

**Note:**

- During the attendance check a sticker containing a unique code will be put on this exam.
- This code contains a unique number that associates this exam with your registration number.
- This number is printed both next to the code and to the signature field in the attendance check list.

## Advanced Computer Networking

**Exam:** IN2097 / Endterm                      **Date:** Wednesday 18<sup>th</sup> February, 2026  
**Examiner:** Prof. Dr.-Ing. Georg Carle        **Time:** 14:00 – 15:15

### Working instructions

- The total amount of achievable credits in this exam is 75 credits.
- Detaching pages from the exam is prohibited.
- Allowed resources:
  - the **provided cheat sheet** distributed together with the exam
  - one **analog dictionary** English ↔ native language
- Subproblems marked by \* can be solved without results of previous subproblems.
- **Answers are only accepted if the solution approach is documented.** Give a reason for each answer unless explicitly stated otherwise in the respective subproblem.
- Do not write with red or green colors nor use pencils.
- Physically turn off all electronic devices, put them into your bag and close the bag.
- This exam consists of **16 pages** with a total of **6 problems**.  
Please make sure now that you received a complete copy of the exam.

Left room from \_\_\_\_\_ to \_\_\_\_\_ / Early submission at \_\_\_\_\_

## Problem 1 Quiz (14 credits)

The following questions cover multiple topics. **For each multiple choice question, exactly one answer is correct.**

### Multiple Choice

Mark correct answers with a cross



To undo a cross, completely fill out the answer option



To re-mark an option, use a human-readable marking



a)\* What is the type of the following identifier or address? 3f:2e:10:af:7f:ex:81:f0

MAC address

IPv4 address

IPv6 address

None of the listed options

IP identifier

Port number

b)\* What does an Ethernet switch do when it receives a frame with a destination MAC address that is not present in its MAC address table?

It sends the frame only to the Default Gateway.

It asks the Root Bridge for instructions.

It drops the frame immediately.

It floods the frame out of all ports except the receiving port.

c)\* What is the primary benefit of VXLAN over traditional 802.1Q VLANs?

Native encryption

Scalability up to 16M IDs

None of the listed options

Reduced MTU size

Layer 1 link speed

Lower header overhead

d)\* Which transport layer protocol is used to encapsulate VXLAN traffic?

ICMP

SCTP

None of the listed options

TCP

QUIC

IGMP

e)\* What is the primary difference between the "Control Plane" and the "Data Plane" in an SDN architecture?

The Control Plane is local to the switch; the Data Plane is centralized.

The Control Plane is implemented in hardware; the Data Plane in software.

The Control Plane makes decisions; the Data Plane forwards packets.

The Control Plane handles user data; the Data Plane handles signaling.

f)\* What is **Network Function Chaining (NFC)** in the context of Network Function Virtualization (NFV)?

A technique for load balancing traffic across different CPU cores.

Connecting multiple virtual machines using a software switch.

Directing traffic through a specific sequence of virtual network functions.

A method for encrypting virtual machine traffic.

g)\* What is the primary mechanism DPDK's **Poll Mode Driver (PMD)** uses to improve performance?

Compressing packets before processing

Increasing the number of hardware interrupts

Continuously checking the NIC for new packets

None of the listed options

h)\* Why is the arithmetic mean or median often a misleading metric for assessing user experience in network latency?

- It overemphasizes the fastest 10 % of packets.
- It ignores the propagation delay of the physical medium.
- It is too computationally expensive to calculate in real-time.
- It hides rare outliers that affect a service.

i)\* If a latency measurement reports a 99th percentile of 250 ms, what does this imply?

- The average latency of the slowest 1 % of users is 250 ms.
- Only 1 % of the total requests were successful.
- 99% of all measurements have a latency of exactly 250 ms.
- 99 % of all requests were completed in 250 ms or less.

j)\* Which of the following options is the definition of **reproducibility** according to ACM?

- Same team executes experiment using same setup
- Same team executes experiment using different setup
- Different team executes experiment using same setup
- Different team executes experiment using different setup

k)\* Which of the following statements about the **Probe Bandwidth** phase in TCP BBR is true?

- The data inflight is reduced to only 4 segments for 200 ms + 1 RTT
- The data inflight is reduced to 70 % of the previous sending rate for 200 ms + 1 RTT
- The sending rate is increased by 25 % every eighth RTT for 10 s
- The sending rate is increased by 1 MSS every eighth RTT for 9 s

l)\* What is the goal of flow control? How is the sending rate changed?

**Goal:**

**Sending rate adjustment:**



We now consider a bloom filter with the following three hash functions  $\forall_{i \in \{1,2,3\}} h_i : \{0, 1\}^* \rightarrow \{0, 1\}^4$ :  
 (1)  $h_1(\text{'world'}) = 2$ , (2)  $h_2(\text{'world'}) = 4$ , (3)  $h_3(\text{'world'}) = 8$ .

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1

Figure 1.1: Bloom filter

m)\* Given the bloom filter (Fig. 1.1), determine the result of the bloom filter lookup for the element  $x = \text{'world'}$ .

- True: the element was definitely added to the filter beforehand
- False: the element was definitely not added to the filter beforehand
- True: the element was likely added to the filter beforehand
- False: the element was likely not added to the filter beforehand

n)\* Given the bloom filter in Figure 1.1, add the element  $x = \text{'world'}$  to the bloom filter in the box below. Only fill in changed values.


Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Value before addition	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	1
Value after addition																




## Problem 2 Transport Layer (10 credits)




You are optimizing the network stack for “LittleLimeLever,” a real-time video conferencing application. The application currently uses HTTP / 2 over TCP but the performance is often suboptimal. You are thinking about different aspects to improve the user experience.

0  1 a)\* When a user walks out of the office, switching from Wi-Fi to 5G, the video call suddenly ends. Shortly explain, why TCP cannot maintain the connection in this scenario.

0  1 b) Which mechanism in QUIC would fix this issue? Why does it recognize the connection after the network change?

**Mechanism:**

**Why it works:**

0  1 c)\* Figure 2.1 shows how the RTT of a TCP connection changes with increasing data inflight in an ideal environment. Update Figure 2.2 accordingly.

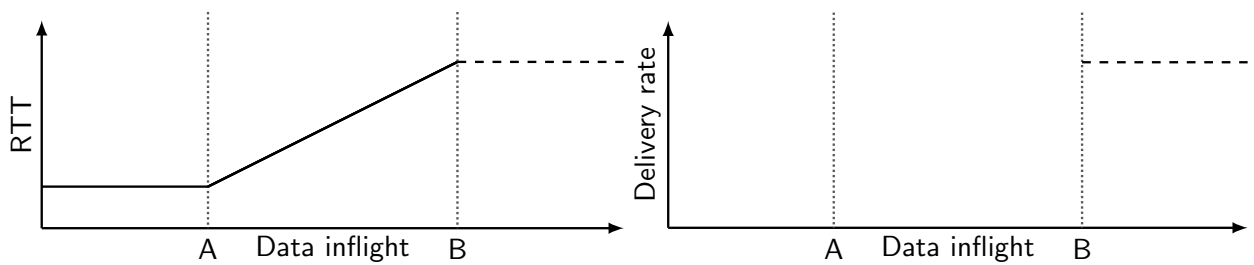




Figure 2.1: RTT

Figure 2.2: Delivery rate

0  1 d)\* How large is the amount of inflight data at the labels A and B in Figures 2.1 and 2.2?

**A:**

**B:**

0  1 e)\* Mark and label the operation point of loss-based and delay-based congestion control algorithms in Figure 2.1.





e) Through which mechanism was the IP address of PC1 most likely obtained? Explain shortly.



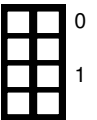
f) Which transport layer protocol is used?

Protocol:	Reasoning:
-----------	------------



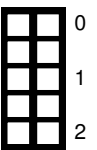
g) Which application layer protocol is most likely used?

Protocol:	Reasoning:
-----------	------------



h) At what index (e.g. 0x0065) in the frame does the PDU of layer 5 start?

Index:	Reasoning:
--------	------------



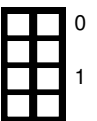
Then, you see another packet on the monitored link with an ICMPv6 message that provides additional information about the underlying problem. Figure 3.3 shows only the header and payload of the ICMP message.

```
0x0000  01 00 ff ff 00 00 00 00    60 07 45 3d 00 84 06 3f
0x0010  20 01 0d b8 11 ab 00 01    32 44 d7 ff fe 65 dc 73
0x0020  20 01 0d b8 11 ab 00 0d    00 00 00 00 00 00 00 02
0x0030  c2 65 01 bb a2 77 24 07    00 00 00 00 80 02 fa ..
```

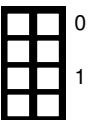
Figure 3.3: ICMPv6 message (truncated)

i)\* What is the underlying cause of the ICMP message? Remember to name and mark respective fields.

Message cause:
Reasoning:



j) Argue which device in the topology created this ICMP message.



k) Explain what you might need to change in your network such that the packets are successfully received.



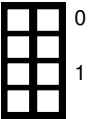
## Problem 4 P4 Switching (15 credits)

This problem investigates a Software-Defined Network (SDN) powered by P4. Parts of the source code for the P4 switch program are given in Listing 1. This program processes frames with and without VLAN header.

```
1 header eth_t      { bit<48> dstAddr;
2                   bit<48> srcAddr;
3                   bit<16> etherType; }
4
5 header veth_ext_t { _____ pcp; // see Subproblem a)
6                   _____ dei; // see Subproblem a)
7                   _____ vid; // see Subproblem a)
8                   bit<16> etherType; }
9 struct std_meta   { bit<16> ingress_port; }
10 struct meta      { //unused
11                 }
12 struct headers   { eth_t eth;
13                   veth_ext_t veth_ext; }
14
15 parser ParserImpl(packet_in packet, out headers hdr, inout meta meta, inout standard_metadata_t
16 std_meta) {
17     state parse_eth {
18         packet.extract(hdr.eth);
19         transition select(hdr.ethernet.etherType) {
20             16w0x8100: parse_veth_ext;
21             default: accept;
22         }
23     }
24     state parse_veth_ext {
25         packet.extract(hdr.veth_ext);
26         transition accept;
27     }
28     state start {
29         transition parse_eth;
30     }
31 }
32
33 control Pipeline(inout headers hdr, inout metadata meta, inout standard_metadata_t std_meta) {
34     action drop() {
35         mark_to_drop();
36     }
37     action decap(bit<16> egress) {
38         std_meta.egress_port = egress;
39         hdr.eth.etherType = hdr.veth_ext.etherType;
40         hdr.veth_ext.setInvalid();
41     }
42     table forward {
43         actions = {
44             decap;
45             drop;
46             NoAction();
47         }
48         key = {
49             std_meta.ingress_port: exact;
50             hdr.eth.srcAddr: exact;
51             hdr.veth_ext.vid: exact;
52         }
53         size = 4;
54         default_action = NoAction();
55     }
56     apply {
57         if (hdr.veth_ext.isValid()) {
58             forward.apply();
59         }
60     }
61 }
62
63 control DeparserImpl(packet_out packet, in headers hdr) {
64     // see Subproblem b)
65 }
66
67 // ...
```

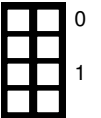
Listing 1: VLAN P4 program

a)\* Complete the veth\_eth\_t header of Listing 1 (Lines 4–6).



```
_____ pcp; // see Subproblem a)
_____ dei; // see Subproblem a)
_____ vid; // see Subproblem a)
```

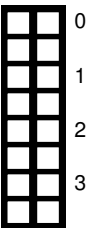
b)\* Create a valid deparser for the P4 program in Listing 1.



```
control DeparserImpl(packet_out packet, in headers hdr) {
  // see Subproblem b)

}
}
```

c)\* For this problem, consider a packet that contains a **VXLAN** header. What happens to the packet according to the ParserImpl of Listing 1? Briefly explain which states are traversed and why.



Empty box for the answer to subproblem c).



## Problem 5 DNS (9 credits)

While debugging the video stream problem, you encounter a DNS message you do not expect on this link. Therefore, you decide to investigate this message in detail.

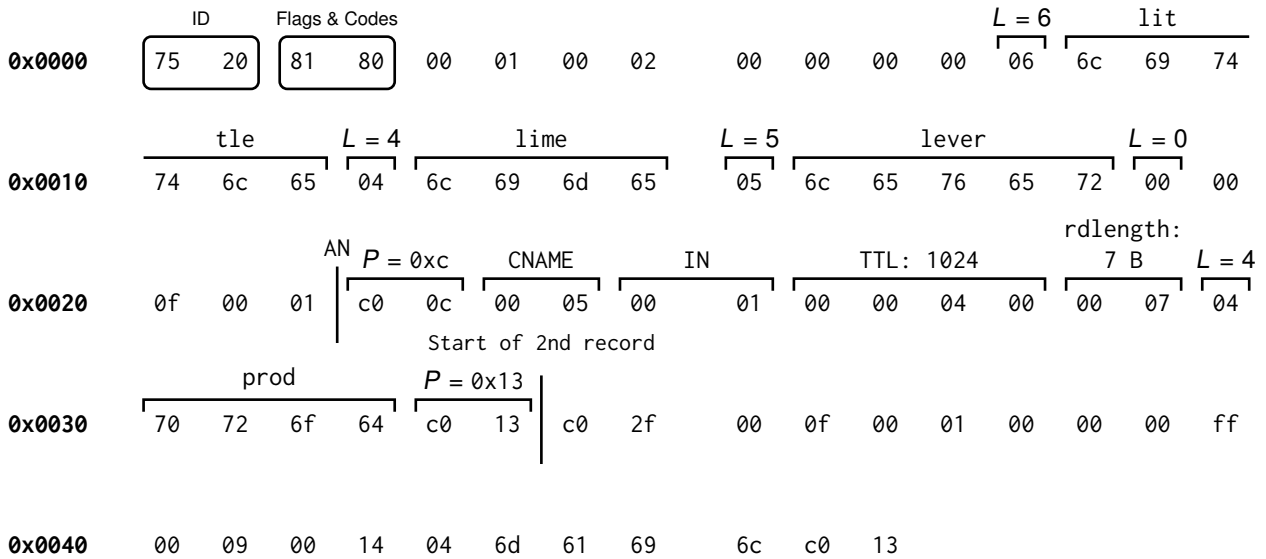
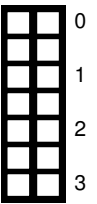


Figure 5.1: Hexdump of a DNS message

a)\* Parse the header of the DNS message in Figure 5.1.

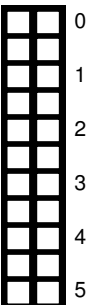
Field	Value	Name/Meaning
ID	34176	–
Flags	–	<input type="checkbox"/> QR <input type="checkbox"/> AA <input type="checkbox"/> TC <input type="checkbox"/> RD <input type="checkbox"/> RA
Opcode (Status)	0	
Rcode		
QDCOUNT		Count of Queries RRs
NSCOUNT		Count of Authority RRs
ANCOUNT		Count of Answer RRs
ARCOUNT		Count of Additional RRs



The answer section begins with byte offset 0x0023 and is marked in Figure 5.1 by the label AN.

b)\* What is the content of the answer section using the template below? Mark and label all used labels, pointers, and fields like the example shown in Figure 5.1.

NAME	TTL	CLASS	TYPE	RDATA
little.lime.lever.	1024	IN	CNAME	prod.lime.lever.



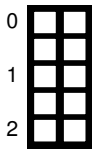
c) What type of DNS entity did likely send this message? Explain.



## Problem 6 Routing (12 credits)

For the following subproblems, we use the AS topology in Figure 6.1. Consider the following hints regarding notation and routing policies.

- $\rightarrow$  represents a customer to provider relationship: customer  $\rightarrow$  provider
- $-$  represents a peering relationship.
- All ASes apply standard routing behavior. Furthermore, the following policies are applied:
  - For routes with the same prefix, the AS selects the most cost-efficient route.
  - For routes with the same prefix and with an equal traffic cost, the shorter route is selected. If routes are equally long, use the next hop with the lower AS number.



a)\* Draw the AS path for packets going from **AS 77** to **AS 40**. Take care to mark the path clearly.

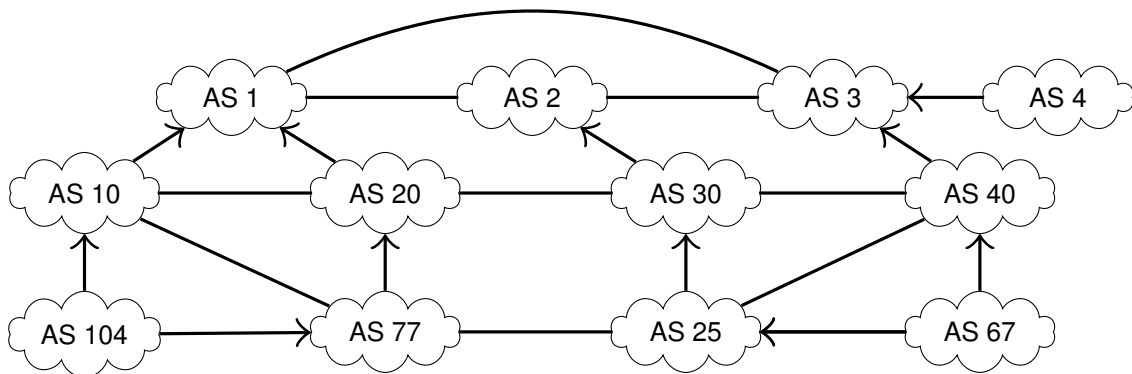
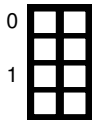
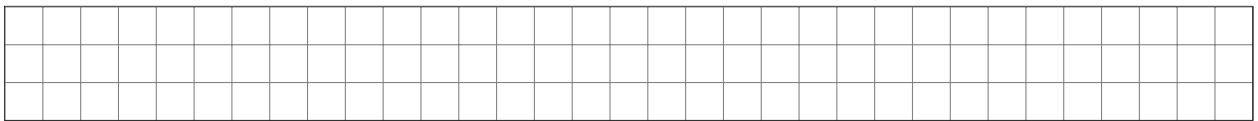


Figure 6.1: AS topology

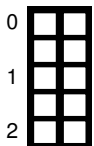


b)\* List which ASes in the topology in Figure 6.1 are *Tier-1 providers*, *stub networks* and *multi-homed ASes*.

**Tier-1 provider(s)**

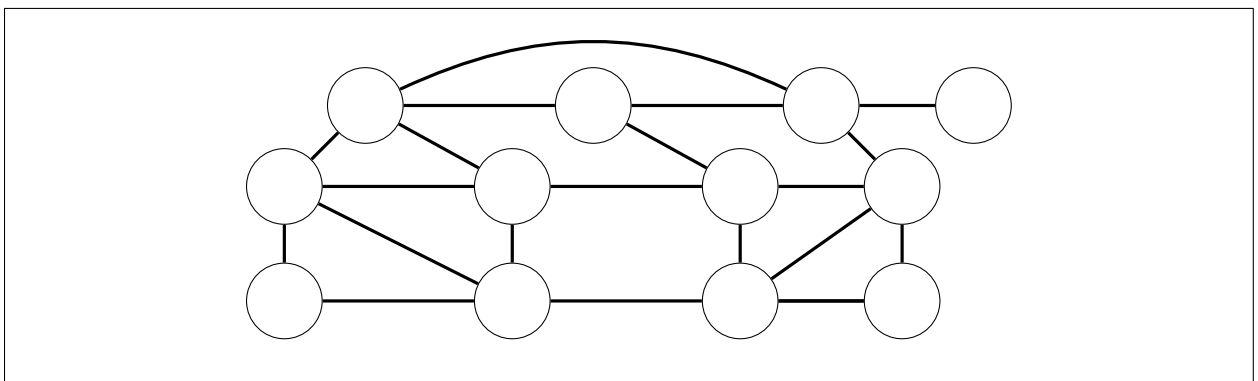
**Stub AS(es)**

**Multi-homes AS(es)**



c)\* Perform the  $k$ -core algorithm for the AS topology below. To visualize this, perform the following subtasks.

1. List the  $k$ -value for every node in the graph, i.e. the current  $k$  value when the node is removed.
2. Mark the core of the network after applying the  $k$ -core algorithm.





**Additional space for solutions—clearly mark the (sub)problem your answers are related to and strike out invalid solutions.**

