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EXAM
TCP/IP NETWORKING
Duration: 3 hours

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INSTRUCTIONS

1. Write your solution into this document and return it to us (you do not need to return the figure sheet). You may use additional sheets if needed. Do not forget to write your name on **each of the four problem sheets** and **all** additional sheets of your solution.
2. All problems have the same weight.
3. You will probably need to make additional assumptions in order to solve some of the questions. In that case, please write those assumptions down explicitly.
4. Figures are on a separate sheet, for your convenience.
5. No documents, no electronic equipments are allowed.
6. Justify every answer with a short explanation.

PROBLEM 1

Consider the network in Figure 1. A, B, C, D and E are hosts; BR is a bridge; X and $Y1, Y2, Y3, Y4$ are network boxes that can be configured in different ways, as explained next. $O1, O2$ and $O3$ are observation points where we observe traffic in both directions of the link. Some selected IPv4 addresses are shown, as well as some selected MAC addresses (denoted with A, B, C, D, E, Xe and $Y1w$). You may need to specify other IP or MAC addresses. All links are full duplex Ethernet. We assume that all machines are correctly configured (unless otherwise specified) and proxy ARP is not used.

1. In this question $X, Y1, Y2, Y3$ and $Y4$ are routers, running RIP with all link costs equal to 1.

   (a) Give one possible value for the netmask at A and one for the netmask at B.

   (b) A sends one ping message to B, B sends one ping message to C, C sends one ping message to D, D sends one ping message to E, and E sends one ping message to A. We assume that A and B have just booted and have empty ARP tables. We observe the traffic resulting from this activity at observation points $O1, O2$ and $O3$. At which of these points are the ARP Requests issued by A and B visible?

   What is the target IP address in the ARP request issued by A ? by B?

   We observe the ping request packets resulting from this activity at observation points $O1, O2$ and $O3$. What are the MAC and IP source and destination addresses in such packets ? What is the TTL field, knowing that the TTL value is equal to 64 in all IPv4 packets generated by all hosts in this problem ? Put your answers in the tables below. Recall that to denote the MAC address of, for example, the "south-side" interface of $Y4$, you should write $Y4s$, etc.

At observation point $O1$:				
MAC source	MAC dest	IP source	IP dest	TTL

At observation point $O2$:				
MAC source	MAC dest	IP source	IP dest	TTL

At observation point $O3$:				
MAC source	MAC dest	IP source	IP dest	TTL

2. In this question X is a NAT box; the WAN port is Xe.
$Y1, Y2, Y3, Y4$ are routers, running RIP with all link costs equal to 1.

   (a) Are the netmasks at A and B obtained in the previous question still valid ?

   (b) A sends one ping message to B, B sends one ping message to C, C sends one ping message to D, D sends one ping message to E, and E sends one ping message to A. We observe the ping request packets resulting from this activity at observation points $O1, O2$ and $O3$. What are the MAC and IP source and destination addresses in such packets ? Put your answers in the tables below.

At observation point $O1$:			
MAC source	MAC dest	IP source	IP dest

At observation point $O2$:			
MAC source	MAC dest	IP source	IP dest

At observation point $O3$:			
MAC source	MAC dest	IP source	IP dest

3. In this question BR is a VLAN switch, which gives different VLAN labels to A and B. Furthermore, $X, Y1, Y2, Y3, Y4$ are routers (none of them is a NAT). $Y1, Y2, Y3, Y4$ run RIP with all link costs equal to 1. X does not run RIP. None of the boxes uses proxy ARP.

   (a) Are the netmasks at A and B obtained in question 1 still valid ?

   (b) Give a possible configuration of the routing table at X that enables full connectivity in this network.

   (c) A sends one ping message to B, B sends one ping message to C, C sends one ping message to D, D sends one ping message to E, and E sends one ping message to A. We observe the ping request packets resulting from this activity at observation point $O1$. What are the MAC and IP source and destination addresses in such packets ? Put your answers in the table below.

At observation point $O1$:			
MAC source	MAC dest	IP source	IP dest

4. In this question $Y1, Y2, Y3, Y4$ are bridges. X is a router.

   A sends one ping message to B, B sends one ping message to C, C sends one ping message to D, D sends one ping message to E, and E sends one ping message to A. We observe the ping request packets resulting from this activity at observation points $O2$ and $O3$. What are the MAC and IP source and destination addresses in such packets ? Put your answers in the tables below.

At observation point $O2$:			
MAC source	MAC dest	IP source	IP dest

At observation point $O3$:			
MAC source	MAC dest	IP source	IP dest

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PROBLEM 2

Consider the network in Figure 2. Boxes $B1, ...B7, C1, D1$ are routers.

All routers in AS B, namely $B1, B2, ...B7$, run an IPv4 distance vector routing protocol with route poisoning and with infinity $= 256$. Unless otherwise specified, the cost of a link between two routers is 1 and the cost from a router to a directly attached network is 1.

There is one IPv4 network between consecutive routers on the figure, with subnet prefix of length 24. All networks shown on the figure, including `30.20.0.0/24` and `40.20.0.0/24` are considered interior by all routers in B. All routers in AS B originate their directly attached networks into the distance vector routing protocol.

Routers do not perform aggregation, unless explicitly mentioned.

1. Assume that BGP is not yet enabled in routers of AS B. Give a possible value of the routing table at router $B2$, at a time t_1 such that the interior routing protocol has stabilized. Give the values in the table below (do not give the value of the "interface" field).

At $B2$		
Destination Network	Next-Hop	Distance

2. BGP is now enabled inside AS B, in routers $B1$ and $B7$ only. Other routers in AS B do not run BGP. At time $t_2 > t_1$, $B1$ receives from $C1$ the announcement

```
66.66/16, AS path = C E F, NEXT-HOP=30.20.0.3
66.66.0/17, AS path = C E F, NEXT-HOP=30.20.0.3
```

No other BGP announcements were received by $B1$ before this one. Explain what BGP protocol actions are performed by $B1$ upon receiving these routes. Say in particular to which BGP routers, if any, $B1$ will send announcements as a result.

At time $t_3 > t_2$, BGP has stabilized and $B1$ redistributes the network prefixes it has learnt from BGP into the interior routing protocol, with cost $= 100$ for networks learnt via I-BGP, and cost $= 50$ for networks learnt via E-BGP. Note that $B7$ does not (yet) redistribute.

$B1$ does its job and sends an interior routing update to all its neighbors inside AS B. Assume that no other redistribution occurs and the interior routing protocol stabilizes again at time t_4. Give a possible value of the routing table at router $B2$ at t_4.

At $B2$		
Destination Network	Next-Hop	Distance

3. Then $B7$ also redistributes BGP into the interior routing protocol with cost $= 100$ for networks learnt via I-BGP, and cost $= 50$ for networks learnt via E-BGP. We assume that at time $t_5 > t_4$ both the interior routing protocol and BGP have stabilized again and at that time $B7$ receives from $D1$ the announcement:

```
66.66/16, AS path = D F, NEXT-HOP=40.20.0.4
```

   Assume no other routing message than previously shown was sent by either $C1$ or $D1$. Explain what BGP protocol actions are performed by $B7$ upon receiving these routes. Say in particular to which BGP routers, if any, $B7$ will send announcements as a result. Also say what BGP computations will be performed at the BGP routers that receive these announcements, if any.

4. At time $t_6 > t_5$ BGP has stabilized again inside ASs B, C and D and at that time, $B1$ redistributes the network prefixes it has learnt from BGP into the interior routing protocol, with cost $= 100$ for networks learnt via I-BGP, and cost $= 50$ for networks learnt via E-BGP. Note that $B7$ does not (yet) redistribute.Then $B1$ does its job and sends an interior routing update to both of its neighbors inside AS B. Assume that no other redistribution occurs no other interior routing message was generated in the time interval $[t_5, t_6]$.

   Explain which computations $B2$ and $B7$ will perform upon receiving the interior routing update from $B1$.

5. Then $B7$ redistributes BGP into the interior routing protocol with cost $= 100$ for networks learnt via I-BGP, and cost $= 50$ for networks learnt via E-BGP and let $t_7 > t_6$ be a time at which the interior routing protocol has stabilized again. Give a possible value of the routing table at $B1$ at t_7.

At $B1$		
Destination Network	Next-Hop	Distance

$B1$ has a packet to forward with destination address `66.66.1.2`. Which path will this packet follow ?

6. At time $t_8 > t_7$ the link between $B1$ and $B2$ breaks; the loss of the link is detected immediately by $B2$. $B2$ does its job and sends an interior routing update to its neighbor $B3$. Assume that no other message was generated in the time interval $[t_6, t_8]$.

   Explain which computation $B3$ will perform upon receiving the interior routing update from $B2$ and give a possible value of the routing table at $B3$ just after performing these computations.

At $B3$		
Destination Network	Next-Hop	Distance

Let $t_9 > t_8$ be the time at which the routing protocol stabilizes again (the link between $B1$ and $B2$ is definitively lost). Give a possible value of the routing table at $B3$ at time t_9.

At $B3$		
Destination Network	Next-Hop	Distance

7. Assume we change the configuration of $B1$ and $B7$ such that they do not re-distribute BGP into the interior routing protocol. Propose one alternative method by which the routes learnt via BGP by $B1$ and $B7$ can be also learnt by all routers inside AS B. Are there any drawbacks to your proposed alternative ?

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PROBLEM 3

Consider the network in Figure 3 on the figure sheet.

- Hosts $A, B1, B2, B3, B4$ are downloading content from server S. $R1, R2$ and $R3$ are routers, unless otherwise specified.
- The link rates are indicated on the figure. All links are full duplex with same rate in both directions.
- There is no other system than shown on the figure, and we neglect all flows other than between A or Bi and S. We also neglect the impact of the acknowledgement flows in the reverse direction.
- The round trip time between A and S is 100 ms, and the round trip time between Bi and S is 20 ms. These numbers include all processing times.
- We neglect all overheads and assume that the link capacities can be fully utilized at bottlenecks.
- The MSS is the same for all flows and is equal to 1250 Bytes = 10^4 bits.

1. Assume that some bandwidth manager is used, which allocates rates to flows according to max-min fairness. What are the values of the rates of the flows $S \rightarrow A$ and $S \rightarrow Bi$?

2. Same question with proportional fairness instead of max-min fairness.

3. We now assume that the five flows are using TCP with ECN. What is the value of the rate of each flow ?

4. We continue to assume that the flows are using TCP with ECN. We observe the IP headers of packets on the link from S to $R1$. Which proportion of packets do we see marked as "Congestion Experienced" ?

5. We continue to assume that the flows are using TCP and ECN, but now A cheats and uses a smart piece of software that allows it to open several TCP connections and use them in parallel in order to transfer one single file. Assume that A uses k TCP connections. What should the value of k be in order for A to obtain the same throughput as $B1$?

6. Assume now that $R2$ is an application layer gateway instead of a router. We assume that all flows are using TCP with ECN. We assume that A is not cheating and is using only one TCP connection with the application layer gateway. The round trip time from S to $R2$ is 20 msec; from $R2$ to A it is 90 msec; from S to Bi it is 20 msec (unchanged). We assume that the application layer gateway has infinite processing power and storage. What is the value of the rate of each flow ?

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PROBLEM 4

Consider the network in Figure 4.

- $D1, D2$ and $S2$ are dual-stack hosts. In particular, $S2$ can be configured either as a NAT64 or as a application layer gateway; $D1$ and $D2$ are DNS servers that serve requests for A and AAAA records over both IPv4 and IPv6;
- $R11$ and $R21$ are IPv4-only routers; $R13$ and $R23$ are IPv6-only routers;
- $R12$ and $R22$ are dual-stack routers.

1. What are the 3rd and 4th bits of B's IPv6 address ? (the first bit is the leftmost one).

   Give the non-compressed form of B's IPv6 address.

   Give a possible value for the IPv6 network mask at B.

2. A is a dual-stack host that receives only an IPv4 address from the network. A uses 6to4 to connect to the IPv6 Internet. Give a possible value for A's 6to4 IPv6 address.

   What should A's default gateway's IPv6 address be ?

3. B is an IPv6-only host. A sends one UDP packet to B. We observe this packet on the Ethernet link between A and $R11$. We find that the Ethernet header contains protocol type = 0800, *i.e.*, this is an IPv4 packet. Say what the IPv4 source and destination addresses in this packet are; what is the protocol field in the IPv4 header ?

   B responds to A with one single UDP packet. We observe this packet on the Ethernet link between B and $R23$. Which protocol type should we see in Ethernet header? Say what the IP (v4 or v6) source and destination addresses in this packet are. Please be consistent with your previous answer.

Will this packet go via $R12$ or via $R22$? Justify your answer.

4. S is an IPv4-only host that runs a web server. Now, $S2$ is a NAT64. B runs a web browser and sends an HTML request to S. No application layer gateway is used.

   (a) Consider the first TCP SYN packet related to this activity, sent by B to S; we observe this packet on the Ethernet link between B and $R23$. Which protocol type should we see in Ethernet header? Say what the IP (v4 or v6) source and destination addresses in this packet are.

(b) We also observe this packet on the Ethernet link between $R21$ and S. Which protocol type should we see in Ethernet header? Say what the IP (v4 or v6) source and destination addresses in this packet are. Specify any assumption you may need to make.

(c) S responds to B with a TCP SYN ACK packet. Will this packet go via $R22$ or $S2$? How does R21 know where to route this packet ? Justify your answer.

(d) S now downloads one object to B using HTML. One of the packets sent by S to B during the download is lost on the link $R23 - B$. There is no other packet loss in this scenario. Explain by which mechanism in which machines the loss will be repaired.

5. A runs a web browser and sends an HTML request to S. Consider the first TCP SYN packet related to this activity, sent by A to S; we observe this packet on the Ethernet link between A and $R11$. Which protocol type should we see in Ethernet header? Say what the IP (v4 or v6) source and destination addresses in this packet are.

6. Assume now that $S2$ is configured as an application layer gateway, and not a NAT64. B would like to download a video file from the web server at S; this server corresponds to the DNS name `ba.ba`. To this end, B would like to use $S2$ as a web proxy but we would not like to configure anything special (other than the normal IPv6 configuration) at B.

   (a) Is this possible ? Justify your answer.

   (b) We assume B found a way to use $S2$ as a web proxy and downloads a video file from S using HTTP. Once the transfer is successfully established, we observe the packets resulting from this activity on the links $R21-S2$ and $S2-R23$, in the direction $S \rightarrow B$. What are the IP addresses, protocol type/next header and TTL/HL that we see ? Put your answers in the table below.

IP source	IP dest	Protocol/ Next Header	TTL / HL
At $R21 - S2$ **, packets** $S \to B$**:**			
At $S2 - R23$ **, packets** $S \to B$**:**			

(c) One of the packets sent by S to B during the download is lost on the link $R23 - B$. There is no other packet loss in this scenario. Explain by which mechanism in which machines the loss will be repaired.

TCP IP EXAM - FIGURES

For your convenience, you can separate this sheet from the main document. Do not write your solution on this sheet, use only the main document. Do not return this sheet.

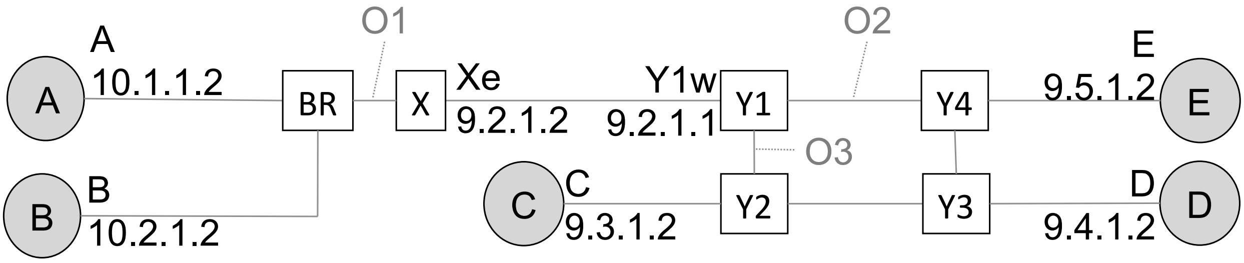

Figure 1: The network used in Problem 1, showing some selected addresses. You may need to specify other addresses.

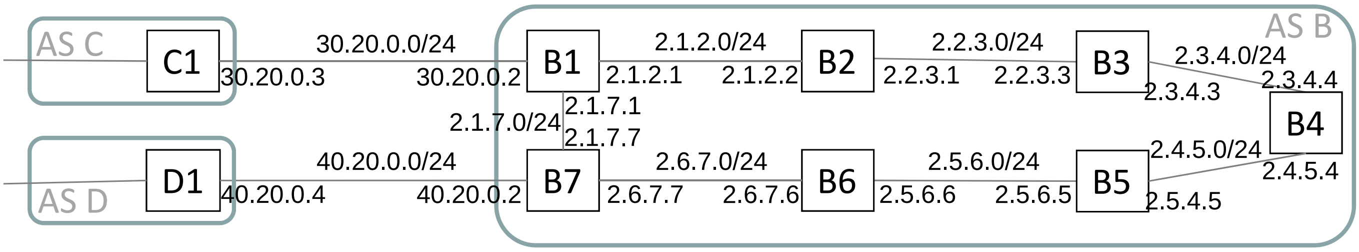

Figure 2: The network used in Problem 2.

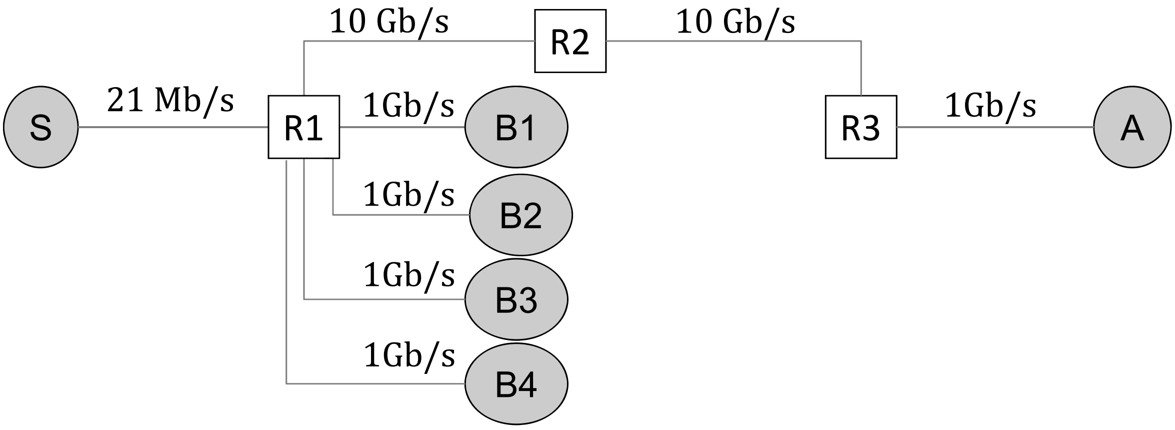

Figure 3: The network used in Problem 3.

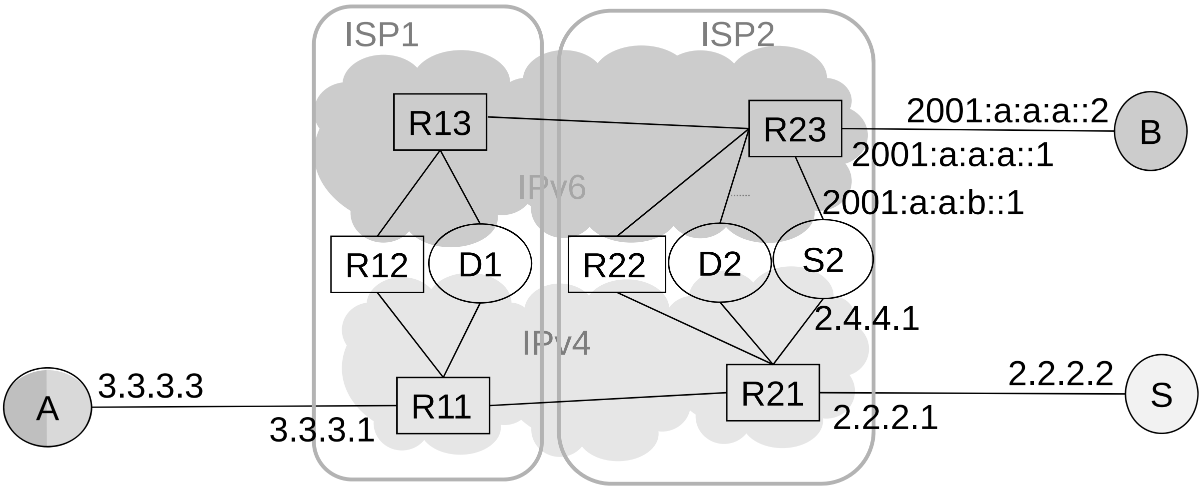

Figure 4: The network used in Problem 4.