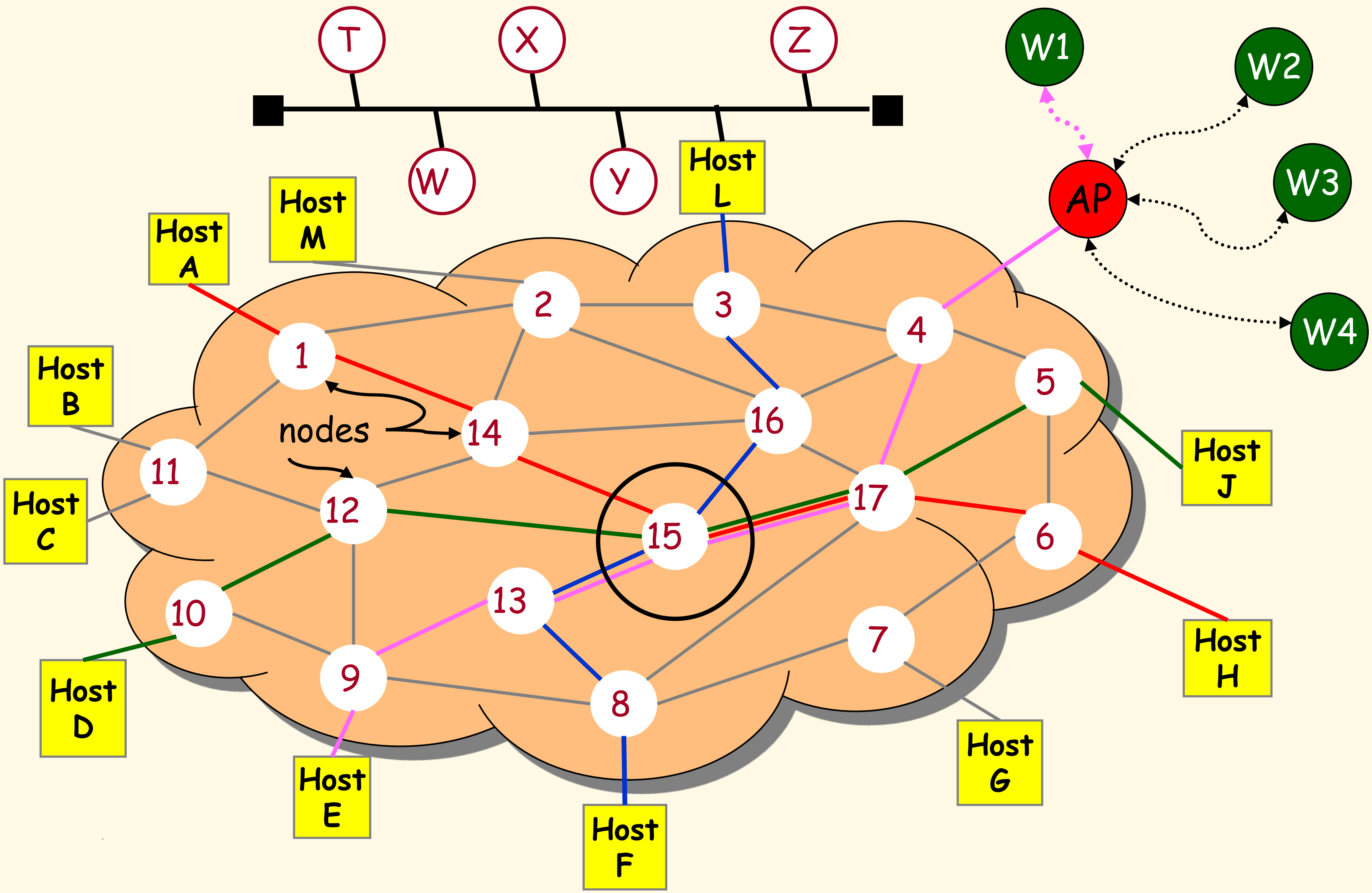
Computer Networks Performance Metrics

Performance Metrics Outline

- Introduce Queueing Model
- Generic Performance Metrics
- Components of Hop and End-to-End Packet Delay
- Traceroute Tool
- Other Performance Measures
  - Packet Loss Rate

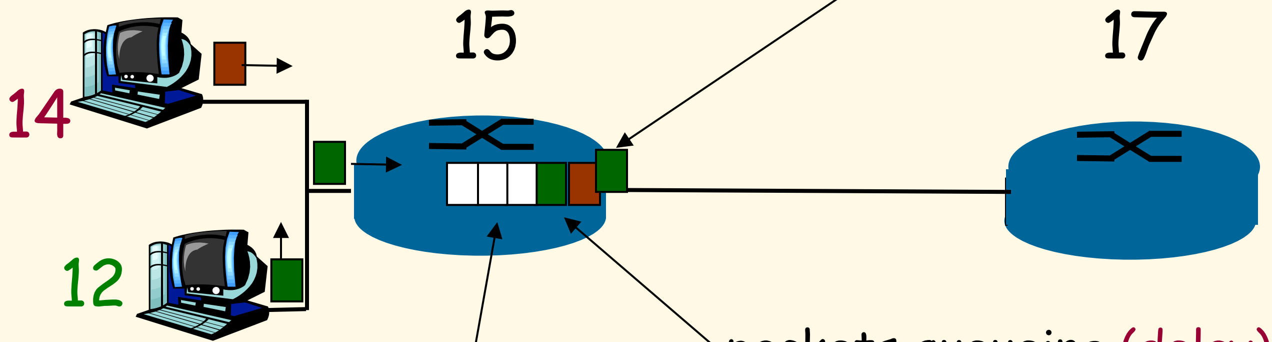
Computer Networks



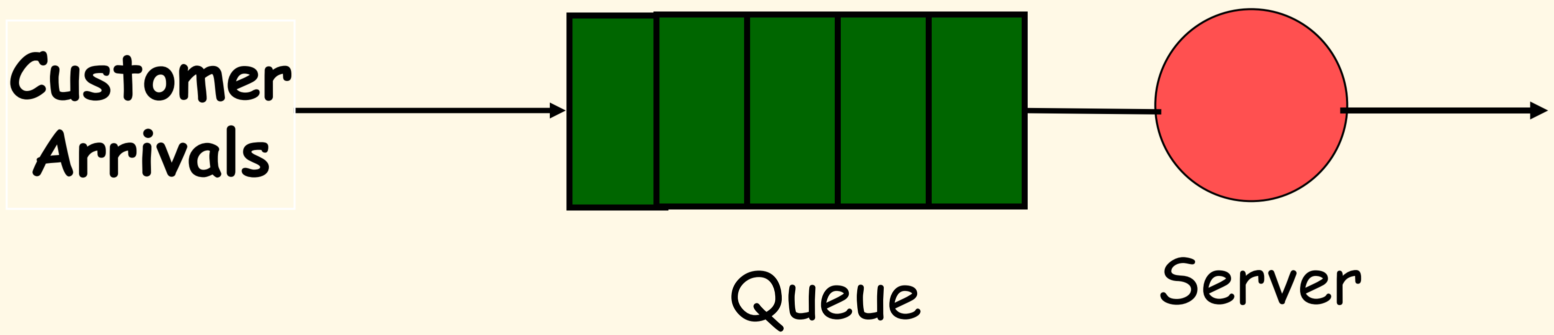
How do Loss and Delay occur?

packets *queue* in router buffers

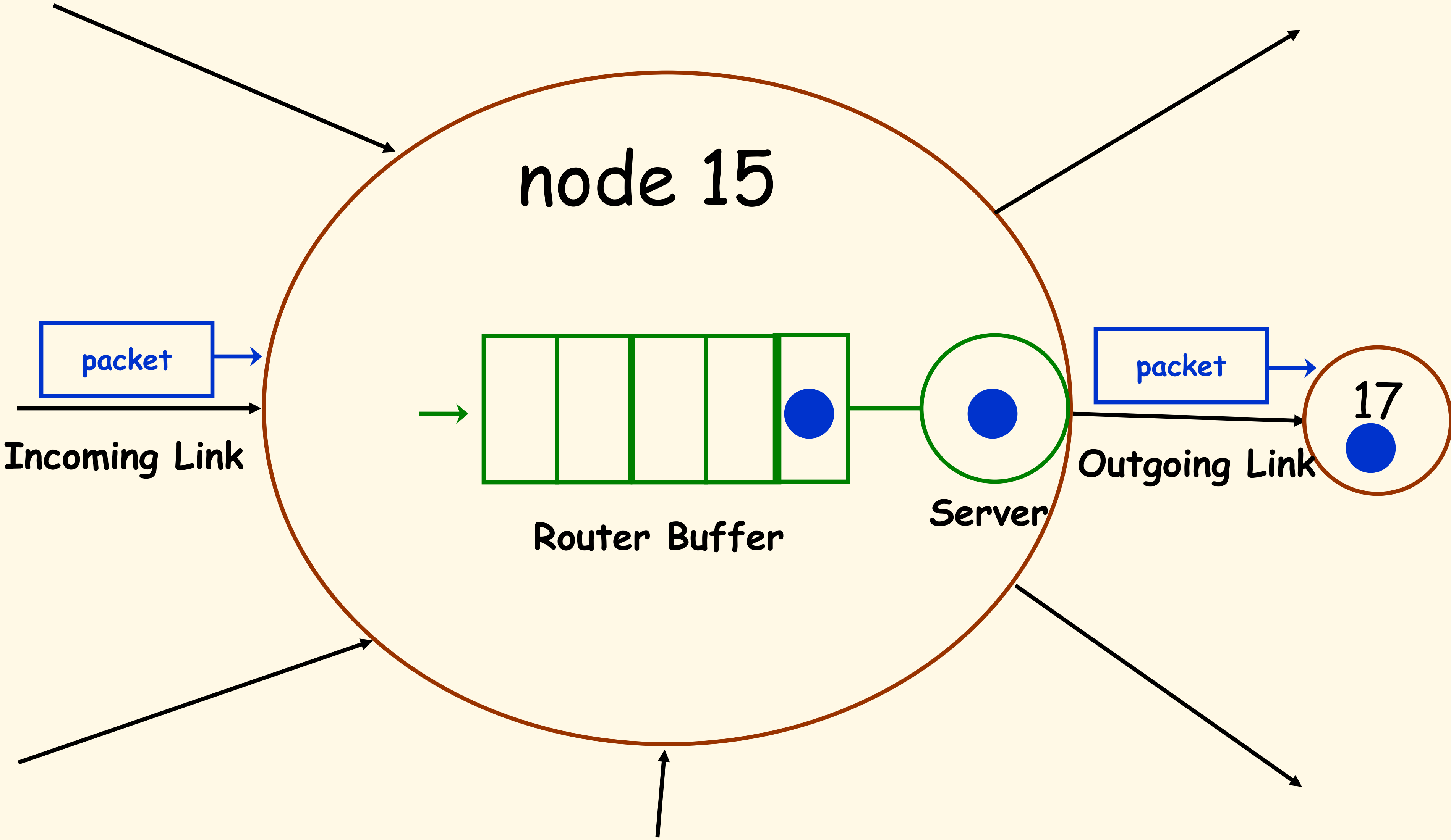
- when the sum of the arriving packets at the router exceeds the output link capacity.



Simple Queueing Model



Router Node


node 15
packet
Incoming Link
Router Buffer
Server
packet
17
Outgoing Link

Generic Performance Metrics

Utilization ::

- the percentage of time a device is busy servicing a "customer".

Throughput ::

- the number of jobs processed by the "system" per unit time.

Response time ::

- the time required to receive a response to a request (round-trip time (RTT)).

Delay ::

- the time to traverse from one end to the other of a system.

Network Performance Measures

- Channel utilization::

  the average fraction of time a channel is busy [e.g. Util = 0.8]

  - when overhead is taken into account (i.e., it is excluded from the useful bits sent), channel utilization is often referred to as channel efficiency.

- Throughput::

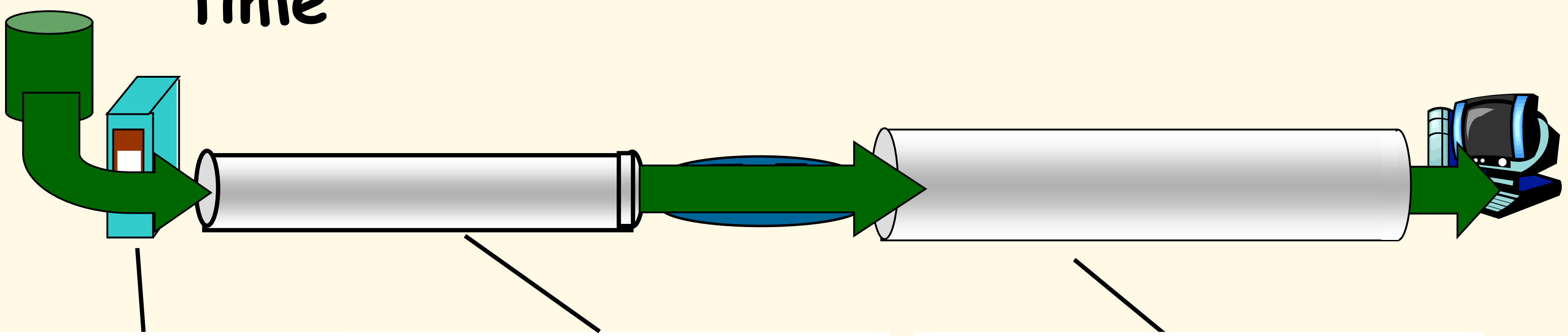
  bits/sec. successfully sent

  [e.g. Tput = 10 Mbps]

Throughput

throughput:: rate (bits/time unit) at which bits transferred between sender/receiver

- *instantaneous:* rate at given point in time
- *average:* rate over longer period of time



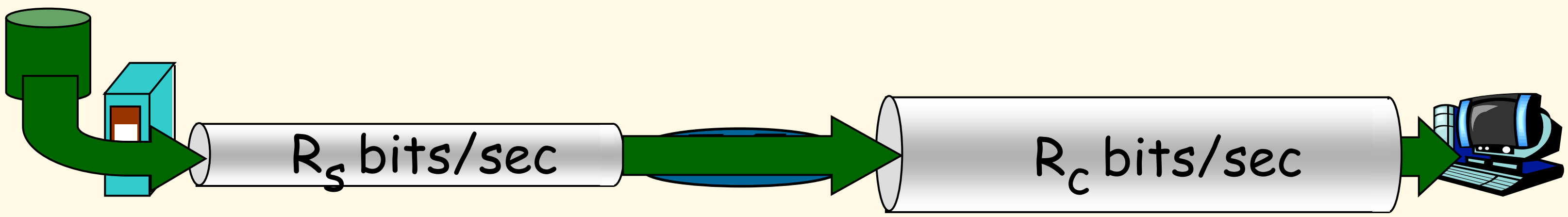
server sends bits (fluid) into pipe

pipe that can carry fluid at rate R_s bits/sec)

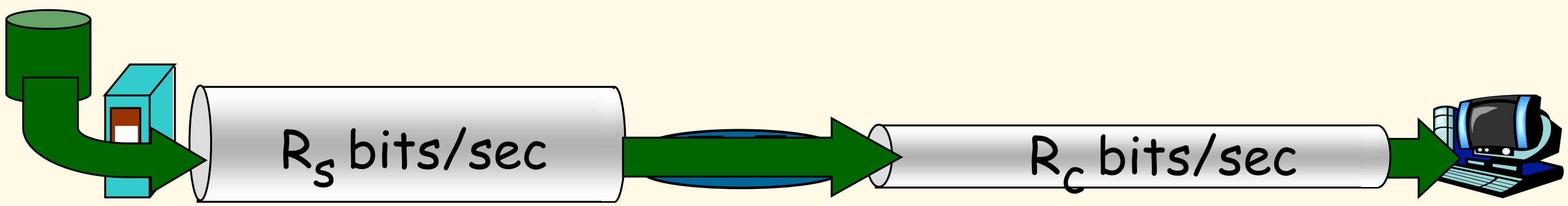
pipe that can carry fluid at rate R_c bits/sec)

Throughput (more)

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



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

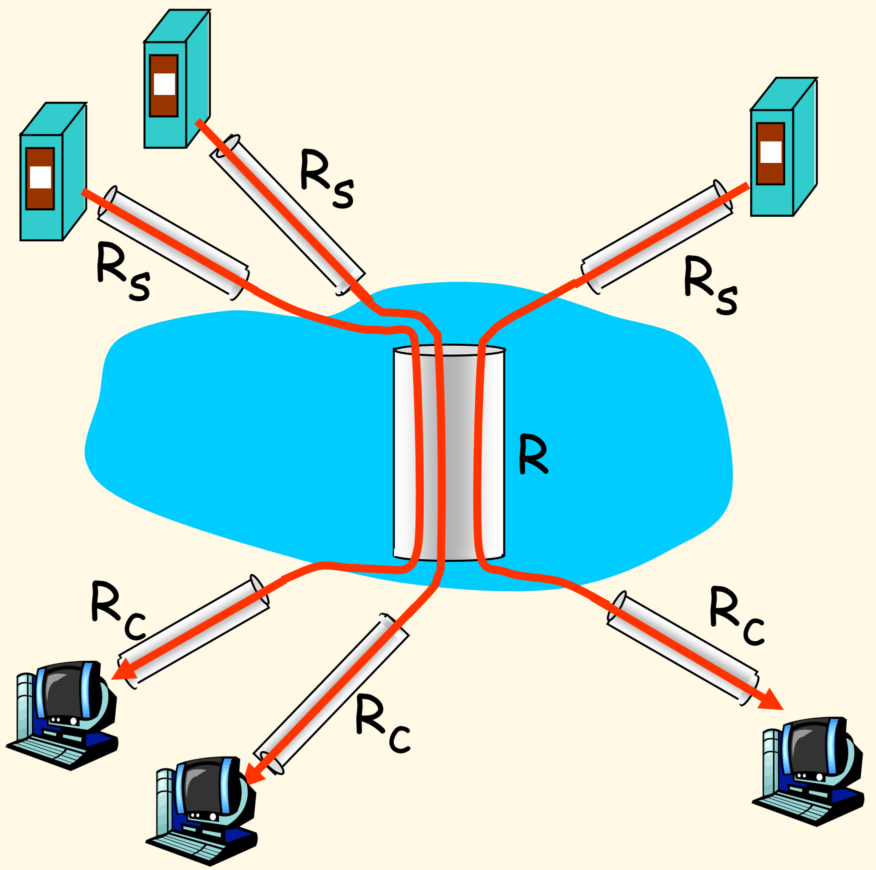


bottleneck link

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

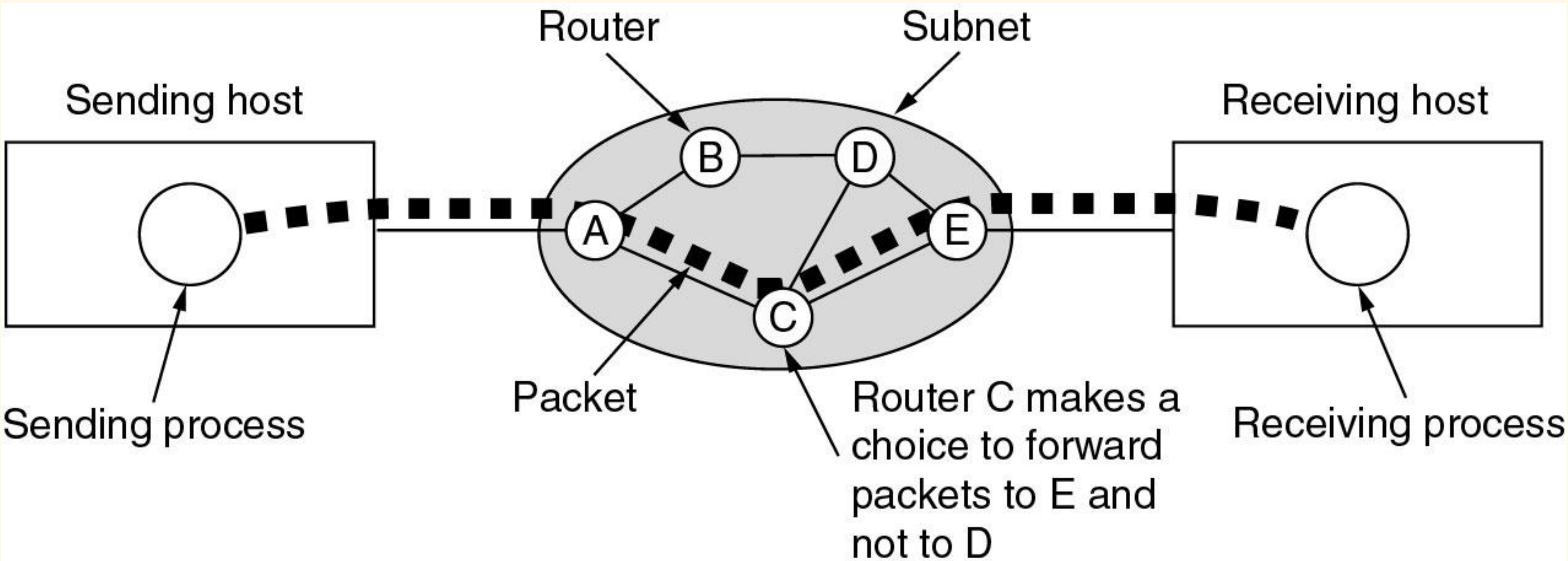
Throughput: Internet Scenario

- per-connection end-end throughput: $\min(R_c, R_s, R/10)$
- in practice: R_c or R_s is often the bottleneck
- The **last mile link** has capacity Rc.



10 connections (fairly) share backbone bottleneck link R bits/sec

End-to-End Packet Delay



End-to-end delay includes multiple hop link delays.

Tanenbaum

Hop Delay Components

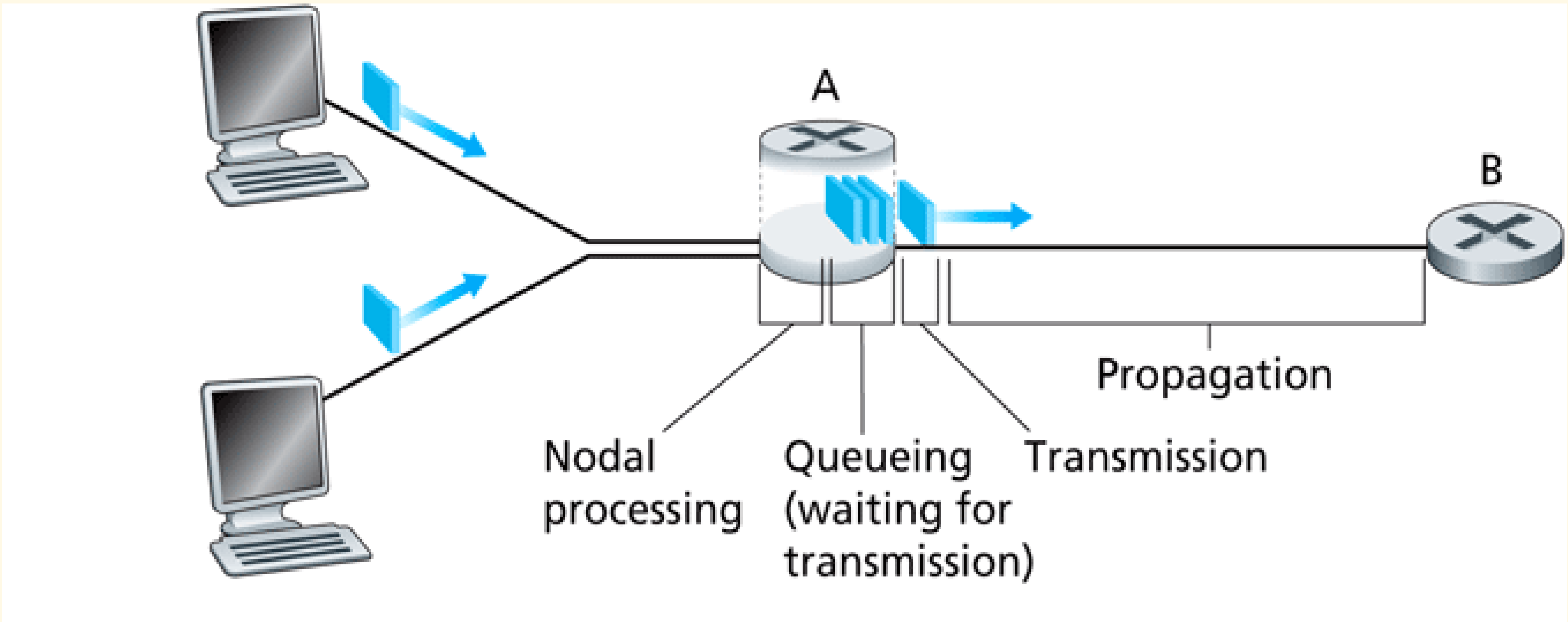
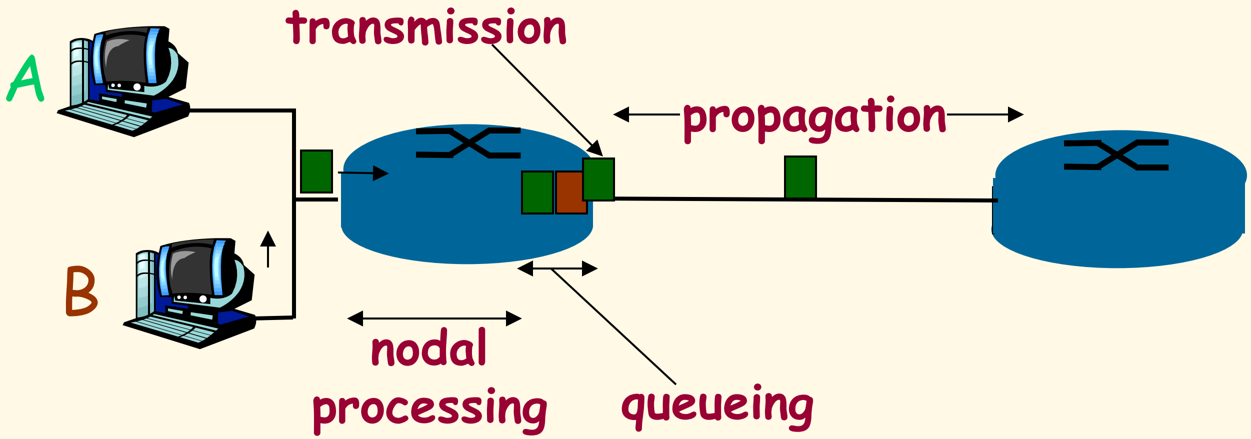


Figure 1.12 ♦ The nodal delay at router A

Four Sources of Packet Delay

1. **processing at node:**
   - Checking for bit errors
   - determine output link
   - Moving packet from input queue to output queue
     - Table lookup time (see routing algorithms)

2. **queueing delay**
   - time waiting at output link for transmission
   - depends on congestion level of router



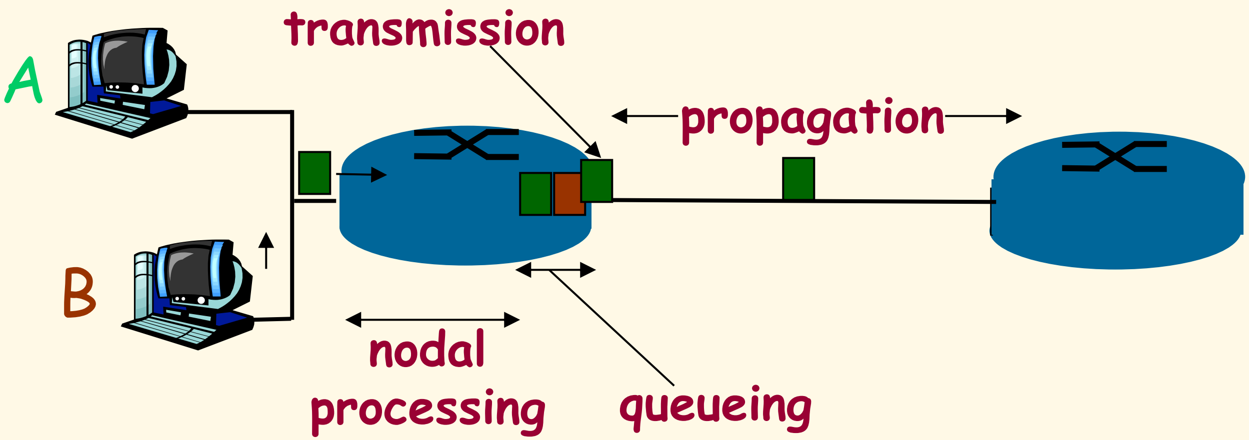
Delay in packet-switched networks

3. Transmission delay:

- R=link capacity (bps)
- L=packet length (bits)
- time to send bits into link = L/R

4. Propagation delay:

- d = length of physical link
- s = propagation speed in medium (~2×10^8 m/sec)
- propagation delay = d/s



Note
s and R are *very* different quantities!

End-to-end Packet Delay

- End-to-end packet delay :: the time to deliver a packet from source to destination Host (or node).
- {Most often, we are interested in the packet delay within the communications subnet.} This delay is the sum of the delays on each subnet link traversed by the packet.
- Each link delay consists of four components[B&G Bertsekas and Gallager]:

Link Packet Delay

1. The processing delay [PROC] between the time the packet is correctly received at the head node of the incoming link and the time the packet is assigned to an outgoing link queue for transmission.
2. The queuing delay [QUEUE] between the time the packet is assigned to a queue for transmission and the time it starts being transmitted. During this time, the packet waits while other packets in the transmission queue are transmitted.

Link Packet Delay

3. The transmission delay [TRANS] between the times that the first and last bits of the packet are transmitted.
4. The propagation delay [PROP] is between the time the last bit is transmitted at the head node of the link queue and the time the last bit is received at the next router. This is proportional to the physical distance between transmitter and receiver.

Nodal (Link) Delay

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

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

K & R

End-to-End Packet Delay

Link packet delay = PROC + QD
+ TRANS + PROP

end-to-end packet delay = sum of ALL link packet delays.

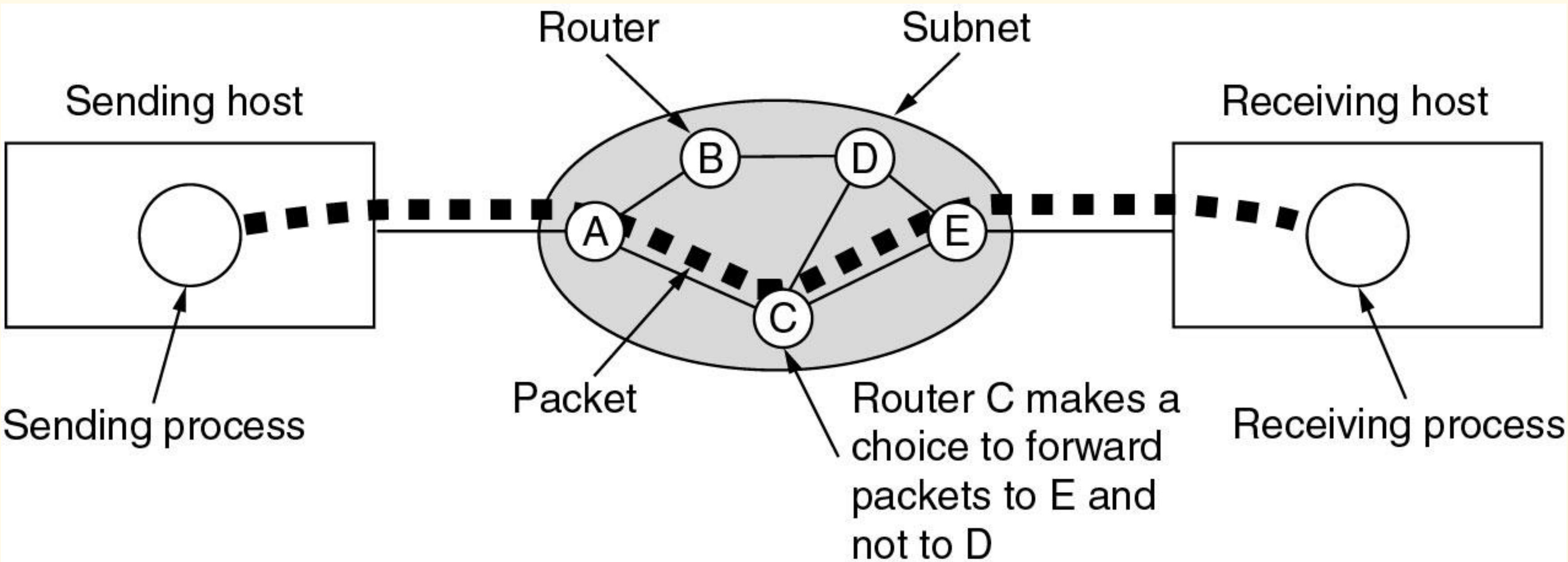
Be Careful !!

end-to-end can be defined either:

- from Host-to-Host
- or only from end-to-end nodes within the subnetwork.

B & G

End-to-End Packet Delay



End-to-end delay includes multiple hop link delays.

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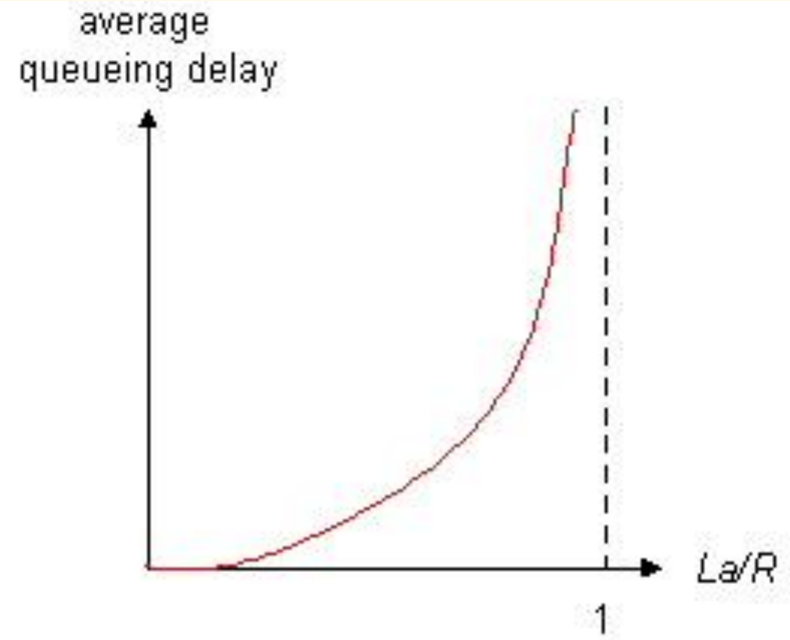
Queueing Delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

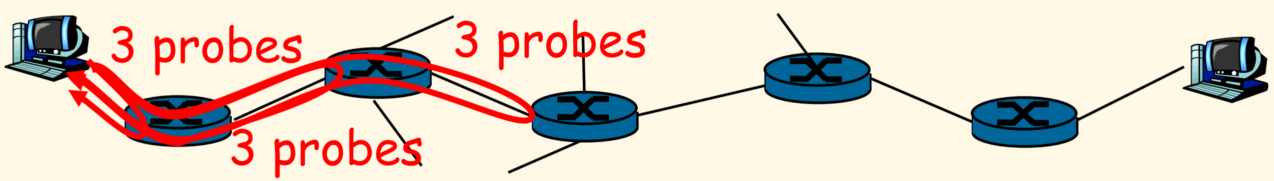
traffic intensity = La/R



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R = or > 1: more "work" arriving than can be serviced, average delay infinite!

"Real" Internet Delays and Routes

- What do "real" Internet delay & loss look like?
- **Traceroute program:** 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.
  - sender times interval between transmission and reply.



WPI

"Real" Internet delays and routes

traceroute: gaia.cs.umass.edu to www.eurecom.fr

Three delay measurements from gaia.cs.umass.edu to cs-gw.cs.umass.edu

```
1  cs-gw (128.119.240.254)  1 ms  1 ms  2 ms
2  border1-rt-fa5-1-0.gw.umass.edu (128.119.3.145)  1 ms  1 ms  2 ms
3  cht-vbns.gw.umass.edu (128.119.3.130)  6 ms 5 ms 5 ms
4  jn1-at1-0-0-19.wor.vbns.net (204.147.132.129)  16 ms 11 ms 13 ms
5  jn1-so7-0-0-0.wae.vbns.net (204.147.136.136)  21 ms 18 ms 18 ms
6  abilene-vbns.abilene.ucaid.edu (198.32.11.9)  22 ms  18 ms  22 ms
7  nycm-wash.abilene.ucaid.edu (198.32.8.46)  22 ms  22 ms  22 ms
8  62.40.103.253 (62.40.103.253)  104 ms 109 ms 106 ms
9  de2-1.de1.de.geant.net (62.40.96.129)  109 ms 102 ms 104 ms
10  de.fr1.fr.geant.net (62.40.96.50)  113 ms 121 ms 114 ms
11  renater-gw.fr1.fr.geant.net (62.40.103.54)  112 ms  114 ms  112 ms
12  nio-n2.cssi.renater.fr (193.51.206.13)  111 ms  114 ms  116 ms
13  nice.cssi.renater.fr (195.220.98.102)  123 ms  125 ms  124 ms
14  r3t2-nice.cssi.renater.fr (195.220.98.110)  126 ms  126 ms  124 ms
15  eurecom-valbonne.r3t2.ft.net (193.48.50.54)  135 ms  128 ms  133 ms
16  194.214.211.25 (194.214.211.25)  126 ms  128 ms  126 ms
17  * * *
18  * * *
19  fantasia.eurecom.fr (193.55.113.142)  132 ms  128 ms  136 ms
```

trans-oceanic link (hop 8)

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

Network Performance Measures

- Latency ::
  - usually implies the minimum possible delay. Latency assumes no queueing and no contention encountered along the path.
- Goodput ::
  - {measured at the receiver} the rate in bits per second of useful traffic received. Goodput excludes duplicate packets and packets dropped along the path.
- Fairness ::
  - either Jain's fairness or max-min fairness are used to measure fair treatment among competing flows.
- Quality of Service (QoS) ::
  - a QoS measure accounts for importance of specific metric to one type of application [e.g. jitter and playable frame rate for streaming media].

Wireless Performance Metrics

WLANs and WSNs are concerned with packet loss and employ additional metrics:

Delivery ratio::

- the ratio of packets received to packets sent {excluding duplicates and retransmissions}.

Packet loss rate::

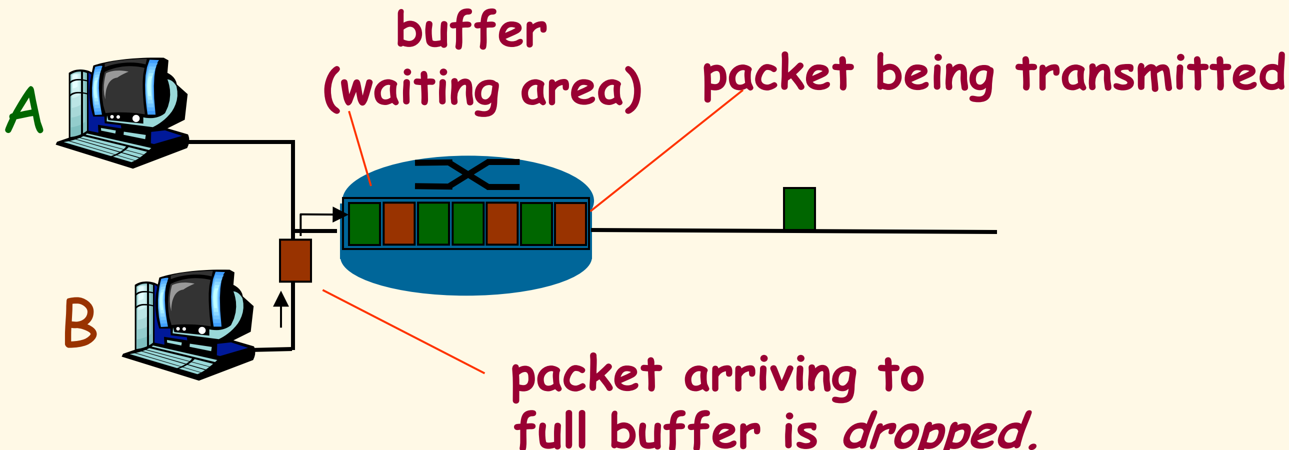
- the percentage of packets lost or dropped.

Link layer retransmission rates::

- the percentage of DL layer frames that are retransmitted.

Packet Loss

- queue (aka buffer) preceding link in buffer has finite capacity.
- packet arriving to full queue is dropped (aka lost) [FIFO Drop Tail router].
- lost packet may be retransmitted by previous node, by source end system, or not at all.



Performance Metrics Summary

- The three most general performance measures are : utilization, throughput and response time.
- In computer networks, end-to-end delay is an important performance metric.
- Queuing models and simulations are used to analyze and estimate computer network performance.

Performance Metrics Summary

- Other useful metrics include: latency, goodput, fairness and QoS metrics such as jitter or playable frame rate.
- In wireless networks, delivery ratio, packet loss rate and link layer retransmission rates are valuable network measures.