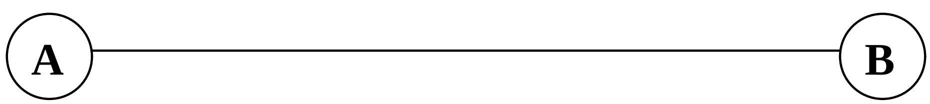
Exercises with Bandwidth and Latency

the simplest case is a single link

we consider a network of a single link, and we ignore transmission errors for now (the link is perfect)

Suppose there are two hosts A and B, and a file of 200 bytes needs to be sent from A to B. The link bandwidth is 500Kbps, the link is a fiber optic link, and the distance between A and B is 35km. How long will it take to send the file to B?

note — total time will be calculated from the time A starts sending the first bit until B receives the last bit.



solution to simple exercise

1. first, calculate time to transmit all bits
   (a) number of bits: 200 bytes $= 200 \times 8 = 1.6 \times 10^3$ bits
   (b) raw bandwidth: 5×10^5 bits/sec
   (c) we want seconds, so calculate (number of bits)/(bits/sec)

$$\frac{1.6 \times 10^3}{5 \times 10^5} = 3.2 \times 10^{-3} \text{ sec}$$

   this means that 3.2 msec after A begins, the last bit of the file is just starting to propagate across the link

2. second, calculate time for last bit to propagate (actually, this is latency for the simple link)
   (a) A-B distance: 3.5×10^4 meters
   (b) speed of light in fiber: 2×10^8 meters per second
   (c) we want seconds, so calculate (meters)/(meters/sec)

$$\frac{3.5 \times 10^4}{2 \times 10^8} = 1.75 \times 10^{-4} \text{ sec}$$

3. total is sum of previous two steps:

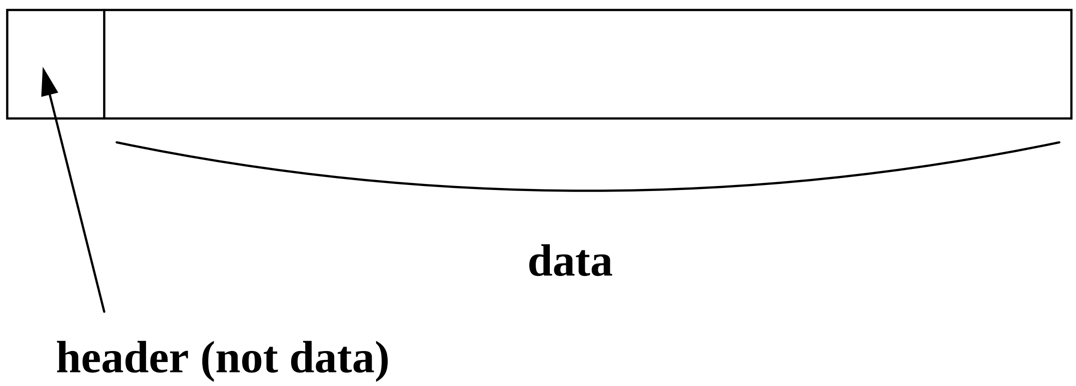
$$3.2 \times 10^{-3} + 1.75 \times 10^{-4} = 3.375 \times 10^{-3} \text{ sec}$$

   (about 3.4 milliseconds)

Simple Exercise with Packets

now we consider overhead of packets

a single link from A to B, but now file is sent in packets



packet length is 48 bytes, header is 5 bytes

Suppose a file of 200KB needs to be sent from A to B. The link bandwidth is 10Mbps, the link is radio (microwave), and the distance between A and B is 200km.

1. How long will it take to send the file to B using packets (above) ?
2. What is the effective bandwidth of this link (using packets) ?

solution to packet exercise

1. first, calculate "payload" of packet in bits

$$(48-5) \text{ bytes/packet} = 43 \times 8 = 344 \text{ bits/packet}$$

2. second, calculate number of bits to transmit

$$200\text{KB} = 200 \times 1024 \times 8 \text{ bits} = 1.6384 \times 10^6 \text{ bits}$$

3. third, calculate total number of packets to send

$$\frac{1.6384 \times 10^6}{344} = 4762.79 \text{ packets}$$

   note: depending on link protocol, maybe not possible to send 79% of a packet — so round up to 4763 packets

4. fourth, calculate total number of bits in all packets

$$4763 \times 48 \times 8 \approx 1.829 \times 10^6 \text{ bits}$$

5. time to transmit all these bits

$$\frac{1.829 \times 10^6}{10 \times 10^6} = 0.1829 \text{ sec}$$

6. propagation delay for last bit of last packet

$$\frac{200 \times 10^3}{3 \times 10^8} = 6.667 \times 10^{-4} \text{ sec}$$

7. total time:

$$0.1829 + 6.667 \times 10^{-4} = 0.1836 \text{ sec}$$

what about effective bandwidth?

$$\frac{\text{data-size}}{\text{total-time}} = \frac{200 \times 1024 \times 8}{0.1836} = 8.93\text{Mbps}$$

Effective Bandwidth Reconsidered

why we usually base this on large files

suppose we reconsider previous exercise, but with small file of only 43 bytes (one packet) — will effective bandwidth be the same?

1. packet payload remains 344 bits
2. only 344 data bits to send in one packet
3. total number of bits to send is $48 \times 8 = 384$
4. time to transmit all these bits
$$\frac{384}{10 \times 10^6} = 3.84 \times 10^{-5}\ \text{sec}$$
5. propagation delay for last bit remains 6.667×10^{-4} sec
6. total time:
$$3.84 \times 10^{-5} + 6.667 \times 10^{-4} = 7.05 \times 10^{-4}\ \text{sec}$$

so the effective bandwidth is
$$\frac{344}{7.05 \times 10^{-4}} = 0.488\text{Mbps}$$

very low effective bandwidth! too much latency was included in this calculation; in this course, we only calculate effective bandwidth for *large* files

Store-and-Forward Packet Switches

sequential versus concurrent processing

packet switching networks can use two techniques for forwarding

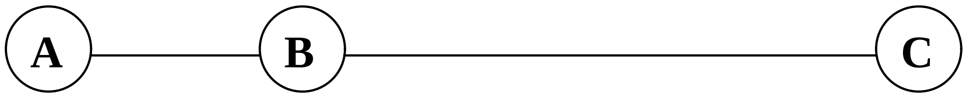
1. "store and forward" — switch reads entire packet first before deciding how to forward it
2. "cut through" — switch starts to forward beginning of packet even as remainder of packet is being received

    requires accurate timing in switch hardware

many packet switching networks use store-and-forward technique, so we consider exercises for this type of switch

simple exercise with store-and-forward switch

consequences of buffering



B is a store-and-forward switch. The A-B link distance is 500 meters and the B-C link distance is 1500 meters. Both links are electric cables at 10Mbps raw bandwidth. Frames are used in the link protocols and the frame size is 1500 bytes (ignore headers in this exercise). What is the total end-to-end delay to send 9000 bytes from A to C?

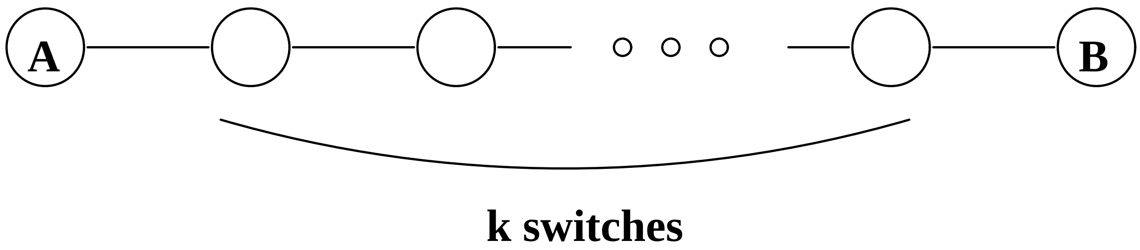
solution

1. number of frames to send: 6
2. number of bits to send: $9000 \times 8 = 7.2 \times 10^4$
3. time to transmit all frames out from A
$$\frac{7.2 \times 10^4}{10 \times 10^6} = 7.2 \text{ msec}$$
4. time for last bit of last frame to propagate to B
$$\frac{500}{2.3 \times 10^8} = 2.17\ \mu\text{sec}$$
5. time when B starts forwarding last frame
$$7.2 \times 10^{-3} + 2.17 \times 10^{-6} \approx 7.2 \times 10^{-3}$$
(assuming that A started at time $t = 0$)
6. time when B sends (forwards) last bit of last frame
$$7.2 \times 10^{-3} + \frac{1500 * 8}{10 \times 10^6} = 8.4 \times 10^{-3}$$
7. time for last bit of last frame to propagate to C
$$\frac{1500}{2.3 \times 10^8} = 6.52\ \mu\text{sec}$$
8. time when C receives last bit of last frame
$$8.4 \times 10^{-3} + 6.52 \times 10^{-6} \approx 8.4 \times 10^{-3}$$

what would it be without store-and-forward switch?

exercise with multiple store-and-forward switches

generalizing to *k* switches



let the link distance be the same for all links, 100 meters (this will make the propagation delay negligible); bandwidth is 10Mbps for every node, and A sends a single 1500 byte frame to B; each of the *k* switches is a store-and-forward switch

what is the total end-to-end latency the packet?

what would it be for a single A-B link covering the same distance?

solution to k switch exercise

1. time to transmit one frame
$$\frac{1500 \times 8}{10 \times 10^6} = 1.2 \times 10^{-3}\ \text{sec}$$
2. link propagation delay
$$\frac{10^2}{2.3 \times 10^8} = 4.35 \times 10^{-7}\ \text{sec}$$
– *we can ignore propagation delay*
3. the one frame is sent, received, sent, received $\ldots k+1$ times
$$(k+1) \times 1.2\ \text{msec}$$
is total time

note: different calculation if A has two or more frames to send!

what if there are no switches between A and B?

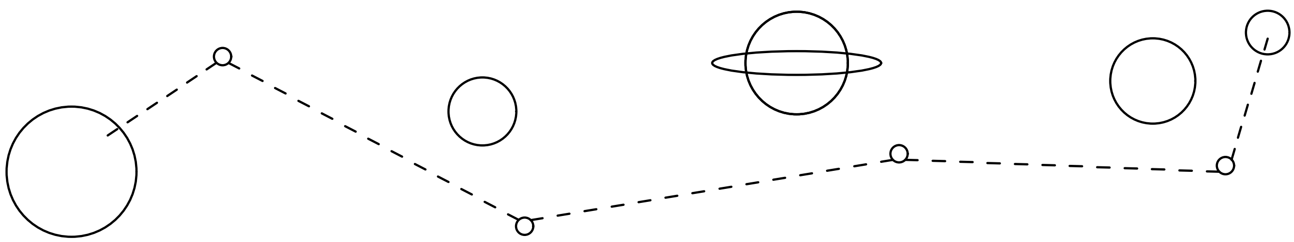
1. same time to transmit frame: 1.2 msec
2. distance is $(k+1) \times 100$ meters
$$\frac{(k+1) \times 10^2}{2.3 \times 10^8} = (k+1) \times 4.35 \times 10^{-7}\ \text{sec}$$
$\Rightarrow$ for reasonable k values,
propagation delay still insignificant

from the examples we have seen, store and forward switches add significant delay unless the amount of data to transmit is large ("large" implies many frames or packets)

interplanetary *k* switch exercise

networking over satellite links

consider two stations, one on a home planet, another on a moon of another planet — satellites are store-and-forward switches to make a network



for convenience, let distance of each link be 80,000km

bandwidth is 100Mbps

packet size is 4000 bits (no header)

amount of data to transmit: one packet

number of store-and-forward switches: *k*

what is total latency in transmitting the data?

what would it be without the store-and-forward swithes?

solution to interplanetary exercise

1. time needed to transmit data from source
$$\frac{4000}{100 \times 10^6} = 4 \times 10^{-5} \text{ sec}$$
2. propagation delay on first (and every) link
$$\frac{8 \times 10^4 \times 10^3 \text{ meters}}{3 \times 10^8 \text{ m/s}} = 0.26667 \text{ sec}$$
3. time when first store-and-forward switch receives last bit of first (and only) packet
$$4 \times 10^{-5} + 0.26667 \approx 0.26667$$
4. forwarding repeats steps 1-3 again k times; total is:
$$(k+1) \times 0.26667 \text{ sec}$$

what if there is a direct link over same distance?

1. transmit time remains 4×10^{-5} seconds
2. propagation delay is
$$\frac{(k+1) \times 8 \times 10^7}{3 \times 10^8} = (k+1) \times 0.26667$$
3. total is
$$4 \times 10^{-5} + (k+1) \times 0.26667 \approx (k+1) \times 0.26667$$

in this exercise, delay by store-and-forward
switches is insignificant!