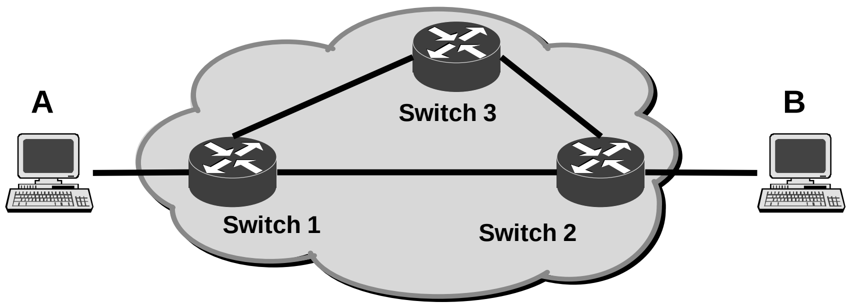
Simple Delay and Throughput Analysis

ECE466 - Tutorial

Overview of Topis

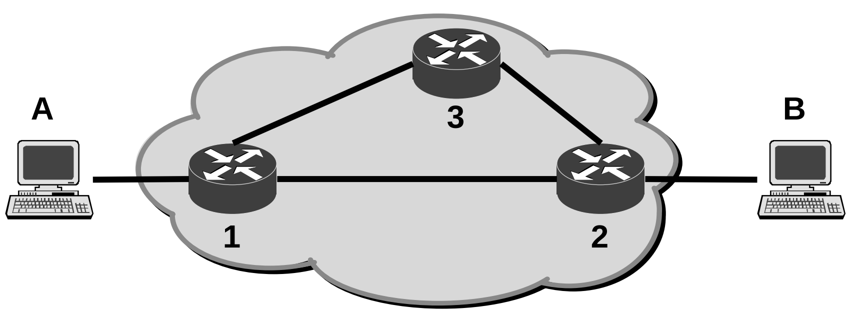
- Delay Analysis
- Throughput Analysis

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?

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 → 1 → 2 → B

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

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

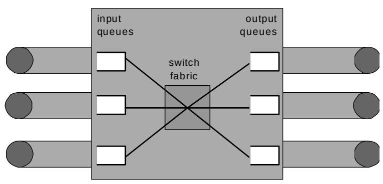
Example:

Distance	d = 50 km
Propagation delay of a link	$T_{prop}^{link} = 50\,km/(2 \cdot 10^8\ m/\sec)$ $= 25 \cdot 10^{-5} \sec = 250 \mu s$
End-to-End Propagation delay	$T_{prop}^{e2e} = \left(T_{prop}^{A \to 1} + T_{prop}^{1 \to 2} + T_{prop}^{2 \to B}\right) = 3 \cdot 250 \mu \sec = 750 \mu s$
Roundtrip delay	$T_{prop}^{rt} = 2 \cdot T_{prop}^{e2e} = 1500 \mu s$

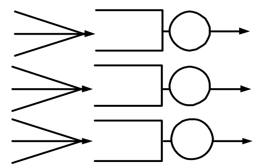
Processing and Queueing Delay in Packet Switches

- 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



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

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 $T_{disconnect}$
- Setup delay consist of the roundtrip propagation delay and processing delay at each node:

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

where

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

Delays for connection setup and termination

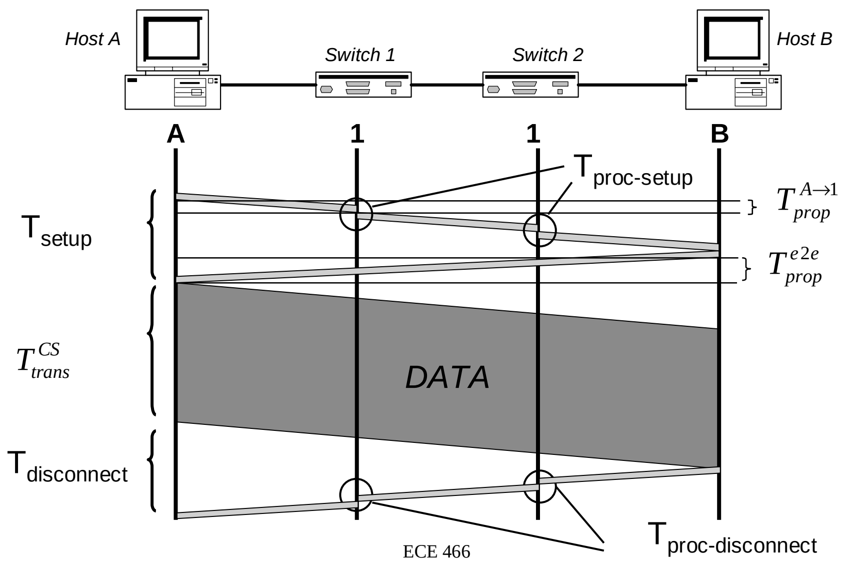
- The connection termination delay depends on the site that terminates the connection
- If the caller disconnects the connection, we have

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

- If the callee disconnects the connection, we get

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

Delay in a Circuit Switched Network



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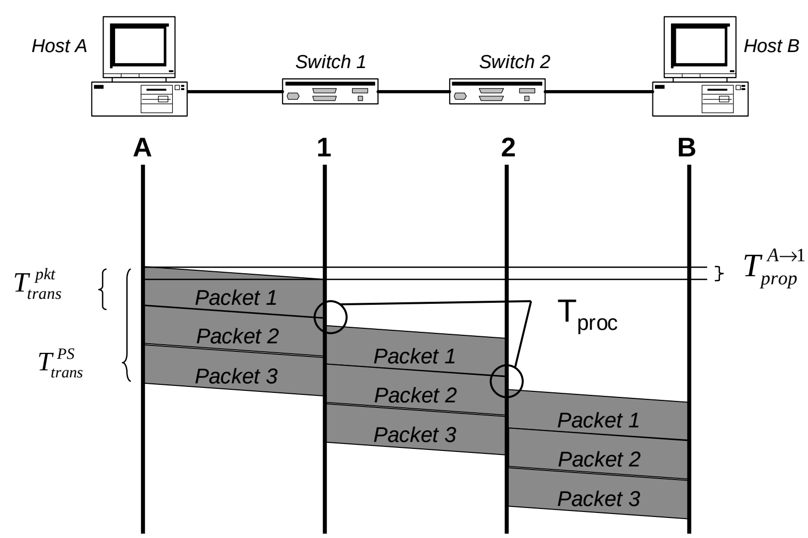
Delay with Datagram Packet Switching



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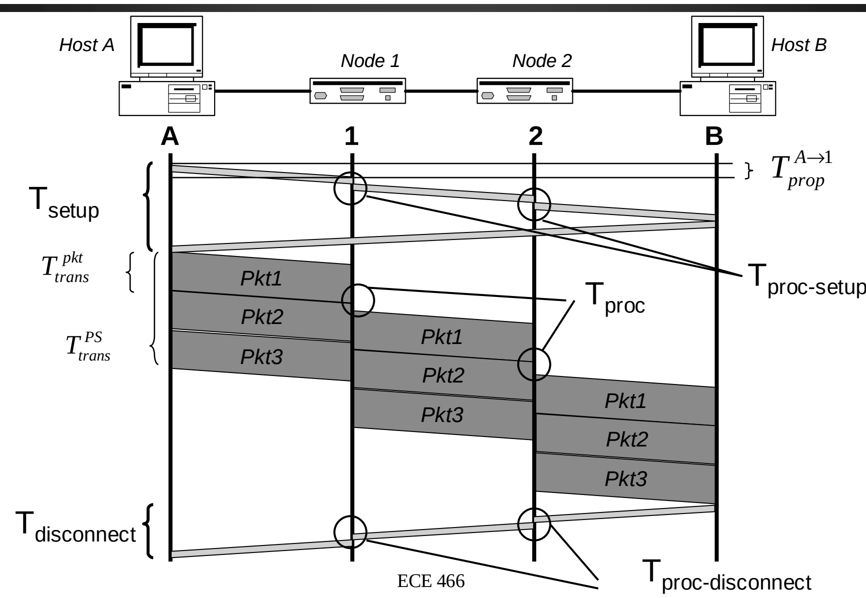
Delay with Virtual Circuit Packet Switching



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

$$Delay^{datagram} = T^{A\to 1}_{prop} + T^{1\to 2}_{prop} + T^{2\to B}_{prop} + \left(T^{1}_{proc} + T^{1}_{queue} + T^{pkt,1}_{trans}\right)$$
$$+ \left(T^{2}_{proc} + T^{2}_{queue} + T^{pkt,2}_{trans}\right) + \left(T^{3}_{proc} + T^{3}_{queue} + T^{pkt,3}_{trans}\right)$$

- Since

$$T^{pkt}_{trans} = T^{pkt,1}_{trans} = T^{pkt,1}_{trans} = T^{pkt,1}_{trans}$$
$$T_{proc} = T^{1}_{proc} = T^{2}_{proc} = T^{3}_{proc}$$

we get

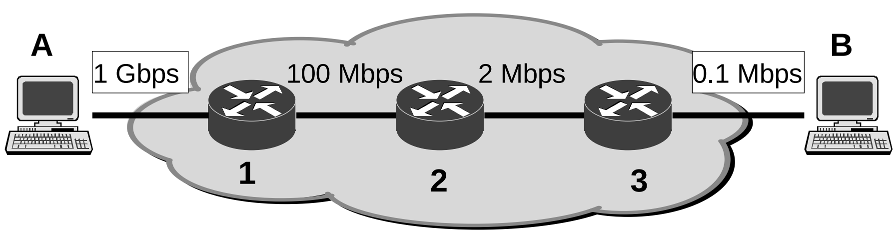
$$Delay^{datagram} = \underbrace{T^{e2e}_{prop} + 3\cdot\left(T_{proc} + T^{pkt}_{trans}\right)}_{\text{fixed}} + \underbrace{\left(T^{1}_{queue} + T^{2}_{queue} + T^{3}_{queue}\right)}_{\text{variable}}$$

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

Bottleneck Link



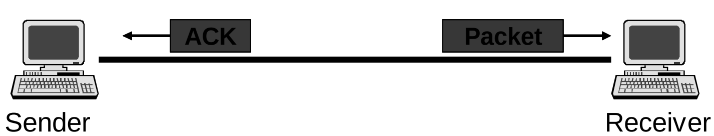
- The maximum throughput of a network is determined by the link with the smallest data rate, the bottleneck link.

- What happens if the input rate exceeds the rate at the bottleneck link?
  Buffer overflows at the bottleneck link, resulting in loss rate

Throughput Analysis

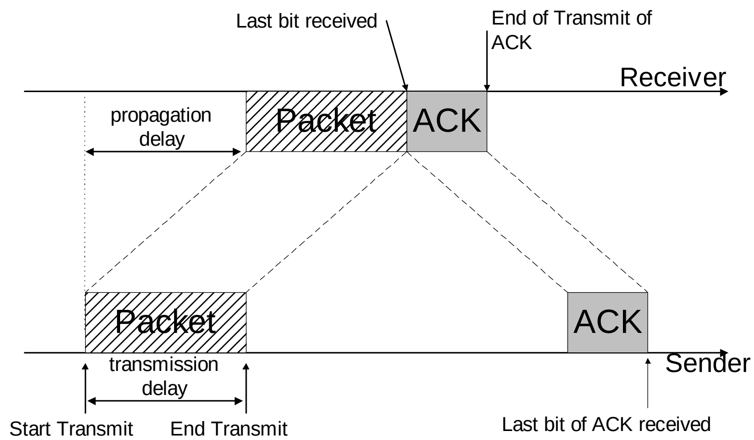
- Ideally, the throughput of each flow is equal to the rate at which the sender wants to transmit data
- Factors which limit the throughput:

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 ?

Analysis of Stop-and-Wait

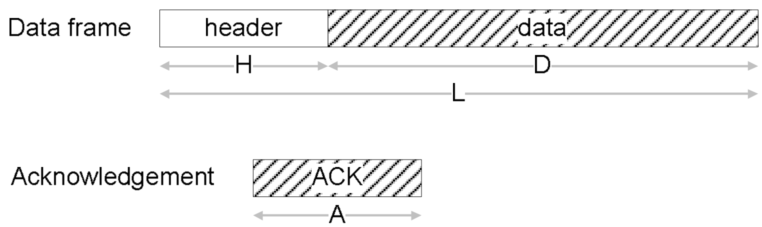


Analysis of Stop-and-Wait

- **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

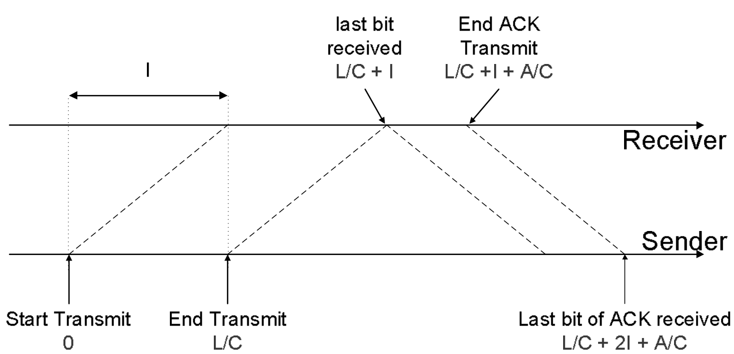
Analysis of Stop-and-Wait



$$a = \frac{propagation \quad delay}{transmission \quad delay} = \frac{I}{L/C}$$

Analysis of Stop-and-Wait

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



Analysis of Stop-and-Wait

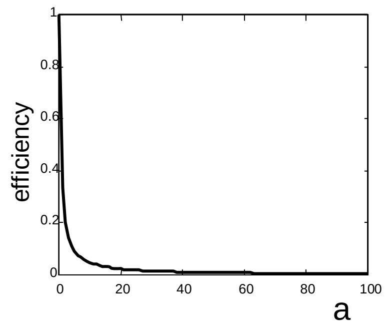
- **Normalized maximum throughput** (**efficiency**) is the maximum fraction of time when the protocol is transmitting data

- Efficiency of Stop-and-Wait Flow Control:

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

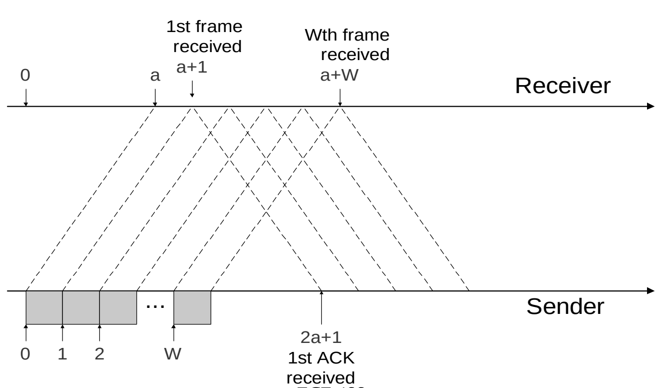
- Assuming that H and A are negligible (H=A=0) we obtain:

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



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

$$\text{efficiency} = 1$$

- **W $<$ 2a+1**:Sender can transmit *W* frames every *2a+1* time units

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