01-
Introduction

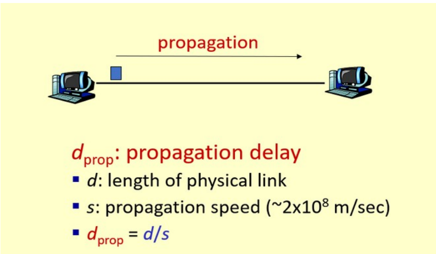
1. **Short Answer Questions**

    a. What's **propagation delay**? How do you compute it for a given link?

Answer:

Propagation Delay: Time it takes for a signal to travel from one endpoint to the other. (on the physical wire).

Calculate: length of physical link / propagation speed (2x10^8 m/sec)



- Make sure to convert the units to be the same. Preferably change the length of the wire to the unit of the speed given.
- ***TO CONVERT PUT THE UNIT CONVERSION = TO WHAT YOU WANT TO CONVERT*** $\frac{1\,kb}{1000\,bytes} = \frac{7\,kb}{x}$***, Cross multiply and cancel out units and you get the answer.***

Meter Conversion	
1 m	1 Meter
1 dam	10 m
1 hm	100 m
1 km	1000 m
1 cm	0.01 m
1 mm	0.001 m

b. If I am sending 1 bit to a host in the moon, which of the following is the dominant factor:
Transmission delay or **propagation delay**? Justify your answer.

Answer:

Transmission delay: the time required to put the bits of a packet on the transmission medium (on the wire)

d_{trans}: transmission delay:

- L: packet length (bits)
- R: link *transmission rate (bps)*
- $d_{trans} = L/R$

- Example:
  - packet size: 1000 bits
  - Bandwidth: 1Mbps
  - $d_{trans} = 1000/10^6 = 1ms$

- ***TO CONVERT PUT THE UNIT CONVERSION = TO WHAT YOU WANT TO CONVERT*** $\frac{1\,kb}{1000\,bytes} = \frac{7\,kb}{x}$***, Cross multiply and cancel out units and you get the answer.***

Packet Sizes Conversion		Bit Rate/Bandwidth Conversions	
1 Bit		1 bps	1 bit per second
1 Byte	8 Bits	1 kbps	1000 bps
1 KB	1000 Bytes	1 Mbps	1,000,000 bps
1 MB	1,000,000 Bytes	1 Gbps	1,000,000,000 bps
1 GB	1,000,000,000 Bytes	1 Tbps	1,000,000,000,000 bps

Propagation delay would be the dominant factor. Since you are placing a single bit, it won't take much time to put on the wire but to send it from here to the moon would take much longer.

c. If I am sending 1Mbits to a host in the same room, which of the following is the dominant factor:
Transmission delay or **propagation delay**? Justify your answer.

Answer: Transmission delay because the host are very close so it won't take much time to send the bits but since its 1Mbits it will take some time to put them on the wire.

d. I have a datacenter where two servers exchange huge amounts of data (in the order of petabytes). I need to reduce the time it takes for the data to go from one server to the other. A friend of mine suggests that I reduce the cable size connecting the two servers by half, and another friend suggests that I increase the bandwidth of the cable two folds. Which suggestion should I follow? Justify your answer.

Answer: Increasing the bandwidth would be the better solution. Since you are dealing with petabytes of data you would need a faster bandwidth to put those bits on the wire. If you had a slow bandwidth but short wire, the data would transfer fast between servers, but it would still be slow to put the data on the wire causing slow transfer times or even congestion.

e. NASA establishes a lunar base and needs to establish a data link between the control station in Houston and the lunar base. They only need to send a packet of 1000 bytes every hour that contains some information about the things to be done. They can set up a low bandwidth 1Kbps link for $1000 or a high bandwidth 1Gbps link for $1,000,000. Which one should they choose and why? Justify your answer.

Answer: They should pay for the $1000 option. They are sending 1000 bytes every hour, so they do not need fast bandwidth to do so. The 1Kbps option is the smarter option as it saves money and does the task.

f. How many layers does the **OSI protocol stack** have? List them from top to bottom.

Answer: Application, Presentation, Session, Transport, Network, Data Link, Physical.

g. How many layers does the **TCP/IP protocol stack** have? List them from top to bottom.

Answer: Application, Transport, Internet, Link Layer, Physical.

h. In a **circuit-switched network** can unused resources belonging to a call be used by other calls to increase network utilization? Why or why not?

Answer: No. After the call setup, the resources are dedicated and is not shared with other calls.

i. List 1 advantage and 1 disadvantage of making the **packet size small** in a packet-switched network.

Answer:

- One **advantage** is that since they are so small they can be discarded if an error occurs which leads to discarding small information not the entire data
- One **disadvantage** is that they all must contain headers so header to payload ratio wastes bandwidth.

j. List 1 advantage and 1 disadvantage of making the **packet size big** in a packet-switched network.

Answer:

- One **advantage** is that the header to payload ratio is low so you do not waste much bandwidth
- One **disadvantage** is that it takes longer to move the packet through the mediums to its destination

k. In a **virtual-circuit switched network**, can packets belonging to the same connection, i.e., communicating pairs, follow different paths in the network and arrive out-of-order at the destination? Justify your answer.

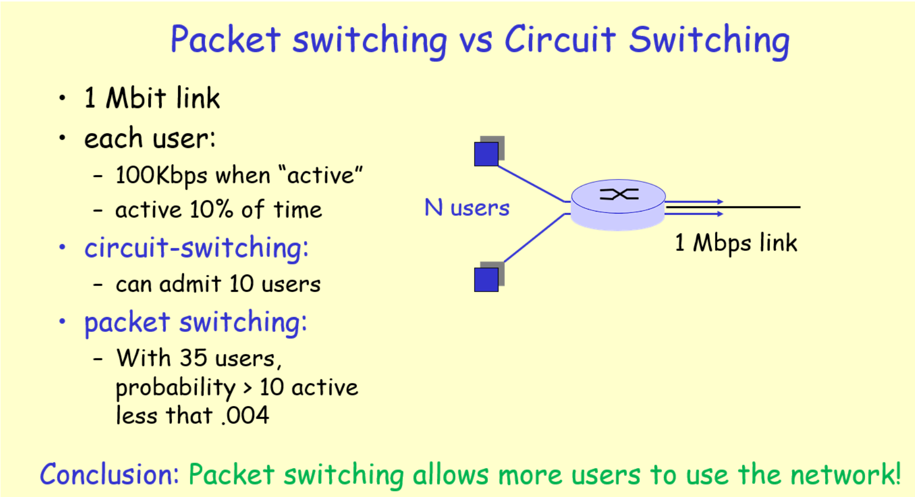
Answer: No packets belonging to the same connection can not follow different paths because the virtual circuit establishes a fixed path during the packet exchange between those two.

l. True/False. In a **datagram network**, each packet carries the destination address in the packet header. Justify your answer.

Answer: True. Destination address is written on top of a packet, and it is simply submitted to the network for delivery. There is no set route like virtual-circuit.

m. What's the main motivation for **packet switching**? Briefly explain.

Answer:



n. True/False. If a node needs to communicate only with **nodes on the same link**, i.e., with another neighbor, **Physical Layer** and **Link Layers** are enough. In other words, no network layer is necessary. Justify your answer.

Answer: True, if they share the same link then they only require the physical layer and link layer since that has MAC address which can help identify to whom but if they were outside then the network layer would be needed and an IP address.

o. How "**wide**" is a bit on a 1 Gbps link?

Answer: 1 bit / 10^9(giga) = $\frac{1}{10^9}$ second or 1 nanosecond

Bit width is speed of transmission/ bit rate

- A bit on a 1-Gbps link is 1 nanosecond wide. This is because 1 Gbps (gigabit per second) is equivalent to 1 billion bits per second, or 1 bit per nanosecond. Therefore, a bit on a 1-Gbps link is 1 nanosecond wide.

p. Suppose you are developing a standard for a new type of network. You need to decide whether your network will use virtual-circuits or datagram forwarding. What are the pros and cons of using **virtual-circuits**?

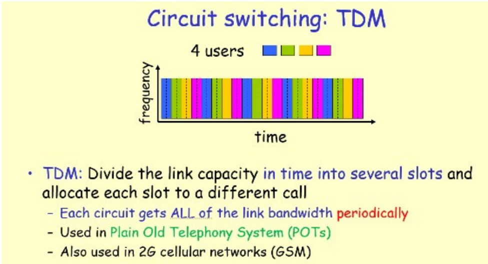
Answer:

- ***Pro:*** Will guarantee that a dedicated resource to me with no drop off/interference like for steaming audio or video
- ***Pro:*** Can have better reliable transfer, less packet delay and loss
- ***Con:*** wasted resources as the circuit is idle

q. Briefly describe how Time Division Multiplexing (TDM) works.

Answer:

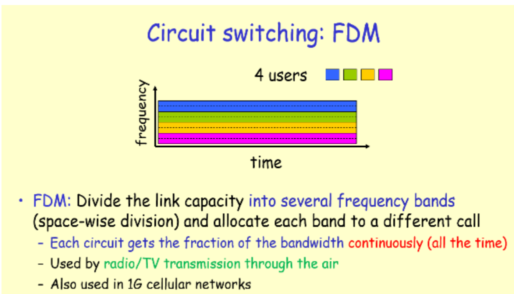
Divides the link capacity in time into several slots and allocate each slot to a different call.



r. Briefly describe how Frequency Division Multiplexing (FDM) works.

Answer:

Divide the link capacity into several frequency bands (space-wise division) and allocate each band to a different call

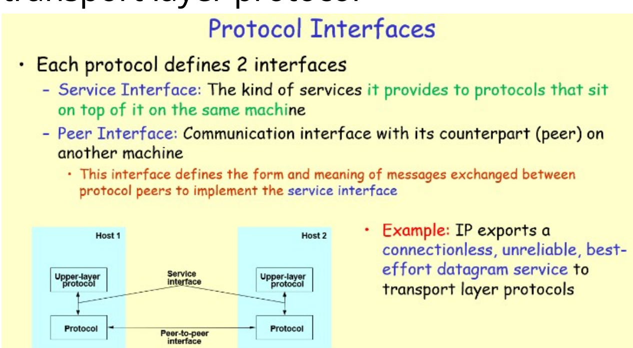


s. Briefly explain what's meant by the "**service interface**" of a protocol? What's the service interface of the Internet Protocol (IP)?

Answer:

Service interface It is a protocol-to-protocol service that provides services from the lower layer protocol to the upper layer protocol

In the ***case of IP***, IP exports a connectionless, unreliable, "best effort" datagram to the transport layer protocol



t. Briefly explain what's meant by the "**peer interface**" of a protocol?

Answer: peer interface is the communication interface with its counterpart (peer) on another machine. This interface defines the form and meaning of messages exchanged between protocol peers to implement the service interface.

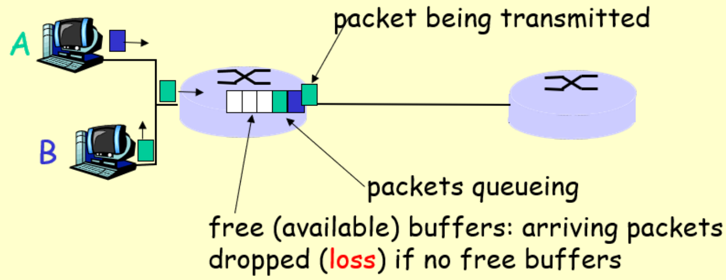
u. How and why do packets get lost during transmission? Briefly explain.

Answer:

- Packets get queued in the buffers of a router
- Buffer is used if packet arrival rate > output capacity
- Buffer is finite
- If packets > buffer, packets get dropped

How and why do packet loss occur?

- Packets get queued in router buffers
- If packet arrival rate exceeds output capacity, packets get buffered and wait for their turn to be transmitted
- Buffer is of finite size
  - If more packets than what buffer can store, new packets will be dropped



2. Consider sending a file **F=M*L** bits over a path of **N** links. Each link transmits at R bits/sec. The network is lightly loaded so that there are **no queuing delays**. When **packet switching** is used, the M*L bits are broken up into **M packets**, each packet **L bits**. Also assume that the **propagation delay is negligible**.

   a. Suppose that the network is **circuit-switched**. Further suppose that the transmission rate of the circuit between the source and the destination is **R bps**. Assuming $\mathbf{t_s}$ set-up time and **h** bits of header appended to the entire file, how long does it take to send the file?

Answer:

Total time = $Ts+\frac{(M*L)+H}{R}$

- Asks for how long to put packets on the wire for this method. Does not consider other delays
- Circuit-switch requires a set up time (Ts)
- File size determined by multiplying number of packets (M) by packet size (L). (M * L)
- Header is said to be appended to entire file since it is circuit-switched so add it to file size. (M * L) + H
- Need to find how long it would take based on transmission rate so divide file by R. $\frac{(M*L)+H}{R}$
- Combine setup time with file transmission time. $Ts+\frac{(M*L)+H}{R}$

   b. Suppose the network is a **packet-switched virtual circuit network** such as X.25. Denote the virtual- circuit set-up time by $\mathbf{t_s}$. Suppose the sending layers add a total of **h** bits of header to each packet. How long does it take to send the file from the source to the destination?

Answer:

Total time = $Ts+\frac{N*L+H}{R}+\frac{(M-1)*L+H}{R}$

- Asks for how long to put packets on the wire for this method. Does not consider other delays
- Virtual circuit involved so time must be taken to create a path (Ts)
- Packet switching so we add the header to all packets. (L + H)
- Divide by R to find the time it takes each packet to be put on the wire for that bitrate.

- Multiply that by N because N links each require to take put that data onto the next wire. $\frac{N*L+H}{R}$

- For each subsequent packet, the first link can start transmitting it after the previous packet has finished on that link, creating a pipelining effect. The additional time to transmit all subsequent (M – 1) with all being the same size of ($\frac{L+H}{R}$). Making $\frac{(M-1)*L+H}{R}$

- Combine all to get ($Ts+\frac{N*L+H}{R}+\frac{(M-1)*L+H}{R}$)

c. Suppose the network is a **packet-switched datagram network** such as the Internet. Now suppose that each packet has **2*h** bits of header. How long does it take to send the file?

Answer:

$$\frac{N*(L+2H)}{R}+(M-1\frac{)*(L+2H)}{R}$$

- Datagram network doesn't require time to set up a fixed circuit since it constantly changes routes so Ts is not needed
- Since we need twice the header for each packet we do. (L + 2H) giving us the size of each packet
- We want to know the time it takes each packet to be put on the wire so we divide length by R. $\frac{L+2H}{R}$
- Same as previous problem with N links we need to put the data on the next wire of each. $\frac{N*L+2H}{R}$

- For each subsequent packet, the first link can start transmitting it after the previous packet has finished on that link, creating a pipelining effect. The additional time to transmit all subsequent (M – 1) with all being the same size of ($\frac{L+2H}{R}$). Making $\frac{(M-1)*L+2H}{R}$

- Combine to get Total Time $=\frac{N*(L+2H)}{R}+(M-1\frac{)*(L+2H)}{R}$

3. Suppose two nodes A and B are connected via a point-to-point link. The length of the link is 10000km and its bandwidth is 1Kbps. Assume the speed of signal on the wire is $3x10^5$ km/sec.

a. Calculate the **minimum RTT** for the link.

Answer:

RTT (Round Trip Time): travel time from A to B then back to A

First calculate Propagation delay = D/S D = length of link S = speed of signal

(REMEMBER TO KEEP UNITS THE SAME SO M DIVIDE M NOT KM/M)

10000/3x10^5 = 0.03333333... seconds

Multiple it by 2 for RTT: 2 x 0.033333... = ***0.066666.... secs***

b. **How long** does it take to transmit 1000 bytes from A to B.

Answer:
Calculate transmission delay must be in bits not MB not KB not bytes, BITS
L: 1000 bytes = 8000 bits
R: 1Kbps = 1000 bits/sec
L/R
8000/1000 = ***8 seconds***
Propagation delay from Part A: 0.033333 seconds
Total = 8 seconds + 0.03333 seconds = **8.0333 seconds**

4. Suppose a **100 Mbps** point-to-point link is being set up between the earth and a new lunar colony. The distance from the moon to the earth is approximately 390,000 km, and data travels over the link at the speed of light, i.e., $3x10^5$ km/sec.

a. Calculate the **minimum RTT** for the link.

Answer:

SEE FORMULA IN #3 & #1 for help

D: 390,000 km

S: 3x10^5

390000/3x10^5 = 1.3 seconds

1.3 x 2 = ***2.6 seconds***

b. A camera on the lunar base takes pictures of the earth and saves them in digital format to disk. Suppose Mission Control on earth wishes to download the most current image, which is 25MB. What is the **minimum amount of time** that will elapse between when the request for the data goes out and the transfer is finished?

Answer:
SEE FORMULA IN #3 & #1 for help
L: 25 mb = 200,000,000 bits (25 x 1,000,000 x 8)
R: 100 mbps = 100,000,000 bits/sec

200,000,000/100,000,000 = ***2 seconds***

Propagation delay from Part A: 1.3 seconds but we sent the request for data then it was transferred

Total = 2 seconds + (1.3 x 2) seconds = **4.6 seconds**

5. Consider two hosts A and B connected by a single link of rate **R bps**. Suppose that the two hosts are separated by **M** meters and suppose the propagation speed along the link is **s** m/sec. Host A is to send a packet of size **L bits** to host B.

   a. Express propagation delay $\mathbf{t_{prop}}$ in terms of **M** and **s**.

Answer:

D: M meters (meters of wire given)

S: S m/sec (propagation speed given)

Tprop= ***M/S***

   b. Determine the transmission time of the packet $\mathbf{t_{trans}}$ in terms of **L** and **R**.

Answer:
L: L bits (given, we don't change since its already in bits)
R: R bits (given, we don't change since its already in bits)
Ttrans = ***L/R***

   c. Ignoring processing and queueing delays, how long does it take for the last bit of the packet to arrive at B?

Answer: Since processing and queueing delays aren't being considered we simply add the two values we got above. If you had the other delays, you would just add all of them together.
M/S + L/R

   d. Suppose host A begins to transmit the packet at time t=0. At time t = $\mathbf{t_{trans}}$ where is the last bit of the packet?

Answer: Transmission time is the time it takes for the packet to be placed on the wire. So from 0 to Ttrans its being placed on the wire. By the end of it the entire packet is finally on the wire. Propagation would be the time it takes to go across the wire to B.

   e. Suppose $\mathbf{t_{prop}}$ is greater than $\mathbf{t_{trans}}$. At time t = $\mathbf{t_{trans}}$ where is the first bit of the packet?

Answer: Since Ttrop is greater than Ttrans, the first bit of the packet will not be all the way to Host B yet but it should be on the wire making its way there.

   f. Suppose s=2.5*105 km/s, L=100 bits, and R=28 Kbps. Find the distance **m** so that **tprop** equals **ttrans**

Answer:

Tprop = D/S
Ttrans = L/R
D/S = L/R
D = ? = ***<u>About 892.9 Km</u>***
S = 2.5 x 10^5 km/sec
L = 100 bits
R = 28 Kbps = 28,000 bps
Solve the equation D/S = L/R

6. Suppose two hosts A and B are separated by 10,000 kilometers and are connected by a direct link of **R=1 Mbps**. Suppose the propagation speed over the link is $2.5*10^8$ m/sec.

   a. Calculate the "**bandwidth-delay**" product **$R*t_{prop}$**.

<u>Answer</u>:

Bandwidth-delay = R x Tprop = 1,000,000 x 0.04 = ***<u>40,000 bits</u>***

Tprop = D/S = 10,000,000 / 2.5 x 10^8 = 0.04 seconds

D = 10,000 km = 10,000,000 m

S = 2.5 * 10^8 m/sec

R = 1 Mbps = 1,000,000 bps

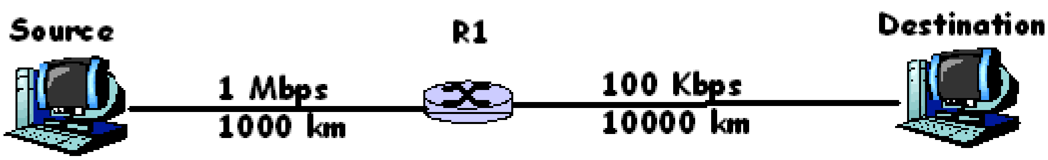
   b. Provide an interpretation of the bandwidth-delay product.

<u>Answer</u>: Bandwidth delay product is the max amount of data that can be in the process of being sent at any given time. 40,000 bits means that at any given time that amount of bits can be transmitted over the link to B.

   c. Consider sending a file of 400,000 bits from host A to host B. Suppose the file is sent continuously as one big message. How long does it take for the last bit of the message to arrive at B.

Tprop + Ttrans = 0.04 + 0.4 = 0.44 seconds
Tprop = D/S = 10,000,000 m /2.5 x 10^8 m/sec = 0.04 seconds
Ttrans = L/R = 400,000 bits / 1,000,000 bps = 0.4 seconds

7. Consider the packet switched network shown below. The bandwidth of the link between the source and router R1 is 1 Mbps and the length of the link is 1000 kms. The bandwidth of the link between router R1 and the destination is 100Kbps and the length of the link is 10000 kms. Assume that the speed of light is $2*10^5$ km/sec.



   a. What's the **RTT**?

Answer: (Note we aren't given the packet sizes so we cant fully compute RTT since we don't know the size of whats being sent so this is the minimum RTT)

RTT = 2 x Tprop = 2 x 0.055 = ***0.110 seconds*** = 110 ms
Tprop = D/S = 0.005 + 0.05 = 0.055 seconds = 55 ms
Source to R1: 1000 km / 2 x 10^5 = 0.005 seconds = 5 ms
R1 to Destination: 10000 km / 2 x 10^5 = 0.05 seconds = 55 ms

   b. Assume that the source sends 1000 packets each of length 1000 bytes to the destination. How long does it take for the transmission to complete?

Answer:

Tprop = 55 ms

Ttrans = L/R = 88 ms

L = 1000 bytes = 8000 bits

R = Varies between Source to R1 and R1 to Destination

Source → R1

8000 / 1000000 = 8 ms

R1 → Destination

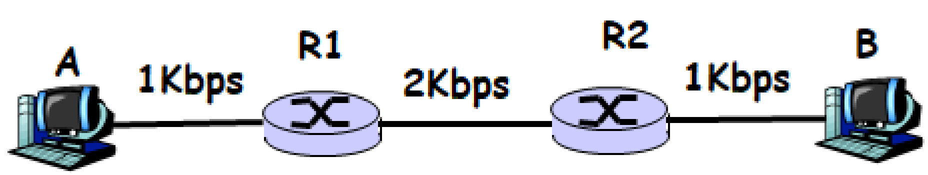
8000 / 1000 = 80 ms

Total time for packet 1 to transfer: 8 + 5 + 80 + 50 = 143 ms

Other packets transfer in: 999 x 80 =79,920 ms

Total: 143 + 79920 = 80,063 ms or 80.063 seconds

8. Consider the following network. Bandwidth of the link between A and R1 is **1 Kbps**. Bandwidth of the link between R1 and R2 is **2 Kbps**. Bandwidth of the link between R2 and B is **1 Kbps**. Assume that an application at A sends 10 packets each of size 1000 bytes. Assuming that the transmission starts at time 0, compute how long it takes for the last packet to arrive at B. Ignore the propagation, processing and queuing delays.



Answer:
Ttrans = L/R = 20 + (8 x 9) = 92 seconds
L = 1000 bytes = 1000 bits
R = Kbps = R x 1000 = bps
A →R1
8000/1000 = 8 seconds
R1 →R2
8000/2000 = 4 seconds
R2 →B
8000/1000 = 8 seconds

(ChatGPT)

Transmission of All Packets

Since packets are sent one after the other, we need to consider how the packets are transmitted over time:

1. The first packet arrives at B after 20 seconds.
2. The second packet starts transmission from A immediately after the first one has been sent.

Time taken for all packets:

- **1st Packet**: 20 seconds
- **2nd Packet**: Starts transmitting after 8 seconds, finishes after 20+8=28 seconds.
- **3rd Packet**: Starts transmitting after 16 seconds, finishes after 20+16=36 seconds.
- **4th Packet**: Starts transmitting after 24 seconds, finishes after 20+24=44 seconds.
- **5th Packet**: Starts transmitting after 32 seconds, finishes after 20+32=52 seconds.
- **6th Packet**: Starts transmitting after 40 seconds, finishes after 20+40=60 seconds.
- **7th Packet**: Starts transmitting after 48 seconds, finishes after 20+48=68 seconds.
- **8th Packet**: Starts transmitting after 56 seconds, finishes after 20+56=76 seconds.
- **9th Packet**: Starts transmitting after 64 seconds, finishes after 20+64=84 seconds.
- **10th Packet**: Starts transmitting after 72 seconds, finishes after 20+72=92 seconds.