CS2105 Introduction to Computer Networks

Prepared by Clinton Law (AY19/20 Sem1)

About me

Clinton Law

- Year 3 CS
- Took this module last year
- TA'd it last semester

Contact Details

- Email me at clintonlaw@u.nus.edu
  - **PLEASE include "CS2105" in the subject of your email!**
- Telegram handle: @clawyq
  - Collate any quick questions you might have (please don't spam me)
  - With regards to assignments, to be fair to the rest I will **only** provide guidelines for understanding and approaching the problem

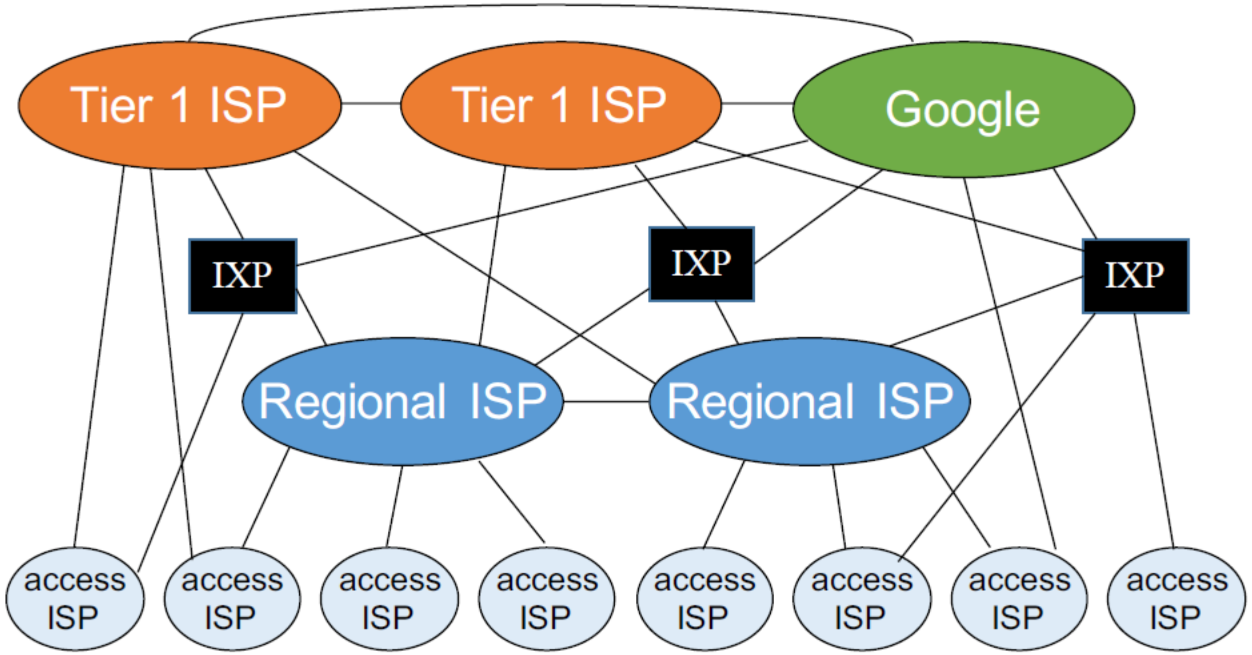
What you can expect

- Tutorial flow
  - Quick recap of the content covered in the lectures
    - Iron out any question marks
  - Going through the tutorial questions

- Grading
  - Participation
    - Questions I ask will be in round – robin style
      - Feel free to add any interesting points for discussion at any juncture

Recap

- The Internet (structural breakdown)



  - network of networks
  - organised into **autonomous systems(ASes)** each owned by an organisation
  - Autonomous systems (owned by major corporations) -> regional ISPs -> access ISPs -> host end users (you!)

Recap

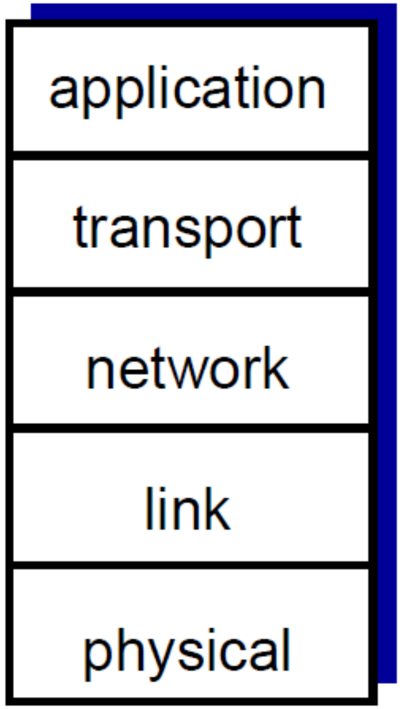
- Applications communicate using **protocols**, which specify the message…
  - Format
  - Order
  - Actions to take upon receiving or sending a message
  - Basically **contracts** containing the blueprints that dictate cross network interactions e.g. HTTP, FTP, SMTP, TCP, RTP

Recap

Recap

Internet protocol stack

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- *physical:* bits “on the wire”



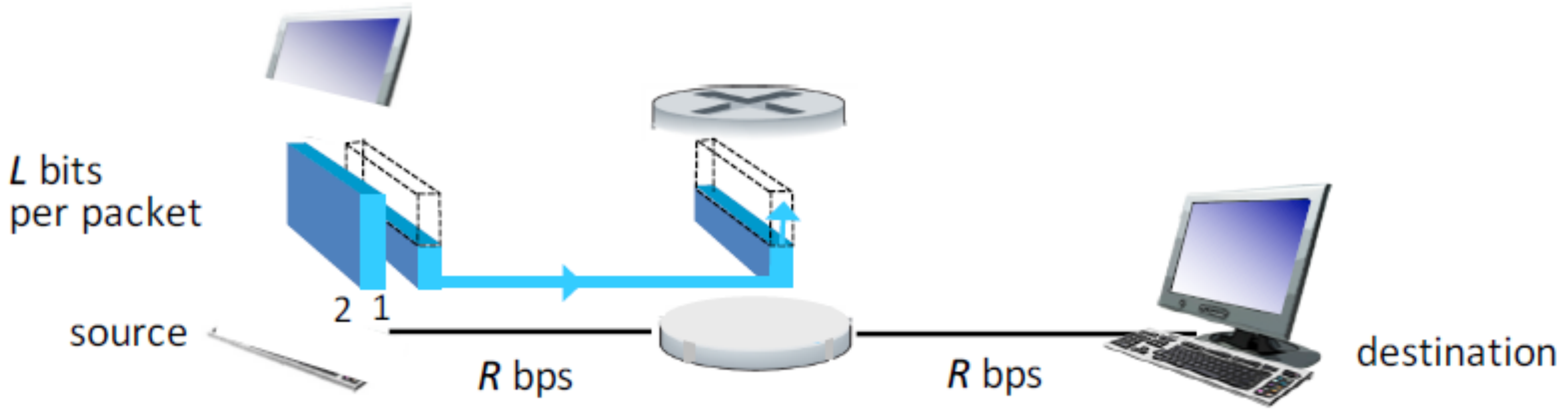
Recap

- Circuit Switching
  - Setup/Teardown required
  - Resources are reserved
  - Service is guaranteed

- Packet Switching
  - No setup/teardown required
  - Resources are not reserved
  - Service is **best effort**
    - Rtx from previous node
    - Rtx from source node
    - Not at all

Recap

- Internet is a packet switching network
  - Resources are not reserved
  - Data is segmented into smaller packets
  - Store & Forward
    - Entire packet must arrive at a router before it can be transmitted onto the next link



End-to-end delay = 2*L/R (assuming no other delay)

Recap

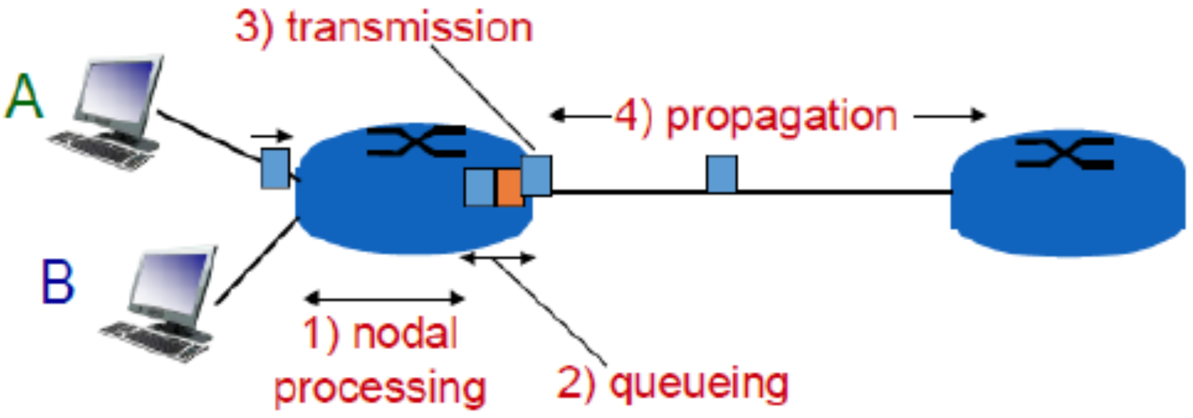
- 4 kinds of delay

d_{proc}: **processing delay**
- check bit errors
- determine output link
- typically < msec

d_{queue}: **queuing delay**
- time waiting in the queue for transmission
- depends on congestion level of router

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

d_{prop}: **propagation delay**
- d: length of physical link
- s: propagation speed in medium (~2×10^8 m/sec)
- $d_{prop} = d/s$



Please ensure that the units are consistent (bytes vs bits)

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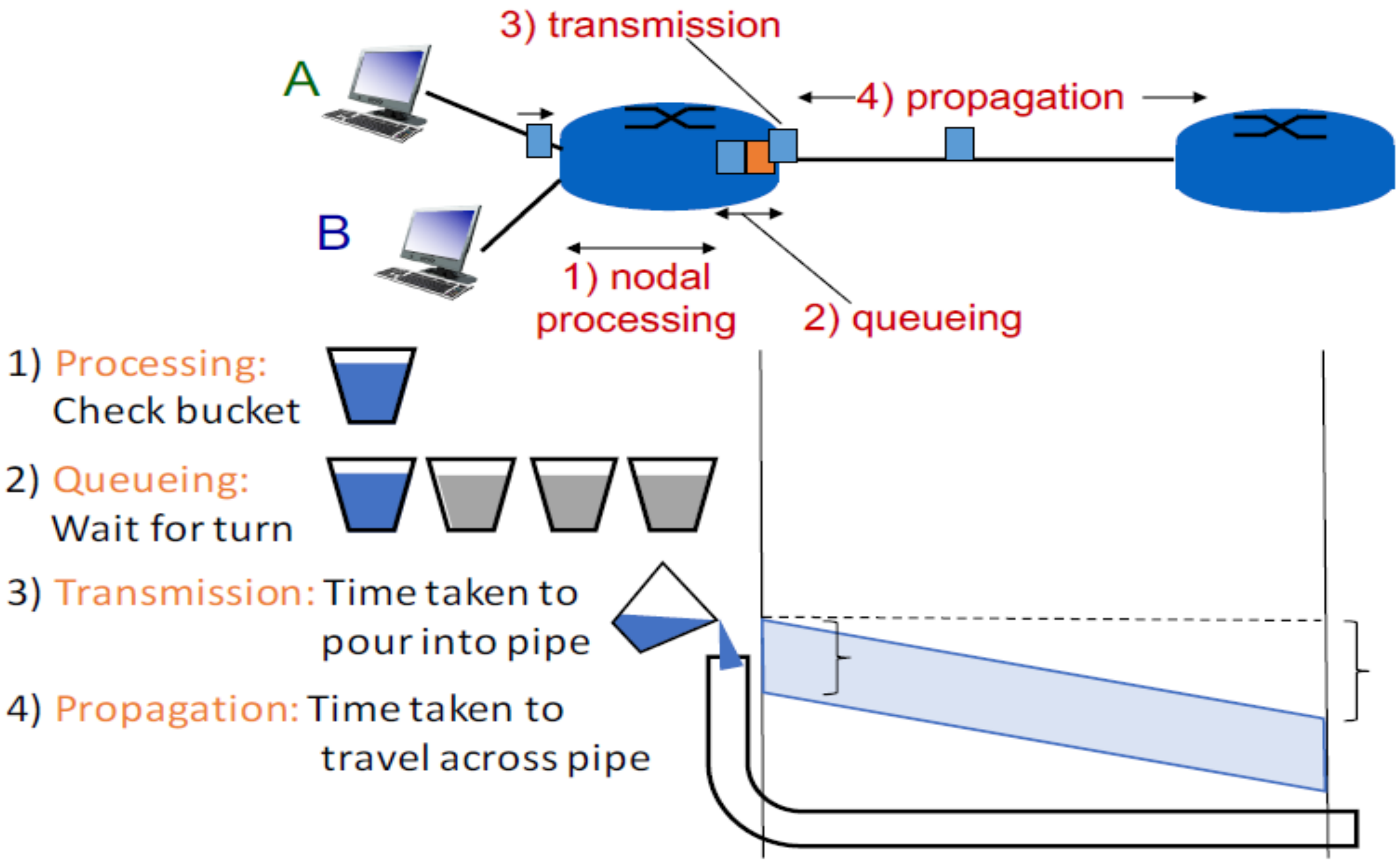
Recap

Four Sources of Packet Delay



Tutorial Questions

Question 1

Consider two hosts, A and B, connected by a single link of rate $\boldsymbol{R}$ bps. Suppose that the two hosts are separated by $\boldsymbol{m}$ meters, and suppose the propagation speed along the link is $\boldsymbol{s}$ meters/sec. Host A is to send a packet of size $\boldsymbol{L}$ bits to Host B.

a) Express the propagation delay, $\boldsymbol{d_{prop}}$, in terms of $\boldsymbol{m}$ and $\boldsymbol{s}$.

$d_{prop} = \frac{m}{s}$ sec (distance between host /propagation speed)

b) Determine the transmission time of the packet, $\boldsymbol{d_{trans}}$, in terms of $\boldsymbol{L}$ and $\boldsymbol{R}$.

$d_{trans} = \frac{L}{R}$ sec (length of packet/ transmission rate; take note bits vs bytes!)

c) Ignoring processing and queuing delays, obtain an expression for the end-to-end delay $\boldsymbol{d_{end\text{-}to\text{-}end}}$.

$d_{end\text{-}to\text{-}end} = d_{prop} + d_{trans}$ sec

Question 1

d) Suppose Host A begins to transmit the packet at time t = 0. At time t = $\boldsymbol{d_{trans}}$, where is the last bit of the packet?

The last bit has just left Host A.

e) Suppose $\boldsymbol{d_{prop}}$ is greater than $\boldsymbol{d_{trans}}$. At time t = $\boldsymbol{d_{trans}}$, where is the first bit of the packet?

The first bit is flowing in the link and has not reached host B (time of transmission < time to propagate through the link) .

f) Suppose $\boldsymbol{d_{prop}}$ is less than $\boldsymbol{d_{trans}}$. At time t = $\boldsymbol{d_{trans}}$, where is the first bit of the packet?

The first bit has already reached Host B.

g) Suppose $\boldsymbol{s} = 2.5 \times 10^8$, $\boldsymbol{L}$ = 120 bits, and $\boldsymbol{R}$ = 56 kbps. Find the distance $\boldsymbol{m}$ so that $\boldsymbol{d_{prop}}$ equals $\boldsymbol{d_{trans}}$.

$$\frac{m}{s} = \frac{L}{R}$$

$$m = \frac{L}{R} \times s = 120 \times 2.5 \times 10^8 / (56 \times 10^3) = 535714.2857 \text{ meters}$$

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Question 2

A packet switch receives a packet and determines the outbound link to which the packet should be forwarded. When the packet arrives, one other packet is halfway done being transmitted on this outbound link and four other packets are waiting to be transmitted. Packets are transmitted in order of arrival. Suppose all packets are 1,500 bytes and the link rate is 2 Mbps.

a) What is the queuing delay for the packet?

The arriving packet must first wait for the link to transmit 4.5*1500 bytes = 6,750 bytes or 54,000 bits. Since these bits are transmitted at 2 Mbps, the queuing delay is 27 msec.

b) More generally, what is the queuing delay when all packets have length $\boldsymbol{L}$ (bits), the transmission rate is $\boldsymbol{R}$, $\boldsymbol{x}$ bits of the currently-being-transmitted packet have been transmitted, and $\boldsymbol{n}$ packets are already in the queue?

Generally, queuing delay is $\frac{nL + (L - x)}{R}$**.**

Question 3

[KR, Chapter 1, Problem 31] In modern packet-switched networks, including the Internet, the source host segments long, application-layer messages (for example, an image or a music file) into smaller packets and sends the packets into the network. The receiver then reassembles the packets back into the original message. We refer to this process as *message segmentation*. Figure 1.27 illustrates the end-to-end transport of a message with and without message segmentation.

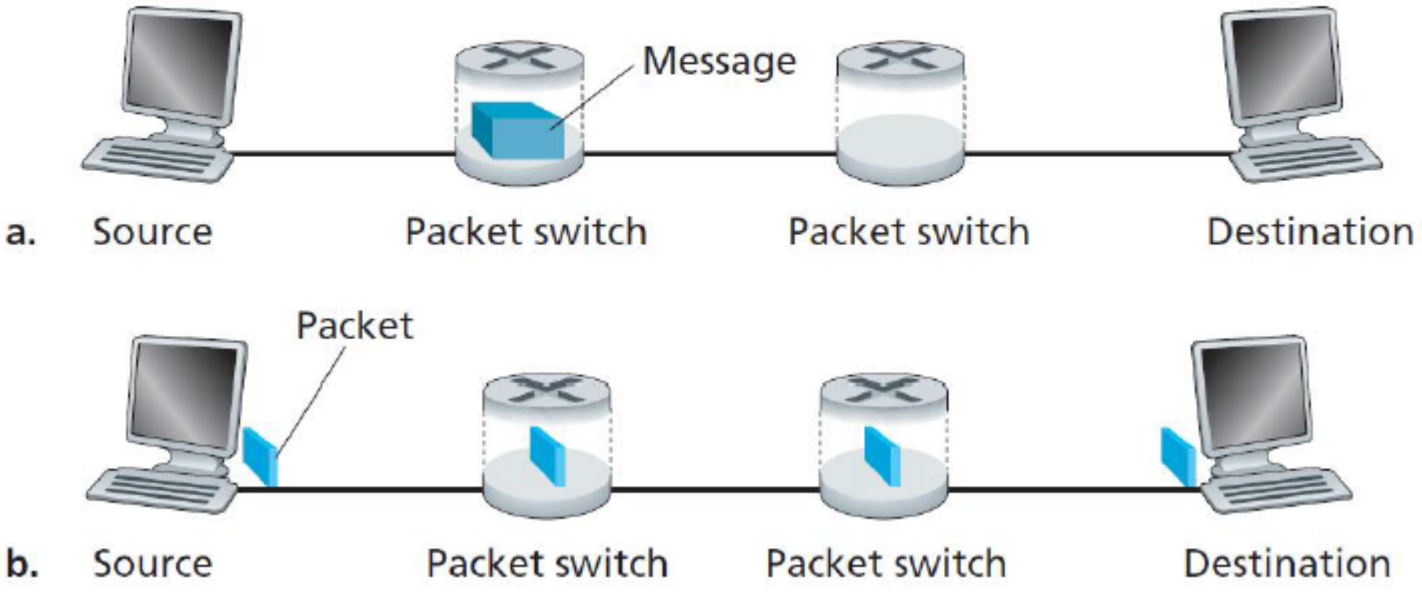

Figure 1.27 ♦ End-to-end message transport: (a) without message segmentation; (b) with message segmentation

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Question 3

Consider a message that is 8×10^6 bits long that is to be sent from source to destination. Suppose each link in the figure is 2 Mbps. Ignore propagation, queuing, and processing delays.

a) Consider sending the message from source to destination ***without*** message segmentation. How long does it take to move the message from the source host to the first packet switch (router)?

Time for source to send out the message = $\frac{8 \times 106}{2 \times 106}$ = 4 sec. Since we assume no propagation delay, packet reaches the first switch at t = 4 sec.

b) Following a), what is the total time to move the message from source host to destination host? Keeping in mind that each switch uses store-and-forward packet switching.

The 1st switch needs to receive the entire message (at t = 4 sec) before it starts forwarding the packet onto the outgoing link. So does the 2nd switch. With store-and-forward switching, the total time to move the message from source host to destination host = 4 + 4 + 4 = 12 sec.

Question 3

c) Now suppose that the message is segmented into 800 packets, with each packet being 10,000 bits long. How long does it take to move the first packet from source host to the first switch? When the first packet is being sent from the first switch to the second switch, the second packet is being sent from the source host to the first switch. At what time will the second packet be fully received at the first switch?

Time to send the 1st packet to the 1st switch = $\frac{10000}{2 \times 106}$ = 5 msec. The source starts sending the 2nd packet at t = 5 msec. It takes another 5 msec to send this packet to the 1st switch. Time when the 2nd packet reaches the 1st switch is therefore 5 + 5 = 10 msec.

d) How long does it take to move the file from source host to destination host when message segmentation is used? Compare this result with your answer in part b) and comment.

The 1st packet reaches destination at t = 15 msec. After that, every 5 milliseconds, one more packet arrives at the destination. Thus, time the 800th packet reaches the destination = 15 + 799 x 5 = 4010 msec = 4.01 sec.

It can be seen that end-to-end delay in using message segmentation (4.01 sec) is significantly less than sending a big file as one message (12 sec).

Question 3

e) In addition to reducing delay, what are reasons to use message segmentation?

(i). Without message segmentation, if bit errors are not tolerated and there is a single bit error, the whole message has to be retransmitted (rather than a single packet).

(ii). Without message segmentation, huge packets (containing HD videos, for example) are sent into the network. Routers have to accommodate these huge packets. Smaller packets have to queue behind enormous packets and suffer unfair delays.

f) Discuss the drawbacks of message segmentation.

(i). Packets have to be put in sequence at the destination (network may re-order packets).

(ii). Message segmentation results in many smaller packets. Each packet needs to carry packet header of size tens of bytes (e.g., to specific destination address and port number). This is the header overhead of each packet to be discussed in later lectures.

Question 4

There are N devices to be connected. There can be either 0 or 1 link between any 2 devices.

a) What is the minimum number of links needed to connect all devices?

N-1 links. Organize all devices into a tree topology, chain topology or star topology. (no loops)

b) What is the maximum number of links that can be used to connect all devices?

$\frac{N \times (N-1)}{2}$ **links. All devices connect to all other devices directly. This is known as mesh topology. (handshake problem)**

c) What are the pros and cons of the network topologies in part a) and b)?

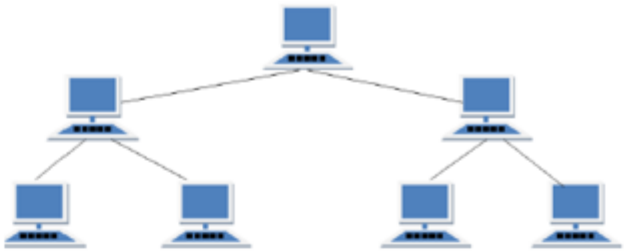
a): Simple topology but failure of a single node or link partitions network. Also it tends to have longer paths between 2 nodes.

b): Most robust topology (deals with localised breakdowns well), 1 hop distance between all nodes, but is most expensive.

Network topologies (extra)

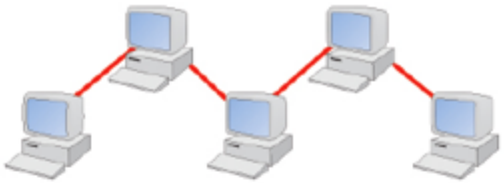
Tree Topology

eg. n = 7, links = 6



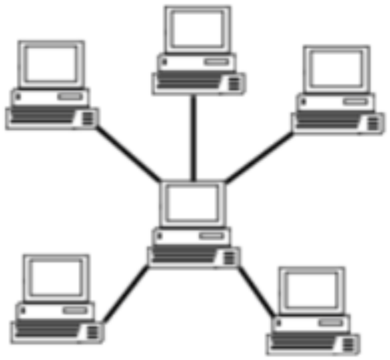
Chain Topology

eg. n = 5, links = 4



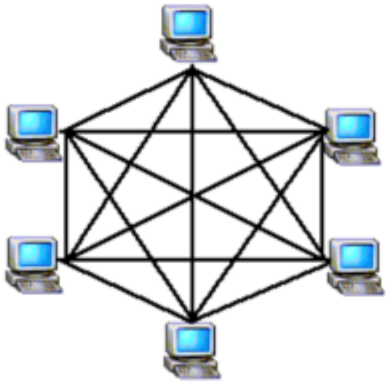
Star Topology

eg. n = 6, links = 5



Full Mesh Topology

eg. n = 6, links = (6x5)/2 =15



<u>Full Mesh Topology</u>

+ Fast
  - ➔ Direct Transmission as every node is connected each other
+ Reliable
  - ➔ Failure of 1 node will not affect the other as there are many alternate paths
- Resource intensive
  - ➔ Many connections required

<u>Chain Topology</u>

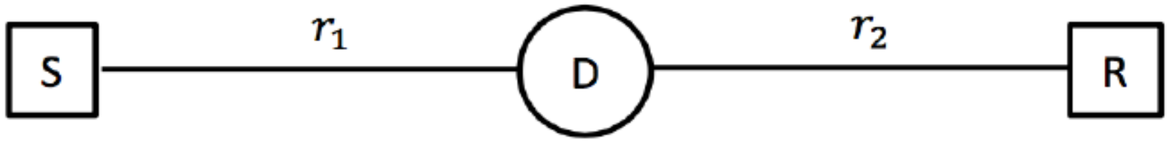
+ Cheaper
  - ➔ Less resources required for the fewer connections
- Unreliable
  - ➔ If 1 node dies, the whole system goes down

Summary

- Internet Architecture
- Circuit switching vs Packet switching
- 4 kinds of delays
  - (Nodal) Processing
  - Queueing
  - Transmission
  - Propagation
- Message segmentation
- Network topologies

Extra Questions

A device (D) is used to connect a sender (S) and a receiver (R). Transmission rates of the links between sender and the device and between the device and receiver are r_1 and r_2 ($r_1 > r_2$) respectively. Ignore other types of delay, what is the end-to-end delay to send a packet of length L?



A. $\frac{Lr_1r_2}{r_1+r_2}$, if this device is a store-and-forward packet switch.

B. $\frac{L}{2r_1} + \frac{L}{2r_2}$, if this device is a store-and-forward packet switch.

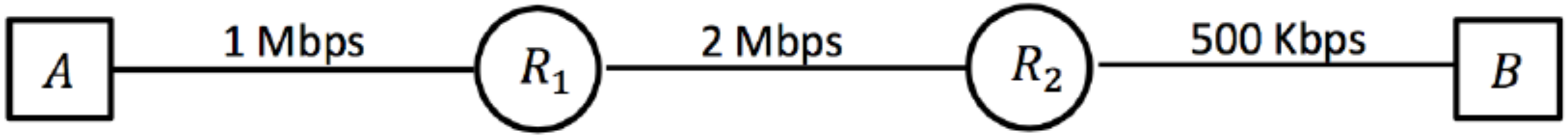
C. $\frac{L(r_1+r_2)}{r_1r_2}$, if this device acts on individual bits and repeats every bit to receiver once receives it from sender.

D. $\frac{L}{r_1} + \frac{1}{r_2}$, if this device acts on individual bits and repeats every bit to receiver once receives it from sender.

E. $\frac{1}{r_1} + \frac{L}{r_2}$, if this device acts on individual bits and repeats every bit to receiver once receives it from sender.

Extra Questions

As shown in the following diagram, the path from host *A* to host *B* comprises three links of rates 1Mbps, 2 Mbps and 500 Kbps respectively. Propagation delay is 500 ms per link. Two network devices R_1 and R_2 each acts on individual bits and forwards every bit to the next hop once it is received. You may assume both R_1 and R_2 have infinite memory.



Suppose *A* sends 80,000 bytes to *B*. What is the throughput of transmission?

A. 45 Kbps

B. 48 Kbps

C. 171 Kbps

D. 230 Kbps

E. 360 Kbps

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Thank you!

Answers:
E, D

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