Link Layer Problems – Subset of problems to focus on are highlighted

Problem 1

1 1 1 0 1
0 1 1 0 0
1 0 0 1 0
1 1 0 1 1
1 1 0 0 0

Problem 2

Suppose we begin with the initial two-dimensional parity matrix:

0 0 0 0
1 1 1 1
0 1 0 1
1 0 1 0

With a bit error in row 2, column 3, the parity of row 2 and column 3 is now wrong in the matrix below:

0 0 0 0
1 1 0 1
0 1 0 1
1 0 1 0

Now suppose there is a bit error in row 2, column 2 and column 3. The parity of row 2 is now correct! The parity of columns 2 and 3 is wrong, but we can't detect in which rows the error occurred!

0 0 0 0
1 0 0 1
0 1 0 1
1 0 1 0

The above example shows that a double bit error can be detected (if not corrected).

Problem 3

```
  01001100  01101001
+ 01101110  01101011
-----------------------------
  10111010  11010100
+ 00100000  01001100
-----------------------------
  11011011  00100000
```

```
+ 01100001  01111001
-----------------------------
  00111100  10011010  (overflow, then wrap around)
+ 01100101  01110010
------------------------------
  10100010  00001100
```
The one's complement of the sum is 01011101 11110011

Problem 4

a) To compute the Internet checksum, we add up the values at 16-bit quantities:

```
00000001  00000010
00000011  00000100
00000101  00000110
00000111  00001000
00001001  00001010
-------------------------
00011001  00011110
```

The one's complement of the sum is 11100110 11100001.

b) To compute the Internet checksum, we add up the values at 16-bit quantities:

```
01000010  01000011
01000100  01000101
01000110  01000111
01001000  01001001
01001010  01001011
-------------------------
10011111  10100100
```

The one's complement of the sum is 01100000 01011011

c) To compute the Internet checksum, we add up the values at 16-bit quantities:

```
01100010  01100011
01100100  01100101
01100110  01100111
01101000  01101001
01101010  01101011
```

00000000 00000101
The one's complement of the sum is 11111111 11111010.

Problem 5

If we divide 10011 into 1010101010 0000, we get 1011011100, with a remainder of R=0100. Note that, G=10011 is CRC-4-ITU standard.

Problem 6

a) we get 1000100011, with a remainder of R=0101.
b) we get 1011111111, with a remainder of R=0001.
c) we get 0101101110, with a remainder of R=0010.

Problem 7

a) Without loss of generality, suppose ith bit is flipped, where 0<= i <= d+r-1 and assume that the least significant bit is 0th bit.
A single bit error means that the received data is K=D*2r XOR R + 2i. It is clear that if we divide K by G, then the reminder is not zero. In general, if G contains at least two 1's, then a single bit error can always be detected.
b) The key insight here is that G can be divided by 11 (binary number), but any number of odd-number of 1's cannot be divided by 11. Thus, a sequence (not necessarily contiguous) of odd-number bit errors cannot be divided by 11, thus it cannot be divided by G.

Problem 8

a)

$$
\begin{aligned}
E(p) &= Np(1-p)^{N-1} \\
E'(p) &= N(1-p)^{N-1} - Np(N-1)(1-p)^{N-2} \\
&= N(1-p)^{N-2}((1-p) - p(N-1))
\end{aligned}
$$

$$E'(p) = 0 \Rightarrow p^* = \frac{1}{N}$$

b)

$$E(p^*) = N\frac{1}{N}(1-\frac{1}{N})^{N-1} = (1-\frac{1}{N})^{N-1} = \frac{(1-\frac{1}{N})^{N}}{1-\frac{1}{N}}$$

$$\lim_{N\to\infty}(1-\frac{1}{N}) = 1 \qquad \lim_{N\to\infty}(1-\frac{1}{N})^{N} = \frac{1}{e}$$

Thus

$$\lim_{N\to\infty} E(p^*) = \frac{1}{e}$$

Problem 9

$$E(p) = Np(1-p)^{2(N-1)}$$
$$E'(p) = N(1-p)^{2(N-2)} - Np2(N-1)(1-p)^{2(N-3)}$$
$$= N(1-p)^{2(N-3)}((1-p) - p2(N-1))$$

$$E'(p) = 0 \Rightarrow p^* = \frac{1}{2N-1}$$

$$E(p^*) = \frac{N}{2N-1}(1-\frac{1}{2N-1})^{2(N-1)}$$

$$\lim_{N\to\infty} E(p^*) = \frac{1}{2}\cdot\frac{1}{e} = \frac{1}{2e}$$

Problem 10

a) A’s average throughput is given by pA(1-pB).
Total efficiency is pA(1-pB) + pB(1-pA).

b) A’s throughput is pA(1-pB)=2pB(1-pB)= 2pB- 2(pB)2.
B’s throughput is pB(1-pA)=pB(1-2pB)= pB- 2(pB)2.
Clearly, A’s throughput is not twice as large as B’s.
In order to make pA(1-pB)= 2 pB(1-pA), we need that pA= 2 – (pA / pB).

c) A’s throughput is 2p(1-p)N-1, and any other node has throughput p(1-p)N-2(1-2p).

Problem 11

a) $(1 – p(A))4\ p(A)$
where, p(A) = probability that A succeeds in a slot
p(A) = p(A transmits and B does not and C does not and D does not)
= p(A transmits) p(B does not transmit) p(C does not transmit) p(D does not transmit)
= p(1 – p) (1 – p)(1-p) = p(1 – p)3

Hence, p(A succeeds for first time in slot 5)
= (1 – p(A))4 p(A) = (1 – p(1 – p)3)4 p(1 – p)3

b) p(A succeeds in slot 4) = p(1-p)3
p(B succeeds in slot 4) = p(1-p)3
p(C succeeds in slot 4) = p(1-p)3
p(D succeeds in slot 4) = p(1-p)3

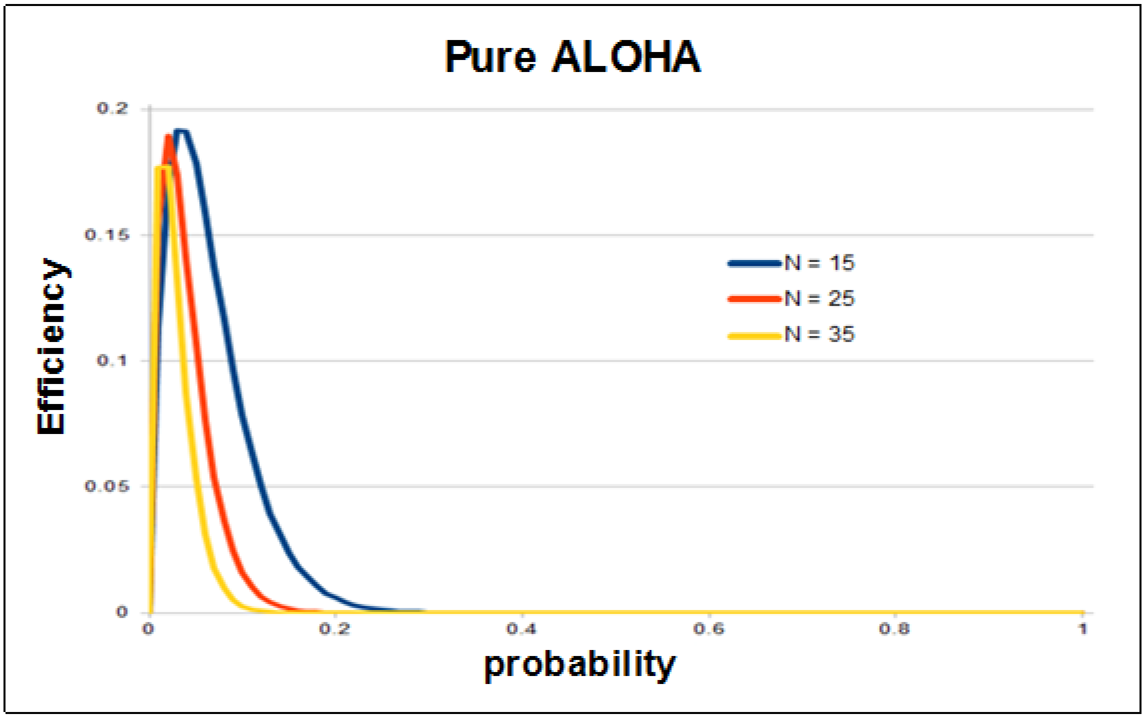
p(either A or B or C or D succeeds in slot 4) = 4 p(1-p)3
(because these events are mutually exclusive)

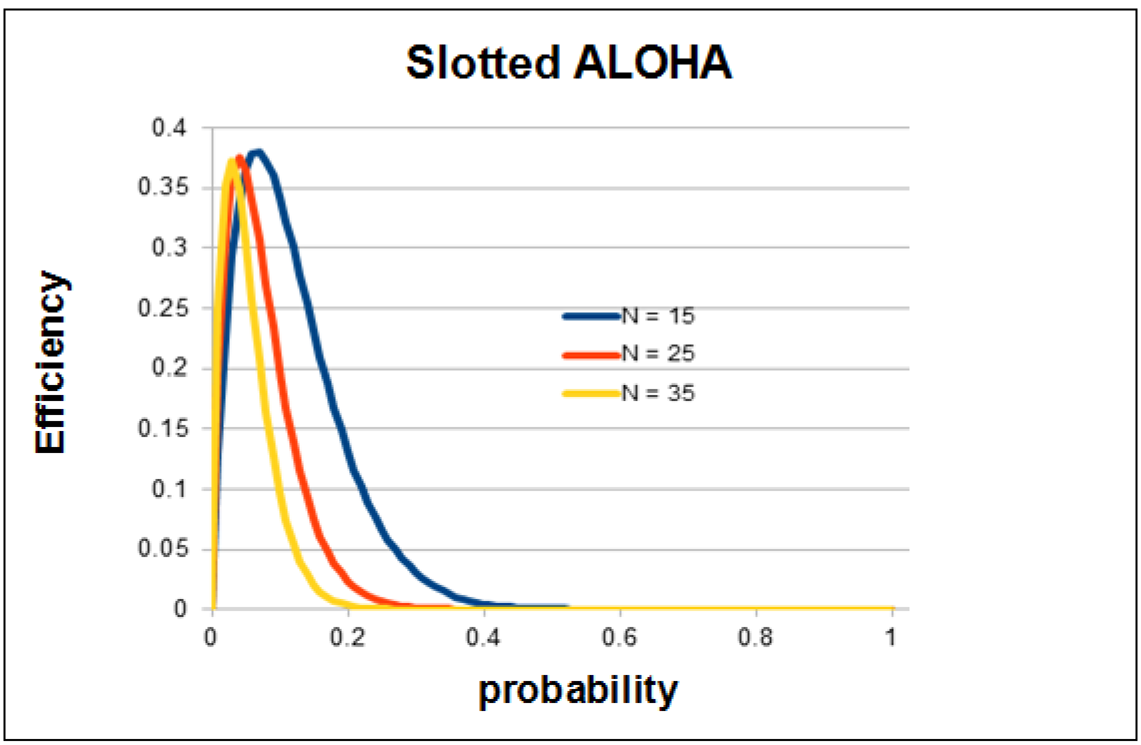
c) p(some node succeeds in a slot) = 4 p(1-p)3
p(no node succeeds in a slot) = 1 - 4 p(1-p)3

Hence, p(first success occurs in slot 3) = p(no node succeeds in first 2 slots) p(some node succeeds in 3rd slot) = (1 - 4 p(1-p)3)2 4 p(1-p)3

d) efficiency = p(success in a slot) =4 p(1-p)3

Problem 12


Pure ALOHA
0.2
0.15
0.1
0.05
0
0
0.2
0.4
0.6
0.8
1
Efficiency
probability
N = 15
N = 25
N = 35


Slotted ALOHA
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.2
0.4
0.6
0.8
1
Efficiency
probability
N = 15
N = 25
N = 35

Problem 13

The length of a polling round is

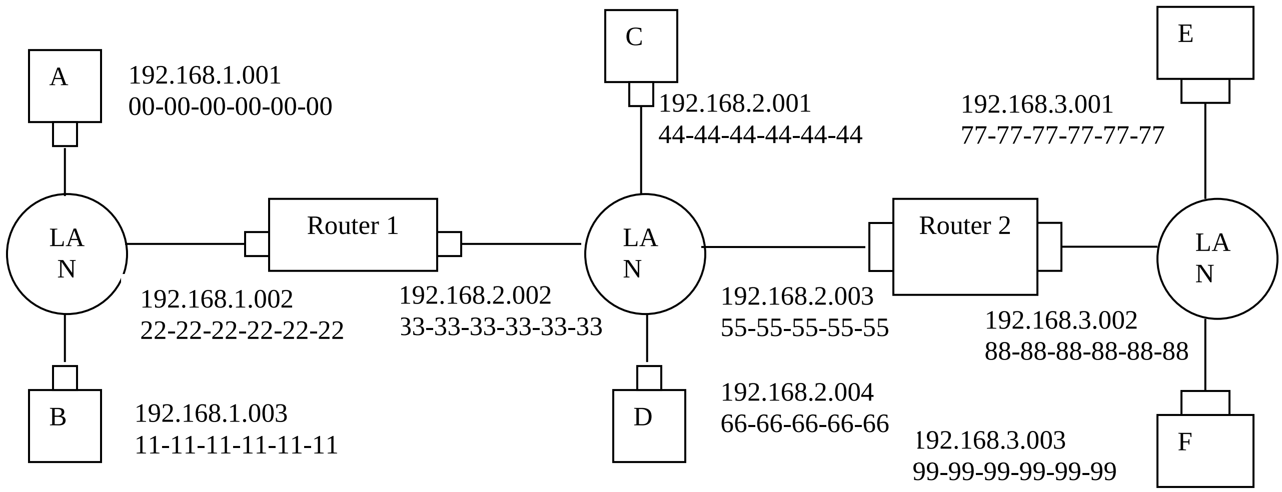
$$N(Q/R + d_{poll}).$$

The number of bits transmitted in a polling round is NQ. The maximum throughput therefore is

$$\frac{NQ}{N(Q/R + d_{poll})} = \frac{R}{1 + \frac{d_{poll}R}{Q}}$$

Problem 14

a), b) See figure below.



c)

1. Forwarding table in E determines that the datagram should be routed to interface 192.168.3.002.
2. The adapter in E creates and Ethernet packet with Ethernet destination address 88-88-88-88-88-88.
3. Router 2 receives the packet and extracts the datagram. The forwarding table in this router indicates that the datagram is to be routed to 198.162.2.002.
4. Router 2 then sends the Ethernet packet with the destination address of 33-33-33-33-33-33 and source address of 55-55-55-55-55-55 via its interface with IP address of 198.162.2.003.
5. The process continues until the packet has reached Host B.

a) ARP in E must now determine the MAC address of 198.162.3.002. Host E sends out an ARP query packet within a broadcast Ethernet frame. Router 2 receives the query packet and sends to Host E an ARP response packet. This ARP response packet is carried by an Ethernet frame with Ethernet destination address 77-77-77-77-77-77.

Problem 15

a) No. E can check the subnet prefix of Host F's IP address, and then learn that F is on the same LAN. Thus, E will not send the packet to the default router R1.
Ethernet frame from E to F:
Source IP = E's IP address
Destination IP = F's IP address
Source MAC = E's MAC address
Destination MAC = F's MAC address

b) No, because they are not on the same LAN. E can find this out by checking B's IP address.
Ethernet frame from E to R1:
Source IP = E's IP address
Destination IP = B's IP address
Source MAC = E's MAC address
Destination MAC = The MAC address of R1's interface connecting to Subnet 3.

c) Switch S1 will broadcast the Ethernet frame via both its interfaces as the received ARP frame's destination address is a broadcast address. And it learns that A resides on Subnet 1 which is connected to S1 at the interface connecting to Subnet 1. And, S1 will update its forwarding table to include an entry for Host A.

Yes, router R1 also receives this ARP request message, but R1 won't forward the message to Subnet 3.

B won't send ARP query message asking for A's MAC address, as this address can be obtained from A's query message.

Once switch S1 receives B's response message, it will add an entry for host B in its forwarding table, and then drop the received frame as destination host A is on the same interface as host B (i.e., A and B are on the same LAN segment).

Problem 16

Let's call the switch between subnets 2 and 3 S2. That is, *router R1 between subnets 2 and 3 is now replaced with switch S2*.

a) No. E can check the subnet prefix of Host F's IP address, and then learn that F is on the same LAN segment. Thus, E will not send the packet to S2.
   Ethernet frame from E to F:
   Source IP = E's IP address
   Destination IP = F's IP address
   Source MAC = E's MAC address
   Destination MAC = F's MAC address

b) Yes, because E would like to find B's MAC address. In this case, E will send an ARP query packet with destination MAC address being the broadcast address.
   This query packet will be re-broadcast by switch 1, and eventually received by Host B.
   Ethernet frame from E to S2:
   Source IP = E's IP address
   Destination IP = B's IP address
   Source MAC = E's MAC address
   Destination MAC = broadcast MAC address: FF-FF-FF-FF-FF-FF.

c) Switch S1 will broadcast the Ethernet frame via both its interfaces as the received ARP frame's destination address is a broadcast address. And it learns that A resides on Subnet 1 which is connected to S1 at the interface connecting to Subnet 1. And, S1 will update its forwarding table to include an entry for Host A.

   Yes, router S2 also receives this ARP request message, and S2 will broadcast this query packet to all its interfaces.

   B won't send ARP query message asking for A's MAC address, as this address can be obtained from A's query message.

   Once switch S1 receives B's response message, it will add an entry for host B in its forwarding table, and then drop the received frame as destination host A is on the same interface as host B (i.e., A and B are on the same LAN segment).

Problem 17

Wait for 51,200 bit times. For 10 Mbps, this wait is

$$\frac{51.2 \times 10^3 \, bits}{10 \times 10^6 \, bps} = 5.12 \, \text{msec}$$

For 100 Mbps, the wait is 512 μsec.

Problem 18

At $t = 0$ A transmits. At $t = 576$, A would finish transmitting. In the worst case, B begins transmitting at time t=324, which is the time right before the first bit of A's frame arrives at B. At time t=324+325=649 B's first bit arrives at A. Because 649> 576, A finishes transmitting before it detects that B has transmitted. So A incorrectly thinks that its frame was successfully transmitted without a collision.

Problem 19

Time, t	Event
0	A and B begin transmission
245	A and B detect collision
293	A and B finish transmitting jam signal
293+245 = 538	B's last bit arrives at A; A detects an idle channel
538+96=634	A starts transmitting
293+512 = 805	B returns to Step2 B must sense idle channel for 96 bit times before it transmits
634+245=879	A's transmission reaches B

Because A's retransmission reaches B before B's scheduled retransmission time (805+96), B refrains from transmitting while A retransmits. Thus A and B do not collide. Thus the factor 512 appearing in the exponential backoff algorithm is sufficiently large.

Problem 20

a) Let Y be a random variable denoting the number of slots until a success:

$$P(Y = m) = \beta(1-\beta)^{m-1},$$

where β is the probability of a success.

This is a geometric distribution, which has mean $1/\beta$. The number of consecutive wasted slots is $X = Y - 1$ that

$$x = E[X] = E[Y] - 1 = \frac{1-\beta}{\beta}$$

$$\beta = Np(1-p)^{N-1}$$

$$x = \frac{1 - Np(1-p)^{N-1}}{Np(1-p)^{N-1}}$$

$$\text{efficiency} = \frac{k}{k+x} = \frac{k}{k + \frac{1 - Np(1-p)^{N-1}}{Np(1-p)^{N-1}}}$$

b)

Maximizing efficiency is equivalent to minimizing x, which is equivalent to maximizing β. We know from the text that β is maximized at $p = \frac{1}{N}$.

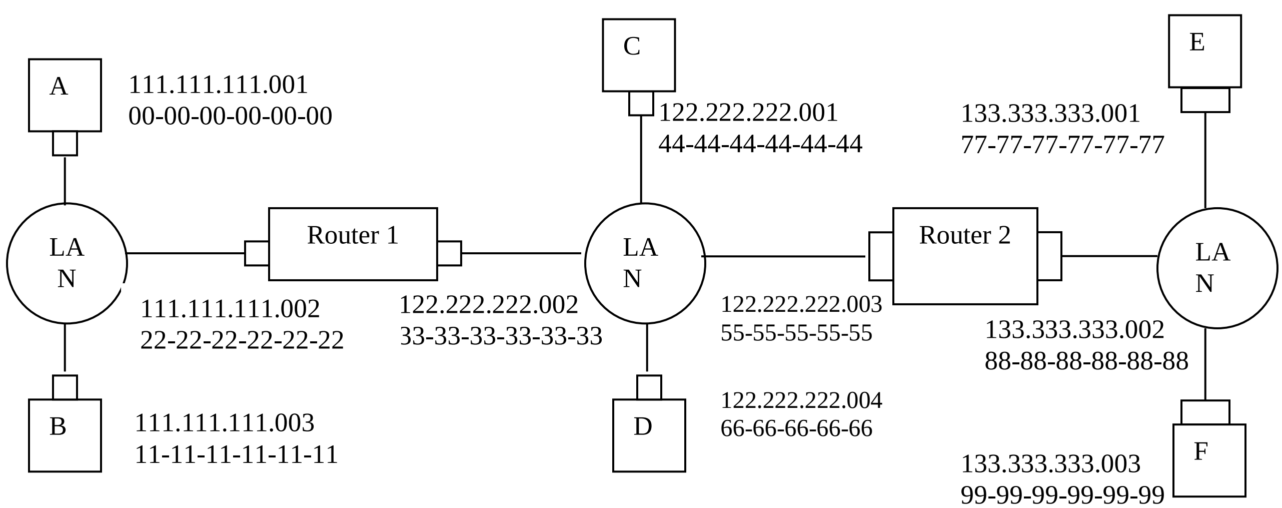
c)

$$\text{efficiency} = \frac{k}{k + \frac{1 - (1 - \frac{1}{N})^{N-1}}{(1 - \frac{1}{N})^{N-1}}}$$

$$\lim_{N \to \infty} \text{efficiency} = \frac{k}{k + \frac{1 - 1/e}{1/e}} = \frac{k}{k + e - 1}$$

d) Clearly, $\frac{k}{k+e-1}$ approaches 1 as $k \to \infty$.

Problem 21



i) from A to left router: Source MAC address: 00-00-00-00-00-00
Destination MAC address: 22-22-22-22-22-22
Source IP: 111.111.111.001
Destination IP: 133.333.333.003

ii) from the left router to the right router: Source MAC address: 33-33-33-33-33-33
Destination MAC address: 55-55-55-55-55-55
Source IP: 111.111.111.001
Destination IP: 133.333.333.003

iii) from the right router to F: Source MAC address: 88-88-88-88-88-88
Destination MAC address: 99-99-99-99-99-99
Source IP: 111.111.111.001
Destination IP: 133.333.333.003

Problem 22

i) from A to switch: Source MAC address: 00-00-00-00-00-00
Destination MAC address: 55-55-55-55-55-55
Source IP: 111.111.111.001
Destination IP: 133.333.333.003
ii) from switch to right router: Source MAC address: 00-00-00-00-00-00
Destination MAC address: 55-55-55-55-55-55
Source IP: 111.111.111.001
Destination IP: 133.333.333.003

iii) from right router to F: Source MAC address: 88-88-88-88-88-88
Destination MAC address: 99-99-99-99-99-99
Source IP: 111.111.111.001
Destination IP: 133.333.333.003

Problem 23

If all the 11=9+2 nodes send out data at the maximum possible rate of 100 Mbps, a total aggregate throughput of 11*100 = 1100 Mbps is possible.

Problem 24

Each departmental hub is a single collision domain that can have a maximum throughput of 100 Mbps. The links connecting the web server and the mail server has a maximum throughput of 100 Mbps. Hence, if the three collision domains and the web server and mail server send out data at their maximum possible rates of 100 Mbps each, a maximum total aggregate throughput of 500 Mbps can be achieved among the 11 end systems.

Problem 25

All of the 11 end systems will lie in the same collision domain. In this case, the maximum total aggregate throughput of 100 Mbps is possible among the 11 end sytems.

Problem 26

Action	**Switch Table State**	**Link(s) packet is forwarded to**	**Explanation**
B sends a frame to E	Switch learns interface corresponding to MAC address of B	A, C, D, E, and F	Since switch table is empty, so switch does not know the interface corresponding to MAC address of E
E replies with a frame to B	Switch learns interface corresponding to MAC address of E	B	Since switch already knows interface corresponding to MAC address of B
A sends a frame to B	Switch learns the interface corresponding to MAC address of A	B	Since switch already knows the interface corresponding to MAC address of B
B replies with a frame to A	Switch table state remains the same as before	A	Since switch already knows the interface corresponding to MAC address of A

Problem 27

a) The time required to fill $L \cdot 8$ bits is

$$\frac{L \cdot 8}{128 \times 10^3} \sec = \frac{L}{16} m\sec.$$

b) For $L = 1{,}500,$ the packetization delay is

$$\frac{1500}{16} m\sec = 93.75 m\sec .$$

For $L = 50,$ the packetization delay is

$$\frac{50}{16} m\sec = 3.125 m\sec .$$

c) Store-and-forward delay $= \dfrac{L \cdot 8 + 40}{R}$

For $L = 1{,}500$, the delay is

$$\frac{1500 \cdot 8 + 40}{622 \times 10^6} \sec \approx 19.4 \mu \sec$$

For $L = 50,$ store-and-forward delay $< 1 \mu \sec$.

d) Store-and-forward delay is small for both cases for typical link speeds. However, packetization delay for $L = 1500$ is too large for real-time voice applications.

Problem 28

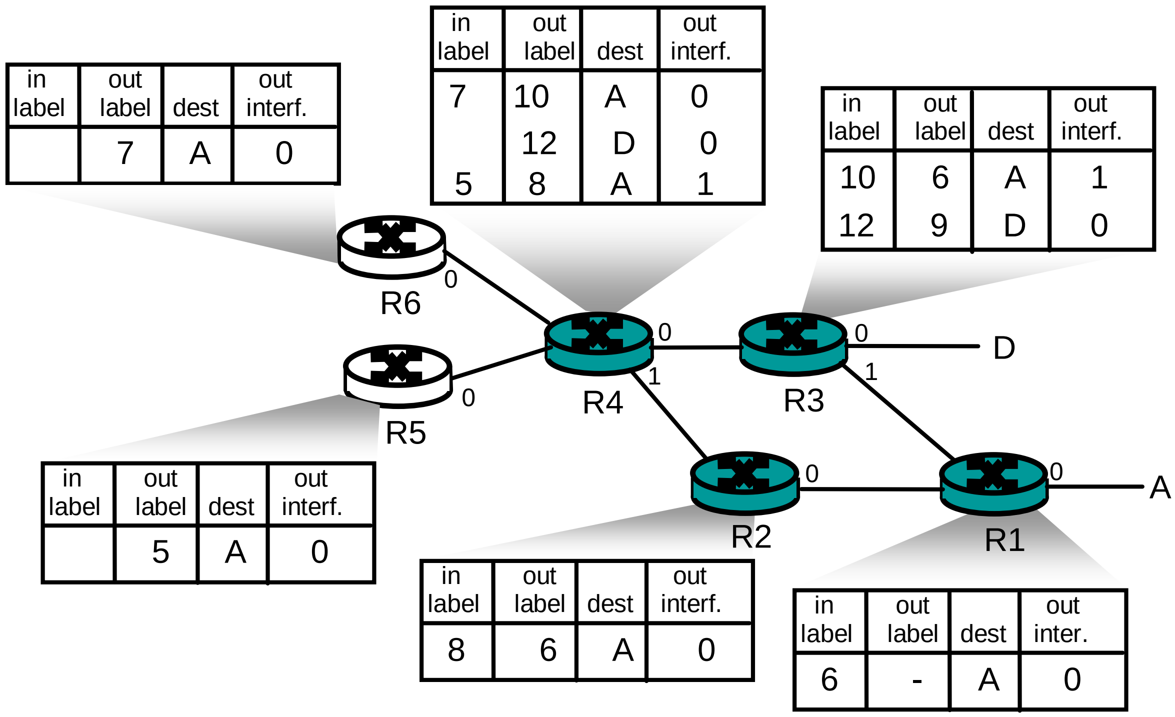
The IP addresses for those three computers (from left to right) in EE department are: 111.111.1.1, 111.111.1.2, 111.111.1.3. The subnet mask is 111.111.1/24.

The IP addresses for those three computers (from left to right) in CS department are: 111.111.2.1, 111.111.2.2, 111.111.2.3. The subnet mask is 111.111.2/24.

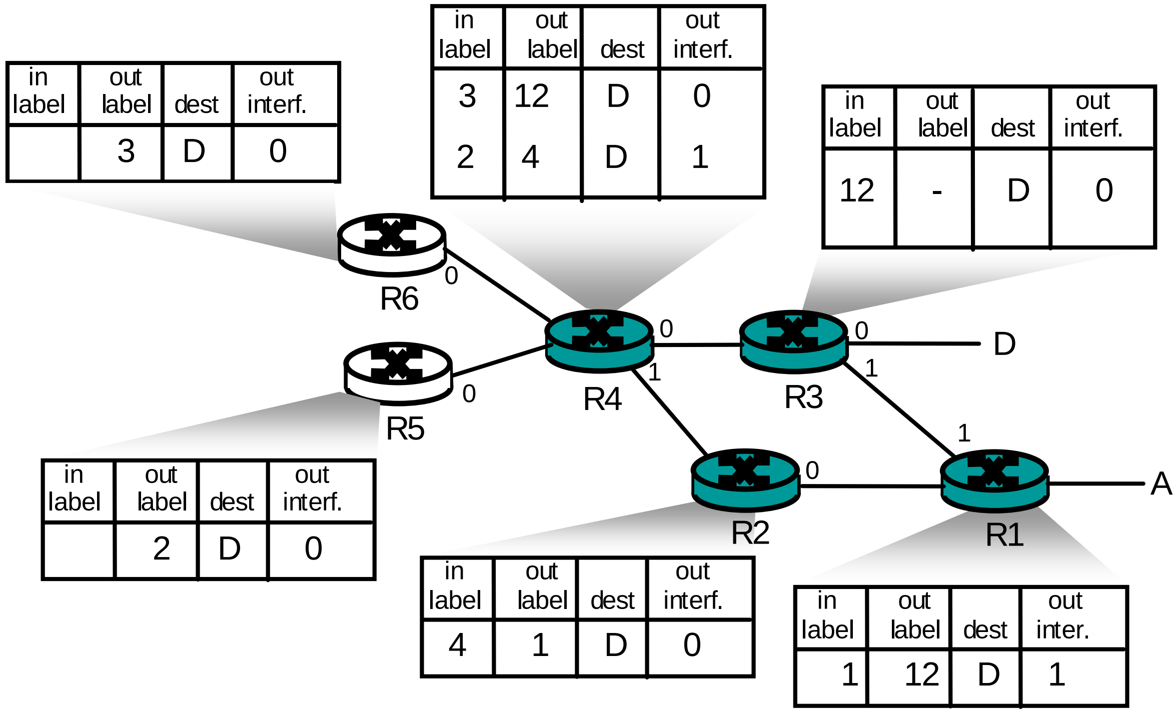
The router's interface card that connects to port 1 can be configured to contain two sub-interface IP addresses: 111.111.1.0 and 111.111.2.0. The first one is for the subnet of EE department, and the second one is for the subnet of CS department. Each IP address is associated with a VLAN ID. Suppose 111.111.1.0 is associated with VLAN 11, and 111.111.2.0 is associated with VLAN 12. This means that each frame that comes from subnet 111.111.1/24 will be added an 802.1q tag with VLAN ID 11, and each frame that comes from 111.111.2/24 will be added an 802.1q tag with VLAN ID 12.

Suppose that host A in EE department with IP address 111.111.1.1 would like to send an IP datagram to host B (111.111.2.1) in CS department. Host A first encapsulates the IP datagram (destined to 111.111.2.1) into a frame with a destination MAC address equal to the MAC address of the router's interface card that connects to port 1 of the switch. Once the router receives the frame, then it passes it up to IP layer, which decides that the IP datagram should be forwarded to subnet 111.111.2/24 via sub-interface 111.111.2.0. Then the router encapsulates the IP datagram into a frame and sends it to port 1. Note that this frame has an 802.1q tag VLAN ID 12. Once the switch receives the frame port 1, it knows that this frame is destined to VLAN with ID 12, so the switch will send the frame to Host B which is in CS department. Once Host B receives this frame, it will remove the 802.1q tag.

Problem 29



Problem 30



Problem 31

(The following description is short, but contains all major key steps and key protocols involved.)

Your computer first uses DHCP to obtain an IP address. You computer first creates a special IP datagram destined to 255.255.255.255 in the DHCP server discovery step, and puts it in a Ethernet frame and broadcast it in the Ethernet. Then following the steps in the DHCP protocol, you computer is able to get an IP address with a given lease time.

A DHCP server on the Ethernet also gives your computer a list of IP addresses of first-hop routers, the subnet mask of the subnet where your computer resides, and the addresses of local DNS servers (if they exist).

Since your computer's ARP cache is initially empty, your computer will use ARP protocol to get the MAC addresses of the first-hop router and the local DNS server.

Your computer first will get the IP address of the Web page you would like to download. If the local DNS server does not have the IP address, then your computer will use DNS protocol to find the IP address of the Web page.

Once your computer has the IP address of the Web page, then it will send out the HTTP request via the first-hop router if the Web page does not reside in a local Web server. The HTTP request message will be segmented and encapsulated into TCP packets, and then further encapsulated into IP packets, and finally encapsulated into Ethernet frames. Your computer sends the Ethernet frames destined to the first-hop router. Once the router receives the frames, it passes them up into IP layer, checks its routing table, and then sends the packets to the right interface out of all of its interfaces.

Then your IP packets will be routed through the Internet until they reach the Web server.

The server hosting the Web page will send back the Web page to your computer via HTTP response messages. Those messages will be encapsulated into TCP packets and then further into IP packets. Those IP packets follow IP routes and finally reach your first-hop router, and then the router will forward those IP packets to your computer by encapsulating them into Ethernet frames.

Problem 32

a) Each flow evenly shares a link's capacity with other flows traversing that link, then the 80 flows crossing the B to access-router 10 Gbps links (as well as the access router to border router links) will each only receive 10 Gbps / 80 = 125 Mbps

b) In Topology of Figure 5.31, there are four distinct paths between the first and third tier-2 switches, together providing 40 Gbps for the traffic from racks 1-4 to racks 9-12. Similarly, there are four links between second and fourth tier-2 switches, together providing 40 Gbps for the traffic from racks 5-8 to 13-16. Thus the total aggregate bandwidth is 80 Gbps, and the value per flow rate is 1 Gbps.

c) Now 20 flows will need to share each 1 Gbps bandwidth between pairs of TOR switches. So the host-to-host bit rate will be 0.5 Gbps.

Problem 33

a) Both email and video application uses the fourth rack for 0.1 percent of the time.

b) Probability that both applications need fourth rack is 0.001*0.001 = 10^{-6}.

c) Suppose the first three racks are for video, the next rack is a shared rack for both video and email, and the next three racks are for email. Let's assume that the fourth rack has all the data and software needed for both the email and video applications. With the topology of Figure 5.31, both applications will have enough intra-bandwidth as long as both are not simultaneously using the fourth rack. From part b, both are using the fourth rack for no more than .00001 % of time, which is within the .0001% requirement.