The Link Layer and LANs

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1 Suppose the information content of a packet is the bit pattern 1110 0110 1001 1101 and an even parity scheme is being used. What would the value of the field containing the parity bits be for the case of a two-dimensional parity scheme? Your answer should be such that a minimum-length checksum field is used.

The i+j+1 = 9 parity bits will be composed of the row parity bits 1001, the column parity bits 1100, and the final bit 0, which equals the parity of the row parity bits and the column parity bits.

$$\begin{array}{cccccc} 1 & 1 & 1 & 0 & & 1 \\ 0 & 1 & 1 & 0 & & 0 \\ 1 & 0 & 0 & 1 & & 0 \\ 1 & 1 & 0 & 1 & & 1 \\ & & & & & \\ 1 & 1 & 0 & 0 & & 0 \end{array}$$

2 Show that two-dimensional parity checks can correct and detect a single bit error. Show a double-bit error that can be detected but not corrected.

Two parity bits in this example appear to be wrong: the parity bit for the third row and the parity bit for the first column. This shows that the bit that is in both the third row and the first column at has been corrupted, and should be switched back from a 0 to a 1.

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

In this example, which is similar to the previous one, four parity bits appear to be wrong. Now, in addition to the two that were wrong before, the parity bits for the first row and the fourth column are wrong as well. There are now four suspicious bits: (1, 1) (1, 3) (3, 1) (3, 3). Either (1, 1) and (3, 3) were corrupted or (1, 3) and (3, 1) were corrupted. There is no way to tell.

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

3 Suppose the information portion of a packet contains 10 bytes consisting of the 8-bit unsigned binary ASCII representation of the string "Networking." Compute the Internet checksum for this data.

0100 1110 0110 0101	1100 0010 1101 1100
0111 0100 0111 0111	0110 1111 0111 0010
= 1100 0010 1101 1100	= 0011 0010 0100 1111
0011 0010 0100 1111	1001 1101 1011 1000
0110 1011 0110 1001	0110 1110 0110 0111
= 1001 1101 1011 1000	= 0000 1100 0010 0000

One's complement (0000 1100 0010 0000) = 1111 0011 1101 1111

4 Repeat the previous problem, but instead suppose those 10 bytes contain:

4.1 The binary representation of the numbers 1 through 10.

0000 0001 0000 0010
0000 0011 0000 0100
= 0000 0100 0000 0110

0000 0100 0000 0110
0000 0101 0000 0110
= 0000 1001 0000 1100

0000 1001 0000 1100
0000 0111 0000 1000
= 0001 0000 0001 0100

0001 0000 0001 0100
0000 1001 0000 1010
= 0001 1001 0001 1110

One's complement (0001 1001 0001 1110) = 1110 0110 1110 0001

4.2 The ASCII representation of the letters B through K (uppercase).

0100 0010 0100 0011
0100 0100 0100 0101
= 1000 0110 1000 1000

1000 0110 1000 1000
0100 0110 0100 0111
= 1100 1100 1100 1111

1100 1100 1100 1111
0100 1000 0100 1001
= 0001 0101 0001 1001

0001 0101 0001 1001
0100 1010 0100 1011
= 0101 1111 0110 0100

One's complement(0101 1111 0110 0100) = 1010 0000 1001 1011

4.3 The ASCII representation of the letters b through k (lowercase).

0110 0010 0110 0011
0110 0100 0110 0101
= 1100 0110 1100 1000

1100 0110 1100 1000
0110 0110 0110 0111
= 0010 1101 0011 0000

0010 1101 0011 0000
0110 1000 0110 1001
= 1001 0101 1001 1001

1001 0101 1001 1001
0110 1010 0110 1011
= 0000 0000 0000 0101

One's complement(0000 0000 0000 0101) = 1111 1111 1111 1010

5 Consider the 5-bit generator G=10011, and suppose that D has the value 1010101010. What is the value of R?

$R = remainder(\frac{D*2^r}{G}) = remainder(\frac{10101010100000}{10011}) = 00110$

6 Repeat the previous problem, but suppose that D has the value:

6.1 1001010101

$R = remainder(\frac{D*2^r}{G}) = remainder(\frac{10010101010000}{10011}) = 01110$

6.2 0101101010

$R = remainder(\frac{D*2^r}{G}) = remainder(\frac{01011010100000}{10011}) = 10000$

6.3 1010100000

$R = remainder(\frac{D*2^r}{G}) = remainder(\frac{10101000000000}{10011}) = 10001$

7 In this problem, we explore some of the properties of the CRC. For the generator G=1001, answer the following questions:

7.1 Why can it detect any single bit error in data D?

Any single bit error would either add or subtract a power of two to the integer value of the data. To go undetected, the difference between the original number and the corrupted number would have to be divisible by $G = (1001)_b = 9$, which is impossible for any power of two.

7.2 Can the above G detect any odd number of bit errors? Why?

A trick of binary division is that a number with an odd number of ones cannot be divided by a number with an even number of ones. (The reverse is not true.) Since G has an even number of ones, an odd number of changes will result in a number than G cannot divide evenly, and the error will be detected.

8 In section 6.3, we provided an outline of the derivation of the efficiency of slotted ALOHA. In this problem we'll complete the derivation.

8.1 Recall that when there are N active nodes, the efficiency of slotted ALOHA is $Np(1-p)^{N-1}$. Find the value of p that maximizes this expression.

Take derivative of efficiency:
$E(p) = Np(1-p)^{N-1}$
$E'(p) = N(1-p)^{N-1} + (Np)(N-1)(1-p)^{N-2}(-1)$
$E'(p) = N(1-p)^{N-1} - (N^2p - Np)(1-p)^{N-2}$
$E'(p) = (1-p)^{N-2} * [(N - Np) - (N^2p - Np)]$
$E'(p) = (1-p)^{N-2} * (N - N^2p)$

Set derivative equal to zero:
$E'(p) = 0 = (1-p)^{N-2} * (N - N^2p)$
$(1-p)^{N-2} = 0$ OR $N - N^2p = 0$
$p = 1$ OR $1 - Np = 0 \rightarrow p = 1/N$
$E(1) = 0$
$E(1/N) = N(1/N)(1-1/N)^{N-1}$
$E(1/N) = (1-1/N)^{N-1} > 0$

Therefore, the efficiency of the slotted ALOHA protocol is maximized when $p = 1/N$.

8.2 Using the value of p found in the previous section, find the efficiency of slotted ALOHA by letting N approach infinity.

$\lim_{N\to\infty} N(1/N)(1-1/N)^{N-1}$
$\lim_{N\to\infty} (1-1/N)^{N-1}$
$\lim_{N\to\infty} \frac{(1-1/N)^N}{(1-1/N)}$
$\lim_{N\to\infty} (1-1/N)^N / \lim_{N\to\infty} (1-1/N)$
$(\lim_{N\to\infty} 1 - 1/N = 1)$
$\lim_{N\to\infty} (1-1/N)^N = 1/e$
Therefore, the limit of the efficiency of slotted ALOHA is $1/e$.

9 Show that the maximum efficiency of pure ALOHA is $1/2e$.

Probability of successful transmission: $p(1-p)^{2(N-1)}$
Efficiency:
$E(p) = Np(1-p)^{2(N-1)}$
$E'(p) = Np(1-p)^{2N-2-1}(2N-2)(-1) + N(1-p)^{2(N-1)}$
$E'(p) = (2-2N)(Np)(1-p)^{2N-3} + N(1-p)^{2N-2}$
$E'(p) = (1-p)^{2N-3} * [(2-2N)(Np) + N(1-p)]$
$E'(p) = 0 = (1-p)^{2N-3}$ OR $0 = (2-2N)(Np) + N(1-p)$
$p = 1$ OR $p = 1/(2N-1)$
$E(1) = 0$
$E(1/(2N-1)) > 0$, so the efficiency is maximized when $p = \frac{1}{2N-1}$.

$\lim\limits_{N\to\infty} N\frac{1}{2N-1}(1-\frac{1}{2N-1})^{2(N-1)} = \frac{1}{2} * \frac{1}{e} = \frac{1}{2e}$

10 Consider two nodes, A and B, that use the slotted ALOHA protocol to contend for a channel. Suppose node A has more data to transmit than node B, and node A's retransmission probability p_A is greater than node B's retransmission probability p_B.

10.1 Provide a formula for node A's average throughput. What is the total efficiency of the protocol with these two nodes?

The probability that A transmits successfully during a slot equals $p_A - p_A p_B$, so it takes $1/(p_A - p_A p_B)$ slots to transmit successfully. This means its average throughput is one packet per $1/(p_A - p_A p_B)$ slots, or $p_A - p_A p_B$ packets per slot.

The total efficiency corresponds to the percentage of the slots where a packet is transmitted successfully, that is, the probability A transmits successfully plus the probability that B transmits successfully: $p_A - p_A p_B + p_B - p_A p_B = p_A + p_B - 2p_A p_B$.

10.2 If $p_A = 2p_B$, is node A's average throughput twice as large as that of node B? Why or why not? If not, how can you choose p_A and p_B to make that happen?

No. If $p_A = 2p_B$, node A's average throughput is $2p_B - 2(p_B)^2$ and node B's is $p_B - 2(p_B)^2$, not $p_B - (p_B)^2$. To realize that ratio, $p_A = \frac{2p_B}{1+p_B}$ and $p_B = \frac{p_A}{2-p_A}$.

10.3 In general, suppose there are N nodes, among which node A has retransmission probability $2p$ and all other nodes have retransmission probability p. Provide expressions to compute the average throughputs of node A and of any other node.

A's average throughput: $2p(1-p)^{N-1}$
Others' average throughput: $p(1-2p)(1-p)^{N-2}$

11 Suppose four active nodes - nodes A, B, C, and D - are competing for access to a channel using slotted ALOHA. Assume each node has an infinite number of packets to send. Each node attempts to transmit in each slot with probability p. The first slot is numbered slot 1, the second slot is numbered slot 2, and so on.

11.1 What is the probability that node A succeeds for the first time in slot 5?

The probability that A succeds on a single slot, $p(success)$ is the probability that it attempts to transmit: p, times the probability that the other three nodes do not: $(1-p)^3$. The probability that A does not succeed, $p(\neg success)$ is $1-p(1-p)^3$. The probability that A fails four times and the succeeds is $p(\neg success)^4 p(success) = p(1-p)^3[1-p(1-p)^3]^4$.

11.2 What is the probability that some node (either A, B, C, or D) succeeds in slot 4?

The possibility of exactly one node transmitting successfully is $p(1-p)^3$, and the probability of any of the four nodes transmitting successfully is four times that probability, $4p(1-p)^3$.

11.3 What is the probability that the first success occurs in slot 3?

This equals the probabilty that each of the first two slots fail times the probability that one node is successful in slot 3: $(1-4p(1-p)^3)^2 * 4p(1-p)^3 = 4p(1-p)^3(1-4p(1-p)^3)^2$.

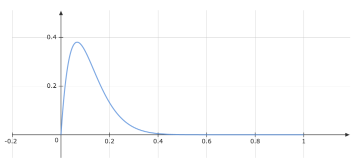
11.4 What is the efficiency of this four-node system?

The efficiency equals the probability that any of the four nodes is successful in a given slot: $4p(1-p)^3$.

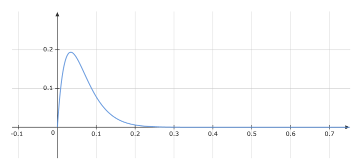
12 Graph the efficiency of slotted ALOHA and pure ALOHA as a function of p for the following values of N:

The probability that any node succeeds in slotted ALOHA is $Np(1-p)^{N-1}$ and the probability in pure ALOHA is $Np(1-p)^{2N-2}$.

12.1 N=15

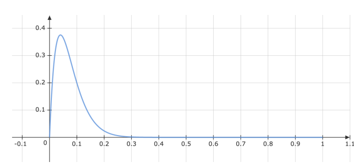


Slotted ALOHA: $f(p) = 15p(1-p)^{14}$

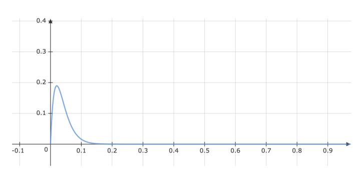


Pure ALOHA: $f(p) = 15p(1-p)^{28}$

12.2 N=25

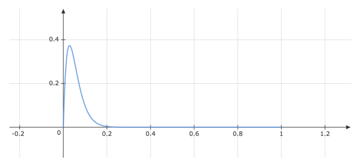


Slotted ALOHA: $f(p) = 25p(1-p)^{24}$

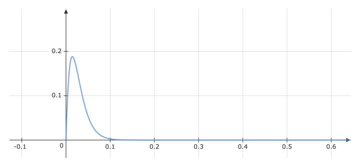


Pure ALOHA: $f(p) = 25p(1-p)^{48}$

12.3 N=35



Slotted ALOHA : $f(p) = 35p(1-p)^{34}$



Pure ALOHA : $f(p) = 35p(1-p)^{68}$

13 Consider a broadcast channel with N nodes and a transmission rate of R bps. Suppose the broadcast channel uses polling (with an additional polling node) for multiple access. Suppose the amount of time from when a node completes transmission until the subsequent node is permitted to transmit (that is, the polling delay) is d_{poll}. Suppose that within a polling round, a given node is allowed to transmit at most Q bits. What is the maximum throughput of the broadcast channel?

Maximum throughput occurs during a polling round when every node transmits the full Q bits on its turn. During such a polling round, NQ bits would be transmitted, and it would take $N(Q/R + d_{poll})$ seconds to complete. Therefore, the maximum throughput is $\frac{NQ}{N(Q/R+d_{poll})} = \frac{QR}{Q+Rd_{poll}}$ bits per second.

14 Consider three LANs interconnected by two routers, as shown in figure 6.33.

14.1 Assign IP addresses to all of the interfaces. For Subnet 1 use addresses of the form 192.168.1.xxx; for Subnet 2 use addresses of the form 192.168.2.xxx, and for Subnet 3 use addresses of the form 192.168.3.xxx.

A - 192.168.1.1
B - 192.168.1.2
Router 1 - 192.168.1.3
C - 192.168.2.1
D - 192.168.2.2
Router 1 - 192.168.2.3
Router 2 - 192.168.2.4
E - 192.168.3.1
F - 192.168.3.2
Router 2 - 192.168.3.3

14.2 Assign MAC addresses to all of the adapters.

A - ac:de:48:00:13:22
B - ac:de:48:00:14:23
Router 1 - ac:de:15:00:11:24
Router 1 - ac:de:15:00:11:25
C - ac:de:48:00:16:25
D - ac:de:48:00:17:26
Router 2 - ac:de:15:00:12:24
Router 2 - ac:de:15:00:12:25
E - ac:de:45:00:12:28
F - ac:de:48:00:11:29

14.3 Consider sending an IP datagram from Host E to Host B. Suppose all of the ARP tables are up to date. Enumerate all the steps, as done for the single-router example in section 6.4.1.

1. Host E uses its forwarding table to determine that the datagram needs to be forwarded to router 2's subnet 3 interface with MAC address ac:de:15:00:12:25.
2. Host E encapsulates the IP datagram with Host B's IP address in a frame with router 2's MAC address and sends it into subnet 3.
3. Router 2 receives the frame, examines the IP address, and determines that it needs to be forwarded to router 1's subnet 2 interface. It uses ARP to find the MAC address.
4. Router 2 encapsulates the IP datagram in a frame with router 1's subnet 2

MAC address and sends it into subnet 2.
5. Router 1 receives the frame, examines the IP address, and determines that it needs to be forwarded to Host B, whose MAC address it knows.
6. Router 1 encapsulates the datagram in a new frame with Host B's MAC address and sends it into subnet 1.

14.4 Repeat the previous problem, assuming that the ARP table in the sending host is empty and the other tables are up to date.

The only difference here is that Host E first sends out an ARP packet with its own IP and MAC addresses as well as router 2's IP address. (Host E can tell that Host B is on a different subnet because it can compare Host B's IP address against its own subnet mask.) This query packet is sent to the MAC broadcast address and received by every adapter on the subnet. The one whose IP address matches the one in the packet (router 2), sends back an ARP response packet with its own MAC address. Host E saves the information in its ARP table and proceeds as before.

15 Consider figure 6.33. Now replace the router between subnets 1 and 2 with a switch S1 and label the router between subnets 2 and 3 as R1.

15.1 Consider sending an IP datagram from Host E to Host F. Will Host E ask router R1 to help forward the datagram? Why? In the Ethernet frame containing the IP datagram, what are the source and destination IP and MAC addresses?

The only reason Host E would ask for help is if it didn't have Host F's MAC address in its ARP table, since hosts E and F are in the same subnet. Then, it would send an ARP request packet out into the subnet with Host F's IP address. Only Host F would respond.
Source IP: Host E's IP
Source MAC: Host E's MAC
Destination IP: Host F's IP
Source MAC: Host F's MAC

15.2 Suppose E would like to send an IP datagram to B, and assume that E's ARP cache does not contain B's MAC address. Will E perform an ARP query to find B's MAC address? Why? In the Ethernet frame (containing the IP datagram destined to B) that is delivered to router R1, what are the source and destination IP and MAC addresses?

No, Host E will not perform an ARP query for Host B's MAC address, since they are part of different subnets.
Source IP: Host E's IP
Source MAC: Host E's MAC
Destination IP: Host B's IP
Destination MAC: R1's subnet 3 MAC

15.3 Suppose Host A would like to send an IP datagram to Host B, Host A's ARP cache doesn't contain B's MAC address, and B's ARP cache doesn't contain A's MAC address. Further suppose that the switch S1's forwarding table contains entries for Host B and router R1 only. Thus, A will broadcast an ARP request message. What actions will switch S1 perform once it receives the ARP request message? Will router R1 also receive this ARP request message? If so, will R1 forward the message to Subnet 3? Once Host B receives this ARP request message, it will send back to Host A an ARP response message. But will it send an ARP query message to ask for A's MAC address? Why? What will switch S1 do once it receives an ARP response message from Host B?

When S1 receives A's ARP request message, it will immediately add A's MAC address to its forwarding table. Since the destination address is the broadcast address, it will forward it on all of its interfaces. R1 will receive it but won't forward it. When Host B receives the request, it will add A's MAC address, given in the request packet, to its ARP cache and use it in its response. When S1 receives Host B's response, it will discard it, since it already has Host B in its forwarding table and the packet is addressed to a host connected to the switch by the same interface it arrived from.

16 Repeat the previous problem, but suppose now that the router between subnets 2 and 3 is replaced by a switch.

16.1 See 15.1

No, it will not. If Host E doesn't have Host F's MAC address, it will send out an ARP request packet, which Host F will respond to.
Source IP: Host E's IP
Source MAC: Host E's MAC
Destination IP: Host F's IP
Destination MAC: Host F's MAC

16.2 See 15.2

No, E will not perform an ARP query, since it can tell from its subnet mask that B is not in the same subnet.
Source IP: Host E's IP
Source MAC: Host E's MAC
Destination IP: Host B's IP
Destination MAC: S2's MAC

16.3 See 15.3

The only thing that changes is that instead of R1 receiving and ignoring the ARP request message, it receives it and forwards it into Subnet 2.

17 Recall that with the CSMA/CD protocol, the adapter waits $K * 512$ bit times after a collision, where K is drawn randomly. For $K = 100$, how long does the adapter wait until returning to Step 2 for a 10 Mbps broadcast channel? For a 100 Mbps broadcast channel?

$\frac{10Mb}{sec} * \frac{10^6\ bits}{Mb} = \frac{10^7\ bits}{sec}$
$100 * 512\ bits / \frac{10^7\ bits}{sec} = 0.00512\ seconds = 5.12\ milliseconds$

$\frac{100Mb}{sec} * \frac{10^6\ bits}{Mb} = \frac{10^8\ bits}{sec}$
$100 * 512\ bits / \frac{10^8\ bits}{sec} = 0.000512\ seconds = 0.512\ milliseconds$

18 Suppose nodes A and B are on the same 10 Mbps broadcast channel, and the propagation delay between the two nodes is 325 bit times. Suppose CSMA/CD and Ethernet packets are used for this broadcast channel. Suppose node A begins transmitting a frame and, before it finishes, node B begins transmitting a frame. Can A finish transmitting before it detects that B has transmitted? Why or why not? If the answer is yes, then A incorrectly believes that its frame was successfully transmitted without a collision.

The worst case scenario is A sending the smallest possible frame, which is 512+64 bits and transmits in 512+64 bit times. Since the propagation delay between the two nodes is 325 bit times, if B started transmitting at any time after 512+64-325=251 bit times after A started, A would finish transmitting before it detects B's transmission.

19 Suppose nodes A and B are on the same 10 Mbps broadcast channel, and the propagation delay between the two nodes is 245 bit times. Suppose A and B send Ethernet frames at the same time, the frames collide, and then A and B choose different values of K in the CSMA/CD algorithm. Assuming no other nodes are active, can the retransmissions from A and B collide? Suppose A and B begin transmission at t=0 bit times. They both detect collisions at t=245 bit times. Suppose KA=0 and KB=1. At what time does B schedule its retransmission? At what time does A begin transmission? At what time does A's signal reach B? Does B refrain from transmitting at its scheduled time?

Note: The book does not provide all the information necessary to solve this problem. From the CSMA/CD wikipedia page, there are two important things to know. First, after a node detects a collision, it continues transmitting a jam signal until all receivers detect the collision. Based on the maximum allowed diameter of an Ethernet installation (232 bit times) and the slot time of 512 bits, the maximum jam-time is 48 bit times. Second, nodes must wait an additional 96 bit times after the channel quiets before beginning transmission.

t=0	A and B begin transmitting
t=245	A and B detect collision and start sending jam signal
t=293	A and B stop sending jam signal
t=538	A senses a quiet channel
t=634	A begins transmitting
t=879	B detects A's transmission, so it cancels its own retransmission
t=901	B is scheduled to start, but it detects A's transmission, so it refrains (293+512*1+96 = 901)

20 In this problem, you will derive the efficiency of a CSMA/CD-like multiple access protocol. For the given protocol, answer the following questions.

20.1 For fixed N and p, determine the efficiency of the protocol.

The probability of a specific slot successfully taking possession of the channel is $p(1-p)^{N-1}$, and the probability of any slot taking it is $Np(1-p)^{N-1}$. Let $q = Np(1-p)^{N-1}$. Since this is a geometric distribution, the expected number of failures before the success will be $\frac{1-q}{q}$. Since the channel efficiency is $\frac{k}{k+x}$ where x is the expected number of failures, the channel efficiency is $\frac{k}{k+x} = \frac{k}{k+\frac{1-q}{q}} = \frac{k}{k+\frac{1-Np(1-p)^{N-1}}{Np(1-p)^{N-1}}}$

20.2 For fixed N, determine the p that maximizes efficiency.

Maximizing efficiency is equivalent to maximizing the probability that exactly one slot claims the channel, $Np(1-p)^{N-1}$.
$d/dp\ Np(1-p)^{N-1}$
$N(1-p)^{N-1} + Np(N-1)(-1)(1-p)^{N-2}$
$N(1-p)^{N-1} + Np(N-1)(-1)(1-p)^{N-2} = 0$
$N(1-p)^{N-1} = Np(N-1)(1-p)^{N-2}$
$1-p = Np-p$
$p = 1/N$

20.3 For the calculated p, determine the efficiency as N approaches infinity.

When $p = 1/N$, the efficiency is $\frac{k}{k+\frac{1-(1-1/N)^{N-1}}{(1-1/N)^{N-1}}}$
Since $\lim_{N\to\infty}(1-1/N)^{N-1} = 1/e$,
$\lim_{N\to\infty} \frac{k}{k+\frac{1-(1-1/N)^{N-1}}{(1-1/N)^{N-1}}} = \frac{k}{k+\frac{1-1/e}{1/e}} = \frac{k}{k+e-1}$

20.4 Show that this efficiency approaches 1 as the frame length becomes large.

$\lim_{k\to\infty} \frac{k}{k+e-1} = 1$ because e and 1 are fixed.

21 Consider figure 6.33. Provide MAC addresses and IP addresses for the interfaces at Host A, both routers, and Host F. Suppose Host A sends a datagram to Host F. Give the source and destination MAC addresses in the frame encapsulating this IP datagram as the frame is transmitted at each of the following points in time. Also give the source and destination IP addresses in the IP datagram encapsulated within the frame.

21.1 From A to the left router

Source MAC: Host A's
Source IP: Host A's
Destination MAC: Left router's subnet 1 MAC address
Destination IP: Host F's

21.2 From the left router to the right router

Source MAC: Left router's subnet 2 MAC address
Source IP: Host A's
Destination MAC: Right router's subnet 2 MAC address
Destination IP: Host F's

21.3 From the right router to F

Source MAC: Right router's subnet 3 MAC address
Source IP: Host A's
Destination MAC: Host F's
Destination IP: Host F's

22 Suppose now that the leftmost router in figure 6.33 is replaced by a switch. Hosts A, B, C, and D and the right router are all star-connected into this switch. Give the source and destination MAC addresses in the frame encapsulating this IP datagram at each of the following points in time. Also give the source and destination IP addresses encapsulated within the frame.

22.1 From A to the switch

Source MAC: Host A's
Source IP: Host A's
Destination MAC: Right router's subnet 1/2 MAC address
Destination IP: Host F's

22.2 From the switch to the right router

Source MAC: Host A's
Source IP: Host A's
Destination MAC: Right router's subnet 1/2 MAC address
Destination IP: Host F's

22.3 From the right router to F

Source MAC: Right router's subnet 3 MAC address
Source IP: Host A's
Destination MAC: Host F's
Destination IP: Host F's

23 Consider figure 6.15. Suppose all links are 100 Mbps. What is the maximum aggregate throughput that can be achieved among the 9 hosts and 2 servers in this network? Why?

1100 Mbps. Each of the 11 hosts and servers can send out 100 Mbps.

24 Repeat the previous problem, supposing the three departmental switches in figure 6.15 are replaced by hubs. All links are 100 Mbps.

Now, each hub can only send out data at a rate of 100 Mbps, so the total is 500 Mbps.

25 Now suppose all of the switches have been replaced by hubs. What is the maximum aggregate throughput?

100 Mbps, since the hubs all must share the same domain.

26 Let's consider the operation of a learning switch in the context of a network in which 6 nodes labeled A through F are star connected into an Ethernet switch. Assuming the switch table is initially empty, show the state of the switch table before and after each of the following events. Also identify the link(s) on which the transmitted frame will be forwarded.

26.1 B sends a frame to E

Before: -
After: B
The switch sends the frame out on all links except B's

26.2 E replies with a frame to B

Before: B
After: B, E
The switch sends the frame only to B

26.3 A sends a frame to B

Before: B, E
After: A, B, E
The switch sends the frame only to B

26.4 B replies with a frame to A

Before: A, B, E
After: A, B, E
The switch sends the frame only to A

27 In this problem, we explore the use of small packets for VOIP applications. One of the drawbacks of a small packet size is that a large fraction of link bandwidth is consumed by overhead bytes. To this end, suppose that the packet consists of L bytes and 5 bytes of header.

27.1 Consider sending a digitally encoded voice source directly. Suppose the source is encoded at a constant rate of 128 kbps. Assume each packet is entirely filled before the source sends the packet into the network. The time required to fill a packet is the packetization delay. In terms of L, determine the packetization delay in milliseconds.

$\frac{L*8}{128\ kbps} * \frac{10^3\ msec}{sec} * \frac{bit}{10^3\ kb} = \frac{L*8}{128} = \frac{L}{16}$ milliseconds

27.2 Packetization delays greater than 20 msec can cause a noticable echo. Determine the packetization delay for L=1,500 bytes and L=50 bytes.

$\frac{1500}{16} = 93.75$ msec
$\frac{50}{16} = 3.125$ msec

27.3 Calculate the store-and-forward delay at a single switch for a link rate of R=622 Mbps for L=1,500 bytes and L=50 bytes.

$d_{s\&f} = \frac{(1500+5)*8}{622*10^6} = 19.36$ microseconds
$d_{s\&f} = \frac{(50+5)*8}{622*10^6} = 0.71$ microseconds

27.4 Comment on the advantages of using a small packet size.

The extra header bytes on smaller packets causes a slightly higher total store-and-forward delay, but this additional cost is dwarfed by the packetization delay. The rapid packetization of small packets increases the perceived quality of the connection and is clearly worth the additional overhead.

28 Consider the single switch VLAN in figure 6.25, and assume an external router is connected to switch port 1. Assign IP addresses to the EE and CS hosts and router interface. Trace the steps taken at both the network layer and the link layer to transfer an IP datagram from an EE host to a CS host.

Electrical Engineering Subnet: 111.111.111.0/24
Computer Science Subnet: 111.111.222.0/24
EE Hosts: 111.111.111.1, 111.111.111.2, 111.111.111.3
CS Hosts: 111.111.222.1, 111.111.222.2, 111.111.222.3
Router Interfaces: 111.111.111.0, 111.111.222.0

1. An IP datagram from one of the EE hosts is sent to router interface 111.111.222.0 in a frame with the destination MAC address corresponding to the electrical engineering subnet interface of the external router.
2. The router examines the destination IP address at the network layer and sends it back to port 1 on interface 111.111.111.0 with source MAC address corresponding to its computer science subnet interface.
3. The switch receives the frame at port 1 on interface 111.111.111.0 and sends it into the computer science subnet. 4. The frame arrives at the CS host.
Note: I don't see that this scenario uses trunking. The answer suggests that it does, adding 802.1q tags with the VLAN ID numbers to each frame. It seems redundant to use trunking as well as the external router interfaces since there is just one VLAN on each interface.

29 **Consider the MPLS network shown in figure 6.29 and suppose that routers R5 and R6 are now MPLS enabled. Suppose that we want to perform traffic engineering so that packets from R6 destined for A are switched to A via R6-R4-R3-R1 and packets from R5 destined for A are switched via R5-R4-R2-R1. Show the MPLS tables in R5 and R6, as well as the modified table in R4 that would make this possible.**

	In label	Out label	Destination	Out Interface
R4	5	8	A	1
R4	7	10	A	0
R5:	-	5	A	-
R6:	-	7	A	-

30 **Consider again the same scenario as in the previous problem, but suppose that packets from R6 destined for D are switched via R6-R4-R3, while packets from R5 destined to D are switched via R4-R2-R1-R3. Show the MPLS tables in all routers that would make this possible.**

	In label	Out label	Destination	Out Interface
R1	1	2	D	1
R2	3	1	D	0
R3	2	-	D	0
R4	5	3	D	1
R4	6	2	D	0
R5	-	5	D	-
R6	-	6	D	-

31 Suppose you walk into a room, connect to Ethernet, and want to download a Web page. What are all the protocol steps that take place, starting from powering on your PC to getting the Web page? Assume there is nothing in our DNS or browser caches when you start.

First, the computer needs an IP address. It uses DHCP, creating and broadcasting a request message. This message is encapsulated within a UDP segment which is encapsulated in an IP datagram which is encapsulated within an Ethernet frame. Once the frame is received and processed by the router, the router assigns the computer an IP address within its CIDR block. It then creates a DHCP ACK message with the new address, the network mask, and the addresses of the DNS server and the default gateway router. After the computer receives the message, it creates and broadcasts an ARP query with the IP address of the gateway router. The gateway router will receive the query and reply with its MAC address. Once the computer knows the MAC address of the gateway router, it has all of the information it needs to get started.
When the user types in the name of the Web page, the operating system creates a DNS query message in order to obtain the IP address of the page's server. The IP datagram lists the destination IP address of the DNS server and the frame lists the MAC address of the gateway router. The router receives the message and forwards it out into the network, where the ISP takes over. The ISP's intra-domain protocol might be RIP, OSPF, or IS-IS, but the inter-domain protocol will be BGP. If the page requested is a common one, its IP address will likely be cached, but if not the request will be forwarded to other DNS servers until either another one has it cached or until it is sent to the authoritative DNS server for that Web page. When the DNS resource record is found, a DNS reply message will be encapsulated within a UDP segment and returned through the network to the computer.
The computer will use TCP and HTTP to load the Web page. First, the computer performs a three-way handshake with the server to create a TCP socket. The computer sends a SYN message, the server sends a SYNACK message, and then the browser creates the HTTP GET message containing the URL. The server will respond with an HTTP response message with the Web page content in the body. Finally, the computer's browser extracts the Web page from the message and displays it.

32 Consider the data center network with hierarchical topology in figure 6.30. Suppose now that there are 80 pairs of flows, with 10 flows between the first and ninth rack, ten flows between the second and tenth rack, and so on. Further suppose that all links in the network are 10 Gbps, except for the links between hosts and TOR switches, which are 1 Gbps.

32.1 Each flow has the same data rate; determine the maximum rate of a flow.

The bottleneck is at the links connected to the border router, through which all traffic between the first eight and second eight routers must flow. For 80 flows to share a 10 Gbps link, each flow's maximum rate is 125 Mbps.

32.2 For the same traffic pattern, determine the maximum rate of a flow for the highly interconnected topology in figure 6.31.

In this topology, there are eight links between the first eight and second eight, so each flow gets 1 Gbps.

32.3 Now suppose there is a similar traffic pattern, but involving 20 hosts on each rack and 160 pairs of flows. Determine the maximum flow rates for the two topologies.

In the first topology, all 160 pairs of flows need to flow through the same 10 Gbps links, giving each one only 62.5 Mbps. In the second, each gets 500 Mbps.

33 Consider the hierarchical network in figure 6.30 and suppose that the data center needs to support e-mail and video distribution among other applications. Suppose four racks of servers are reserved for e-mail and four racks are reserved for video. For each of the applications, all four racks must lie below a single tier-2 switch since the tier-2 to tier-1 links do not have sufficient bandwidth to support the intra-application traffic. For the e-mail application, suppose that for 99.9% of the time only three racks are used, and that the video application has identical usage patterns.

33.1 For what fraction of time does the e-mail application need to use a fourth rack? How about for the video application?

Each uses their fourth rack 0.1% of the time.

33.2 Assuming e-mail usage and video usage are independent, for what fraction of the time do both applications need their fourth rack?

0.0001% of the time

33.3 Suppose that it is acceptable for an application to have a shortage of servers for 0.001% of time or less. Discuss how the topology in figure 6.31 can be used so that only seven racks are collectively assigned to the two applications.

The second topology allows for the sharing of a rack between e-mail and video because even though the shared rack will necessarily be under a different tier-2 switch from some of the other racks running the same application, there is more bandwidth available between switches. The exception is when both applications are trying to use the shared rack, but that happens infrequently enough to be within parameters.