21AIE211
Introduction to COMPUTER NETWORKS
2-0-3 3

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DEEMED TO BE UNIVERSITY

Chancellor's Inspirational Message

- ***"Along with a connection to the Internet, we also need to rediscover our 'Inner-net' connection.*** **Real Education teaches us how to manage both our internal and external worlds" Amma, Sri Mata Amritanandamayi, Chancellor**

Delays

Key points in Delay, Loss and Throughput in Networks

- Understand bandwidth and delay calculations in store and forward transmission
- Understand different delays in a network
  - Transmission delay
  - Propagation delay
  - Processing delay
  - Queuing delay

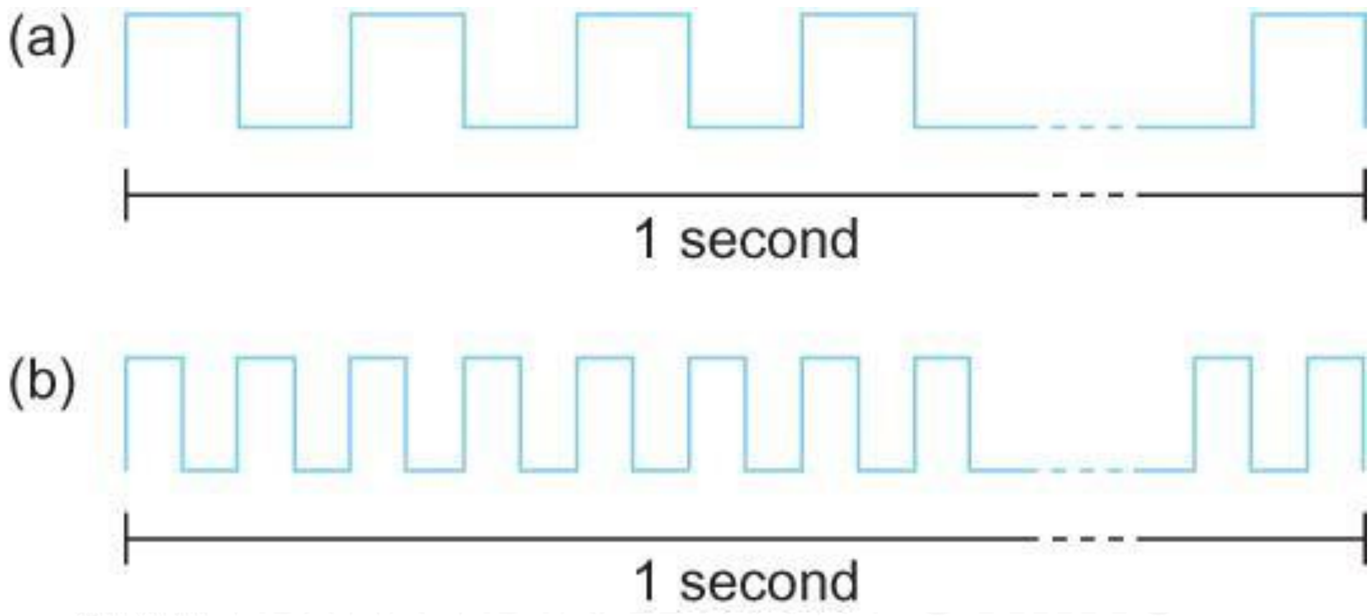
- Packet Loss
- Throughput

- Real Internet delays

Sending packets over a link with bandwidth(B)

- Bandwidth
  - Width of the frequency band
  - Number of bits per second (bps) that can be transmitted over a communication link
- Consider a link with bandwidth 1Mbps example
  - 1 Mbps: 1 x 10^6 bits/second
- How long it takes to send 1 bit? 1 x 10^{-6} seconds
  - Each bit occupies 1 micro second space.

Bandwidth



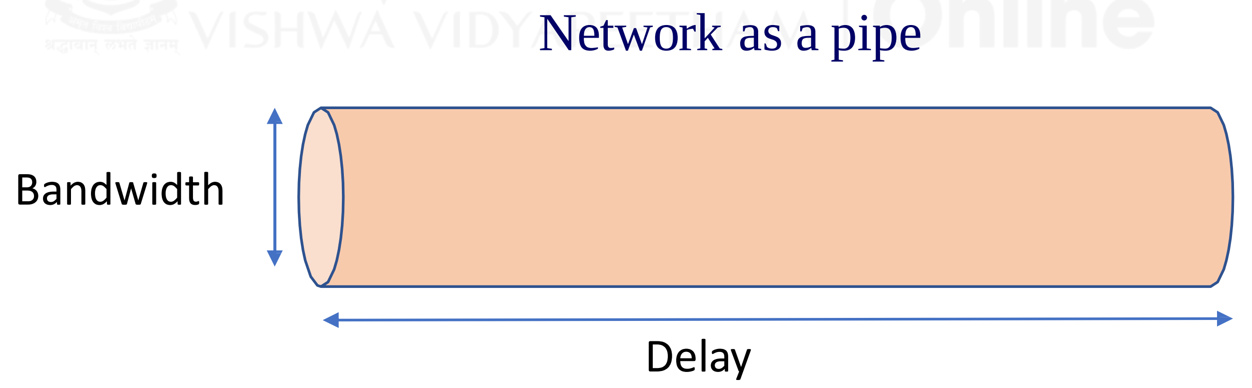
Bits transmitted at a particular bandwidth can be regarded as having some width:

(a) bits transmitted at 1Mbps (each bit 1 μs wide);

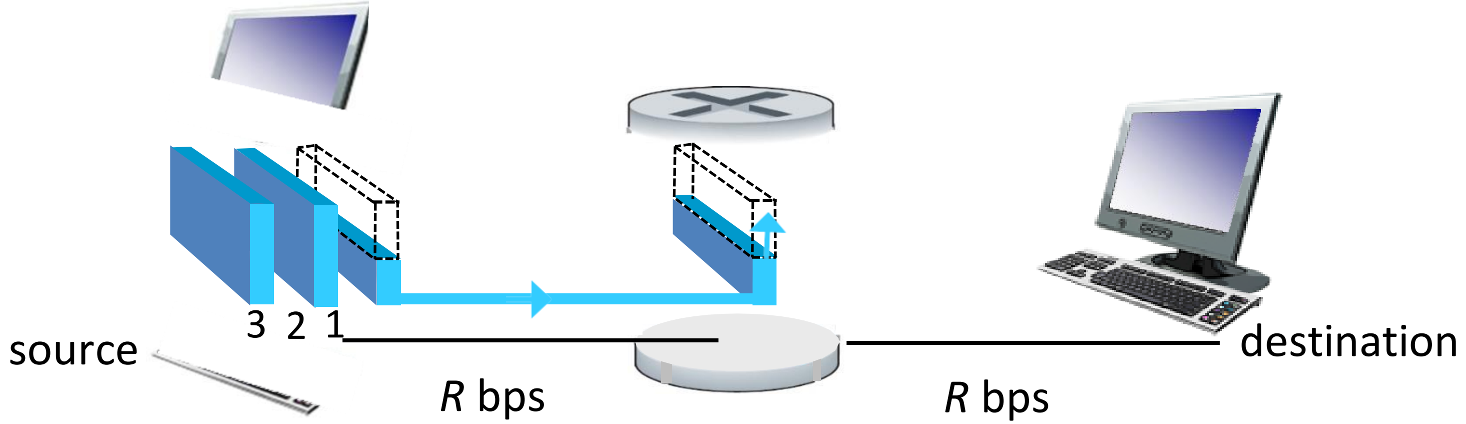
(b) bits transmitted at 2Mbps (each bit 0.5 μs wide).

Delay x Bandwidth

- Link between a pair of processes can be thought of a hollow pipe
    - Latency (delay) = length of the pipe
    - bandwidth = the width of the pipe



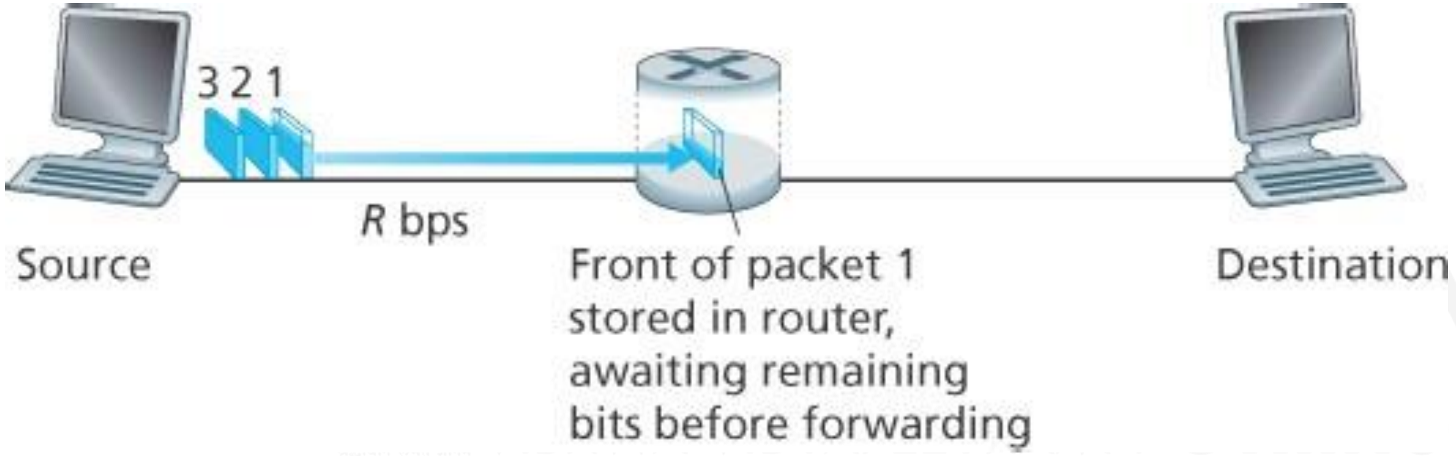
Packet Switching: Delay calculation(D)



- **Store and forward** - entire packet must arrive at router before it can be transmitted on next link
- *L*: length of the packet= 7.5 Mbits (1Mb= 10^6 bits)
- *R*: capacity of the link/bandwidth = 1.5Mbps
- takes *L/R* seconds to transmit (push out) *L*-bit packet into link at *R bps*
- one-hop transmission delay = *L/R* = 5sec
- Two-hop transmission delay = 2L/R = 10sec

Store-and-forward transmission

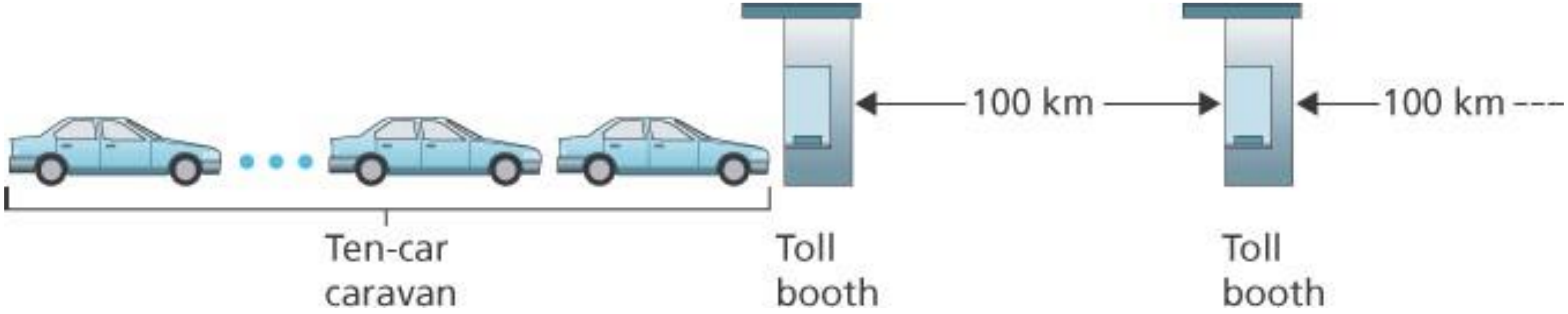
Store-and-forward transmission means that the packet switch must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link



In this example, the source has three packets, each consisting of L bits, to send to the destination.

At time L/R, the router begins to forward the first packet. But also at time L/R the source will begin to send the second packet, since it has just finished sending the entire first packet. Thus, at time 2L/R, the destination has received the first packet and the router has received the second packet. Similarly, at time 3L/R, the destination has received the first two packets and the router has received the third packet. Finally, at time 4L/R the destination has received all three packets

Delay in Packet-Switched Networks

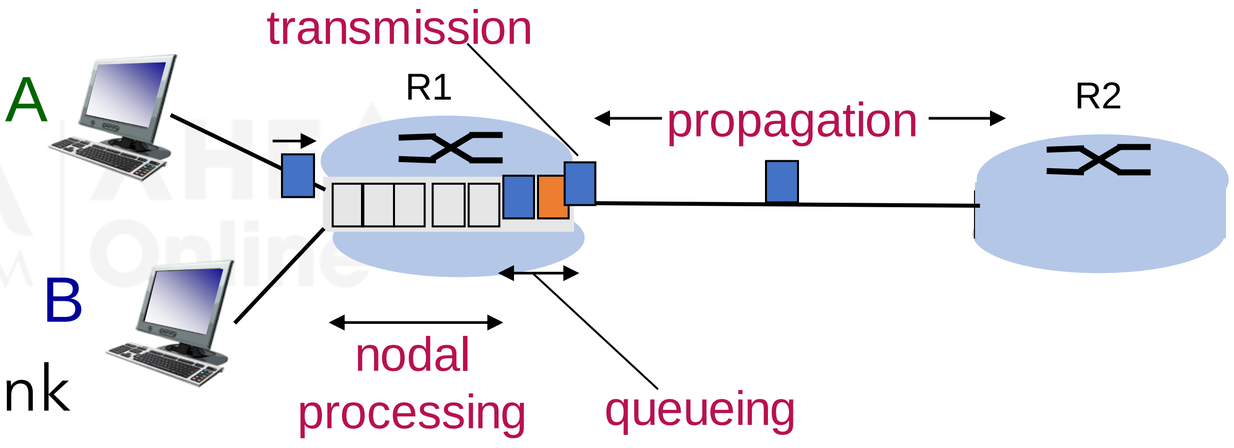


- As a packet travels from one node (host or router) to the subsequent node (host or router) along this path, the packet suffers from several types of delays at *each* node along the path.

- The performance of many Internet applications–such as search, Web browsing, e-mail, maps, instant messaging, and voice-over-IP–are greatly affected by network delays

Four sources of Packet Delay

- Transmission delay d_{trans}
  - Time taken to drop the packet into the output link for transmission
  - Length of the Packet say L bits
  - Bandwidth of the link say R bps
  - d_{trans} = L/R seconds
- Propagation delay d_{prop}
  - Time - Bits to move in the media or link
  - Distance of Physical link – d meter
  - Propagation speed in medium – s
    - Ex: fiber optic – 0.7 * 3 *10^8 m/s
  - d_{prop} = d/s seconds

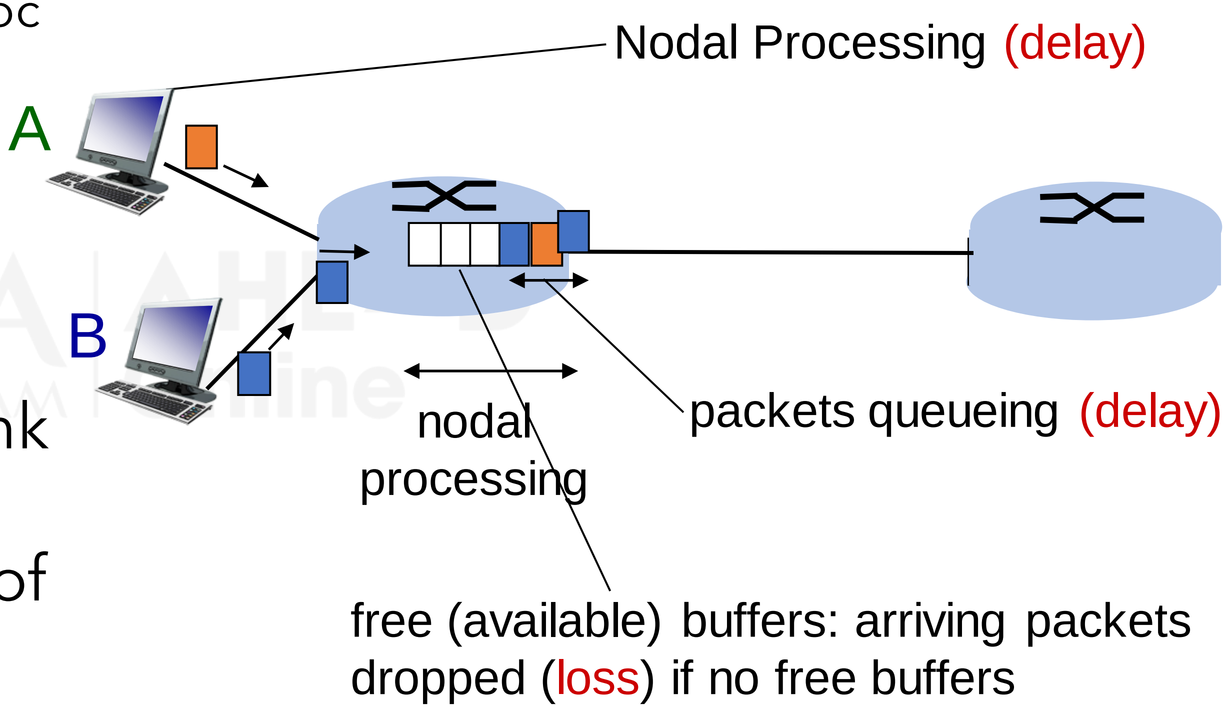


$$d_{nodal} = d_{trans} + d_{prop} + d_{proc} + d_{queue}$$

Ref: J. Kurose and K. Ross 2012, Computer Network,6th ed.

Four sources of Packet Delay

- Processing delay in all nodes d_{proc}
  - Check bit errors
  - Determine output link
  - Typically < msec
- Queuing delay in router d_{queue}
  - Time waiting in buffer at output link for transmission
  - Depends on congestion level of router
- Both delays depends on node hardware capacity



$$d_{nodal} = d_{trans} + d_{prop} + d_{proc} + d_{queue}$$

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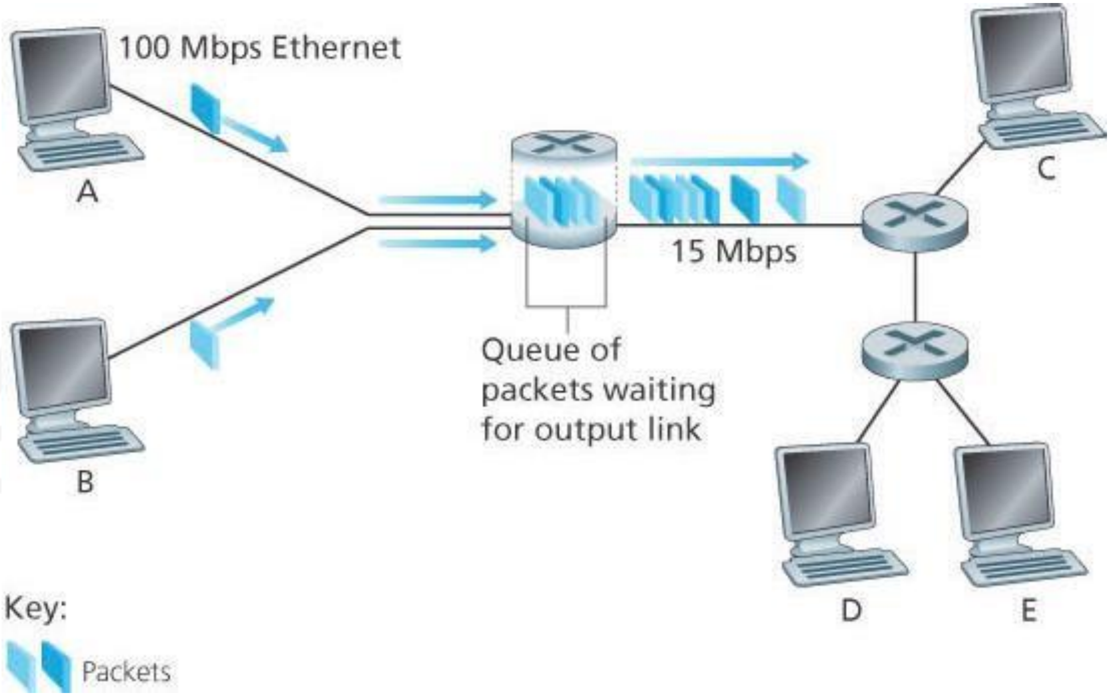
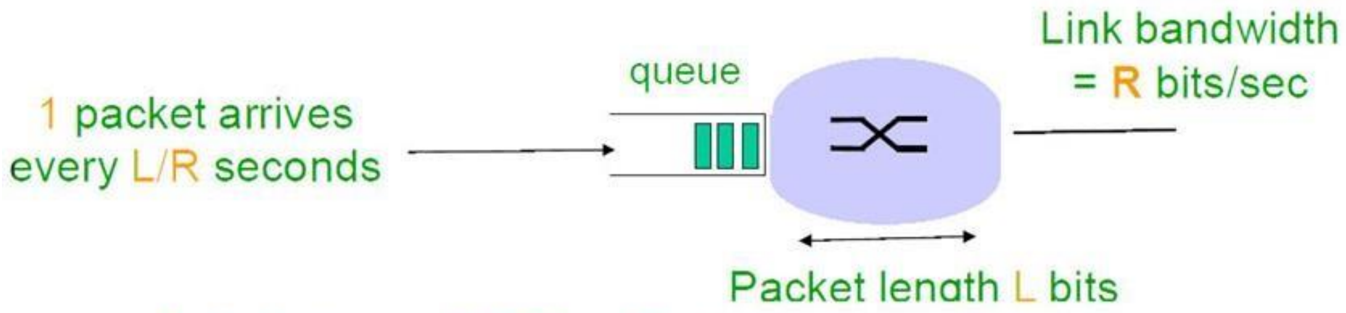
Queuing Delays

- Each packet switch has multiple links attached to it.
- For each attached link, the packet switch has an output buffer (also called an output queue), which stores packets that the router is about to send into that link
- If an arriving packets needs to be transmitted onto a link but finds the link busy with the transmission of another packet, the arriving packet must wait in the output buffer



Queuing Delay

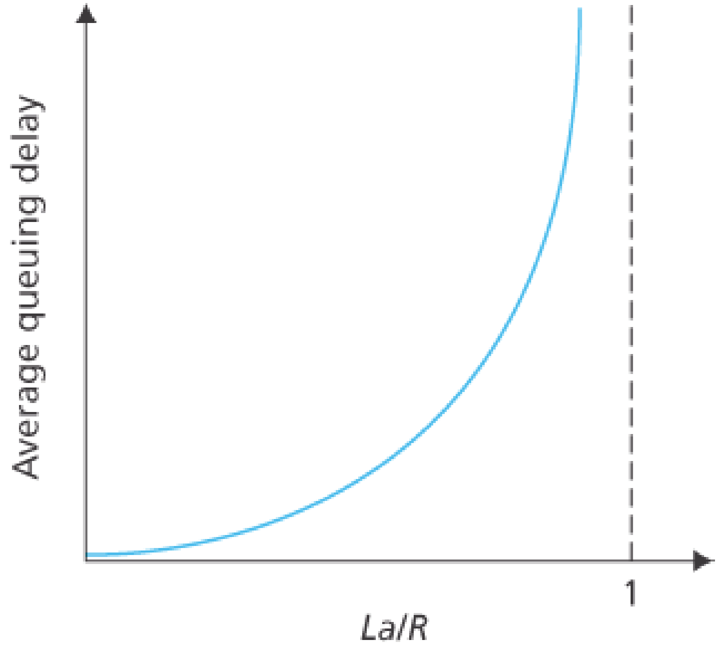
Waiting time for the packets in front to betransmitted



Arrival rate: a = 1/(L/R) = R/L (packet/second)

Traffic intensity = aL/R = (R/L) (L/R) = 1

Average queueing delay = 0
(queue is initially empty)



Dependence of average queuing delay on traffic intensity.

If *La/R* > 1, then the average rate at which bits arrive at the queue exceeds the rate at which the bits can be transmitted from the queue ,then queue will tend to increase without bound and the queueing delay will approach infinity!

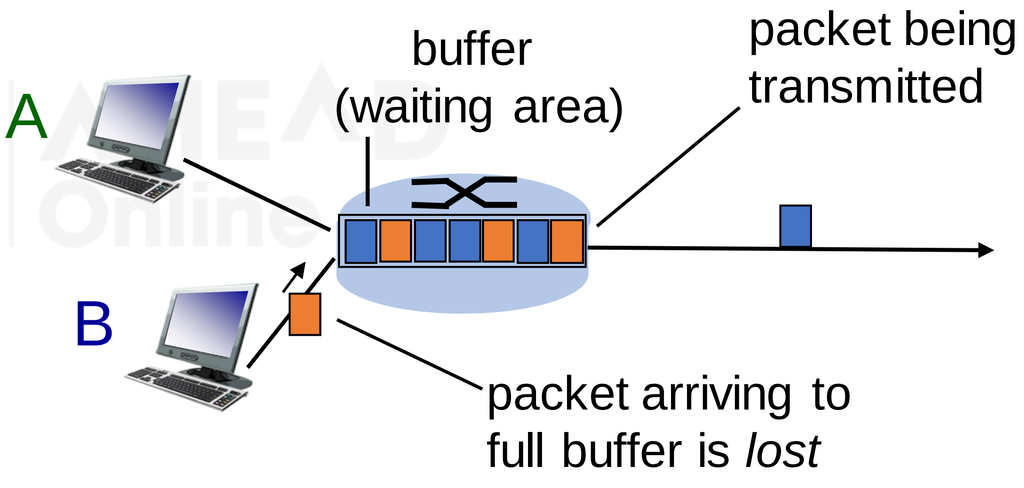
Design your system so that the traffic intensity is no greater than 1.

Queuing Delay :

- Queuing delay is the time a job waits in a queue until it can be executed. It depends on congestion.
- Sum of the delays encountered by a packet between the time of insertion into the network and the time of delivery to the address.
- The delay is dependent on the arrival rate of the incoming packets, the transmission capacity of the outgoing link, and the nature of the network's traffic.

Packet Loss

- Packets coming to the router are stored in buffer and waits there till it gets transmitted to the link.
- Buffer size are limited in the hardware.
- Arriving packets are dropped (loss) if there are no free buffer (full queue)
- Handling lost packets are discussed later in the course



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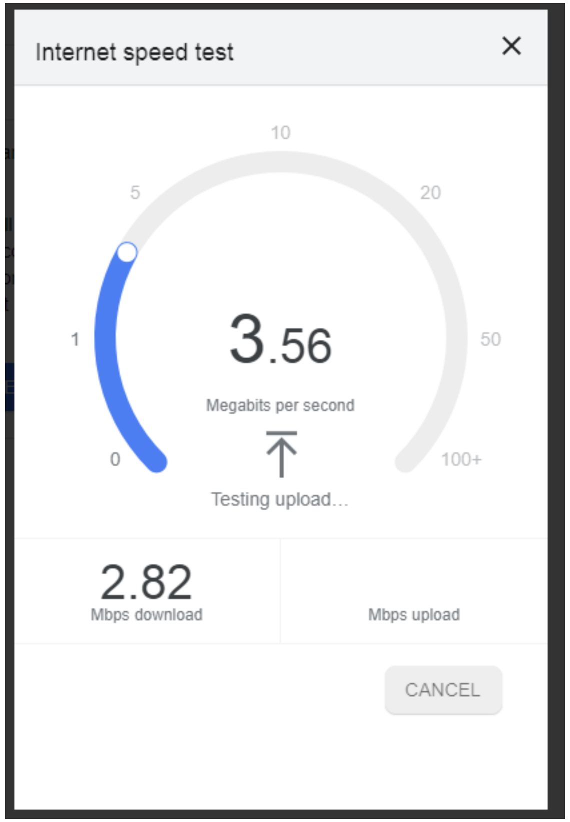
Bandwidth, Throughput and Speed

- Speed is a general term used by common user
- Measured in bits per second (bps)
- Bandwidth often refers to the maximum amount of data transfer per second
    - Refers to the physical total capacity
    - Ex: Gigabit Ethernet bandwidth – 1 Gbps
    - Analogy – 24 hours per day
- Throughput is actual amount of data passing through media or a connection
    - Analogy – working hours as 8 or 10 hours per day



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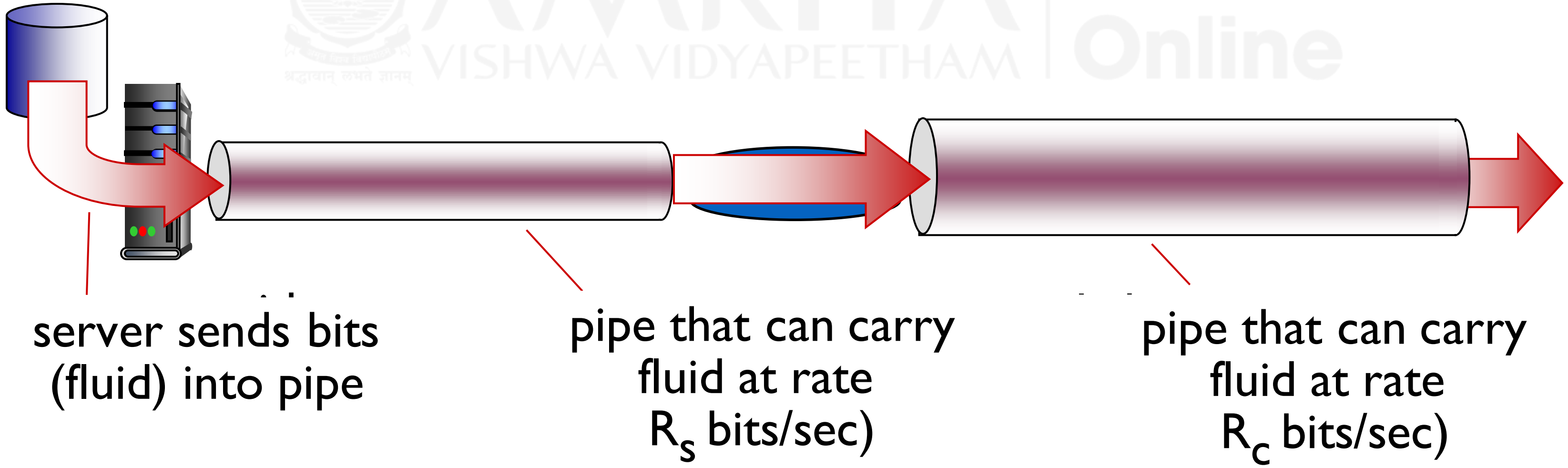
Throughput

- Rate at which bits transferred between sender/receiver
  - Instantaneous: rate at given point of time
  - Average: rate over longer period of time
  - Measured in bits per second
- Analogy: Water flow through a pipe



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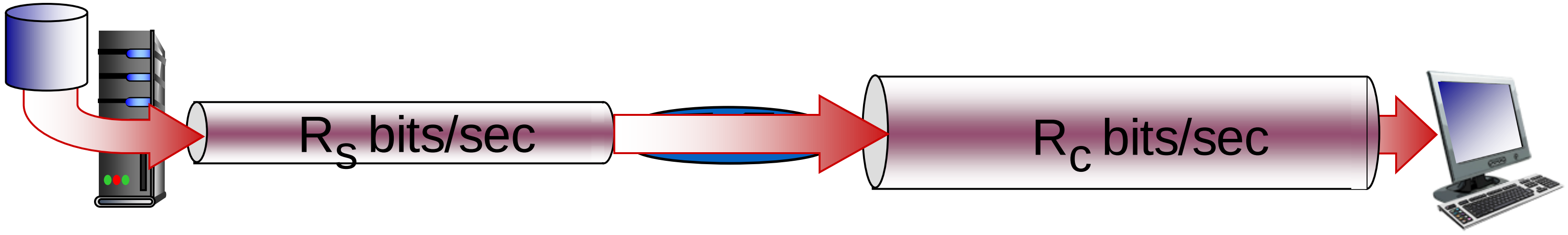
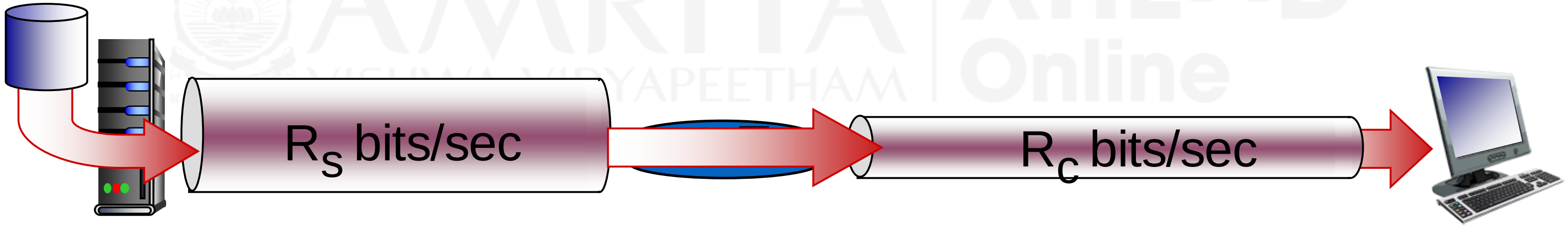
Throughput

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?

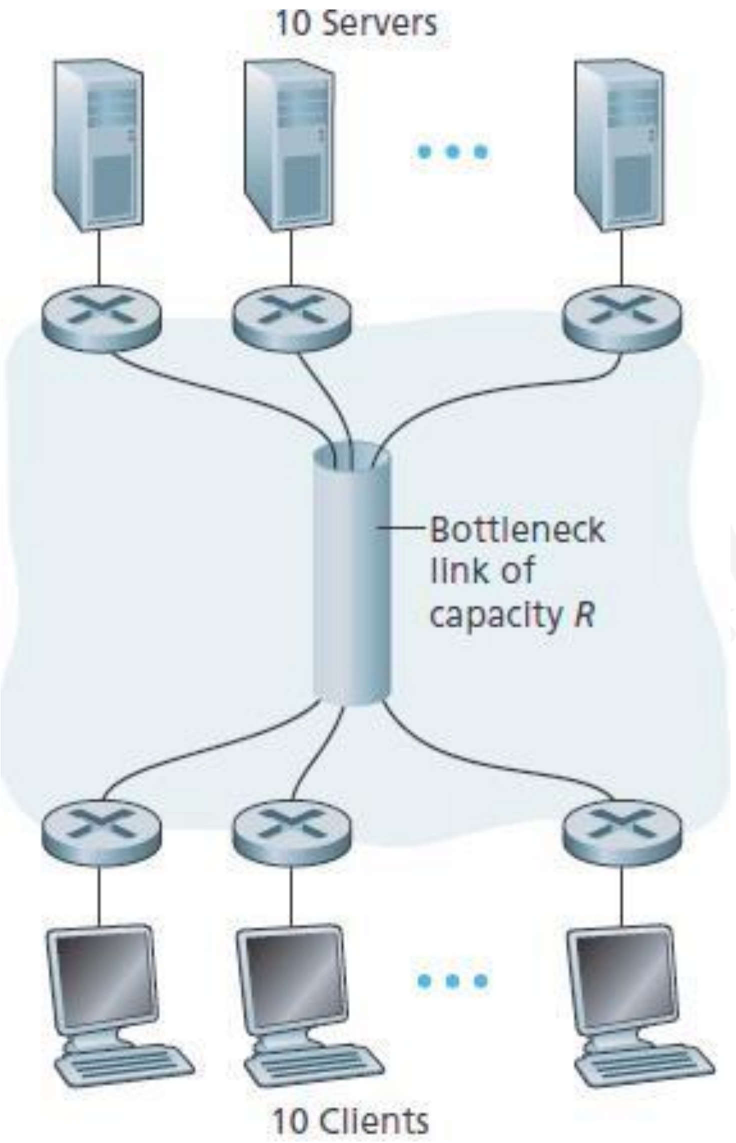


bottleneck link

link on end-end path that constrains end-end throughput

Ref: J. Kurose and K. Ross 2012, Computer Network, 6th ed.

Throughput in Computer Networks



there are 10 servers and 10 clients connected to the core of the computer network. In this example, there are 10 simultaneous downloads taking place, involving 10 client-server pairs

Suppose that these 10 downloads are the only traffic in the network:

There is a link in the core that is traversed by all 10 downloads. Denote *R* for the transmission rate of this link *R*.

what if the rate of the common link R is of the same order as *Rs* and *Rc*? -common link divides its transmission rate equally among the 10 downloads

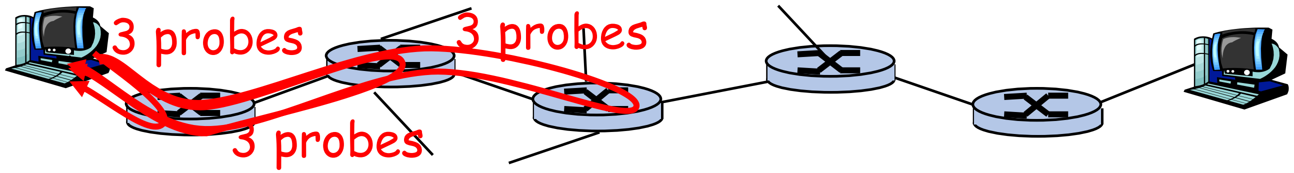
Rs=5 Mbps, Rc=5 Mbps,

R=5Mbps, Throughput =(5Mbps/10) =500kbps

Generally, per-connection end-end throughput: min(R_c,R_s,R/10)

Real time Internet delays

- Delay = Time taken after the request before responding request
- How to understand Internet delay experienced by us?
- Traceroute: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
  - sends three packets that will reach router *i* on path towards destination
  - router *i* will return packets to sender



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Tracert example

- Ex: tracert google.co.in from 192.168.42.253
- 8 hop routers
- 3 probe messages sent to each router
- No response to reach india.com hop routers

* means no response (probe lost, router not replying)

```
C:\WINDOWS\system32\cmd.exe
C:\Users\student3>ipconfig

Windows IP Configuration


Ethernet adapter Ethernet 2:

   Connection-specific DNS Suffix  . :
   Link-local IPv6 Address . . . . . : fe80::859d:c25c:c87a:7983%11
   IPv4 Address. . . . . . . . . . . : 192.168.42.253
   Subnet Mask . . . . . . . . . . . : 255.255.255.0
   Default Gateway . . . . . . . . . : 192.168.42.129

C:\Users\student3>tracert google.co.in

Tracing route to google.co.in [216.58.200.131]
over a maximum of 30 hops:

  1     2 ms     1 ms    <1 ms  192.168.42.129
  2    65 ms    49 ms    48 ms  10.47.100.100
  3    51 ms    48 ms    49 ms  10.174.19.110
  4    66 ms     *       62 ms  192.168.23.13
  5    58 ms    48 ms    62 ms  100.64.0.94
  6   310 ms    52 ms    57 ms  72.14.197.130
  7    61 ms    53 ms    60 ms  74.125.242.129
  8    66 ms    44 ms    47 ms  216.239.54.197
  9    60 ms    47 ms    53 ms  maa05s10-in-f3.1e100.net [216.58.200.131]

Trace complete.

C:\Users\student3>tracert india.com

Tracing route to india.com [54.173.62.149]
over a maximum of 30 hops:

  1     1 ms    <1 ms    <1 ms  192.168.42.129
  2     *        *        *     Request timed out.
  3   ^C
```

3 Packet delays measurements from the first router 192.168.42.129

Recap

- Different delays in a network
  - Transmission delay
  - Propagation delay
  - Processing delay
  - Queuing delay

- Packet Loss
- Bandwidth & Throughput

- Real Internet delays
  - Tracert command

Problems

Problem I

1. What is the end-to-end packet latency in this store-and-forward subnet from router 1 to router 6 ?

Assume: All links: 2.5 km; C = 100Mbps; propagation speed = 200m/microsec. queuing delay = processing delay =0; packet size = 1000 bytes

Problem 1- answer

1. What is the end-to-end packet latency in this store-and-forward subnet from router 1 to router 6 ?

Assume: All links: 2.5 km; C = 100Mbps; propagation speed = 200m/microsec.
queuing delay = processing delay =0; packet size = 1000 bytes

Source@1, Destination@6,

Node processing transmission @ 1, 14, 15,17 = 4 nodes

$$End - to - end\ packet\ delay = 4d_{nodal}$$

$$d_{nodal} = d_{trans} + d_{prop} + d_{proc} + d_{queue}$$

d_{trans} = L/R = 1000 bytes / 100 Mbps

= 10^3 * 8 bits /10^8 bps

= 8 *10^-5 seconds = 80 microseconds

Problem 1- answer

1. What is the end-to-end packet latency in this store-and-forward subnet from router 1 to router 6 ?

Assume: All links: 2.5 km; C = 100Mbps; propagation speed = 200m/microsec.
queuing delay = processing delay =0; packet size = 1000 bytes

$$d_{nodal} = d_{trans} + d_{prop} + d_{proc} + d_{queue}$$

d_{prop} = distance between links / propagation speed of the link

= 2.5 km = 2500 m / 200m/microseconds = 12.5 microseconds

End-to-end delay = 4 * d_{nodal} = 4 * (80 microsec + 12.5 microsec + 0 + 0)

= 4 * 92.5 microsec = 370 microseconds

Problem II

What is the end-to-end packet delay in this store-and-forward subnet from router 1 to router 6 under the scenario that when a packet from router 1 arrives at router 15 there are three packets enqueued for the link to router 17?

Delays in Packet switching

Total time *or* **End-to-End delay**= Transmission delay + Propagation delay+ Queuing delay + Processing delay

For M hops –

End –to End Packet latency or delay = M* **Link delay + Queuing delay**

End to End delay or OneWay Delay(OWD) refers to the time taken for a **packet** to be transmitted across a **network** from source to destination

Problem II- answer

2. What is the end-to-end packet delay in this store-and-forward subnet from router 1 to router 6 under the scenario that when a packet from router 1 arrives at router 15 there are three packets enqueued for the link to router 17?

Assume: All links: 2.5 km; C = 100Mbps; propagation speed = 200m/microsec.

processing delay =0; all packet sizes = 1000 bytes

Implied Assumption: queues at 1, 14, and 17 are empty when the packet arrives at node 15.

Required Insight: there will be no queuing delay at 17 even if all three queued packets are going to 6.

Solution: Queueing delay exist only at node 15 & not there in all other nodes

Queueing delay at node 15 = 3 packets * transmission time

= 3 * 80 microseconds = 240 microseconds

End-to-end delay = 4 * d_{nodal} = 4 * (80 microsec + 12.5 microsec + 0 + 0) + queueing delay at node 15

End-to-end delay = 4* 92.5 + 240 =610 microseconds

Delays in Packet switching

Total time *or* **End-to-End delay**= Transmission delay + Propagation delay+ Queuing delay + Processing delay

For M hops –

End –to End Packet latency or delay = M*Link Delay + Queuing delay

Link Delay=Transmission delay + Propagation delay+ Processing delay

For M hops and N packets –

Total delay = M*(Transmission delay + propagation delay)+ (M-1)*(Processing delay + Queuing delay) + (N-1)*(Transmission delay)

Delay can also be calculated as : Delay for 1st packet to reach + delay for (N-1) packets
Delay for 1st packet = M*(Propagation delay + Transmission delay) + (M-1)*(Processing delay + Queuing delay)
Delay for N-1 remaining packets = (N-1)*(Transmission delay)

End to End delay or OneWay Delay(OWD) refers to the time taken for a **packet** to be transmitted across a **network** from source to destination

Delays in Packet switching

Total time *or* **End-to-End delay**= Transmission delay + Propagation delay+ Queuing delay + Processing delay

For M hops –

End –to End Packet latency or delay = M*Link Delay + Queuing Delay

For M hops and N packets –

Total delay = M*(Transmission delay + propagation delay)+ (M-1)*(Processing delay + Queuing delay) + (N-1)*(Transmission delay)

End to End delay or OneWay Delay(OWD) refers to the time taken for a **packet** to be transmitted across a **network** from source to destination

Problem III

- In a Packet switch network having Hops= 4, transfer 10 packets from A to B given packet size is L bits. Bandwidth to transfer data is R Mbps and speed of propagation is S meter/sec. Assume processing delay= P seconds and distance between two point is D meters. Find total time required for 10 packets to reach A from B.

A---R1---R2---R3---B

Solution

Total delay = M*(Transmission delay + propagation delay)+ (M-1)*(Processing delay + Queuing delay) + (N-1)*(Transmission delay)

- No. of hops= No. of links = M= 4
- Here we send 10 packets, also since there is no acknowledgement of packet received required we perform parallel processing. When the 1st packet reaches R2, the second packet reaches R1.

- Formulas used-
  - R is in Mbps so convert to bps by multiplying 10^6.
  - Bandwidth=R*(10^6) bps
  - Packet size =L bits
  - Transmission delay= Packet size/Bandwidth =L/(R*(10^6))
  - Propagation Delay = Distance / Speed = D /S
  - Processing delay is in seconds no change
  - Delay can also be calculated as : Delay for 1st packet to reach + delay for (N-1) packets
  - Delay for 1st packet = M*(Propagation delay + Transmission delay) + (M-1)*(Processing delay + Queuing delay)
  - Delay for N-1 remaining packets = (N-1)*(Transmission delay)

- So finally applying the formula and putting the values we get-
- Total delay = 4*(L/(R*(10^6) + D/S) + (4-1)*(P + 0) + (10-1)*(L/(R*(10^6))

Delays in Packet switching

Total time *or* **End-to-End delay(Link Delay)** = Transmission delay + Propagation delay+ Queuing delay + Processing delay

For M hops –

End –to End Packet latency or delay = M*Link Delay

For M hops and N packets –

Total delay = M*(Transmission delay + propagation delay)+
(M-1)*(Processing delay + Queuing delay) +
(N-1)*(Transmission delay)

For N connecting link in the circuit – Transmission delay = N*L/R
Propagation delay = N*(d/s)

End to End delay or OneWay Delay(OWD) refers to the time taken for a **packet** to be transmitted across a **network** from source to destination

Namah Shivaya