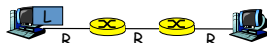


Packet-switching: store-and-forward



- Takes L/R seconds to transmit (push out) packet of L bits on to link or R bps
- Entire packet must arrive at router before it can be transmitted on next link: *store and forward*
- delay = $3L/R$

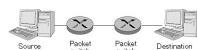
Example:

- $L = 7.5$ Mbits
- $R = 1.5$ Mbps
- delay = 15 sec

Introduction

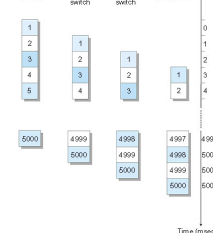
1-1

Packet Switching: Message Segmenting



Now break up the message into 5000 packets

- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining*: each link works in parallel
- Delay reduced from 15 sec to 5.002 sec



Time (msec)

Introduction

1-2

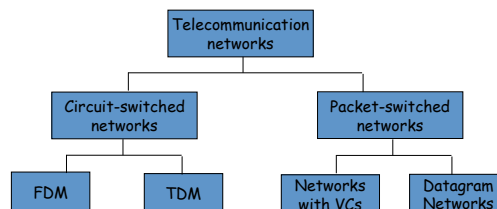
Packet-switched networks: forwarding

- *Goal*: move packets through routers from source to destination
 - we'll study several path selection (i.e. routing) algorithms (chapter 4)
- *datagram network*:
 - *destination address* in packet determines next hop
 - routes may change during session
 - analogy: driving, asking directions
- *virtual circuit network*:
 - each packet carries tag (virtual circuit ID), tag determines next hop
 - fixed path determined at *call setup time*, remains fixed thru call
 - *routers maintain per-call state*

Introduction

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Network Taxonomy



• Internet provides both connection-oriented (TCP) and connectionless services (UDP) to apps.

Introduction

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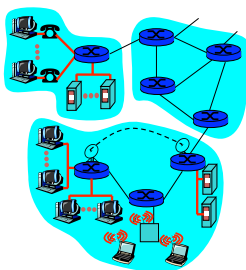
Access networks and physical media

Q: How to connect end systems to edge router?

- residential access nets
- institutional access networks (school, company)
- mobile access networks

Keep in mind:

- bandwidth (bits per second) of access network?
- shared or dedicated?

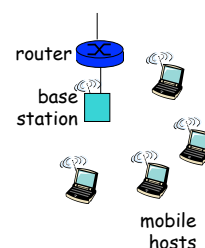


Introduction

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Wireless access networks

- shared *wireless access* network connects end system to router
 - via base station aka "access point"
- *wireless LANs*:
 - 802.11b (WiFi): 11 Mbps
 - Bluetooth ([IEEE 802.15.1](#))
 - ZigBee ([IEEE 802.15.4](#))
- *wider-area wireless access*
 - provided by telco operator
 - 3G ~ 384 kbps
 - WAP/GPRS in Europe



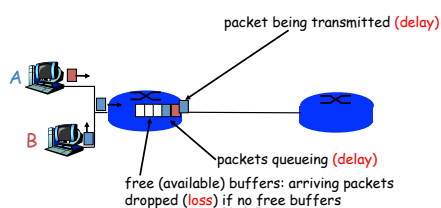
Introduction

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How do loss and delay occur?

packets *queue* in router buffers

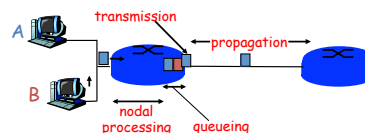
- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn



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Four sources of packet delay

- 1. nodal processing:
 - check bit errors
 - determine output link
- 2. queueing
 - time waiting at output link for transmission
 - depends on congestion level of router



Introduction

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Delay in packet-switched networks

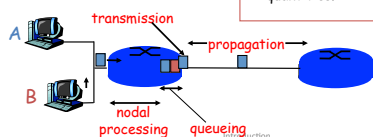
3. Transmission delay:

- R = link bandwidth (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 ($\sim 2 \times 10^8$ m/sec)
- propagation delay = d/s

Note: s and R are very different quantities!



Introduction

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Nodal delay

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

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

Introduction

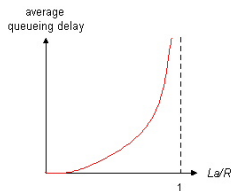
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Queueing delay (revisited)

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

$$\text{traffic intensity} = La/R$$

- $La/R \sim 0$: average queueing delay small
- $La/R \rightarrow 1$: delays become large
- $La/R > 1$: more "work" arriving than can be serviced, average delay infinite!



Introduction

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"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.



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“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.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 chl-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.fr.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)

Introduction

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Packet loss

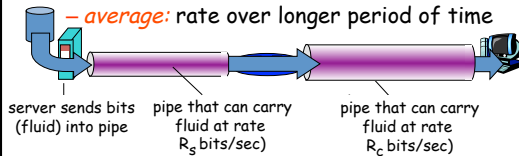
- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all

Introduction

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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



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