Introduction to Computer Networks **Name:** ______________
Fall 2023
Homework (Due: 12/24/2023) **ID:** ______________

This homework contains 9 questions. The deadline is on Sec. 24 (Sun) at 23:59.

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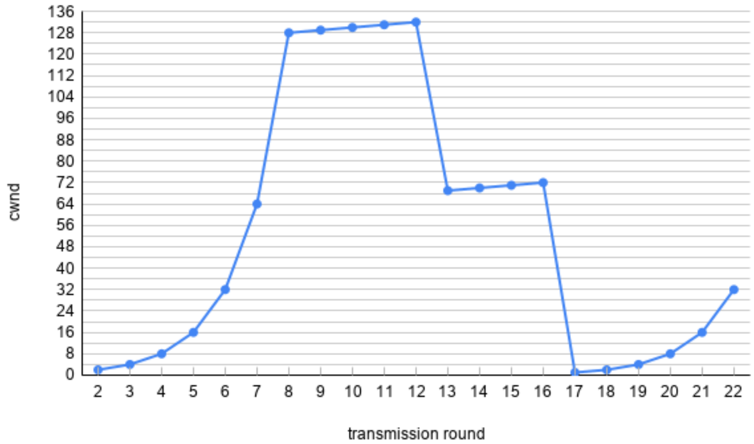
1. (10 points) **TCP congestion control:** Consider the following figure. Assuming TCP Reno is the protocol.



(a) (3 points) Identify the intervals of time when TCP slow start is operating.

> **Solution:**
> 1-8 transmission rounds
> 17-22 transmission rounds

(b) (3 points) Identify the intervals of time when TCP congestion avoidance is operating.

> **Solution:**
> 8-17

(c) (4 points) What is the initial value of `ssthresh` at the 7th and 15th transmission round, respectively?

> **Solution:**
> 128 at 7th.
> $132/2 = 66$ at 15th

2. (8 points) **Network layer:**

(a) (4 points) Explain what is the difference between the control plane and data plane.

> **Solution:**
> Control plane: decide how data is forwarded
> Data plane: actually forward every packet

(b) (4 points) Explain what is the major difference between traditional routers and programmable switches.

> **Solution:**
> traditional: can only adopt built-in routing algorithm and forwarding functionalities
> programmable: reconfigurable via software and flexible for implementing user-defined algorithms

3. (12 points) **Router:**

(a) (4 points) List the four components of a router.

> **Solution:**
> input port, switching fabric, output port, routing processor

(b) (4 points) When will the input queue (or the output queue) of a router overflow, leading to packet losses?

> **Solution:**
> When the arrival rate is larger than the service rate

(c) (4 points) Define what is *prefix matching* and *longest prefix matching*.

> **Solution:**
> prefix matching: check whether the prefix of an address matches a pre-defined rule
> longest prefix matching: among all the matched rules, the one that matches the maximum number of prefix bits

4. (10 points) **Queueing.** Consider a router that help forward packets classified into two classes. Say that ten packets arrive the router with the following class and arrival time:

sequence	1	2	3	4	5	6	7	8	9	10
class	1	2	2	1	1	2	2	2	1	1
time (second)	0.5	1.0	1.2	1.6	3.0	3.5	4	4.2	4.6	5

Assume that the transmission time of each packet is *one second*.

(a) (5 points) Assume that class 1 has a high priority, while class 2 has a low priority. When will each packet be sent if the router forwards packets using priority queueing? (Note that there is no preemptive.)

Solution:
order: id: sending time

1: 1: 0.5-1.5
2: 2: 1.5-2.5
3: 4: 2.5-3.5
4: 5: 3.5-4.5
5: 3: 4.5-5.5
6: 9: 5.5-6.5
7: 10: 6.5-7.5
8: 6: 7.5-8.5
9: 7: 8.5-9.5
10: 8: 9.5-10.5

(b) (5 points) When will each packet be sent if the router forwards packets using round robin queueing?

Solution:

1: 1: 0.5-1.5
2: 2: 1.5-2.5
3: 4: 2.5-3.5
4: 3: 3.5-4.5
5: 5: 4.5-5.5
6: 6: 5.5-6.5
7: 9: 6.5-7.5
8: 7: 7.5-8.5
9: 10: 8.5-9.5
10: 8: 9.5-10.5

5. (20 points) **Subnet.**

   (a) (5 points) What is the maximum number of hosts in the subnet 140.113.20.0/21?

   Solution:
   $2^{32-21} - 2 = 4094$

   (b) (5 points) Following the above question, what is the IP address reserved for broadcasting?

   Solution:
   $(20)_{10} = (00010100)_2$
   broadcasting: $140.113.(00010111)_2.(11111111)_2 = 140.113.23.255$

   (c) (5 points) What is the subnet mask of subnet 140.113.20.0/21 in decimal?

   Solution:
   $(11111111)_2.(11111111)_2.(11111000)_2.(00000000)_2 = 255.255.248.0$

   (d) (5 points) If this subnet only includes 800 host, what is a more efficient subnet mask? (hint: minimize the number of non-occupied IP addresses)

   Solution:
   $\min_x 2^x - 2 > 800 \rightarrow x = 10$

   $(11111111)_2.(11111111)_2.(11111100)_2.(00000000)_2 = 255.255.252.0$
   subnet: 255.255.252.0

6. (10 points) **DHCP.**

   (a) (5 points) Explain why DHCP uses link-layer broadcasting to send requests.

   Solution:
   since a new arriving node has not been assigned an IP address and, in addition, does not know the IP address of its DHCP servers.

   (b) (5 points) Why does a DHCP request require four messages (including DHCP request and ACK), instead of just two messages?

   Solution: since there may be multiple DHCP servers in a LAN

7. (10 points) **SDN:**

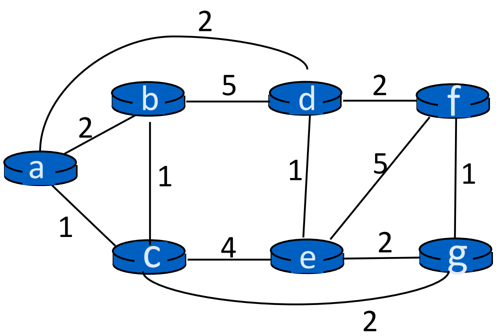
   (a) (4 points) Define what is the 5-tuple of a flow.

   Solution:
   src IP / dst IP / src port / dst port / protocol type

(b) (6 points) Give the match forwarding rules if we want to (1) drop all packets toward the destination port of 80 and (2) forward the packet from the MAC address 12-34-56-78-ab-cd to port 3.

> **Solution:**
>
> if (TCP dport == 80) then discard
> if (MAC src == 12-34-56-78-ab-cd) then port 3

8. (15 points) **Link-state routing.** Consider the following network topology with 6 nodes. Let the number associated with each link be the cost of the link. Try to find the shortest path from node a to the remaining nodes using the link-state algorithm.



(a) (8 points) Write down the step-by-step procedure of the link-state algorithm as building the distance/predecessor table from node a to all the remaining nodes.

> **Solution:** (ignore)

(b) (3 points) What is the routing path from a to f?

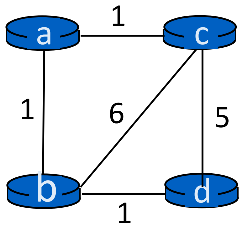
> **Solution:** $a \to c \to g \to f$
> or $a \to d \to f$

(c) (4 points) What is the forwarding table at node g?

> **Solution:**

destination	next hop
f	f

9. (15 points) **Distance-vector routing.** Consider the following network topology with 4 nodes. Let the number associated with each link be the cost of the link. Try to find the shortest path from each node to the remaining nodes using the distance-vector algorithm.



(a) (4 points) What is the initial distance vector of each of the four nodes?

> **Solution:**
> $D_a = (0, 1, 1, \infty)$
> $D_b = (1, 0, 6, 1)$
> $D_c = (1, 6, 0, 5)$
> $D_d = (\infty, 1, 5, 0)$

(b) (4 points) Assume that all the nodes broadcast their distance vectors $\mathbf{D}_i$ at the same time. What will be the distance vector of each of the four nodes after receiving the initial distance vector from the neighbors (i.e., the distance vector of all nodes after the first information exchange)?

> **Solution:**
> $D_a = (0, 1, 1, \infty), D_{a\to b} = (2, 1, 7, 2), D_{a\to c} = (2, 7, 1, 6)$
> $D_a = (0, 1, 1, 2)$
> $D_b = (1, 0, 6, 1), D_{b\to a} = (1, 2, 2, \infty), D_{b\to c} = (7, 12, 6, 11), D_{b\to d} = (\infty, 2, 6, 1)$
> $D_b = (1, 0, 2, 1)$
> $D_c = (1, 6, 0, 5), D_{c\to a} = (1, 2, 2, \infty), D_{c\to b} = (7, 6, 12, 7), D_{c\to d} = (\infty, 6, 10, 5)$
> $D_c = (1, 2, 0, 5)$
> $D_d = (\infty, 1, 5, 0), D_{d\to b} = (2, 1, 7, 2), D_{d\to c} = (6, 11, 5, 10)$
> $D_d = (2, 1, 5, 0)$

(c) (4 points) Define that the algorithm converges when it gets the same solution twice. How many iterations of updates it requires to converge to the optimal solution? (Note that the iteration that gets the duplicated result should be counted.)

> **Solution:** (ignore)

(d) (3 points) Explain how to get the shortest path from node c to node d based on the DV algorithm.

> **Solution:**
> $c \to a \to b \to d$