal ini dikarenakan energi akan dipancarkan secara bersamaan pada semua arah sekitar porosnya.

Energi Radiasi Dipole

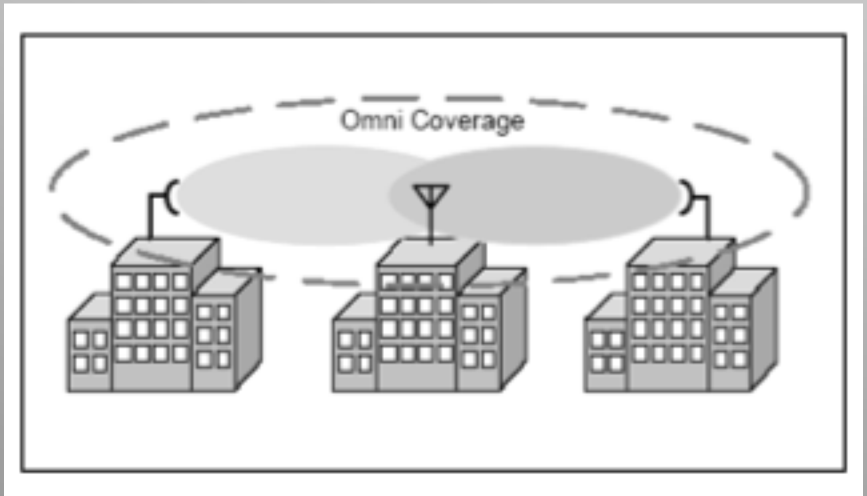


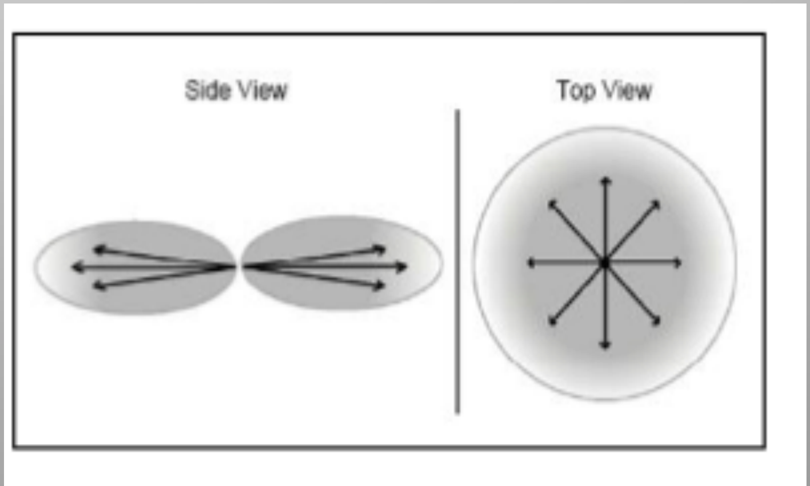
Gambar diatas menunjukkan bahwa energi radiasi *dipole* dipusatkan pada daerah yang tampak seperti sebuah donat, dengan *dipole* secara *vertical* melalui “lubang” dari “donat”. Sinyal dari antena *omni-directional* memancar dalam 360 derajat horizontal *beam*. Antena yang memiliki arah pancaran pada semua arah secara bersamaan (membentuk sebuah bulatan), ini disebut radiator *isotropic*.

a. Antena Omni-Directional (cont.)

Antena *omni-directional* digunakan ketika melingkupi semua arah sekitar poros horizontal dari antena dibutuhkan. Antena *omni-directional* sangat efektif dimana jangkauan besar dibutuhkan di sekitar titik pusat. Sebagai contohnya, menempatkan antena *omni-directional* di tengan-tengah sebuah ruangan terbuka dan besar akan melengkapi lingkungan yang bagus. Antena omni-directional umumnya digunakan untuk desain point-to-multipointdengan bentuk bintang

(lihat gambar).



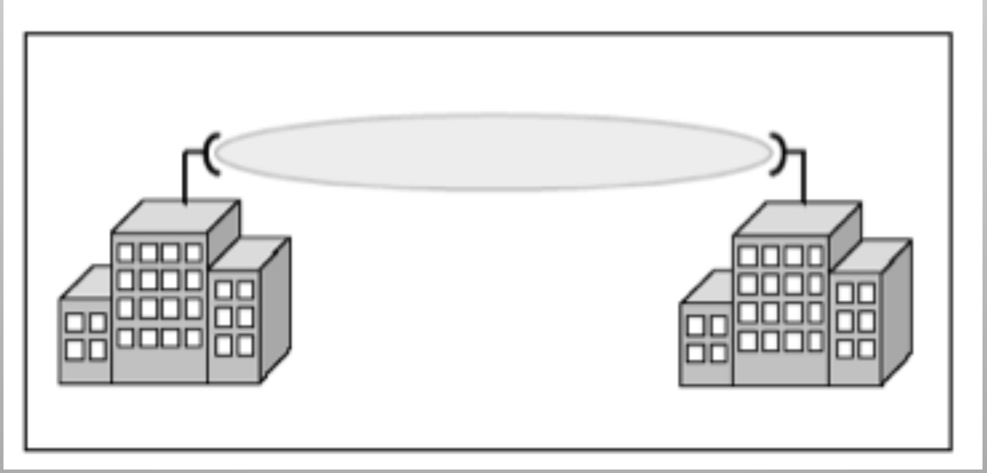


b. Antena Semi-directional….1

Antena semi-directional terdiri dari bermacam-macam bentuk dan jenis. Beberapa tipe antena semi-directional yang sering digunakan bersama wireless LAN adalah antena Patch, Panel dan Yagi (dibaca “YAH-gee”). Semua antena tersebut umumnya berbentuk datar dan dirancang untuk dinding gunung.

b. Antena Semi-directional….2

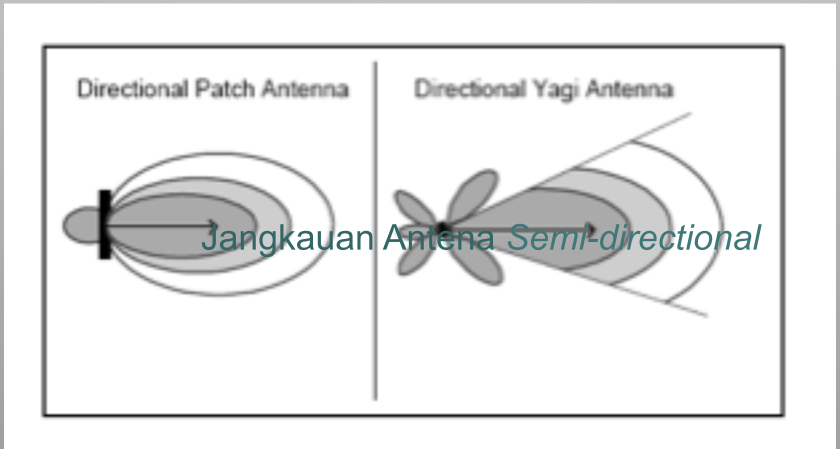
Antena semi-*directional* idealnya cocok untuk jembatan dengan jarak pendek atau rata-rata. Sebagai contoh, dua bangunan kantor yang berseberangan jalan satu sama lain dan perlu membagi koneksi jaringan akan menjadi skenario yang bagus untuk mengimplementasikan antena *semi-directional*.



Hubungan point-to-multipoint menggunakan antena *semi-directional*

Jangkauan Antena semi-directional

Antena tersebut merubah energi dari pemancar lebih ke satu arah khusus dari pada ke arah yang sama. Antena semi-directional sering memancarkan pada bentuk hemispherical atau pola lingkup silinder seperti bisa dilihat pada gambar



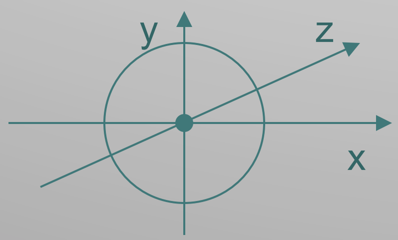
Jangkauan Antena *Semi-directional*

Line Of Sight (LOS)

Microwave radiolink atau sistem transmisi radio gelombang mikro adalah suatu sistem transmisi dengan menggunakan gelombang radio di atas frekuensi 1 GHz. Suatu sistem transmisi radio gelombang mikro dapat berupa sebuah hop atau sebuah backbone yang berupa multiple hop dengan jarak sampai ratusan atau ribuan kilometer. Secara garis besar tujuan dari sistem komunikasi radio gelombang mikro adalah untuk mentransmisikan informasi dari satu tempat ke tempat lain tanpa gangguan. Ketinggian antena diperlukan pada transmisi microwave untuk memenuhi syarat line-of-sight. Tinggi minimum saluran radio harus diperhitungkan terhadap rata-rata ketinggian permukaan laut (mean sea level), hal ini dikarenakan tinggi minimum saluran tersebut sangat dipengaruhi oleh tinggi penghalang dan kontur permukaan bumi yang dilaluinya

Isotropic Antennas

- Isotropic radiator: equal radiation in all directions (three dimensional) - only a theoretical reference antenna
- Real antennas always have directive effects (vertical and/or horizontal)
- Radiation pattern: measurement of radiation around an antenna



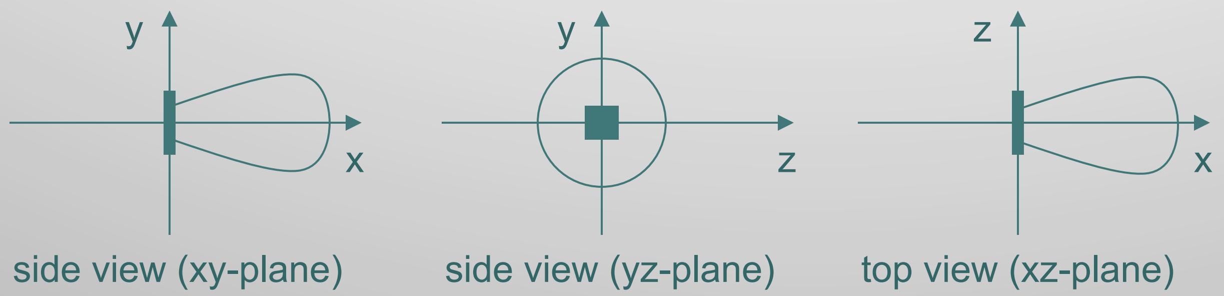
ideal isotropic radiator

Directivity

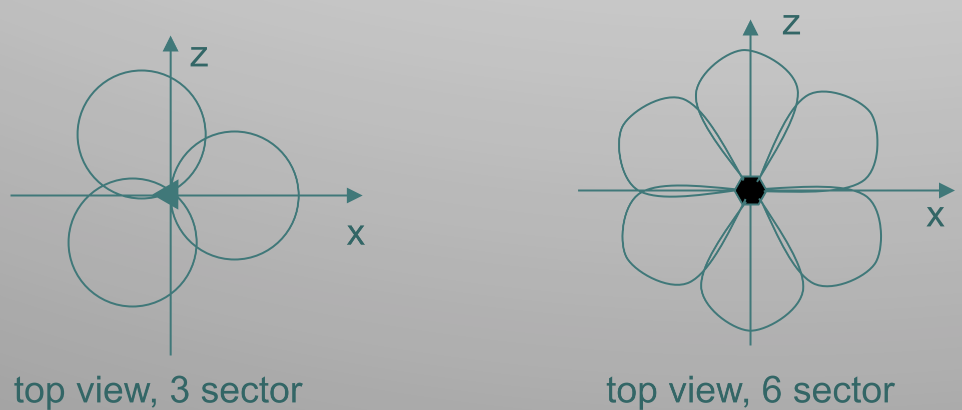
Directivity adalah kemampuan antena untuk memusatkan energi di arah yang tertentu sewaktu memancarkan, atau untuk menerima energi dari arah yang tertentu sewaktu menerima. Jika sebuah sambungan nirkabel menggunakan lokasi tetap untuk kedua sisi, maka sangat memungkinkan untuk menggunakan antena directivity untuk memusatkan sorotan radiasi di arah yang diinginkan. Pada aplikasi mobile yang bisa berpindah-pindah di mana transceiver tidak tetap, mungkin mustahil untuk meramalkan di mana transceiver akan berada, dan oleh sebab itu antena secara ideal sebaiknya menyebar secara sebaik-baiknya ke segala arah. Antena Omnidirectional dipakai dalam aplikasi ini.

Directional Antennas

Often used for microwave connections (directed point to point transmission) or base stations for mobile phones (e.g., radio coverage of a valley or sectors for frequency reuse)



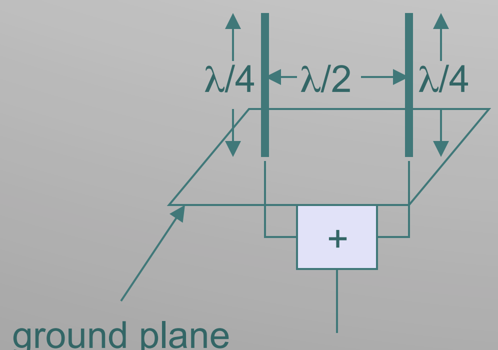
directed antenna

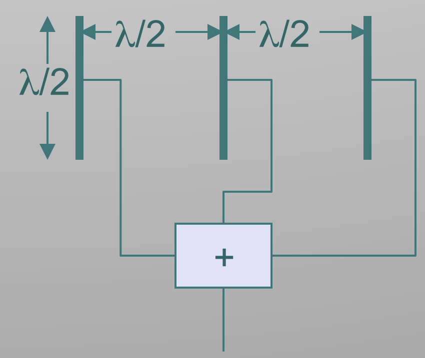


sectorized antenna

Array Antennas

- Grouping of 2 or more antennas to obtain radiating characteristics that cannot be obtained from a single element
- Antenna diversity
  - switched diversity, selection diversity
    - receiver chooses antenna with largest output
  - diversity combining
    - combine output power to produce gain
    - cophasing needed to avoid cancellation



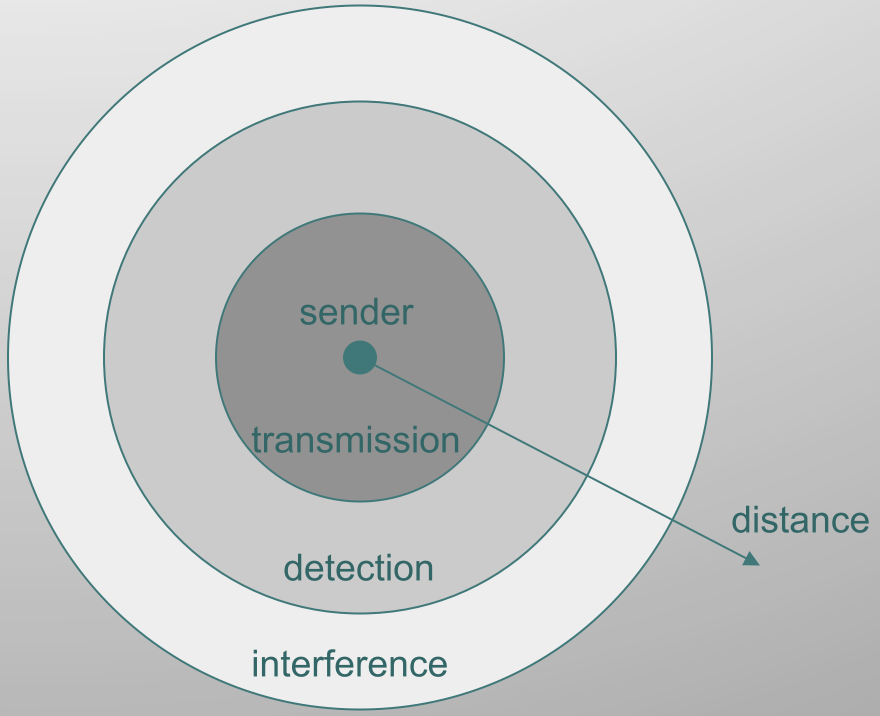


Gain

Gain (Penguatan) bukanlah kuantitas yang bisa didefinisikan dalam bentuk fisik seperti Watt atau Ohm, tetapi Gain adalah rasio yang tidak berdimensi. Gain diberikan sesuai dengan rujukan kepada antena standar. Dua antena yang biasanya digunakan sebagai rujukan adalah antena isotropic dan antena dipole setengah gelombang.

Signal Propagation Ranges

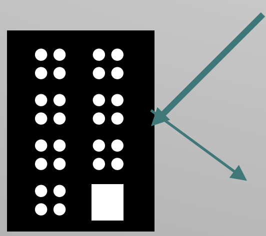
- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible, high error rate
- Interference range
  - signal may not be detected
  - signal adds to the background noise



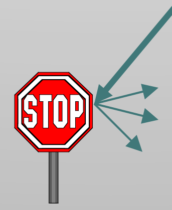
Signal Propagation….1

Radio wave propagation is affected by the following mechanisms:

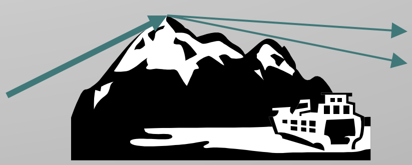
- reflection at large obstacles
- scattering at small obstacles
- diffraction at edges



reflection



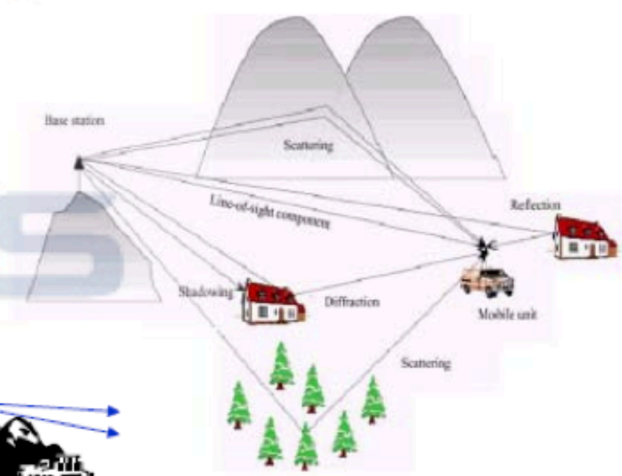
scattering

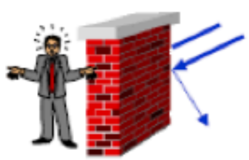


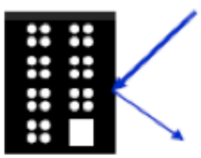
diffraction

Propagasi Radio

- Propagasi sinyal pada ruang bebas bersifat seperti cahaya (lurus, line of sight)
- Daya yang diterima di sisi receiver sebanding dengan:
  - $1/d^2$ (ideal)
  - $1/d^{\alpha}$ (α=3,4,..) → d=jarak antara Tx dan Rx
- Daya yang diterima dipengaruhi oleh:
  - Fading (bergantung frekuensi)
  - Shadowing
  - Refleksi (pada penghalang lebar)
  - Scatering (pada penghalang kecil)
  - Difraksi (tepi penghalang)




shadowing


reflection

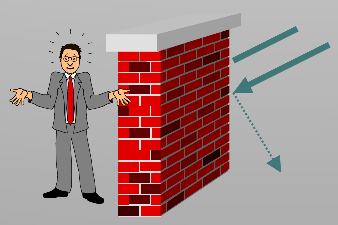
scattering


diffraction

Signal Propagation….2

The signal is also subject to degradation resulting from propagation in the mobile radio environment. The principal phenomena are:

- pathloss due to distance covered by radio signal (frequency dependent, less at low frequencies)
- fading (frequency dependent, related to multipath propagation)
- shadowing induced by obstacles in the path between the transmitted and the receiver



shadowing

Signal Propagation….3

- Interference from other sources and noise will also impact signal behavior:
  - co-channel (mobile users in adjacent cells using same frequency) and adjacent (mobile users using frequencies adjacent to transmission/reception frequency) channel interference
  - ambient noise from the radio transmitter components or other electronic devices,
- Propagation characteristics differ with the environment through and over which radio waves travel. Several types of environments can be identified (dense urban, urban, suburban and rural) and are classified according to the following parameters:
  - terrain morphology
  - vegetation density
  - buildings: density and height
  - open areas
  - water surfaces

Pathloss….1

Free-space pathloss:

To define free-space propagation, consider an isotropic source consisting of a transmitter with a power P_t W. At a distance ‘d’ from this source, the power transmitted is spread uniformly on the surface of a sphere of radius ‘d’. The power density at the distance ‘d’ is then as follows:

$$S_r = P_t/4\pi d^2$$

- The power received by an antenna at a distance ‘d’ from the transmitter is then equal to:

$$P_r = P_t A_e/4\pi d^2$$

where A_e is the effective area of the antenna.

Pathloss…..2

- Noting that $A_e = G_r/(4\pi/\lambda^2)$
  where G_r is the gain of the receiver
- And if we replace the isotropic source by a transmitting antenna with a gain G_t the power received at a distance 'd' of the transmitter by a receiving antenna of gain G_r becomes:

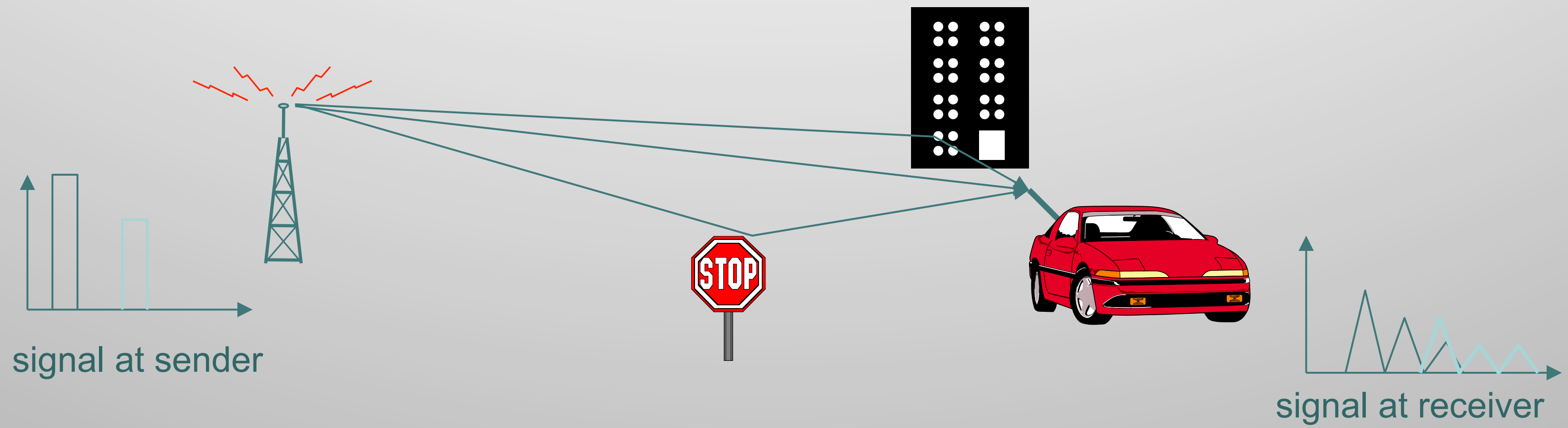
$$P_r = P_t G_r G_t/[4\pi(d/\lambda)]^2$$

- In decibels the propagation pathloss (PL) is given by:

$$PL(db) = -10\log_{10}(Pr/Pt) = -10\log_{10}(G_r G_t/[4\pi(d/\lambda)]^2)$$

- This is for the ideal case and can only be applied sensibly to satellite systems and short range LOS propagation.

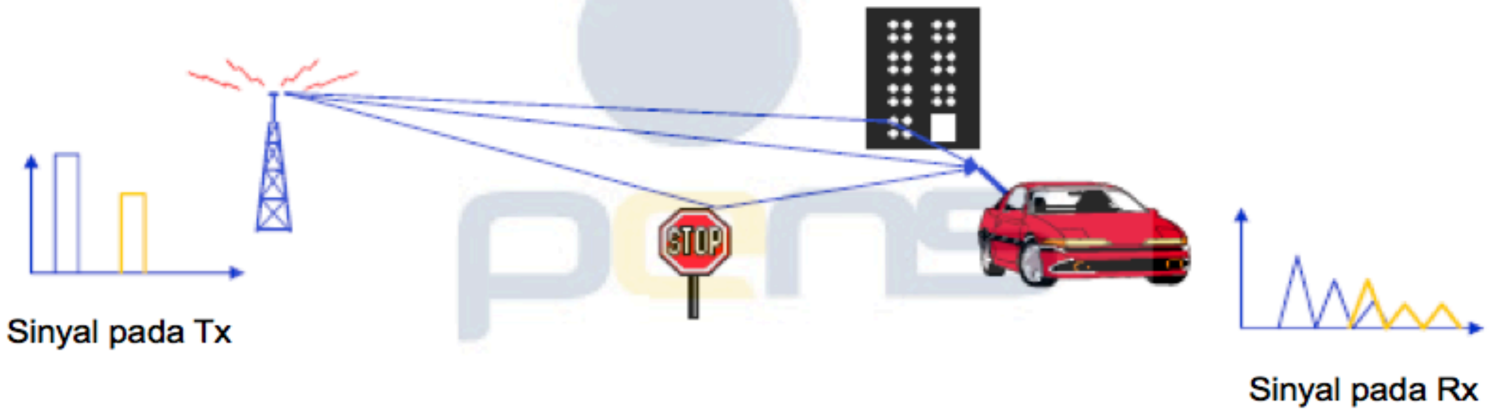
Multipath Propagation….1



- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction
- Positive effects of multipath:
  - enables communication even when transmitter and receiver are not in LOS conditions - allows radio waves effectively to go *through* obstacles by getting around them thereby increasing the radio coverage area

Multipath Propagation…..2

- *Propagasi Multipath*: Sinyal dapat berubah bentuk dan lintasan disebabkan adanya refleksi (pantulan), scatering (sebaran) dan difraksi (hamburan)



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Multipath Propagation….3

- Negative effects of multipath:
  - Time dispersion or delay spread: signal is dispersed over time due signals coming over different paths of different lengths

    ➔ Causes interference with "neighboring" symbols, this is referred to as Inter Symbol Interference (ISI)

    multipath spread (in secs) = (longest$_1$ – shortest$_2$)/c

    For a 5μs symbol duration a 1μs delay spread means about a 20% intersymbol overlap.
  - The signal reaches a receiver directly and phase shifted (due to reflections)

    ➔ Distorted signal depending on the phases of the different parts, this is referred to as Rayleigh fading, due to the distribution of the fades. It creates fast fluctuations of the received signal (fast fading).
  - Random frequency modulation due to Doppler shifts on the different paths. Doppler shift is caused by the relative velocity of the receiver to the transmitter, leads to a frequency variation of the received signal.

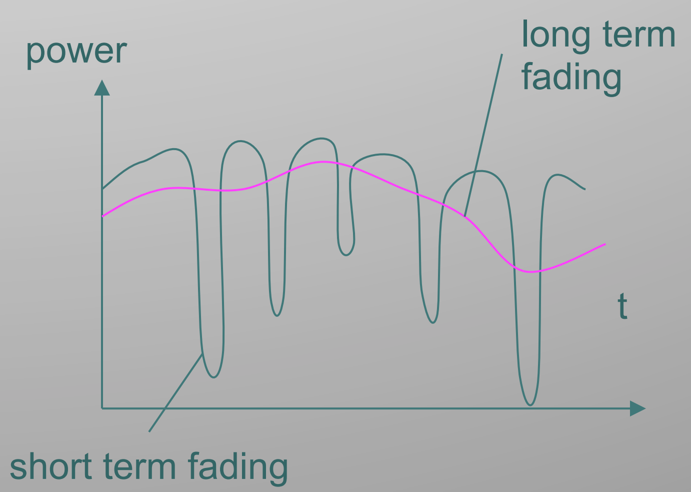
Effects of Mobility…..1

- 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

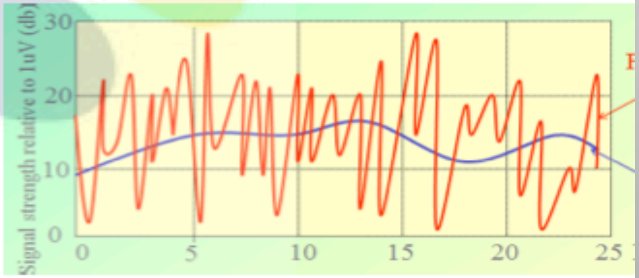
➔ slow changes in the average power received (long term fading)



Effects of Mobility…..1

Disebabkan adanya propagasi multipath (scatering, refleksi, difraksi)

1. **Slow /Long-term Fading:**
   – Disebut sebagai "shadowing". Perubahan sinyal dalam jangka waktu yang lama
   – Diukur pada jarak 1-2km
   – Biasanya disebabkan karena:
   – Kontur medan (bukit, area datar)
   – Kontur bangunan (antara pengirim dan penerima)



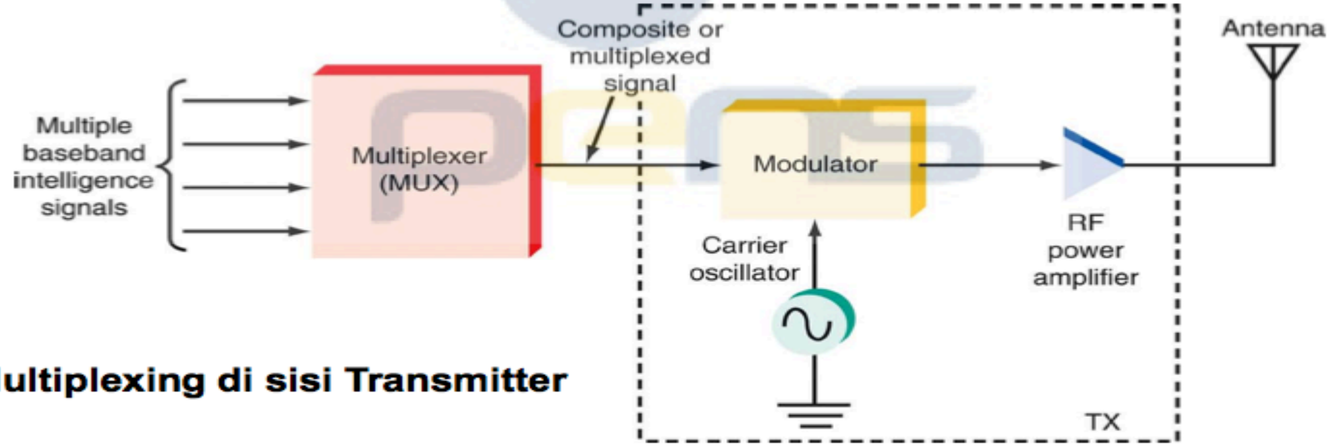
2. **Fast / Short-term Fading**
   – Perubahan sinyal dalam waktu cepat disebabkan karena obyek berpindah-pindah di sebuah lingkungan
   – Diukur di jarak = $\lambda/2$
   – Variasi sinyal hingga 30 dB

Multiplexing Techniques…..1

- Multiplexing techniques are used to allow many users to share a common transmission resource. In our case the users are mobile and the transmission resource is the radio spectrum. Sharing a common resource requires an access mechanism that will control the multiplexing mechanism.
- As in wireline systems, it is desirable to allow the simultaneous transmission of information between two users engaged in a connection. This is called duplexing.
- Two types of duplexing exist:
  - Frequency division duplexing (FDD), whereby two frequency channels are assigned to a connection, one channel for each direction of transmission.
  - Time division duplexing (TDD), whereby two time slots (closely placed in time for duplex effect) are assigned to a connection, one slot for each direction of transmission.

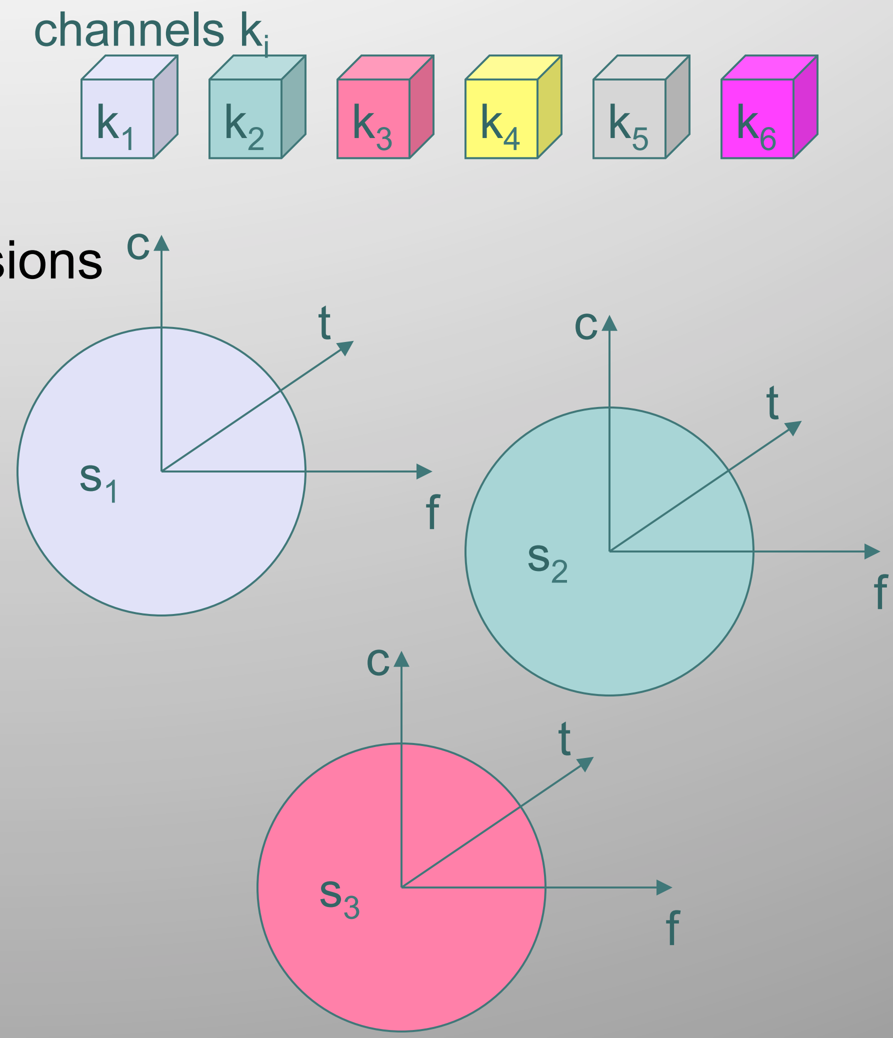
Multiplexing…..2

- Proses men-share media / kanal yang sama untuk dua atau lebih sinyal (termodulasi)
- Ada 3 jenis multiplexing:
  - Frequency Division Multiplexing
  - Time Division Multiplexing
  - Code Division Multiplexing



Tenik Multiplexing di sisi Transmitter

Multiplexing….3



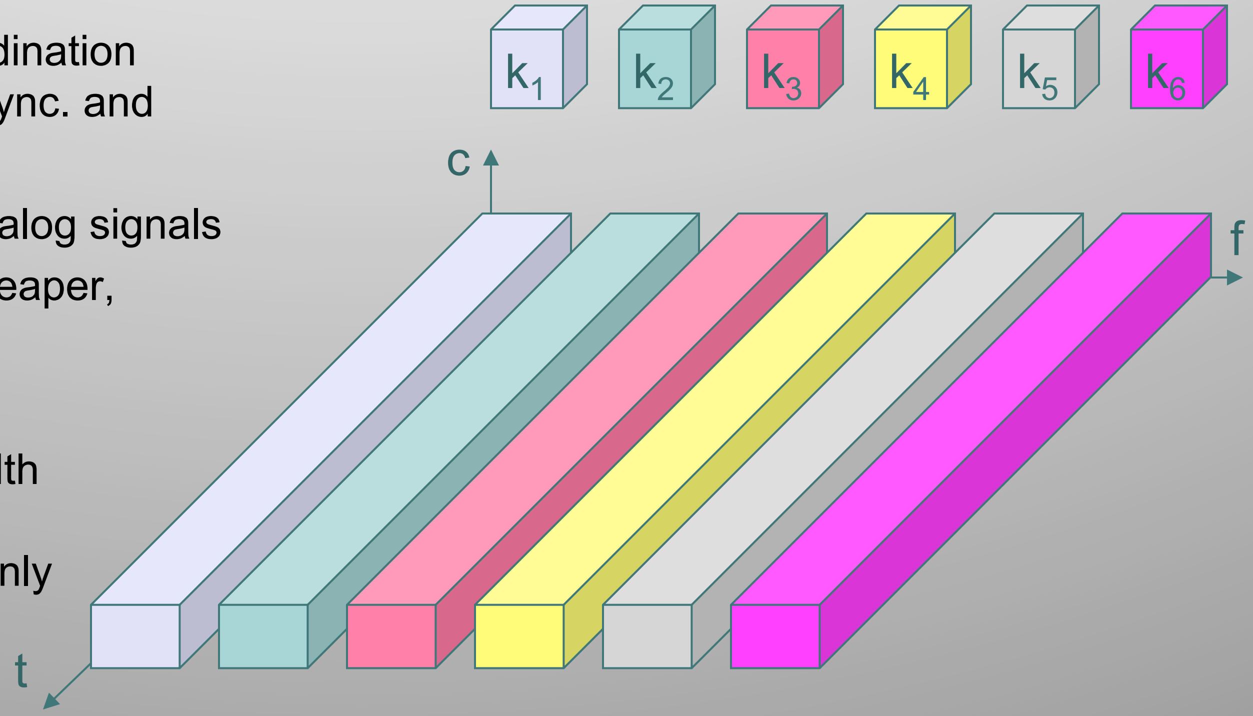
- Multiplexing in 3 dimensions
  - time (t) (TDM)
  - frequency (f) (FDM)
  - code (c) (CDM)
- Goal: multiple use of a shared medium

Narrowband versus Wideband

- These multiple access schemes can be grouped into two categories:
  - Narrowband systems - the total spectrum is divided into a large number of narrow radio bands that are shared.
  - Wideband systems - the total spectrum is used by each mobile unit for both directions of transmission. Only applicable for TDM and CDM.

Frequency Division Multiplexing (FDM)

- Separation of the whole spectrum into smaller frequency bands
- A channel gets a certain band of the spectrum for the whole time – orthogonal system
- Advantages:
  - no dynamic coordination necessary, i.e., sync. and framing
  - works also for analog signals
  - low bit rates – cheaper, delay spread
- Disadvantages:
  - waste of bandwidth if the traffic is distributed unevenly
  - inflexible
  - guard bands
  - narrow filters



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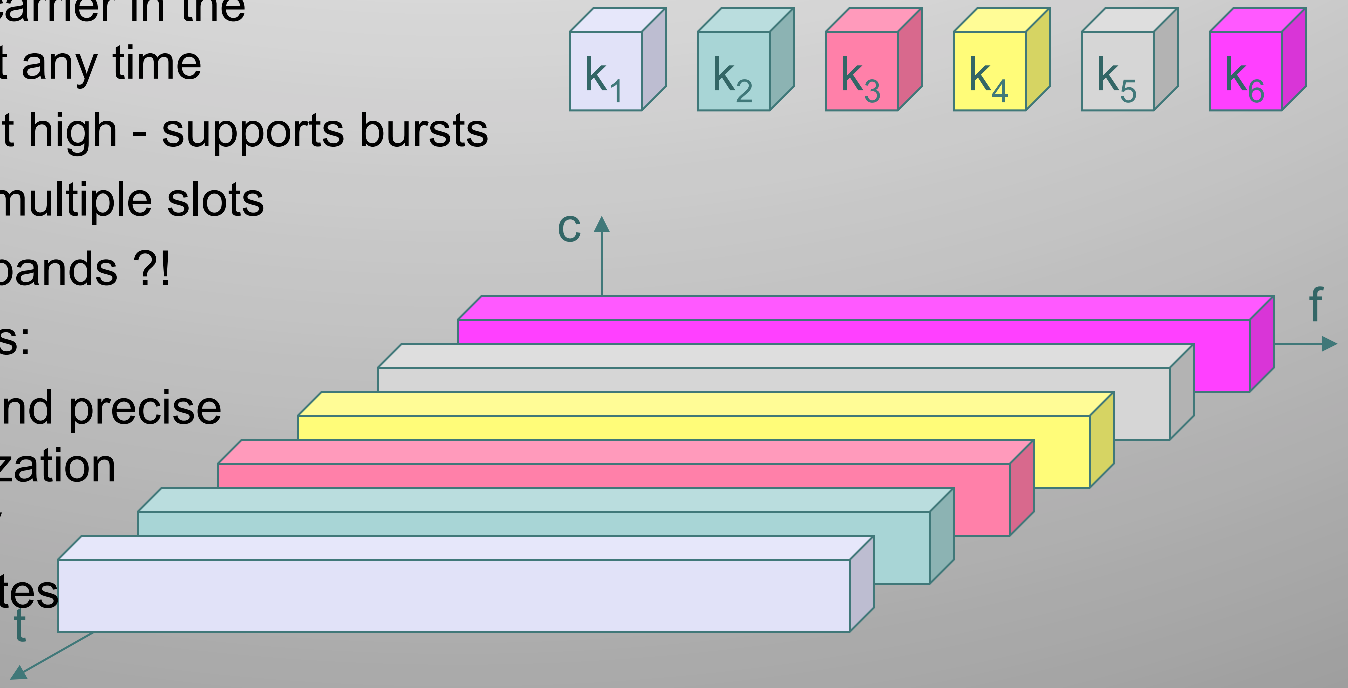
Time Division Multiplexing (TDM)

- A channel gets the whole spectrum for a certain amount of time – orthogonal system
- Advantages:
  - only one carrier in the medium at any time
  - throughput high - supports bursts
  - flexible – multiple slots
  - no guard bands ?!
- Disadvantages:
  - Framing and precise synchronization necessary
  - high bit rates at each Tx/Rx



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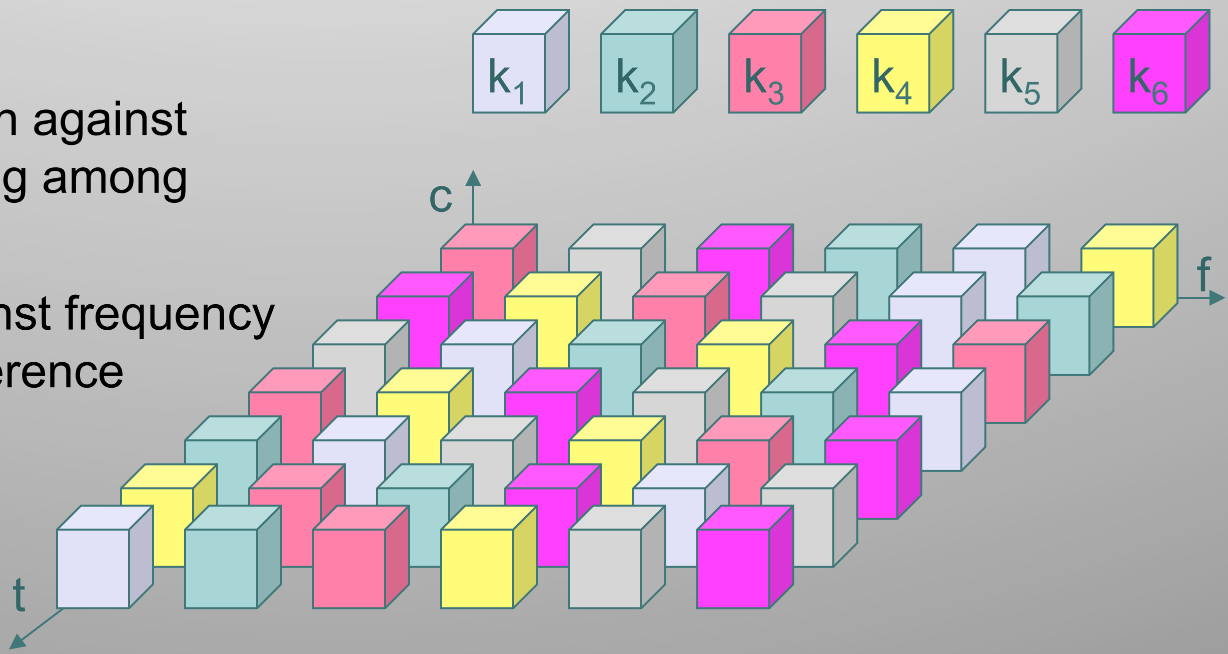
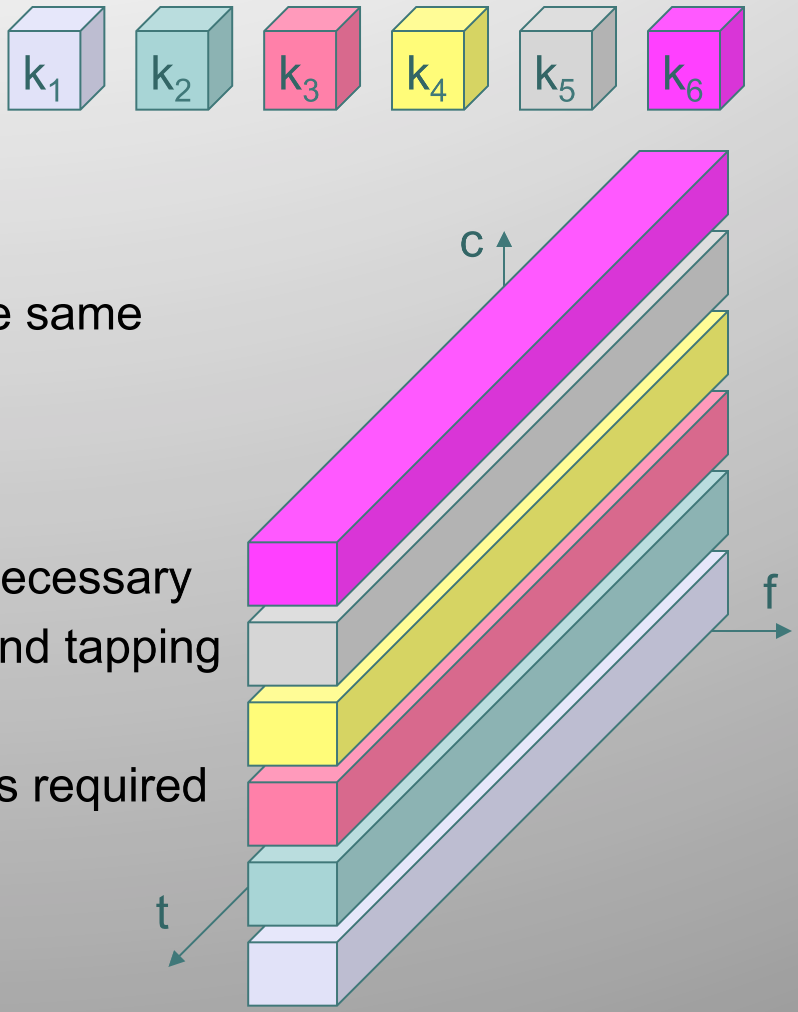
Hybrid TDM/FDM

- Combination of both methods
- A channel gets a certain frequency band for a certain amount of time (slot).
- Example: GSM, hops from one band to another each time slot
- Advantages:
  - better protection against tapping (hopping among frequencies)
  - protection against frequency selective interference
- Disadvantages:
  - Framing and sync. required



Code Division Multiplexing (CDM)



- Each channel has a unique code
  (not necessarily orthogonal)
- All channels use the same spectrum at the same time
- Advantages:
  - bandwidth efficient
  - no coordination and synchronization necessary
  - good protection against interference and tapping
- Disadvantages:
  - lower user data rates due to high gains required to reduce interference
  - more complex signal regeneration

Issues with CDM

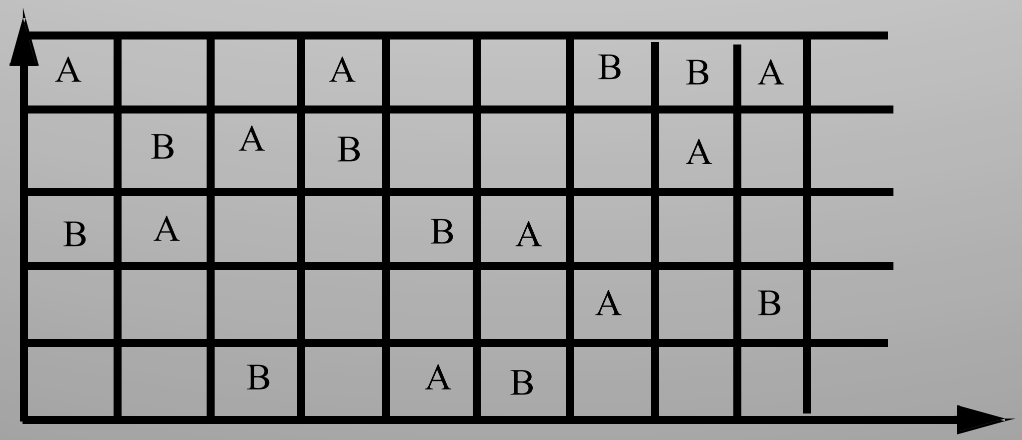
- CDM has a soft capacity. The more users the more codes that are used. However as more codes are used the signal to interference (S/I) ratio will drop and the bit error rate (BER) will go up for all users.
- CDM requires tight power control as it suffers from far-near effect. In other words, a user close to the base station transmitting with the same power as a user farther away will drown the latter's signal. All signals must have more or less equal power at the receiver.
- Rake receivers can be used to improve signal reception. Time delayed versions (a chip or more delayed) of the signal (multipath signals) can be collected and used to make bit level decisions.
- Soft handoffs can be used. Mobiles can switch base stations without switching carriers. Two base stations receive the mobile signal and the mobile is receiving from two base stations (one of the rake receivers is used to listen to other signals).
- Burst transmission - reduces interference

Types of CDM…..1

- Two types exist:
  - Direct Sequence CDM (DS-CDM)
    - spreads the narrowband user signal (Rbps) over the full spectrum by multiplying it by a very wide bandwidth signal (W). This is done by taking every bit in the user stream and replacing it with a pseudonoise (PN) code (a long bit sequence called the chip rate). The codes are orthogonal (or approx.. orthogonal).
    - This results in a processing gain G = W/R (chips/bit). The higher G the better the system performance as the lower the interference. G^2 indicates the number of possible codes. Not all of the codes are orthogonal.

Types of CDM…..2

- Frequency hopping CDM (FH-CDM)
  - FH-CDM is based on a narrowband FDM system in which an individual user's transmission is spread out over a number of channels over time (the channel choice is varied in a pseudorandom fashion). If the carrier is changed every symbol then it is referred to as a fast FH system, if it is changed every few symbols it is a slow FH system.



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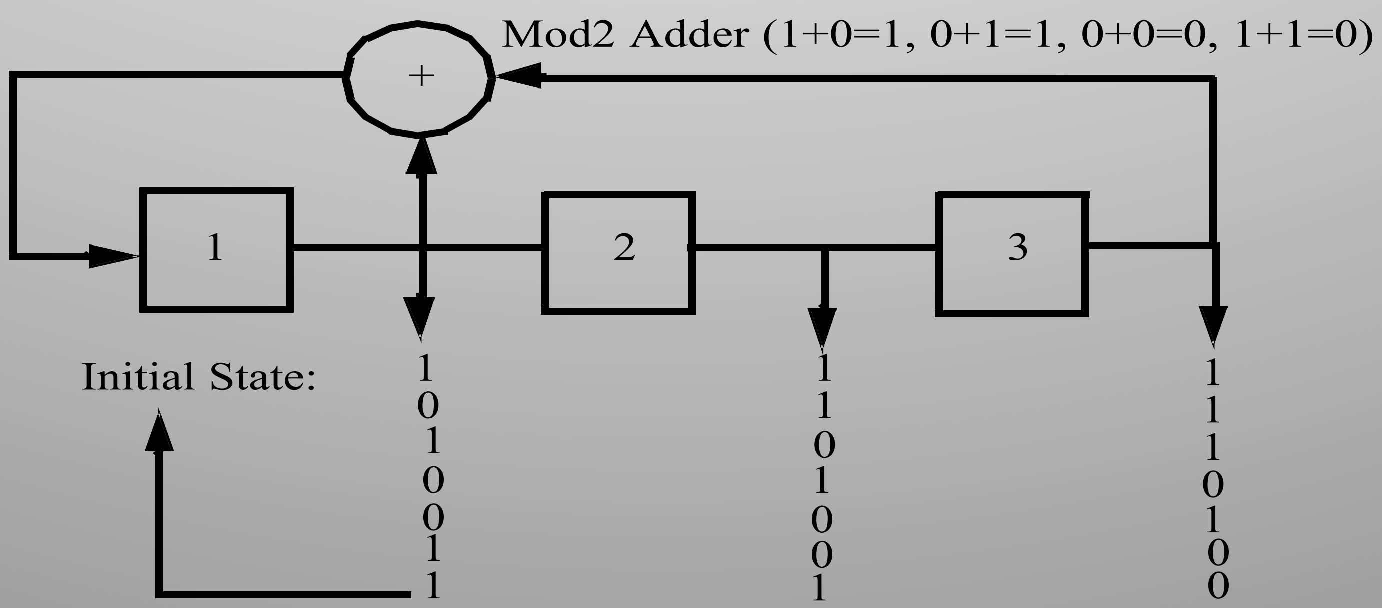
Orthogonality and Codes

- An m-bit PN generator generates $N=2^m - 1$ different codes.
- Out of these codes only 'm' codes are orthogonal -> zero cross correlation.
- For example a 3 bit shift register circuit shown below generates N=7 codes.



Orthogonal Codes

- A pair of codes is said to be orthogonal if the cross correlation is zero: $R_{xy}(0) = 0$.

- For two m-bit codes: $x_1,x_2,x_3,\ldots,x_m$ and $y_1,y_2,y_3,\ldots,y_m$:

For example: x = 0011 and y = 0110. Replace 0 with -1, 1 stays as is. Then:

$$x = -1\ -1\ \ 1\ \ 1$$

$$y = -1\ \ 1\ \ 1\ -1$$

$$R_{xy}(0) = 1 -1 +1 -1 = 0$$

Example of an Orthogonal Code: Walsh Codes

In 1923 J.L. Walsh introduced a complete set of orthogonal codes. To generate a Walsh code the following two steps must be followed:

- Step 1: represent a NxN matrix as four quadrants (start off with 2x2)
- Step 2: make the first, second and third quadrants indentical and invert the fourth

b	b	=	1	1	or	0	0	Code 1
b	b’		1	0		0	1	Code 2

2 codes: 11 and 10   2 codes: 00 and 01

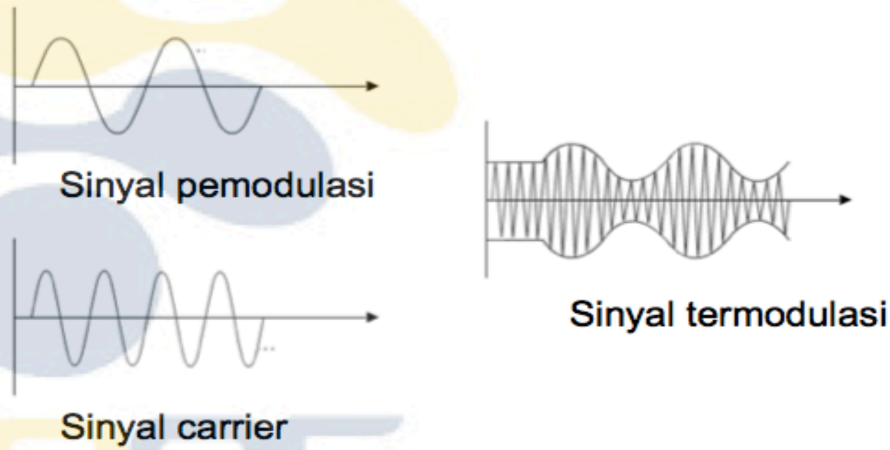
b b	b b	=	1 1	1 1	or	0 0	0 0	Code 1
b b’	b b’		1 0	1 0		0 1	0 1	Code 2
b b	b b		1 1	0 0		0 0	1 1	Code 3
b b’	b b’		1 0	0 1		0 1	1 0	Code 4

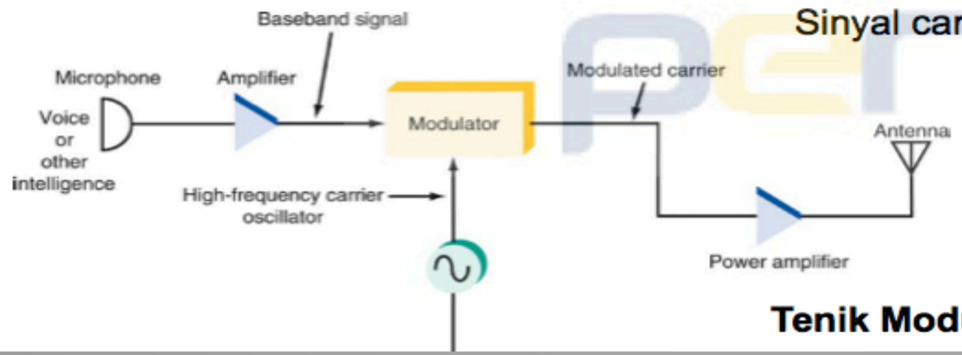
Modulation.....1

- Digital modulation
  - digital data is translated into an analog signal (baseband)
  - ASK, FSK, PSK - main focus in this chapter
  - 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…..2

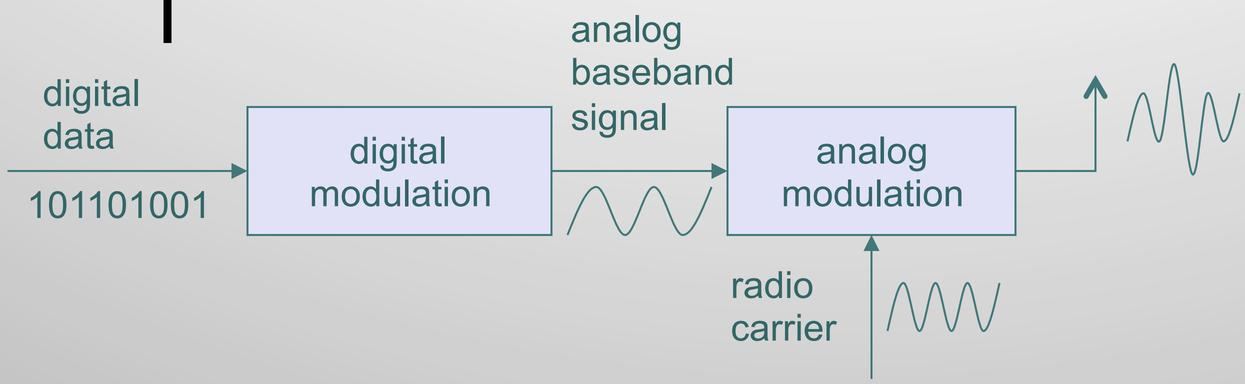
- Teknik menumpangkan sinyal informasi kepada sinyal carrier yang memiliki frekuensi lebih tinggi



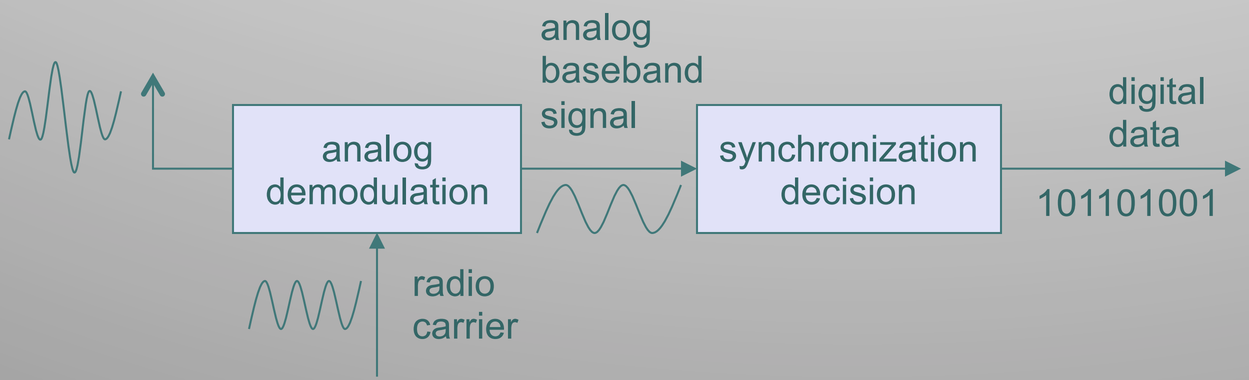


Tenik Modulasi di sisi Transmitter

Modulation and Demodulation



radio transmitter



radio receiver

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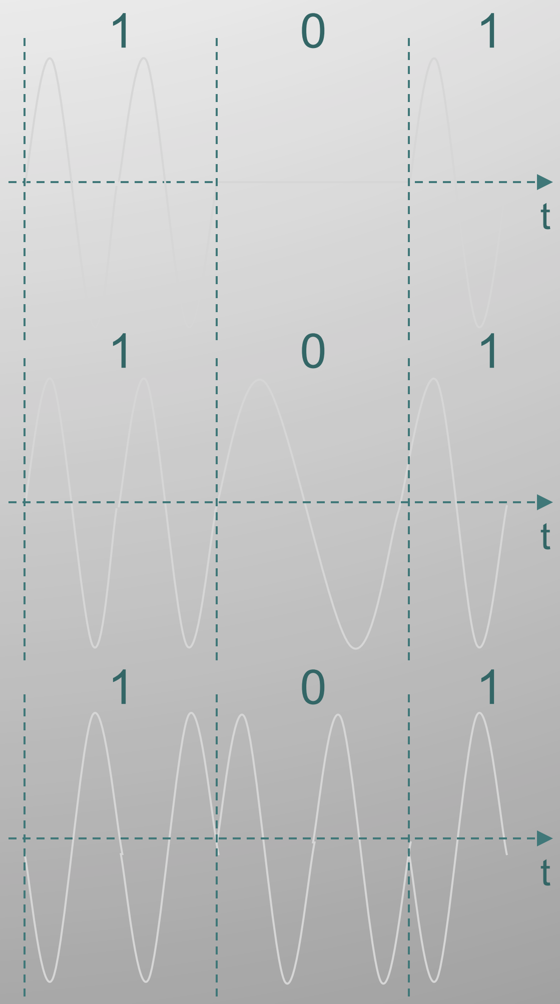
Digital Modulation

- 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



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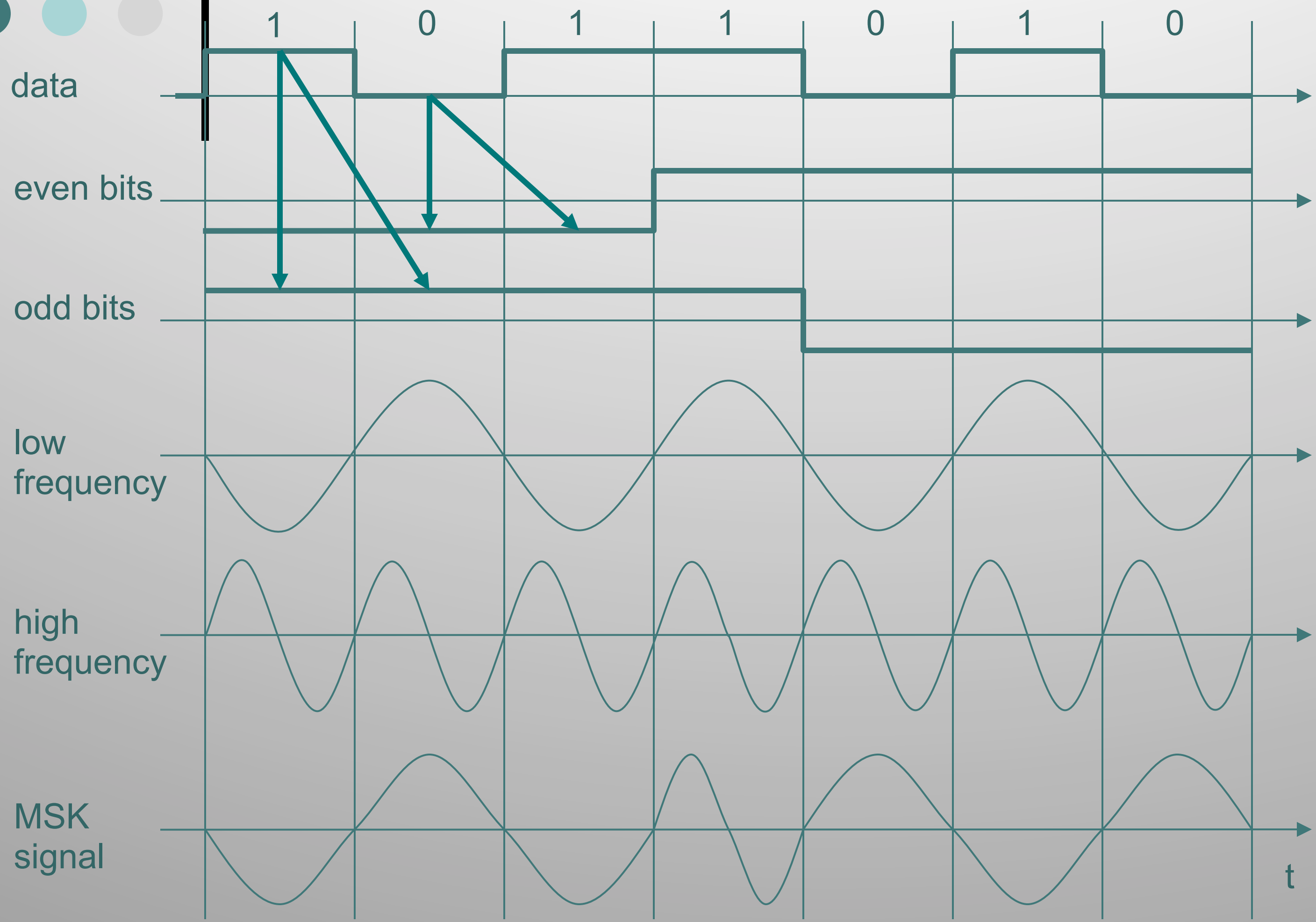
Advanced Frequency Shift Keying

- bandwidth needed for FSK depends on the distance between the carrier frequencies
- special pre-computation avoids sudden phase shifts
  ➔ MSK (Minimum Shift Keying)
- bit separated into even and odd bits, the duration of each bit is doubled
- depending on the bit values (even, odd) the higher or lower frequency, original or inverted is chosen
- the frequency of one carrier is twice the frequency of the other
- even higher bandwidth efficiency using a Gaussian low-pass filter
  ➔ GMSK (Gaussian MSK), used in GSM

Example of MSK



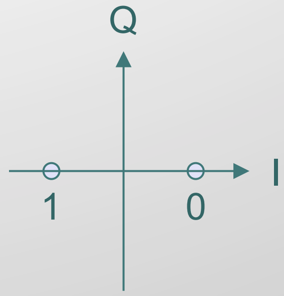
bit	
even	0 1 0 1
odd	0 0 1 1
signal value	h n n h - - + +

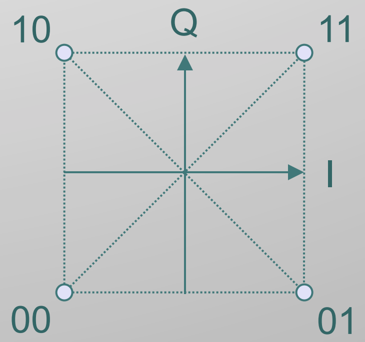
h: high frequency
n: low frequency
+: original signal
-: inverted signal

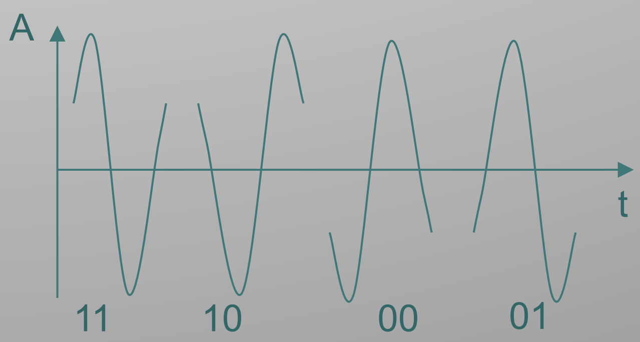
No phase shifts!

Advanced Phase Shift Keying

- BPSK (Binary Phase Shift Keying):
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - low spectral efficiency
  - robust, used e.g. in satellite systems
- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - symbol determines shift of sine wave
  - needs less bandwidth compared to BPSK
  - more complex
- Often also transmission of relative, not absolute phase shift: DQPSK - Differential QPSK (IS-136, PACS, PHS)

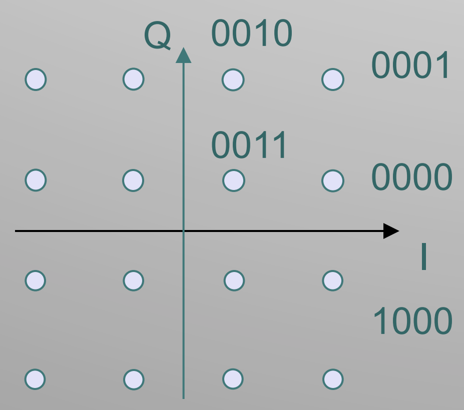






Quadrature Amplitude Modulation

- Quadrature Amplitude Modulation (QAM): combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK schemes



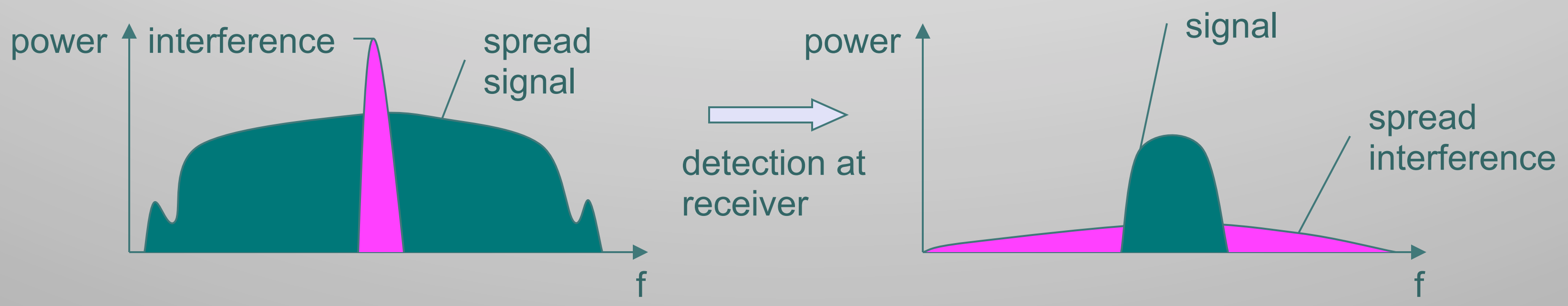
Example: 16-QAM (4 bits = 1 symbol)

Symbols 0011 and 0001 have the same phase, but different amplitude. 0000 and 1000 have different phase, but same amplitude.

➔ used in standard 9600 bit/s modems

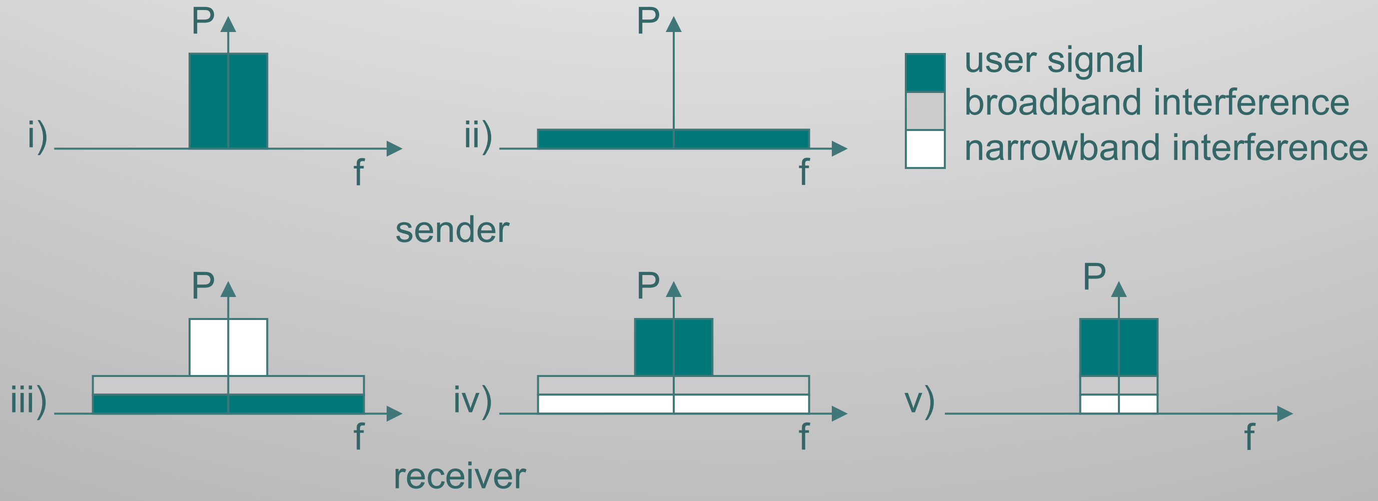
Spread spectrum technology: CDM

- Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference
- Solution: spread the narrow band signal into a broad band signal using a special code

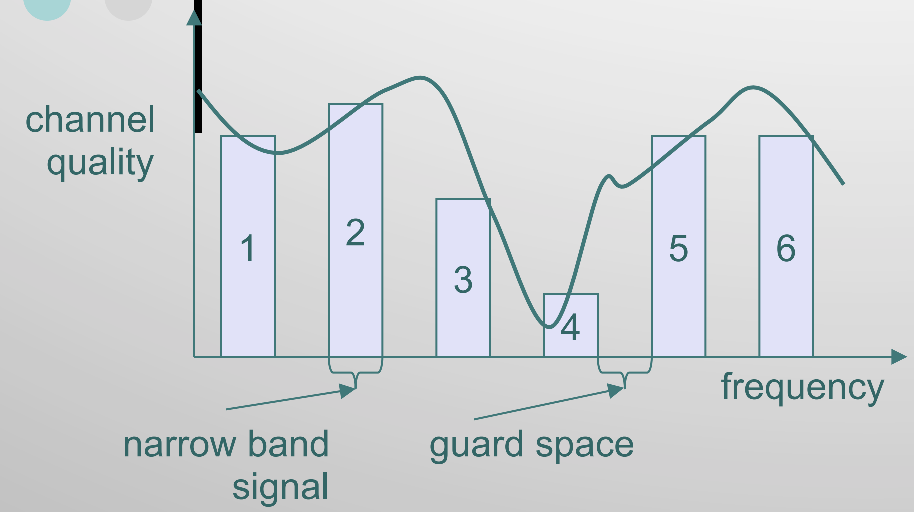


- Side effects:
  - coexistence of several signals without dynamic coordination
  - tap-proof
- Alternatives: Direct Sequence, Frequency Hopping

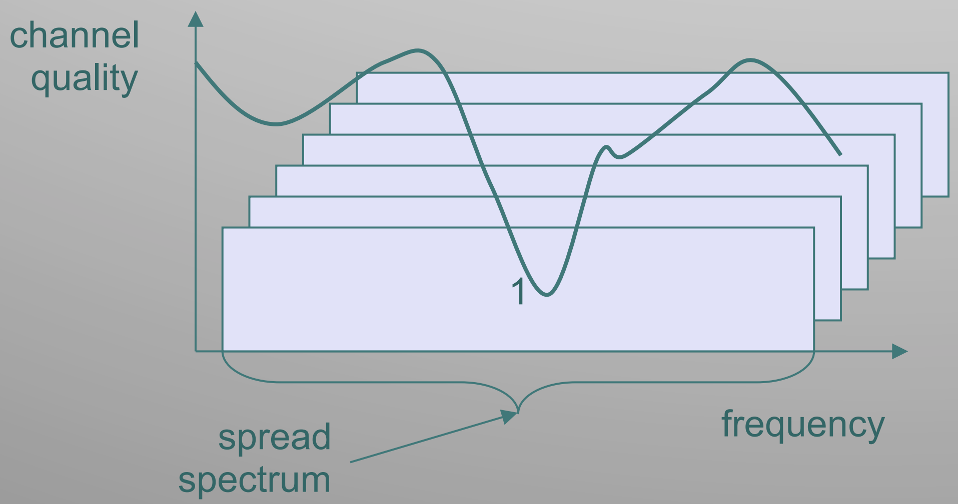
Effects of spreading and interference



Spreading and frequency selective fading



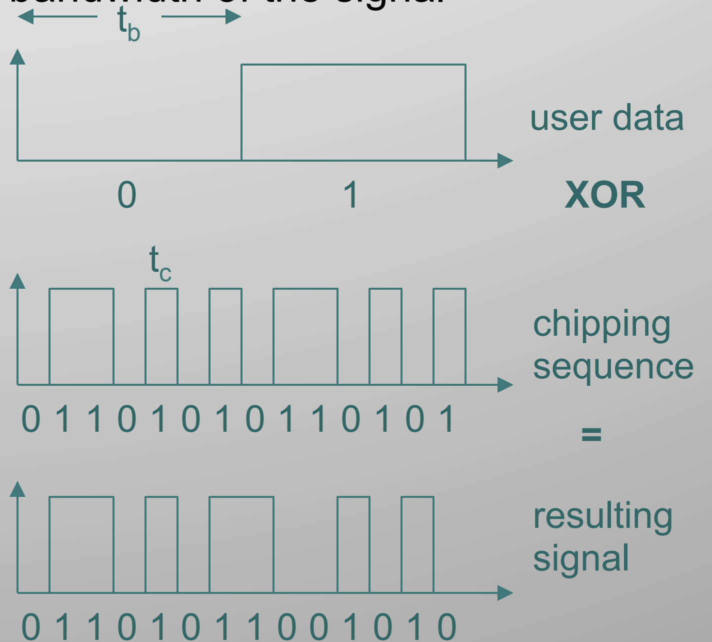
narrowband channels



spread spectrum channels

DSSS (Direct Sequence Spread Spectrum)….1

- 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

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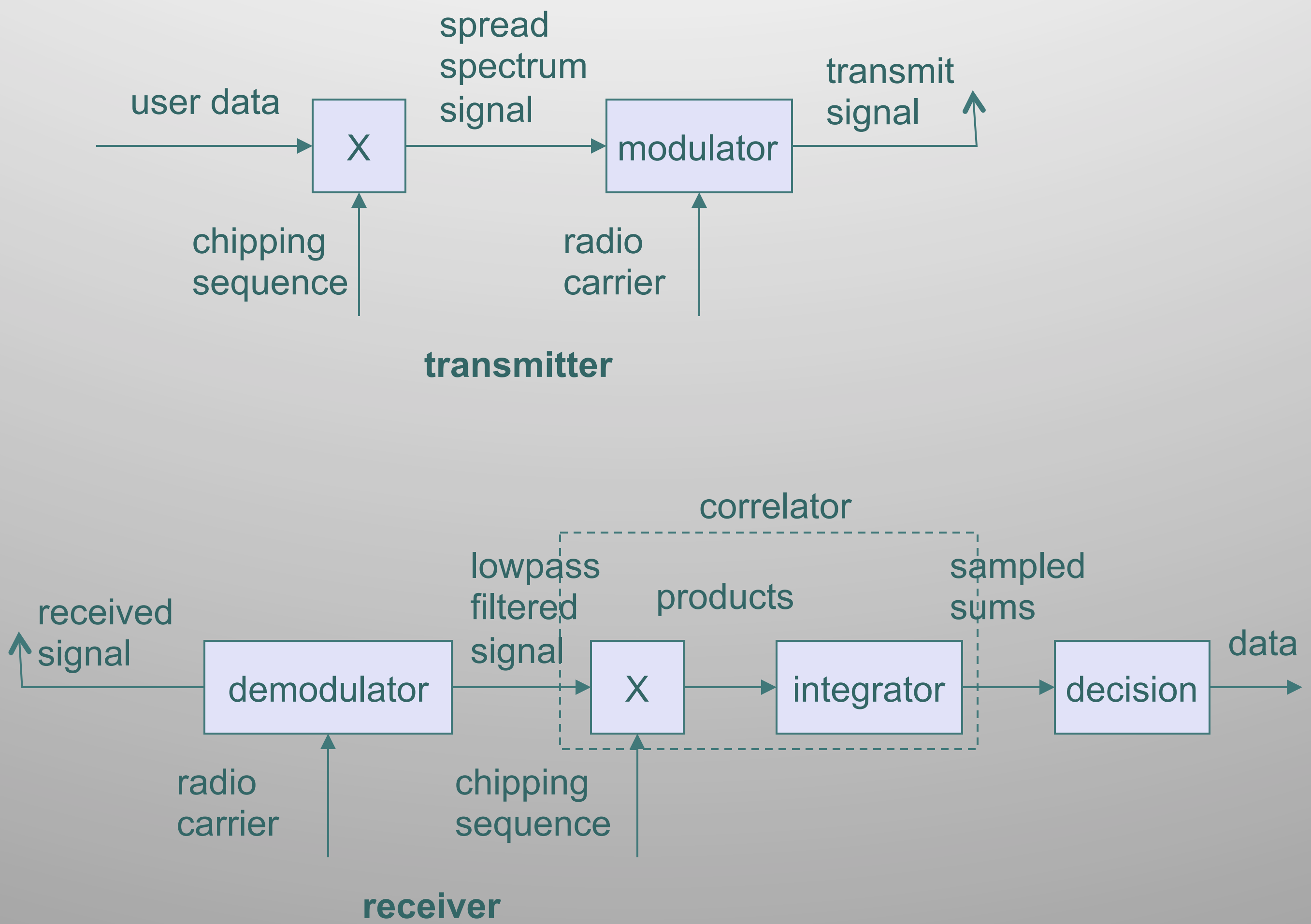
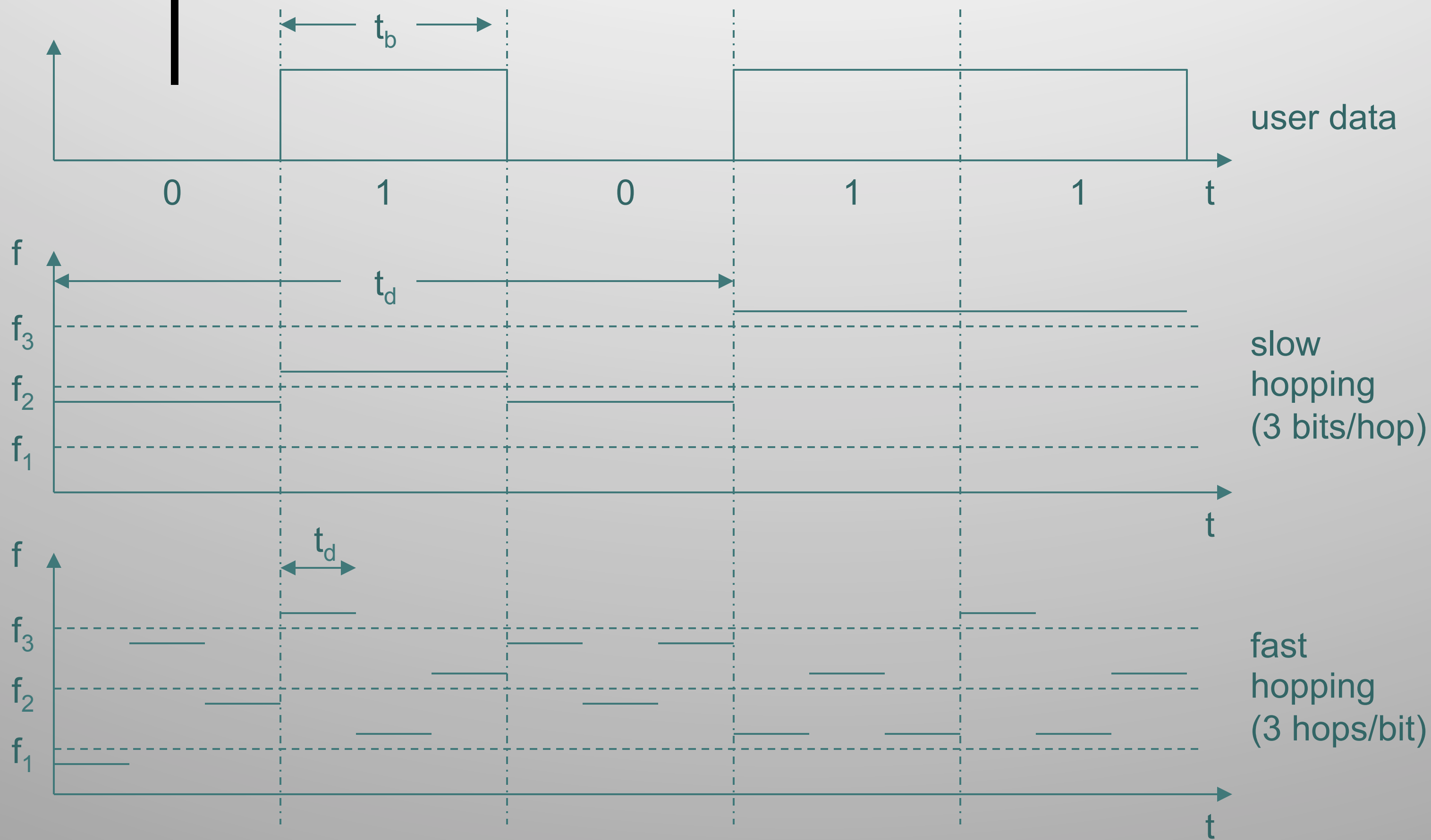
DSSS (Direct Sequence Spread Spectrum)….2



FHSS (Frequency Hopping Spread Spectrum)…..1

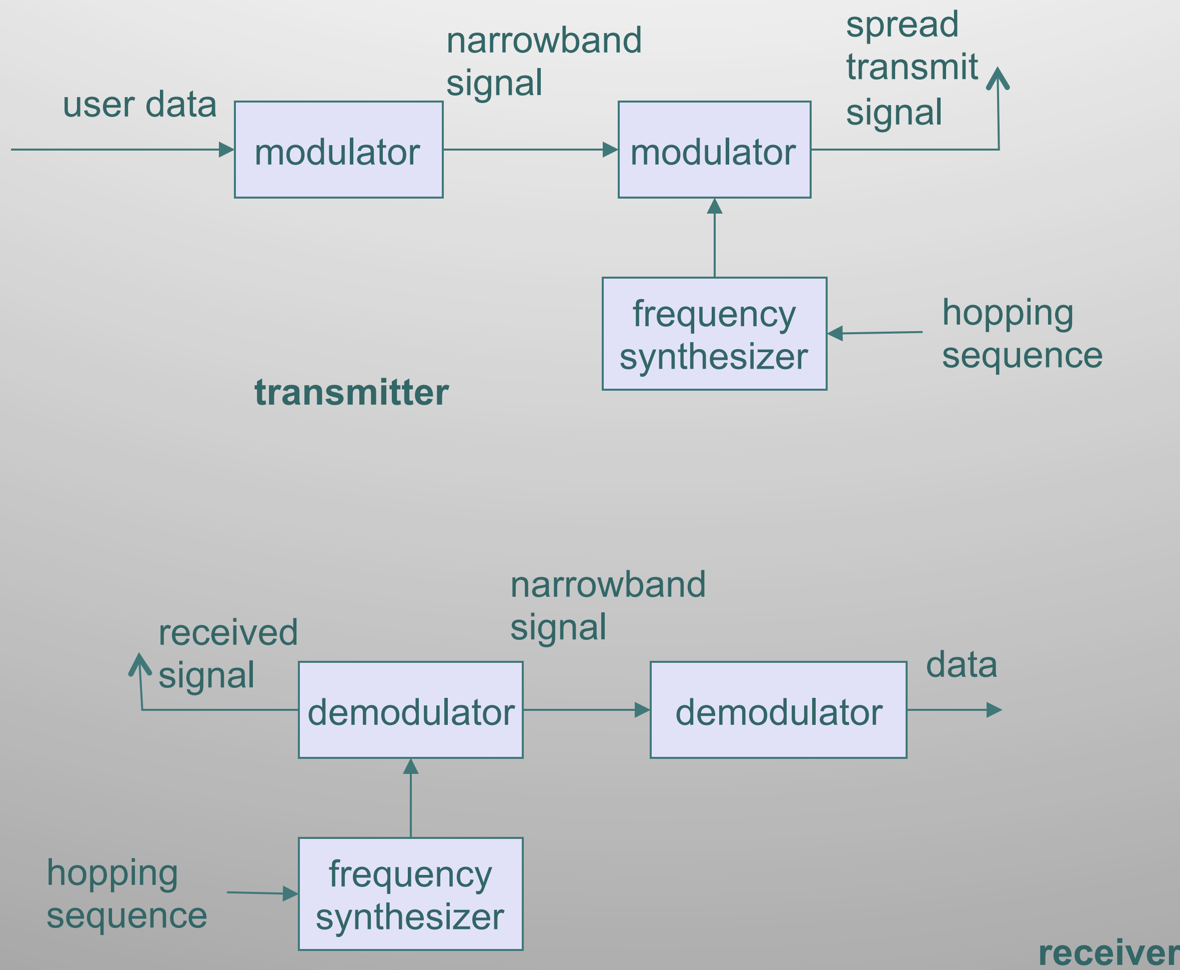
- Discrete changes of carrier frequency
  - sequence of frequency changes determined via pseudo random number sequence
- Two versions
  - Fast Hopping:
    several frequencies per user bit
  - Slow Hopping:
    several user bits per frequency
- Advantages
  - frequency selective fading and interference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

FHSS (Frequency Hopping Spread Spectrum)…..2



t_b: bit period t_d: dwell time

FHSS (Frequency Hopping Spread Spectrum)…..3



Concept of mobile cellular communication

NEXT WEEK

QUESTION?