Network Layer

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Forwarding

Assuming that all routers and hosts are working properly and that all software in both is free of all errors, is there any chance, however small, that a packet will be delivered to the wrong destination?

- Yes. A large noise burst could garble a packet badly. With a *k*-bit checksum, there is a probability of 2^(-k) that the error is undetected.
- If the destination field or, equivalently, virtual-circuit number, is changed, the packet will be delivered to the wrong destination and accepted as genuine.

What Are The IP Addresses

The IP address has two functions: for host and network interface *identification*, as well as location *addressing*.

IPv4 addresses are represented in dot-decimal notation, which consists of four decimal numbers, each ranging from 0 to 255, separated by dots (eg. 172.16.254.1).

What Are The IP Addresses

IPv4 addresses can be divided into three categories named classes

Class	Leading bit(s)	Number of bits for network	Number of bits for host	First address	Last address
A	0	8	24	0.0.0.0	127.255.255.255
B	10	16	16	128.0.0.0	191.255.255.255
C	110	24	8	192.0.0.0	223.255.255.255

Other classes

Class	Leading bits	First address	Last address	Notes
D	1110	224.0.0.0	239.255.255.255	Used for multicast addressing
E	11110	240.0.0.0	255.255.255.255	Used in experimental ways

What Is The Subnet Mask?

A *Subnet mask* is a 32-bit number that masks an IP address, and divides the IP address into network address and host address.

Subnet Mask is made by setting network bits to all "1" and setting host bits to all "0".

The Subnet mask can be represented in two ways: one is the usual dot-decimal notation like an IP address, and the second using the *CIDR notation*.

IP Addressing

What is the default mask for class A,B and class C Networks?

Class A - 255.0.0.0
11111111.00000000.00000000.00000000
Class B - 255.255.0.0
11111111.11111111.00000000.00000000
Class C - 255.255.255.0
11111111.11111111.11111111.00000000

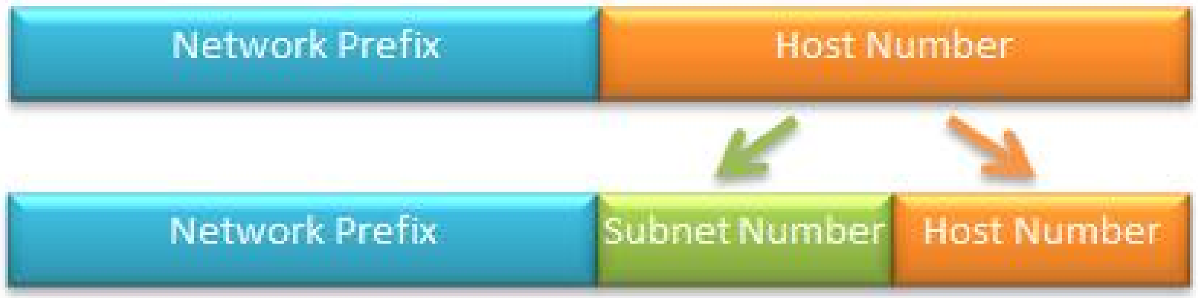
IP Addressing

Given the network address 133.22.0.0, find the class, the network id, and the range of the addresses

The 1^{st} byte is between 128 and 191.
Hence, Class B The block has a network id of 132.22.
The addresses range from 133.22.0.0 to 133.22.255.255.

Subnetting

- *Subnetting* involves dividing the network into smaller portions called subnets.
- An IP address is divided in two parts, one for network identification and one for host identification
- Using the subnet mask the main network is divided in one or more smaller networks.
- This is performed by a bitwise AND operation between the IP address and the (sub)network mask.
- In simple terms, this means that a part of the bits from the *host number* are used for the new (sub)network identification.



IP Addressing - Subnetting

What is the subnetwork address if the destination address is 200.45.34.56 and the subnet mask is 255.255.240.0?

Ans.

IP address 200.45.34.56

Subnet Mask 255.255.240.0

	11001000 00101101 00100010 00111000
AND	11111111 11111111 11110000 00000000
	11001000 00101101 00100000 00000000

The subnetwork address is 200.45.32.0

IP Addressing - Subnetting

A company is granted the site address 201.70.64.0 (class C). The company needs six subnets. Design the subnets. Find the number of addresses of each subnet.

Ans.

The number of 1s in the default mask is 24 (class C).

The company needs six subnets. This number 6 is not a power of 2. The next number that is a power of 2 is 8 (2^3). We need 3 more 1s in the subnet mask. The total number of 1s in the subnet mask is 27 (24 + 3). The total number of 0s is 5 (32 - 27). The mask is 11111111 11111111 11111111 11100000 or 255.255.255.224 The number of subnets is 8. The number of addresses in each subnet is 2^5 (5 is the number of 0s) or 32.

IP Addressing - Subnetting

You currently use the default mask for your IP network 192.168.1.0. You need to subnet your network so that you have 30 additional networks, and 4 hosts per network. Is this possible, and what subnet mask should you use?

Ans.
Yes it is possible.
The default subnet mask is 24. So 8 bits are remaining in host id
We need to 8 = bb (bits borrowed) + bl (bits left)
$4 \leq 2^{bl} - 2$ hence bl = 3
$30 \leq 2^{bb} - 2$ hence bb = 5
so the subnet mask is: 11111111.11111111.11111111.1111000
255.255.255.248.

IP Addressing - Subnetting

A small organization is given a block with the beginning address and the prefix length 205.16.37.24/29 (in slash notation). What is the range of the block?

Ans.

The beginning address is 205.16.37.24.

To find the last address we keep the first 29 bits and change the last 3 bits to 1s.

Beginning: 11001111 00010000 00100101 00011000

Ending : 11001111 00010000 00100101 00011111

There are only 8 addresses in this block. We can argue that the length of the suffix is 32 - 29 or 3. So there are $2^3 = 8$ addresses in this block. If the first address is 205.16.37.24, the last address is 205.16.37.31 (24 + 7 = 31).

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IP Addressing

In the TCP/IP model, which layer is responsible for logical addressing of host computers and routing messages? Say as much as you can about how the following sequences identify a particular network, host computer and application, assuming the classfull addressing system:

•129.8.45.13:25

•124.42.5.45:23

•220.3.6.23:80

Ans.

Logical addressing and routing: Internet or Network (not Network Access) layer.

129.8.45.13:25 First two octets (decimal 129.8) identify network as class B (in range 128.n.n.n - 191.n.n.n or binary version starts with 10); two octets before colon identify host machine; final number identifies port number of email application (SMTP)).

124.42.5.45:25 First octet (decimal 124) identifies network as class A (in range 1.n.n.n - 126.n.n.n or binary version starts with 0); three octets before colon identify host machine; final number identifies port number of Telnet.

220.3.6.23:80 First three octets (decimal 220.3.6) identify network as class C (in range 192.n.n.n - 223.n.n.n or binary version starts with 110); octet before colon identifies host machine; final number identifies port number of WWW application (HTTP)

IP Addressing - Supernetting

We need to make a supernetwork out of 16 class C blocks. What is the supernet mask?

Ans.
We need 16 blocks. For 16 blocks we need to change four 1s to 0s in the default mask. So the mask is
11111111 11111111 11110000 00000000

or 255.255.240.0

IP Addressing - Supernetting

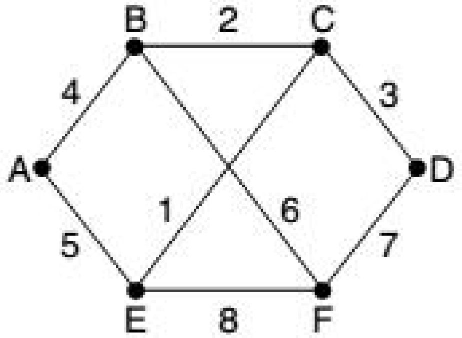
Given the following IP in CIDR format 192.167.12.0/23.Find the network, the host addresses, and the range of addresses.

Ans.
192.167.12.0/23.

IP 11000001 10100111 0000100 00000000
Mask 11111111 11111111 11111110 00000000
network address 193.167.12.0 host address 0.0[2] the range of host addresses is between 0.0.0.0 to 0.0.1.255

Routing

Distance vector routing is used, and the following vectors have just come in to router *C*: from *B*: (5, 0, 8, 12, 6, 2); from *D*: (16, 12, 6, 0, 9, 10); and from *E*: (7, 6, 3, 9, 0, 4). The cost of the links from *C* to *B*, *D*, and *E*, are 6, 3, and 5, respectively. What is *C*'s new routing table? Give both the outgoing line to use and the cost.



Ans.

C's new table (11,6,0,3,5,8)

Outgoing line (B, B, -, D, E, B)

Routing

If costs are recorded as 8-bit numbers in a 50-router network, and distance vectors are exchanged twice a second, how much bandwidth per (full-duplex) line is chewed up by the distributed routing algorithm? Assume that each router has three lines to other routers.

Ans. The routing table is 400 bits. Twice a second this table is written onto each line, so 800 bps are needed on each line in each direction.

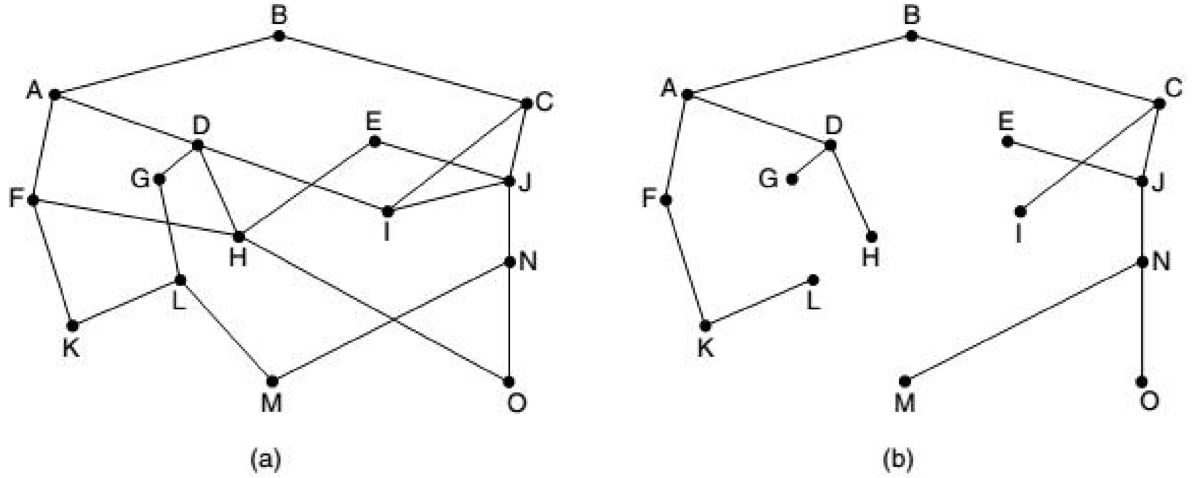
Routing

For hierarchical routing with 4800 routers, what region and cluster sizes should be chosen to minimize the size of the routing table for a three-layer hierarchy? A good starting place is the hypothesis that a solution with *k* clusters of *k* regions of *k* routers is close to optimal, which means that *k* is about the cube root of 4800 (around 16). Use trial and error to check out combinations where all three parameters are in the general vicinity of 16.

Ans. Use a convenient tool to search for three sizes with a product of at least 4800 (to be large enough to cover the entire network) and minimum sum (to have the smallest routing table). We found six solutions of clusters, regions and routers of sizes: (17, 17, 17), (16, 17, 18), (16, 16, 19), (15, 18, 18), (15, 17, 19), and (15, 16, 20). Of these (17, 17, 17) is the most straightforward choice. In all cases the table size is 51.

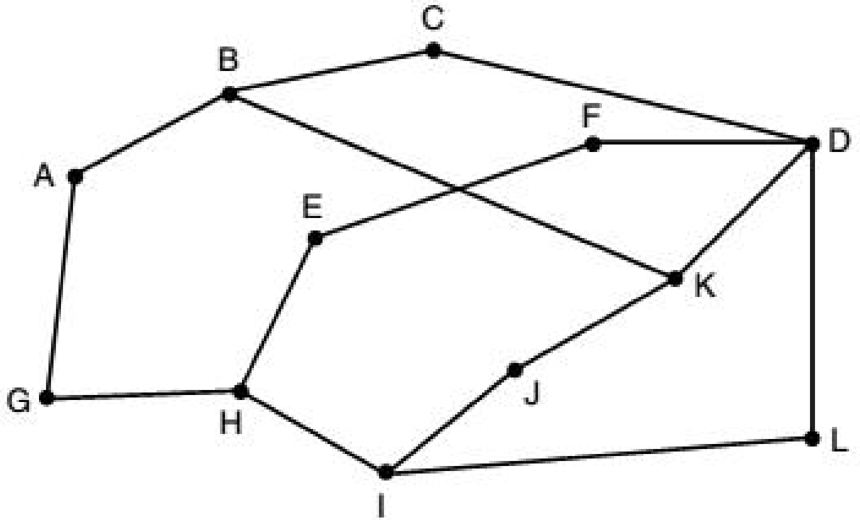
Routing

How many packets are generated by a broadcast from *B*, using
(a) reverse path forwarding?
(b) the sink tree?



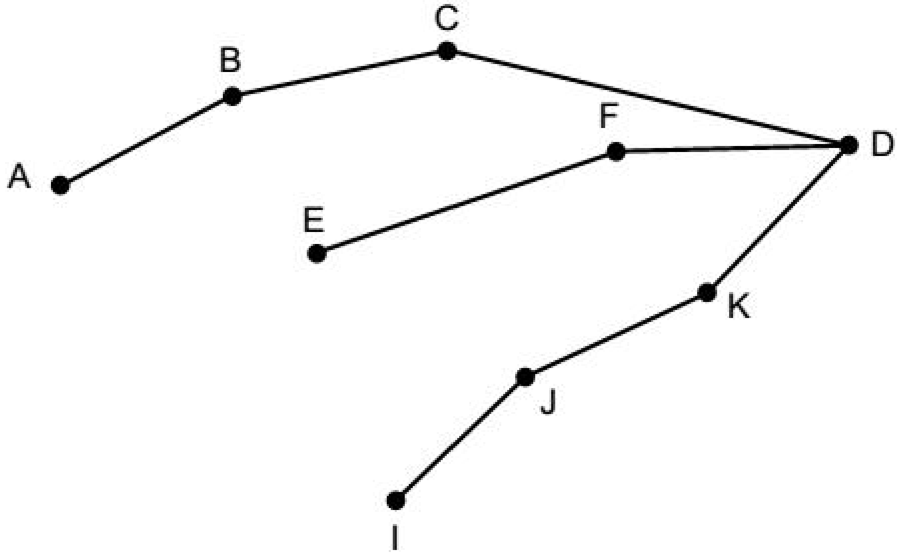
Ans. (a) The reverse path forwarding algorithm takes five rounds to finish. The packets sent on these rounds, where * denotes a recipient that received the broadcast along the sink tree and will broadcast in the next round, are:
Round 1: *B* sends to *A*C**
Round 2: *A* sends to *D*F**, and *C* sends to *I *J **
Round 3: *D* to *G*H *I*, *F* to *HK **, *I* to *DJ*, and *J* to *E*IN **.
Round 4: *G* to *L*, *H* to *EFO*, *K* to *L**, *E* to *H*, and *N* to *M *O**.
Round 5: *L* to *GM*, *M* to *L*, and *O* to *H*.
There is a total of 28 packets across the rounds.
(b) The sink tree is shown in the figure. It needs four rounds and 14 packets.

Routing



Compute a multicast spanning tree for router *C* for a group with members at routers *A*, *B*, *C*, *D*, *E*, *F*, *I*, *K*.

Ans. Multiple spanning trees are possible. One of them is:



Traffic Shaping

A token bucket scheme is used for traffic shaping. A new token is put into the bucket every 5 μsec. Each token is good for one short packet, which contains 48 bytes of data. What is the maximum sustainable data rate?

Ans. With a token every 5 μsec, 200,000 cells/sec can be sent. Each packet holds 48 data bytes or 384 bits. The net data rate is then 76.8 Mbps.

48*8/5*10^-6

Traffic Shaping

A computer on a 6-Mbps network is regulated by a token bucket. The token bucket is filled at a rate of 1 Mbps. It is initially filled to capacity with 8 megabits. How long can the computer transmit at the full 6 Mbps?

Ans. The naive answer says that at 6 Mbps it takes 4/3 sec to drain an 8 megabit bucket. However, this answer is wrong, because during that interval, more tokens arrive. The correct answer can be obtained by using the formula $S = B/(M - R)$. Substituting B = 8 Mbit, M = 6 Mbps and R = 1 Mbps, we get $S = 8/(6 - 1)$ or 1.6 seconds.

Traffic Shaping

Imagine a flow specification that has a maximum packet size of 1000 bytes, a token bucket rate of 10 million bytes/sec, a token bucket size of 1 million bytes, and a maximum transmission rate of 50 million bytes/sec. How long can a burst at maximum speed last?

Ans. Call the length of the maximum burst interval Δt. In the extreme case, the bucket is full at the start of the interval (1 Mbyte) and another $10\Delta t$ Mbytes come in during the interval. The output during the transmission burst contains $50\Delta t$ Mbytes. Equating these two quantities, we get $1 + 10\Delta t = 50\Delta t$.
Solving this equation, we get Δt is 25 msec.

Traffic Shaping

In a leaky bucket used to control liquid flow, how many gallons of liquid are left in the bucket if the output rate is 5 gal/min, there is an input burst of 100 gal/min for 12 s, and there is no input for 48 s?

Ans. Here we have to compute total input we have in one minute
So For 12 second input burst is 100 gallons and for 48 seconds no input.
Total Input = 100*12/60 + 0*48/60 = **20 gallons**.

The output rate is 5 Gallon per minute so in one minute, 20 – 5 = **15 gallons** are left.

IP Fragmentation

Suppose that host *A* is connected to a router *R* 1, *R* 1 is connected to another router, *R* 2, and *R* 2 is connected to host *B*. Suppose that a TCP message that contains 900 bytes of data and 20 bytes of TCP header is passed to the IP code at host *A* for delivery to *B*. Show the *Total length, Identification*, *DF*, *MF*, and *Fragment offset* fields of the IP header in each packet transmitted over the three links. Assume that link *A-R1* can support a maximum frame size of 1024 bytes including a 14-byte frame header, link *R1-R2* can support a maximum frame size of 512 bytes, including an 8-byte frame header, and link *R2-B* can support a maximum frame size of 512 bytes including a 12-byte frame header.

IP Fragmentation

Ans. We have an IP payload of 920 bytes to send. Assume a 20 byte IPv4 header. The first link can carry IP packets up to 1010 bytes, so there will be no fragmentation. The second link can carry IP packets up to 504 bytes, so there will be fragmentation. There may be up to 484 bytes of data, but fragments must carry a multiple of 8 bytes of data (except the last fragment). So the first fragment will carry 480 bytes of data, and the second fragment will carry 440 bytes. The third link can carry IP packets up to 500 bytes, so both fragments will fit and no other fragmentation will occur. The value of the fields is:

Link *A-R1*:

Length = 940; *ID* = x; *DF* = 0; *MF* = 0; *Offset* = 0

Link *R1-R2*:

(1) *Length* = 500; *ID* = x; *DF* = 0; *MF* = 1; *Offset* = 0

(2) *Length* = 460; *ID* = x; *DF* = 0; *MF* = 0; *Offset* = 60

Link *R2-B*:

(1) *Length* = 500; *ID* = x; *DF* = 0; *MF* = 1; *Offset* = 0

(2) *Length* = 460; *ID* = x; *DF* = 0; *MF* = 0; *Offset* = 60

IP Fragmentation

A 4480 octet datagram is to be transmitted and needs to be fragmented because it will pass through an Ethernet with a maximum payload of 1500 octets. Show the Total Length, More flag, Fragment Offset values in each of the resulting fragments.

Ans.

4480 octet datagram has 20 octets Header and 4460 octet Payload.

1500 octet Ethernet frame has 20 octets Header and 1480 octet Payload.

So, Total Number of Datagrams: 3*1480=4440 octets 4460-4440=20 octets

Last datagram that carries 20 data octets and 20 IP header.

So total Fragments=4

Header	Data	More Fragment	Fragment Offset
20	1480	1	0
20	1480	1	185
20	1480	1	370
20	20	0	555

IP

A router is blasting out IP packets whose total length (data plus header) is 1024 bytes. Assuming that packets live for 10 sec, what is the maximum line speed the router can operate at without danger of cycling through the IP datagram ID number space?

Ans

If the bit rate of the line is *b*, the number of packets/sec that the router can emit is *b*/8192, so the number of seconds it takes to emit a packet is 8192/*b*.

To put out 65,536 packets takes 229/*b* sec.

Equating this to the maximum packet lifetime, we get 229/*b* = 10. Then, *b* is about 54 Mbps.

IP

Suppose that instead of using 16 bits for the network part of a class B address originally, 20 bits had been used. How many class B networks would there have been?

Ans

With a 2-bit prefix, there would have been 18 bits left over for the network. Consequently, the number of networks would have been 2^{18} or 262,144. However, all 0s and all 1s are special, so only 262,142 are available.

IP

While IP addresses are tried to specific networks, Ethernet addresses are not. Can you think of a good reason why they are not?

Ans

Each Ethernet adapter sold in stores comes hardwired with an Ethernet (MAC) address in it. When burning the address into the card, the manufacturer has no idea where in the world the card will be used, making the address useless for routing. In contrast, IP addresses are either assigned either statically or dynamically by an ISP or company, which knows exactly how to get to the host getting the IP address.

IP

A large number of consecutive IP addresses are available starting at 198.16.0.0. Suppose that four organizations, *A*, *B*, *C*, and *D*, request 4000, 2000, 4000, and 8000 addresses, respectively, and in that order. For each of these, give the first IP address assigned, the last IP address assigned, and the mask in the *w.x.y.z/s* notation.

Ans

To start with, all the requests are rounded up to a power of two. The starting address, ending address, and mask are as follows:

A: 198.16.0.0 – 198.16.15.255 written as 198.16.0.0/20

B: 198.16.16.0 – 198.16.23.255 written as 198.16.16.0/21

C: 198.16.32.0 – 198.16.47.255 written as 198.16.32.0/20

D: 198.16.64.0 – 198.16.95.255 written as 198.16.64.0/19

IP

A router has just received the following new IP addresses: 57.6.96.0/21, 57.6.104.0/21, 57.6.112.0/21, and 57.6.120.0/21. If all of them use the same outgoing line, can they be aggregated? If so, to what? If not, why not?

Ans

They can be aggregated to 57.6.96.0/19.

IP

The set of IP addresses from 29.18.0.0 to 29.18.127.255 has been aggregated to 29.18.0.0/17. However, there is a gap of 1024 unassigned addresses from 29.18.60.0 to 29.18.63.255 that are now suddenly assigned to a host using a different outgoing line. Is it now necessary to split up the aggregate address into its constituent blocks, add the new block to the table, and then see if any reaggregation is possible? If not, what can be done instead?

Ans

It is sufficient to add one new table entry: 29.18.60.0/22 for the new block. If an incoming packet matches both 29.18.0.0/17 and 29.18.60.0./22, the longest one wins. This rule makes it possible to assign a large block to one outgoing line but make an exception for one or more small blocks within its range.

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IP

A router has the following (CIDR) entries in its routing table:

Address/mask Next hop

135.46.56.0/22 Interface 0

135.46.60.0/22 Interface 1

192.53.40.0/23 Router 1

default Router 2

For each of the following IP addresses, what does the router do if a packet with that address arrives?

(a) 135.46.63.10

(b) 135.46.57.14

(c) 135.46.52.2

(d) 192.53.40.7

(e) 192.53.56.7

Ans

The packets are routed as follows:

(a) Interface 1

(b) Interface 0

(c) Router 2

(d) Router 1

(e) Router 2

Switching

Consider an application that transmits data at a steady rate (for example the sender generates an N-bit unit of data every K time units, where K is small and fixed). Also, when such an application starts, it will continue running for a relatively long period of time. Answer the following questions, briefly justifying your answers.

a) Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why?

b) Suppose a packet-switched network is used and the only traffic in this network comes from this application as described above. Furthermore, assume that the sum of the application data rates is less than the capacities of each and every link. Is some form of congestion control needed? Why?

IP

Ans.

a) A circuit-switched network would be well suited to the application, because the application involves long sessions with predictable smooth bandwidth requirements. Since the transmission rate is known and not bursty, bandwidth can be reserved for each application session without significant waste. In addition, the overhead costs of setting up and tearing down connections are amortized over the lengthy duration of a typical application session.

b) In the worst case, all the applications simultaneously transmit over one or more network links. However, since each link has sufficient bandwidth to handle the sum of all of the applications' data rates, no congestion (very little queuing) will occur. Given such generous link capacities, the network does not need congestion control mechanisms

Circuit Switching

Consider the Parameters:

N = Number of Hops between two given system = 4

L = Message Length in bits = 3200

B = Data rate in BPS = 9600

P = Fixed Packet size in Bits = 1024

H = Overhead Bits per Packet = 16

S = Call setup time in Second = 0.2

D = Propagation Delay per hop in second. = 0.001

Find End to End Delay For circuit switching only.

Ans:

T = C1 + C2 where C1 = Call Setup Time C2 = Message Delivery Time

C1 = S = 0.2

C2 = Propagation Delay + Transmission Time = N * D + L/B = 4 * 0.001 + 3200/9600
= 0.337

T = 0.2 + 0.337 = **0.537 sec**