Computer Networks

Exercise Session 02

Prof. Dr. Oliver Hahm

Frankfurt University of Applied Sciences
Faculty 2: Computer Science and Engineering
oliver.hahm@fb2.fra-uas.de
https://teaching.dahahm.de

November 02 – 04, 2021

General Schedule

All exercises will follow this general schedule

- Identify potential understanding problems
  $\rightarrow$ Ask your questions
  $\rightarrow$ Recap of the lecture
- Address the understanding problems
  $\rightarrow$ Answer your questions
  $\rightarrow$ Repeat certain topics
- Walk through the exercises/solutions $\rightarrow$ Some hints and guidance
  $\rightarrow$ Work time or presentation of results

Reference Models

You have seen ...

- how a Computer Network can be broken down into layers
- what a reference model is and which relevant ones exist
- which layers exist in the hybrid reference model and what tasks they have

Topologies

You have seen . . .

- what a topology is
- what the difference between the physical and the logical topology is
- the advantages and drawbacks of the different topologies
- which topologies are used in current networks

Fundamentals of Data Signals

You have seen ...

- how an analog signal can be transformed into a digital signal (and vice versa) using quantization and sampling
- how often a channel needs to be sampled to reconstruct the original analog signal
- how a square wave signal can be constructed by a fundamental frequency and its harmonics
- the difference between bandwidth, data rate, and symbol rate
- what data date can be achieved on a noiseless and a noisy channel with finite bandwidth

Data Encoding

You have seen ...

- what a baseband transmission is
- which requirements exist for a good encoding (robustness, efficiency, and clock recovery)
- several line codes and how they relate to these requirements
- what the problems of baseline wander and clock recovery are and how to tackle them
- how an encoding of group of bits in combination of another encoding can be used to address all requirements → e.g., 4B/5B

Modulation

You have seen . . .

- how data can be modulated onto a carrier frequency in broadband
- what amplitude, frequency, and phase modulation are
- which advantages and drawbacks these methods have

Any other questions left?

Exercise 1.1: Data Encoding – Data rate

- *Each station of the telegraphic communications system has 6 telegraph arms with 4 positions each.*

Exercise 1.1: Data Encoding – 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.*

Exercise 1.1: Data Encoding – 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.*

Exercise 1.1: Data Encoding – 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.*

Exercise 1.1: Data Encoding – 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.*

Exercise 1.1: Data Encoding – 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.*

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

Exercise 1.2: Data Encoding – Latency

Latency = Propagation delay + Transmission delay + Waiting time

Exercise 1.2: Data Encoding – Latency

$$\text{Latency} = \text{Propagation delay} + \text{Transmission delay} + \text{Waiting time}$$

$$\textbf{Propagation delay} = \frac{\text{Distance}}{\text{Speed of light} * \text{Velocity factor}}$$

$$\Rightarrow \frac{550 \text{ km}}{299{,}792{,}458 \text{ m/s}} = \frac{550{,}000 \text{ m}}{299{,}792{,}458 \text{ m/s}}$$

$$\approx 0.0018s = \textbf{1.8 ms}$$

Exercise 1.2: Data Encoding – Latency

$$\text{Latency} = \text{Propagation delay} + \text{Transmission delay} + \text{Waiting time}$$

$$\textbf{Propagation delay} = \frac{\text{Distance}}{\text{Speed of light} * \text{Velocity factor}}$$

$$\Rightarrow \frac{550\ \text{km}}{299{,}792{,}458\ \text{m/s}} = \frac{550{,}000\ \text{m}}{299{,}792{,}458\ \text{m/s}}$$

$$\approx 0.0018s = \mathbf{1.8\ ms}$$

$$\textbf{Waiting time} = 61 * 1\ \text{min} = 61 * 60\ \text{s} = \mathbf{3660\ s}$$

Exercise 1.2: Data Encoding – Latency

$$\text{Latency} = \text{Propagation delay} + \text{Transmission delay} + \text{Waiting time}$$

$$\textbf{Propagation delay} = \frac{\text{Distance}}{\text{Speed of light} * \text{Velocity factor}}$$

$$\Rightarrow \frac{550 \text{ km}}{299{,}792{,}458 \text{ m/s}} = \frac{550{,}000 \text{ m}}{299{,}792{,}458 \text{ m/s}}$$

$$\approx 0.0018s = \mathbf{1.8 \text{ ms}}$$

$$\textbf{Waiting time} = 61 * 1 \text{ min} = 61 * 60 \text{ s} = \mathbf{3660 \text{ s}}$$

$$\textbf{Transmission delay} = \frac{\text{Message size}}{\text{Bandwidth}}$$

$$\Rightarrow \frac{24 \text{ bit}}{1.2 \text{ bit/s}} = \mathbf{20 \text{ s}}$$

$$\Rightarrow \frac{512 \text{ bit}}{1.2 \text{ bit/s}} \approx \mathbf{426.7 \text{ s}}$$

Exercise 1.2: Data Encoding – Latency

$$\text{Latency} = \text{Propagation delay} + \text{Transmission delay} + \text{Waiting time}$$

$$\textbf{Propagation delay} = \frac{\text{Distance}}{\text{Speed of light} * \text{Velocity factor}}$$

$$\Rightarrow \frac{550\text{ km}}{299{,}792{,}458\text{ m/s}} = \frac{550{,}000\text{ m}}{299{,}792{,}458\text{ m/s}}$$

$$\approx 0.0018s = \textbf{1.8 ms}$$

$$\textbf{Transmission delay} = \frac{\text{Message size}}{\text{Bandwidth}}$$

$$\Rightarrow \frac{24\text{ bit}}{1.2\text{ bit/s}} = \textbf{20 s}$$

$$\Rightarrow \frac{512\text{ bit}}{1.2\text{ bit/s}} \approx \textbf{426.7 s}$$

$$\textbf{Waiting time} = 61 * 1\text{ min} = 61 * 60\text{ s} = \textbf{3660 s}$$

$$\textbf{Latency (24 bit)} \approx 0.0018\text{ s} + 20\text{ s} + 3660\text{ s} = 3680.0018\text{ s}$$

$$= 1{:}01{:}20.0018\text{ h}$$

$$\textbf{Latency (512 bit)} \approx 0.0018\text{ s} + 426.7\text{ s} + 3660\text{ s} = 4086.7.0018\text{ s}$$

$$= 1{:}08{:}06.7018\text{ h}$$

Exercise 1.3/1.4: Data Encoding

1.3

- If the telegraph arms could be newly adjusted every 5 seconds . . .

- If each station would require 5 minutes for forwarding . . .

1.4

Exercise 1.3/1.4: Data Encoding

1.3

- If the telegraph arms could be newly adjusted every 5 seconds ...
  - the data rate would double

$$\Rightarrow \text{Data rate} = \frac{12 \text{ bit}}{5 \text{ s}} = 2.4 \text{ bit/s}$$

- If each station would require 5 minutes for forwarding ...

1.4

Exercise 1.3/1.4: Data Encoding

1.3

- If the telegraph arms could be newly adjusted every 5 seconds . . .
  - the data rate would double

$$\Rightarrow \text{Data rate} = \frac{12 \text{ bit}}{5 \text{ s}} = 2.4 \text{ bit/s}$$

  - the latency would be reduced by 10 s/$\sim$ 213 s
- If each station would require 5 minutes for forwarding . . .

1.4

Exercise 1.3/1.4: Data Encoding

1.3

- If the telegraph arms could be newly adjusted every 5 seconds . . .
  - the data rate would double

$$\Rightarrow \text{Data rate} = \frac{12 \text{ bit}}{5 \text{ s}} = 2.4 \text{ bit/s}$$

  - the latency would be reduced by 10 s/$\sim$ 213 s
- If each station would require 5 minutes for forwarding . . .
  - the data rate would stay the same

1.4

Exercise 1.3/1.4: Data Encoding

1.3

- If the telegraph arms could be newly adjusted every 5 seconds . . .
  - the data rate would double

$$\Rightarrow \text{Data rate} = \frac{12 \text{ bit}}{5 \text{ s}} = 2.4 \text{ bit/s}$$

  - the latency would be reduced by 10 s/∼ 213 s
- If each station would require 5 minutes for forwarding . . .
  - the data rate would stay the same
  - the latency would increase by $61 * 4 * 60s = 244min = 04 : 04h$

1.4

Exercise 1.3/1.4: Data Encoding

1.3

- If the telegraph arms could be newly adjusted every 5 seconds ...
  - the data rate would double

$$\Rightarrow \text{Data rate} = \frac{12 \text{ bit}}{5 \text{ s}} = 2.4 \text{ bit/s}$$

  - the latency would be reduced by 10 s/$\sim$ 213 s
- If each station would require 5 minutes for forwarding ...
  - the data rate would stay the same
  - the latency would increase by $61 * 4 * 60s = 244min = 04:04h$

1.4

- More positions would be harder to distinguish

$\Rightarrow$ Noise on the medium (e.g., rain) would increase the error probability

Exercise 2: Transmission Media

2.1 **What transmission media are used for computer networks?**

2.2 **What is the transmission media used in cellular networks like LTE?**

Exercise 2: Transmission Media

2.1 **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.

2.2 **What is the transmission media used in cellular networks like LTE?**

Exercise 2: Transmission Media

2.1 **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.

2.2 **What is the transmission media used in cellular networks like LTE?**

→ Unguided transmission media, i.e., radio waves travelling through the air.

Exercise 3.1: Transfer Time

Image size

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

- 56 kbps Modem connection?
- 64 kbps ISDN connection?
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$
$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?
- 64 kbps ISDN connection?
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$

$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?

  $\frac{49{,}766{,}400 \text{ bit}}{56{,}000 \text{ bit/s}} = 888.686 \text{ s} \Longrightarrow 14 \text{ min } 48.686 \text{ s}$
- 64 kbps ISDN connection?
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$
$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?
  $\frac{49{,}766{,}400 \text{ bit}}{56{,}000 \text{ bit/s}} = 888.686 \text{ s} \Longrightarrow$ 14 min 48.686 s
- 64 kbps ISDN connection?
  $\frac{49{,}766{,}400 \text{ bit}}{64{,}000 \text{ bit/s}} = 777.6 \text{ s} \Longrightarrow$ 12 min 57.6 s
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$

$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?

  $\frac{49{,}766{,}400 \text{ bit}}{56{,}000 \text{ bit/s}} = 888.686 \text{ s} \Longrightarrow 14 \text{ min } 48.686 \text{ s}$
- 64 kbps ISDN connection?

  $\frac{49{,}766{,}400 \text{ bit}}{64{,}000 \text{ bit/s}} = 777.6 \text{ s} \Longrightarrow 12 \text{ min } 57.6 \text{ s}$
- 1 Mbps DSL connection?

  $\frac{49{,}766{,}400 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} = 49.7664 \text{ s}$
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$

$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?

  $\frac{49{,}766{,}400 \text{ bit}}{56{,}000 \text{ bit/s}} = 888.686 \text{ s} \Longrightarrow$ 14 min 48.686 s
- 64 kbps ISDN connection?

  $\frac{49{,}766{,}400 \text{ bit}}{64{,}000 \text{ bit/s}} = 777.6 \text{ s} \Longrightarrow$ 12 min 57.6 s
- 1 Mbps DSL connection?

  $\frac{49{,}766{,}400 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} =$ 49.7664 s
- 10 Mbps Ethernet connection?

  $\frac{49{,}766{,}400 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} =$ 4.97664 s
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$

$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?
  $\frac{49{,}766{,}400 \text{ bit}}{56{,}000 \text{ bit/s}} = 888.686 \text{ s} \Longrightarrow$ 14 min 48.686 s
- 64 kbps ISDN connection?
  $\frac{49{,}766{,}400 \text{ bit}}{64{,}000 \text{ bit/s}} = 777.6 \text{ s} \Longrightarrow$ 12 min 57.6 s
- 1 Mbps DSL connection?
  $\frac{49{,}766{,}400 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} =$ 49.7664 s
- 10 Mbps Ethernet connection?
  $\frac{49{,}766{,}400 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} =$ 4.97664 s
- 16 Mbps DSL connection?
  $\frac{49{,}766{,}400 \text{ bit}}{16{,}000{,}000 \text{ bit/s}} =$ 3.1104 s
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$

$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?
  $\frac{49{,}766{,}400 \text{ bit}}{56{,}000 \text{ bit/s}} = 888.686 \text{ s} \Longrightarrow 14 \text{ min } 48.686 \text{ s}$
- 64 kbps ISDN connection?
  $\frac{49{,}766{,}400 \text{ bit}}{64{,}000 \text{ bit/s}} = 777.6 \text{ s} \Longrightarrow 12 \text{ min } 57.6 \text{ s}$
- 1 Mbps DSL connection?
  $\frac{49{,}766{,}400 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} = 49.7664 \text{ s}$
- 10 Mbps Ethernet connection?
  $\frac{49{,}766{,}400 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} = 4.97664 \text{ s}$
- 16 Mbps DSL connection?
  $\frac{49{,}766{,}400 \text{ bit}}{16{,}000{,}000 \text{ bit/s}} = 3.1104 \text{ s}$
- 100 Mbps Ethernet connection?
  $\frac{49{,}766{,}400 \text{ bit}}{100{,}000{,}000 \text{ bit/s}} = 497.664 \text{ ms}$
- 1 Gbps Ethernet connection?

Exercise 3.1: Transfer Time

Image size

$$1920x1080 pixels = 2,073,600 pixels * 3 bytes/pixel = 6,220,800 bytes * 8$$
$$= 49,766,400 bits$$

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

- 56 kbps Modem connection?
  $\frac{49{,}766{,}400 \text{ bit}}{56{,}000 \text{ bit/s}} = 888.686 \text{ s} \Longrightarrow$ 14 min 48.686 s
- 64 kbps ISDN connection?
  $\frac{49{,}766{,}400 \text{ bit}}{64{,}000 \text{ bit/s}} = 777.6 \text{ s} \Longrightarrow$ 12 min 57.6 s
- 1 Mbps DSL connection?
  $\frac{49{,}766{,}400 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} =$ 49.7664 s
- 10 Mbps Ethernet connection?
  $\frac{49{,}766{,}400 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} =$ 4.97664 s
- 16 Mbps DSL connection?
  $\frac{49{,}766{,}400 \text{ bit}}{16{,}000{,}000 \text{ bit/s}} =$ 3.1104 s
- 100 Mbps Ethernet connection?
  $\frac{49{,}766{,}400 \text{ bit}}{100{,}000{,}000 \text{ bit/s}} =$ 497.664 ms
- 1 Gbps Ethernet connection?
  $\frac{49{,}766{,}400 \text{ bit}}{1{,}000{,}000{,}000 \text{ bit/s}} =$ 49.7664 ms

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

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

- 56 kbps Modem connection?
- 64 kbps ISDN connection?
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
- 64 kbps ISDN connection?
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
  $\frac{7{,}464{,}960 \text{ bit}}{56{,}000 \text{ bit/s}} = 133.3 \text{ s} \Longrightarrow$ 2 min 13.3 s
- 64 kbps ISDN connection?
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
  $\frac{7{,}464{,}960 \text{ bit}}{56{,}000 \text{ bit/s}} = 133.3 \text{ s} \Longrightarrow$ 2 min 13.3 s
- 64 kbps ISDN connection?
  $\frac{7{,}464{,}960 \text{ bit}}{64{,}000 \text{ bit/s}} = 116.64 \text{ s} \Longrightarrow$ 1 min 56.64 s
- 1 Mbps DSL connection?
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
  $\frac{7{,}464{,}960 \text{ bit}}{56{,}000 \text{ bit/s}} = 133.3 \text{ s} \Longrightarrow$ 2 min 13.3 s
- 64 kbps ISDN connection?
  $\frac{7{,}464{,}960 \text{ bit}}{64{,}000 \text{ bit/s}} = 116.64 \text{ s} \Longrightarrow$ 1 min 56.64 s
- 1 Mbps DSL connection?
  $\frac{7{,}464{,}960 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} =$ 7.46496 s
- 10 Mbps Ethernet connection?
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
  $$\frac{7{,}464{,}960 \text{ bit}}{56{,}000 \text{ bit/s}} = 133.3 \text{ s} \implies 2 \text{ min } 13.3 \text{ s}$$
- 64 kbps ISDN connection?
  $$\frac{7{,}464{,}960 \text{ bit}}{64{,}000 \text{ bit/s}} = 116.64 \text{ s} \implies 1 \text{ min } 56.64 \text{ s}$$
- 1 Mbps DSL connection?
  $$\frac{7{,}464{,}960 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} = 7.46496 \text{ s}$$
- 10 Mbps Ethernet connection?
  $$\frac{7{,}464{,}960 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} = 746.496 \text{ ms}$$
- 16 Mbps DSL connection?
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
  $\frac{7{,}464{,}960 \text{ bit}}{56{,}000 \text{ bit/s}} = 133.3 \text{ s} \Longrightarrow$ 2 min 13.3 s
- 64 kbps ISDN connection?
  $\frac{7{,}464{,}960 \text{ bit}}{64{,}000 \text{ bit/s}} = 116.64 \text{ s} \Longrightarrow$ 1 min 56.64 s
- 1 Mbps DSL connection?
  $\frac{7{,}464{,}960 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} =$ 7.46496 s
- 10 Mbps Ethernet connection?
  $\frac{7{,}464{,}960 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} =$ 746.496 ms
- 16 Mbps DSL connection?
  $\frac{7{,}464{,}960 \text{ bit}}{16{,}000{,}000 \text{ bit/s}} =$ 466.56 ms
- 100 Mbps Ethernet connection?
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
  $\frac{7{,}464{,}960 \text{ bit}}{56{,}000 \text{ bit/s}} = 133.3 \text{ s} \Longrightarrow$ 2 min 13.3 s
- 64 kbps ISDN connection?
  $\frac{7{,}464{,}960 \text{ bit}}{64{,}000 \text{ bit/s}} = 116.64 \text{ s} \Longrightarrow$ 1 min 56.64 s
- 1 Mbps DSL connection?
  $\frac{7{,}464{,}960 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} =$ 7.46496 s
- 10 Mbps Ethernet connection?
  $\frac{7{,}464{,}960 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} =$ 746.496 ms
- 16 Mbps DSL connection?
  $\frac{7{,}464{,}960 \text{ bit}}{16{,}000{,}000 \text{ bit/s}} =$ 466.56 ms
- 100 Mbps Ethernet connection?
  $\frac{7{,}464{,}960 \text{ bit}}{100{,}000{,}000 \text{ bit/s}} =$ 74.6496 ms
- 1 Gbps Ethernet connection?

Exercise 3.2: Transfer Time

Assume the image is compressed with a compression algorithm that reduces the image size by 85%.

Compressed image size

$$49,766,400 bits * 15\% = 7,464,960 bits$$

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

- 56 kbps Modem connection?
  $\frac{7{,}464{,}960 \text{ bit}}{56{,}000 \text{ bit/s}} = 133.3 \text{ s} \Longrightarrow 2 \text{ min } 13.3 \text{ s}$
- 64 kbps ISDN connection?
  $\frac{7{,}464{,}960 \text{ bit}}{64{,}000 \text{ bit/s}} = 116.64 \text{ s} \Longrightarrow 1 \text{ min } 56.64 \text{ s}$
- 1 Mbps DSL connection?
  $\frac{7{,}464{,}960 \text{ bit}}{1{,}000{,}000 \text{ bit/s}} = 7.46496 \text{ s}$
- 10 Mbps Ethernet connection?
  $\frac{7{,}464{,}960 \text{ bit}}{10{,}000{,}000 \text{ bit/s}} = 746.496 \text{ ms}$
- 16 Mbps DSL connection?
  $\frac{7{,}464{,}960 \text{ bit}}{16{,}000{,}000 \text{ bit/s}} = 466.56 \text{ ms}$
- 100 Mbps Ethernet connection?
  $\frac{7{,}464{,}960 \text{ bit}}{100{,}000{,}000 \text{ bit/s}} = 74.6496 \text{ ms}$
- 1 Gbps Ethernet connection?
  $\frac{7{,}464{,}960 \text{ bit}}{1{,}000{,}000{,}000 \text{ bit/s}} = 7.46496 \text{ ms}$

Exercise 4.1: Storing and transmitting data – CDs

Solution for CDs with 15 PB

Number of CDs:

CD stack height:

Solution for CDs with 15 PiB

Number of CDs:

CD stack height:

Exercise 4.1: Storing and transmitting data – CDs

Solution for CDs with 15 PB

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

CD stack height:

Solution for CDs with 15 PiB

Number of CDs:

CD stack height:

Exercise 4.1: Storing and transmitting data – CDs

Solution for CDs with 15 PB

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 PiB

Number of CDs:

CD stack height:

Exercise 4.1: Storing and transmitting data – CDs

Solution for CDs with 15 PB

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 PiB

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

CD stack height: $28,147,498 * 1.2\text{ mm} = 33,776,997.6\text{ mm}$

$= 3,377,699.76\text{ cm}$

$\approx 33,777\text{ m}$

$= 33.78\text{ km}$

Exercise 4.1: Storing and transmitting data – DVDs

Solution for DVDs with 15 PB

Number of DVDs:

DVD stack height:

Solution for DVDs with 15 PiB

Number of DVDs:

DVD stack height:

Exercise 4.1: Storing and transmitting data – DVDs

Solution for DVDs with 15 PB

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

DVD stack height: $3,488,373 * 1.2 \text{ mm} = 4,186,047.6 \text{ mm}$

$= 418,504.76 \text{ cm}$

$\approx 4,186.048 \text{ m}$

$\approx 4.186 \text{ km}$

Solution for DVDs with 15 PiB

Number of DVDs:

DVD stack height:

Exercise 4.1: Storing and transmitting data – DVDs

Solution for DVDs with 15 PB

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

DVD stack height: $3,488,373 * 1.2\text{ mm} = 4,186,047.6\text{ mm}$
$= 418,504.76\text{ cm}$
$\approx 4,186.048\text{ m}$
$\approx 4.186\text{ km}$

Solution for DVDs with 15 PiB

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

DVD stack height: $3,927,558 * 1.2\text{ mm} = 4,713,069.6\text{ mm}$
$= 471,306.96\text{ cm}$
$\approx 4,713.048\text{ m}$
$\approx 4.713\text{ km}$

Exercise 4.1: Storing and transmitting data – Blu-rays

Solution for Blu-rays with 15 PB

Number of Blu-rays:

Blu-ray stack height:

Solution for Blu-rays with 15 PiB

Number of Blu-rays:

Blu-ray stack height:

Exercise 4.1: Storing and transmitting data – Blu-rays

Solution for Blu-rays with 15 PB

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 PiB

Number of Blu-rays:

Blu-ray stack height:

Exercise 4.1: Storing and transmitting data – Blu-rays

Solution for Blu-rays with 15 PB

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 PiB

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

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

$= 81,064.8\text{ cm}$

$= 810,648\text{ m}$

Exercise 4.1: Storing and transmitting data – HDDs

Solution for HDDs with 15 PB

Number of HDDs:

HDD stack height:

Solution for HDDs with 15 PiB

Number of HDDs:

HDD stack height:

Exercise 4.1: Storing and transmitting data – HDDs

Solution for HDDs with 15 PB

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 PiB

Number of HDDs:

HDD stack height:

Exercise 4.1: Storing and transmitting data – HDDs

Solution for HDDs with 15 PB

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 PiB

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

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

Exercise 4.2: Storing and transmitting data – 40 Gbit/s

Solution for the 40 Gbit/s network with 15 PB

40 Gbit/s bandwidth:

Duration of transmission:

Solution for the 40 Gbit/s network with 15 PiB

40 Gbit/s bandwidth:

Duration of transmission:

Exercise 4.2: Storing and transmitting data – 40 Gbit/s

Solution for the 40 Gbit/s network with 15 PB

40 Gbit/s bandwidth: $40 \text{ Gbit/s} = 40,000,000,000 \text{ Bit/s}$
$= 5,000,000,000 \text{ Byte/s}$

Duration of transmission:

Solution for the 40 Gbit/s network with 15 PiB

40 Gbit/s bandwidth:

Duration of transmission:

Exercise 4.2: Storing and transmitting data – 40 Gbit/s

Solution for the 40 Gbit/s network with 15 PB

40 Gbit/s bandwidth: $40 \text{ Gbit/s} = 40,000,000,000 \text{ Bit/s}$
$= 5,000,000,000 \text{ Byte/s}$

Duration of transmission: $\frac{15*10^{15} \text{ Byte}}{5*10^{9} \text{ Byte/s}} = 3*10^6 \text{ s} = 3,000,000 \text{ s}$
$= 50,000 \text{ min}$
$\approx 833.333 \text{ h}$
$= 34.722 \text{ d}$

Solution for the 40 Gbit/s network with 15 PiB

40 Gbit/s bandwidth:

Duration of transmission:

Exercise 4.2: Storing and transmitting data – 40 Gbit/s

Solution for the 40 Gbit/s network with 15 PB

40 Gbit/s bandwidth: $40 \text{ Gbit/s} = 40,000,000,000 \text{ Bit/s}$
$= 5,000,000,000 \text{ Byte/s}$

Duration of transmission: $\frac{15*10^{15} \text{ Byte}}{5*10^{9} \text{ Byte/s}} = 3 * 10^{6} \text{ s} = 3,000,000 \text{ s}$
$= 50,000 \text{ min}$
$\approx 833.333 \text{ h}$
$= 34.722 \text{ d}$

Solution for the 40 Gbit/s network with 15 PiB

40 Gbit/s bandwidth: $40 \text{ Gbit/s} = 40,000,000,000 \text{ Bit/s}$
$= 5,000,000,000 \text{ Byte/s}$

Duration of transmission: $\frac{15*2^{50} \text{ Byte}}{5*10^{9} \text{ Byte/s}} = 3,377,699.72 \text{ s}$
$\approx 56,295 \text{ min}$
$\approx 938.25 \text{ h}$
$\approx 39.09 \text{ d}$

Exercise 4.2: Storing and transmitting data – 100 Mbit/s

Solution for the Fast Ethernet network with 15 PB

100 Mbit/s bandwidth:

Duration of transmission:

Solution for the Fast Ethernet network with 15 PiB

100 Mbit/s bandwidth:

Duration of transmission:

Exercise 4.2: Storing and transmitting data – 100 Mbit/s

Solution for the Fast Ethernet network with 15 PB

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

Duration of transmission: $\frac{15*10^{15} \text{ Byte}}{12{,}500{,}000 \text{ Byte/s}} = 1,200,000,000 \text{ s}$
$= 20,000,000 \text{ min}$
$\approx 333,333.333 \text{ h}$
$\approx 13,888.888 \text{ d}$
$\approx 38.02570538 \text{ y}$

$\Longrightarrow$ approx. 38 Years, 9 Days, 9 Hours, 20 Minutes

Solution for the Fast Ethernet network with 15 PiB

100 Mbit/s bandwidth:

Duration of transmission:

Exercise 4.2: Storing and transmitting data – 100 Mbit/s

Solution for the Fast Ethernet network with 15 PB

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

Duration of transmission: $\frac{15*10^{15} \text{ Byte}}{12{,}500{,}000 \text{ Byte/s}} = 1,200,000,000 \text{ s}$
$= 20,000,000 \text{ min}$
$\approx 333,333.333 \text{ h}$
$\approx 13,888.888 \text{ d}$
$\approx 38.02570538 \text{ y}$

$\Longrightarrow$ approx. 38 Years, 9 Days, 9 Hours, 20 Minutes

Solution for the Fast Ethernet network with 15 PiB

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

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

$\Longrightarrow$ approx. 42 Years, 296 Days, 23 Hours, 58 Minutes

Exercise 4: Storing and transmitting data

What do the results that mean for the given assumptions?

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 56 kbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay
Transmission delay
Waiting time

Latency for the file transfer at 64 kbps

File size: 30,000,000 bit
Data rate: 64,000 bit/s
Propagation delay
Transmission delay
Waiting time

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 56 kbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/56,000bit/s \approx 535.714s$
Waiting time $= 0$

Latency for the file transfer at 64 kbps

File size: 30,000,000 bit
Data rate: 64,000 bit/s
Propagation delay
Transmission delay
Waiting time

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 56 kbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/56,000bit/s \approx 535.714s$
Waiting time $= 0$

$\Rightarrow$ **Latency** $\approx 0.025s + 535.714s = 535.739s = 8:55min$

Latency for the file transfer at 64 kbps

File size: 30,000,000 bit
Data rate: 64,000 bit/s
Propagation delay
Transmission delay
Waiting time

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 56 kbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/56,000bit/s \approx 535.714s$
Waiting time $= 0$

$\Rightarrow$ **Latency** $\approx 0.025s + 535.714s = 535.739s = 8:55min$

Latency for the file transfer at 64 kbps

File size: 30,000,000 bit
Data rate: 64,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/64,000bit/s = 468.75s$
Waiting time $= 0s$

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 56 kbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/56,000bit/s \approx 535.714s$
Waiting time $= 0$

$\Rightarrow$ **Latency** $\approx 0.025s + 535.714s = 535.739s = 8:55min$

Latency for the file transfer at 64 kbps

File size: 30,000,000 bit
Data rate: 64,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/64,000bit/s = 468.75s$
Waiting time $= 0s$

$\Rightarrow$ **Latency** $= 0.025s + 468.75s = 468.775 \approx 7:49min$

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 1 Mbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay
Transmission delay
Waiting time

Latency for the file transfer at 16 Mbps

File size: 30,000,000 bit
Data rate: 16,000,000 bit/s
Propagation delay
Transmission delay
Waiting time

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 1 Mbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/1,000,000bit/s = 30s$
Waiting time $= 0s$

$\Rightarrow$ **Latency** $= 0.025s + 30s \approx 30s$

Latency for the file transfer at 16 Mbps

File size: 30,000,000 bit
Data rate: 16,000,000 bit/s
Propagation delay
Transmission delay
Waiting time

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 1 Mbps

File size: 30,000,000 bit
Data rate: 1,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/1,000,000bit/s = 30s$
Waiting time $= 0s$

$\Rightarrow$ **Latency** $= 0.025s + 30s \approx 30s$

Latency for the file transfer at 16 Mbps

File size: 30,000,000 bit
Data rate: 16,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/16,000,000bit/s = 1.875s$
Waiting time $= 0s$

$\Rightarrow$ **Latency** $= 0.025s + 1.875s = 1.9s$

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 100 Mbps

File size: 30,000,000 bit
Data rate: 100,000,000 bit/s
Propagation delay
Transmission delay
Waiting time

Exercise 5.1: Transfer time = Latency

Latency for the file transfer at 100 Mbps

File size: 30,000,000 bit
Data rate: 100,000,000 bit/s
Propagation delay $= 5,000,000m/200,000,000m/s = 0.025s$
Transmission delay $= 30,000,000bit/100,000,000bit/s \approx 0.3s$
Waiting time $= 0s$

$\Rightarrow$ **Latency** $= 0.025s + 0.3s = 325ms$

Exercise 5.2: Transfer time = Latency

Volume of the network

Volume of the network $\sim$ bandwidth-delay product

Exercise 5.2: Transfer time = Latency

Volume of the network

Volume of the network $\sim$ bandwidth-delay product

$\rightarrow$ Only the propagation delay is relevant here!

$\Rightarrow$ Transmission delay $= 0\,\text{s}$

$\Rightarrow$ Waiting time $= 0\,\text{s}$

Exercise 5.2: Transfer time = Latency

Volume of the network

Volume of the network $\sim$ bandwidth-delay product
$\rightarrow$ Only the propagation delay is relevant here!
$\Rightarrow$ Transmission delay $= 0\,\mathrm{s}$
$\Rightarrow$ Waiting time $= 0\,\mathrm{s}$

Propagation delay $= 0.025s = 25ms$

Exercise 5.2: Transfer time = Latency

Volume of the network

Volume of the network $\sim$ bandwidth-delay product

$\rightarrow$ Only the propagation delay is relevant here!

$\Rightarrow$ Transmission delay $= 0\,\text{s}$

$\Rightarrow$ Waiting time $= 0\,\text{s}$

Propagation delay $= 0.025s = 25ms$

```
     56,000 bit/s * 0.025 s =     1,400 bit
     64,000 bit/s * 0.025 s =     1,600 bit
  1,000,000 bit/s * 0.025 s =    25,000 bit =  25 kbit
 16,000,000 bit/s * 0.025 s =   400,000 bit = 400 kbit
100,000,000 bit/s * 0.025 s = 2,500,000 bit = 2.5 Mbit
```

Exercise 6.1: Bandwidth-Delay Product

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

Exercise 6.1: Bandwidth-Delay Product

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

$RTT = (2 * distance)/$**signal propagation speed**

Exercise 6.1: Bandwidth-Delay Product

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

$RTT = (2 * distance)/$**signal propagation speed**

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

Exercise 6.2: Bandwidth-Delay Product

Calculate the bandwidth-delay product

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

Exercise 6.2: Bandwidth-Delay Product

Calculate the bandwidth-delay product

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

$$\textbf{Propagation delay} = \frac{\text{Distance}}{\text{Signal propagation speed}}$$

$$\Rightarrow \frac{55{,}000{,}000\ \text{km}}{299{,}792{,}458\ \text{m/s}} = \frac{55{,}000{,}000{,}000\ \text{m}}{299{,}792{,}458\ \text{m/s}}$$

$$\approx 183.460s$$

$$128,000bit/s * 183.460252359s = 23,482,912.302bit \approx 23.48Mbit$$

Exercise 6.3: Bandwidth-Delay Product

File size: 20 MB
Data rate: 128,000 Bits/s
Propagation delay =

Transmission delay =

Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time

Exercise 6.3: Bandwidth-Delay Product

```
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 min 54.18025236 s
```

Exercise 7: Unicast, Broadcast, Multicast, Anycast

- **Writing a WhatsApp message to your classmate**
  Unicast
- **Shouting to a friend on the university yard**
  Unicast
- **Open a ticket at the CIT service desk**
  Anycast
- **Fire alarm siren**
  Broadcast
- **Sending a message to Telegram group**
  Multicast
- **Broadcasting a radio program**
  Multicast
- **Writing an email to the Linux kernel mailing list**
  Multicast

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation

8.2 Directional dependence of walkie-talkies

8.3 Systems that operate according to the simplex principle

8.4 Advantage and drawback of simplex communication systems

8.5 Systems that operate according to the full-duplex principle

8.6 Advantage and drawback of full-duplex communication systems

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation
Only a single channel is used.

8.2 Directional dependence of walkie-talkies

8.3 Systems that operate according to the simplex principle

8.4 Advantage and drawback of simplex communication systems

8.5 Systems that operate according to the full-duplex principle

8.6 Advantage and drawback of full-duplex communication systems

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation
Only a single channel is used.

8.2 Directional dependence of walkie-talkies
Half-duplex

8.3 Systems that operate according to the simplex principle

8.4 Advantage and drawback of simplex communication systems

8.5 Systems that operate according to the full-duplex principle

8.6 Advantage and drawback of full-duplex communication systems

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation
Only a single channel is used.

8.2 Directional dependence of walkie-talkies
Half-duplex

8.3 Systems that operate according to the simplex principle
Radio, TV, pager, satellite, GPS, radio clock signal.

8.4 Advantage and drawback of simplex communication systems

8.5 Systems that operate according to the full-duplex principle

8.6 Advantage and drawback of full-duplex communication systems

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation
Only a single channel is used.

8.2 Directional dependence of walkie-talkies
Half-duplex

8.3 Systems that operate according to the simplex principle
Radio, TV, pager, satellite, GPS, radio clock signal.

8.4 Advantage and drawback of simplex communication systems
Advantage: When using a wireless network, only a single channel is required. When using a wired network, lesser cabeling effort is required.

8.5 Systems that operate according to the full-duplex principle

8.6 Advantage and drawback of full-duplex communication systems

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation
Only a single channel is used.

8.2 Directional dependence of walkie-talkies
Half-duplex

8.3 Systems that operate according to the simplex principle
Radio, TV, pager, satellite, GPS, radio clock signal.

8.4 Advantage and drawback of simplex communication systems
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

8.5 Systems that operate according to the full-duplex principle

8.6 Advantage and drawback of full-duplex communication systems

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation
Only a single channel is used.

8.2 Directional dependence of walkie-talkies
Half-duplex

8.3 Systems that operate according to the simplex principle
Radio, TV, pager, satellite, GPS, radio clock signal.

8.4 Advantage and drawback of simplex communication systems
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

8.5 Systems that operate according to the full-duplex principle
Ethernet via twisted pair cables, telephone

8.6 Advantage and drawback of full-duplex communication systems

Exercise 8: Directional Dependence – Anisotropy

8.1 Reason for the limitation
Only a single channel is used.

8.2 Directional dependence of walkie-talkies
Half-duplex

8.3 Systems that operate according to the simplex principle
Radio, TV, pager, satellite, GPS, radio clock signal.

8.4 Advantage and drawback of simplex communication systems
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

8.5 Systems that operate according to the full-duplex principle
Ethernet via twisted pair cables, telephone

8.6 Advantage and drawback of full-duplex communication systems
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.

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	
Topology contains a single point of failure	
Topology used for Thin Ethernet and Thick Ethernet	
Topology contains a performance bottleneck	
Topology used for WLAN, when no Access Point exists	
Topology used for Token Ring (logical)	
Topology used for mobile phones (GSM standard)	
Topology used for Token Ring (physical)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	
Topology used for Thin Ethernet and Thick Ethernet	
Topology contains a performance bottleneck	
Topology used for WLAN, when no Access Point exists	
Topology used for Token Ring (logical)	
Topology used for mobile phones (GSM standard)	
Topology used for Token Ring (physical)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	Bus (the medium!), Ring (the medium!), Star, Cellular
Topology used for Thin Ethernet and Thick Ethernet	
Topology contains a performance bottleneck	
Topology used for WLAN, when no Access Point exists	
Topology used for Token Ring (logical)	
Topology used for mobile phones (GSM standard)	
Topology used for Token Ring (physical)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	Bus (the medium!), Ring (the medium!), Star, Cellular
Topology used for Thin Ethernet and Thick Ethernet	Bus
Topology contains a performance bottleneck	
Topology used for WLAN, when no Access Point exists	
Topology used for Token Ring (logical)	
Topology used for mobile phones (GSM standard)	
Topology used for Token Ring (physical)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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	
Topology used for Token Ring (logical)	
Topology used for mobile phones (GSM standard)	
Topology used for Token Ring (physical)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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)	
Topology used for mobile phones (GSM standard)	
Topology used for Token Ring (physical)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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)	
Topology used for Token Ring (physical)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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)	
Cable failure leads to complete network failure	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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	
Topology contains no central component	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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	
Topology used for WLAN, when an Access Point exists	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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	
Topology used with modern Ethernet standards	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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	

Exercise 9: Network Topologies

Statement	
Cable failure can separate the network in two functioning parts	Mesh, Tree, Bus
Topology contains a single point of failure	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 10: Do some research

10.1 What is the sender address for the first email sent to Germany?

10.2 The ISO/OSI reference model comprises seven layers (1 – 7). Sometimes computer scientists speak about layer 0 or layer 8. What is meant?

10.3 Would it be a good idea to deliver YouTube videos via broadcast?

10.4 Which of the following protocols have not been specified by the IETF? Why not?

Exercise 10: Do some research

10.1 What is the sender address for the first email sent to Germany?

`Laura Breeden <breeden%csnet-sh.arpa@csnet-relay.csnet`

The mail was sent from BBN, Boston, to KIT, Karlsruhe.

10.2 The ISO/OSI reference model comprises seven layers (1 – 7). Sometimes computer scientists speak about layer 0 or layer 8. What is meant?

10.3 Would it be a good idea to deliver YouTube videos via broadcast?

10.4 Which of the following protocols have not been specified by the IETF? Why not?

Exercise 10: Do some research

10.1 What is the sender address for the first email sent to Germany?
`Laura Breeden <breeden%csnet-sh.arpa@csnet-relay.csnet`
The mail was sent from BBN, Boston, to KIT, Karlsruhe.

10.2 The ISO/OSI reference model comprises seven layers (1 – 7). Sometimes computer scientists speak about layer 0 or layer 8. What is meant?
The *wire* resp. the *user*.

10.3 Would it be a good idea to deliver YouTube videos via broadcast?

10.4 Which of the following protocols have not been specified by the IETF? Why not?

Exercise 10: Do some research

10.1 What is the sender address for the first email sent to Germany?

`Laura Breeden <breeden%csnet-sh.arpa@csnet-relay.csnet`

The mail was sent from BBN, Boston, to KIT, Karlsruhe.

10.2 The ISO/OSI reference model comprises seven layers (1 – 7). Sometimes computer scientists speak about layer 0 or layer 8. What is meant?

The *wire* resp. the *user*.

10.3 Would it be a good idea to deliver YouTube videos via broadcast?

No, because of the huge amount of unnecessary traffic.

10.4 Which of the following protocols have not been specified by the IETF? Why not?

Exercise 10: Do some research

10.1 What is the sender address for the first email sent to Germany?

`Laura Breeden <breeden%csnet-sh.arpa@csnet-relay.csnet`

The mail was sent from BBN, Boston, to KIT, Karlsruhe.

10.2 The ISO/OSI reference model comprises seven layers (1 – 7). Sometimes computer scientists speak about layer 0 or layer 8. What is meant?

The *wire* resp. the *user*.

10.3 Would it be a good idea to deliver YouTube videos via broadcast?

No, because of the huge amount of unnecessary traffic.

10.4 Which of the following protocols have not been specified by the IETF? Why not?

WIFI, Ethernet are specifications of the physical layer. The IETF works "above the wire and below the application".