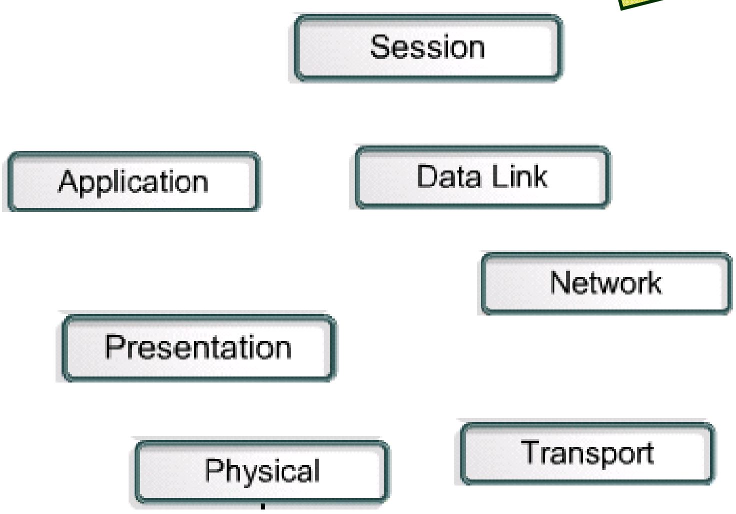
Datacommunication I

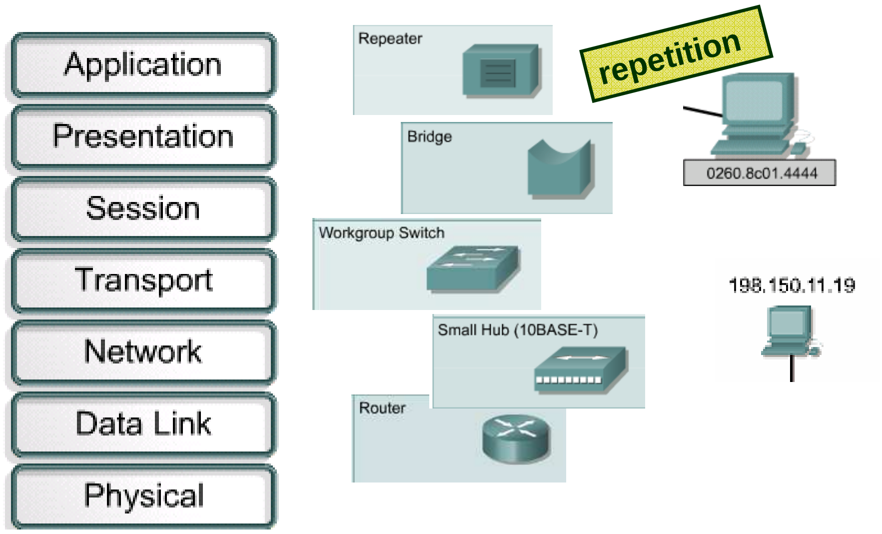
Lecture 3 –
signal encoding, error detection/correction

Layers of the OSI-model

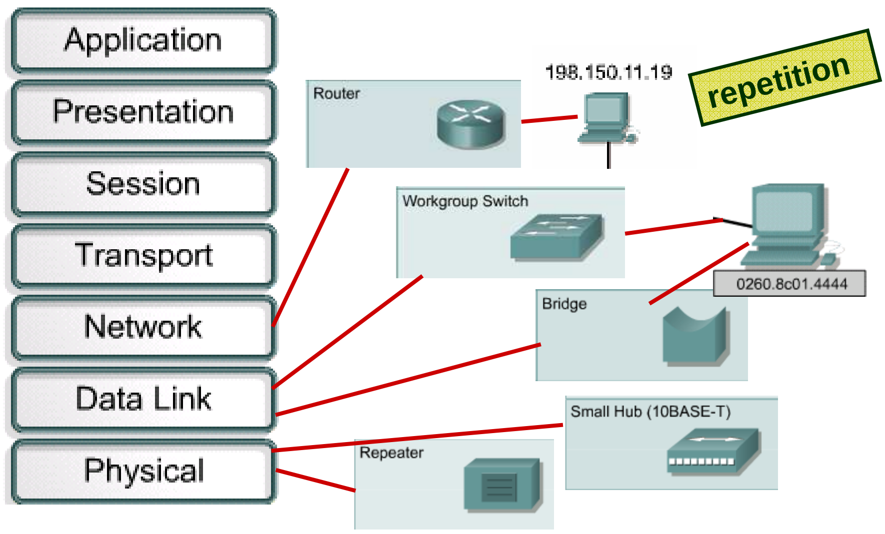
repetition



The OSI-model and its networking devices



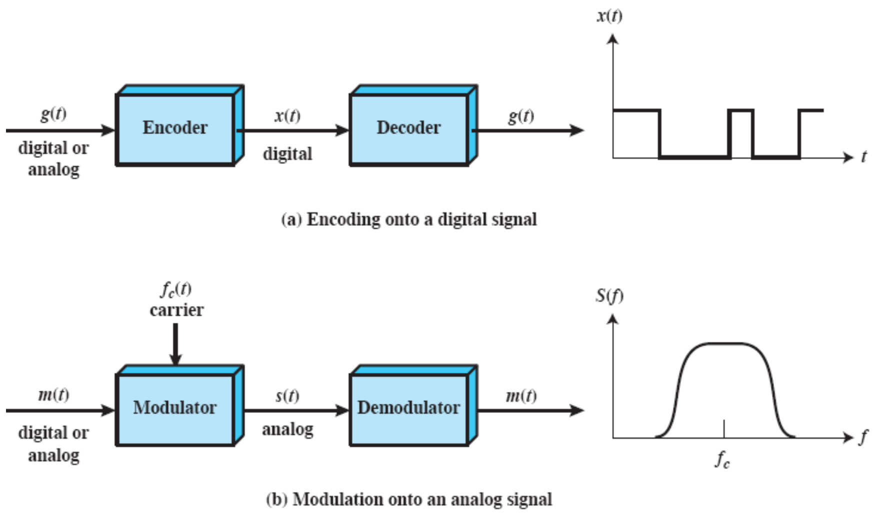
The OSI-model and its networking devices



Data encoding

- Turning data (digital or analog) into signals (digital or analog)
  - Encoders and decoders ("codec") are used for digital signals
  - Modulators and demodulators ("modem") are used for analog signals
- Why change between analog and digital?
  - Copper wires e.g. can handle both digital and analog signals. But cheap and fast networking equipment (e.g. switching technology) only works on digital signals
  - Unguided media and optical fibers only operate with analog signals
- In this course: focus on digital data as input

Data encoding



Repetition of some terms

- Simplest form:
  - One data element <-> one signal element
- Data rate (measured in bits/s)
- Signal rate
  - measured in signal elements per second or ”baud”
  - Also called modulation rate or baud rate
- Bit error rate (BER)
  - the number of erroneous bits received divided by the total number of bits transmitted
- Signal to Noise Ratio (SNR)
  - Ratio of a signal power to the noise power corrupting the signal

Bit rate vs. Signal rate

Term	Units	Definition
Data element	Bits	A single binary one or zero
Data rate	Bits per second (bps)	The rate at which data elements are transmitted
Signal element	Digital: a voltage pulse of constant amplitude Analog: a pulse of constant frequency, phase, and amplitude	That part of a signal that occupies the shortest interval of a signaling code
Signaling rate or modulation rate	Signal elements per second (baud)	The rate at which signal elements are transmitted

Some general truths about data rate etc.

An increase in data rate ____________ the BER

An increase in SNR ____________ the BER

An increase in bandwidth allows an _________ in data rate

Increase????

Decrease?????

Some general truths about data rate etc.

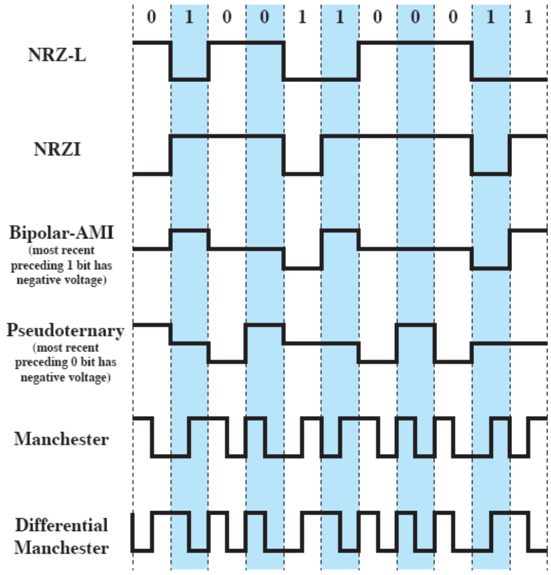
An increase in data rate increases the BER

An increase in SNR decreases the BER

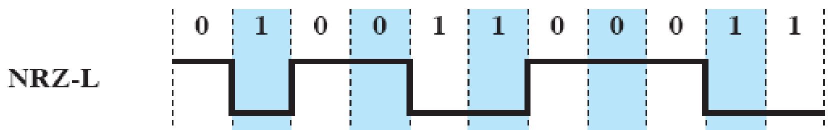
An increase in bandwidth allows an increase in data rate

Digital data, digital signals

Digital signal encoding schemes

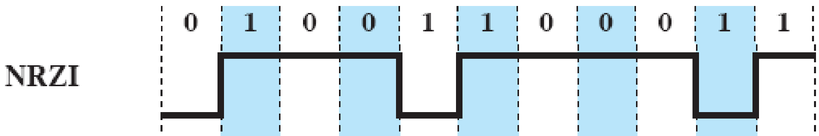


NRZ(-L) – Nonreturn to Zero (-Level)



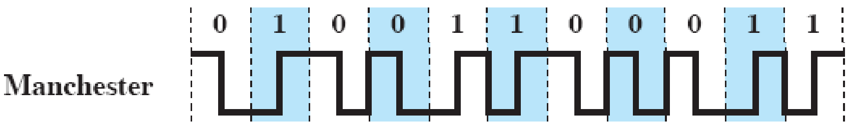
- Different types:
  - E.g. no voltage = 0, +voltage = 1
  - NRZ-L: -voltage = 1, +voltage = 0
- Data rate = signal rate
- Constant value during the whole bit duration
- Problems
  - Lack of synchronization possibilities

NRZI – Nonreturn to Zero, invert on ones



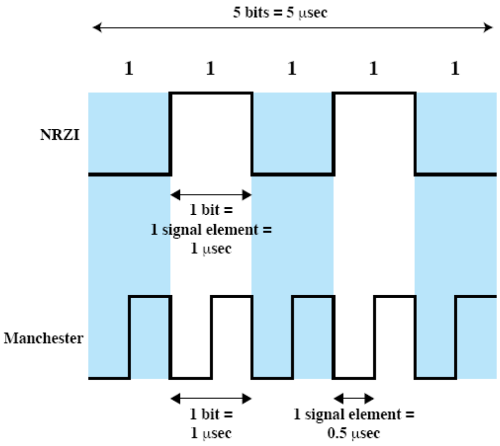
- Bits are encoded not through the voltage level itself but through the existance or absense of transitions between the levels (”Differential encoding”)
  - Transition = 1
  - No transition = 0
- Easier to detect transition than a signal level (especially in the presence of noise)

Manchester encoding (”Biphase encoding”)



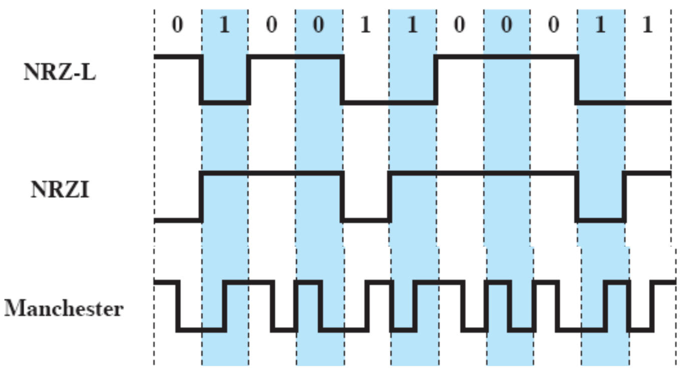
- Transition in the middle of the bit
  - High to low for 0
  - Low to high for 1
- Offers a chance to clock synchronize at every bit (”self-clocking code”)
- Offers ”error detection”
  - No transition during a bit -> error
- Signal rate = 2 x data rate
- Popular (used e.g. in Ethernet standard)

More about the signal rate



- D=R/L
  - D = signal rate (baud or signal elements/s)
  - R = data rate (bits/s)
  - L = nbr. bits per signal element

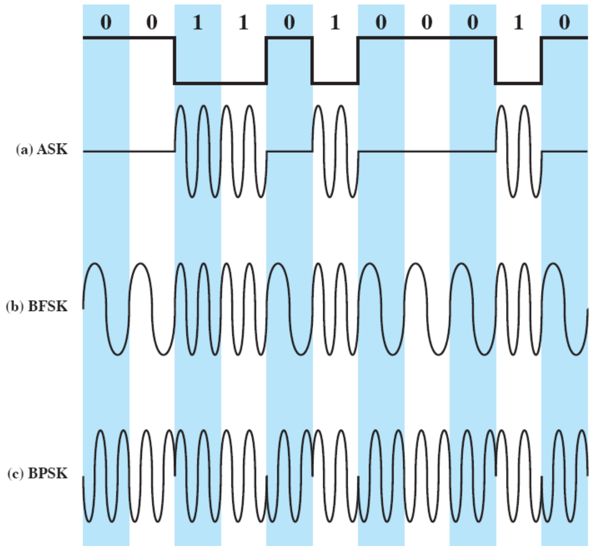
Signal transition rate



Signal transition rate

	min	101010…	max
NRZ-L	0 (all 0 or 1)	1	1
NRZI	0 (all 0)	0,5	1 (all 1)
Manchester	1	1	2 (all 0 or 1)

Digital data, analog signals



Amplitude Shift Keying (ASK)

- E.g. used for optical fibers
- No amplitude = 0
- Amplitude = 1

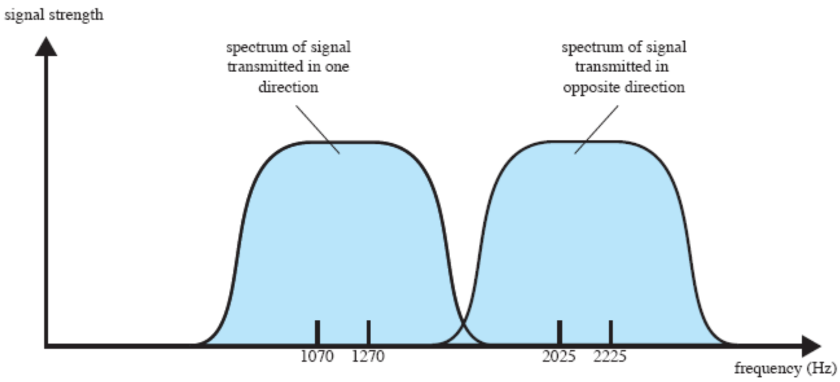
$$s(t) = \begin{cases} A\cos(2\pi f t) \\ 0 \end{cases}$$

Binary Frequency Shift Keying (BPSK)

- Used frequently
- 2 different frequencies used to encode 0 and 1
- Less susceptible to error than ASK
- Full duplex possile
  - Use separated frequency bands, one for each transmission direction

$$s(t) = \begin{cases} A\cos(2\pi \; f_1 t) \\ A\cos(2\pi \; f_2 t) \end{cases}$$

Full duplex in BFSK

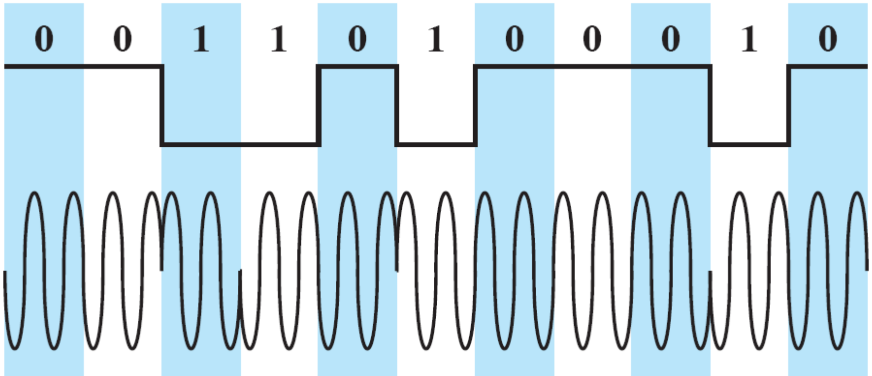


Phase Shift Keying (PSK)

- Binary Phase Shift Keying (BPSK)
  - A phase denotes 1, another phase denotes 0
- Differential PSK (DPSK)
  - A transition denotes 1
  - No transition denotes 0

$$s(t) = \begin{cases} A\cos(2\pi ft) \\ A\cos(2\pi ft + \pi) \end{cases}$$

Example DPSK



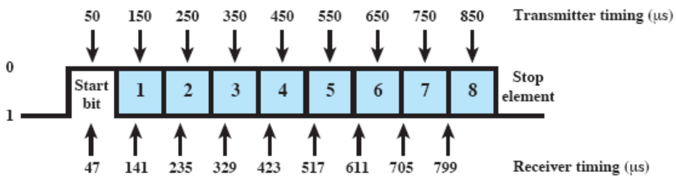
Quadrature Phase Shift Keying (QPSK)

- 4 different phases used
- Each phase denotes 2 bits

$$s(t) = \begin{cases} A\cos(2\pi ft + \frac{\pi}{4}) \longrightarrow 11 \\ A\cos(2\pi ft + \frac{3\pi}{4}) \longrightarrow 01 \\ A\cos(2\pi ft - \frac{3\pi}{4}) \longrightarrow 00 \\ A\cos(2\pi ft - \frac{\pi}{4}) \longrightarrow 10 \end{cases}$$

Synchronization

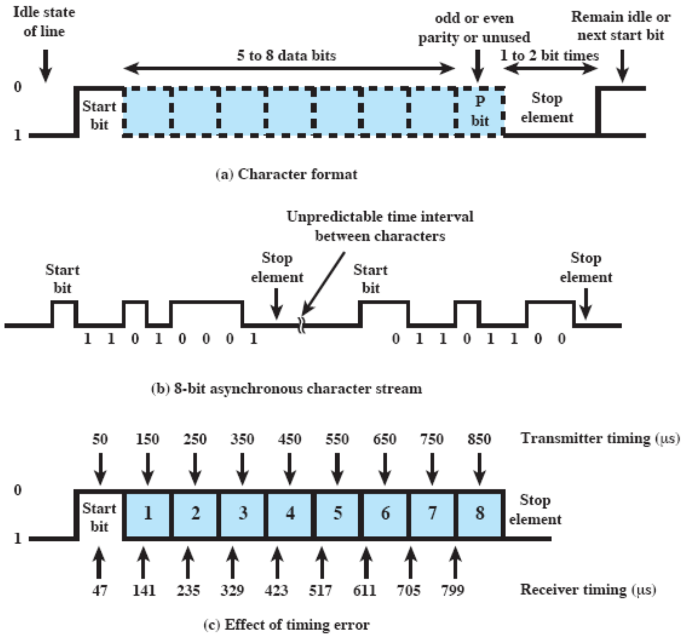
- Needed between transmitter and receiver
  - Receiver needs to ”read” the incoming stream once a signal
  - Clock drifting leads to synchronization errors
- Two types of transmission
  - Asynchronous transmission
  - Synchronous transmission



(c) Effect of timing error

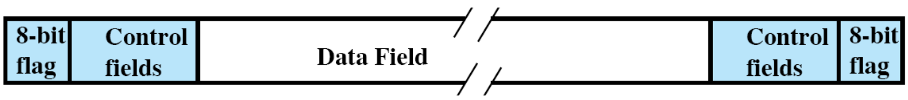
Asynchronous transmission

- New definitions
  - ”character” = block of a couple of bits (5-8)
  - ”idle” = a state where no data is sent (or ready to be sent and the equipment is in a waiting state
- Synchronization done before every character
  - Start bit at the beginning of each character
  - Stop element ends a character
  - Possible idle state between character transmissions
- Disadvantages
  - Simple and cheap but much overhead



Synchronous transmission

- Blocks of bits are sent in a steady stream
  - No start and stop bits
- Synchronization through
  - self-clocking code (e.g. Manchester)
  - Separate clock line between transmitter and receiver
- Data ”frame”
  - Preamble to let the receiver know that a frame start
  - Block of data
- Far less overhead than assynchronous transm.



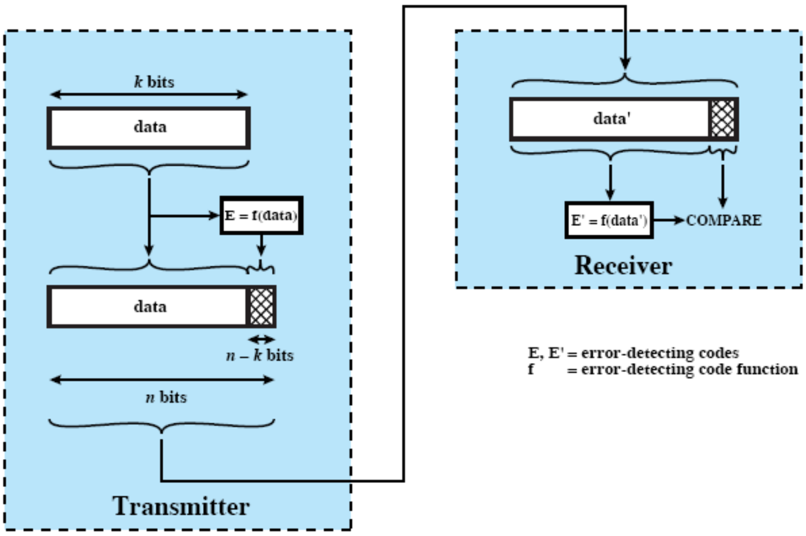
Error detection and correction

- Bit errors occur as
  - Single bit errors
  - Error bursts
    - Large number of bits affected
    - Due to impulse noise
- Bit errors can be detected by error detecting code or detected and corrected by error correcting code

Error detection

- A function is applied to a block of data
- The result is sent together with the data
- The receiver applies the same function to the data and compares the results
- Transmitter is informed about the erroneous data transmission (and asked for retransmission)
- Receiver cannot correct the errors
- Examples:
  - Parity check
  - Cyclic Redundancy Check (CRC)

Error detection



Parity Check

- Add a parity bit to the data block
- Two types
  - Even parity
    - Create an even number of "ones" by adding a parity bit
  - Odd parity
    - Create an odd number of "ones" by adding a parity bit

Even parity:	1001000111100
	1101110100101
Odd parity:	1001000111101
	1101110100100

Cyclic Redundancy Check (CRC)

- Commonly used
- Able to detect most errors
- Transmitter creates a frame check sequence (FCS) and sends it along with the data
  - The FSC gives no remainder when the data block is divided by it
  - Gives the receiver a chance to check for errors
- How to create a suitable FCS?
  - Several methods
  - E.g. through XOR with a predetermined bit pattern

CRC example

Data block: 1101001110100
Bit pattern: 1011

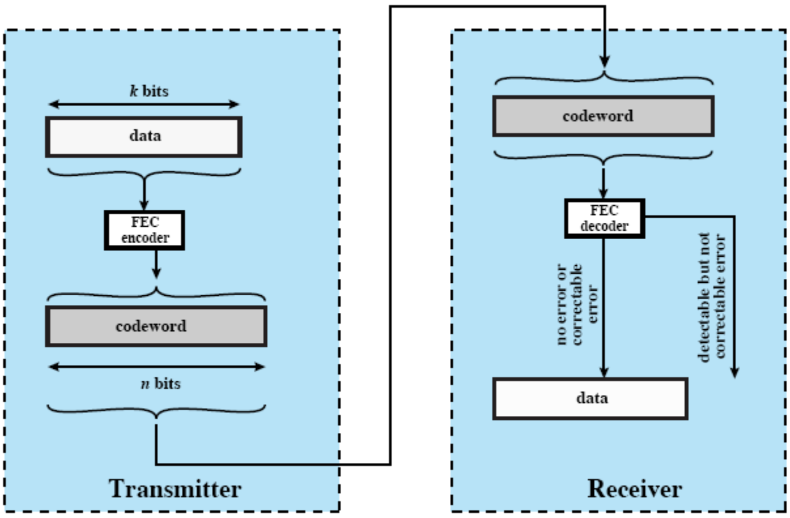
1101001110100
1011 **xor**
0110001110100
_1011
0011101110100
__1011
…
0000000001110
__________1011
0000000000101

FCS: 101

Error correcting codes

- Receiver can detect and correct the error by itself
  - No retransmission required
  - Saves resources
- Codeword is created out of data block
- Receiver decodes the codeword and sees correctable and non-correctable errors
  - Some errors can be corrected using the codeword
  - Some errors are not detected or only detected without being corrected
- Always a compromise between error correction abilities and limiting overhead
  - ”Best error correcting code” = sending the whole block of data twice, or multiple times

Error correcting codes



Block codes

- Definition:
  - Hamming distance *d* = number of bits in which two binary sequences disagree
    - Example:
      - S1: 001101
      - S2: 110000
      - Hamming distance *d* = 5
  - Code rate = k/n (number of bits in the original data / number of bits in the codeword)
    - The code rate is a measurement for how much extra resources (bandwidth) that a certain code requires

Block codes

k = number of bits in the original data block
n = number of bits in the codeword

Example:
k=2, n= 5

Data block	codeword		received
00	00000	← Most probable	00100
01	00111		
10	11001		
11	11110		

- Receive wrong (non-existing) codeword → must be error
- Chose codeword with least Hamming distance to recreate correct data
- Never 100% sure the right codeword is chosen, but you chose the codeword with the highest probability to correspond to the correct data block

Key terms

- Encoder-decoder
- Modulator-demodulator
- Signal rate (baud rate, modulation rate)
- NRZ encoding
- Manchester encoding
- Differential coding
- Amplitude Shift Keying (ASK)
- Binary Frequency Shift Keying (BFSK)
- Binary Phase Shift Keying (BPSK)
- Differential Phase Shift Keying (DPSK)
- Quadrature Phase Shift Keying (QPSK)
- Asynchronous transmission
- Synchronous transmission
- Error correction vs detection
- Clock synchronization
- Idle state
- Self-clocking code
- Parity check
- Odd vs even parity
- Block coding
- Codeword
- Hamming distance
- Code rate