ECE 1150: Computer Networks

Performance Measures: Delay and Throughput

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Objectives

- What are the main components of delay?
- Perform computations to calculate delay
- Difference between bit rate and throughput

Units

- Bits: Data
- Byte is 8 bits
- Data Rate, unit is bits per second (bps):
  - How many bits you can transmit in one sec?

Table 2.1 Units used to express data rates

Unit	Equivalent in bits per second
Bits per second (bps)	–
Kilobits per second (Kbps)	1,000 (10^3 bps)
Megabits per second (Mbps)	1,000,000 (10^6 bps)
Gigabits per second (Gbps)	1,000,000,000 (10^9 bps)
Terabits per second (Tbps)	1,000,000,000,000 (10^{12} bps)

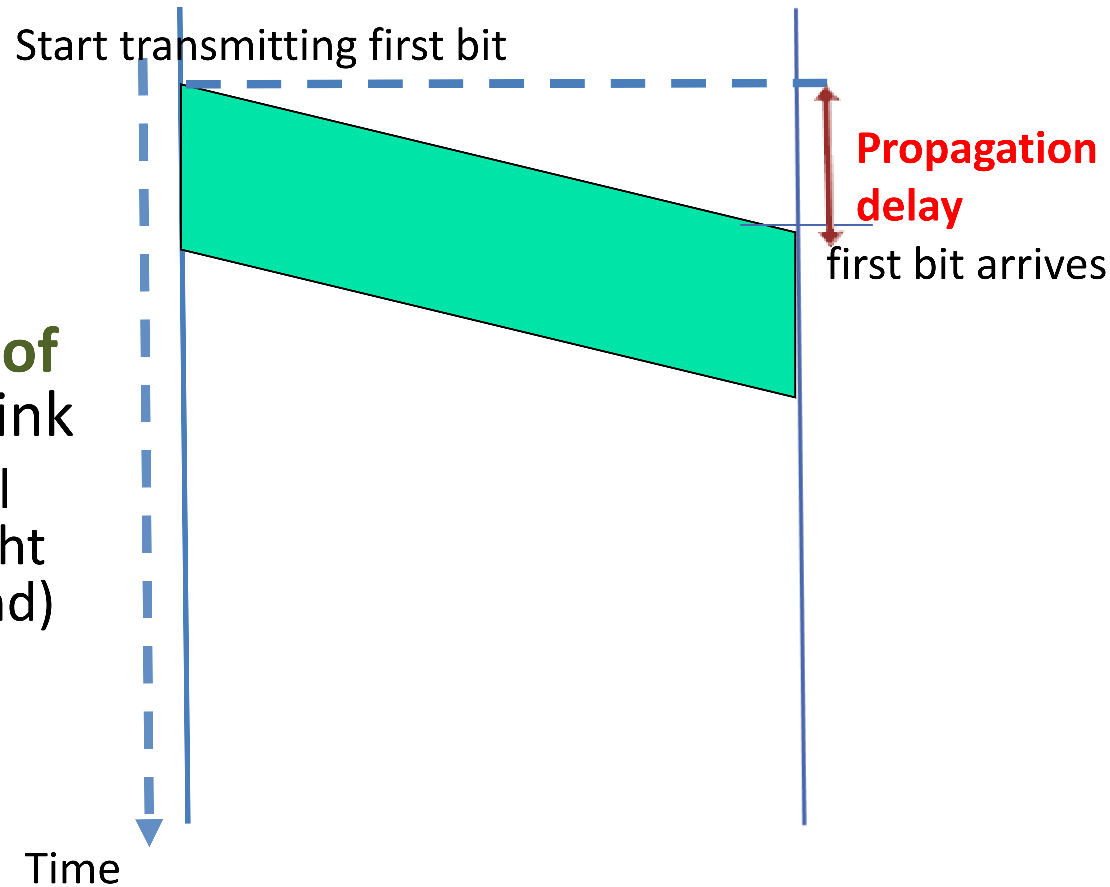
Exp.	Explicit	Prefix	Exp.	Explicit	Prefix
10^{-3}	0.001	milli	10^{3}	1,000	Kilo
10^{-6}	0.000001	micro	10^{6}	1,000,000	Mega
10^{-9}	0.000000001	nano	10^{9}	1,000,000,000	Giga
10^{-12}	0.000000000001	pico	10^{12}	1,000,000,000,000	Tera
10^{-15}	0.000000000000001	femto	10^{15}	1,000,000,000,000,000	Peta

Delay

- Propagation delay
- Transmission delay
- Processing delay
- Queuing delay

Propagation Delay

- How long does it take for *a* **bit to travel** from the source to the destination?
- Let L be the physical **length of the link**
- Let V be the propagation **velocity of the signal** along the link
  - Wireless signal travel with the speed of light ($3*10^8$ meters/second)
- **Propagation delay** is: $T_p = L/V$



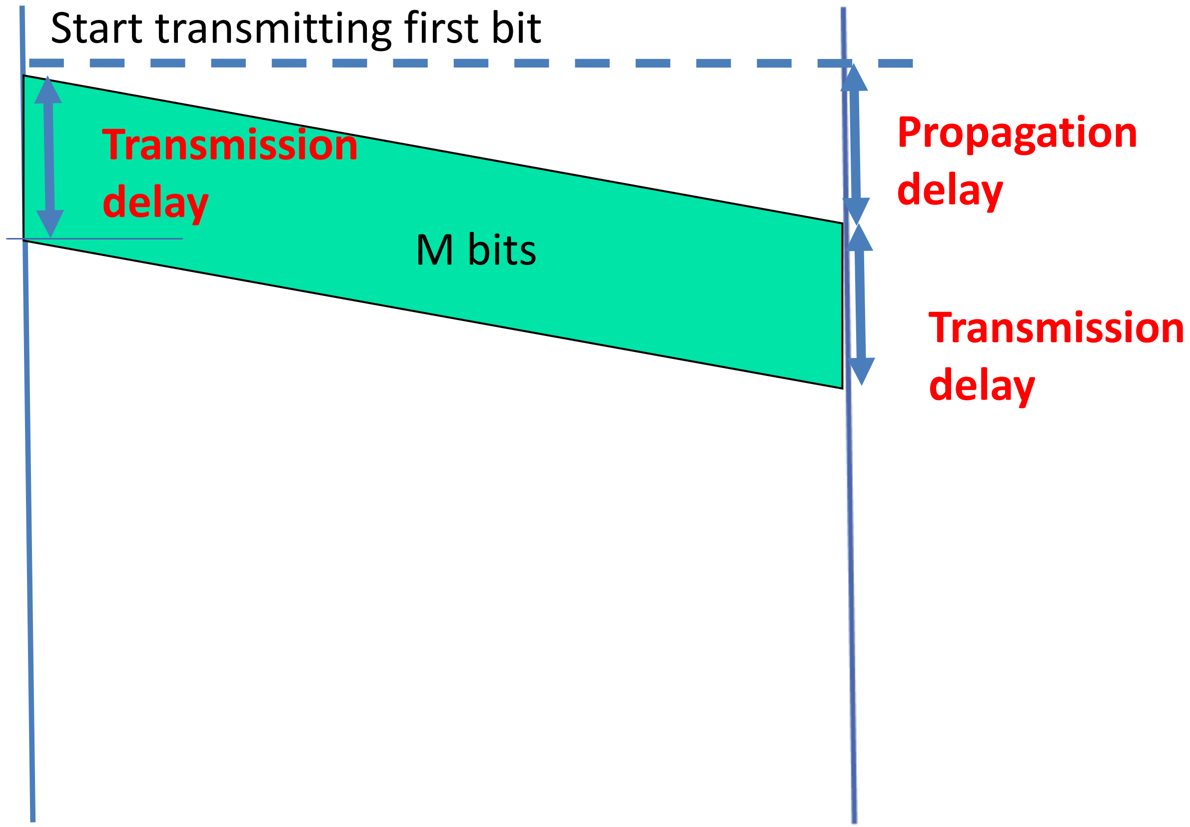
Thunderstorm:
Do you hear first thunder or see first the lightning? Why?

Sample Calculation – Propagation Delay

Question: How long does it take for one bit to travel from New York to San Francisco, over a link of length 4500 km and signal travels with speed 0.8 * speed of light. Speed of light is $3*10^8$ m/sec

Transmission Delay

- Time required to get message of M bits over a link of bit rate B



- $T_t = M/B$
  - Number of bits/bit rate of link

Question

- Assume a 100 Kbyte file and a link (channel) of 28.8Kb/s, how long does it take to transmit the file?

Tophat: Q_Transmission delay

Get Link Speed based on Maximum Delay

- If you know the maximum delay you application can tolerate, then you can choose the speed of the link accordingly
  - Know max delay T_t and file size (M)

- What is the bit rate of a link that can send an M bit message in T_t seconds?
  - $B = M/T_t$

Question

- Assume an application that requires a maximum transmission delay of 100msec and a channel of 28.8kbps, what is the maximum file size?

Final answer: 360 bytes

- Assume an application that requires a maximum transmission delay of 100msec and a channel of 28.8kbps, what is the maximum file size?
  - Max. file size (M) = Max delay (T_t) x Bit rate (B)

    =(0.1 sec)*(28,800 bits/sec)

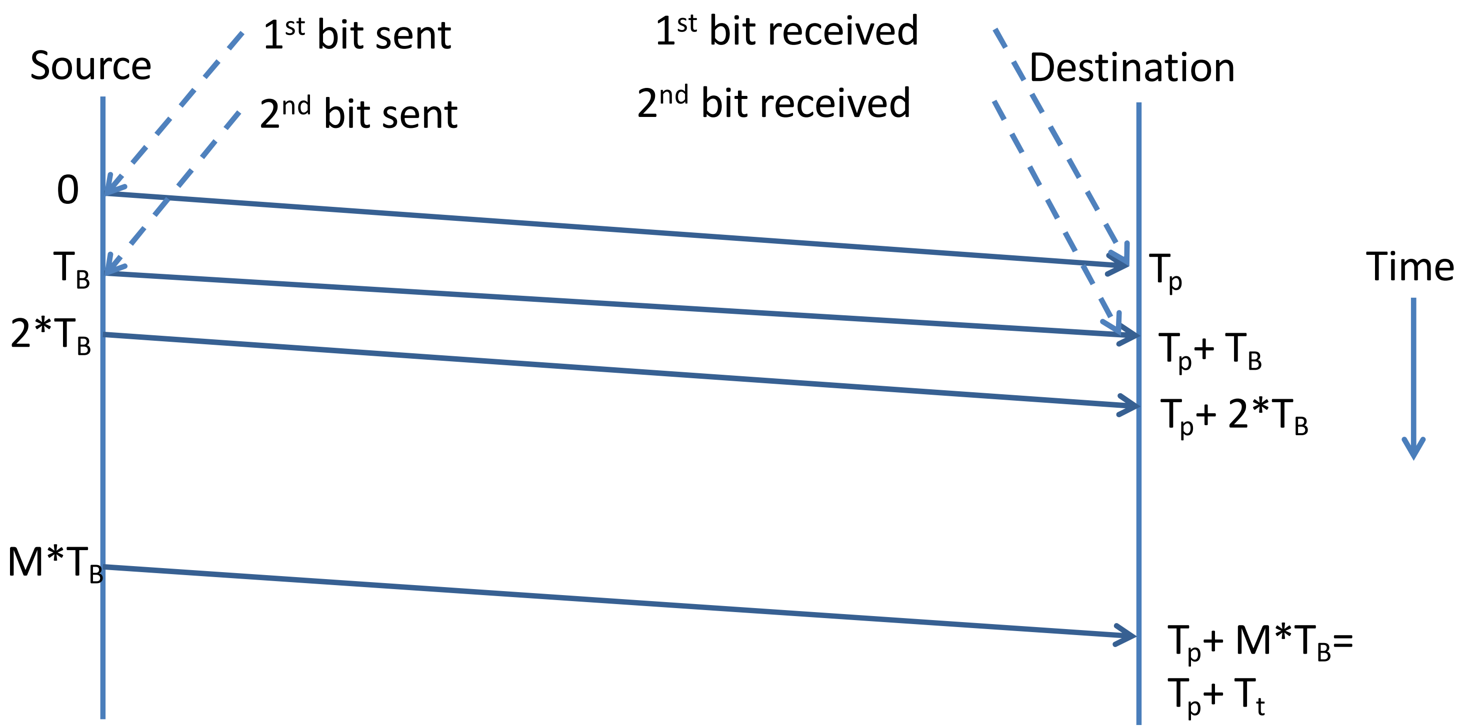
    = 2,880 bits
  - 2,880 bits / 8 = 360 bytes

Total delay over a link

- How long would it take for a receiver to get an M bits file sent over a link of L meters, along which a signal propagates at speed V m/sec. The bit rate over the link is B bits. Time is calculated from start of transmission of first bit

Tophat: Q_Total delay over a link

T_p+T_T?



Note that a bit is sent every 1/B sec = T_B

In this case this is every $1/128*10^5$ = 8 microseconds (µsec)

Question 4

- How long would it take to receive a 10 megabyte file over a 5 km channel. The signal propagates with speed of V=0.9*speed of light, and bit rate is 128kbps (single link)?Find the delay in seconds. Round to nearest integer.

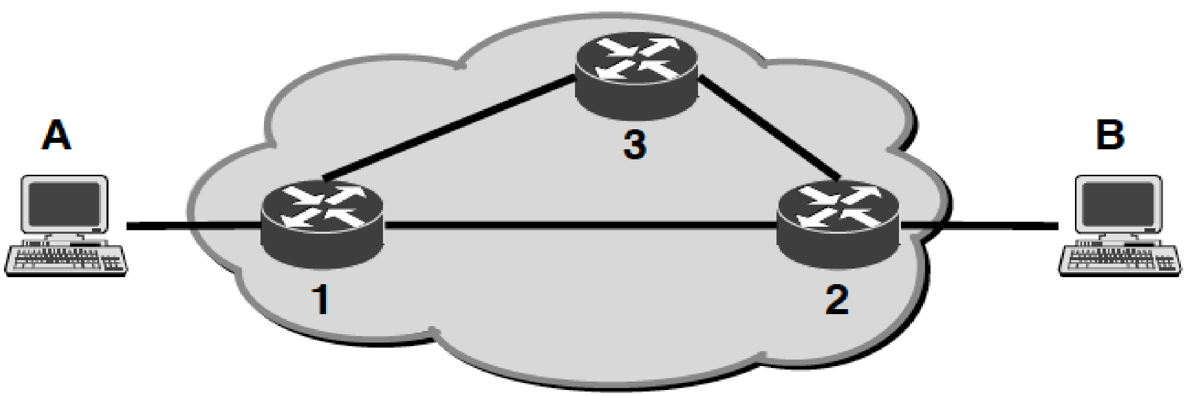
Solution

- How long would it take to receive a 10 megabyte file over a 5 km channel (V=0.9*speed of light) on a 128kbps channel?
- Answer
  - Total time = Propagation delay (T_p)+ Transmission delay (T_t)
  - $T_p = L/V = (5*10^3 \text{ m})/(0.9 *3*10^8 \text{ m/s})$
  - $T_t = M \text{ (bits) } /B = 8*10*10^6/(128*10^3)= 8/128 * 10^4 = 0.0625*10^4 = 625$ sec.
  - Total time =

Transmission delay is much larger than propagation delay

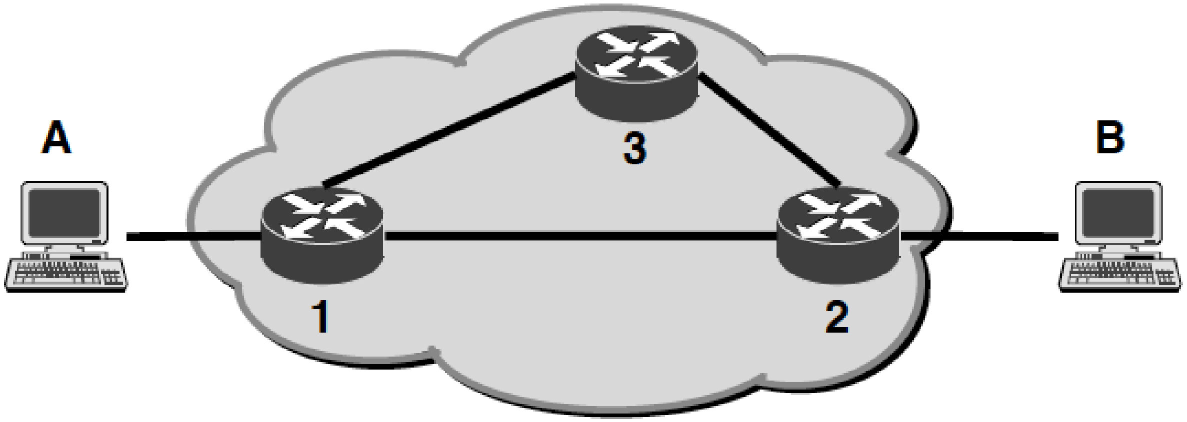
Multiple Hops Network

- End-to-end delay is the **sum of the delay encountered at each hop** from the source to the destination
  - There could be multiple hops..
    - E.g. Laptop to switch, switch to router, router to router, router to destination/server
    - E.g. A to router 1, to router 2, to destination B



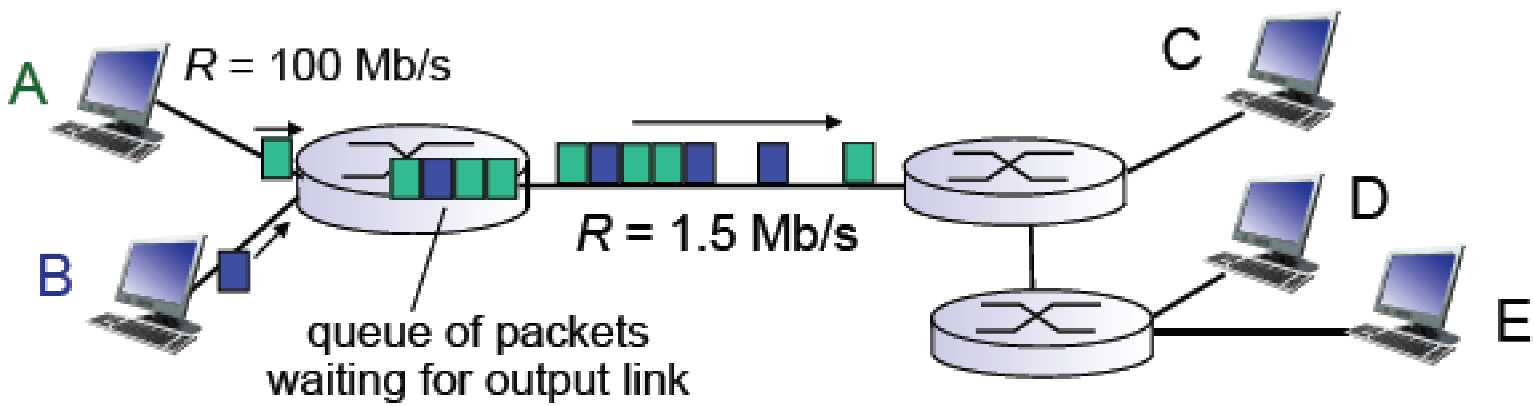
End to End Delay

- Assume path A -- 1 -- 2 -- B
  - Delay (A -> 1) + Delay (1 -> 2) + Delay (2->B)
  - This is called **end-to-end delay**



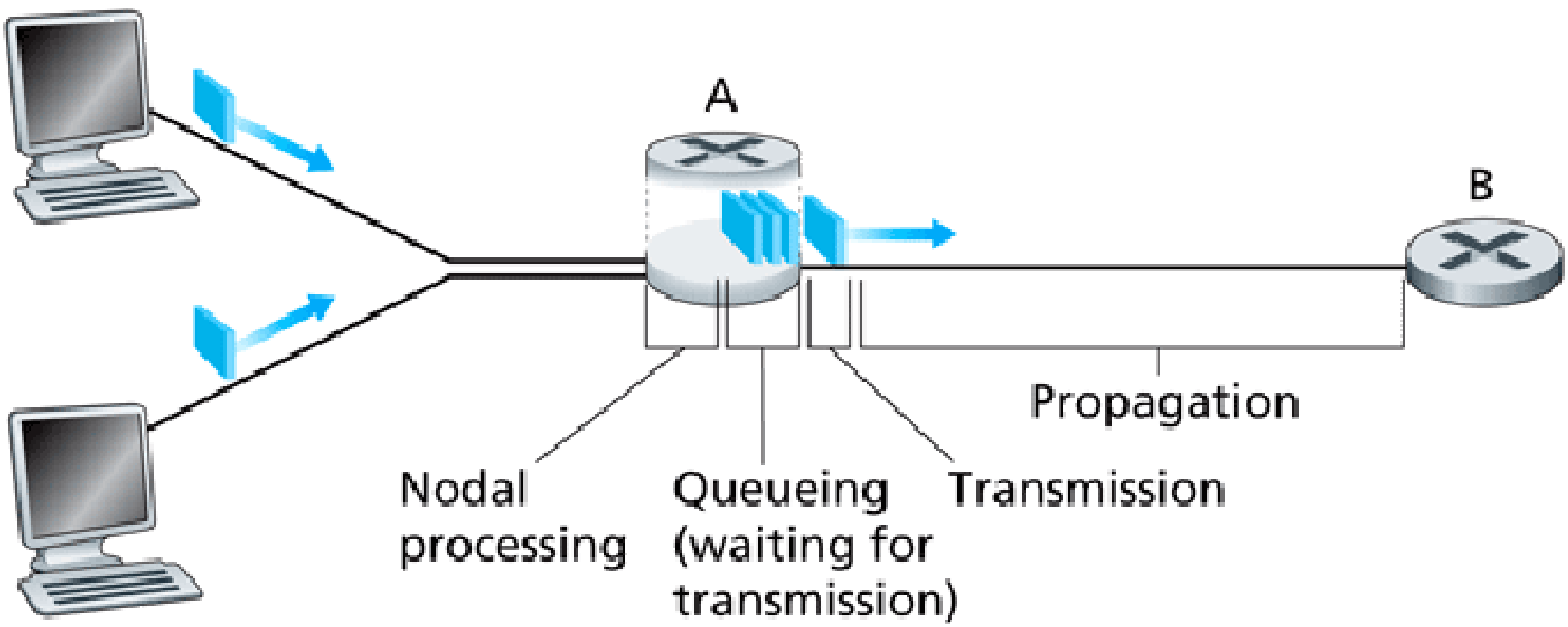
Processing Delay and Queuing Delay

- **Processing delay** is the time to process the packet within each intermediate node
  - for example to find what the next hop will be
- **Queuing delay** is another element where packet needs to wait in queue to be served



Total Delay

- Total delay = processing + queuing + transmission + propagation



Queuing Delay

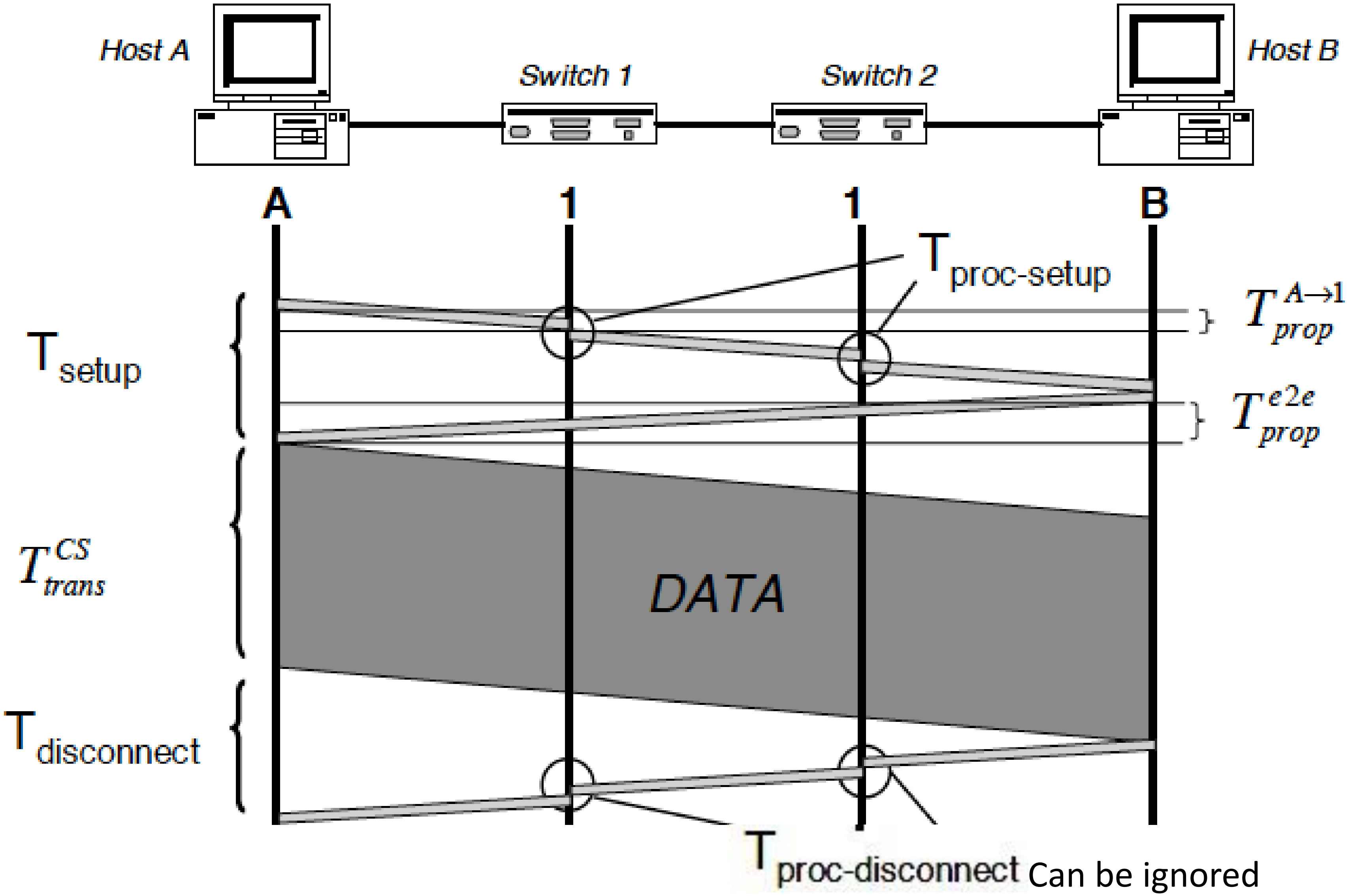
- More on queuing delay later

Delay in Circuit Switching

Delay in Circuit Switching

Total delay = time to set-up circuit + transmit message + time to release resources

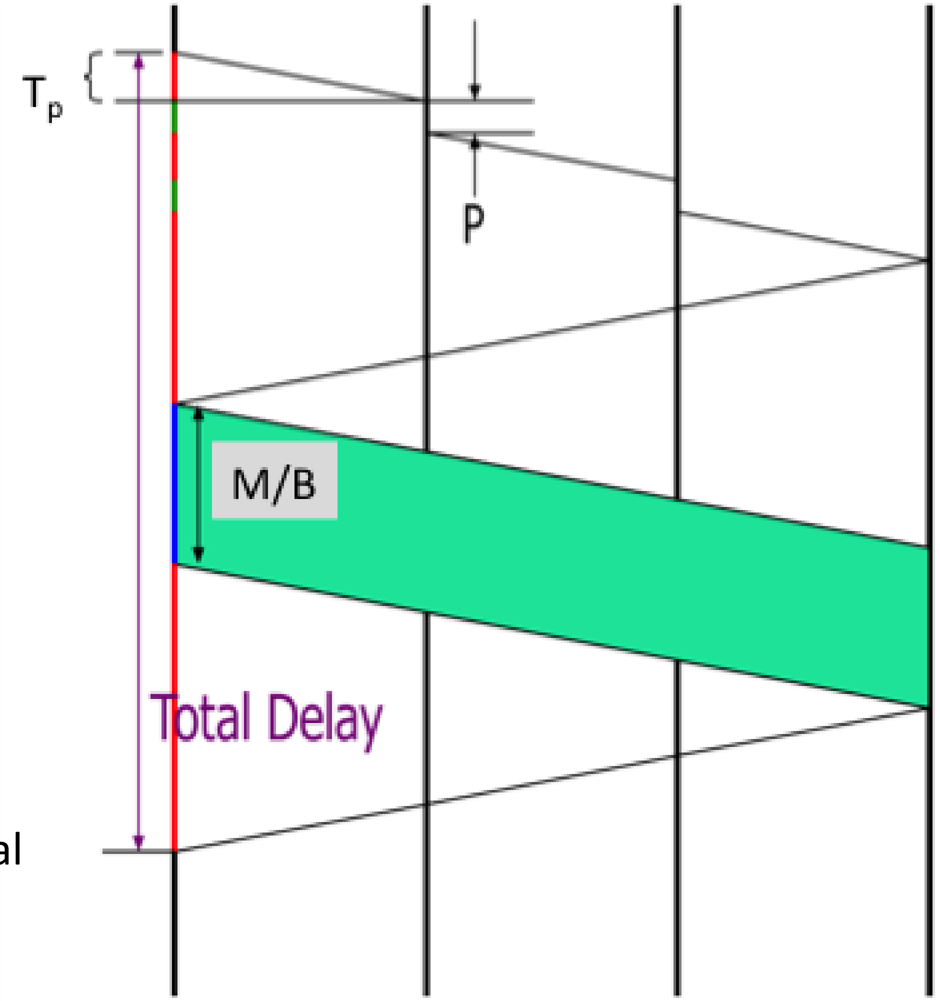
= total Propagation+ total transmission + total processing (to establish circuit)



Can be ignored

Example: Delay in Circuit Switching

- P: Per hop processing delay
- N_h: number of hops
- T_p: propagation delay per link
- B: Bit rate
- M: message size



total transmission delay = message size/bit rate = M/B

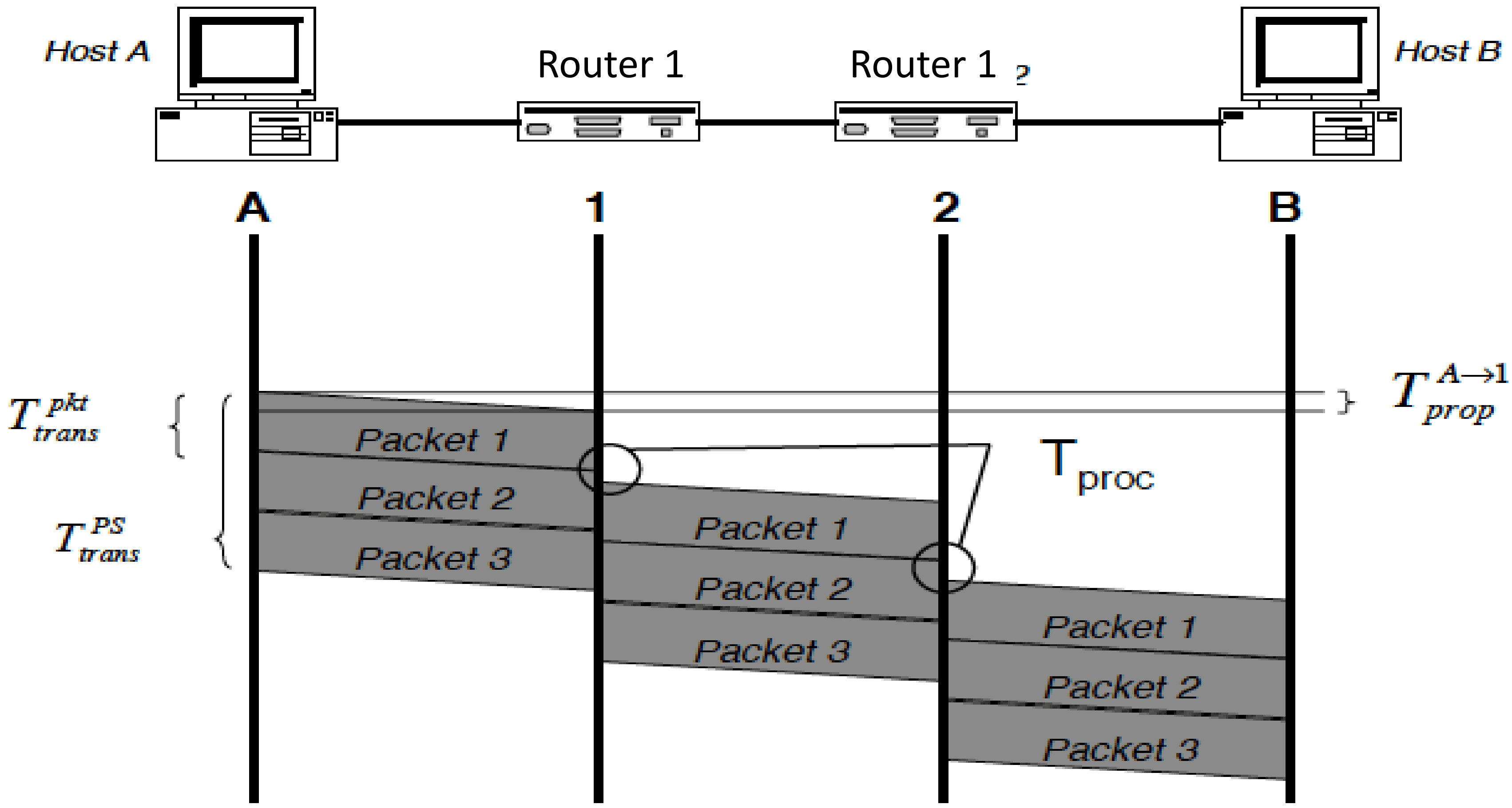
Processing delay = $(N_h - 1)\ P$

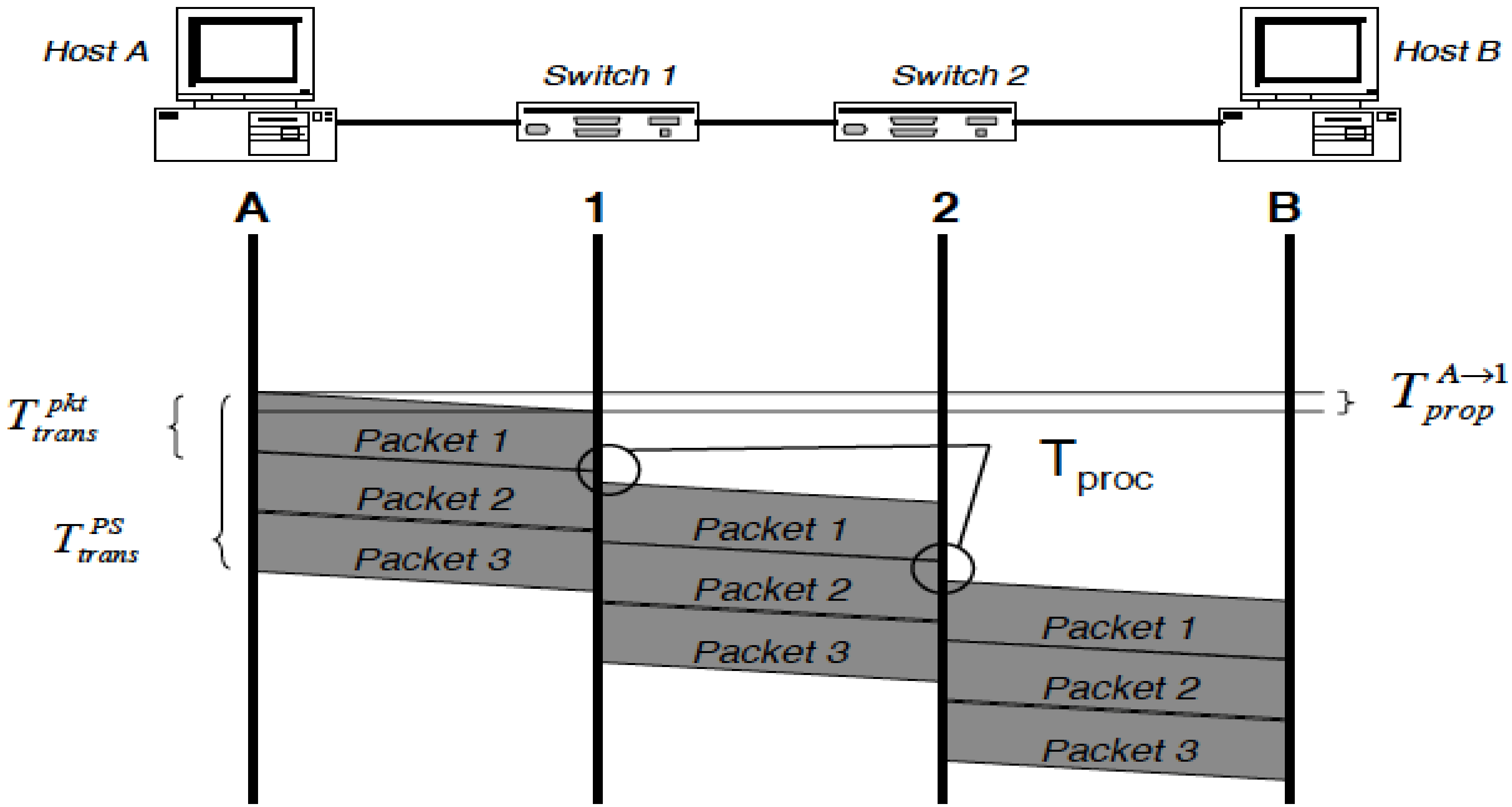
Propagation delay **one way** = $N_h\ T_p$

Total delay= time to set up connection + total transmission time + time to release the connection

Delay in Packet Switching

Total delay= total propagation+ total transmission delay of all packets + total queuing + total processing





Host A
Switch 1
Switch 2
Host B
A
1
2
B
T^{pkt}_{trans}
T^{PS}_{trans}
$T^{A\to 1}_{prop}$
T_{proc}
Packet 1
Packet 2
Packet 3
Packet 1
Packet 2
Packet 3
Packet 1
Packet 2
Packet 3

Example: Delay in Packet Switching

- P: Per hop processing delay
- Q_d: Queuing wait time
- N_h: number of hops
- N_m: number of packets
- T_p: Link propagation delay
- T_t: transmission delay per packet

Total delay= total propagation along all links + total transmission of the Nm packets + delay of store and forward + total processing in intermediate nodes + total queuing wait time

$$= N_h\ T_p + N_m\ T_t + (N_h - 1)\ (T_t + P) + Q_d$$

Note: Total store and forward for the first packet at intermediate routers = $(N_h-1)\ T_t$

Tophat

Q_Propagation delay in multihops

If a transmission goes over N hops. Each link along the transmission has propagation delay Tp. Then total propagation delay is

A	N x Tp
B	(N-1)x Tp

Q_ Queuing delay

If a transmission goes over a path of a total of N hops, and each intermediate device adds Q seconds in queuing. Then total queuing delay in the transmission is

A	N x Q
B	(N-1) x Q

Packet Switching - Problem

Alice and Bob are **4 hops** apart on a datagram packet-switched network where each link is **1 mile long**. The speed of light in the wire is approximately **125,000 miles/s. Processing delay at intermediate devices is 5ms**. **Packets are 1500 bytes** long. The **bit rate** over each link is **56kbit/s** (original speed of Internet backbone links in the 80s). If Bob sends a **10-packet message to Alice**, how long will it take Alice to receive the entire message. Routers store and forward. Ignore the queuing delay.

Packet Switching - Solution

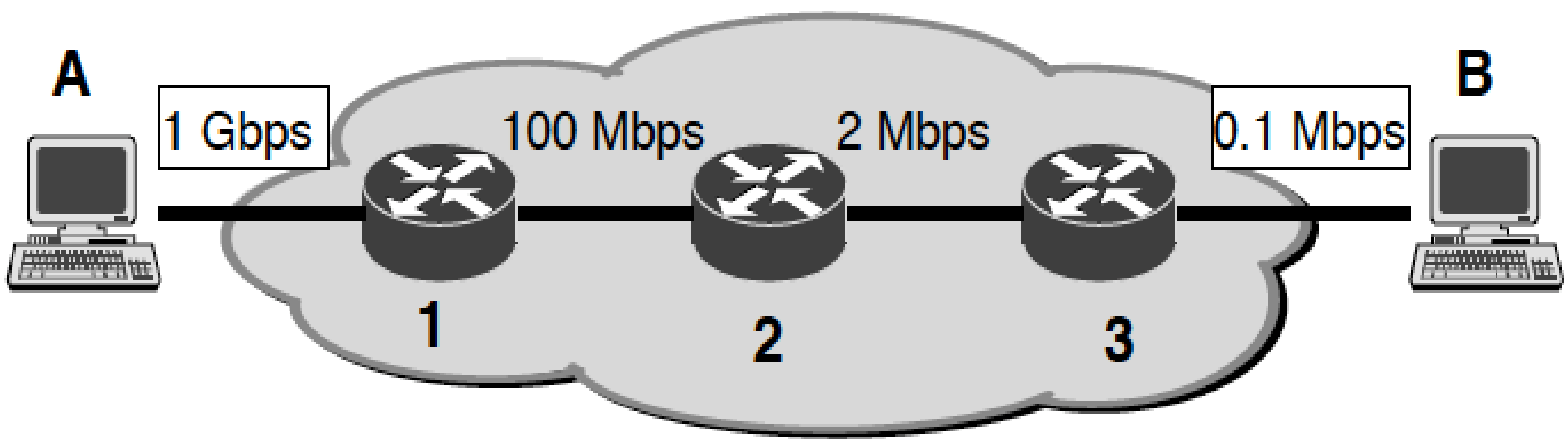
Alice and Bob are 4 hops apart on a datagram packet-switched network where each link is 1 mile long. Per-hop processing delay is 5µs. Packets are 1500 bytes long. All links have a transmission speed of 56kbit/s (original speed of Internet backbone links in the 80s). The speed of light in the wire is approximately 125,000 miles/s. If Bob sends a 10-packet message to Alice, how long will it take Alice to receive the entire message?

- Answer:
  - Number of hops N_h=4,
  - Number of packets N_m=10,
  - Per-hop processing delay P=5µs=0.00005s,
  - Link propagation delay T_p = distance/speed of light = 1/125,000
  - Packet size = 1500 bytes = 1500*8=12,000 bits,
  - Packet transmission delay T_t = packet size/transmission speed = 12,000/56000 =**0.214s**.

Delay=N_h T_p + N_m T_t + (N_h-1) (T_t +P)=0.000032 + 2.14 + 0.642 + 0.000015 = 2.78s.

Bottleneck Link

- In multihop network, the overall rate is determined by the link with the lowest data rate
- Exceeding that rate results in overflow and data loss



Throughput

- Throughput is the effective rate

- In real situations, actual data rate as seen in the system is influenced by many factors besides the transmitter's data rate.
  - Channel access mechanisms, loading, queuing delays etc may affect the actual (average) data rate seen by the user.

Throughput example

- If it takes **10 sec** on an average to send a **1MByte** file from point A to B, what is the effective throughput of the network.

Throughput = amount of useful data (payload)/total time required to transmit this data

= $(8*10^6)/10=0.8$Mbps

Note that 10 sec includes all delay sources (transmission, queuing..)

Question: throughput

Q_Throughput

Tophat Q_ throughput

Suppose you want to send a 1000Bytes file as chunks of data (as packets) but in doing so , you add a total of 300 Bytes overhead bit to the file you want to send! The bit rate is 10Kbps. If the delay after adding overhead is 1.04seconds. What is the throughput?

A	(1300x8)/1.04
B	(1000x8)/1.04
C	None of the above

Throughput - Overheads Question

Suppose you want to send a 1000Bytes file as chunks of data (as packets) but in doing so , you add a total of 300 Bytes overhead bit to the file you want to send! Your transmitter's data rate (also the link data rate) is 10Kbps.

A) You now transmit 1000B+ 300B through the channel. How long does it take for your to transmit the entire file?

B) How long will it take you if there were no overheads?

C) What is the throughput . Compare with the original transmission rate?

D) How efficient is your sending mechanism (due to the overheads)?

Final Answers

a) 1.04sec b) 0.8 sec c) 7.69kbps d) 76.9%

Exercise

File of size $M=10^6$ bytes. If packet switching is used then the file will be segmented into N_m=500 packets, each contains 48 Bytes of header in addition to the data. Bit rate of link is B=1Mbps

- What is the difference in the **transmission delay** between circuit switching and packet switching.
- What is throughput and efficiency of packet switching?
  - Assuming the total delay is approximated by the transmission delay only

Summary

- Delay components
- Delay in circuit switching and packet switching
- Throughput

Next

- Queuing delay analysis