Sample solution of the written examination in

Computer Networks

February 20th 2024

Last name: _____

First name: _____

Student number: _____

Mit dem Bearbeiten dieser schriftlichen Prüfung (Klausur) bestätigen Sie, dass Sie diese alleine bearbeiten und dass Sie sich gesund und prüfungsfähig fühlen. Mit dem Erhalt der Aufgabenstellung gilt die Klausur als angetreten und wird bewertet.

By attending this written exam, you confirm that you are working on it alone and feel healthy and capable to participate. Once you have received the examination paper, you are considered to have participated in the exam, and it will be graded.

- Use the provided sheets. Do *not* use own paper.
- You are allowed to use a *self prepared*, *single sided DIN-A4 sheet* in the exam. Only *hand-written originals* are allowed, but no copies.
- You are allowed to use a non-programmable calculator.
- Do *not* use a red pen.
- Time limit: *90 minutes*
- Turn off your mobile phones!

Grade: _____

Questions:	1	2	3	4	5	6	7	8	9	10	11	**Σ**
Maximum Points:	10	5	7	7	8	8	9	8	10	14	4	90
Achieved Points:												

1.0: 90.0-85.5, **1.3**: 85.0-81.0, **1.7**: 80.5-76.5, **2.0**: 76.0-72.0, **2.3**: 71.5-67.5,
2.7: 67.0-63.0, **3.0**: 62.5-58.5, **3.3**: 58.0-54.0, **3.7**: 53.5-49.5, **4.0**: 49.0-45.0, **5.0**: <45

Question 1)

Points: ..... of 10

1 Point (1) Name two systems, that operate according to the simplex principle.

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

1 Point (2) Name two systems, that operate according to the full-duplex principle.

Ethernet via twisted pair cables, telephone.

1 Point (3) Name two systems, that operate according to the half-duplex principle.

Networks with fiber-optic cables or coaxial cables, Wireless networks with just a single channel (Bluetooth, Wifi).

5 Points (4) A file with a size of $15 * 10^7$ 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 20,000 km. The file is transferred as a single message, that has a size of $15 * 10^7$ bits. No network protocol headers or trailers exist.

Calculate the transfer time (latency) of the file, when the data rate of the computer network between both terminal devices is 50 Mbps.

```
File size: 150,000,000 Bits
Data rate:  50,000,000 Bits/s
Propagation delay = 20,000,000 m / 200,000,000 m/s = 0.1 s
Transmission delay = 150,000,000 Bits / 50,000,000 Bits/s = 3 s
Waiting time = 0 s
Latency = propagation delay + transmission delay + waiting time
        = 0.1 s + 3 s = 3.1 s.
```

2 Points (5) Calculate the bandwidth-delay product for subtask (4) to find out 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 = 0.1 s

```
50,000,000 Bits/s * 0.1 s = 5.000.000 Bits
```

Question 2)

Points: ..... of 5

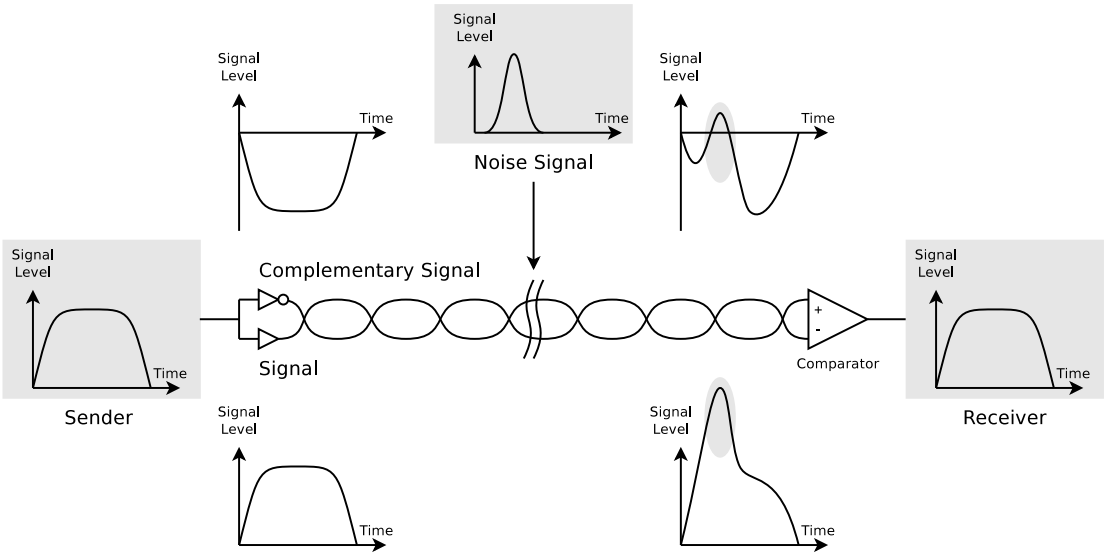
1 Point (1) Explain why the outer conductor (the shield) of coaxial cables is kept at ground potential and does completely surround the inner conductor.

The shielding of the signal-carrying conductor by the shield, that is kept at ground potential, reduces electromagnetic interferences.

1 Point (2) Explain why is it impossible to connect different buildings with shielded cables.

Shields must be electrically grounded on both sides of the cable. If only one end of a shielded cable is grounded, an antenna effect occurs, which results in a compensation current.

3 Points (3) Explain the technique and the effect that this figure demonstrates.



Ethernet sends via each wire pair signals and complementary signals. This allows the receiver to filter out interfering signals. Furthermore, it reduces electromagnetic emission. The difference of the signal levels of line A and line B at receiver side is:

$[+\text{Payload Signal}+\text{Noise}] - [-\text{Payload Signal}+\text{Noise}] = 2*\text{Payload Signal}$

Result: Regardless of the level of the noise signal, the difference between the payload signal and the complementary signal remains the same.

Question 3)

Points: ..... of 7

½ Point (1) Name the hybrid reference model layer that specifies signals.

Physical Layer

½ Point (2) Name the hybrid reference model layer that specifies segments.

Transport Layer

½ Point (3) Name the hybrid reference model layer that specifies packets.

Network Layer

½ Point (4) Name the hybrid reference model layer that specifies frames.

Data Link Layer

1 Point (5) Explain what the purpose of Repeaters in computer networks is.

A Repeater retransmits all received signals at a higher level or higher power, so that the signal can cover longer distances.

1 Point (6) Name and explain the network topology(s) that Hubs implement.

Physical topology: Star network because of the cabling.
Logical topology: Bus network, because equal to a long cable, where all network devices are connected with, a Hub forwards incoming signals to all other interfaces.

1 Point (7) Explain what a collision domain is.

The collision domain is a network or a section of a network where multiple network devices use a shared transmission medium. It includes all network devices which compete for accessing a shared transmission medium.

1 Point (8) Explain why computer networks require line codes.

Computers are digital machines. Transmission media work analogous. The line codes specify the conversion of binary data ($\Longrightarrow$ binary numbers) into signals (encoding).

1 Point (9) Explain the way Non-Return-To-Zero (NRZ) works.

It represents logical 0 and 1 by using different voltage levels.

Question 4)

Points: ..... of 7

1 Point (1) Name the two problems that can occur when NRZ is used to encode data.

Baseline Wander and Clock Recovery.

2 Points (2) Explain both problems from subtask (1) in detail.

Baseline Wander = shift of the average when using NRZ. The receiver distinguishes the physical signal levels by using the average of a certain number of received signals. Signals far below the average, interprets the receiver as logical 0 bit. Signals significantly above the average, interprets the receiver as logical 1 bit. When transmitting a long series of logical 0 bits or 1 bits, the average can shift so much, making it difficult to detect a significant change in the physical signal.

Clock Recovery when using NRZ. Even if the processes for encoding and decoding run on different computers, they need to be controlled by the same clock. In each clock cycle, the sender transmits a bit and the receiver receives a bit. If the clocks of sender and receiver drift apart, the receiver may lose count during a long sequence of logical 0 bits or 1 bits.

2 Points (3) Explain how the problems from subtask (1) can be avoided.

In order to prevent Baseline Wander, when using a line code with 2 physical signal levels, the usage of both signal levels must be equally distributed.

One way to avoid the Clock Recovery problem is by using a separate line, which transmits just the clock. In computer networks, a separate signal line just for the clock is not practical because of the cabling effort. Instead, it is recommended to increase the number of guaranteed signal level changes to enable the Clock Recovery from the data stream.

1 Point (4) Explain what the purpose of Bridges in computer networks is.

For connecting different physical networks, Bridges are required because they forward frames from one physical network to another one.

Bridges and Switches check the correctness of the frames via checksums.

1 Point (5) Explain why Bridges and Layer-2-Switches do not require physical or logical addresses.

Bridges do not need addresses for filtering and forwarding the frames, because they do not actively participate in the communication. They work transparent, just like the devices of the Physical Layer.

Question 5)

Points: ..... of 8

½ Point (1) Name one example of a Bridge implementation.

WLAN Bridge, Laser Bridge.

1 Point (2) Name the information that is stored in the forwarding tables of Bridges.

The information, which network devices are accessible via which port in local forwarding tables.

1 Point (3) Explain what a Designated Bridge is and what its task is.

For each physical network, a single one of the directly connected Bridges needs to be selected as responsible for forwarding the frames towards in the direction of the Root Bridge. This Bridge is called Designated Bridge for this network.

1 Point (4) Give the number of Designated Bridges, a computer network contains.

For each physical network, a single Designated Bridge exists.

1 Point (5) Give the selection criteria for determining, whether a Bridge becomes a Designated Bridge.

The Bridge with the lowest path costs to the Root Bridge is selected as Designated Bridge.

1½ Points (6) Name three devices that split the collision domain

Bridge, L2-Switch, L3-Switch, Router

½ Point (7) Name one device that splits the broadcast domain

L3-Switch, Router

½ Point (8) Name the protocol that is used for translating Network Layer addresses into Data Link Layer addresses.

Address Resolution Protocol (ARP)

1 Point (9) Explain the purpose of Routers in computer networks.
(*Also explain the difference to Layer-3-Switches.*)

They forward packets between networks with different logical address ranges and provide a WAN interface.

Layer-3-Switches are are Routers too, which means they forward packets between networks with different logical address ranges, but they do not provide a WAN interface.

Question 6)

Points: ..... of 8

4 Points

(1) Error detection via CRC: Calculate the frame to be transferred.

```
Generator polynomial: 100101
Payload: 11010011
```

The generator polynomial has 6 digits ⟹ five 0 bits are appended

```
Frame with appended 0 bits: 1101001100000

1101001100000
100101|||||||
------v||||||
 100011||||||
 100101||||||
 ------vvv|||
    110100|||
    100101|||
    ------v||
     100010||
     100101||
     ------vv
        11100 = Remainder

Remainder: 11100
Transferred frame: 1101001111100
```

3 Points

(2) Error detection via CRC: Check if the received frame was transmitted correctly.

```
Transferred frame: 1011010110110
Generator polynomial: 100101
```

```
1011010110110
100101|||||||
------vv|||||
  100001|||||
  100101|||||
  ------vvv||
     100101||
     100101||
     ------vv
           10 => Error
```

1 Point

(3) Explain why up-to-date Data Link Layer protocols, such as Ethernet and WLAN, only provide error detection but no error correction method.

Error detection requires lesser parity bits than error correction ⟹ less overhead.

Question 7)

Points: ..... of 9

1 Point (1) One way to mark the frames' borders is via character count in the frame header. Name a potential issue that can arise from this method.

If the field, which contains the number of bytes payload inside the frame is modified during transmission, the receiver is unable to correctly detect the end of the frame.

1 Point (2) One way to mark the frames' borders is via Byte Stuffing. Name a drawback of this method.

The strong relationship with the ASCII character encoding.

1 Point (3) Explain why up-to-date Data Link Layer protocols, such as Ethernet and WLAN, work bit-oriented and not byte-oriented.

Because this allows using any character encoding.

1 Point (4) Explain why Gateways in the Network Layer of computer networks are seldom required nowadays.

Modern computer networks operate almost exclusively with the Internet Protocol (IP). For this reason, a protocol conversion at the Network Layer is mostly not required.

½ Point (5) Explain the meaning of Unicast in the Network Layer.

An IP address is assigned to a single receiver.

½ Point (6) Explain the meaning of Broadcast in the Network Layer.

An IP address is assigned to all receivers in the subnet.

½ Point (7) Explain the meaning of Anycast in the Network Layer.

An IP address is used to reach a single device of a group of devices.

½ Point (8) Explain the meaning of Multicast in the Network Layer.

An IP address is assigned to a group of receivers.

1 Point (9) Name <u>one</u> private IPv4 address space.

10.0.0.0/8 or *172.16.0.0/12* or *192.168.0.0/16*

2 Points (10) Describe in simple words the functioning of CIDR.
(*Focus on the way, how IP addresses are treated and subnets are created.*)

Since the introduction of CIDR, the address class of an IPv4 address is no longer important. All hosts in a network have a subnet mask assigned, which has a length of 32 bits (4 bytes) and is used to specify the number of subnets and hosts. The network mask splits the host ID of an IP address into subnet ID and host ID. 1-bits in the subnet mask indicate, which part of the address space is used for subnet IDs and 0-bits indicate, which part of the address space is used for host IDs.

Question 8)

Points: ..... of 8

4 Points (1) Calculate the first and last host addresses, the network address and the broadcast address of the subnet.

```
IP Address:          151.175.30.100   10010111.10101111.00011110.01100100

Subnet mask:         255.255.240.0    11111111.11111111.11110000.00000000

Part for host IDs:                                          xxxx xxxxxxxx

Network address?     151.175.16.0     10010111.10101111.00010000.00000000

First host address? 151.175.16.1      10010111.10101111.00010000.00000001

Last host address?   151.175.31.254   10010111.10101111.00011111.11111110

Broadcast address?   151.175.31.255   10010111.10101111.00011111.11111111
```

binary representation	decimal representation	binary representation	decimal representation
10000000	128	11111000	248
11000000	192	11111100	252
11100000	224	11111110	254
11110000	240	11111111	255

½ Point (2) Give the class of the IP address in subtask (1).
The prefix 10 means class B

½ Point (3) Give the number of bits for host IDs in subtask (1).
12

½ Point (4) Give the number of host IDs per subnet in subtask (1).
$2^{12} - 2 = 4094$

½ Point (5) Give the number of bits for subnet IDs in subtask (1).
4

½ Point (6) Give the number of possible subnets in subtask (1).
$2^4 = 16$

½ Point (7) Give the name of the scope of IPv6 addresses that have the prefix `fe80::/10`.
Link-Local Scope.

½ Point (8) Give the name of the scope of IPv6 addresses that have the prefix `fc00::/7`.
Unique-Local Scope.

½ Point (9) Give the name of the scope of IPv6 addresses that have the prefix `2000::/3`.
Global Scope.

Question 9)

Points: ..... of 10

1 Point (1) Explain what the Host Scope is in IPv6.

The Host Scope includes the loopback address `::1/128`.

1 Point (2) Explain what the Link-Local Scope is in IPv6.

The Link-Local Scope includes Link-Local (Unicast) Addresses (LLA). Every network interface requires a Link-Local Address at any time. Link-Local Addresses fe80::/10 are only valid in the local network. Routers do not forward packages with these addresses.

1 Point (3) Explain what the Unique-Local Scope is in IPv6.

The Unique-Local Scope includes Unique Local Addresses (ULA). Routers should not forward packages with these addresses outside the local administrative domain (organization or site). They are private addresses intended for local communication inside an administrative domain, but can be globally valid (unique) if they are assigned by a provider. Local generated ULA are very likely unique.

1 Point (4) Explain what the Global Scope is in IPv6.

The Global Scope includes Global Unicast Addresses. Routers forward packages with these addresses.

1 Point (5) IPv6 has no broadcast addresses but for some purposes, a broadcast-like functionality is required. Explain how IPv6 emulates the broadcast functionality.

In IPv6, Multicast addresses are used to emulate the Broadcast functionality. The address `ff02::1` has the Link-Local Scope and addresses all nodes in the local network.

1 Point (6) Give the prefix of Multicast addresses in IPv6.

Multicast addresses start with the first 8 bits set to value `11111111`. Thus, they have the multicast prefix `ff::/8`.

3 Points (7) Name three ways of setting the Interface-ID in IPv6.

- *Static manual addressing*
- *Stateless Address Autoconfiguration (SLAAC)*
- *Setting the network configuration via DHCPv6*

1 Point (8) Explain why IPv6 requires Duplicate Address Detection (DAD).

If a node has created an Interface-ID via SLAAC, it must validate that no other node in the network has the same Interface-ID (address). This procedure is called Duplicate Address Detection (DAD). The node sends a Neighbor Solicitation (NS) message to the address that it wants to use itself. If a node in the local network already uses this IP address, it is a duplicate. The node will reply with a Neighbor Advertisement (NA) message. The node that was sending NS message needs to generate a new address and carry out the Duplicate Address Detection again. If no Neighbor Advertisement (NA) message is received for some time, the address can be used ($\Longrightarrow$ no duplicate).

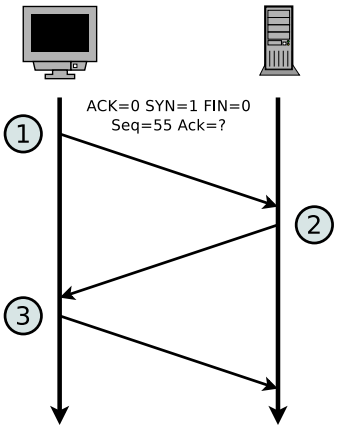
Question 10)

Points: ..... of 14

4 Points

(1) The diagram shows the establishment of a TCP connection. Complete the table.

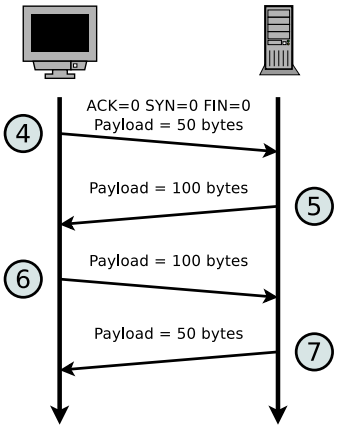
Message	ACK flag	SYN flag	FIN flag	Payload length	Seq number	Ack number
1	*0*	*1*	*0*	*0*	55	*irrelevant*
2	*1*	*1*	*0*	*0*	20	*56*
3	*1*	*0*	*0*	*0*	*56*	*21*



5 Points

(2) The diagram shows an excerpt of the transmission phase of a TCP connection. Complete the table.

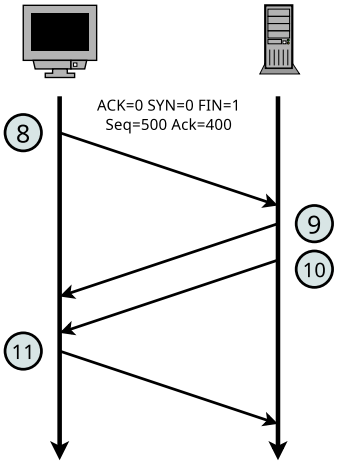
Message	ACK flag	SYN flag	FIN flag	Payload length	Seq number	Ack number
4	*0*	*0*	*0*	50	200	300
5	*1*	*0*	*0*	100	*300*	*250*
6	*1*	*0*	*0*	*100*	*250*	*400*
7	*1*	*0*	*0*	*50*	*400*	*350*



5 Points

(3) The diagram shows the termination of a TCP connection. Complete the table.

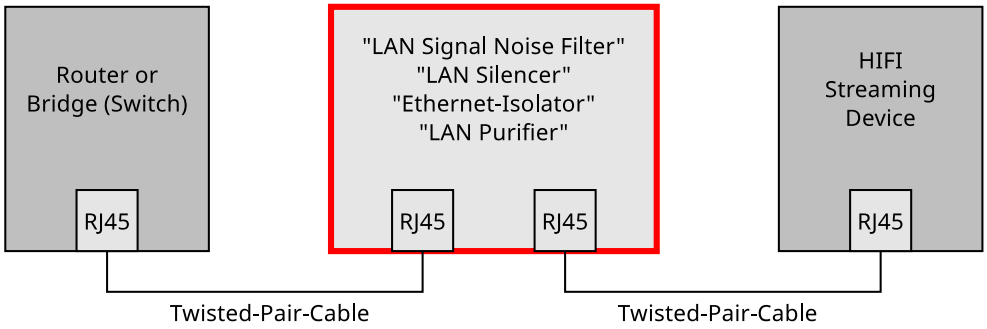
Message	ACK flag	SYN flag	FIN flag	Payload length	Seq number	Ack number
8	*0*	*0*	1	0	500	400
9	*1*	*0*	*0*	*0*	*400*	*501*
10	*0*	*0*	*1*	*0*	*400*	*501*
11	*1*	*0*	*0*	*0*	*501*	*401*



Question 11)

Points: ..... of 4

Some vendors sell so-called „LAN Signal Noise Filters“ (sometimes called „Ethernet Filter“, „LAN Silencer“, „LAN Purifier“, or „Ethernet-Isolator“) that are supposed to remove Electrical interference (noise signals) from Ethernet connections (twisted-pair cables with RJ45 connectors) between a Router/Switch and a streaming device, aiming to improve the music quality in HIFI applications. The figure demonstrates the concept of using such a device.



1 Point (1) Has such a device the potential to improve the music quality?

☐ yes ☒ no ☐ maybe

3 Points (2) Explain your opinion on the effectiveness in detail.

Music that is transferred via a computer network is encoded as digital data (e.g. MP3, AAC, OGG or FLAC). An Application Layer protocol like HTTP is used to request and transport the music files or streams. The music is transferred as Application Layer data that is transported as payload in Transport Layer TCP segments. The TCP segments are transported as payload in Network Layer IP packages. The IP packages are transported as payload in Data Link Layer Ethernet frames. The bit stream representing the Ethernet frames is encoded in Physical Layer as analogous signals and transferred via the transmission medium twisted-pair cable.

Ethernet frames and TCP segments include checksums that are used to validate the correctness of the transmission. IPv4 packages also include a checksum field, but it is not used in practice. Ethernet frames that are modified during transmission are thrown away by the receiver. TCP segments that are modified during transmission are requested again by the receiver. Thus, it is impossible that lower-quality music is used by the steaming device to decode and play the music. The mentioned device is useless, by principle.