Mobile Communications Networks

Wireless Transmission

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- *How is a signal affected when it propagates in a wireless link?*
- *How are bits transported by a carrier?*
- *What is the maximum bitrate transportable by a wireless link?*
- *Why do characteristics such as bitrate vary along the time?*
- *What will future radio functions look like?*

Electromagnetic Waves – Generation and Propagation

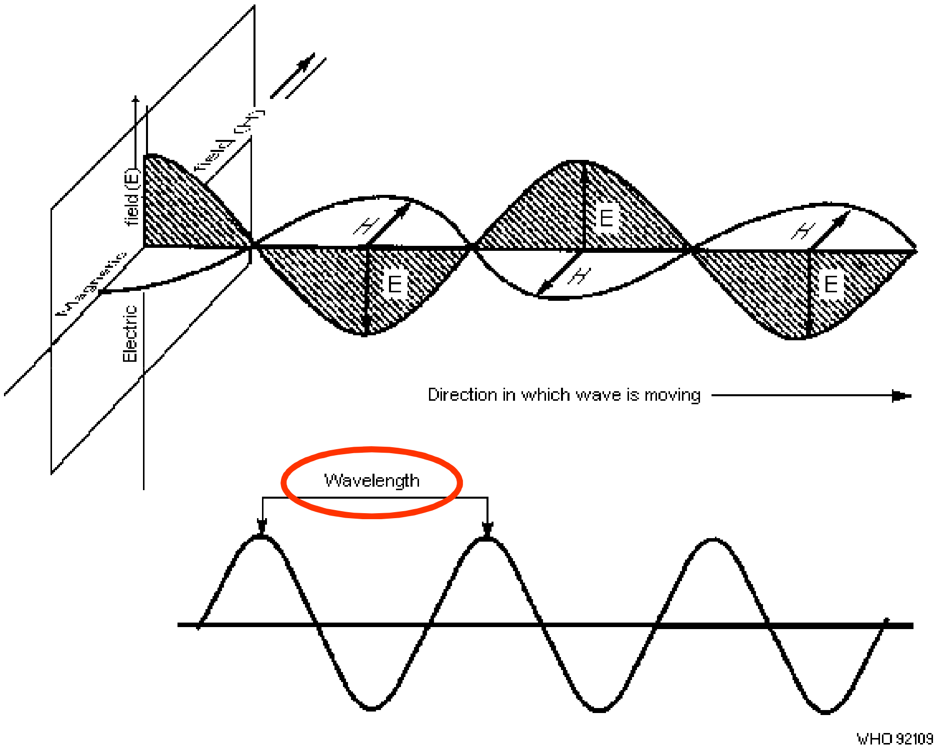
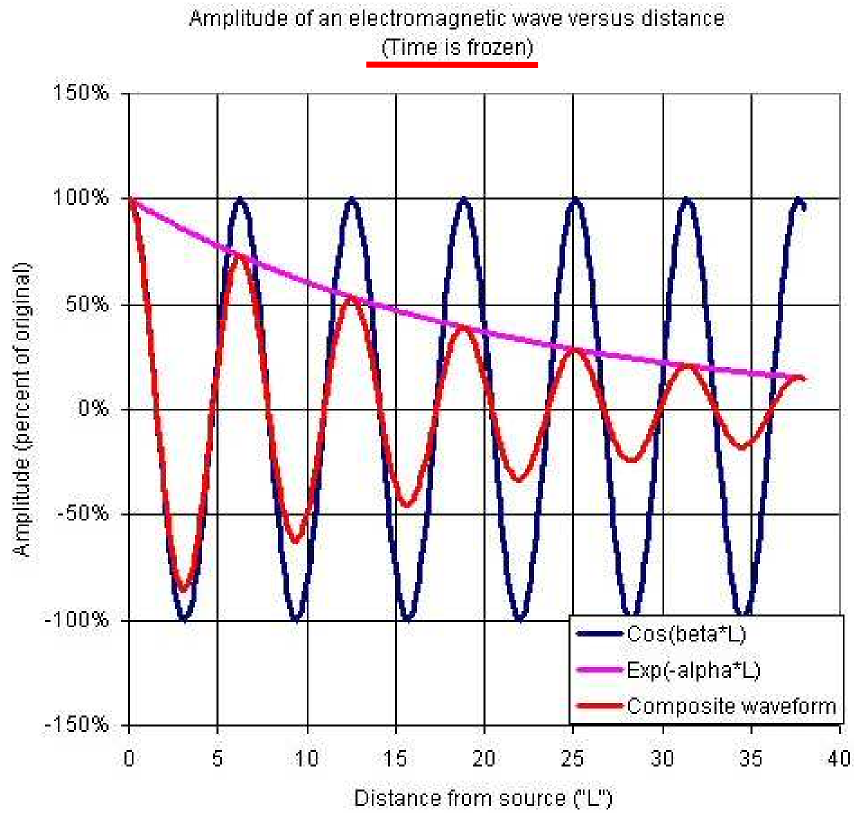


Fig. 1. An electromagnetic monochromatic wave. Electromagnetic waves consist of electrical and magnetic forces that move in consistent wave-like patterns at right angles to each other for far-field propagation, but at varying angles in the near-field.



Frequencies for Radio Transmission

- Frequency bands as defined by the ITU-R ***Radio Regulations***

$$band_i \in [0.3 \times 10^i Hz, 3 \times 10^i Hz[.$$

Band Number	Symbol	Frequency Range
4	VLF	3-30 kHz
5	LF	30-300 kHz
6	MF	3000-3000 kHz
7	HF	3-30 MHz
8	VHF	30-300 MHz
9	UHF	300-3000 MHz
10	SHF	3-30 GHz
11	EHF	30-300 GHz
12		300-3000 GHz

$$\lambda = c/f$$

λ – wave length

$c = 3 \times 10^8\ m/s$ represents the speed of the light

f_c= 3 GHz ➔ λ =10 cm

Wireless Systems in Europe

- In Portugal
  ANACOM attributes the frequencies
  http://www.anacom.pt
- FWA
  Fixed Wireless Access
- ISM
  Industrial, Scientific and Medical

Wireless Systems in Europe	Frequency Range
Broadcast TV	47-68 MHz 174-216 MHz 470-582 MHz 582-862 MHz
2G PLMN (GSM)	890-914 MHz 935-959 MHz 1710-1785 MHz 1805-1880 MHz
3G PLMN (UMTS)	1900-1980 MHz 2010-2025 MHz 2110-2170 MHz
FWA	3400-3600 MHz 3600-4200 MHz 24.5-26.5 GHz 27.5-29.5 GHz
ISM	13553-13567 kHz 26957-27283 kHz 40.66-40.70 MHz 2400-2500 MHz 5725-5875 MHz 24-24.25 GHz

To Think About

- What factors may affect the power of the signal received by a mobile phone?
- How does the power of a received signal depend on the
  - » distance?
  - » wavelength (λ)?

Signal Propagation and Wireless channels

Power of the signal received depends on 3 factors

- Path loss

  Dissipation of radiated power; depends on the distance

- Shadowing
  - caused by the obstacles between the transmitter and the receiver
  - attenuates the signal 🡐 absorption, reflection, scattering, diffraction

- Multipath

  constructive and destructive addition of multiple signal components

W, dBW, dBm, dB, Gain

$$P_{r_W},\left(power = \frac{energy}{time} \right), 1W = \frac{1J}{1s}$$

$$P_{r_{dBW}} = 10.\log\left(\frac{P_{r_W}}{1W}\right) = 10.\log P_{r_W}$$

$$P_{r_{dBm}} = 10 * \log\left(\frac{P_{r_W}}{1mW}\right)$$

$$Gain_{dB} = 10.\log\left(P_{r_W} / P_{s_W}\right) = 10.\log P_{r_W} - 10.\log P_{s_W} = P_{r_{dBW}} - P_{s_{dBW}} = P_{r_{dBm}} - P_{s_{dBm}}$$

$$Loss_{dB} = Atenuation_{dB} = -Gain_{dB} = P_{s_{dBW}} - P_{r_{dBW}} = P_{s_{dBm}} - P_{r_{dBm}}$$

Path Loss – Free Space Model

$$\boxed{P_r/P_s = \left[\frac{\lambda\sqrt{G_l}}{4\pi d}\right]^2}$$

$$\boxed{PL_{dB} = -PG_{dB} = P_{s_{dB}} - P_{r_{dB}}}$$

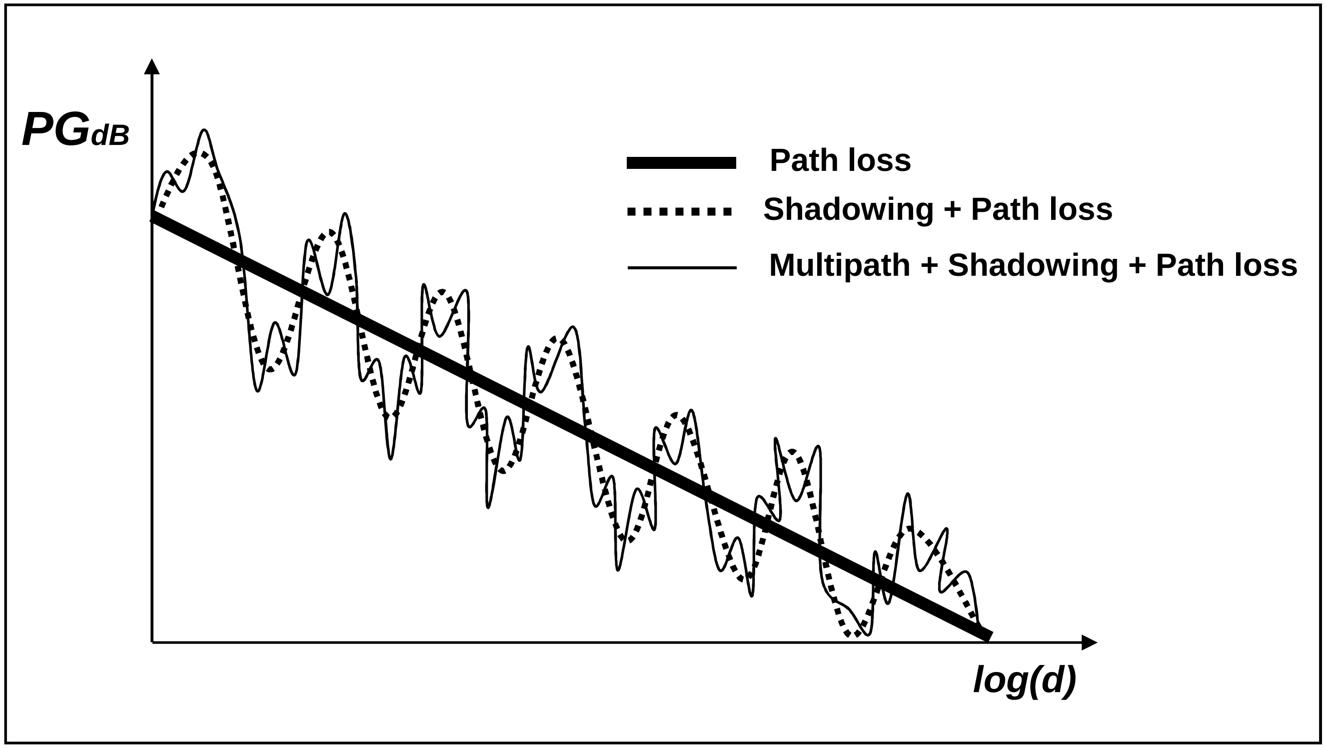
$$\boxed{PG_{dB} = 10\ log(Pr/Ps)}$$

$$\boxed{PL_{dB} = -10\ log\frac{\lambda^2 G_l}{(4\pi d)^2}}$$

$$PG_{dB} = 20.\log\left(\frac{\lambda\sqrt{G_l}}{4\pi}\right) - 20.\log(d) = b - 20x$$

Signal Propagation and Wireless Channels

$$\boxed{PG_{dB} = 10\ log(Pr/Ps)}$$



Path Loss – Free Space Model

Assume a receiver needs to receive, at least, 0.1 μW ➔ $\boxed{P_r = 0.1\ \mu W}$

$$\boxed{P_{r_{dBW}} = 10\ log\left(\frac{P_{r_W}}{1\ W}\right) = 10\ log\left(\frac{10^{-7}\ W}{1\ W}\right) = -70\ dBW}$$

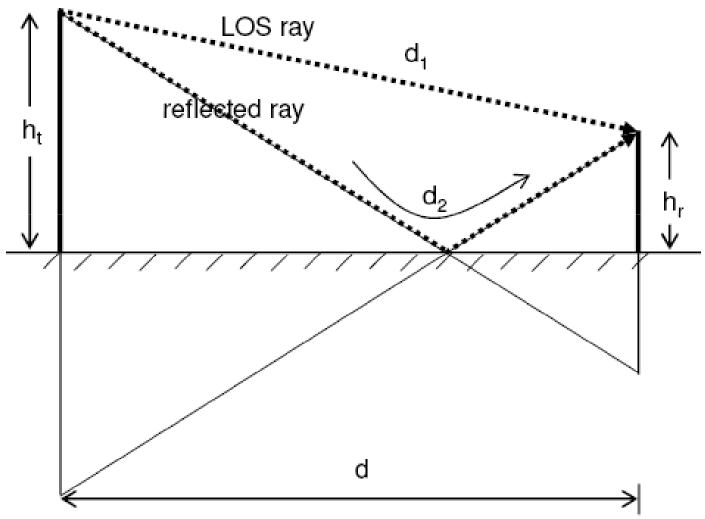
$$\boxed{P_{r_{dBm}} = 10\ log\left(\frac{P_{r_W}}{1\ mW}\right) = 10\ log\left(\frac{10^{-7}\ W}{10^{-3}\ W}\right) = -40\ dBm}$$

f_c (MHz)	λ $\left(\frac{c}{f_c}\right)$ (cm)	d (m)	PL_{dB} $\left(-10\ log\frac{\lambda^2 G_l}{(4\pi d)^2}\right)$ (dB)	$P_{s_{dBm}}$ $(P_{r_{dBm}} + PL_{dB})$ (dBm)	P_s $\left(10^{\frac{P_{s_{dBm}}}{10}-3}\right)$ (W)
900	33	10	51.5	11.5	0.014
		100	71.5	31.5	1.42
		1000	91.5	51.5	142
3000	10	10	62	22	0.158
		100	82	42	15.8
		1000	102	62	1579

P_L increases 20 db per logd

Path Loss – Other models

Two-ray model



$$P_{r_{dBm}} = P_{s_{dBm}} + 10\ log(G_l) + 20\ log(h_t h_r) - 40\ log(d)$$

Simplified model

$$P_{r_{dBm}} = P_{s_{dBm}} + K_{dB} - 10\ \gamma\ log\left[\frac{d}{d_0}\right]$$

$$K_{dB} = 10\ log\left[\frac{\lambda}{4\pi d_0}\right]^2$$

$$d_0 \approx 10\lambda$$

Environment	γ
Urban macrocells	3.7 - 6.5
Urban microcells	2.7 - 3.5
Office building	1.6 - 3.5
Store	1.8 - 2.2
Factory	1.6 - 3.3
Home	3

Path Loss – Indoor Factors

- Walls, floors, layout of rooms, location and type of objects
  - Impact on the path loss
  - The losses introduced **must be added** to the free space losses

Partition	Loss (dB)
hollow brick	8
concrete wall	13
aluminum siding	20
window	6
floor	10

Shadowing

- Signal traversing wireless channel ➔ suffers ***random*** attenuation
- Random attenuation
  - » described as a statistical process
  - » having a log-normal distribution

- If the simplified path loss model is used, then

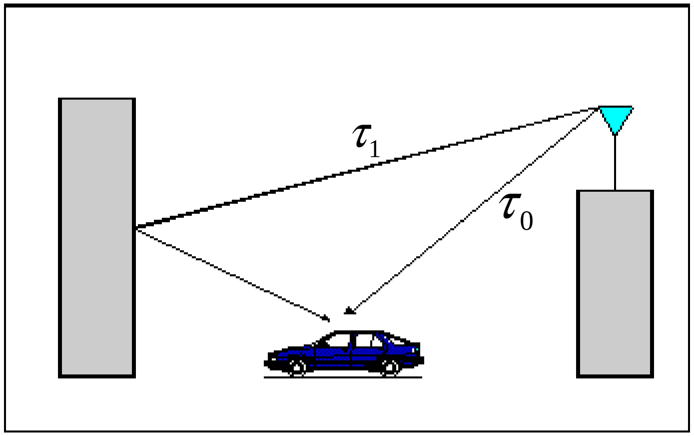
$$\left(\frac{P_r}{P_s}\right)_{dB} = 10\ logK - 10\gamma\ log\frac{d}{d_0} - \psi_{dB}$$

where ψ_{dB} is a Gaussian distributed random variable

$\boxed{\text{characterized by } \mu_{\psi_{dB}} = 0 \text{ and } \sigma_{\psi_{dB}}}$

Multipath

- Multipath → multiple rays
  - » multiple delays from transmitter to receiver → τ_i
  - » time delay spread $T_m = max_n|\tau_n - \tau_0|$
- The time-varying nature of the multipath channel
  - » caused by the transmitter / receiver movements
  - » location of reflectors which originate the multipath



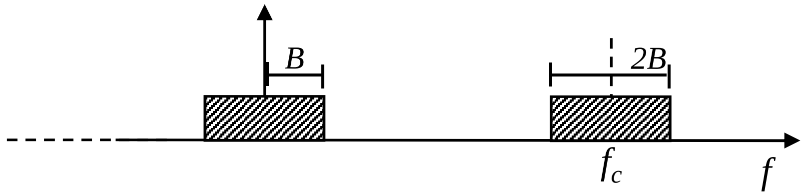
Multipath – Narrowband Channel

- For a narrowband channel

  low B → low symbol rate (symbol/s) → large time/symbol

  → multipath components arrive in the time period of their symbol

$$T_m << B^{-1}$$

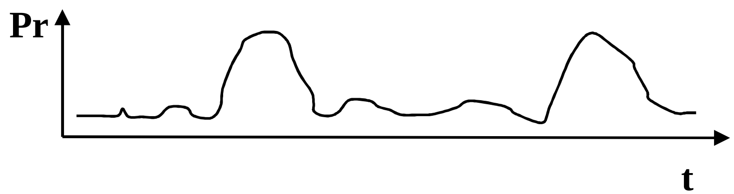


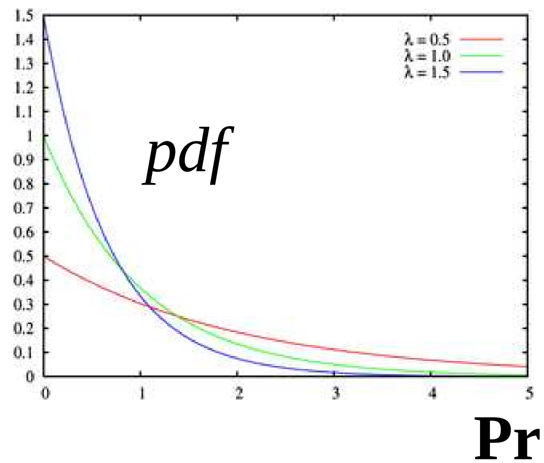
- Narrowband channel has Rayleigh fading →

  The power received

  has an exponential

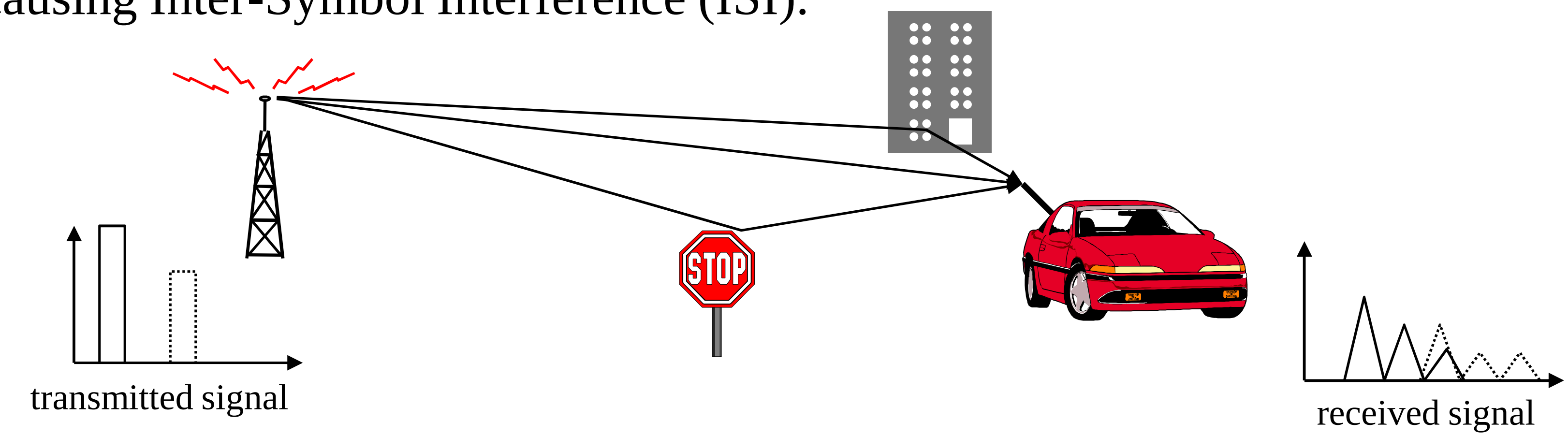
  probability density function





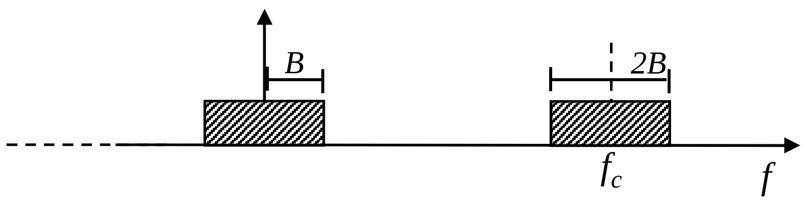
Multipath – Wideband Channel

- Multipath components
  - » may arrive at the receiver within the time period of the next symbol
  - » causing Inter-Symbol Interference (ISI).

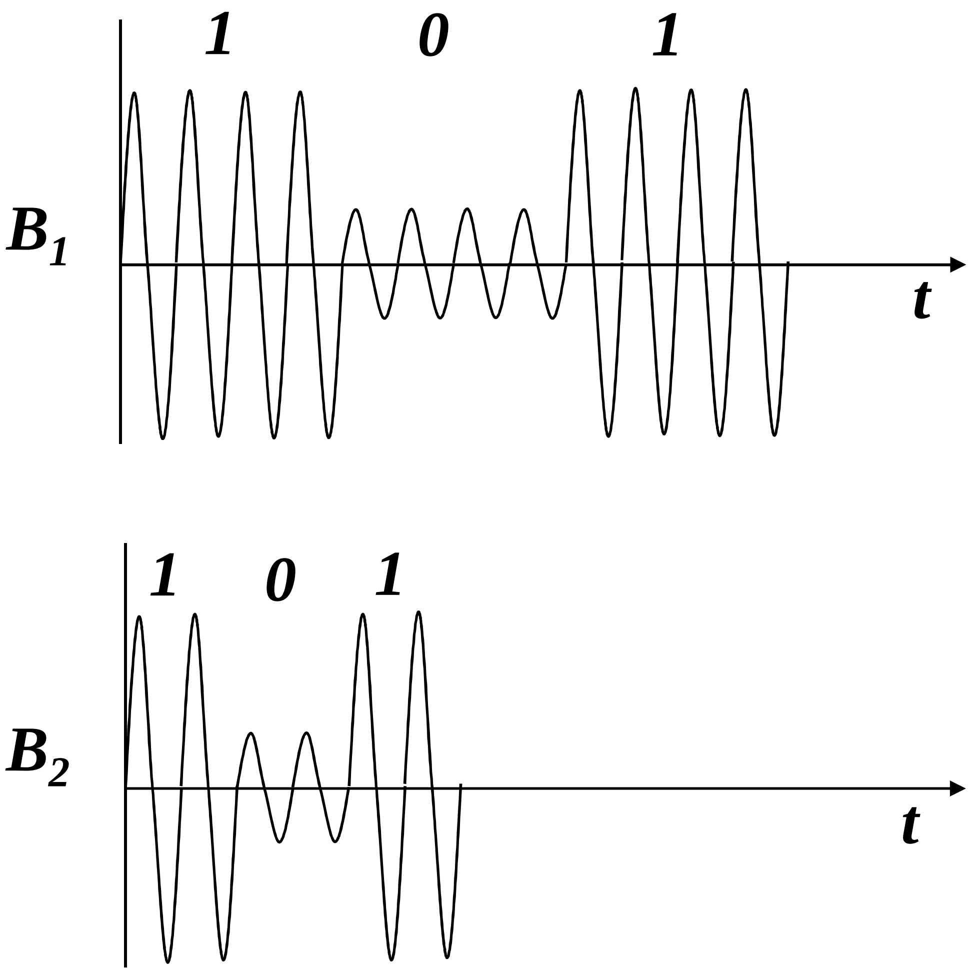


- Techniques used to mitigate ISI
  - » multicarrier modulation
  - » spread spectrum

To Think About



- What is the difference betweeen B and f_c?



$B_1 \overset{?}{>,<} B_2$

Capacity of an Wireless Channel

- Assuming **A**dditive **W**hite **G**aussion **N**oise (AWGN)
  - » Given by Shannon´s law

$$C = B\ log_2(1+\gamma)\ \text{(bit/s)}$$

$$\gamma = P_r/(N_0 B)$$

N_0 – power spectral density of the Noise

- Capacity in a fading channel (shadowing + multipath)
  - ➔ <u>usually smaller</u> than the capacity of an AWGN channel

Capacity of an Wireless Channel

$P_r(d) = (d_0/d)^3\, P_t$, for $d_0 = 10m$.

d (m)	$\gamma = P_r(d)/(N_0 B)$	$SNR = \gamma_{dB} = 10\ log\gamma$ (dB)	$C = B\ log_2(1+\gamma)$ ($kbit/s$)	Efficiency (bit/s/Hz)
50	267	24	242	8
100	33	15	153	5.1
500	0.27	-6	10	0.3
1000	0.033	-15	1.4	0.05

Table 2.6: Shannon capacities for wireless channels. The limiting capacities of wireless channels depend on the channel bandwidth and on the power received. The capacity C of the channel and its efficiency are given for a transmitted power $P_s = 1\, W$, $d_0 = 10\, m$, a narrow bandwidth of $30\, kHz$ and a noise power spectral density $N_0 = 10^{-9}\ W/Hz$. The capacity decreases significantly as the distance between the sender and the receiver increases

To Think About

- How can we transmit bits using a continuous carrier?

Digital Modulation

- Digital modulation
  - » maps information bits into an analogue signal (carrier)
- Receiver
  - » determines the original bit sequence based on the signal received
- Two categories of digital modulation
  - » amplitude/phase modulation
  - » frequency modulation

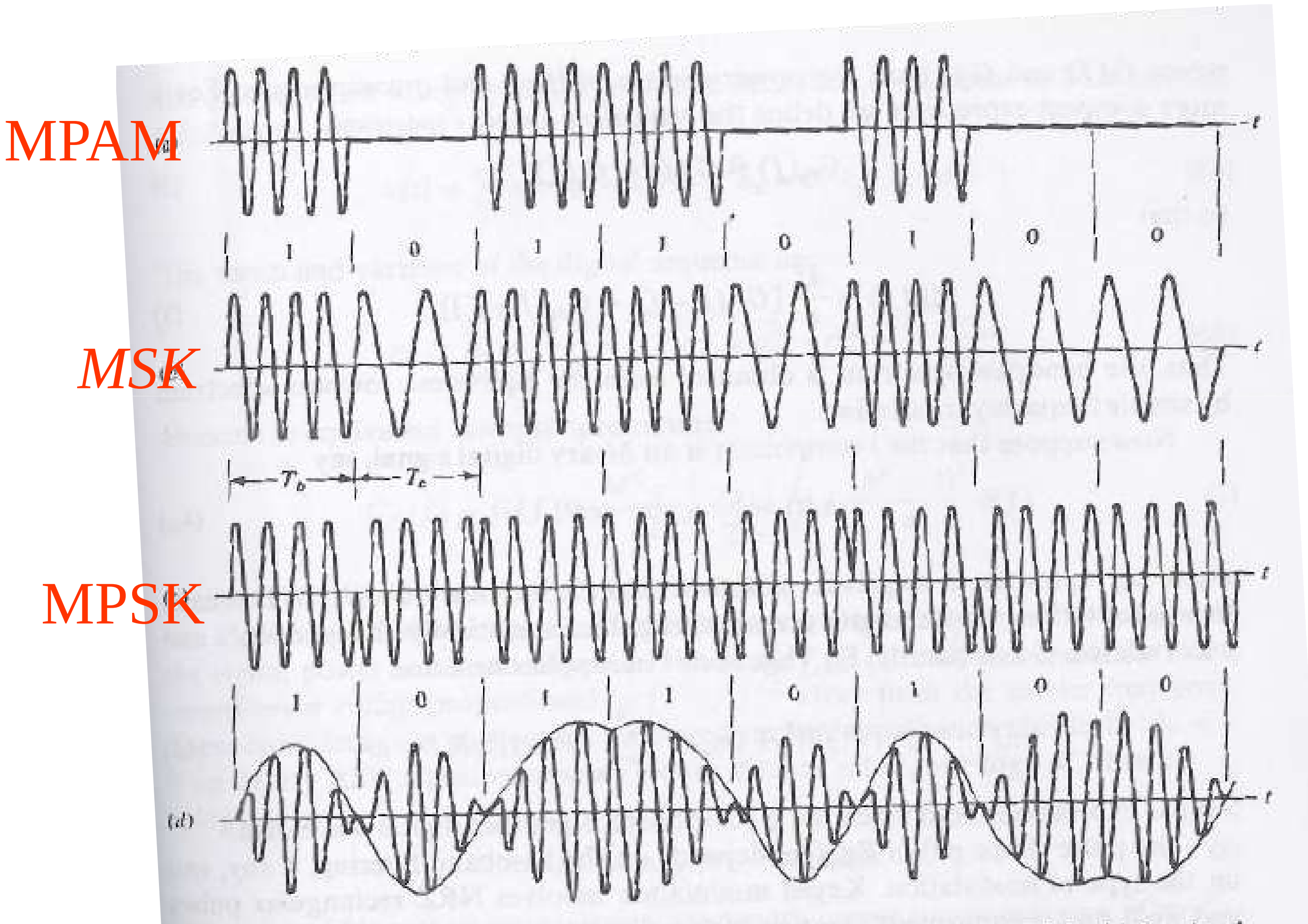


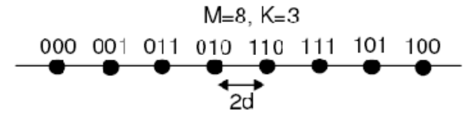
Figure 14.1-1 Binary modulated waveforms. (a) ASK; (b) FSK; (c) PSK; (d) DSB with baseband pulse shaping.

Amplitude and Phase modulation

- $K = log_2 M$ bits sent over a time symbol interval
- Amplitude/phase modulation can be:
  - » Pulse Amplitude Modulation (MPAM)

    information coded in amplitude

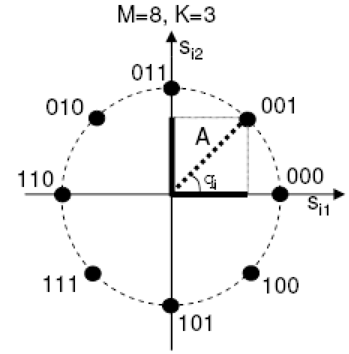
    MPAM - $s_i(t) = Re\left\{A_i \; g(t) e^{j2\pi f_c t}\right\}$



  - » Phase Shift Keying (MPSK),

    information coded in phase

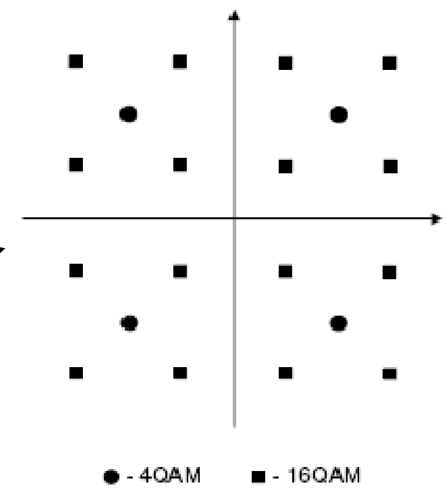
    MPSK - $s_i(t) = Re\left\{A \; g(t) e^{j\theta_i} e^{j2\pi f_c t}\right\}$



  - » Quadrature Amplitude Modulation (MQAM)

    information coded both in amplitude and phase

    MQAM - $s_i(t) = Re\left\{A_i \; e^{j\theta_i} g(t) e^{j2\pi f_c t}\right\}$



Differential Modulation

- Bits associated to a symbol

  depend on the bits transmitted over prior symbol times

- Differential BPSK (DPSK)
  - 0 → no change phase
  - 1 → change phase by π

- Diferential 4PSK (DQPSK) the bit
  - 00 → change phase by 0
  - 01 → change phase by $\pi/2$
  - 10 → change phase by $-\pi/2$
  - 11 → change phase by π

Frequency Modulation, Minimum Shift Keying (MSK)

- Frequency modulation
  - » encodes information bits into the frequency of the carrier

$$s_i(t) = Acos(2\pi f_i t + \phi_i)$$

- Minimum Shift Keying

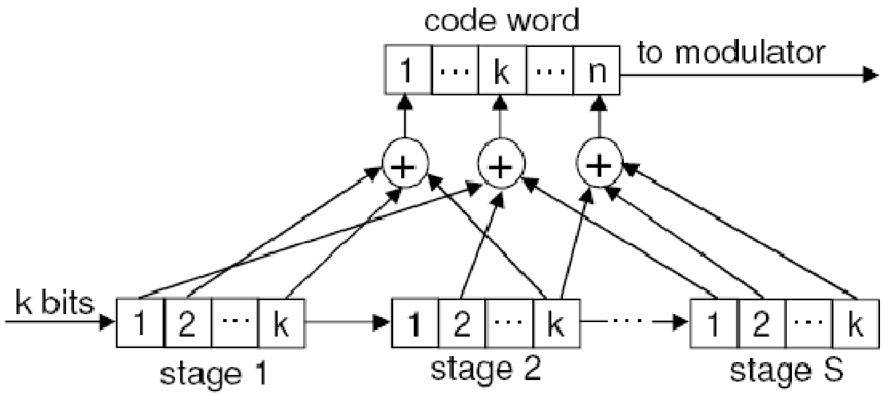
$$s_i(t) = Acos[2\pi f_c t + 2\pi \alpha_i \Delta f_c t + \phi_i],\ 0 \leq t < T_s,$$

Coding for Wireless Channels

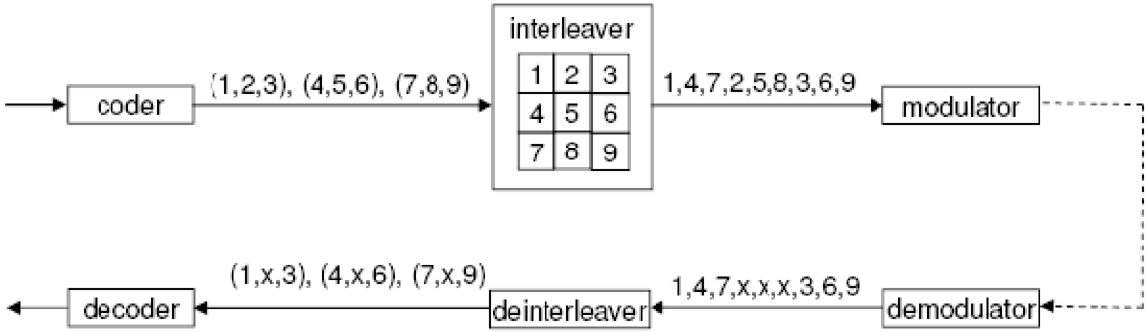
- Coding enables bit errors to be either detected or corrected by receiver
- Codes designed for AWGN channels
  - » do not work well on fading channels
  - » cannot correct the long error bursts that occur in fading
- Codes for fading channels are normally
  - » based on an AWGN channel code
  - » combined with interleaving
  - » objective → spread error bursts over multiple codewords

Convolutional Code; Interleaving

Example: convolutional code



Interleaving



To Think About

- Why does your WLAN interface change dynamically its working bitrate?
- What happens, from the modulation and coding points of view, when the WLAN interface changes from 54 Mbit/s to 6 Mbit/s?

802.11a – Rate Dependent Parameters

Data rate (Mbits/s)	Modulation	Coding rate (R)	Coded bits per subcarrier (N_{BPSC})	Coded bits per OFDM symbol (N_{CBPS})	Data bits per OFDM symbol (N_{DBPS})
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

% of useful information

250 kSymbol/s

Adaptive Modulation/Coding

- Adaptive transmission techniques
  - » aim at maintaining the quality → low/stable BER
  - » works by varying: data rate, power transmitted, codes
- Adapting the data rate
  - » symbol rate is kept constant
  - » modulation schemes / constellation sizes depend on γ → multiple data rates
- Adapting the transmit power
  - » compensate $\gamma = P_r/N_0B$ variation due to fading
  - » maintain a constant received γ
- Adapting the codes
  - » γ large → weaker or no codes
  - » γ small → stronger code may be used

$$\gamma = P_r/(N_0 B)$$

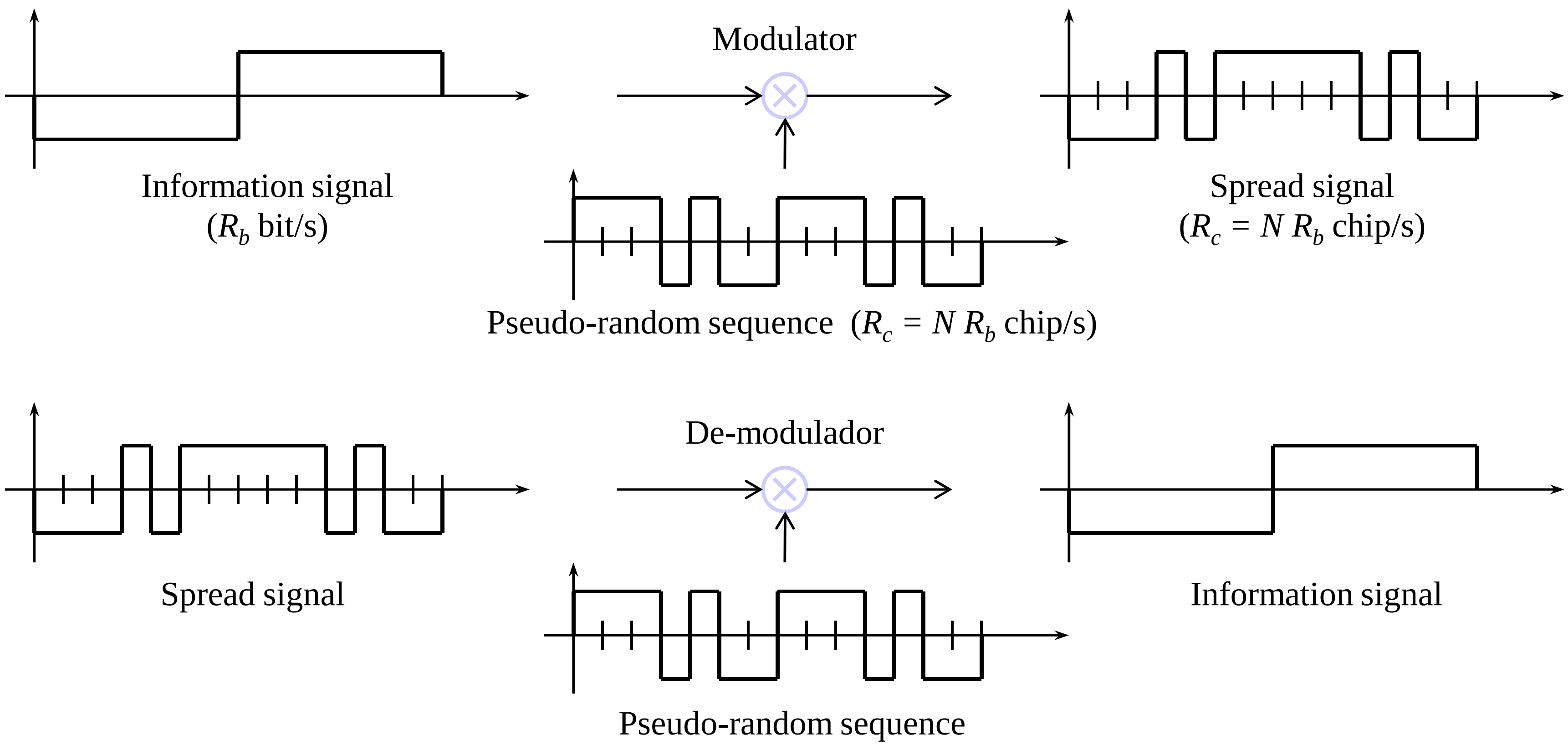
$$C = B\ log_2(1+\gamma)$$

Spread Spectrum

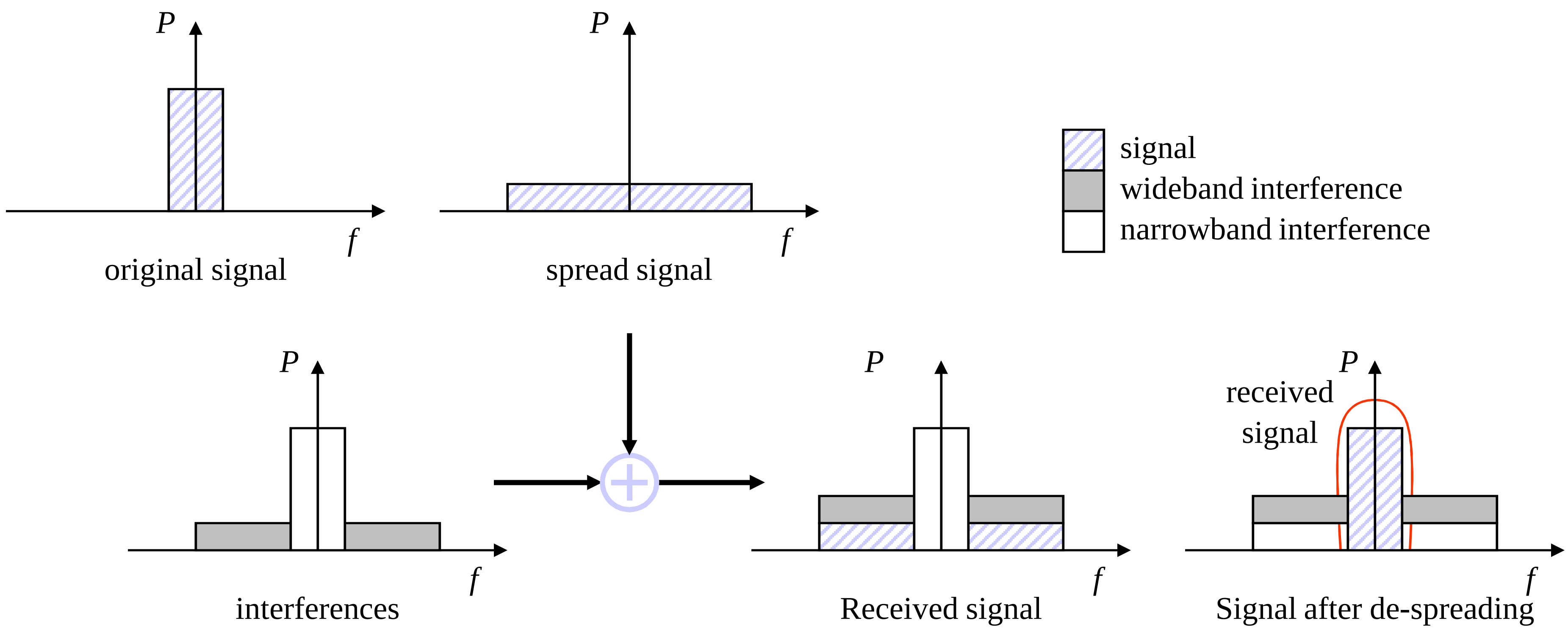
- Spread spectrum techniques
  - » hide the information signal below the noise floor
  - » mitigate inter-symbol interferences
  - » combine multipath components

- The spread spectrum techniques
  - » multiply the information signal by a spreading code

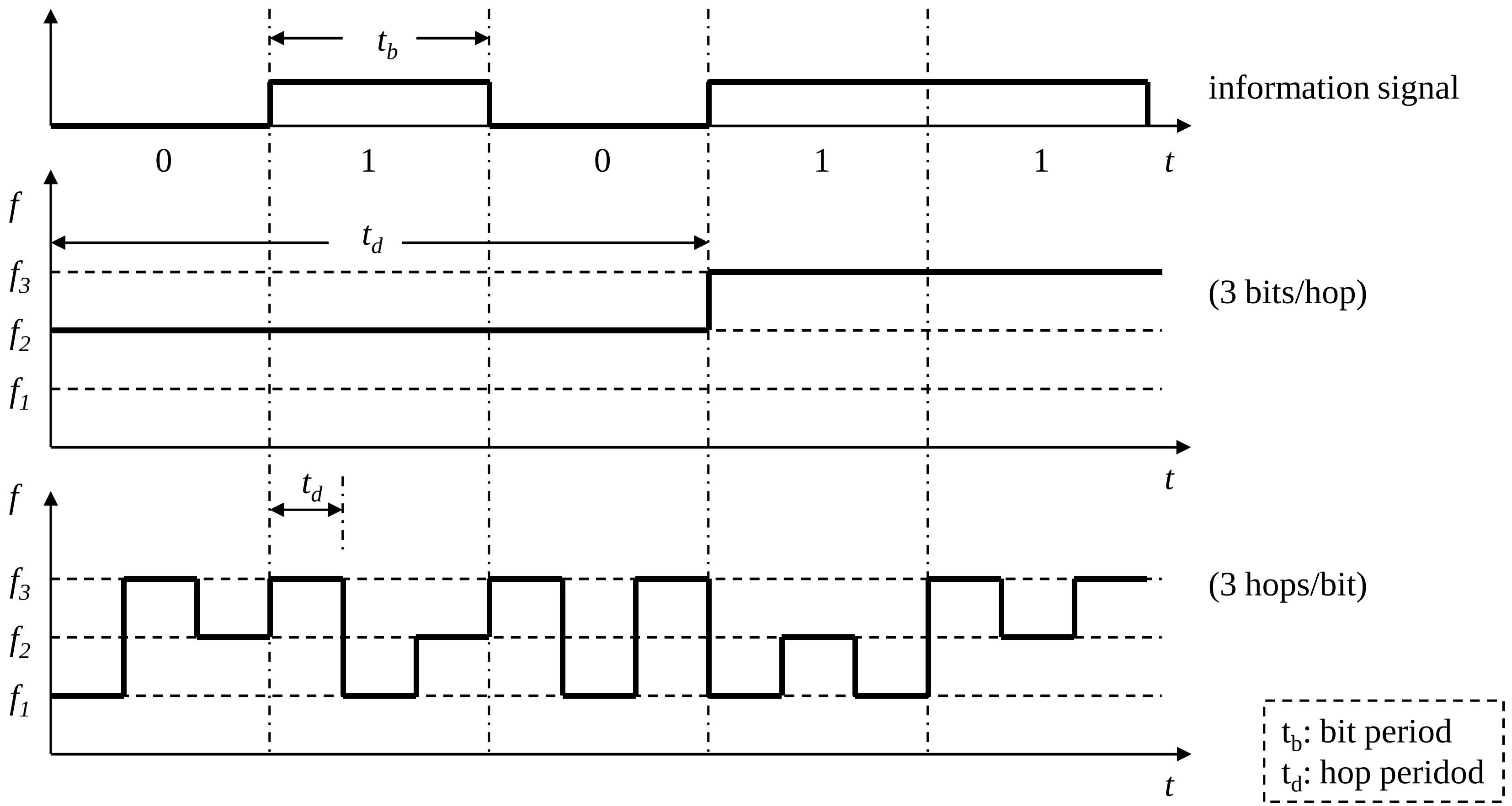
Spread Spectrum – Direct Sequence



Direct Sequence Spread Spectrum – Immunity to Interferences

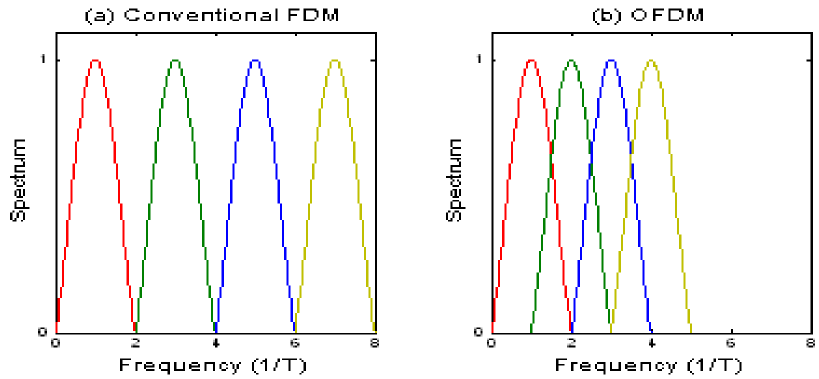


Spread Spectrum –Frequency Hopping



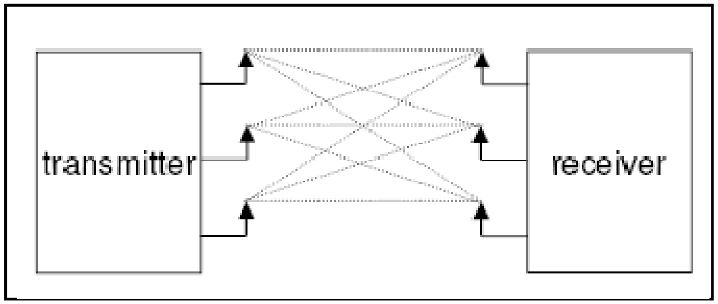
Multicarrier Modulation

- Multicarrier modulation (e.g. OFDM) consists
  - » dividing a bitstream into multiple low rate sub-streams
  - » sending sub-streams simultaneously over sub-channels
- Subchannel
  - » has bandwidth $\boldsymbol{B_N = B/N}$
  - » provides a data rate $\boldsymbol{R_N \approx R/N}$
  - » For $\boldsymbol{N}$ large, $B_N = B/N << 1/T_m$
    - ➔ flat fading (narrowband like effects) on each sub-channel, no ISI
- Orthogonal sub-carriers
  - » space between carriers → minimised
  - » system capacity → maximised



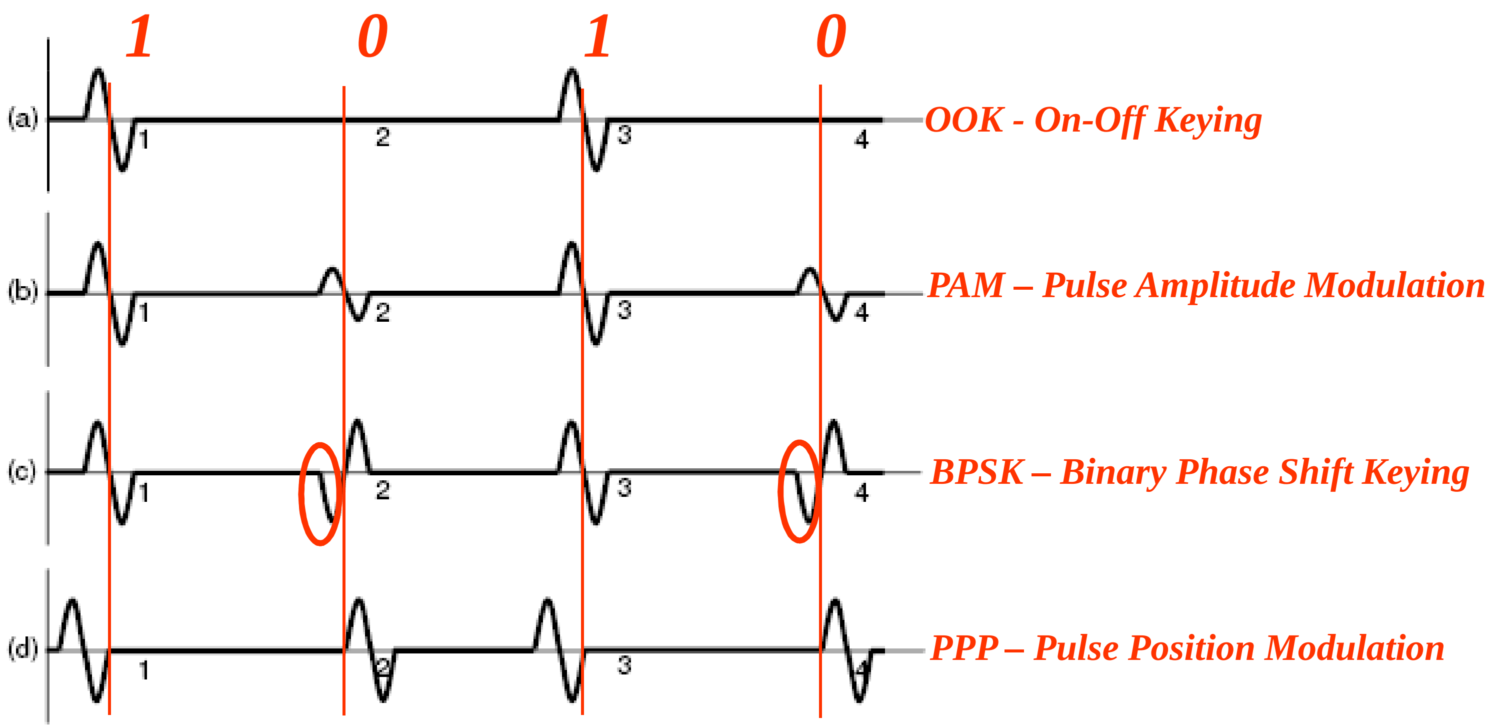
Multiple Antennas and Space-Time Communications

- Multiple Input Multiple Output combines
  - » signals generated by multiple transmit antennas
  - » signals received by multiple receive antennas
- MIMO used to improve data rate (bits/s) or quality (BER)



Ultra Wide Band

- » UWB transmits very short duration pulses
  - – individual pulse → much shorter than a single bit
  - – very large bandwidth
  - – very low transmission power ➔ low interference



Software Defined Radio

- Software Defined Radio

  aims at implementing the radio functions in software

- Digital Signal Processors being integrated with microcontroller

  better integration of radio and communications functions

  (e.g. de-coding, de-framing, error detection, MAC, mobility management)

Cognitive Radio

- Cognitive radio
  - » fills unused bands
  - » avoids interferences
  - » increases spectral efficiency
- Paves the way to
  - » dynamic spectrum licensing
  - » secondary markets in spectrum usage
- SDR is the mean required by cognitive radio