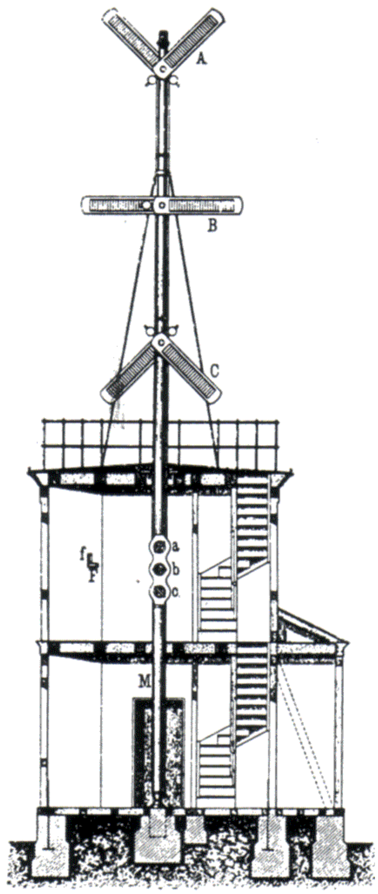
Solution of Exercise Sheet 1

Exercise 1 (Data Rate and Latency)

The Prussian semaphore system (dt. *Preußischer optischer Telegraf*) was a telegraphic communications system used between Berlin and Koblenz in the Rhine Province and was in operation from 1832 until 1849.

Official and military messages were transmitted using optical signals over a distance of nearly 550 km via 62 telegraph stations.

Each station was equipped with 6 telegraph arms each with 4 positions for encoding.



1. **Data rate**: How many bits can be transmitted per second when a new adjustment of the telegraph arms can be performed every 10 seconds?
2. **Latency**: If each station requires 1 minute for the forwarding, what is the end-to-end delay? To be precise, we're looking for the answer of this question: How long it takes to transmit a message from Berlin to Koblenz?

   Hint 1: You don't need a complex formula to calculate this exercise.
   Hint 2: The last station does not need to forward the message.

Source: Jörg Roth. Prüfungstrainer Rechnernetze. Vieweg (2010) and Wikipedia

Data Rate:

Each station of the telegraphic communications system has 6 telegraph arms with 4 positions each.
$\Longrightarrow$ *This means* $4^6 = 4096$ *telegraph arm positions (= states) are possible.*
$\Longrightarrow$ *With 4096 states per adjustment, 12 Bits can be encoded per adjustment.*
Explanation: With 2 states, 1 bit can be encoded. With 4 states, 2 Bits can be encoded. With 8 states, 3 Bits can be encoded... and with 4096 states, 12 Bits can be encoded.
A new adjustment of the telegraph arms can be performed every 10 seconds.

$$\text{Data rate} = \frac{12 \text{ Bits}}{10 \text{ s}} = 1.2 \text{ Bits/s}$$

Latency:

62 stations exist $\Longrightarrow$ just 61 stations need to forward the message because the last station does not need to forward the message $\Longrightarrow$ 61 minutes.

Exercise 2 (Transmission Media)

1. What transmission media are used for computer networks?

Guided transmission media exist and can be Copper cables, where data is transferred as electrical impulses or fiber-optic cables, where data is transferred as light impulses.

Wireless transmission can base on radio technology, infrared and laser.

2. Why is not one transmission medium used for all wired and wireless computer networks?

Not all transmission media can be used to cover large distances.

Exercise 3 (Transfer Time)

An image has a size of 1920x1080 pixels (Full HD) with true color, which means that 3 Bytes per pixel are used for the color information.

1. How long does it take to transmit the uncompressed image via a ...

   - 56 kbps Modem connection?

     1920x1080 pixels = 2,073,600 pixels ∗ 3 Bytes/pixel = 6,220,800 Bytes ∗ 8 = 49,766,400 Bits

     $\frac{49{,}766{,}400 \text{ Bits}}{56{,}000 \text{ Bits/s}} = 888.686 \text{ s} \Longrightarrow 14 \text{ min } 48.686 \text{ s}$

   - 64 kbps ISDN connection?

     $\frac{49{,}766{,}400 \text{ Bits}}{64{,}000 \text{ Bits/s}} = 777.6 \text{ s} \Longrightarrow 12 \text{ min } 57.6 \text{ s}$

   - 1 Mbps DSL connection?

     $\frac{49{,}766{,}400 \text{ Bits}}{1{,}000{,}000 \text{ Bits/s}} = 49.7664 \text{ s}$

   - 10 Mbps Ethernet connection?

     $\frac{49{,}766{,}400 \text{ Bits}}{10{,}000{,}000 \text{ Bits/s}} = 4.97664 \text{ s}$

- 16 Mbps DSL connection?

$$\frac{49{,}766{,}400 \text{ Bits}}{16{,}000{,}000 \text{ Bits/s}} = 3.1104 \text{ s}$$

- 100 Mbps Ethernet connection?

$$\frac{49{,}766{,}400 \text{ Bits}}{100{,}000{,}000 \text{ Bits/s}} = 0.497664 \text{ s}$$

- 1 Gbps Ethernet connection?

$$\frac{49{,}766{,}400 \text{ Bits}}{1{,}000{,}000{,}000 \text{ Bits/s}} = 0.0497664 \text{ s}$$

Hint: 1 kbps = 1,000 Bits per second
1 Mbps = 1,000,000 Bits per second
1 Gbps = 1,000,000,000 Bits per second

2. Assume the image is compressed with a compression algorithm that reduces the image size by 85%. How long does it take to transmit the image via a ...

- 56 kbps Modem connection?

$$\frac{7{,}464{,}960 \text{ Bits}}{56{,}000 \text{ Bits/s}} = 133.3 \text{ s} \Longrightarrow 2 \text{ min } 13.3 \text{ s}$$

- 64 kbps ISDN connection?

$$\frac{7{,}464{,}960 \text{ Bits}}{64{,}000 \text{ Bits/s}} = 116.64 \text{ s} \Longrightarrow 1 \text{ min } 56.64 \text{ s}$$

- 1 Mbps DSL connection?

$$\frac{7{,}464{,}960 \text{ Bits}}{1{,}000{,}000 \text{ Bits/s}} = 7.46496 \text{ s}$$

- 10 Mbps Ethernet connection?

$$\frac{7{,}464{,}960 \text{ Bits}}{10{,}000{,}000 \text{ Bits/s}} = 0.746496 \text{ s}$$

- 16 Mbps DSL connection?

$$\frac{7{,}464{,}960 \text{ Bits}}{16{,}000{,}000 \text{ Bits/s}} = 0.46656 \text{ s}$$

- 100 Mbps Ethernet connection?

$$\frac{7{,}464{,}960 \text{ Bits}}{100{,}000{,}000 \text{ Bits/s}} = 0.0746496 \text{ s}$$

- 1 Gbps Ethernet connection?

$$\frac{7{,}464{,}960 \text{ Bits}}{1{,}000{,}000{,}000 \text{ Bits/s}} = 0.00746496 \text{ s}$$

Exercise 4 (Parallel and Serial Data Transmission)

1. Explain the difference between serial data transmission and parallel data transmission.

   A single data line exists, when serial data transmission is used. The bits are transmitted one after another via the bus.

   Separate data lines exist, when parallel data transmission is used.

2. Name an advantage of serial data transmission compared with parallel data transmission.

   Fewer wires are required.

3. Name an advantage of parallel data transmission compared with serial data transmission.

   Higher throughput.

4. Do computer networks usually implement parallel or serial data transmission? (*Explain your answer!*)

   Computer networks usually implement serial data transmission because parallel data transmission is cost-intensive for long distances.

Exercise 5 (Storing and transmitting Data)

Common assumptions about data are:

- It is easy to store data today.
- It is easy to transport or transmit data today.

In this exercise, we verify the correctness of these statements.

1. A scientific experiment produces 15 PB of data per year, which need to be stored. What is the height of a stack of storage media, if for storing the data...

   - CDs (capacity: 600 MB = $600 * 10^6$ Byte, thickness: 1.2 mm) are used?
   - DVDs (capacity: 4.3 GB = $4.3 * 10^9$ Byte, thickness: 1.2 mm) are used?
   - Blu-rays (capacity: 25 GB = $25 * 10^9$ Byte, thickness: 1.2 mm) are used?
   - HDDs (capacity: 2 TB = $2 * 10^{12}$ Byte, thickness: 2.5 cm) are used?

   Attention: Calculate the solutions for both options:

- 15 PB = $15*10^{15}$ Byte $\Longleftarrow$ this way, the hardware manufacturer calculate
- 15 PB = $15*2^{50}$ Byte $\Longleftarrow$ this way, the operating systems calculate

Solution for CDs with 15 PB = $15*10^{15}$ Byte:

Number of CDs: $\frac{15*10^{15}\text{ Byte}}{600*10^{6}\text{ Byte}} = 25,000,000$

CD stack height:
$$25,000,000 * 1.2 \text{ mm} = 30,000,000 \text{ mm} = 3,000,000 \text{ cm} = 30,000 \text{ m} = 30 \text{ km}$$

Solution for CDs with 15 PB = $15*2^{50}$ Byte:

Number of CDs: $\frac{15*2^{50}\text{ Byte}}{600*10^{6}\text{ Byte}} = 28,147,498$

CD stack height:
$$28,147,498 * 1.2 \text{ mm} = 33,776,997.6 \text{ mm} = 3,377,699.76 \text{ cm} = \text{approx. } 33,777 \text{ m} = 33.78 \text{ km}$$

Solution for DVDs with 15 PB = $15*10^{15}$ Byte:

Number of DVDs: $\frac{15*10^{15}\text{ Byte}}{4.3*10^{9}\text{ Byte}} = 3,488,372.093$

An integer number is required $\Longrightarrow 3,488,373$

DVD stack height:
$$3,488,373 * 1.2 \text{ mm} = 4,186,047.6 \text{ mm} = 418,604.76 \text{ cm} = 4,186.0476 \text{ m} = 4.1860476 \text{ km}$$

Solution for DVDs with 15 PB = $15*2^{50}$ Byte:

Number of DVDs: $\frac{15*2^{50}\text{ Byte}}{4.3*10^{9}\text{ Byte}} = 3,927,557.814$

An integer number is required $\Longrightarrow 3,927,558$

DVD stack height:
$$3,927,558 * 1.2 \text{ mm} = 4,713,069.6 \text{ mm} = 471,306.96 \text{ cm} = 4,713.0696 \text{ m} = 4.7130696 \text{ km}$$

Solution for Blu-rays with 15 PB $= 15 * 10^{15}$ *Byte:*

Number of Blu-rays: $\frac{15*10^{15} \text{ Byte}}{25*10^{9} \text{ Byte}} = 600,000$

Blu-ray stack height:
$$600,000 * 1.2 \text{ mm} = 720,000 \text{ mm} = 72,000 \text{ cm} = 720 \text{ m}$$

Solution for Blu-rays with 15 PB $= 15 * 2^{50}$ *Byte:*

Number of Blu-rays: $\frac{15*2^{50} \text{ Byte}}{25*10^{9} \text{ Byte}} = 675,539.944$

An integer number is required $\implies 675,540$

Blu-ray stack height:
$$675,540 * 1.2 \text{ mm} = 810,648 \text{ mm} = 81,064.8 \text{ cm} = 810.648 \text{ m}$$

Solution for HDDs with 15 PB $= 15 * 10^{15}$ *Byte:*

Number of HDDs: $\frac{15*10^{15} \text{ Byte}}{2*10^{12} \text{ Byte}} = 7,500$

HDD stack height:
$$7,500 * 2.5 \text{ cm} = 18,750 \text{ cm} = 187.5 \text{ m}$$

Solution for HDDs with 15 PB $= 15 * 2^{50}$ *Byte:*

Number of HDDs: $\frac{15*2^{50} \text{ Byte}}{2*10^{12} \text{ Byte}} = 8,444.2493$

An integer number is required $\implies 8,445$

HDD stack height:
$$8,445 * 2.5 \text{ cm} = 21,112.5 \text{ cm} = 211.125 \text{ m}$$

2. The data of the scientific experiment is transmitted via networks that use fiber-optic cables and provide a bandwidth of 40 Gbit/s.

   - How long does it take to transfer the 15 PB via a 40 Gbit/s network?
   - How long does it take to transfer the 15 PB via a 100 Mbps Ethernet?

   Attention: Calculate the solutions for both options:

   - 15 PB $= 15 * 10^{15}$ Byte
   - 15 PB $= 15 * 2^{50}$ Byte

Solution for the 40 Gbit/s network with 15 PB $= 15 * 10^{15}$ *Byte:*

40 Gbit/s bandwidth:

$$\begin{aligned} 40 \text{ Gbit/s} &= 40,000,000,000 \text{ Bit/s} \\ &= 5,000,000,000 \text{ Byte/s} \end{aligned}$$

Duration of transmission:

$$\begin{aligned} \frac{15*10^{15} \text{ Byte}}{5*10^{9} \text{ Byte/s}} &= 3 * 10^{6} \text{ s} = 3,000,000 \text{ s} \\ &= 50,000 \text{ m} \\ &= 833.333333333 \text{ h} \\ &= 34.722222222 \text{ d} \end{aligned}$$

$\Longrightarrow$ approx. 34 Days, 17 Hours, 20 Minutes

Solution for the 40 Gbit/s network with 15 PB $= 15 * 2^{50}$ *Byte:*

40 Gbit/s bandwidth:

$$\begin{aligned} 40 \text{ Gbit/s} &= 40,000,000,000 \text{ Bit/s} \\ &= 5,000,000,000 \text{ Byte/s} \end{aligned}$$

Duration of transmission:

$$\begin{aligned} \frac{15*2^{50} \text{ Byte}}{5*10^{9} \text{ Byte/s}} &= 3,377,699.72 \text{ s} \\ &= \text{approx. } 56,295 \text{ m} \\ &= \text{approx. } 938.25 \text{ h} \\ &= \text{approx. } 39.09 \text{ d} \end{aligned}$$

$\Longrightarrow$ approx. 39 Days, 2 Hours, 15 Minutes

Solution for the Ethernet network with 15 PB $= 15 * 10^{15}$ *Byte:*

Ethernet bandwidth:

$$\begin{aligned} 100 \text{ Mbit/s} &= 100,000,000 \text{ Bit/s} \\ &= 12,500,000 \text{ Byte/s} \end{aligned}$$

Duration of transmission:

$$\begin{aligned} \frac{15*10^{15} \text{ Byte}}{12{,}500{,}000 \text{ Byte/s}} &= 1,200,000,000 \text{ s} \\ &= 20,000,000 \text{ m} \\ &= 333,333.3333 \text{ h} \\ &= 13,888.88889 \text{ d} \\ &= 38.02570538 \text{ y} \end{aligned}$$

$\Longrightarrow$ approx. 38 Years, 13 Days, 21 Hours, 20 Minutes

Solution for the Ethernet network with 15 PB $= 15 * 2^{50}$ *Byte:*

Ethernet bandwidth: $100 \text{ Mbit/s} = 100,000,000 \text{ Bit/s} = 12,500,000 \text{ Byte/s}$

Duration of transmission:

$$\frac{15*2^{50} \text{ Byte}}{12{,}500{,}000 \text{ Byte/s}} = 1,351,079,888 \text{ s}$$
$$= 22,517,998.13 \text{ m}$$
$$= 375,299.9688 \text{ h}$$
$$= 15,637.4987 \text{ d}$$
$$= 42.81313812 \text{ y}$$

(each year has 365,25 days!)

$\Longrightarrow$ approx. 42 Years, 296 Days, ...

Exercise 6 (Physical and Logical Topology)

1. What describes the physical topology of a computer network?

   It describes the wiring.

2. What describes the logical topology of a computer network?

   It describes the flow of data between the network devices.

Exercise 7 (Network Topologies)

Several network topologies (Bus, Ring, Star, Mesh, Tree and Cellular) exist. Consider the following table and fill in the names of the network topologies for which the sentences are true.

Statement	
Cable failure can separate the network in two functioning parts	*Mesh, Tree, Bus may work but it is not ensured*
Topology contains a single point of failure (*A single point of failure can be a device or a cable*)	*Bus (the medium!), Ring (the medium!), Star, Cellular*
Topology used for Thin Ethernet and Thick Ethernet	*Bus*
Topology contains a performance bottleneck	*Star, Tree (the root!), Cellular*
Topology used for WLAN, when no Access Point exists	*Mesh*
Topology used for Token Ring (logical)	*Ring*
Topology used for mobile phones (GSM standard)	*Cellular*
Topology used for Token Ring (physical)	*Star*
Cable failure leads to complete network failure	*Ring, Bus*
Topology contains no central component	*Bus, Ring, Mesh*
Topology used for WLAN, when an Access Point exists	*Cellular*
Topology used with modern Ethernet standards	*Star*

Exercise 8 (Directional Dependence – Anisotropy)

1. With handheld transceivers, often called *walkie-talkie*, two or more participants can talk to each other. However, at no time, more than one participant can speak. Please describe the reason for this limitation.

   Only a single channel is used.

2. According to what directional dependence principle do *walkie-talkies* operate?

   ☐ Simplex ☐ Full-duplex ☒ Half-duplex

3. Name 2 systems, that operate according to the simplex principle.

   Radio, TV, pager, satellite, GPS, radio clock signal.

4. Name an advantage and a drawback of communication systems that operate according to the simplex principle?

   Advantage: When using a wireless network, only a single channel is required. When using a wired network, lesser cabeling effort is required.
   Drawback: The information transfer only works in one direction.

5. Name 2 systems, that operate according to the full-duplex principle.

   Ethernet via twisted pair cables, telephone.

6. Name an advantage and a drawback of communication systems that operate according to the full-duplex principle?

   Advantage: The information transfer works in both directions simultaneously.
   Drawbacks: When using a wireless network, multiple channels are required. When using a wired network, the cabeling effort is higher.

Picture of a handheld transceiver „*walkie-talkie*“

Image source: Google image search

Exercise 9 (Transfer Time = Latency)

A MP3 file with a size of $30 * 10^6$ bits must be transferred from terminal device A to terminal device B. The signal propagation speed is 200,000 km/s. A and B are directly connected by a link with a length of 5,000 km. The file is transferred as a single message, that has a size of $30 * 10^6$ bits. No network protocol headers or trailers exist.

1. Calculate the transfer time (latency) of the file, when the data rate of the computer network between both terminal devices is...

   - 56 kbps

```
File size: 30,000,000 Bits
Data rate:     56,000 Bits/s
Propagation delay = 5,000,000 m / 200,000,000 m/s = 0.025 s
Transmission delay = 30,000,000 Bits / 56,000 Bits/s = 535.714285714 s
Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time
        = 0.025 s + 535.714285714 s = 535.739 s = approx. 9 min.
```

   - 64 kbps

```
File size: 30,000,000 Bits
Data rate:     64,000 Bits/s
Propagation delay = 5,000,000 m / 200,000,000 m/s = 0.025 s
Transmission delay = 30,000,000 Bits / 64,000 Bits/s = 468.75 s
Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time
        = 0.025 s + 468.75 s = 468.775 s = approx. 7 min 49 s
```

   - 1 Mbps

```
File size: 30,000,000 Bits
Data rate:  1,000,000 Bits/s
Propagation delay = 5,000,000 m / 200,000,000 m/s = 0.025 s
Transmission delay = 30,000,000 Bits / 1,000,000 Bits/s = 30 s
Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time
        = 0.025 s + 30 s = 30.025 s = approx. 30 s.
```

   - 16 Mbps

```
File size: 30,000,000 Bits
Data rate: 16,000,000 Bits/s
Propagation delay = 5,000,000 m / 200,000,000 m/s = 0.025 s
Transmission delay = 30,000,000 Bits / 16,000,000 Bits/s = 1.875 s
Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time
        = 0.025 s + 1.875 s = 1.9 s
```

   - 100 Mbps

```
File size:  30,000,000 Bits
Data rate: 100,000,000 Bits/s
Propagation delay = 5,000,000 m / 200,000,000 m/s = 0.025 s
Transmission delay = 30,000,000 Bits / 100,000,000 Bits/s = 0.3 s
Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time
        = 0.025 s + 0.3 s = 0.325 s
```

2. Calculate for each one of the above alternatives what the volume of the network connection is. What is the maximum number of bits that can reside inside the line between the sender and receiver?

> *Hint: Only the propagation delay is relevant here!*
> *Transmission delay = 0 s*
> *Waiting time = 0 s.*

Propagation delay = 0.025 s = 25 ms

```
     56,000 Bits/s * 0.025 s =     1,400 Bits
     64,000 Bits/s * 0.025 s =     1,600 Bits
  1,000,000 Bits/s * 0.025 s =    25,000 Bits
 16,000,000 Bits/s * 0.025 s =   400,000 Bits
100,000,000 Bits/s * 0.025 s = 2,500,000 Bits
```

Exercise 10 (Bandwidth-Delay Product)

Imagine, NASA sent a spacecraft to planet Mars, which landed there. A 128 kbps (kilobit per second) point-to-point link is set up between planet Earth and the spacecraft.

The distance between Earth and Mars fluctuates between approx. 55,000,000 km and approx. 400,000,000 km. For the further calculations, we use the 55,000,000 km, which is the distance from Earth to Mars, when they are closest together.

The signal propagation speed is $299,792,458$ m/s, which is the speed of light.

1. Calculate the Round Trip Time (RTT) for the link.

   RTT = (2 * distance) / signal propagation speed

```
RTT = (2 * distance) / signal propagation speed
    = (2 * 55,000,000,000 m) / 299,792,458 m/s
    = 110,000,000,000 m / 299,792,458 m/s
    = 366.920504718 s
```

2. Calculate the bandwidth-delay product for the link to find out what is the maximum number of bits, that can reside inside the line between the sender and receiver?

   Signal propagation speed = 299.792.458 m/s
   Distance = 55.000.000.000 m
   Transmission delay = 0 s
   Waiting time = 0 s

```
                    55,000,000,000 m
Propagation delay = ------------------ = 183.460252359 s
                       299,792,458 m/s

     128,000 Bits/s * 183.460252359 s = 23,482,912.302 Bits
                                      = approx. 23.48 Mbits
```

3. A webcam at the surface of planet Mars sends pictures to Earth. Each image has a size of 20 MB (1 MB = 2^{20} Byte). How quickly, after a picture is taken, can it reach Mission Control on Earth?

```
File size: 20 MB = 20,971,520 Bytes = 167,772,160 Bits
Data rate: 128,000 Bits/s
Propagation delay = 55,000,000,000 m / 299,792,458 m/s
                  = 183.460252359 s
Transmission delay = 167,772,160 Bits / 128,000 Bits/s
                   = 1,310.72 s
                   = 21 m 50.72 s
Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time
        = 183.460252359 s + 1,310.72 s
        = 1,494.18025236 s
        = 24 m 54.18025236 s
```

Source: Larry L. Peterson, Bruce S. Davie. Computernetzwerke. dpunkt (2008)