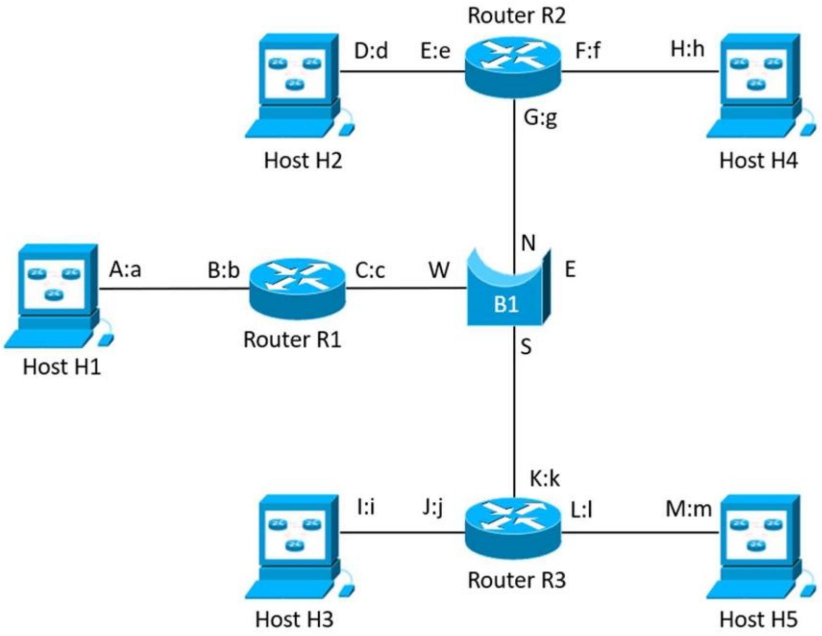
EP2120 Internetworking
IK2218 Protocols and Principles of the Internet

Homework assignment 2
(Solutions due 19:00, Mon.,18 Sep 2023)
(Review due 19:00, Wed., 20 Sep 2023)

1. ARP (20/100)



The figure above illustrates five hosts H_1, H_2, H_3, H_4, and H_5 connected by an internetwork running IPv4. The learning bridge B_1 connects routers R_1, R_2 and R_3. For the hosts and routers, the interfaces' logical (IP) addresses are shown with capital letters, and physical (MAC) addresses are shown with small letters. The North, East, South, and West interfaces of the bridge are denoted by N, E, S and W.
Assume that the ARP caches of the routers and of the hosts, and the MAC address tables of the bridges are initially empty and that no packets have been sent yet. The forwarding tables of all hosts and routers are correctly configured. All hosts know the IP addresses of each other. ARP snooping (also called passive ARP learning) is enabled.
Consider that host H_1 sends an IPv4 unicast datagram to host H_5.

1) Host H1 knows the IP address of h5 and based on the forwarding table it knows that host h5 is not on the same subnet and knows that router r1 is the next hop. Hence, H1 has to send datagram to router r1but it doesn't know the mac address of R1 so it performs a ARP request for IP address B.
2) Router R1 receives the request and replies it by providing its mac address. Host h1 learns the mac address of R1(B:b) and R1 learns the mac address of Host h1. Now h1 can forward datagram to R1.

3) After the datagram is received, Router R1 consults forwarding table and figures out that router R3 is the next hop. So R1 now sends datagram to R3.
4) Since R1 does not know the mac address of R3, R1 will send ARP request for IP address 'K'. Now the request has been received by R2 & R3. They learn binding (C:c). Bridge B1 learns the mac address 'c' on its west interface.
5) Router R3 replies back to R1 with ARP response and its mac address.
6) Bridge B1 learns the mac address 'k' on its south interface.
7) Bridge B1 forwards ARP reply to its west interface R1 and R1 stores the mac address(K:k) in the ARP table.
8) Router R1 can now send datagram to R3 .
9) Upon receiving datagram to R3, it now checks the forwarding table and finds that Host h5 is the next hop and H5 is connected to its subnet in its east interface. Hence R3 sends an ARP request 'M'.
10) The ARP req is received by H5 which will learn the binding (L:l).
11) The Host H5 notices the ARP request is for itself and replies by giving its mac address.
12) Router R3 recieves ARP reply and saves pair (M:m) in the arp table.
13) Router R3 can now forward the datagram to host H5 now.

a) Provide the state of the ARP caches of the hosts and routers as they will appear after the IPv4 unicast datagram has been delivered to host H_5, that is, after dynamic ARP resolution has been made (12p).

Based on the above description the ARP tables of the hosts are:

H1: (B,b)
H2: nill
H3: nill
H4: nill
H5: (L:l)
R1: (A:a)
R2: (C:c)
R3: (C:c)(M:m)

b) Provide the state of the MAC table of bridge B_1 as it will appear after the IPv4 unicast datagram has been delivered to host H_6, that is, after dynamic ARP resolution has been made. (4p)

B1 : (c, West), (k, South)

c) Assume now that ARP snooping was disabled from the beginning on all the hosts and routers. Provide the state of the eight ARP caches of the hosts and routers as they would appear after the IPv4 unicast datagram has been delivered to host H_5, that is, after dynamic ARP resolution has been made (4p).

H1: (B,b)
H2: nill
H3: nill
H4: nill
H5: (L:l)
R1: (A:a) (K:k)
R2: nill
R3: (C:c)(M:m)

2. UDP and fragmentation (15/100)

Assume that an Ethernet network with an MTU of 1000 bytes connects hosts A and B. An application process on Host A sends 6592 bytes of application data via UDP to a process on Host B. IPv4 is used at the network layer. IP options are not used.

a) How many fragments are transmitted? (5p)

Ans:

Total Packet Size = UDP Header + IPv4 Header + Application Data + Ethernet Frame Overhead

Total Packet Size = 8 + 20 + 6592 + 18 = 6628 bytes

To determine the number of fragments transmitted the goal is to split the packet into smaller fragments with each size <= 1000 bytes.

6638/1000= 6.62

Fraction of fragment is not possible so after rounding up it becomes 7.

Therefore, **7 fragments** are transmitted.

b) Give the values of the MF bit, the offset and the total length field of the IP header of each fragment. (10p)

1) Fragment 1:
MF- set to 1
Offset- set to 0 as it's the first fragment.
Total length: 1000 bytes (MTU)
2) Fragment 2:
MF- set to 1
Offset- 1000 bytes as its second fragment.
Total length: 1000 bytes (MTU)
3) Fragment 3:
MF- set to 1
Offset- 2000 bytes as it's the third fragment.
Total length: 1000 bytes (MTU)
4) Fragment 4:
MF- set to 1

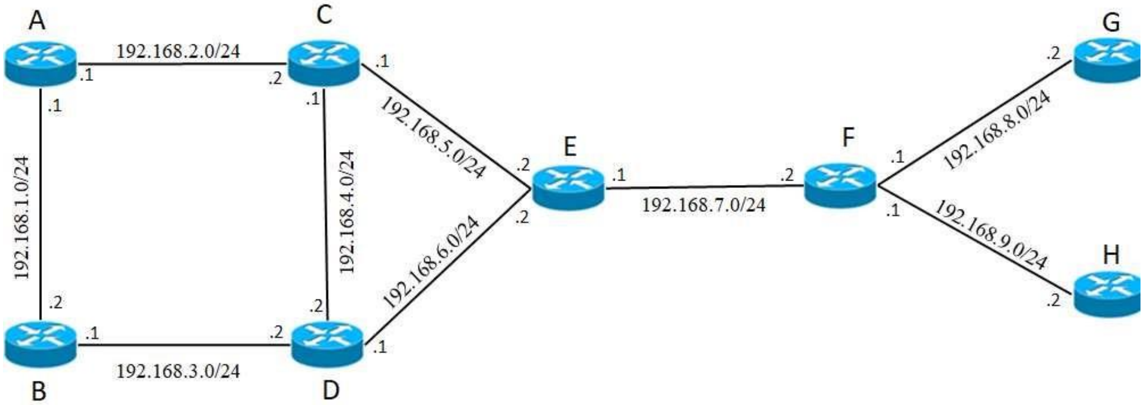
Offset- 3000 bytes as it’s the fourth fragment.
Total length: 1000 bytes (MTU)

5) Fragment 5:
MF- set to 1
Offset- 4000 bytes (5th fragment).
Total length: 1000 bytes (MTU)

6) Fragment 6:
MF- set to 1
Offset- 5000 bytes (sixth fragment)
Total length: 1000 bytes (MTU)

7) Fragment 1:
MF- set to ‘0’ as it’s the last fragment
Offset- 6000 bytes (7th and last fragment)
Total length: 592 bytes (the remaining bytes)

3. Routing (25/100)



In the IPv4 network shown in the figure, all routers (A-H) run RIPv2 and all link metrics are 1. The address block of the subnets and the associated interface addresses are given in the figure. Note that the letters A-H denote routers. Assume that initially only the addresses of the directly connected networks are known to the routers. All destinations in the network are /24 prefixes. Assume also that all RIP implementations support Equal-cost-multi-path (ECMP). All routers implement split horizon with poison reverse.

For the following questions, express routes as 'destination, metric, next-hop'. If the destination is a directly connected network, the route is given as 'destination, metric, -'.

a) What is the initial routing state of D? (2p)
Ans:

192.168.3.0/24, 1, -
192.168.4.0/24, 1, -
192.168.6.0/24, 1, -

b) Assume that the first event that happens in the network is that E starts by sending RIP responses to its neighbors. What is the routing state of D after it has received the distancevector from E? (4p)

Ans:
192.168.5.0/24, 2, E (192.168.6.2)
192.168.7.0/24, 2, E ((192.168.6.2)

192.168.3.0/24, 1, -
192.168.4.0/24, 1, -
192.168.6.0/24, 1, -

c) Assume that the second event that happens in the network is that router F sends RIP responses to its neighbors. Please list the RIP responses that F sends. You should indicate the source and destination address of each RIP response, on which interface they are sent out (and to which IP address(es)) and which distance-vectors (destination, metric tuples) are contained in each message. (10p)

Ans:
Initial routing state of F is :
192.168.9.0/24, 1, -
192.168.8.0/24, 1, -
192.168.7.0/24, 1, -

After (b) the routing states of f change to
192.168.9.0/24, 1, -
192.168.7.0/24, 1, -
192.168.8.0/24, 1, -
192.168.5.0/24, 2, 192.168.7.1
192.168.6.0/24, 2, 192.168.7.1

1) Source: 192.168.7.2
Destination: 192.168.7.1 (West)
D.vector:
192.168.9.0/24, 1, -
192.168.7.0/24, 1, -
192.168.8.0/24, 1, -

2) Source: 192.168.8.1
Destination: 192.168.8.2
D.vector:
192.168.9.0/24, 1, -
192.168.7.0/24, 1, -
192.168.8.0/24, 1, -
192.168.5.0/24, 2, 192.168.7.1
192.168.6.0/24, 2, 192.168.7.1

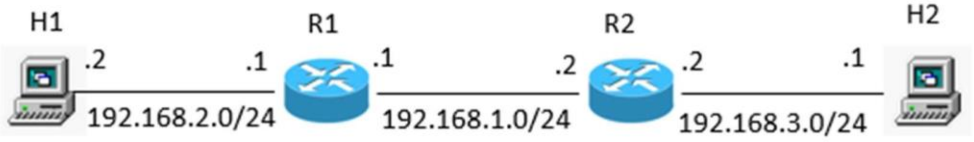
3) Soure: 192.168.9.1
Destination: 192.168.9.2
D.vector:
192.168.9.0/24, 1, -
192.168.8.0/24, 1, -
192.168.7.0/24, 1, -
192.168.5.0/24, 2, 192.168.7.1
192.168.6.0/24, 2, 192.168.7.1

d) After step (c) the routers send out RIP responses to their neighbors simultaneously every 30 seconds. Denote by t=0 the time instant when the first RIP responses after (c) are sent out. How long does it take for G to learn all the networks? Motivate your answer. (5p)
Ans:
So G needs to learn all networks except 192.168.0/24 from f and f knows the networks except 192.168.4.0/24, 192.168.2.0/24, 192.168.3.0/24, 192.168.1.0/24 because of (b) and (c). As the routers send out RIP responses to their neighbors simultaneously every 30 seconds and there are about 4 routers between the network and G, we can say that it would take around 4*30 = 120 secs in order for G to know all the networks.

e) Assume now that the routers in the above network run OSPF instead of RIPv2. Propose a set of designated routers (DRs) for the network. Given the DRs you identified, how many network link state advertisements (LSAs) and how many router LSAs does the link state database consist of? (4p)
Ans:
The link state database consists of:

8 Router LSAs
9 Network LSAs
This is the total number of LSAs in the OSPF link state database for this network

4. ICMP (15/100)



The hosts H1 and H2 are connected by an internetwork running IPv4. The forwarding tables of all hosts and routers are correctly configured.

a) H2 performs a traceroute to host H1 relying on ICMP. Traceroute is configured to send one message for each hop. Please list the first and the last ICMP messages that H2 sends, and the corresponding replies that H2 receives. For each IP datagram specify the source and the destination IP address, the value of the TTL field and the payload. (10p)

Ans:

1) First ICMP message sent:
   Source: 192.168.3.1 (H2's IP)
   Destination: 192.168.2.2 (H1's IP)
   TTL: 1
   Payload: Traceroute-specific data

2) First ICMP message received:
   Source: 192.168.3.2
   Destination: 192.168.3.1
   TTL: 0 (TTL expired)
   Payload: ICMP time exceeded

3) Last ICMP message sent:
   Source: 192.168.3.1
   Destination: 192.168.2.2
   TTL: 3
   Payload: Traceroute-specific data

4) Last ICMP received:
   Source: 192.168.2.2
   Destination: 192.168.3.1
   TTL: 0 (TTL expired)
   Payload: ICMP time exceeded

b) Assume that a program on H1 sends a UDP unicast datagram to 192.168.3.1 with the DF flag set to 1. The datagram size is below the MTU for the networks 192.168.2.0/24 and 192.168.1.0/24 but it exceeds the MTU of the network 192.168.3.0/24. Router R2 can thus not forward the datagram to H2. Will H1 receive any ICMP error message? If yes, then what is the type of message? (5p)

   Ans:

   Yes, H1 will receive an error message saying "ICMP Destination Unreachable" type 3 and code 4 "Fragmentation Needed and Don't Fragment (DF) bit set".

5. TCP (25/100)

Consider a recently established TCP connection between processes P_A and P_B, running on hosts A and B, respectively. The three-way handshake has been completed, but no data has been sent yet. TCP on Host B announced a receiver window size of 2400 bytes to TCP on Host A, and Process P_B can read the received data from TCP as soon as they arrive. Process P_A has 6000 bytes to send via TCP. The path MTU between the two hosts is known to be 640 bytes. The

one-way propagation time is 60ms, and the link speed is 1.6 Mbps. It takes 1ms for TCP to generate a segment (with or without data) and this can be done in parallel with sending a previously generated segment.

The receiver uses delayed acknowledgments with a delay of 200ms (or at most two full segments). The size of a segment having a TCP header only is negligible in terms of transmission time. Moreover, for segments containing TCP payload, the size of the headers can be neglected when computing the transmission time of the segment. IPv4 is used as the network layer protocol and IP options are not used. Process P_A sends the first segment at time t_0 with sequence number 0. CWND is originally set to 1 MSS (packet loss was experienced during connection establishment, as per RFC5681) and the slow start threshold is 65535 bytes. Assume that the granularity G of the heartbeat timer is 0.5 seconds.

a) What is the MSS used by TCP? (2p)
Ans:
MSS = MTU - IP header size - TCP header size
MSS = 640 bytes - 20 bytes - negligible
MSS = **620 bytes** and if tcp header size is considered it is **600 bytes**.

b) What is the bandwidth-delay product of the communication channel? Is the advertised receiver window of B big enough to fully utilize the channel? If not, how big should it be for A to be able to fully utilize the channel? (5p)
Ans:
The quantity of data that may be transmitted over a communication channel at any given moment is measured by its bandwidth-delay product (BDP).

BDP = link speed × Round-trip Time
BDP = 1.6 Mbps × 0.06 seconds (60ms)
BDP = 96,000 bits = 12000 bytes*2 = 24000bytes

Therefore, the bandwidth-delay product of the communication channel is 24000 bytes.

Since the BDP is 24,000 bytes and the size of the B receiver window is 2400 bytes. The stated receiver window of B is not large enough to use the channel to its full potential because 2400 bytes is less than the BDP of 24,000 bytes.

The receiver window size should be equal to or larger than the BDP in order to properly utilize the channel. Therefore, for Host A to fully utilize the channel, B's receiver window size must be at least 24,000 bytes.

c) Provide the sequence of segments sent by TCP from host A. For each segment sent from host A provide the time it is sent and the sequence number of the first byte it contains. For the first five segments sent from host A, also provide the SRTT, RTTVAR and the RTO values of the sender TCP at the time the segment is sent. Assume that outgoing segments are handled before incoming segments in case more than one event happens at the same time! (15p)

Ans:
Given:
Receiver window size (RWND) = 2400 bytes
Maximum Segment Size (MSS) = 640 bytes (path MTU)
Congestion Window (CWND) = 1 MSS
Slow Start Threshold (SSTHRESH) = 65535 bytes
Propagation time (one-way) = 60 ms

Link speed = 1.6 Mbps
Segment generation time = 1 ms
Delayed Acknowledgment = 200 ms
Initial RTO = 200 ms (as per RFC 6298)

1) The first segment is sent at time t0 with sequence number 0.
Time = t0
Sequence number = 0
SRTT = 0ms
RTTVAR = 0ms
RTO= 200ms (initial)

2) 2nd segment:
Time = t0 + 1ms
Sequence number = 640
SRTT = 1
RTTVAR = 0.5ms
RTO= 202ms (initial)
CWND= 2 MSS

3) 3rd segment:
Time = t0 + 2ms
Sequence number = 1280
SRTT = 2
RTTVAR = 1ms
RTO= 204ms (initial)
CWND= 4 MSS

4) 4th segment:
Time = t0 + 3ms
Sequence number = 1920
SRTT = 3
RTTVAR = 1.5ms
RTO= 206ms (initial)
CWND= 8MSS

5) 5th segment:
Time = t0 + 4ms
Sequence number = 2560
SRTT = 4
RTTVAR = 2ms
RTO= 208ms (initial)
CWND= 16 MSS

6) 6th segment:
Time = t0 + 5ms
Sequence number = 3200

7) 7th segment:
Time = t0 + 6ms
Sequence number = 3840

When all 6000 bytes have been transferred, the process is complete. In a multiplicative approach, PA will steadily increase its CWND. We won't calculate every segment transmitted because this is a simplified example; rather, we'll keep going until all the data has been sent.

d) At what time does A receive the acknowledgement for the last segment? (3p)

We already know that Segment 7 with a sequence number of 3840 was the last segment sent from A at time t0 + 6 ms.

Now, taking into account propagation time, we must determine how long it takes for Segment 7's acknowledgment to reach A:

Segment 7 send time plus propagation time equals the time it took to get the acknowledgment.

Time to get acknowledgement is equal to (t0 + 6 ms) plus 60 ms, or (t0 + 66 ms).

Thus, at t0 + 66 ms, host A receives the acknowledgment for the final segment (Segment 7).

Hint 1: Try to first draw the sequence of segment exchanges to get the order of the segments right.

Hint 2: Consult RFC 6298 for details on how to calculate the SRTT, RTTVAR and the RTO. The description provided in the course book (3ed and 4ed) is not correct. Consult RFC5681 for congestion control.