ETH zürich

Institut für Technische Informatik und Kommunikationsnetze

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# Exam: Communication Networks

6 August 2024, 9:00–11:30, Room HIL F 41

General remarks:

- Write **legibly** your ETH student number (legi number) below on this front page.
- **Do not write your name** or use a stamp with your name on it.
- **TRIPLE-check that your legi number is correct!**
  You will not be graded if you make a mistake when writing your number.
- Put your **legitimation card** on the top right corner of your desk. Make sure that the side containing your name and **student number** is visible.

- Check that you have received **all task sheets** (Pages **1 − 34**).
- Do **not separate** the **task sheets** as we collect the exams **only after you left** the room.

- Write your answers directly on the task sheets.
- **All answers fit within the allocated space and often in much less.**
- If you need more space, use the three extra sheets at the **end of the exam**. Indicate the **task** in the corresponding field.

- Read each task **completely before you start solving it**.
- **For the best mark, it is not required to score all points.**

- Please answer either in **English or German**.
- **Write clearly** in blue or black ink (not red) using a **pen**, not a pencil.
- **Cancel** invalid parts of your solutions **clearly**.
- At the end of the exam, **place the exam face up on the top left corner** of your desk. Then collect all your belongings and **exit the room** according to the given instructions.

Special aids:

- All written materials (vocabulary books, lecture and lab scripts, exercises, etc.) are allowed.
- Using a calculator is allowed, but the use of electronic communication tools (mobile phone, computer, etc.) is strictly forbidden.

Student legi nr.:

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**Do not write in the table below** (used by correctors only):

| Task | Points |
|---|---|
| Ethernet & IP | /30 |
| Intra-domain routing | /28 |
| Inter-domain routing | /38 |
| Reliable transport | /35 |
| Applications | /19 |
| Total | /150 |

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## Task 1: Ethernet & IP 30 Points

### a) Warm-Up (6 Points)

**(i)** Name the type of links where collisions can happen even when two directly-connected hosts communicate with each other. (1 Point)

**(ii)** Name a mechanism to mitigate forwarding loops present at the **network layer**. (1 Point)

**(iii)** Why would it be interesting for a layer-2 switch to also have a MAC address? (1 Point)

**(iv)** Briefly explain why switches do **exact** (MAC) lookups instead of the **longest-prefix-match** (IP) lookups that routers do. (1 Point)

**(v)** State one disadvantage of allowing access links to carry VLAN identifiers. (1 Point)

**(vi)** Can we always remove an entry from a routing table that refers to a sub-prefix of a prefix that exists in the table without changing the forwarding? Briefly explain. (1 Point)

**b) MACs and IPs** **(8 Points)**

leave blank

Consider two networks (Network 1 and 2) connected through the Internet (Figure 1):

- $S_1$, $S_2$, and $S_3$ are layer-2 switches;
- $R_1$ and $R_2$ are layer-3 routers;
- $S_2$ is connected to a DHCP server;
- $H_x$ are hosts where $x$ is the host number: Network 1 has 2 hosts, $H_1$ and $H_2$; Network 2 has 1000 hosts, $H_3$, $H_4$, ..., $H_{1002}$ (not all of them are shown);
- layer-2 switches do not have any MACs or IPs, while each of the other devices has one MAC and one IP address for each network they are part of.

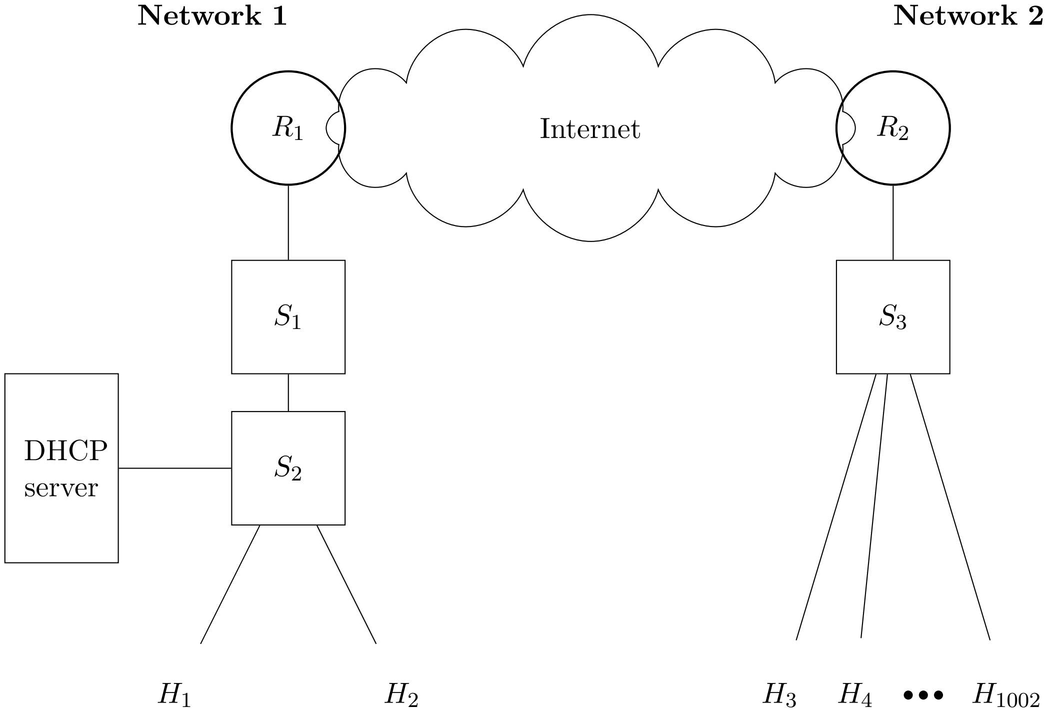


Figure 1: Two networks connected through the Internet.

**(i)** Assume that the devices in Network 1 communicate only with each other. If you monitor *all* traffic in Network 1, you will observe at most ________ distinct MACs, and at most ________ distinct IPs. **Fill in the blanks.** (2 Points)

**(ii)** Assume that prefix $p_1$ is assigned to Network 1, and prefix $p_2$ is assigned to Network 2 such that:

- $p_1$ and $p_2$ belong to prefix $p =$ `125.0.0.0/8`;
- the first addresses from $p$ are assigned to Network 1;
- each of $p_1$ and $p_2$ has the smallest possible size to accommodate all the hosts;
- the last address of $p_1$ is as consecutive as possible with the first address of $p_2$.

Then, $p_1 =$________________________ and $p_2 =$________________________

**Fill in the blanks.** (2 Points)

**(iii)** Assume that all switch forwarding tables and all ARP tables are empty. Only the DHCP server and $H_2$ already know/have learned their IP addresses ($H_1$ does not). Devices in Network 1 have the following MAC addresses:

- $H_1$ has MAC a;
- $H_2$ has MAC b;
- the DHCP server has MAC c;
- $R_1$ has MAC d.

$H_1$ knows $H_2$'s IP and $H_1$ wants to send a packet to $H_2$.

State all the frames/packets that $S_1$ and $S_2$ observe in **ascending chronological order**, respectively, up until $H_2$ receives $H_1$'s packet. Answer by filling in Table 1 for $S_1$ and Table 2 for $S_2$. As an example for the "Protocol & Purpose" column, if a table row indicates a DNS request for resolving `fun.nsg.ee.ethz.ch`, its "Protocol & Purpose" would be "DNS request for `fun.nsg.ee.ethz.ch`'s IP." (You may not need all the table entries.) (4 Points)

| # | **MAC** | | **Protocol & Purpose** |
|---|---|---|---|
| | **src** | **dst** | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

Table 1: Frames/packets observed by **S1**.

| # | **MAC** | | **Protocol & Purpose** |
|---|---|---|---|
| | **src** | **dst** | |
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |

Table 2: Frames/packets observed by **S2**.

**c) Spanning Tree Protocol** **(16 Points)**

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Consider the topology in Figure 2. Squares represent layer-2 switches ($S_X$ indicates a switch with ID $X$), and circles represent layer-3 routers ($R_Y$ indicates a router with ID $Y$). Upon running the Spanning Tree Protocol (STP), if there exist multiple shortest paths to the root node, a node picks the next hop which has the lowest node ID.

**Throughout this task, assume that links don't fail, there are *no* VLANs, and that you *cannot* change the topology, switch IDs, or STP, unless explicitly stated.**

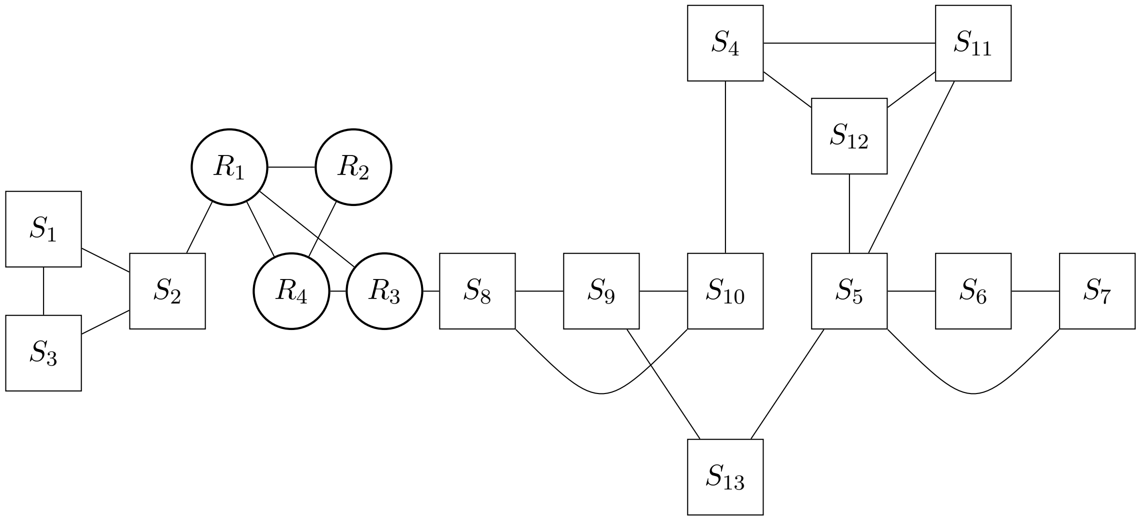


Figure 2: Topology of layer-2 switches (squares) and layer-3 routers (circles). (You can find a copy for taking notes on page 29.)

**(i)** Indicate below which links are **de-**activated after running the STP in Figure 2. For example, write "$S_X - S_Y$" to indicate that the link between $S_X$ and $S_Y$ is de-activated. Indicate each de-activated link on a different line. (You may not need all the lines.) (4 Points)

de-activated link #1: __________

#2: __________

#3: __________

#4: __________

#5: __________

#6: __________

#7: __________

#8: __________

#9: __________

#10: __________

**(ii)** Hosts $H_7$ and $H_8$ (not shown in the figure) are attached to $S_7$ and $S_8$, respectively, and frequently communicate with each other.

Is it possible to make the number of *switches* between $H_7$ and $H_8$ equal to 5 after **removing a single link** from Figure 2 and re-applying STP? If yes, state which link should be removed and the path that will be used between $H_7$ and $H_8$. If not, briefly explain why. (3 Points)

**(iii)** Consider now only the right-hand side of the topology depicted in Figure 2 (switches $S_8$, $S_9$, ..., $S_{13}$). Assume that an attacker can take over *one* switch and modify the fields of the BDPU messages sent by the switch. (The attacker can only modify the originated BPDU, it cannot drop any traffic.) The attacker's goal is to maximize the number of switches that cannot reach S4 after re-applying STP.

Which switch should the attacker take over, how should she attack, and why does that maximize the number of switches that cannot reach S4? (4 Points)

**(iv)** Assume now that there can exist multiple VLANs (the spanning tree that you computed in subtask i) does *not* need to be one of the spanning trees of those VLANs). You can adapt the switch IDs for each VLAN.

State the **minimum** number of VLANs that we need for all links to remain active after applying STP in Figure 2 and briefly explain why. What is the root of the spanning tree in each of those VLANs? (5 Points)

leave blank

leave blank

## Task 2: Intra-domain routing **28 Points**

### a) Warm-Up (5 Points)

**(i)** You set the weights of your links to be proportional to their **propagation delay**. Is it guaranteed that the packets following the shortest path will arrive earlier than packets using any other path? Why or why not? (1 Point)

**(ii)** How can limiting the maximum routing weight in distance vector protocols improve convergence time? (1 Point)

**(iii)** Why link state protocols do not work well in large networks such as large-scale data center networks? (1 Point)

**(iv)** Consider a network with non-negative link weights. Consider two scenarios: (i) Add 1 to each link weight; or (ii) multiply each weight by 2. Explain which scenario does *not* guarantee that the shortest paths remain unchanged. Provide an example. (2 Points)

## b) Load Balancing and Traceroute (9 Points)

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**(i)** Congratulations, you just got hired as a network engineer! Your first task is to load balance traffic in the network shown below using Equal Cost Multipath (ECMP). The list of nodes and the corresponding paths you should load balance the traffic on can be found in Table 3. Write down the four missing link weights that accomplish the load balancing in Figure 3 (one weight per highlighted box). Recall that ECMP makes routers load balance traffic on all the shortest-paths towards a destination node. (6 Points)

| Nodes: | Path 1 | Path 2 |
|---|---|---|
| (A, E) | A-B-C-D-E | A-B-F-G-D-E |
| (G, H) | G-H | G-F-H |
| (C, F) | C-B-F | C-D-G-F |
| (B, H) | B-H | B-F-H |

Table 3: Paths to load balance

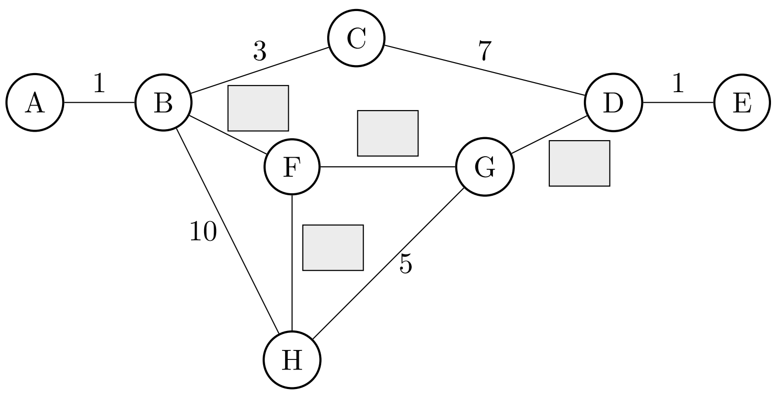


Figure 3: The network to load balance. (You can find a copy for taking notes on page 30.)

**(ii)** You now try to see if the load balancing worked and run a traceroute from A to E. Assume that the IP address of node A is `a.a.a.a`, node B is `b.b.b.b`, etc. and that the RTT increases by 10 ms for each hop. Briefly explain how the following traceroute output where some nodes show up on multiple lines with different RTTs can happen. (2 Points)

```
traceroute to E (e.e.e.e), 30 hops max, 60 byte packets
1  B (b.b.b.b) 10ms 10ms 10ms
2  C (c.c.c.c) 20ms F (f.f.f.f) 20ms C (c.c.c.c) 20ms
3  D (d.d.d.d) 30ms 30ms G (g.g.g.g) 30ms
4  E (e.e.e.e) 40ms D (d.d.d.d) 40ms 40ms
```

**(iii)** Considering the traceroute output from above: are the correct two paths between A and E used? Explain your answer. (1 Point)

## c) Reverse Dijkstra (14 Points)

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You are looking at a drawing of your network (Figure 4) but it clearly seems some links are missing. Table 4 shows the *partial* output of the Dijkstra's algorithm (some cells are empty) as performed in the lecture starting from the node **U**. For each iteration, the table indicates the weights of the shortest paths found so far. If after one iteration there are multiple nodes with an equally-shortest path, the algorithm continues with the node which comes first in the alphabet. There is at most one link between two nodes and each link has a strictly positive weight $[1, \infty]$.

You feel confident that, with the information from Figure 4 and the partial output from Dijkstra's algorithm in Table 4, you can find some of those missing links and link weights.

**(i)** First, fill in the highlighted cells in Table 4 using the information available in Figure 4. Write your answers directly in Table 4. (3 Points)

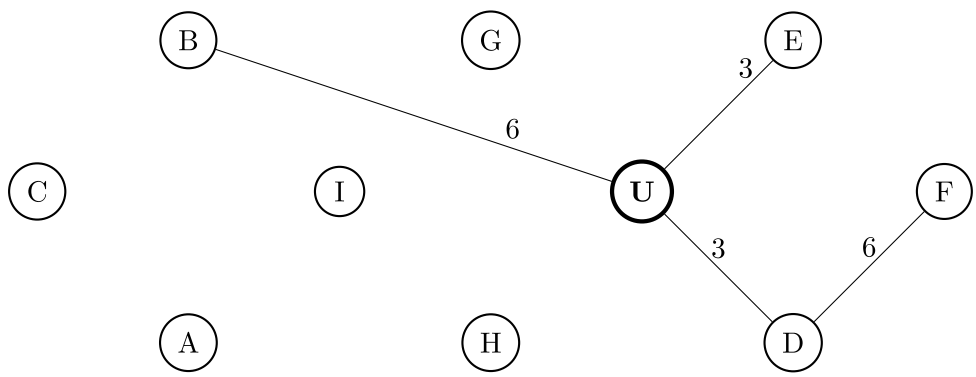


Figure 4: A network consisting of 10 nodes with missing links and link weights. (You can find a copy for taking notes on page 31.)

**(ii)** Now that you have completed Table 4 you can use this information to piece together the missing links in Figure 4. Draw all the links and corresponding weights you can identify directly in Figure 4. (6 Points)

**(iii)** You now wonder whether you actually found all the links or not. For all the following links, mark if they could exist or not. (5 Points)

Use the following format:

- If the link could exist, indicate the range of weights this link is allowed to have;
- If the link could not exist, write down the iteration in which the link would have showed up.

| # | **U** | A | B | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | | ∞ | | | ∞ | ∞ | ∞ | ∞ |
| 2 | 0 | 1 | 5 | 2 | 3 | 3 | ∞ | ∞ | ∞ | ∞ |
| 3 | 0 | 1 | 4 | 2 | 3 | 3 | ∞ | ∞ | ∞ | ∞ |
| 4 | 0 | 1 | 4 | 2 | 3 | 3 | | ∞ | 8 | ∞ |
| 5 | 0 | 1 | 4 | 2 | 3 | 3 | 5 | ∞ | 8 | ∞ |
| 6 | 0 | 1 | 4 | 2 | 3 | 3 | 5 | 10 | 8 | ∞ |
| 7 | 0 | 1 | 4 | 2 | 3 | 3 | 5 | 9 | 8 | ∞ |
| 8 | 0 | 1 | 4 | 2 | 3 | 3 | 5 | 9 | 8 | 13 |
| 9 | 0 | 1 | 4 | 2 | 3 | 3 | 5 | 9 | 8 | 12 |
| 10 | 0 | 1 | 4 | 2 | 3 | 3 | 5 | 9 | 8 | 12 |

Table 4: For each iteration (1 to 10) the table shows the shortest path found by Dijkstra's algorithm performed on node **U** towards all other nodes.

Link `U-C`: ____________________

Link `B-E`: ____________________

Link `U-I`: ____________________

Link `A-D`: ____________________

Link `E-G`: ____________________

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leave blank

## Task 3: Inter-domain routing 38 Points

### a) BGP 201 (10 Points)

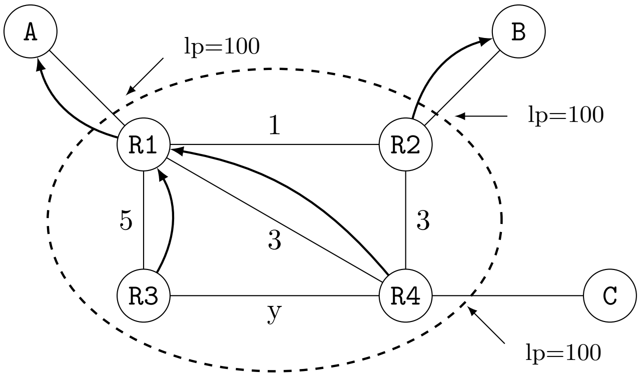


Figure 5: A BGP network of 4 internal routers and 3 external neighbors.

Figure 5 shows a BGP network with 4 internal routers and 3 external neighbors. Each IGP link between two internal routers has a weight. The network forms an iBGP **full-mesh** (not shown in the figure). Each external neighbor has an eBGP session with one border router. Each border router sets the local preference (lp) to 100 for any BGP route received from its external neighbor. The network does not have any other BGP policy configured.

A, B, C announce the same prefix $p$ to the network. The announcements are such that R1, R3, and R4 select the route from A, while R2 selects the route from B. (The thick arrows in the figure represent the current forwarding paths each internal router takes to reach $p$.)

**(i)** Let $len(x)$ be the AS path length of the BGP route $x$ announces to the network. Given the forwarding paths depicted above, briefly explain whether each of the following relation is possible or not. (2 Points)

$len(A) > len(B)$: __________

$len(B) = len(C)$: __________

**(ii)** Let $y$ be the IGP weight of link R3 – R4. Given the forwarding paths shown in the figure, what is the complete range of possible values for $y$? (1 Point)

**(iii)** Assume `A` and `B` belong to the same AS X. How can AS X attract traffic to $p$ via `B` rather than via `A`? List two distinct approaches. (2 Points)

Approach 1: ______________________

______________________

Approach 2: ______________________

______________________

**(iv)** Assume `R4` increases the local preference of the routes learned on session `R4` – `C` to 200. Select the BGP message type that will be seen on each of the following BGP session. Select `N/A` if the BGP session will not see any message following the change.

(2 Points)

| | | | |
|---|---|---|---|
| `R1` → `A`: | ☐ `UPDATE` | ☐ `WITHDRAW` | ☐ `N/A` |
| `R1` → `R2`: | ☐ `UPDATE` | ☐ `WITHDRAW` | ☐ `N/A` |
| `R3` → `R4`: | ☐ `UPDATE` | ☐ `WITHDRAW` | ☐ `N/A` |
| `R4` → `C`: | ☐ `UPDATE` | ☐ `WITHDRAW` | ☐ `N/A` |

**(v)** Assuming equal local preferences again (100 for all learned routes), we consider the case where `A` withdraws its route to $p$. Briefly explain whether a blackhole can occur for $p$ during the first and the last BGP message the network will see for this event. Recall that a blackhole occurs if a router receives a packet but does not know how to forward it. (3 Points)

______________________

______________________

______________________

______________________

**b) Mini Mini-Internet** **(18 Points)**

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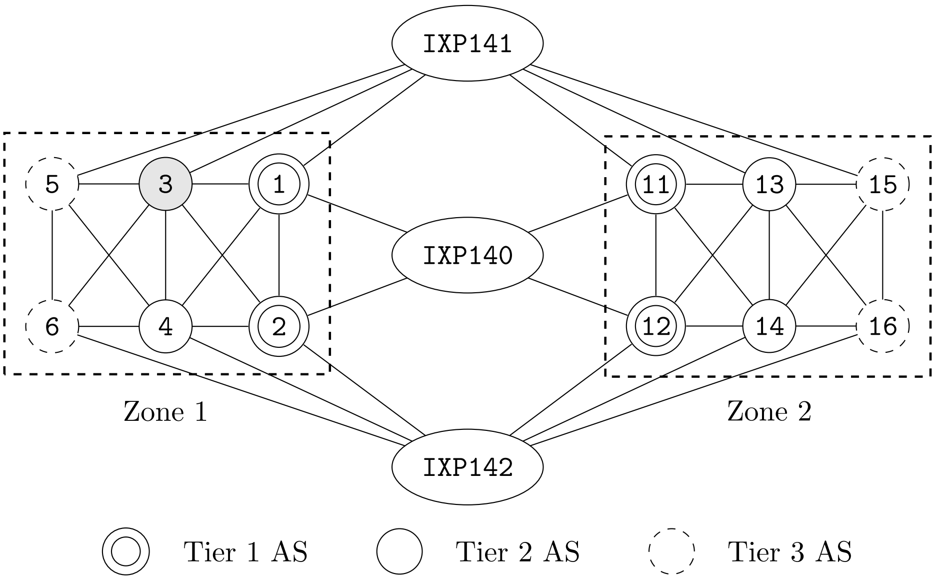


Figure 6: A mini-mini-internet with 2 zones and 3 IXPs.

Figure 6 shows a "mini mini-Internet" with 2 zones and 3 IXPs. Each zone contains 6 ASes acting at different tiers. Within each zone, each AS belonging to tier $k$ is a provider of all the tier $k+1$ ASes, a customer of all the tier $k-1$ ASes, and a peer of all the same-tier ASes. For instance, AS 3 (a tier-2 AS) is a provider of AS 5 and AS 6, a customer of AS 1 and AS 2, and a peer of AS 4; AS 5 has no customer; and AS 1 has no provider. Each AS also maintains a **peer session** with at least one IXP, as drawn in the figure.

Each AS X announces its prefix `X.0.0.0/8` onto **all** connected sessions. Each IXP announces **any** prefix it receives from one zone to the **other** zone. For instance, IXP 141 announces any prefix its receives from AS 5 to AS 11, 13 and 15. An IXP does **not** append its number to the AS path when announcing prefixes.

All ASes strictly follow the classical business relationships as seen in the lecture defined over providers, peers and customers. Note that an IXP is also a **peer**. When two routes are equally preferred, each AS selects the route with the **smallest** next-AS in the AS path (note that IXPs do not appear in the AS path) as a final tie-breaker.

**(i)** List the AS path that AS 3 selects to reach the following 3 prefixes. (3 Points)

`11.0.0.0/8`: ______________________

`12.0.0.0/8`: ______________________

`14.0.0.0/8`: ______________________

**(ii)** Which IXP is the most important to maintain the connectivity between the two zones? Justify your answer. (3 Points)

The most important IXP: ______________________

Justification: ______________________

______________________

______________________

______________________

**(iii)** Assume now that some ASes violate business relationships. Table 5 lists the AS paths for **all** the routes that some border router in AS 3 receives for `16.0.0.0/8`. The symbol `>` indicates the route that the router selects as best.

Based on these received routes, list 3 ASes that do not strictly follow business relationships and justify how each AS selects or exports routes incorrectly. (4 Points)

| | Network | AS Path |
|---|---|---|
| *> | 16.0.0.0/8 | 1 4 6 16 |
| * | | 2 4 6 16 |
| * | | 6 16 |
| * | | 11 13 16 |

Table 5: All routes AS 3 receives for `16.0.0.0/8`.

Violating AS: ______________________

Justification: ______________________

______________________

Violating AS: ______________________

Justification: ______________________

______________________

Violating AS: ______________________

Justification: ______________________

______________________

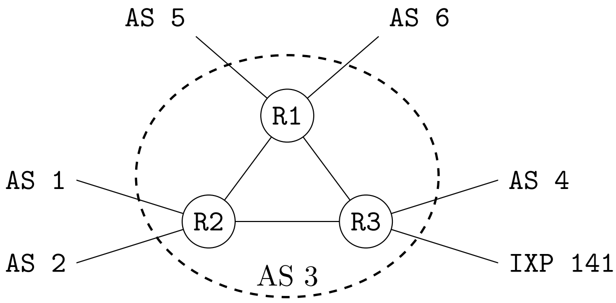


Figure 7: The internal topology of AS 3.

**We now consider again the case in which all ASes in Figure 6 properly follow the classical business relationships. Figure 7 shows the internal topology of AS 3 and its external connections. AS 3 runs an iBGP full-mesh.**

**(iv)** Assume both `R2` and `R3` can reach `14.0.0.0/8`, but `R1` cannot reach it. What could be the reason for this issue and how can you confirm it. (2 Points)

Reason: ____________________

How to confirm: ____________________

**(v)** Assume no router in AS 3 can ping `14.0.0.0/8`. You contacted the operator of AS 14 and she confirmed that AS 14 has received your packets. What could be the reason for this issue and how can you confirm it. (3 Points)

Reason: ____________________

How to confirm: ____________________

**(vi)** Assume `R2` accidentally stops advertising `3.0.0.0/8` to AS 1 and AS 2. Can AS 1 and AS 2 still reach `3.0.0.0/8`? Justify your answer.

*Hint:* You do not necessarily need to consider all possible routing paths. (3 Points)

Can AS 1 or AS 2 reach `3.0.0.0/8`? ____________________

Justification: ____________________

**c) Amongst us** **(10 Points)**

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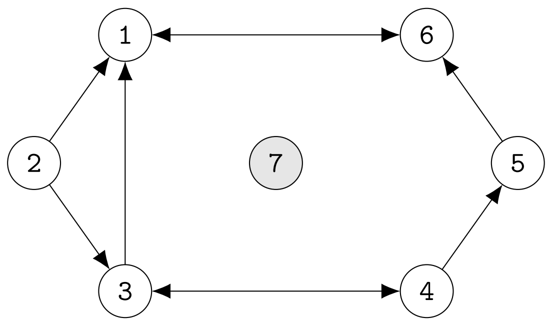


Figure 8: An internet of 7 ASes.

Figure 8 depicts an Internet of 7 ASes. Each single-headed arrow points **from** a provider **to** a customer (AS 3 is a provider of AS 1), each double-headed arrow points between two peers (AS 3 is a peer of AS 4).

All ASes *except AS 7* (highlighted) strictly follow the classical business relationships defined over providers, peers and customers.

Each AS X announces its prefix `X.0.0.0/8` to **all** connected sessions. Each AS has registered and published a Route Origin Authorization (ROA) for its own prefix in the Resource Public Key Infrastructure (RPKI) repository. **Each AS filters any invalid route using RPKI.**

**(i)** Describe one generic attack that an AS using RPKI-based filtering can defend against, and one attack that it cannot defend against. (2 Points)

Defend against: ______________________________

______________________________

Cannot defend against: ______________________________

______________________________

**(ii)** Assume AS 7 can establish one or more BGP sessions of any type with any AS and consistently announce a route for `7.0.0.0/8` on the established session(s). Is it possible for AS 7 to trigger a BGP oscillation for `7.0.0.0/8` amongst AS 1, AS 2, and AS 3, i.e., that **none** of AS 1, AS 2 or AS 3 can converge to a stable state? Justify your answer. (3 Points)

Is it possible: ______________________________

Justification: ______________________________

______________________________

______________________________

______________________________

**(iii)** Assume AS 7 wants to hijack the traffic for `3.0.0.0/8`. To do that, AS 7 needs to establish BGP sessions with other ASes and to announce routes. (5 Points)

What are **all** possible ASes that AS 7 can hijack traffic from without alarming AS 3? An AS is alarmed if it receives **any** route (valid or invalid) for its own prefix.

All ASes that AS 7 can hijack traffic from: ______________________________

______________________________________________

What is the **minimum** number of BGP sessions that AS 7 needs to establish to hijack all this traffic? For each BGP session AS 7 establishes: identify the session type (provider-to-customer, customer-to-provider or peer-to-peer) and specify the AS path it announces on that session.

*Hint:* You do not necessarily need to fill all the sessions.

Session 1: ______________________________

AS path announced onto session 1: ______________________________

Session 2: ______________________________

AS path announced onto session 2: ______________________________

Session 3: ______________________________

AS path announced onto session 3: ______________________________

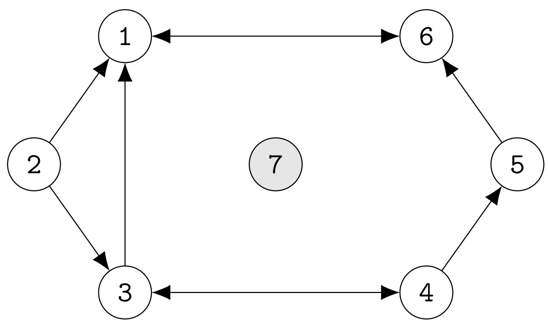


Figure 9: Copy of Figure 8.

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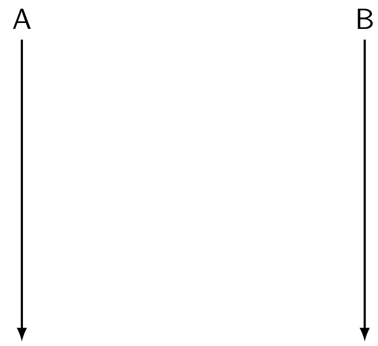
## Task 4: Reliable transport **35 Points**

### a) Warm-Up **(6 Points)**

**(i)** Consider a TCP connection between host A and B. Give a minimal sequence of packets such that host A considers the connection *half-closed*. Draw the packet exchange in the diagram below. (1 Point)




**(ii)** Consider a TCP implementation that immediately removes a socket after having sent the final ACK. Briefly describe two problems that can happen. (2 Points)

Problem 1: ______________________________

______________________________

Problem 2: ______________________________

______________________________

**(iii)** Consider a TCP connection between two hosts. Explain why the three-way handshake is not used to negotiate the receive window size. Justify your answer with an example. (2 Points)

______________________________

______________________________

______________________________

______________________________

**(iv)** Consider two web servers. Web server A listens on port number 443, whereas web server B listens on port number 444. Explain what information a user needs to enter into a web browser to access each website. (1 Point)

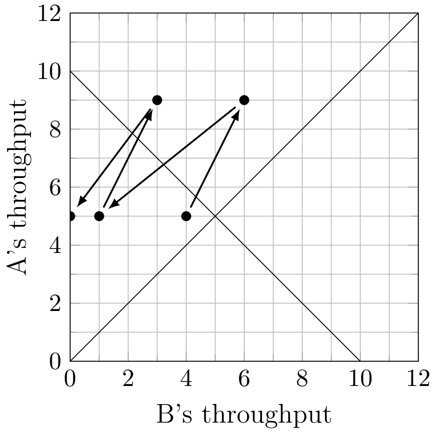
Web Server A: ______________________________

Web Server B: ______________________________

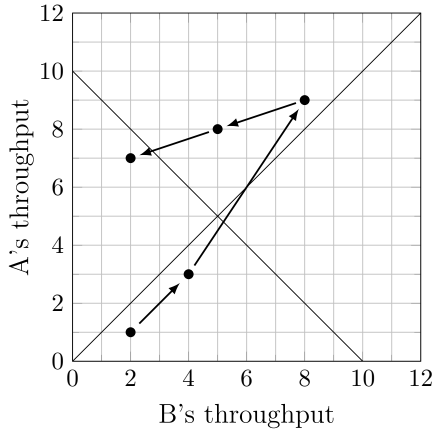
**b) Efficiency and Fairness** **(12 Points)**

leave blank

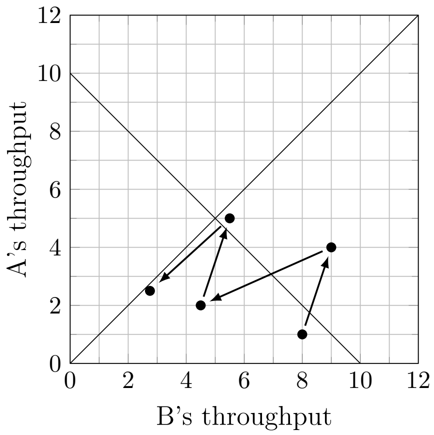
**(i)** Below are multiple system trajectory plots. For each plot, indicate which congestion control algorithm is shown. **Select one algorithm per plot**. (4 Points)




☐ AIAD ☐ AIMD
☐ MIAD ☐ MIMD




☐ AIAD ☐ AIMD
☐ MIAD ☐ MIMD

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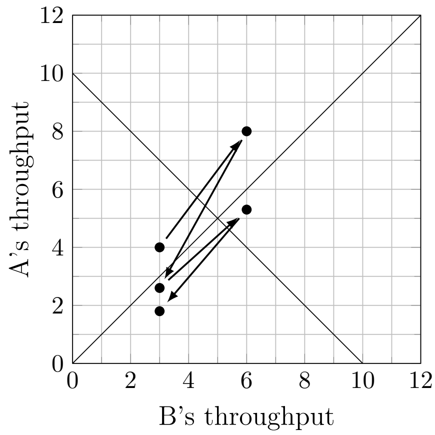


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**(ii)** Two independent flows with AIMD CC algorithms share the same link. You notice that no matter how often you restart the flows, flow A *always* ends up starving flow B. What could be the reason for this behavior? Could this problem also arise in the public internet? *Justify your answer.* (4 Points)

**(iii)** Two independent flows with MIAD CC algorithms share the same link. As a reminder, MIAD is defined in the following way:

$$\texttt{cwnd}_{i+1} = \begin{cases} \texttt{cwnd}_i \cdot \alpha & \text{if no congestion detected} \\ \texttt{cwnd}_i \ - \beta & \text{if congestion detected} \end{cases}$$

$$\text{with } \alpha > 1 \text{ and } \beta > 0$$

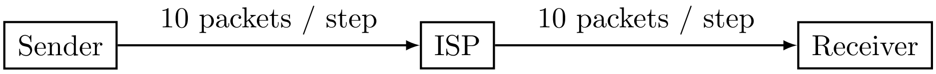
Given an initial bandwidth allocation ($\texttt{cwnd}_0^A, \texttt{cwnd}_0^B$), is there a set of parameters (i.e., $\alpha_A$, $\alpha_B$, $\beta_A$ and $\beta_B$) for which the flows will *always* converge to a fair bandwidth allocation? Justify your answer.

*Hint:* Perform a case distinction, $\texttt{cwnd}_0^A = \texttt{cwnd}_0^B$, and $\texttt{cwnd}_0^A \neq \texttt{cwnd}_0^B$. (4 Points)

leave blank

**c) Congestion Control** **(17 Points)**

In this question, we explore the impact of fluctuating network conditions on congestion control algorithms. We will model the network as a discrete event system, consisting of a sender, an ISP, and a receiver:




Both parties have an access link with a bandwidth of 10 packets per step. We assume that the sender operates in the following, fixed order. At each step $t$, it first processes incoming ACKs and checks for packet losses, then it updates its sending rate ($y_t$), retransmission timeout ($\texttt{RTO}_t$), and slow-start threshold ($\texttt{ssthresh}_t$) accordingly, before finally sending $y_t$ packets. The sender computes the sending rate $y_t$ as follows:

$$y_t = \begin{cases} 1 & \textit{Timeout:} \text{ if a timeout occurs in step } t \\ 2y_{t-1} & \textit{Slow start:} \text{ if } y_{t-1} < \texttt{ssthresh}_t \\ y_{t-1}+1 & \text{otherwise} \end{cases}$$

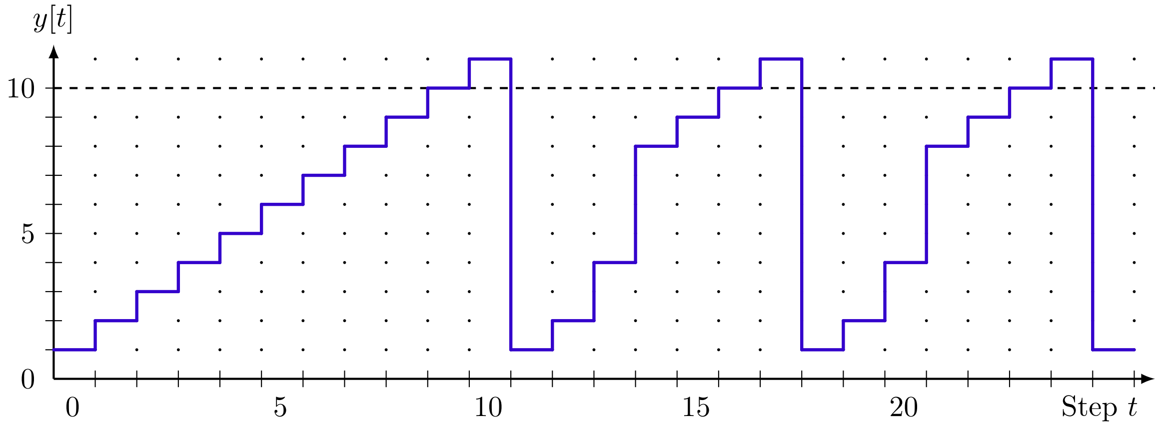
For each packet sent at step $t$, the sender sets a timer that times out in $\texttt{RTO}_t$ steps. If a timeout occurs, and the respective packet has not been ACK'ed yet, the sender considers the packet lost. In that case, **all timers are reset**, and $\texttt{ssthresh}_t$ is updated as follows:

$$\texttt{ssthresh}_t = \begin{cases} \left\lfloor \max\left(y_{t-1}/2, 1\right) \right\rfloor & \textit{Timeout:} \text{ if a timeout occurs in step } t \\ \texttt{ssthresh}_{t-1} & \text{otherwise} \end{cases}$$

In this question, you will draw multiple throughput diagrams that consist of three parts:

1. The number of packets $y_t$ sent by the sender at step $t$.
2. The **given** $\texttt{RTO}_t$ timeout for packets sent at step $t$ (empty means unchanged).
3. The number of packets considered lost at step $t$ (empty means zero).

As an example, here is the throughput diagram for $\texttt{ssthresh}_0 = 0$ and a fixed $\texttt{RTO} = 1$:

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$\texttt{RTO}_t$

| | | | | | | | | | | | | | | | | | | | | | | | | | |
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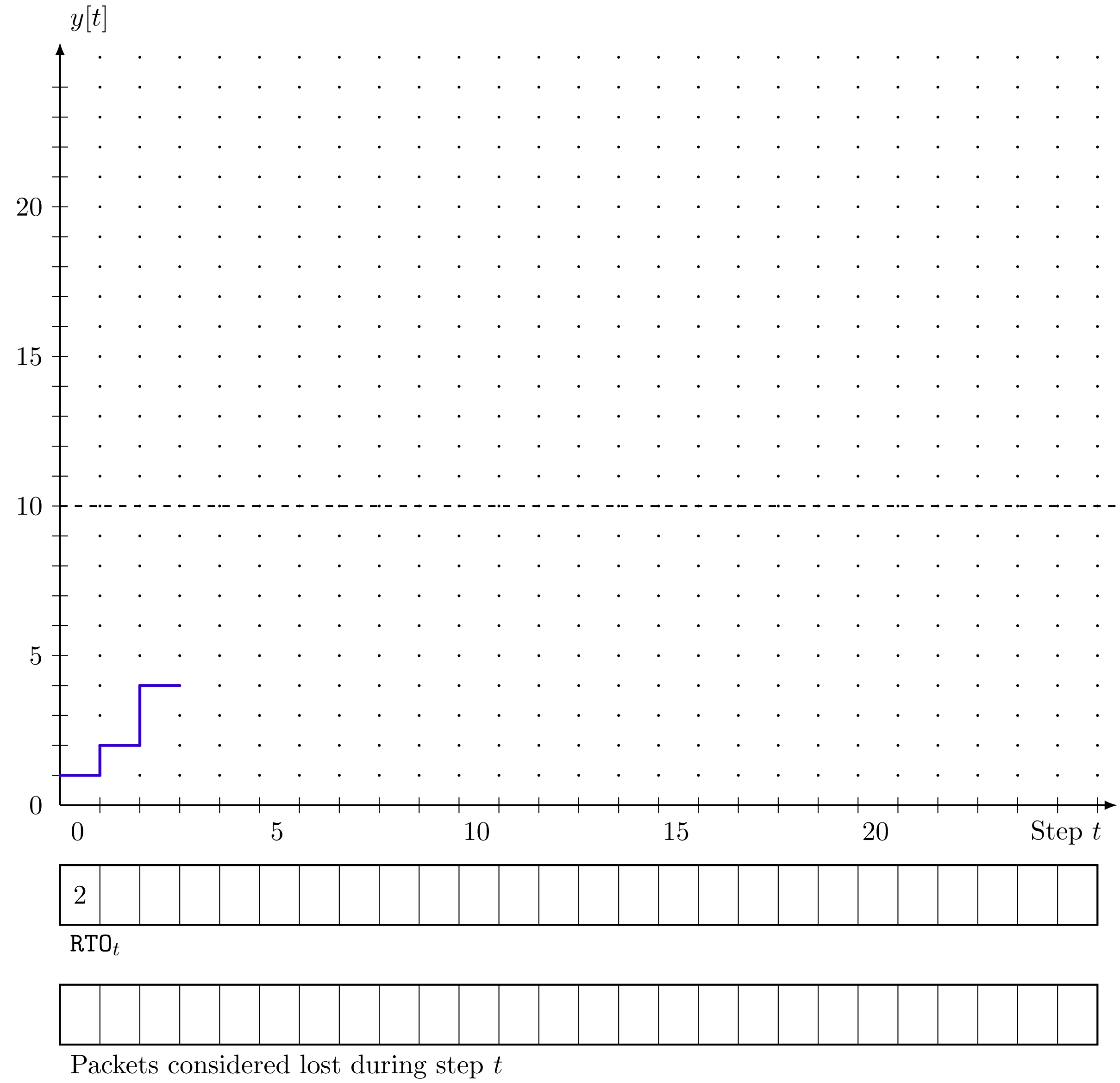
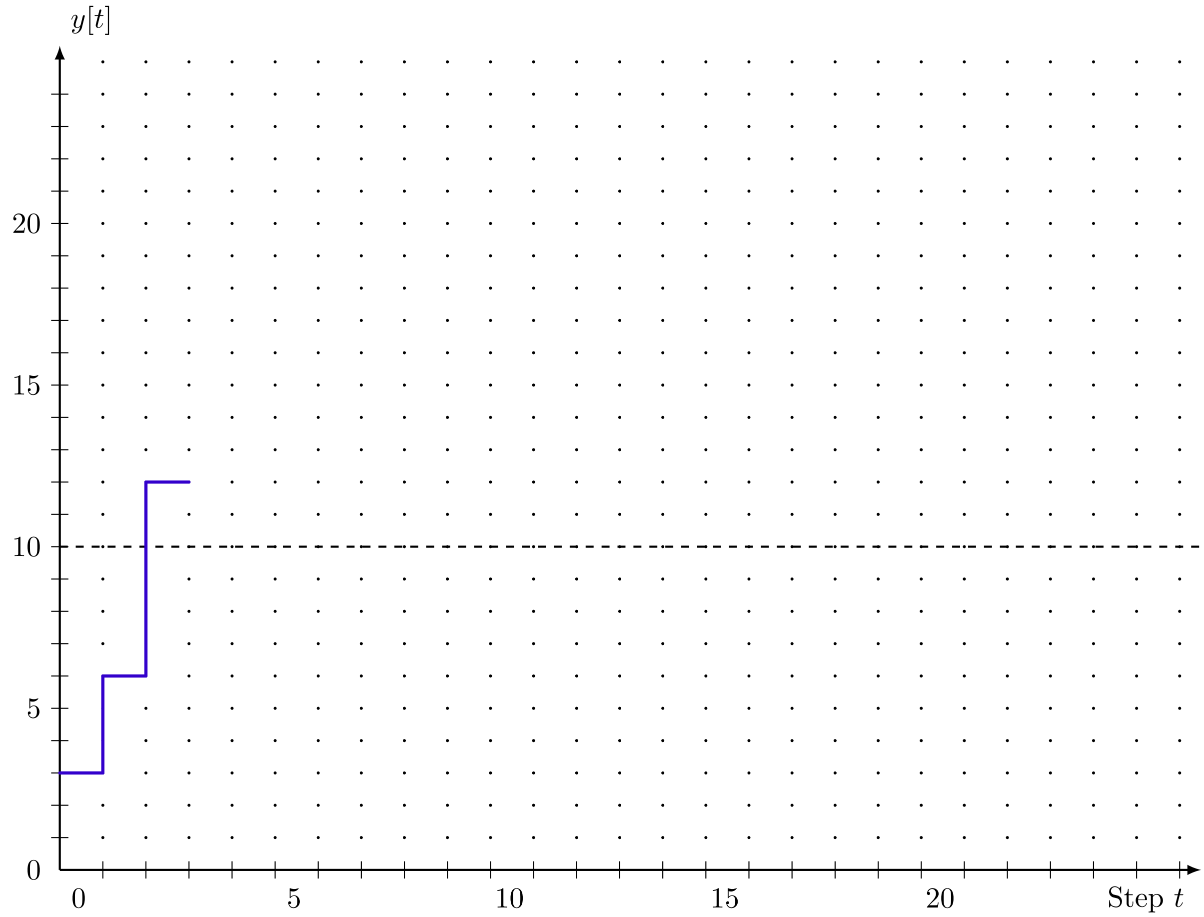
Packets considered lost during step $t$

**(i)** For this question, consider a sender that uses a fixed $\texttt{RTO}_t = 2$ for every step $t$. Draw the throughput diagram for $\texttt{ssthresh}_0 = 10$ and the given $\texttt{RTO}_t$. Make sure to include the number of packets considered lost. (8 Points)




Use for your own notes. This *will not* be graded!

**(ii)** Now, consider a sender that approximates `RTO`$_t$ at each step (e.g. at $t = 7$, `RTO`$_7$ is updated to 3). Draw the throughput diagram for `ssthresh`$_0 = \infty$ and the given `RTO`$_t$. Make sure to include the number of packets considered lost. (9 Points)

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`RTO`$_t$

| | | | | | | | | | | | | | | | | | | | | | | | | | |
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Packets considered lost during step $t$

Use for your own notes. This *will not* be graded!

leave blank

leave blank

## Task 5: Applications **19 Points**

### a) Warm-Up **(6 Points)**

**(i)** Feeling adventurous, you type:

`https://comm-net.ethz.ch:4242/pdfs/exam_august_24.pdf`

in your browser's address bar, and press enter. (4 Points)

Write down the DNS requests issued by your local DNS server, assuming its cache is completely empty. For each request, indicate: the queried name, the server being queried (describe the server in English, e.g. "the DNS server responsible for `a.b.c`)", alongside with the DNS query type. You can assume that each DNS request is replied to correctly, and you do *not* need to write down the DNS replies.

*Hint:* You do not necessarily need to fill in all the entries.

**DNS request #1:**

- Queried name: ____________________________

- Queried server: ____________________________

- Query type: ____________________________

**DNS request #2:**

- Queried name: ____________________________

- Queried server: ____________________________

- Query type: ____________________________

**DNS request #3:**

- Queried name: ____________________________

- Queried server: ____________________________

- Query type: ____________________________

**DNS request #4:**

- Queried name: ____________________________

- Queried server: ____________________________

- Query type: ____________________________

Write down a source and a destination port that could be used by the corresponding TCP connection.

- Source port: ______

- Destination port: ______

Write down the content of the HTTP `GET` query your browser will send to the server. (Only include the mandatory fields in your answer.)

**(ii)** Briefly explain one way to automatically redirect users browsing an unsecure version of a website (e.g. `http://ubs.ch`) to the secure version (e.g. `https://ubs.ch`).

(2 Points)

**b) Anycast strikes back** **(6 Points)**

leave blank

Inspired by DNS root servers, you would like to rely on BGP anycast for hosting your website `routing.is.fun` which currently sits behind `129.132.19.216` (you own `129.132.19.0/24`) and `2001:67c::200` (you own `2001:67c::/8`). Your goal is to deploy and serve content from three replicas servers located in New York (AS 10), Zürich (AS 20), and Singapore (AS 30).

**(i)** Describe the steps necessary to realize this from a routing viewpoint. Be precise.

(2 Points)

**(ii)** Assuming no DNS records exist for your website yet, write down the DNS record(s) you would need to add to the DNS server responsible for `is.fun`. *Hint:* You might not need all 3 records. (2 Points)

Record #1. Name: __________ Type: ______ Value: __________

Record #2. Name: __________ Type: ______ Value: __________

Record #3. Name: __________ Type: ______ Value: __________

**(iii)** A typical challenge when using anycast for load-balancing web traffic is that web traffic relies on reliable transport (it uses TCP), whereas DNS does not (it uses UDP). Explain why this could be a problem for `routing.is.fun` with a concrete example. (2 Points)

**c) Fun with proxies** **(7 Points)**

leave blank

Consider that ETH Zürich has 10 Gbps of access capacity towards the Internet which it uses to serve the web (HTTP) requests of 20 000 users. Each user issues 4 HTTP requests per second on average, and each requested HTTP object is exactly 100 kbit. The ETH network operators notice two problems: *(i)* frequent overloads of the access link; and *(ii)* continuous slow loading times for the users, *even when the access link is lightly loaded.*

ETH is considering setting up a proxy server acting as a cache to reduce the access link load and loading times. Concretely, whenever an ETH user would request an HTTP object, the request would first go to the proxy server which will serve the object from its cache, if it can, or contact the origin server on behalf of the user, if it cannot.

**(i)** To avoid congestion, the ETH operators would like to maintain the average access link load below 20% (2 Gbps). What should the minimum cache hit rate be in order to guarantee this? Describe your computation. (3 Points)

**(ii)** Consider that the round trip time (RTT) between an ETH user and the proxy is 10 msec, and the RTT between the proxy and any Internet server is 150 msec. What is the average delay experienced by users assuming a cache hit rate of 60%? Describe your computation. (2 Points)

**(iii)** Analyzing the traffic going over the access link, the ETH operators realize that most of the HTTP-based video traffic (such as Netflix's) is *not* cached, yet they know that a lot of students are watching the same shows at exactly the same time. The ETH operators suspect that Netflix is using strategies to prevent its video chunks from being cached. (You can assume that video chunks are sent unencrypted.) Explain two distinct techniques Netflix could use to achieve this.

(2 Points)

Technique #1:

Technique #2:

## Copy of Figure 2 (not graded)

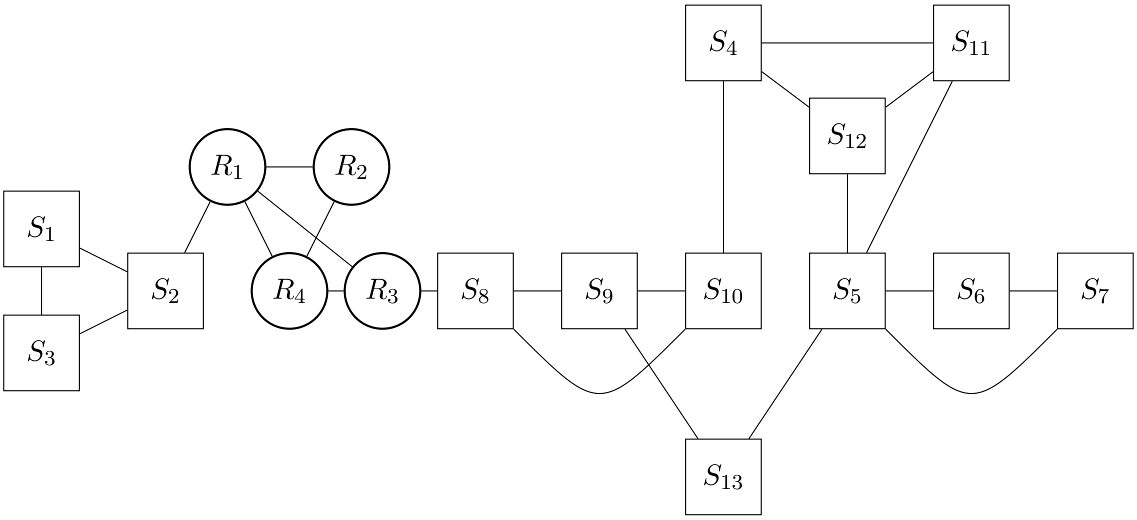


Figure 10: Topology of layer-2 switches (squares) and layer-3 routers (circles).

## Copy of Figure 3 (not graded)

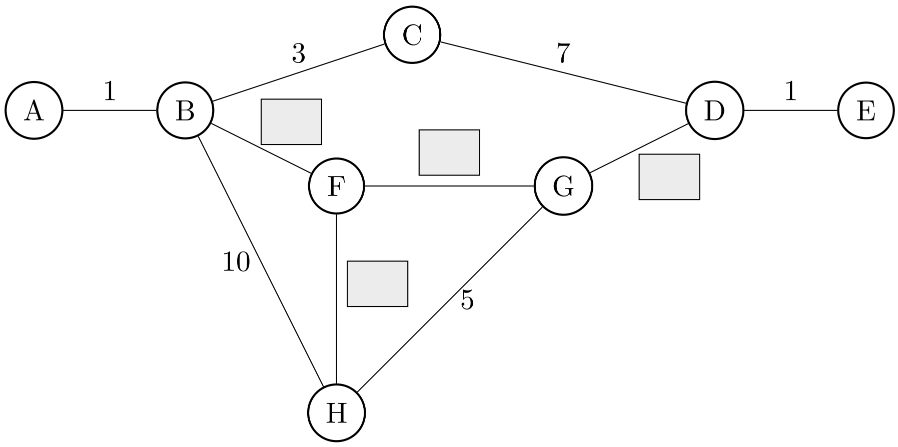


Figure 11: The network to load balance.

## Copy of Figure 4 (not graded)

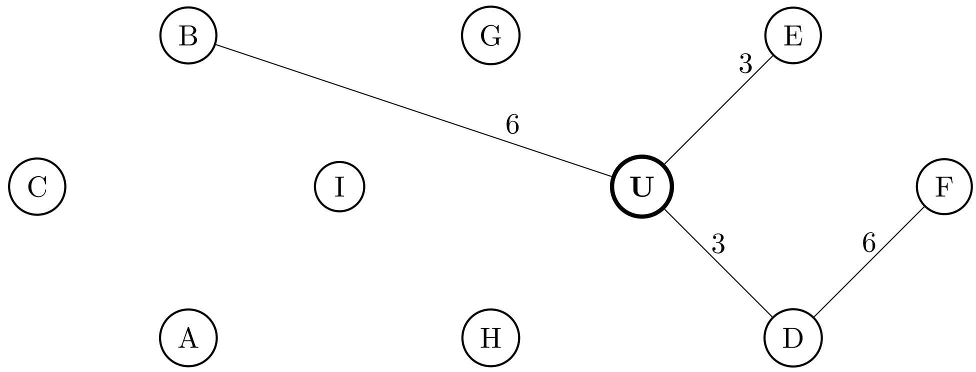


Figure 12: A network consisting of 10 nodes with missing links and link weights.

## Extra Sheet 1

In case you need more space, use the following pages. Make sure to always indicate the task to which the answer belongs (e.g., *3 d) (ii)*).

Task: ________________

Task: ________________

**Extra Sheet 2**

Task: ________________

Task: ________________

**Extra Sheet 3**

Task: ________________

Task: ________________