

Simple Delay and Throughput Analysis

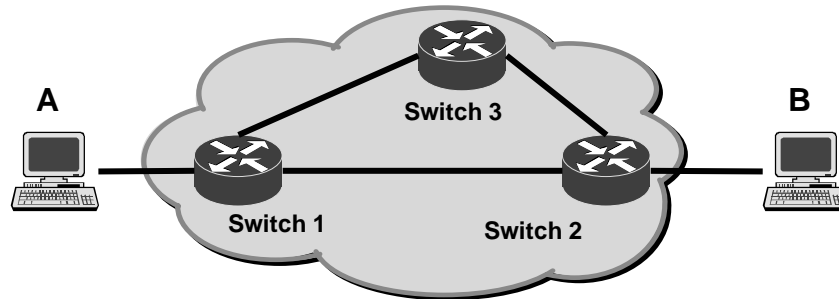
ECE466 - Tutorial

Overview of Topics

- Delay Analysis
- Throughput Analysis

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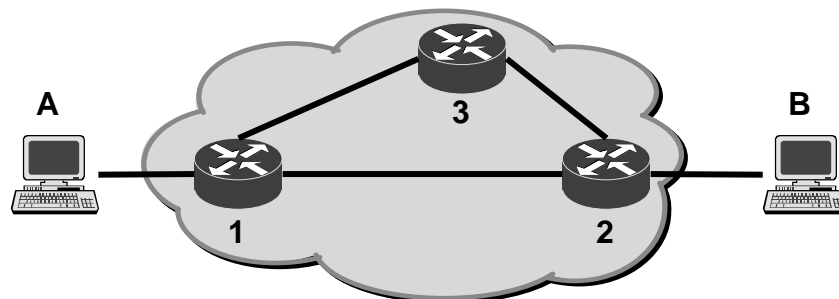
Delays in a Switched Network



- How long does it take to send three packets from A to B in
 - A packet switching network
 - A circuit switching network
- Which factors determine the delay?

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Delays in a Switched Networks



- All links have a transmission rate of $C=100$ Megabits per second (Mbps)
- We want to send 200 bytes of user data from A to B
 - Max. packet size is $L = 100$ bytes (including 50 byte header)
- Distance between any pair of hosts and routers is 50 kilometers (km)
- Routing is fixed: $A \rightarrow 1 \rightarrow 2 \rightarrow B$

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Transmission delay

- **Transmission delay** is the time it takes to transmit data on a link, and is determined by
 - D: Amount of data
 - C: Max. transmission rate (“capacity”) of a link
- In packet networks, transmission delay accounts for headers

Example:

Data X = 200 bytes
 Transmission rate C = 100 Mbps

Transmission delay in circuit switched networks: $T_{trans}^{CS} = X/C = 200 \text{ bytes} / 100 \text{ Mbps} =$

Packet size L = 100 bytes

Header size A = 50 bytes

Number of packets =

$$\lceil X / (L - A) \rceil = 4$$

Transmission delay in packet network

$$T_{trans}^{PS} = 4 * A/C + X/C =$$

Transmission delay of packet

$$T_{trans}^{pkt} = L/C =$$

- In packet-switched networks (=store-and-forward networks), the transmission delay is experienced at each node
- In circuit-switched networks, the transmission delay is experienced only at the first node

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Propagation delay

- **Propagation delay** T_{prop} is the time that a transmitted bit needs to travel from one end of a link to the other end
- Propagation delay is only dependent on the speed at which signals travel on the transmission medium and the length of the link

Speed of light: $3 \cdot 10^8$ meters/sec,

Speed in guided media (approx.): $2 \cdot 10^8$ meters/sec

- Roundtrip propagation delay is twice the end-to-end propagation delay

Example:

Distance d = 50 km

Propagation delay of a link $T_{prop}^{link} = 50 \text{ km} / (2 \cdot 10^8 \text{ m/sec})$

$$= 25 \cdot 10^{-5} \text{ sec} = 250 \mu\text{s}$$

End-to-End Propagation delay $T_{prop}^{e2e} = (T_{prop}^{A \rightarrow 1} + T_{prop}^{1 \rightarrow 2} + T_{prop}^{2 \rightarrow B}) = 3 \cdot 250 \mu\text{ sec} = 750 \mu\text{s}$

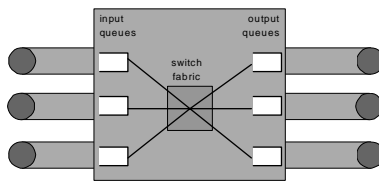
Roundtrip delay $T_{prop}^{rt} = 2 \cdot T_{prop}^{e2e} = 1500 \mu\text{s}$

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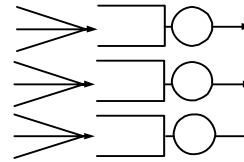
Processing and Queueing Delay in Packet Switches

- Processing delay of a packet includes time to lookup the routing table and to move packet over the switch fabric
- Queueing delay of a packet is the waiting time in the output buffers (input queue in some case)
- Circuit-switched networks do not have processing or queueing delay

concrete view



abstract view



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Processing and Queueing Delay in Packet Switches

- **Processing delay T_{proc}** of a packet is a constant delay at each switch
 - No processing delay in circuit-switched networks
 - Since T_{proc} is small it is often neglected
- **Queueing delay T_{queue}** of a packet which arrives at time t consists of the transmission delay of packets that
 1. are in the node at time t , and
 2. go to the same output link,
 3. and are transmitted earlier than the arrival at time t .
 - Queueing delay is variable, i.e., it depends on the backlog in the node due to other traffic
 - Variable queueing delay is what makes analysis of packet networks hard

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Delays for connection setup and termination

- In circuit-switched and virtual-circuit packet networks, there is in addition a connection setup delay T_{setup} and a connection termination delay $T_{\text{disconnect}}$
- Setup delay consist of the roundtrip propagation delay and processing delay at each node:

$$T_{\text{setup}} = T_{\text{prop}}^{\text{rt}} + N \cdot T_{\text{proc-setup}}$$

where

N is the number of nodes

$T_{\text{proc-setup}}$ is the per-node processing delay for setup

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Delays for connection setup and termination

- The connection termination delay depends on the site that terminates the connection
- If the caller disconnects the connection, we have

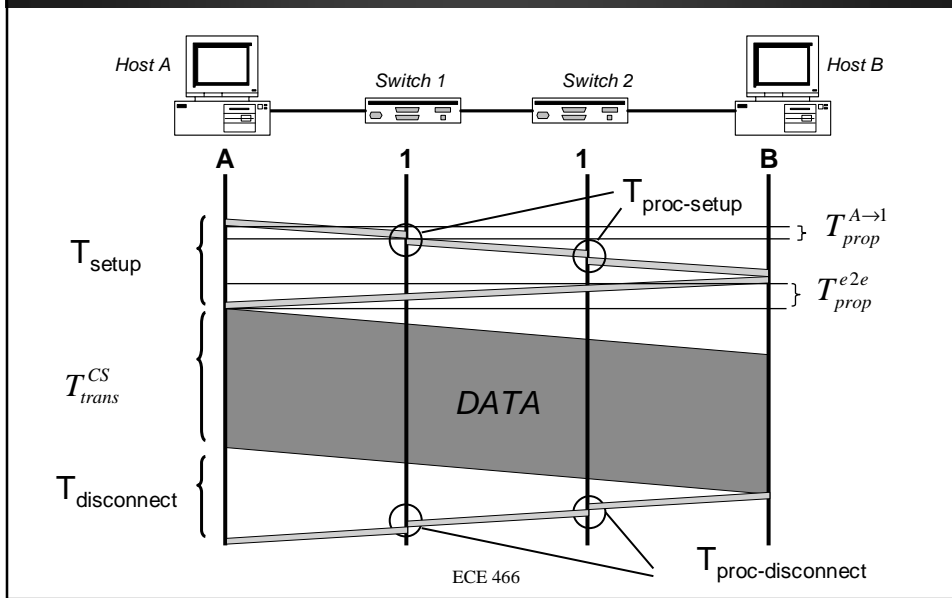
$$T_{\text{disconnect}} = T_{\text{prop}}^{\text{rt}} + N \cdot T_{\text{proc-dicsonnect}}$$

- If the callee disconnects the connection, we get

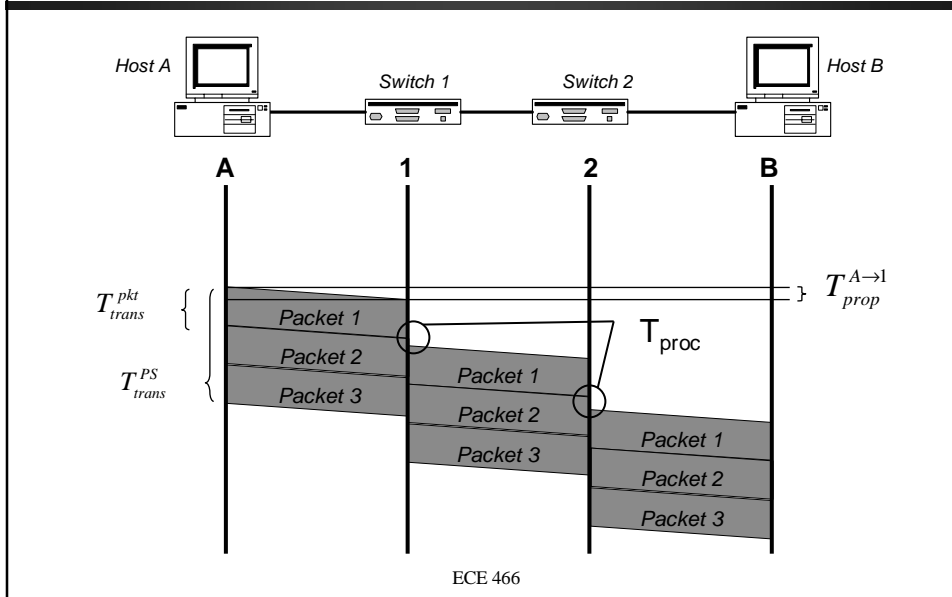
$$T_{\text{disconnect}} = T_{\text{prop}}^{\text{e2e}} + N \cdot T_{\text{proc-dicsonnect}}$$

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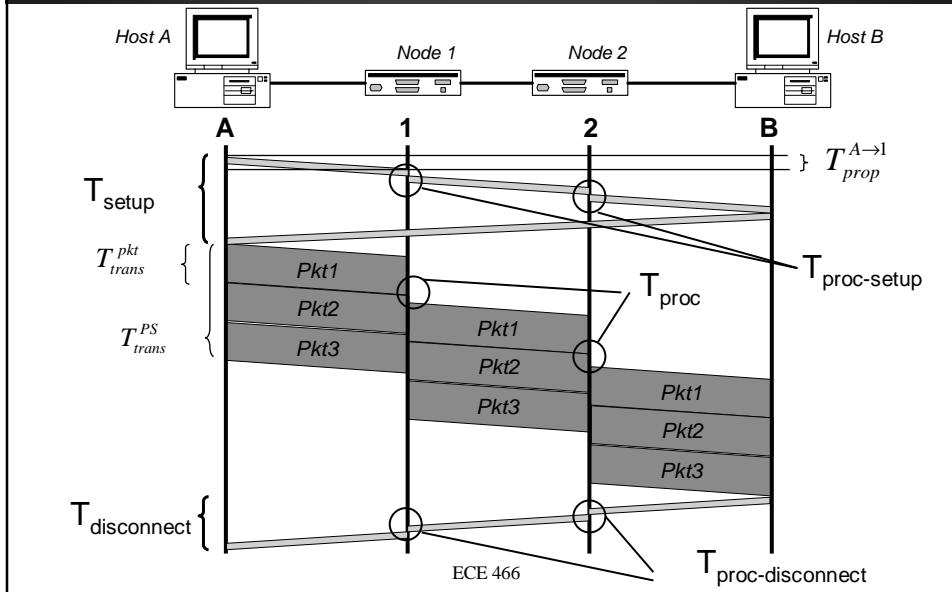
Delay in a Circuit Switched Network



Delay with Datagram Packet Switching



Delay with Virtual Circuit Packet Switching



Putting it all together

•**Exercise:** Do the calculations also for virtual circuit and circuit-switched network. Plug in the numbers and compare !

- Determine the delay for transmitting three packets in a datagram network
- We use superscripts to denote the delay at nodes

$$\begin{aligned}
 \text{Delay}^{\text{datagram}} = & T_{prop}^{A \rightarrow 1} + T_{prop}^{1 \rightarrow 2} + T_{prop}^{2 \rightarrow B} + (T_{proc}^1 + T_{queue}^1 + T_{trans}^{pkt,1}) \\
 & + (T_{proc}^2 + T_{queue}^2 + T_{trans}^{pkt,2}) + (T_{proc}^3 + T_{queue}^3 + T_{trans}^{pkt,3})
 \end{aligned}$$

- Since $T_{trans}^{pkt} = T_{trans}^{pkt,1} = T_{trans}^{pkt,2} = T_{trans}^{pkt,3}$

$$T_{proc} = T_{proc}^1 = T_{proc}^2 = T_{proc}^3$$

we get
$$\text{Delay}^{\text{datagram}} = T_{prop}^{e2e} + \underbrace{3 \cdot (T_{proc} + T_{trans}^{pkt})}_{\text{fixed}} + \underbrace{(T_{queue}^1 + T_{queue}^2 + T_{queue}^3)}_{\text{variable}}$$

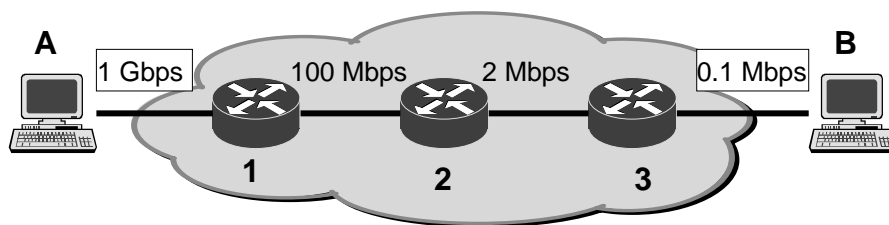
Throughput Analysis

- Throughput denotes the output rate in bits per seconds of an
 - End-to-end flow: Data rate at which packets are transmitted between sender and receiver
 - Node: Data rate at which a node transmits packets
 - Network: Rate at which traffic departs from the network

* This is called Stop-and-Wait flow control

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Bottleneck Link



- The maximum throughput of a network is determined by the link with the smallest data rate, the bottleneck link.
- What happens if the input rate exceeds the rate at the bottleneck link?
Buffer overflows at the bottleneck link, resulting in loss rate

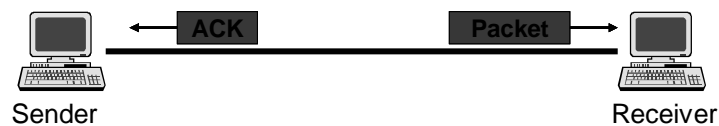
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Throughput Analysis

- Ideally, the throughput of each flow is equal to the rate at which the sender wants to transmit data
- Factors which limit the throughput:

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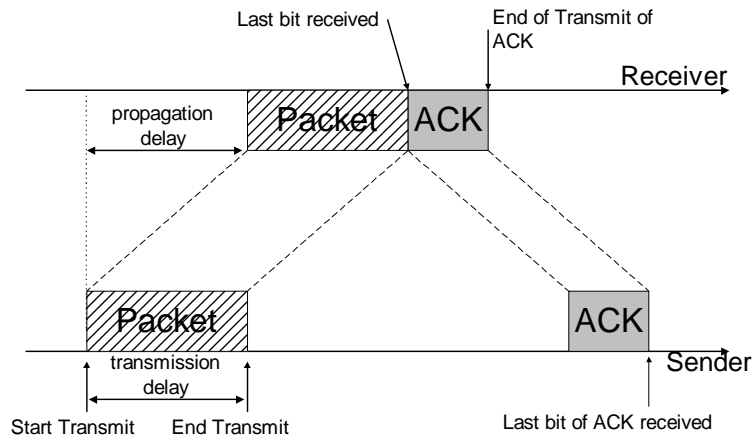
Case Study: Throughput Analysis of Flow Control Protocol



- Sender has to wait for an acknowledgement before it can send the next packet.
- This algorithm called **Stop-and-Wait flow control**
- **Question:** What is the maximum data rate (Maximum Throughput) at which the sender can transfer data to the receiver throughput in bits per second ?

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Analysis of Stop-and-Wait



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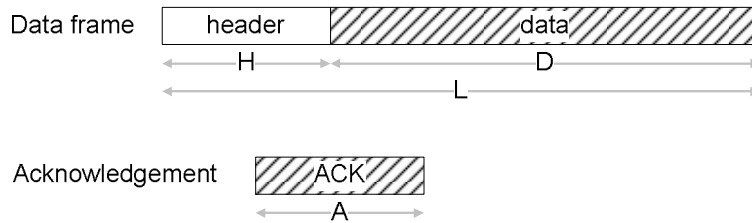
Analysis of Stop-and-Wait

- **Notation:**

C	= Transmission rate in bps
I	= Propagation delay
H	= Number of bits in a packet header
D	= Number of data bits in a packet
L	= Total length of a packet ($L = D + H$)
A	= Total length of an ACK frame
L/C	= Transmission delay for a frame

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Analysis of Stop-and-Wait

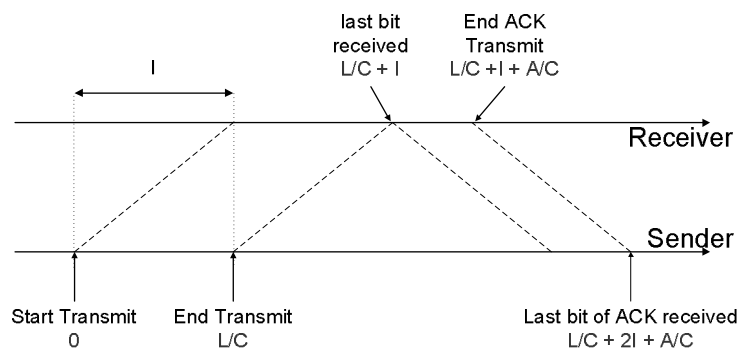


$$a = \frac{\text{propagation delay}}{\text{transmission delay}} = \frac{l}{L/C}$$

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Analysis of Stop-and-Wait

- Transmission of a frame (in Stop-and-Wait):



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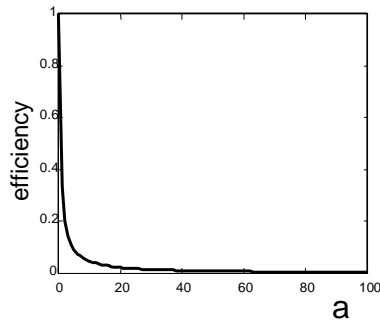
Analysis of Stop-and-Wait

- **Normalized maximum throughput (efficiency)** is the maximum fraction of time when the protocol is transmitting data
- Efficiency of Stop-and-Wait Flow Control:

$$efficiency = \frac{D/C}{L/C + A/C + 2I} = \frac{D}{L + A + 2IC}$$

- Assuming that H and A are negligible (H=A=0) we obtain:

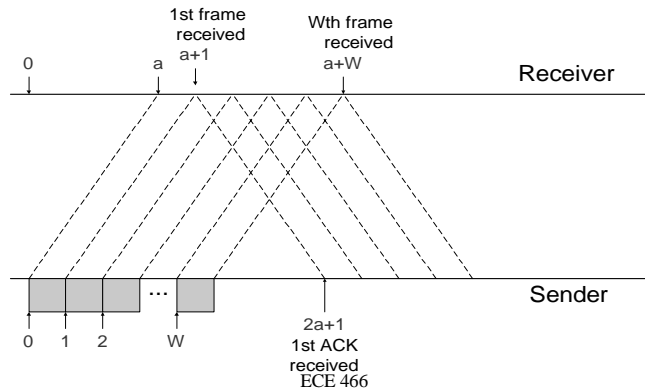
$$efficiency = \frac{D}{D + 2IC} = \frac{1}{1 + 2a}$$



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Sliding Window Flow Control

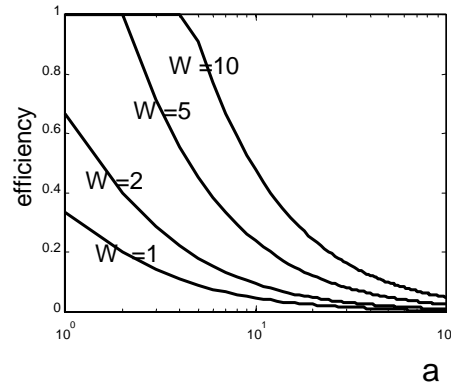
- **Sliding Window Flow Control**
 - Each packet is acknowledged (Assume: L=1)
 - Sender can have up to W acknowledgements outstanding



Analysis of Sliding Windows

- If the window size is sufficiently large the sender can continuously transmit packets:
- $W \geq 2a+1$: Sender can transmit continuously
efficiency = 1
- $W < 2a+1$: Sender can transmit W frames every $2a+1$ time units

$$\text{efficiency} = \frac{W}{1+2a}$$



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