Computer Networks

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Chapter 2. Direct Link Networks

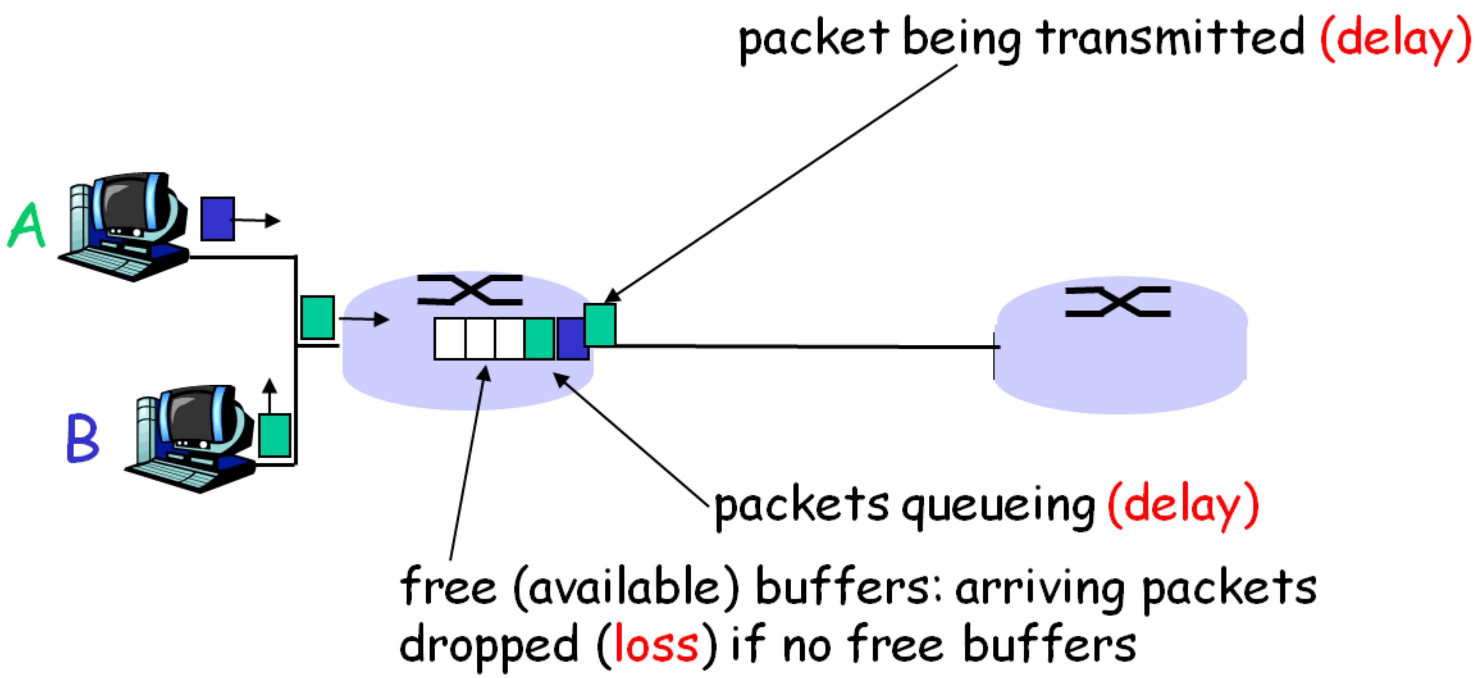
- Link Service and Framing
- Error Detection and Reliable Transmission
- HDLC, PPP, and SONET
- Token Ring
- Ethernet
- Bridges and Layer-2 switch
- Wireless Networks
- Network Performance

Network Performance

Delay

Packets queue in switch buffers

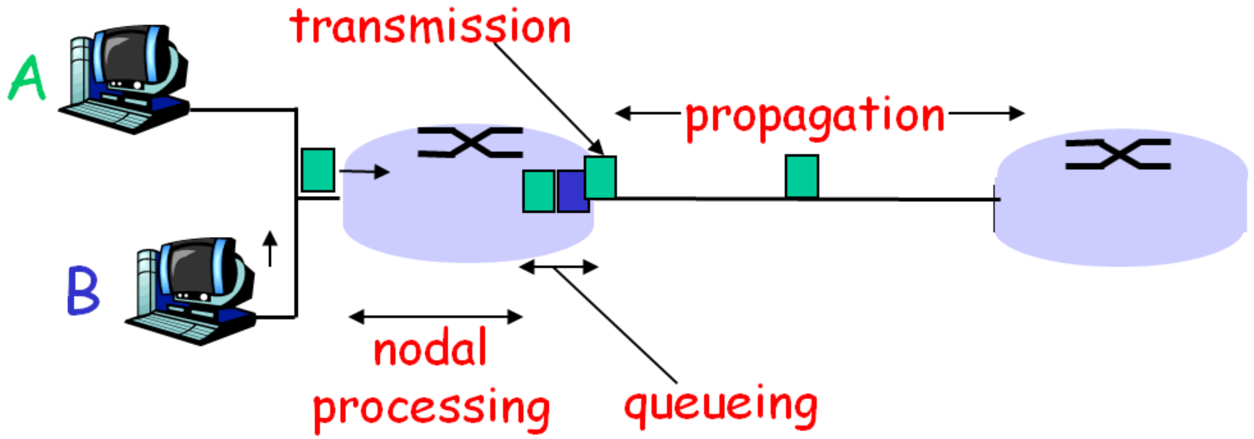
- Packet arrival rate exceeds output link capacity
- Packet queues, wait for its turn



Four Sources of Packet Delay

1. Transmission
- R=link bandwidth (bps)
- L=packet length (bits)
- Time to send bits into link = L/R

2. Propagation
- d = length of physical link
- s = propagation speed in medium (~2x10^8 m/sec)
- Propagation delay = d/s



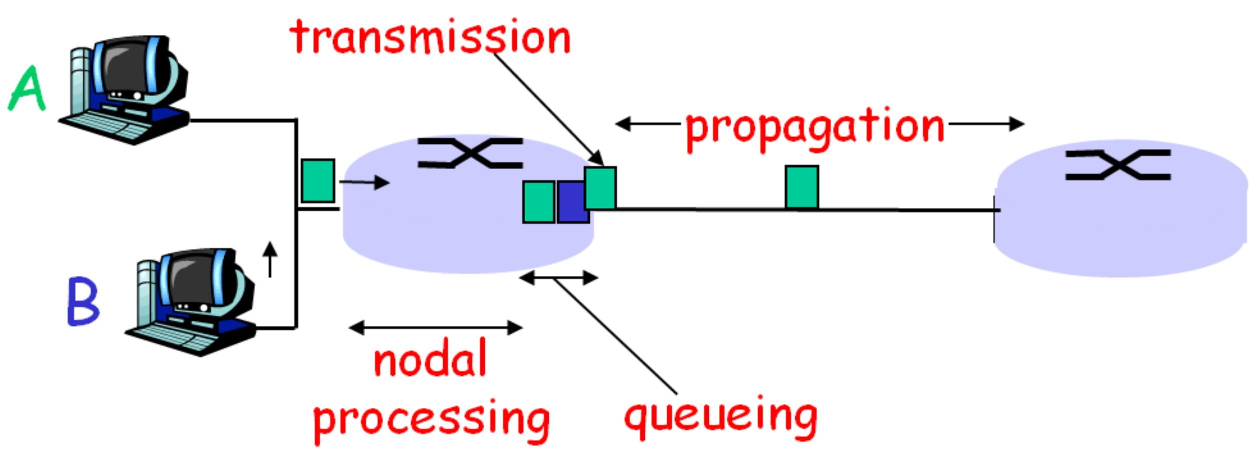
Four Sources of Packet Delay

3. Nodal processing

- Check bit errors
- Determine output link

4. Queuing

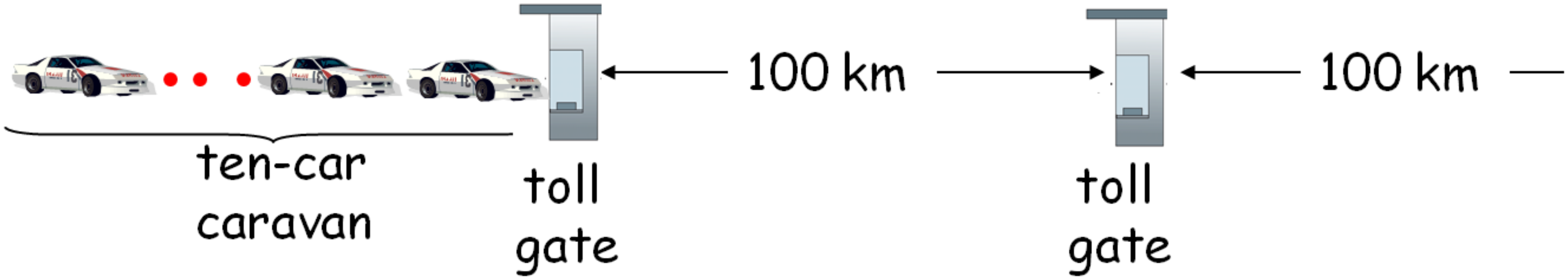
- Time waiting at output link for transmission
- Depending on congestion level of router



Magnitude of Different Delay

- Transmission delay
  - Significant for low-speed links, now typically a few microseconds or less
- Propagation delay
  - A few micro-seconds to hundreds of milliseconds
- Nodal processing delay
  - Typically a few microseconds or less
- Queuing delay
  - Depends on congestion, maybe seconds

Caravan Analogy



- Cars "propagate" at 100 km/hr
- Toll gate takes 12 sec to service car (nodal+trans)
- Car: packet; Caravan: packet flow
- Q: How long until caravan is lined up before 2nd toll gate?

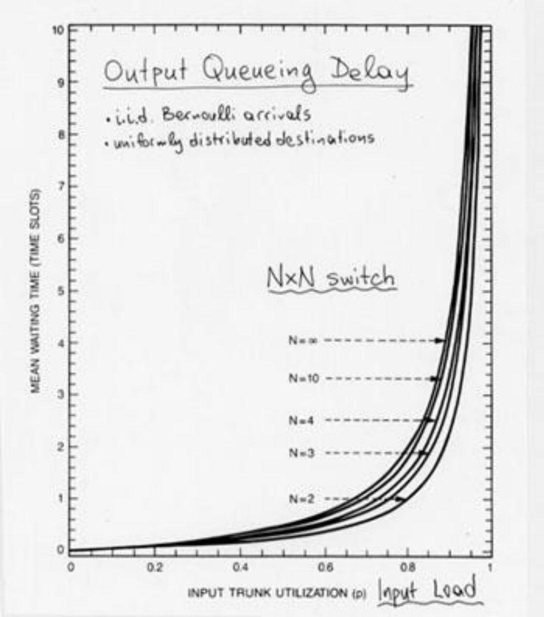
- Time to "push" entire caravan through toll gate = 12×10 = 120 sec
- Time for last car to propagate from 1st to 2nd toll gate: 100km/(100km/hr)= 1 hr
- Answer: 62 minutes
- Q: what about a single car?

Queuing Delay

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

流量强度

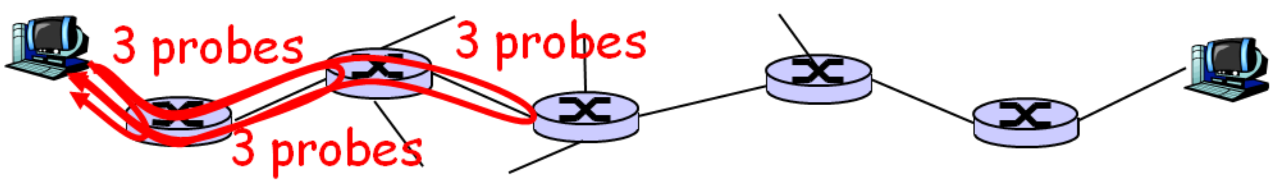
Traffic intensity $\rho = L \times \alpha / R$



- Intensity $\rho \sim 0$: average queuing delay small
- Intensity $\rho \rightarrow 1$: delays become large, and huge
- Intensity $\rho \geq 1$: average delay infinite

"Real" Internet Delays and Routes

- traceroute
  - www.traceroute.org
  - Provides delay measurement from source to router along end-to-end Internet path towards destination
  - Each intermediate router will return packets to sender
  - Sender records time interval between transmission and reply



“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
```

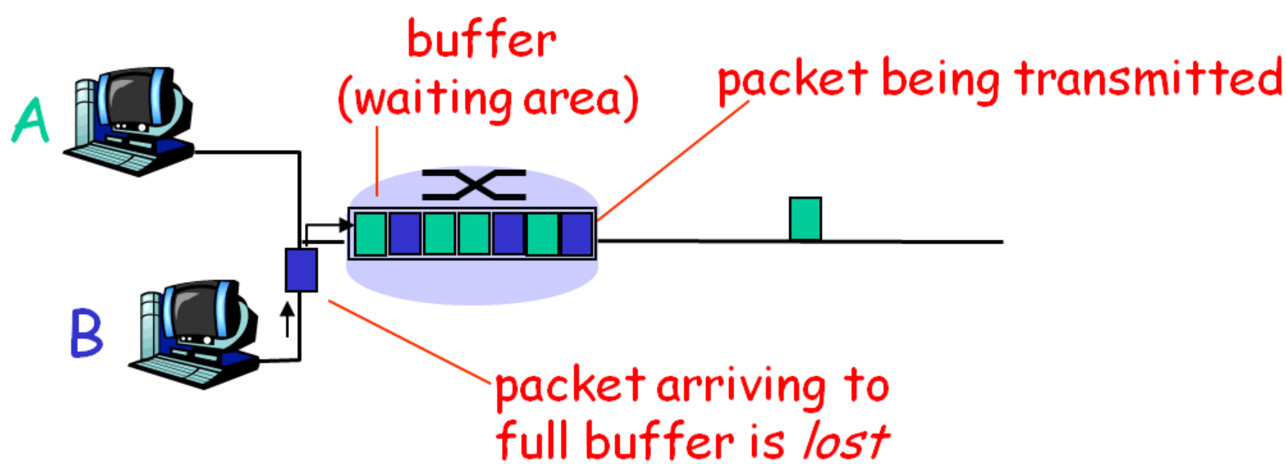
trans-oceanic link

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

Packet Loss

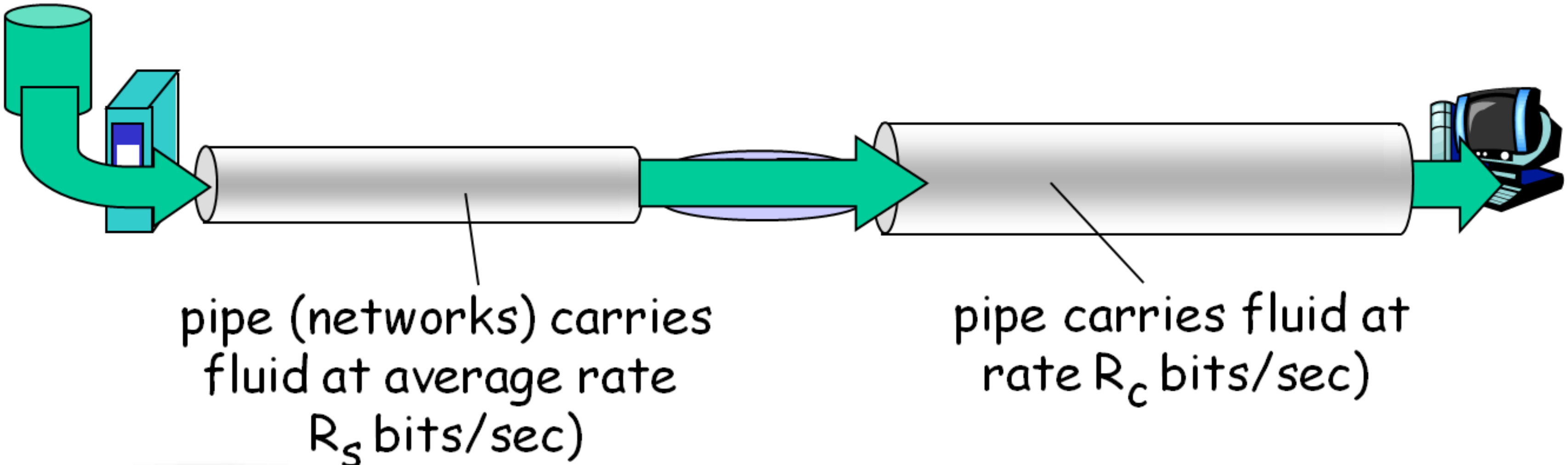
- Link in buffer of a router has finite capacity
- Packet arriving to full queue dropped (i.e. lost)

- Lost packet may be retransmitted by previous node, by source end system, or not at all



Throughput

- Throughput
  - Rate (bits/unit per time) at which bits transferred between sender/receiver
  - Instantaneous: rate at given point in time
  - Average: rate over a period of time

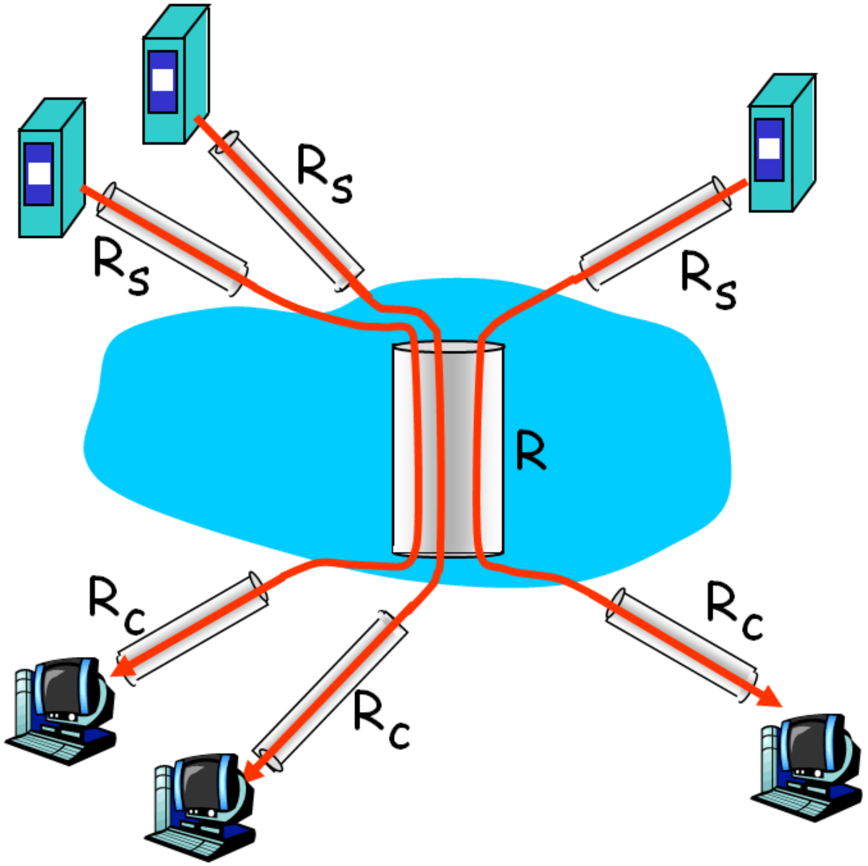


Throughput – Multiplexing

- Per-connection end-to-end throughput:

  $\min(R_c, R_s, R/10)$

- In practice: R_s (or R) is often the bottleneck



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

Transmission time and Propagation time

1. Transmission

- R=link bandwidth (bps)
- L=packet length (bits)
- Time to send bits into link = L/R

2. Propagation

- d = length of physical link
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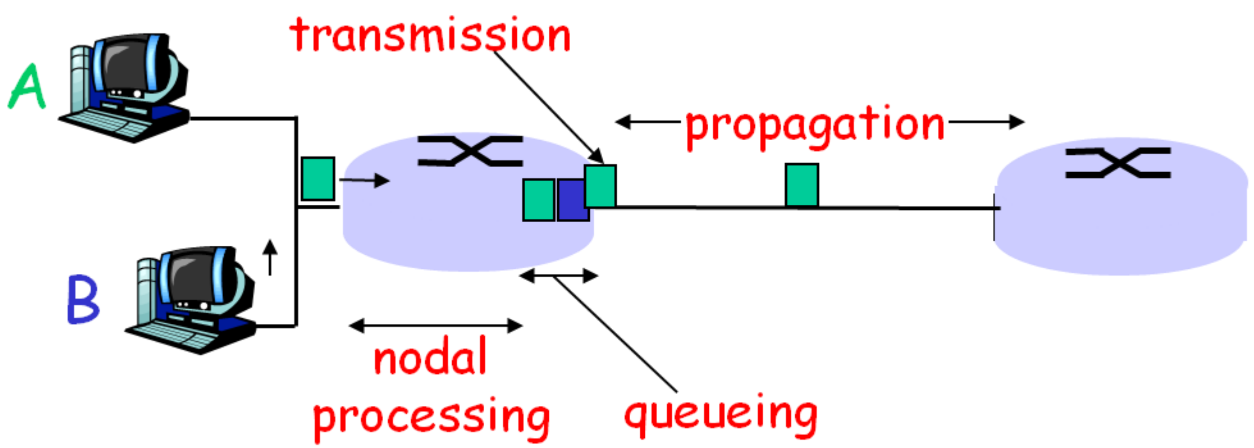
- Propagation delay = d/s



Network Performance

- Media Utilization
  - Time used for frame transmission vs. time the shared media is occupied

$$U = \frac{\text{Time for frame transmission}}{\text{total time for a frame}}$$

- Relative Propagation Time

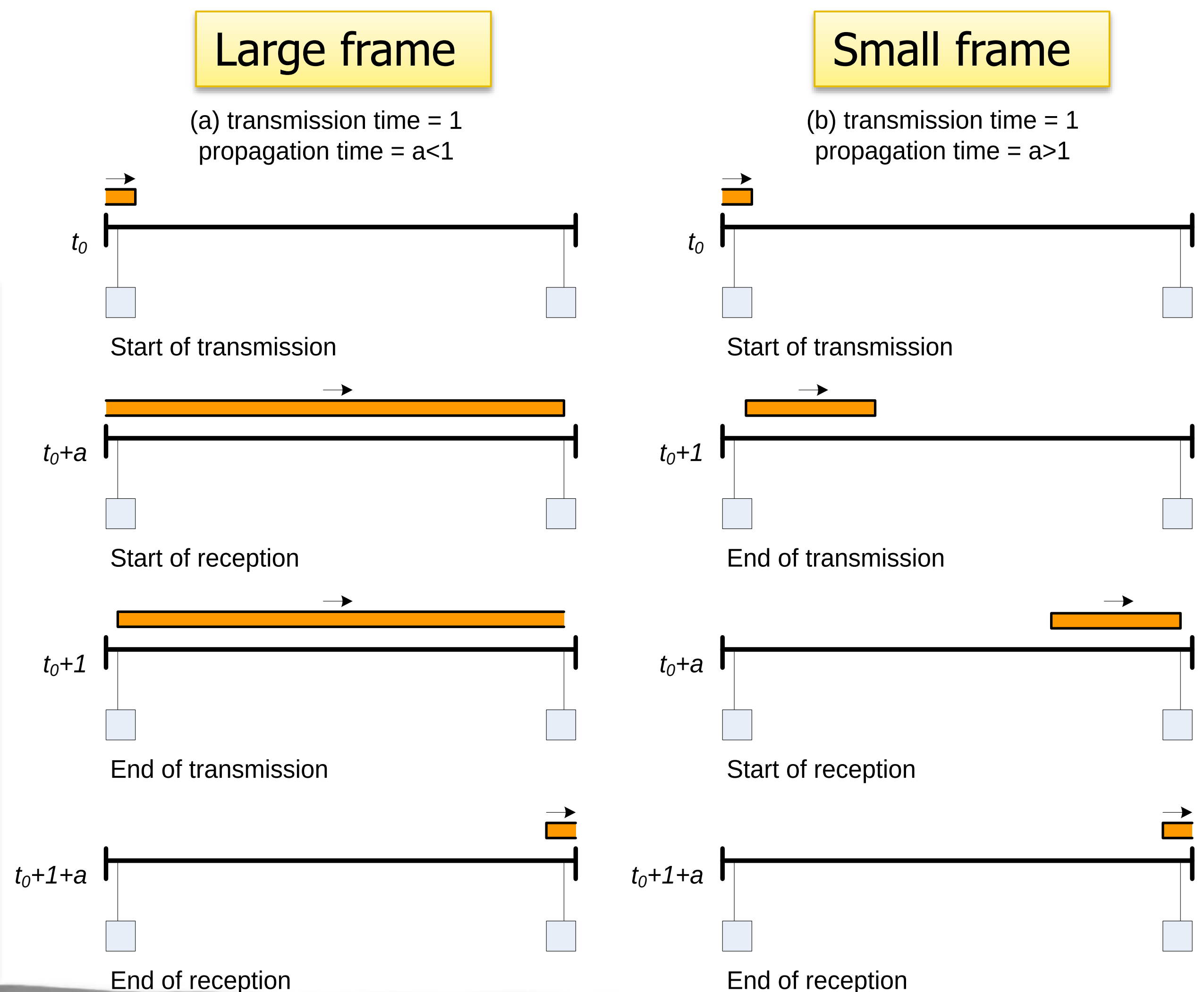
$$a = \frac{\text{propagation time}}{\text{transmission time}} \quad or$$

$$a = \frac{\text{length of the data path (in bits)}}{\text{length of a standard frame (in bits)}}$$

Different Networks

- Contention free
  - Point-to-Point Link
  - Ring LAN
- Random access
  - ALOHA
  - CSMA/CD

Point-to-Point Link with No ACK



Define

1: normalized frame transmission time

a: end to end propagation delay

N: number of stations

Q:
Max Utilization U=?

Max Utilization for Point-to-Point Link

- Parameters and assumptions
  - 1: normalized frame transmission time
  - a: end to end propagation delay
  - N: number of stations

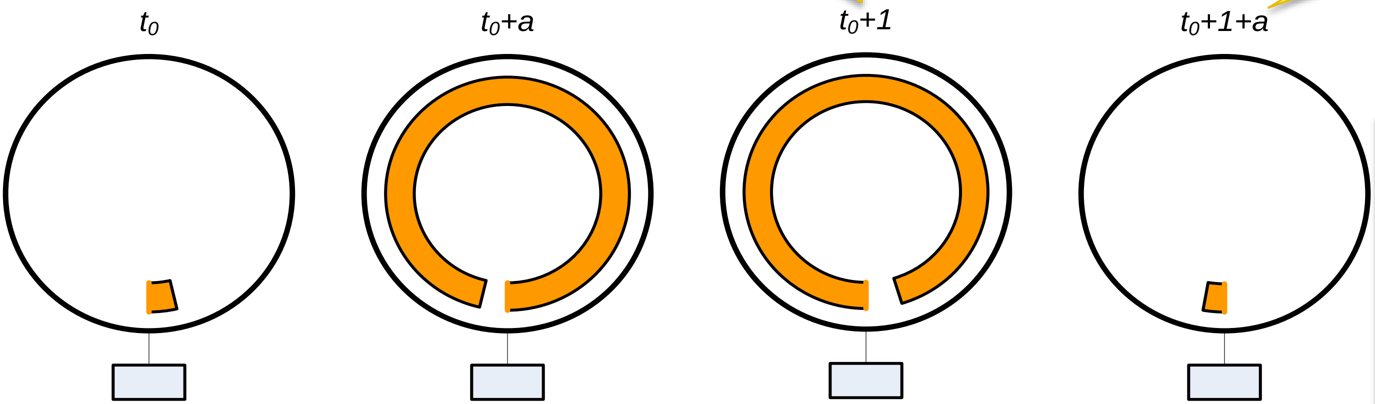
- Each station has frames to transmit
- Total frame time=transmission delay + propagation delay: $1+a$
- Max Utilization:

$$U = \frac{1}{1+a}$$

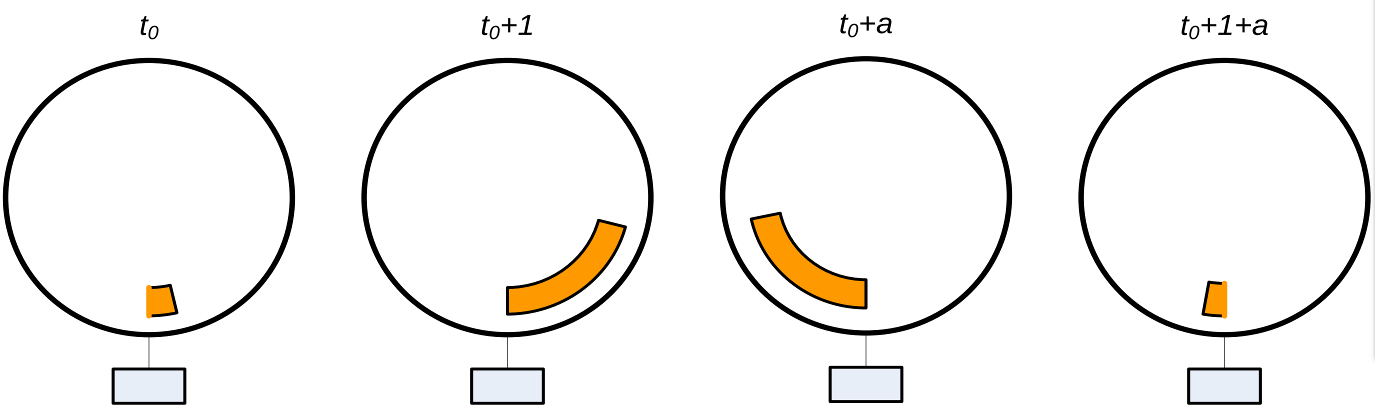
Ring LAN

Token is released at t_0+1, and it will arrive the next station at t_0+1+a/N (next transmission starts).

End of the previous transmission at t_0+1+a.



(a) transmission time = 1, propagation time = a<1



(b) transmission time = 1, propagation time = a>1

Token is released at t_0+a, and it will arrive the next station at t_0+a+a/N (next transmission starts).

End of the previous transmission at t_0+1+a.

Define:

T_1 : Average time to transmit a frame, i.e. $T_1 = 1$

T_2 : Average time to pass the token after frame transmission

N: number of stations

Q:

Max Utilization: $U = ?$

Max Utilization for Ring LAN

- Define
  - T_1 : Average time to transmit a frame, i.e. $T_1 = 1$
  - T_2 : Average time to pass the token after frame transmission
- Max Utilization: $U = T_1/(T_1+T_2)$

2 cases

- Case 1: $a<1$ (frame longer than ring)
  - T_2 = time to pass token to the next station = a/N
- Case 2: $a>1$ (frame shorter than ring)
  - T_2 = sender wait for frame returns after transmission = $a-1+a/N$

$$U = \begin{cases} \dfrac{1}{1+a/N} & a<1 \\ \dfrac{1}{a+a/N} & a>1 \end{cases}$$

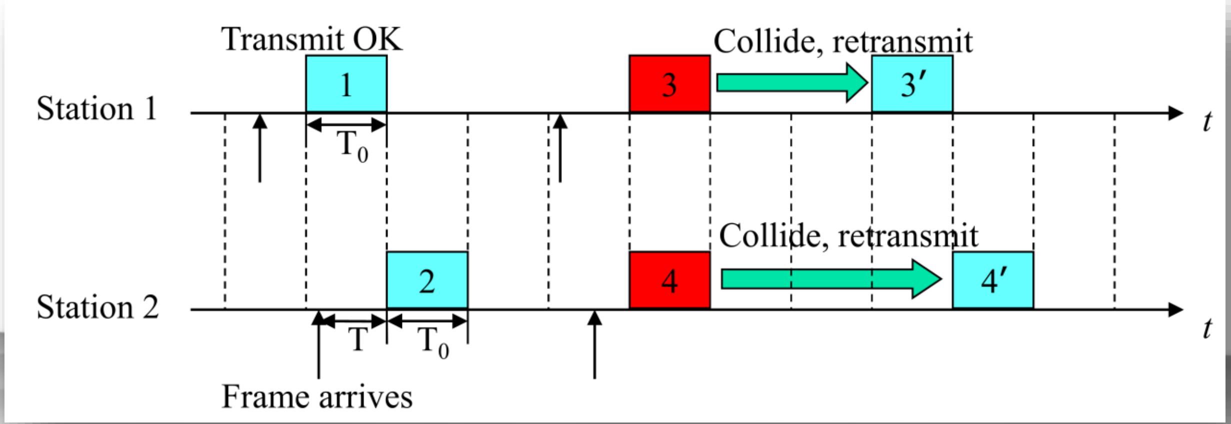
Slotted ALOHA

- All frames have same size
- Time is uniformly slotted
- Nodes are synchronized
- Transmission begins at slot boundary
- Frames either miss or overlap totally

operation:

- N nodes with many frames to send
- Each transmits in each slot with probability p until success

- Q:
- Max Utilization: $U = ?$



Slotted ALOHA

- Suppose:
  - N nodes with many frames to send, each transmits in slot with probability p
- Probability of successful transmission
  - One node has success in a slot $= p(1-p)^{N-1}$
  - Any node has a success $A = Np(1-p)^{N-1}$
- Maximize value of A (let A'(p)=0)

$$p = \frac{1}{N} \implies A = \left(1 - \frac{1}{N}\right)^{N-1}$$

Slotted ALOHA Efficiency

Before data transmission, it takes a to detect collision;
After transmission, it takes a to make sure the transmission of the last bit

- Utilization if a slot is successfully used

$$U_s = \frac{1}{1+2a} \approx 1 \quad (a \ll 1)$$

- Since A is the rate of success slot

efficiency: long-run fraction of successful slots (many nodes, all with many frames to send)

$$U = U_s \times A \approx \left(1 - \frac{1}{N}\right)^{N-1}$$

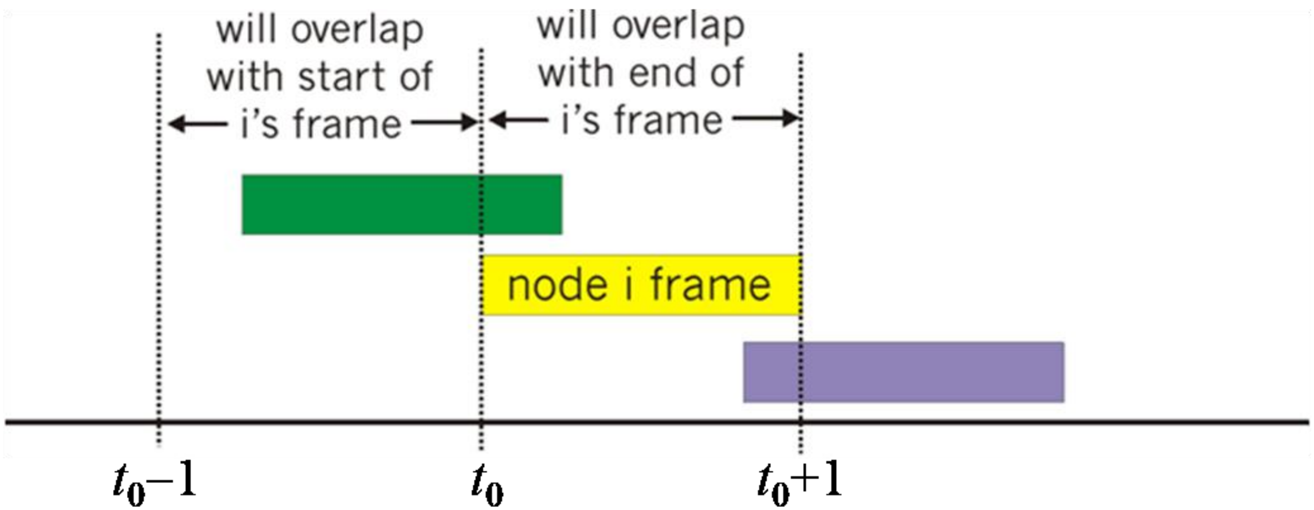
$$\text{Let } N \to \infty$$

$$U \approx e^{-1} = 0.367879$$

$$\lim_{x \to \infty} (1 - \frac{1}{x})^x = e^{-1}$$

Pure ALOHA

- Simpler but collision probability increases
  - Frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Suppose:
N nodes with many frames to send, each transmits in any time with probability p

Q: Max Utilization: $U=?$

Pure ALOHA Efficiency

- Probability of successful transmission

$$
\begin{aligned}
A =& N \cdot P(\text{one transmits in the slot}) \cdot \\
& P(\text{no other node transmits in } [t_{0-1}, t_0] \cdot \\
& P(\text{no other node transmits in } [t_0, t_{0+1}]
\end{aligned}
$$

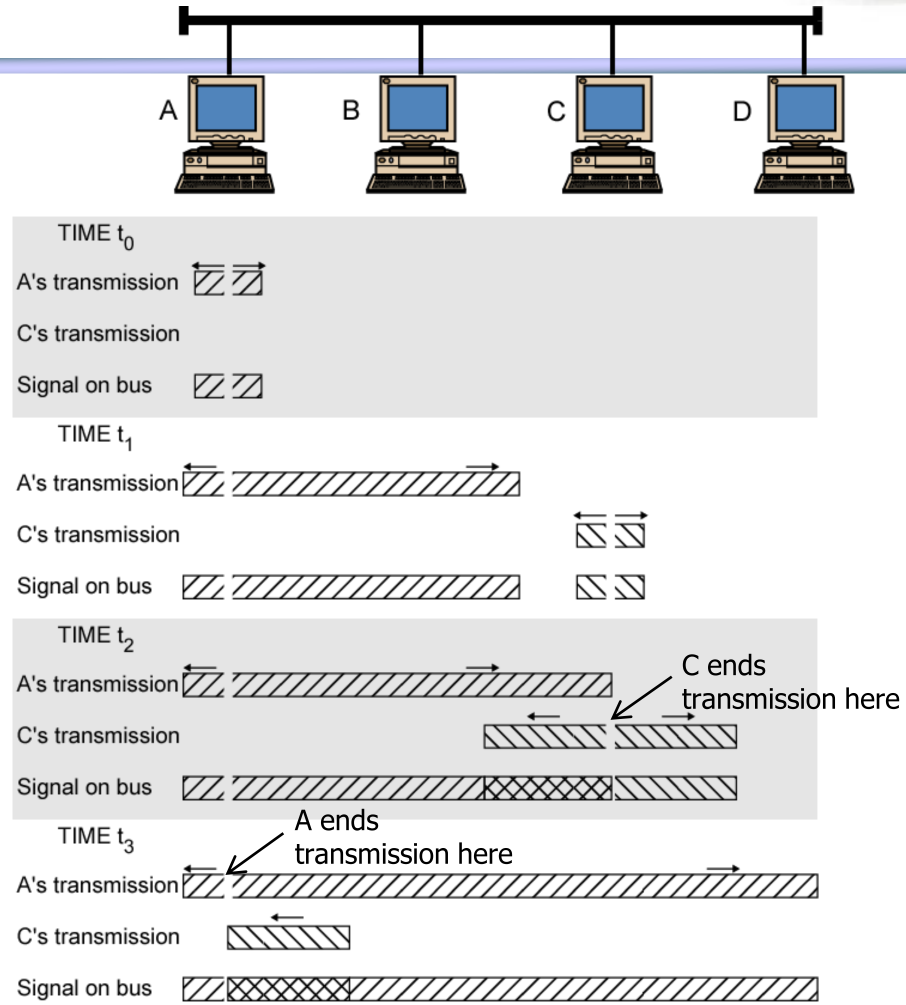
$$
\begin{aligned}
U \approx A &= Np \cdot (1-p)^{2N-1} \\
&\approx \frac{1}{2}(1 - \frac{1}{2N})^{2N-1} \quad (p = \frac{1}{2N}) \\
&\approx 1/(2e) = 0.183940 \quad (N \to \infty)
\end{aligned}
$$

CSMA/CD

- With CSMA, collision occupies medium for duration of transmission
  - Colliding transmissions aborted once detected

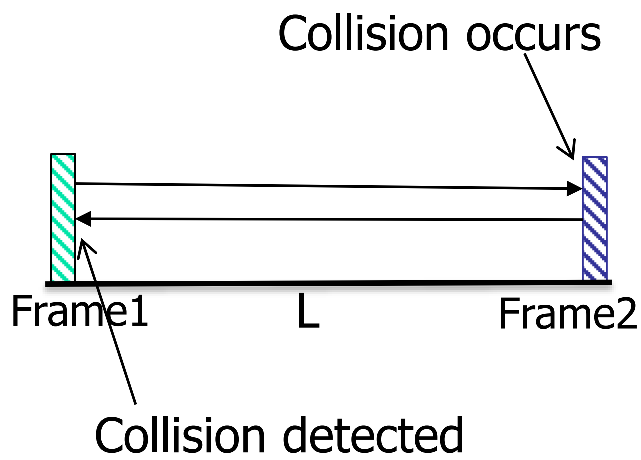
- Stations listen whilst transmitting
  1. If medium idle, transmit; otherwise, step 2
  2. If busy, listen for idle, then transmit immediately
  3. If collision detected, send jam signal then abort
  4. After jam, wait random time then start from step 1

CSMA/CD Operation



CSMA/CD: Minimum Frame Size

- B: bandwidth
- L: length of the link
- V: propagation speed
- Size: size of a frame

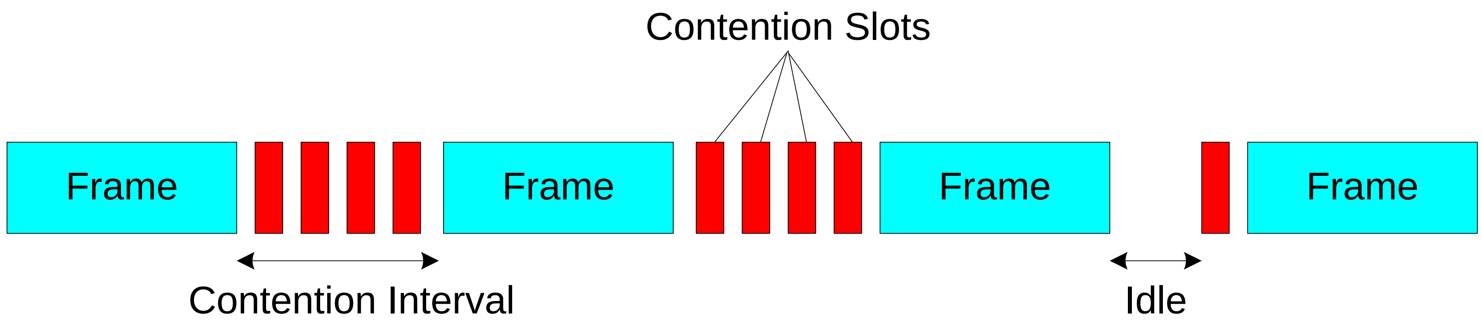


- Propagation time: T_a=L/v
- Transmission time for one frame: T_b=Size/B

- In the worse case, collision detection takes $2T_a$.
  - Minimum contention interval= $2T_a$

- Minimum frame size:
  - If the transmission time of a frame is less than $2T_a$, it may not be able to detect collision if collision occurs.
  - To assure collision detection, it must satisfies $T_b >= 2T_a$
  - Thus size/B>=2L/v, minimum frame size: size>=2*L*B/v

CSMA/CD (p-persistent): Max Utilization



- Contention slots end in a collision
- Contention interval is a sequence of contention slots
  - Length of a slot in contention interval is $2a$

    (in worst case it takes $2a$ time to detect contention)
- Assume p-persistent:
  - The probability that a station attempts to transmit in a slot is p
- Q: Max Utilization: $U = ?$

Max Utilization for CSMA/CD (1)

- Let A be the probability that some station can successfully transmit in a slot, then:

$$A = \binom{N}{1} p^1 (1-p)^{N-1} = Np(1-p)^{N-1}$$

- In above formula, A is maximized when $p=1/N$, thus:

$$A = \left(1 - \frac{1}{N}\right)^{N-1}$$

Max Utilization for CSMA/CD (2)

- Probability of a contention interval with j slots

  $Prob[\,j \text{ unsuccessful attempts}] \times Prob[1 \text{ successful attempt}] =$

  $A(1-A)^j$

- The expected number of slots in a contention interval is then calculated as (Geometric distribution, mean=(1-p)/p):

$$\sum_{j=1}^{\infty} jA(1-A)^j = \frac{1-A}{A}$$

Max Utilization for CSMA/CD (3)

- Maximum Utilization

$$U = \frac{\text{Frame time}}{\text{Frame time+Propagation time+Average contention interval}}$$

$$= \frac{1}{1+a+2a\dfrac{1-A}{A}} = \frac{1}{1+\dfrac{2-A}{A}a}$$

- Let $N \rightarrow \infty$, $A = (1-1/N)^{N-1} = 1/e$ (e=2.718)

$$U = \frac{1}{1+\dfrac{2-A}{A}a} = \frac{1}{1+(2e-1)a} \approx \frac{1}{1+4.44a}$$

Summary

- 网络性能指标
  - 网络时延、丢包、吞吐量概念
  - 四种时延：处理、排队、传输、传播
- 传输媒介利用率分析
  - Point-to-point link
  - Ring LAN
  - ALOHA, Slotted ALOHA
  - CSMA/CD （ p-persistent ）

Homework

- 第5章：P8, P10, P18, P19