

# EITF25 Internet--Techniques and Applications

Stefan Höst

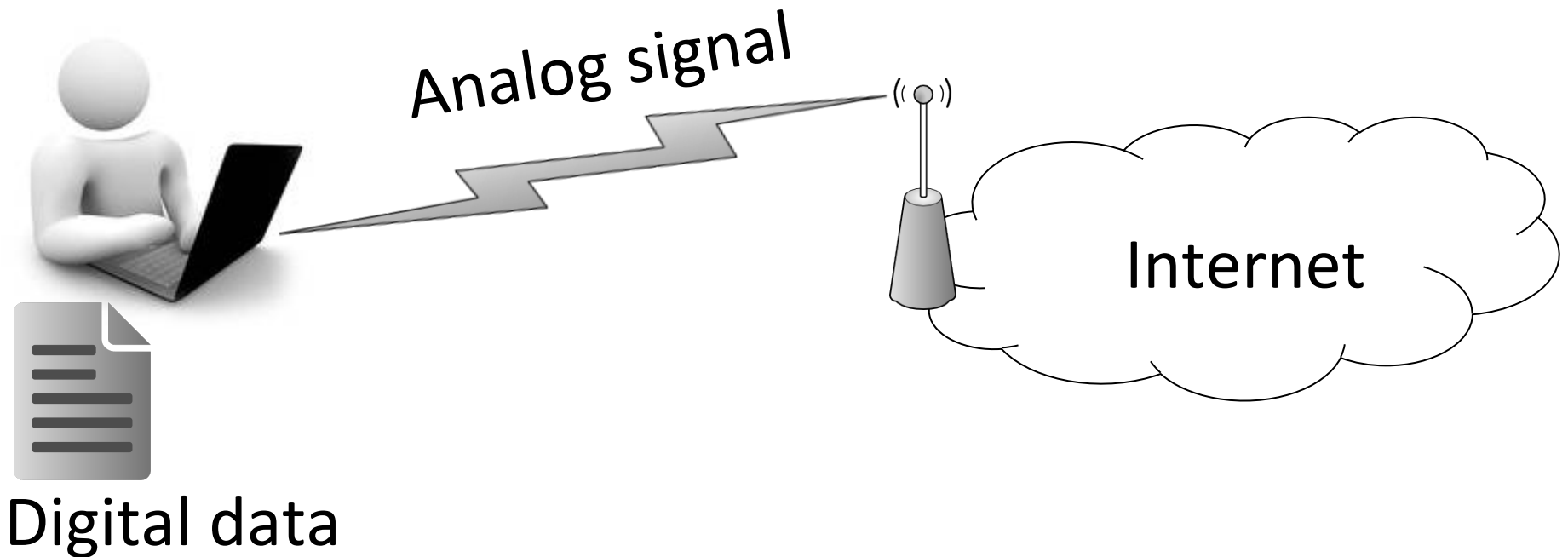
## L3 Physical layer (part 2)



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# From bits to signals

## Principles of digital communications

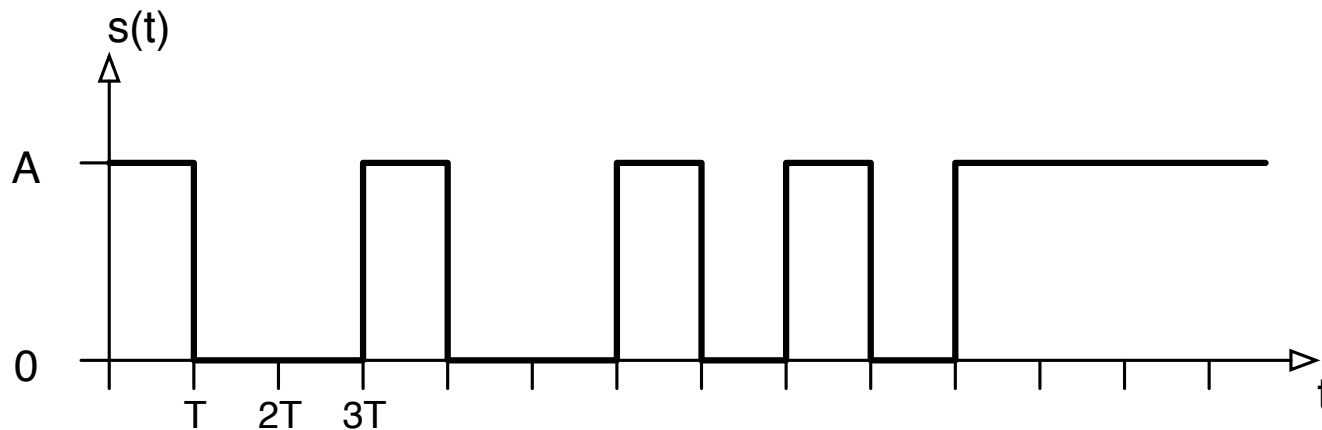


# On-off keying

- Send one bit during  $T_b$  seconds and use two signal levels, “on” and “off”, for 1 and 0.

Ex.

$x=10010010101111100$





# Mathematical description

With  $g(t)=A$ ,  $0 < t < T$ , the signals can be described as

$$s(t) = \sum_n a_n g(t - nT)$$

- On-off

$$a_n = x_n$$

- NRZ

$$a_n = (-1)^{x_n}$$

Two signal alternatives

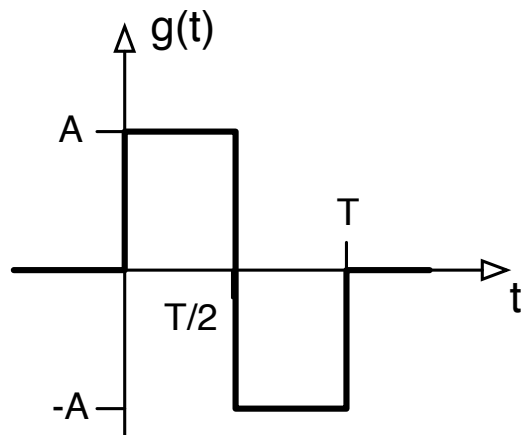
- $s_0(t)=0$  and  $s_1(t)=g(t)$

- $s_0(t)=g(t)$  and  $s_1(t)=-g(t)$

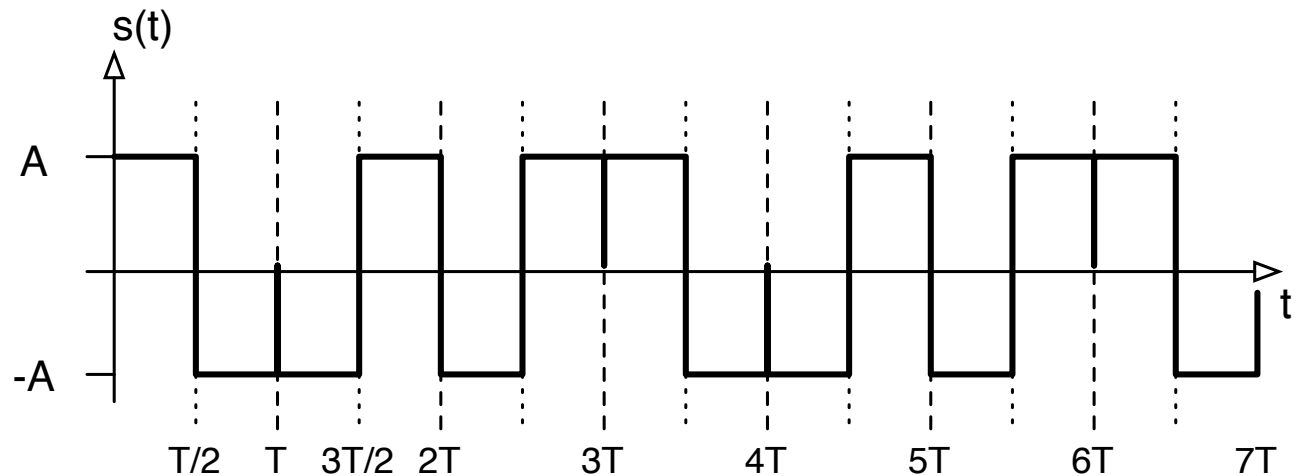
# Manchester coding

- To get a zero passing in each signal time, split the pulse shape  $g(t)$  in two parts and use +/- as amplitude.

Ex.



$x=10010010101111100$

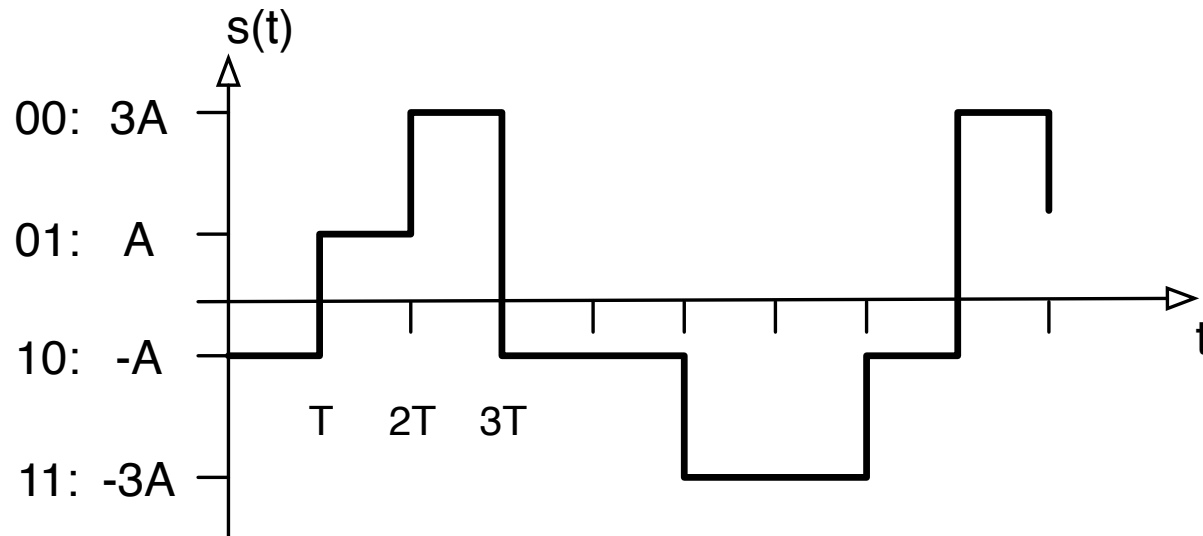


# Multi level modulation

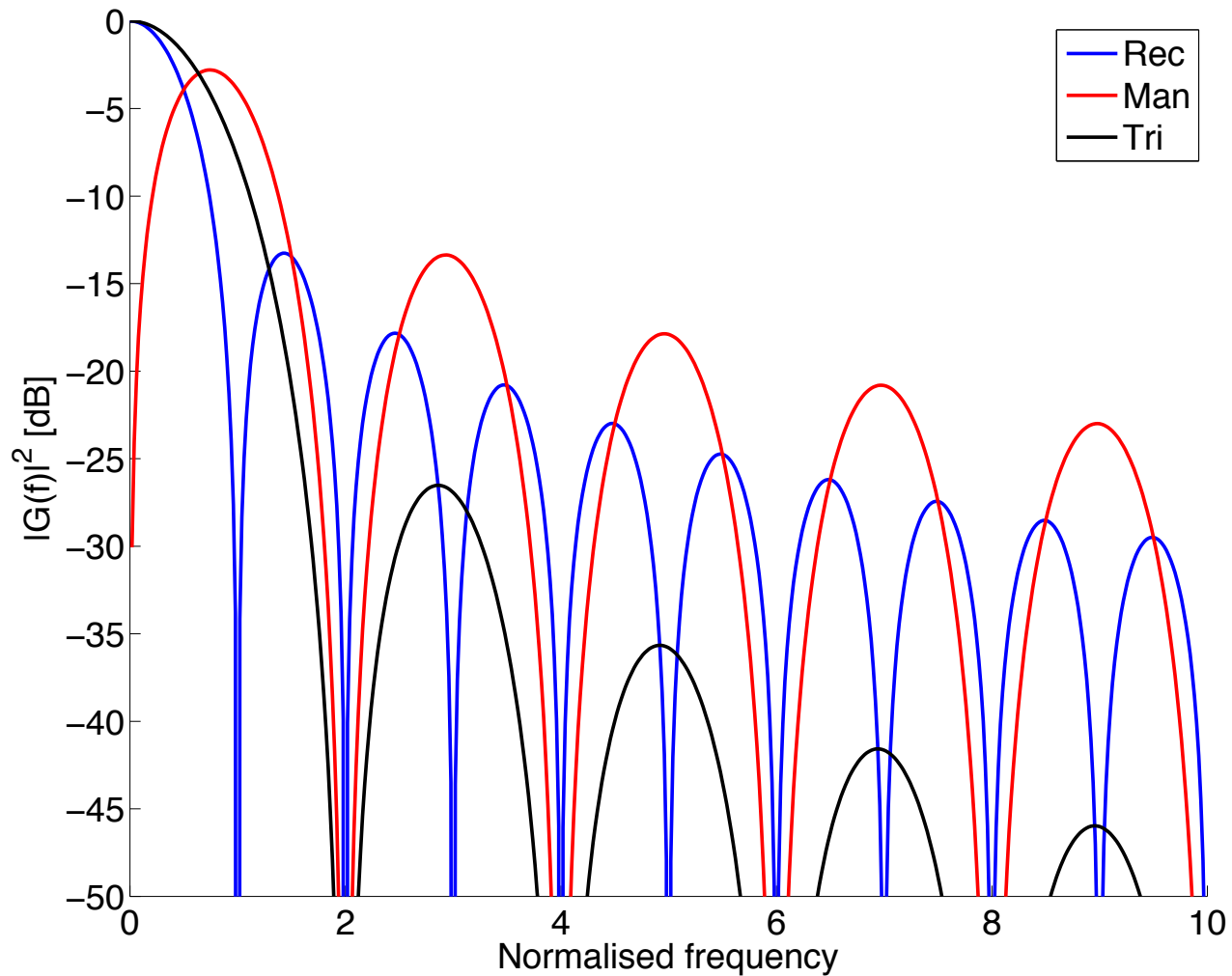
- To transmit  $k$  bits in one signal alternative of duration  $T_s$ , use  $M=2^k$  levels.

Ex. Two bits per signal

$x=10\ 01\ 00\ 10\ 10\ 11\ 11\ 10\ 00$



# Pulses in frequency





# Bandwidth

- The bandwidth is the positive frequency interval occupied by the main part of the signal power
  - Main lobe
  - $W_{X\%}$  bandwidth contains X% of power in signal

Typical X:

- 90%
- 99%
- 99.9%

Pulse	$W_{\text{lobe}}$	$W_{90\%}$	$W_{99\%}$
Rect	$2/T$	$1.7/T$	$20.6/T$
Man	$4/T$	$\approx 6/T$	$\approx 60/T$
Tri	$4/T$	$1.7/T$	$2.6/T$
TRC	$4/T$	$1.9/T$	$2.82/T$
HCS	$3/T$	$1.6/T$	$2.36/T$

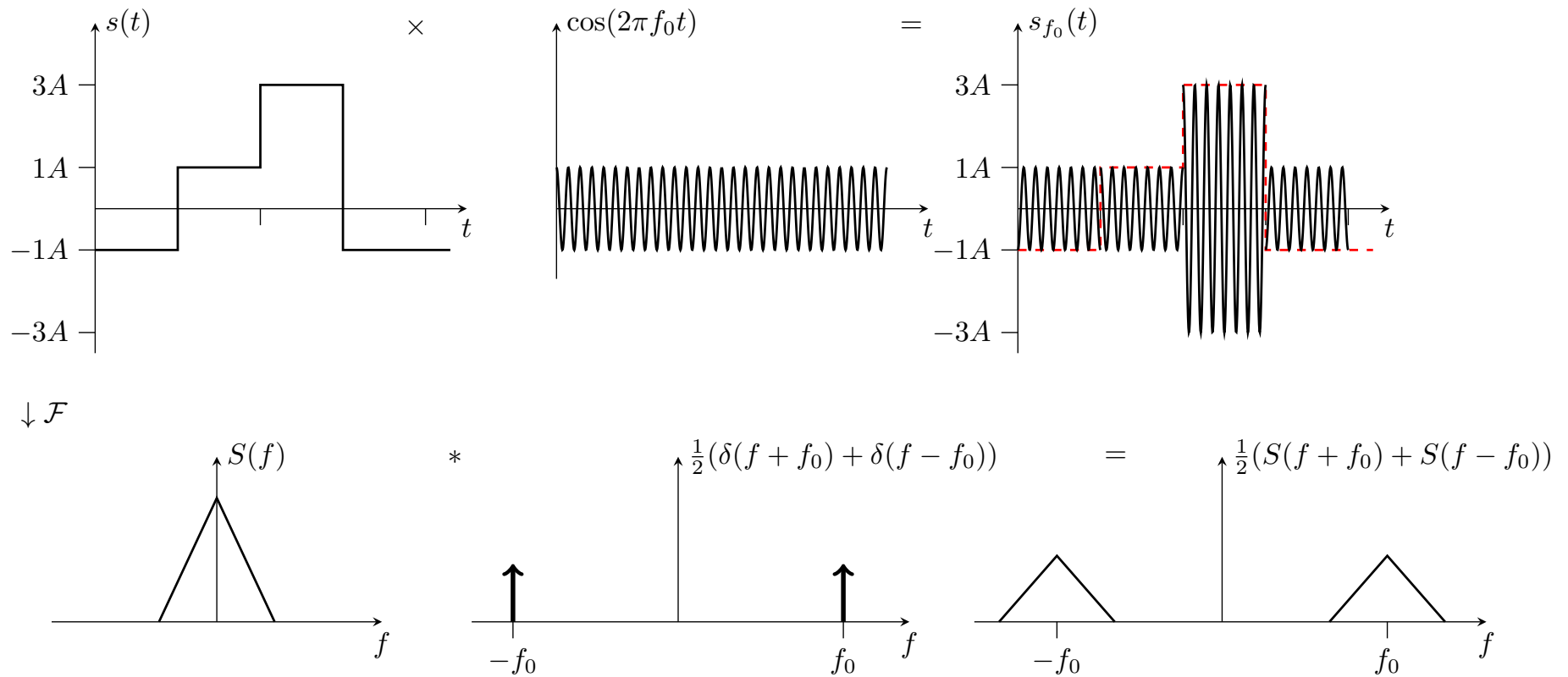
# Some system parameters

- With signal time  $T_s$  the signal rate is  $R_s=1/T_s$ . The unit of the signal rate is often Hz.
- If  $k$  bits are transmitted each signal alternative, the time per bit is  $T_b=T_s/k$ . The bit rate, or data rate, is  $R_b=1/T_b$ . The unit is b/s or bps.  $R_b=kR_s$
- Bandwidth efficiency  $R_b/W$ , in *bps/Hz*
- If  $P$  signal power, then
  - $E_s = T_s P$  is energy per signal alternative
  - $E_b = T_b P = E_s/k$  energy per bit

# Modulation in frequency

- Baseband signal centered around  $f=0$ .
- Pass-band signal centered around  $f=f_0$ ,  $f_0 \gg W$ .
- Shift a BB signal up in frequency to PB by multiplying with  $\cos(2 \pi f_0 t)$ .
- Shift a PB signal down to BB by multiplying with  $\cos(2 \pi f_0 t)$  followed by low-pass filtering.

# Modulation in frequency



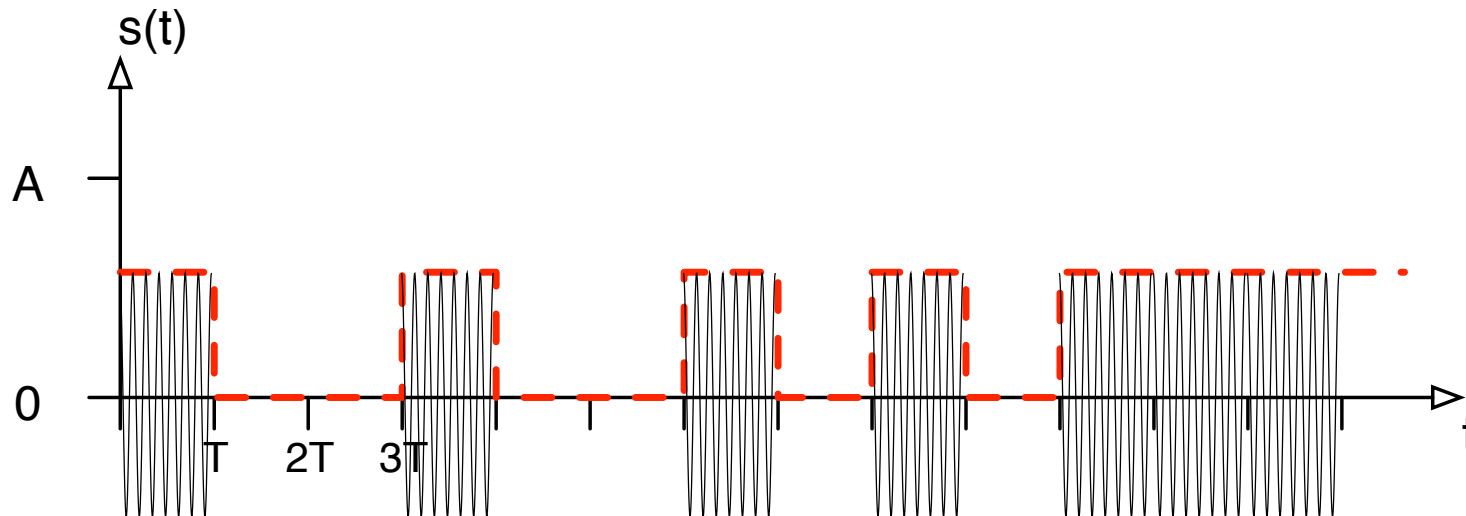
# ASK (Amplitude Shift Keying)

Use on-off keying at frequency  $f_0$ .

$$s(t) = \sum_n x_n g(t - nT) \cos(2\pi f_0 t)$$

Ex.

$x=10010010101111100$

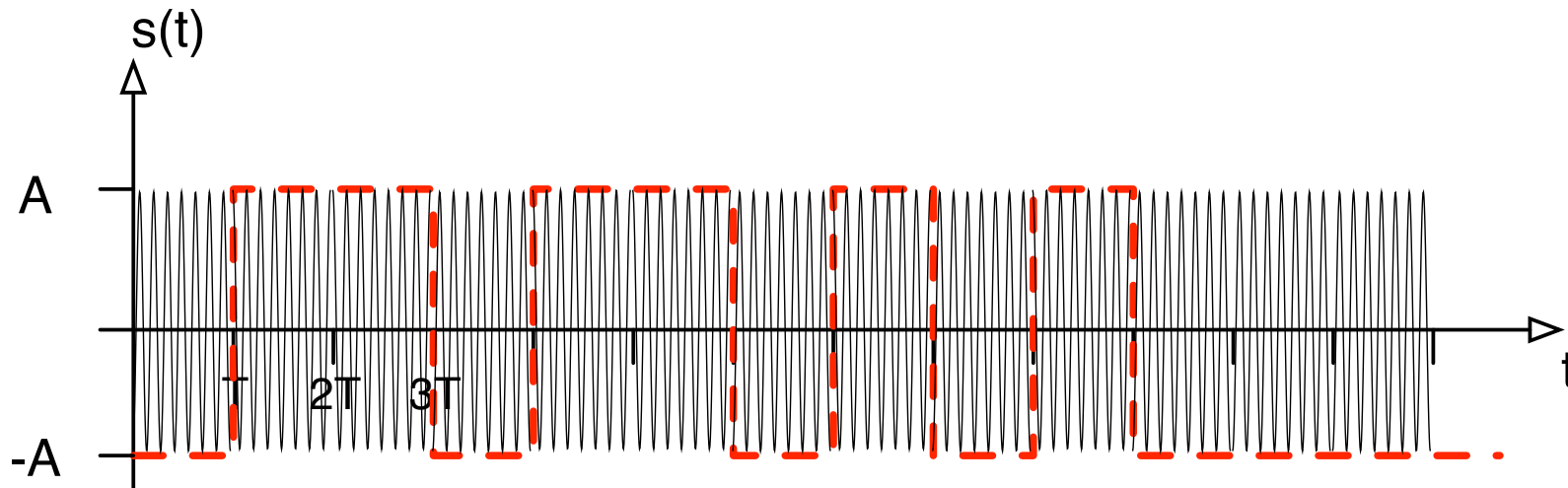


# BPSK (Binary Phase Shift Keying)

Use NRZ at frequency  $f_0$ , but view information in phase

$$s(t) = \sum_n (-1)^{x_n} g(t - nT) \cos(2\pi f_0 t) = \sum_n g(t - nT) \cos(2\pi f_0 t + x_n \pi)$$

$x=10010010101111100$



# QPSK and M-PSK

## Quadrature PSK

- 2 bits/signal gives 4 different phase levels,

$$s(t) = \sum_n g(t - nT) \cos\left(2\pi f_0 t + x_n \frac{\pi}{2}\right)$$

$$x_n \in \{0, 1, 2, 3\}$$

## M-PSK

- k bits/signal gives  $M=2^k$  different phase levels,

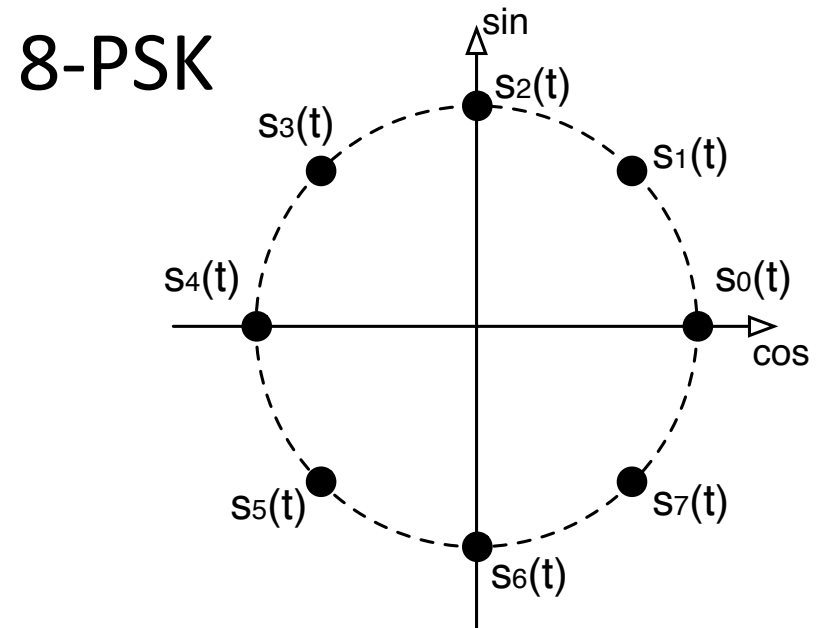
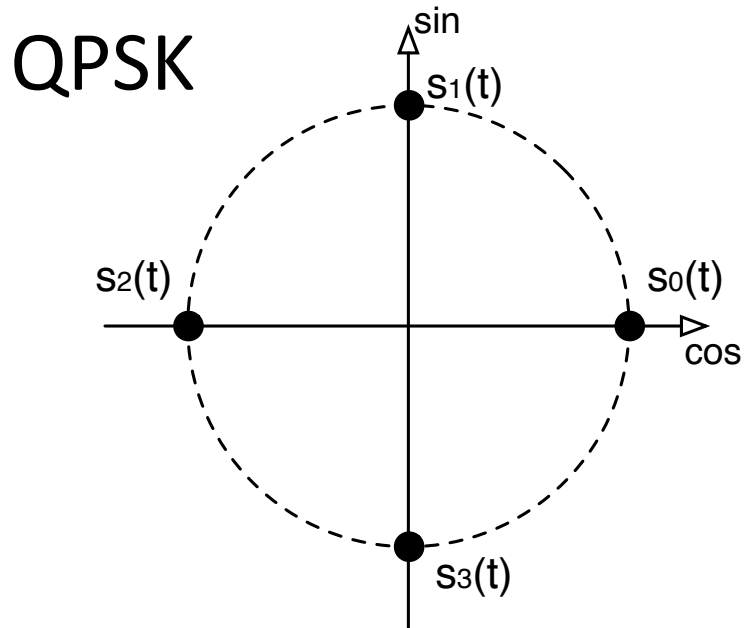
$$s(t) = \sum_n g(t - nT) \cos(2\pi f_0 t + \varphi_n)$$

$$\varphi_n = \frac{x_n}{M} 2\pi$$

$$x_n \in \{0, 1, \dots, M - 1\}$$

# Signal space

Since  $\cos(2\pi f_0 t + \frac{\pi}{2}) = \sin(2\pi f_0 t)$  and cos and sin behaves orthogonal, view PSK signals as points on a circle.

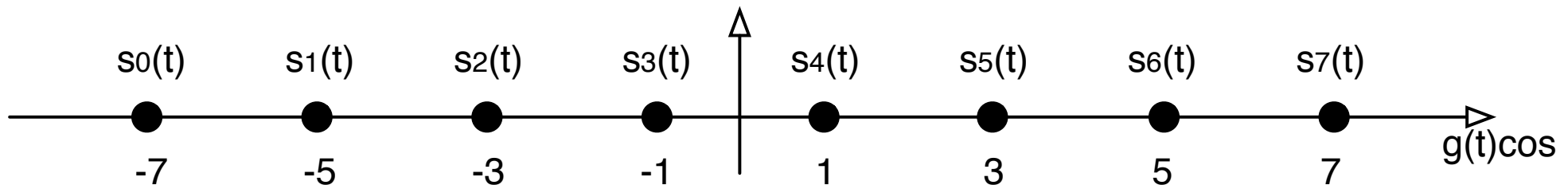




# M-PAM (Pulse Amplitude Modulation)

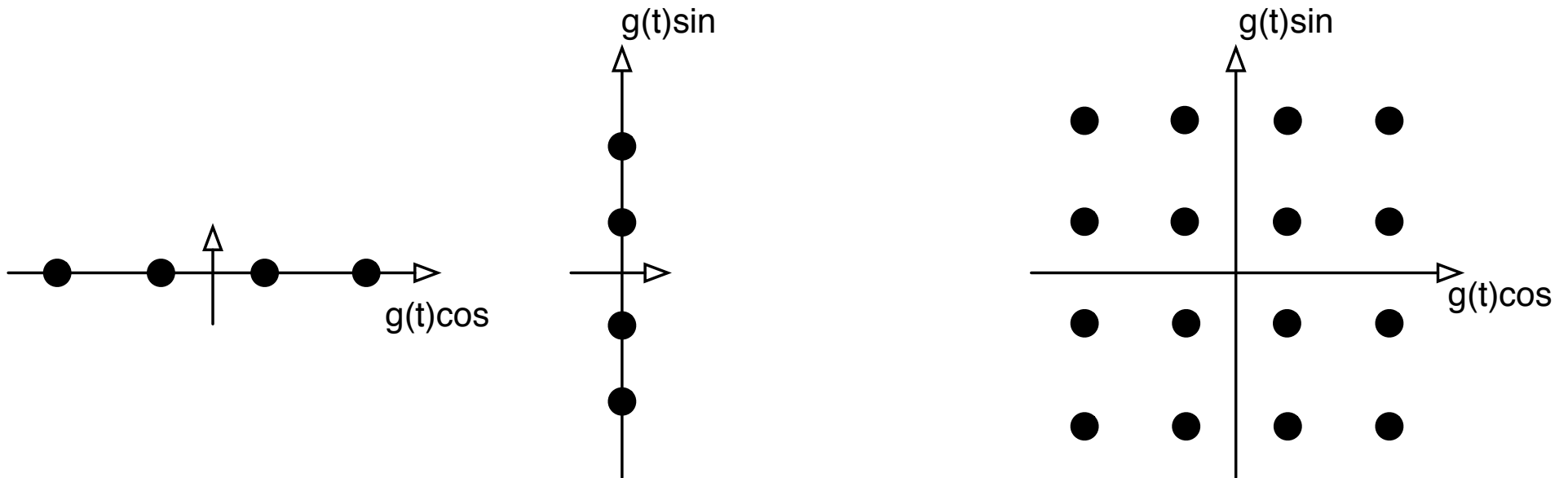
- Use amplitude for information carrier.
- $M=2^k$  amplitudes

$$s(t) = \sum_n a_n g(t - nT) \cos(2\pi f_0 t) \quad \text{where} \quad a_n = -M + 1 + 2x_n$$



# M-QAM (Quadrature amplitude Modulation)

Use that *cos* and *sin* are orthogonal to combine two orthogonal PAM constellations

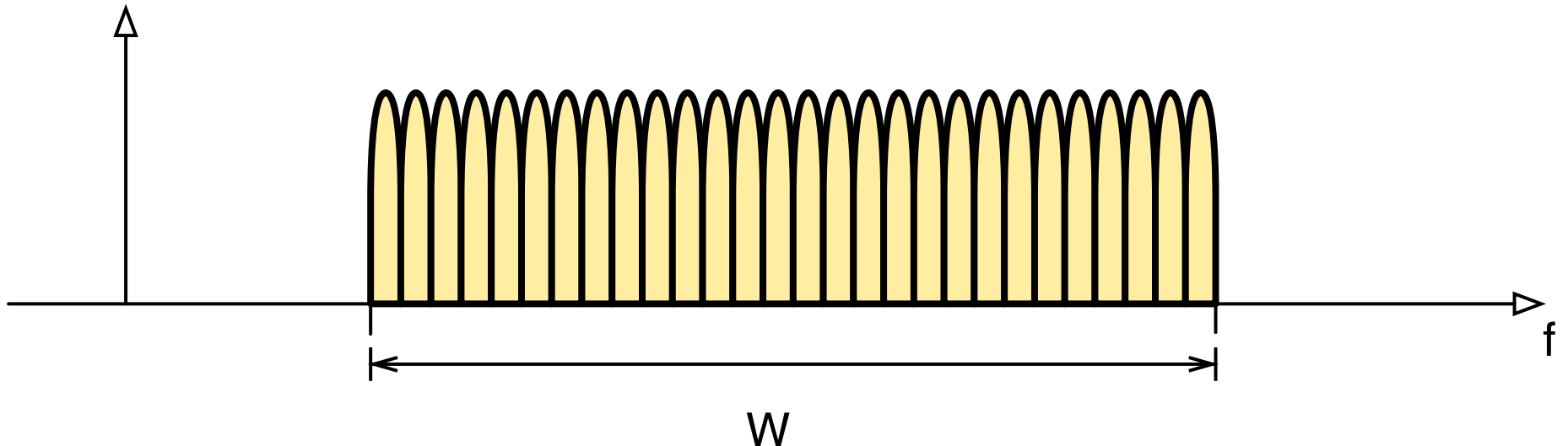


# OFDM

## Orthogonal Frequency Division Multiplexing

N QAM signals combined in an orthogonal way

- Used in e.g. ADSL, VDSL, WiFi, DVB-C&T&H, LTE, LTE-A



# Transmission media

## Guided media

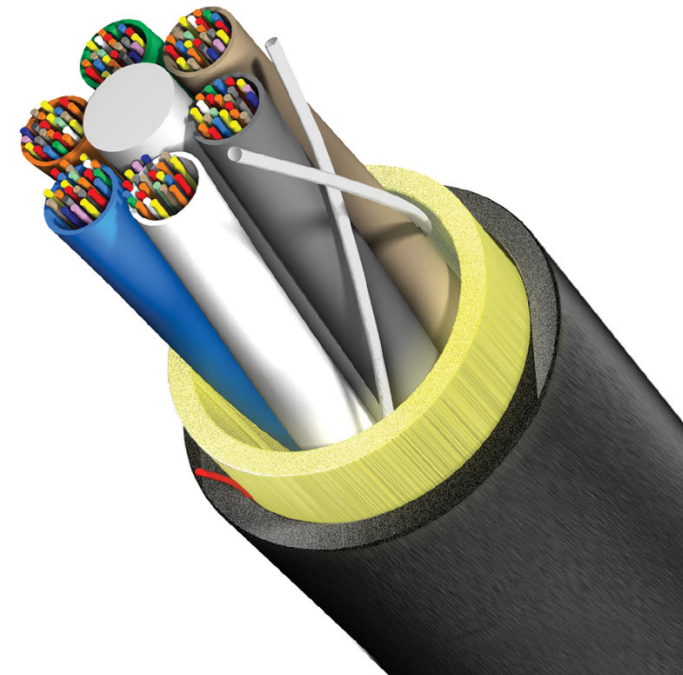
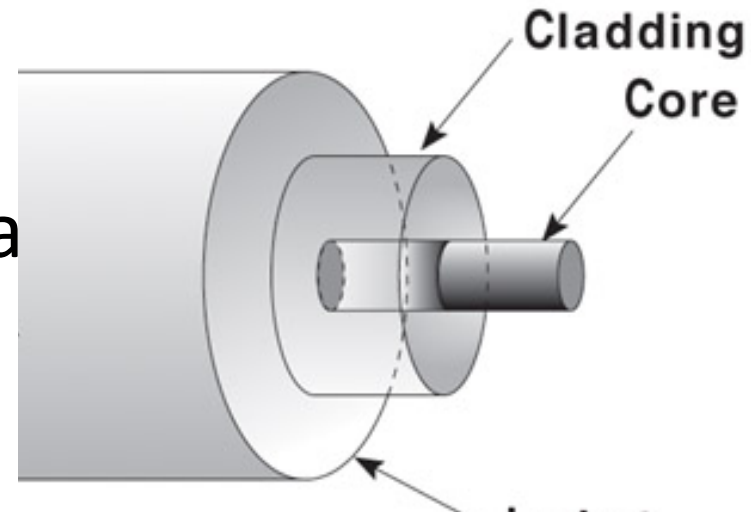
- Twisted pair copper cables
- Coax cable
- Fibre optic cable

## Unguided media

- Radio
- Microwave
- Infra red

# Fibre optic

- Transmission is done by light in a glass core (very thin)
- Total reflection from core to cladding
- Bundle several fibres in one cable
- Not disturbed by radio signals



# Optical network architecture

## Point to point

- Two nodes are connected by one dedicated fibre

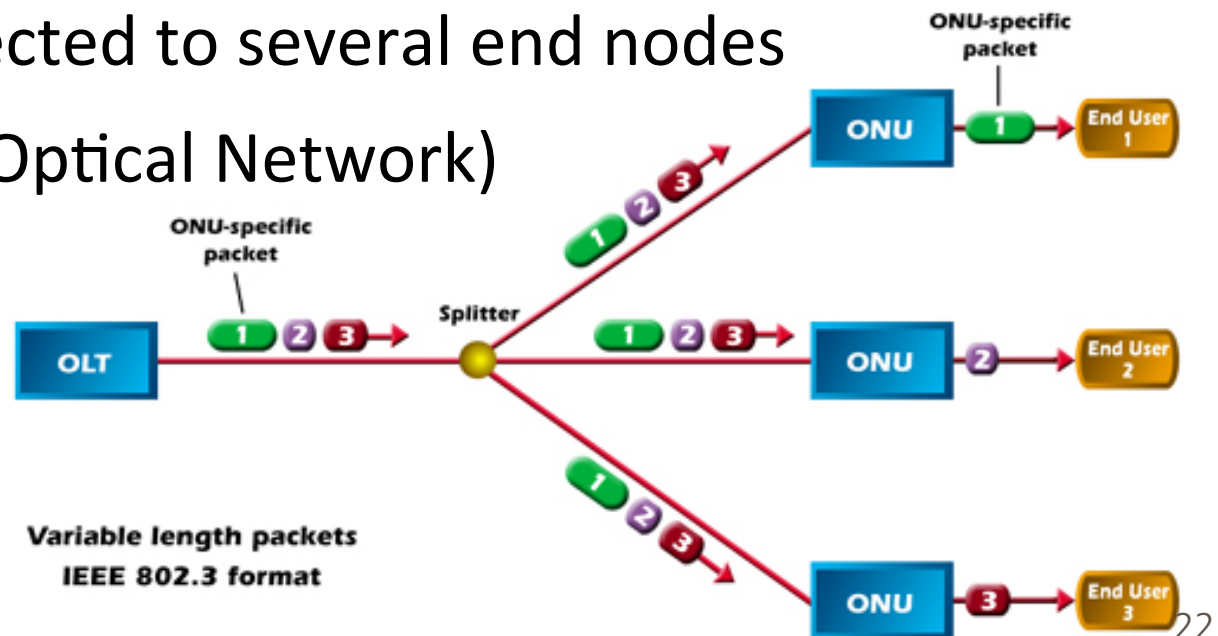
## Point to multi-point

- One node is connected to several end nodes

- PON (Passive Optical Network)  
2.5/1 Gbps

- Used in

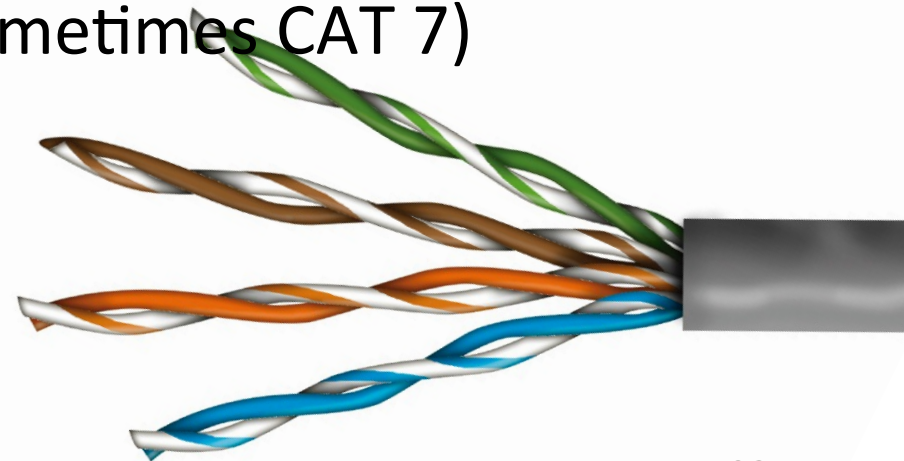
- Core network
- FttH



# Twisted pair copper cables

Two conductors twisted around each other

- Twisting decreases disturbances (and emission)
- Used for
  - Telephony grid (CAT3)
  - Ethernet (CAT5, CAT6 and sometimes CAT 7)



# Coax cable

One conductor surrounded by a shield

- Used for
  - Antenna signals
  - Measurement instrumentations



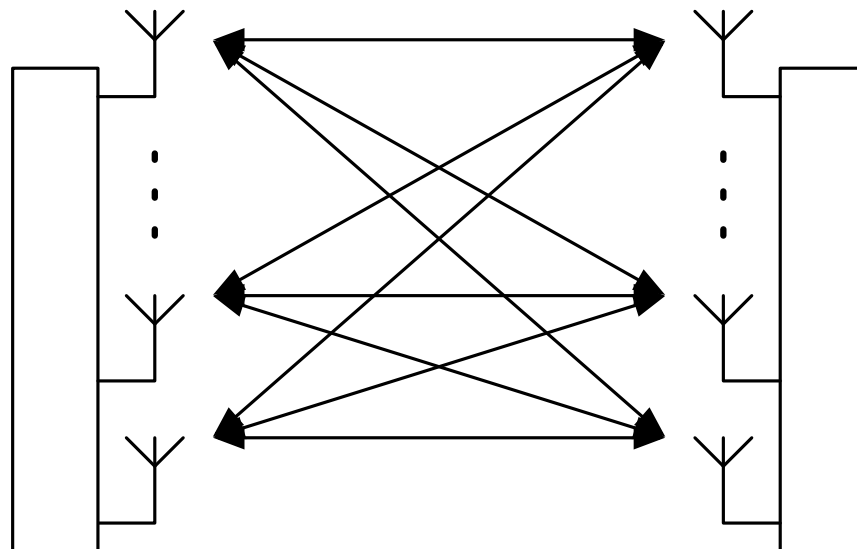


# Radio structures

Single antenna system



MIMO (Multiple In Multiple Out)



# Transmission impairments

When a signal is transmitted on a link, it will deteriorate due to transmission impairment:

- Attenuation, loss of energy
  - Electromagnetic emission
- Distortion, modification of signal shape
  - Multi-path propagation
- Noise, various noise sources

$$\text{Signal-to-noise ratio (SNR)} = \frac{\text{Average signal power}}{\text{Average noise power}}$$

# Noise disturbances

## Thermal noise

(Johnson-Nyquist)

- Generated by current in a conductor
- -174 dBm/Hz  
( $3.98 \cdot 10^{-18}$  mW/Hz)
- Relatively white

## Impulse noise

- Often user generated

## Intermodulation noise

- Different systems disturb each other

## Cross-talk

- User in the same system disturb each other

## Background noise

- Misc disturbances (e.g. Telephony cable -140 dBm/Hz)

# Additive white noise

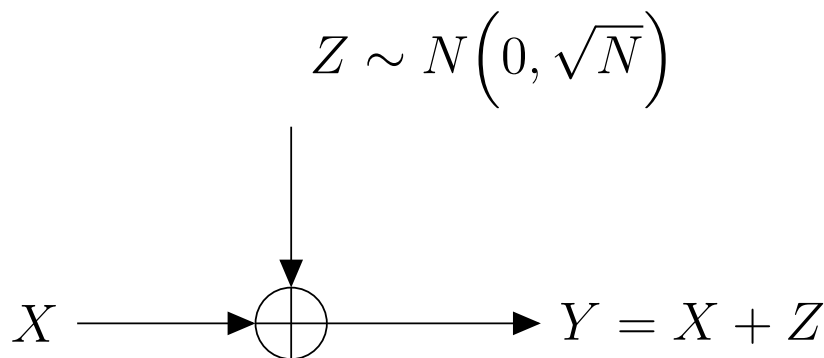
A commonly used model for noise is the AWGN channel (Additive White Gaussian Noise)

- White noise with  $PSD(f) = N_0/2$  is added to the signal
- After LP filter and sampling the added noise samples are Gaussian distributed

$$z_n \sim N\left(0, \sqrt{N_0/2}\right)$$

# Gaussian channel

A Gaussian channel is a statistical transmission model with input variable  $X$  of total power  $E[X^2] < P$  and output variable  $Y = X + Z$ , where  $Z$  is Normal distributed with zero mean and variance  $N$ .



# A glimpse of Information Theory



- The channel represents all impairments during transmission.
- The information about  $X$  by observing  $Y$  is given by the mutual information

$$I(X;Y) = \int_{R^2} f(x,y) \log_2 \frac{f(x,y)}{f(x)f(y)} dx dy$$

Maximise for  $E[X^2]=P$  over all distributions to get the channel capacity

$$C = \max_{f(x), E[X^2]=P} I(X;Y)$$

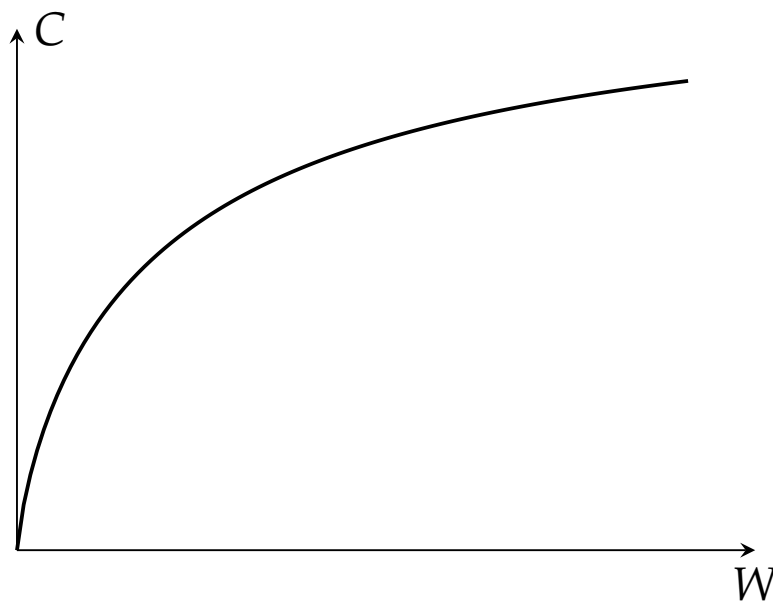
For the Gaussian channel

$$\begin{aligned} C &= \frac{1}{2} \log_2 \left( 1 + \frac{P}{N} \right) \\ &= \frac{1}{2} \log_2 (1 + SNR) \end{aligned}$$

# Shannon capacity

If  $s(t)$  is a band limited signal with bandwidth  $W$  and power  $P$  is transmitted over an AWGN channel, the maximum achievable data rate [b/s] is given by

$$C = W \log_2 \left( 1 + \frac{P}{N_0 W} \right)$$
$$= W \log_2 (1 + SNR)$$



# Fundamental Shannon limit

Letting the bandwidth approach infinity gives

$$C_{\infty} = \lim_{W \rightarrow \infty} W \log \left( 1 + \frac{P/N_0}{W} \right) = \frac{P/N_0}{\ln 2}$$

The achieved bit rate is  $R_b = T_s/k$ . Then  $\frac{C_{\infty}}{R_b} = \frac{E_b/N_0}{\ln 2} > 1$

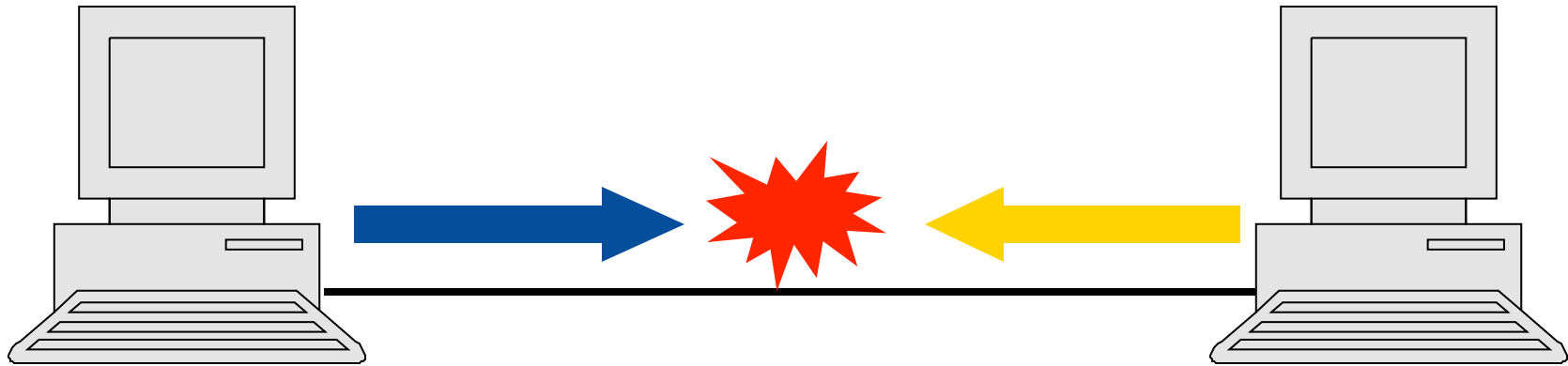
Hence, communication is only possible if

$$\frac{E_b}{N_0} > \ln 2 = 0.69 = -1.59 \text{ dB}$$

Approaching the limit means letting the computational complexity go to infinity.

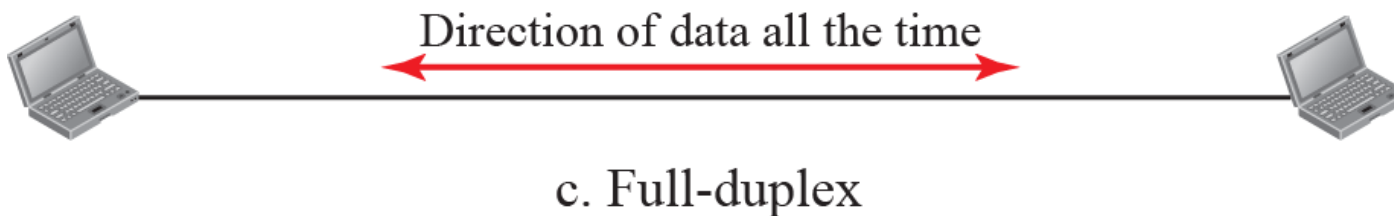
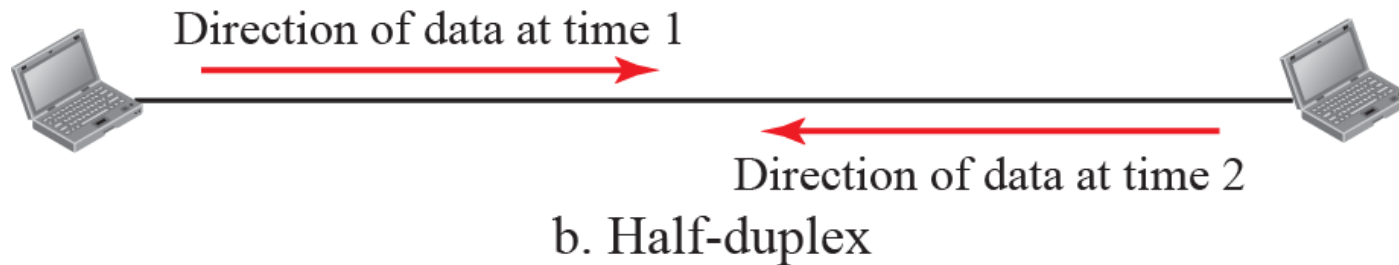
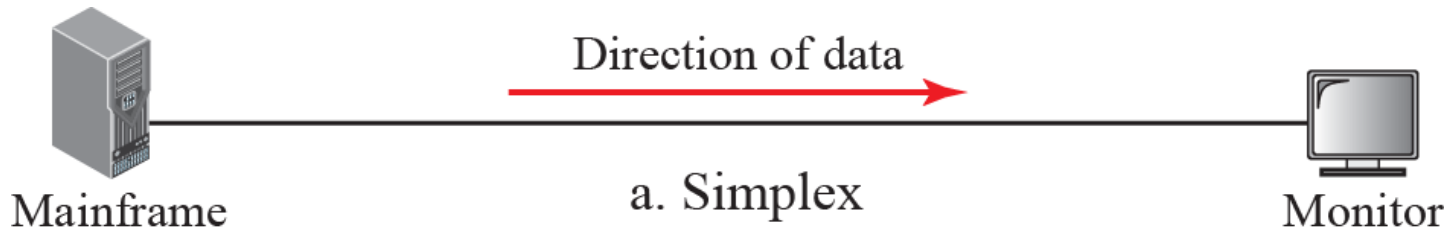


# Data communication



Two nodes that transmit data on a physical link cannot do this simultaneously on the same frequencies with the same coding scheme.

# Data flow concepts



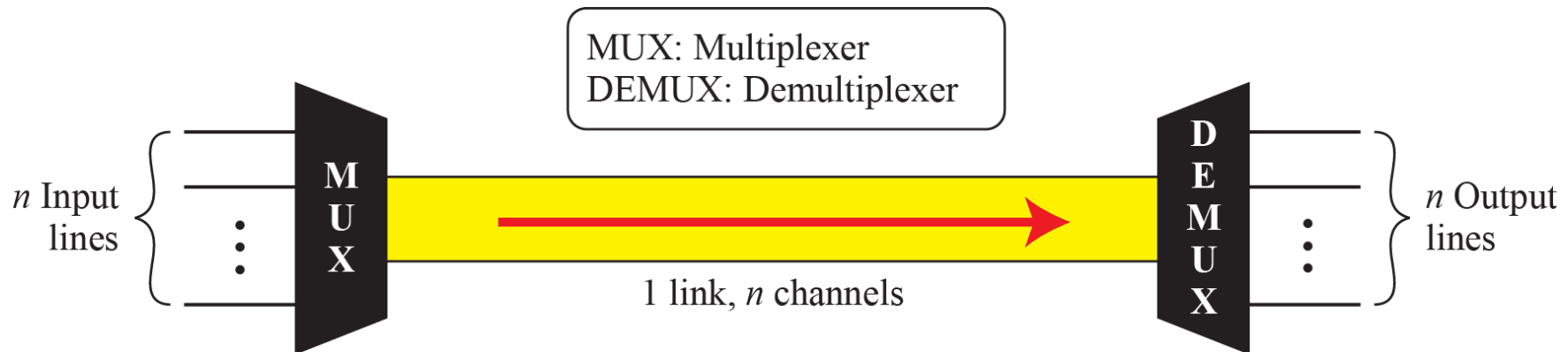
# Duplexing

Duplex communication can be achieved by

- TDD (Time Division Duplexing)  
Each direction has its time slots to transmit in.
- FDD (Frequency Division Duplexing)  
Each direction has its frequency slots to transmit in

# Multiplexing of links

Also, physical links need to be shared. This is called *multiplexing*, where one physical link is divided into several *channels*.



# Multiplexing techniques

5 basic types of multiplexing techniques:

- Space-Division multiplexing (SDM)
- Time-Division Multiplexing (TDM)
- Frequency-Division Multiplexing (FDM)
- Wavelength-Division Multiplexing (WDM)
- Code-Division Multiple Access (CDMA)

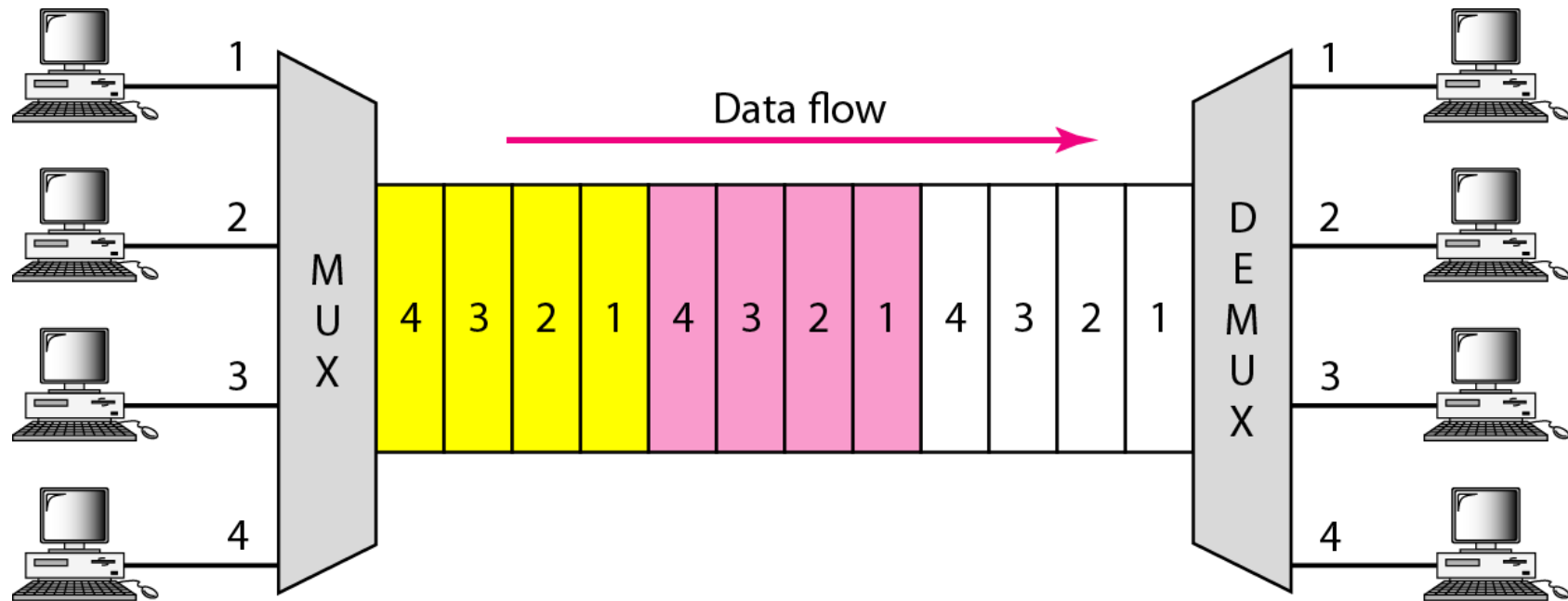
# Space-Division Multiplexing (SDM)

SDM is used in cables. Each channel uses one line (optical fibre or twisted pair).



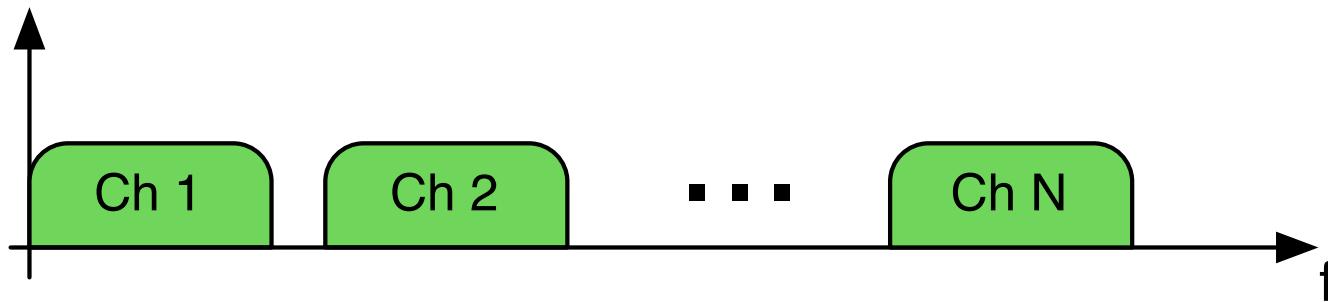
# Time-Division Multiplexing (TDM)

In TDM, each channel occupies a portion of the **time** in the link.



# Frequency-Division Multiplexing (FDM)

FDM is an analog multiplexing technique where each link has its own frequency band

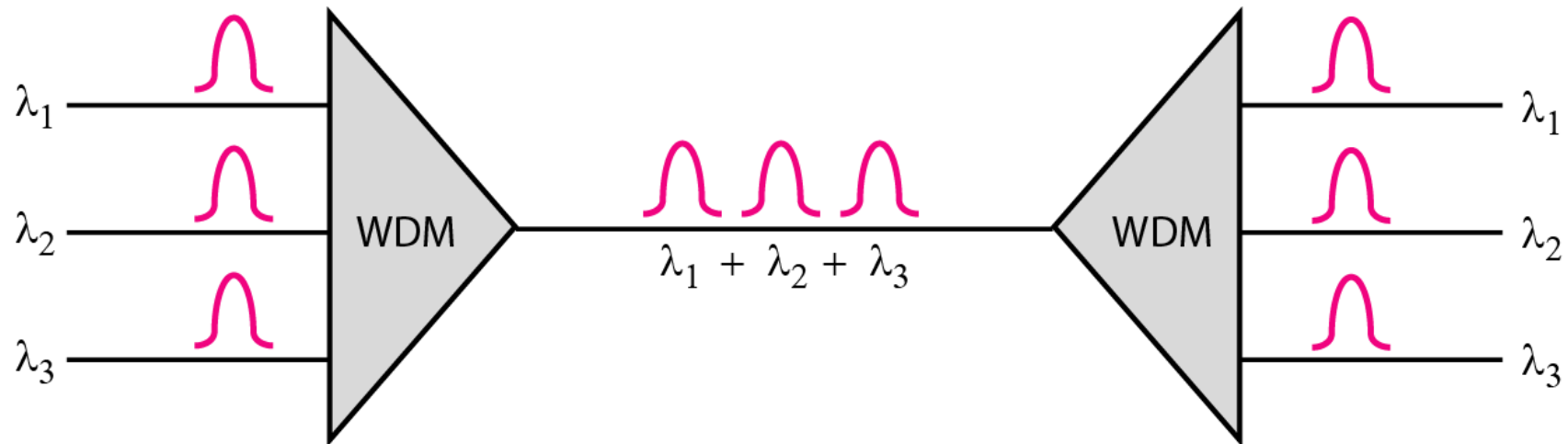


Each channel uses a unique carrier frequency.



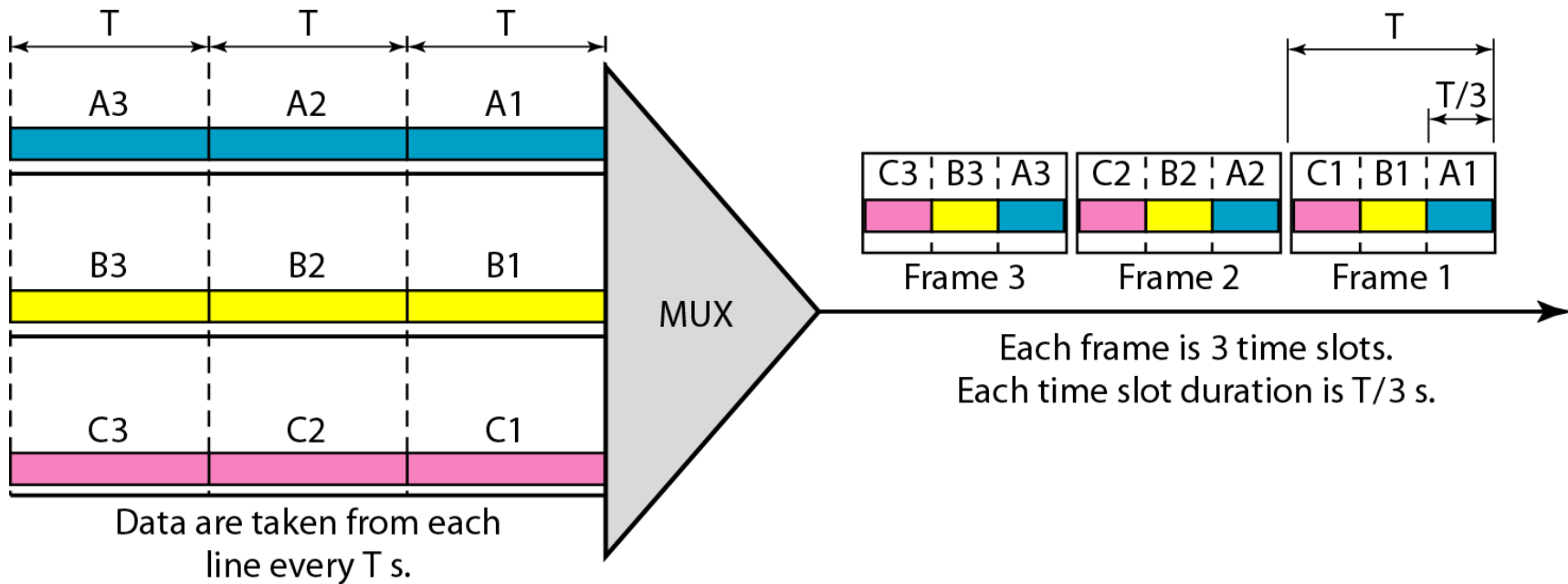
# Wavelength-Division Multiplexing (WDM)

In an optical fibre different wavelengths can be combined.

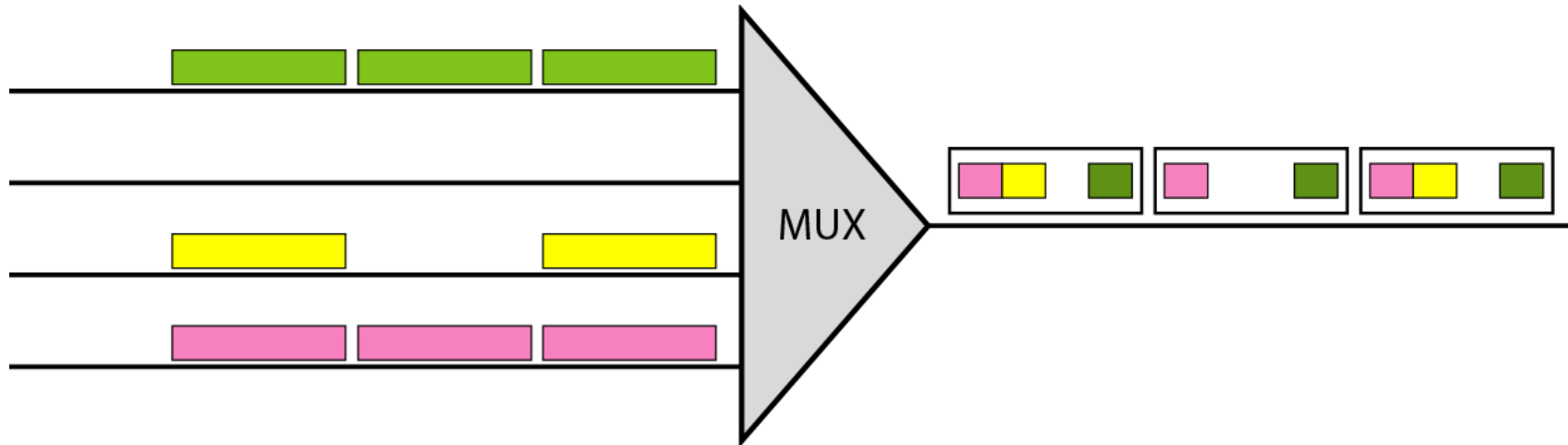


# Synchronous TDM

If a channel has nothing to send, its time slots will be empty!



# Example: Empty slots



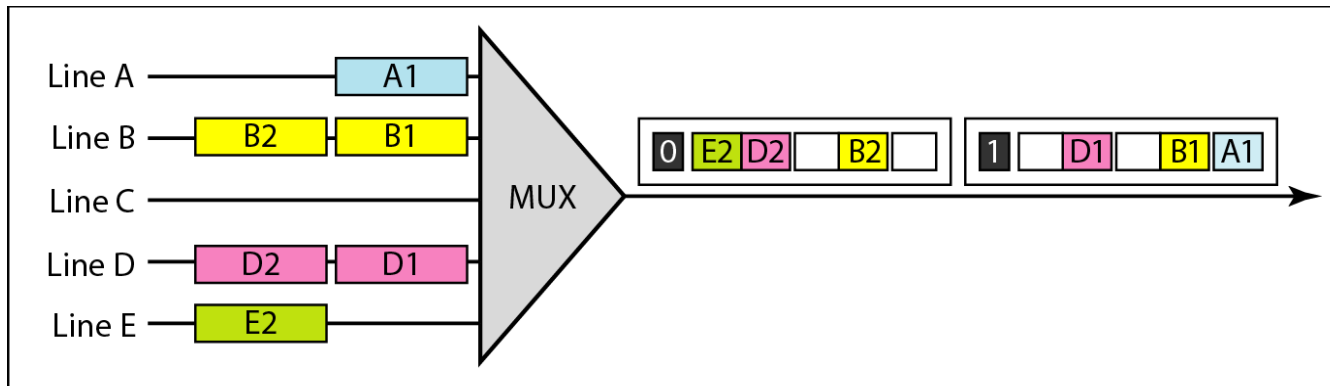
# Statistical Time-Division Multiplexing

In Statistical TDM, the channels have no reserved time slots. Instead, slots are dynamically allocated.

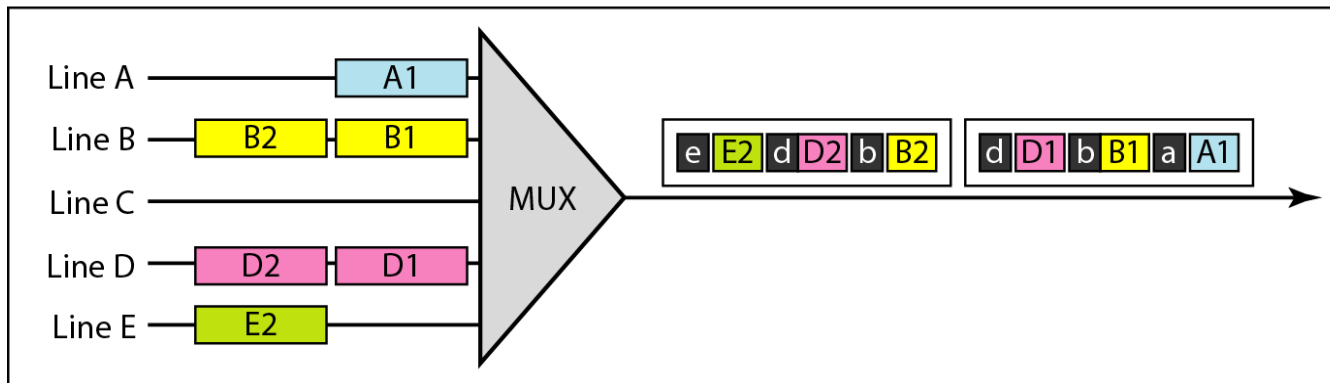
Data about the destination is added to each slot.

Statistical TDM usually has better performance than Synchronous TDM when not all channels transmit data all the time.

# TDM comparison



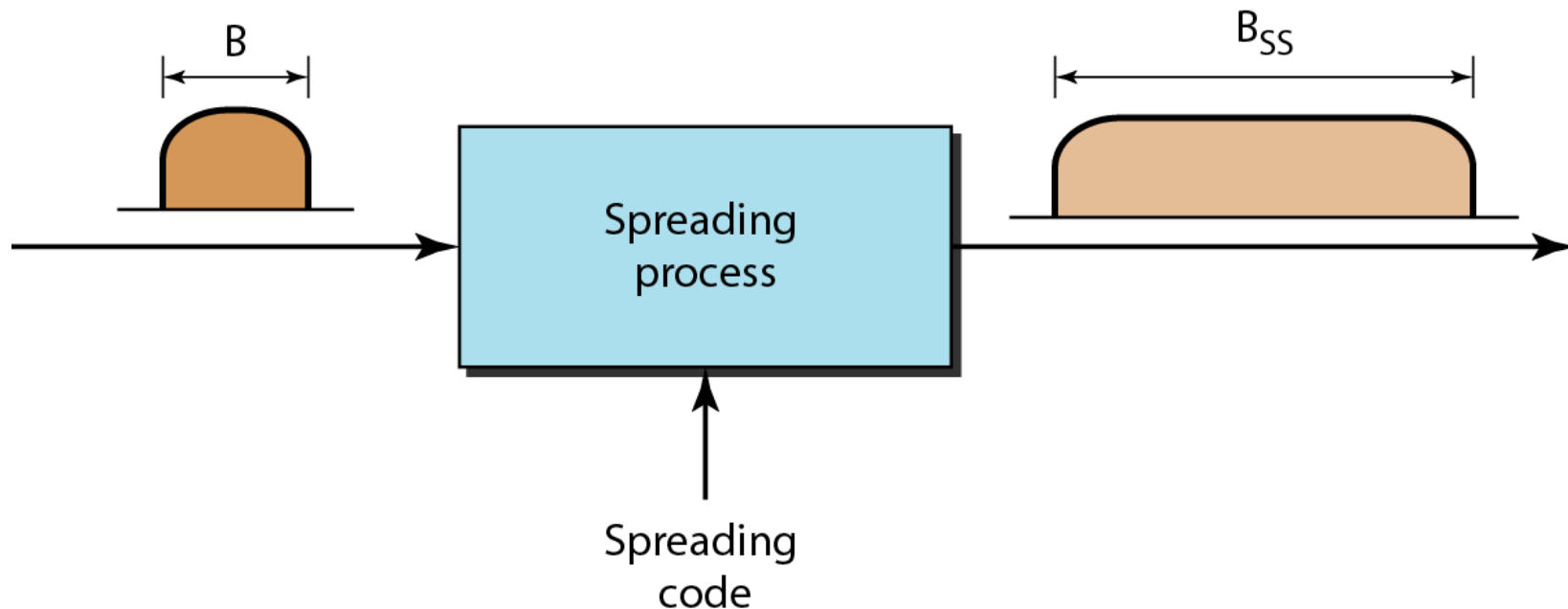
a. Synchronous TDM



b. Statistical TDM

# CDMA (Code-Division Multiple Access)

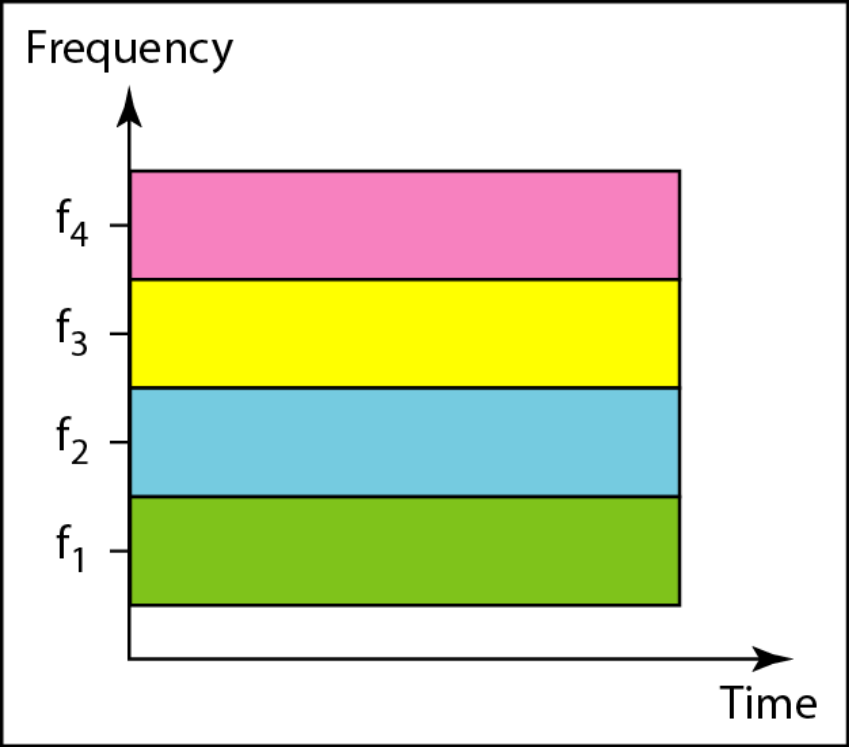
CDMA, or Spread Spectrum, is a multiple access technique for wireless links. The original signal is changed in a spreading process.



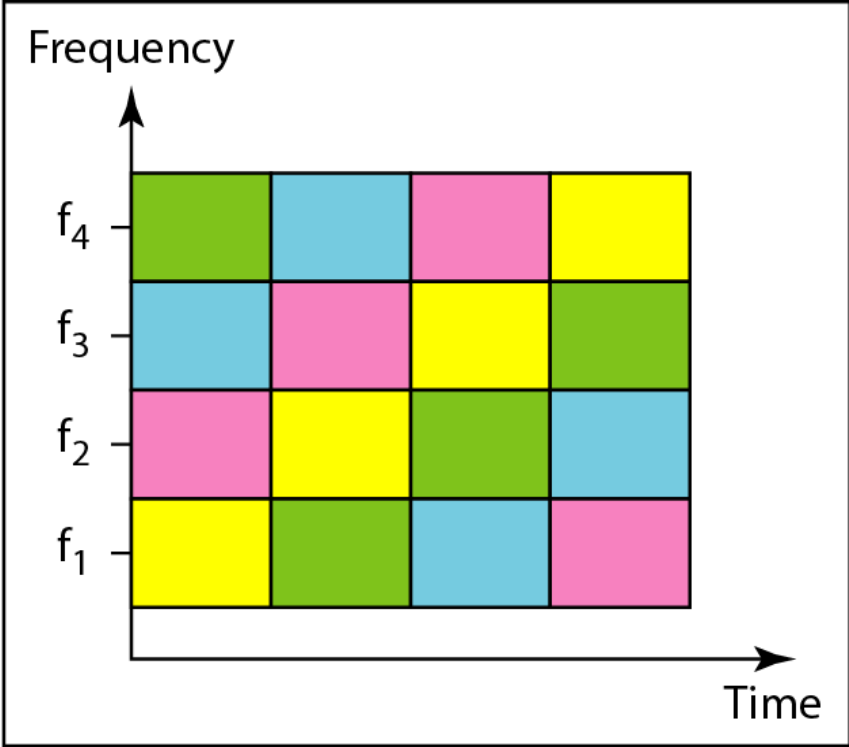
# Spread Spectrum techniques

- Frequency Hopping Spread Spectrum (FHSS)
  - A source uses many carrier frequencies. One frequency is used at a time, but the frequencies are changed very often (e.g. 1000 times a second).
- Direct Sequence Spread Spectrum (DSSS)
  - Each data bit is replaced with  $n$  bits (called chips) using a unique spreading code. The chip sequences for all users are orthogonal.

# Comparison with FDM



a. FDM

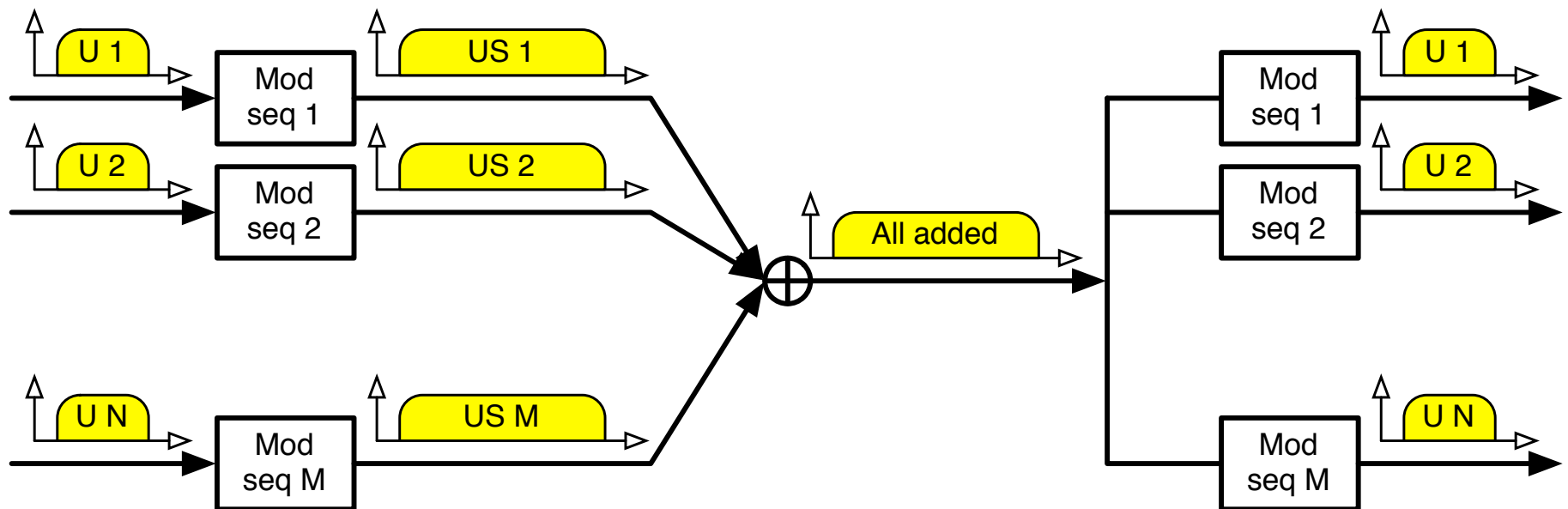


b. FHSS

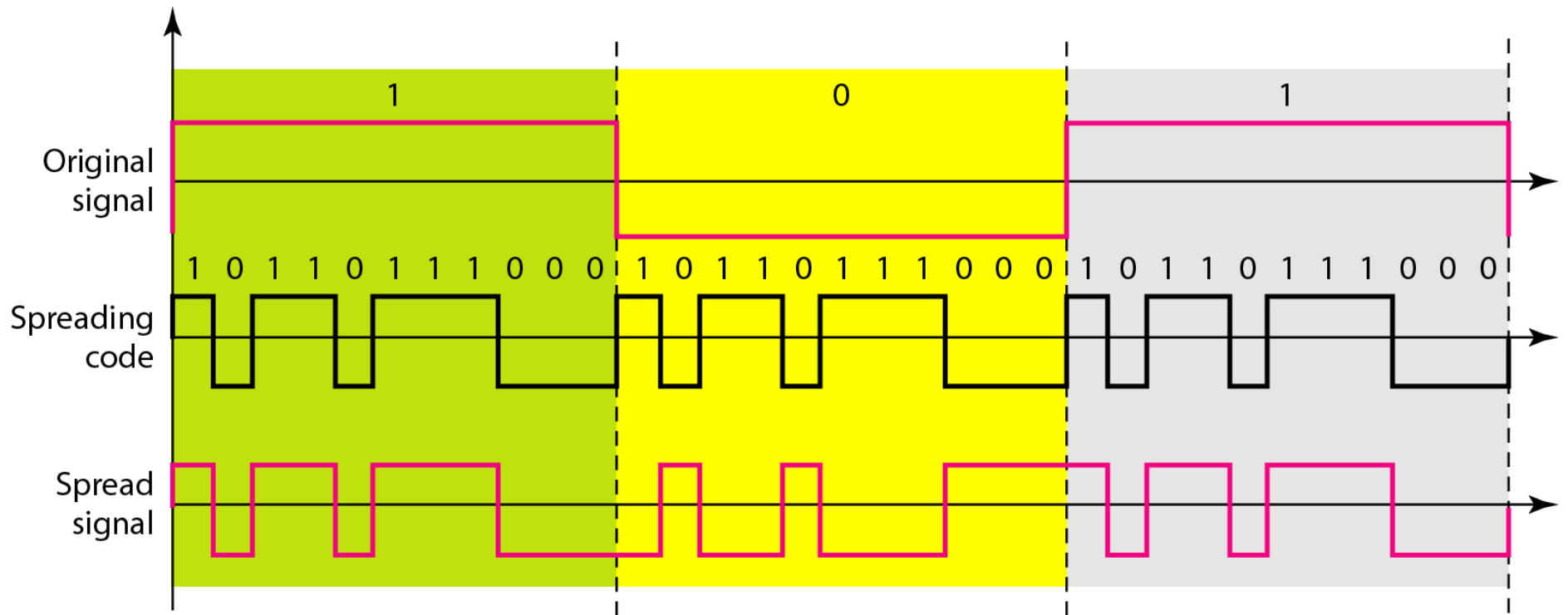


# DSSS

The original signal is combined with the spreading code.



# DSSS example



# OFDMA (OFDM access)

## Multi-user OFDM

