CS 307 Computer Networks

Spring 2019

Week # 3 (Lecture # 7 and #8)

30th Jamadi ul Awwal, 1440 A.H

6th February 2019

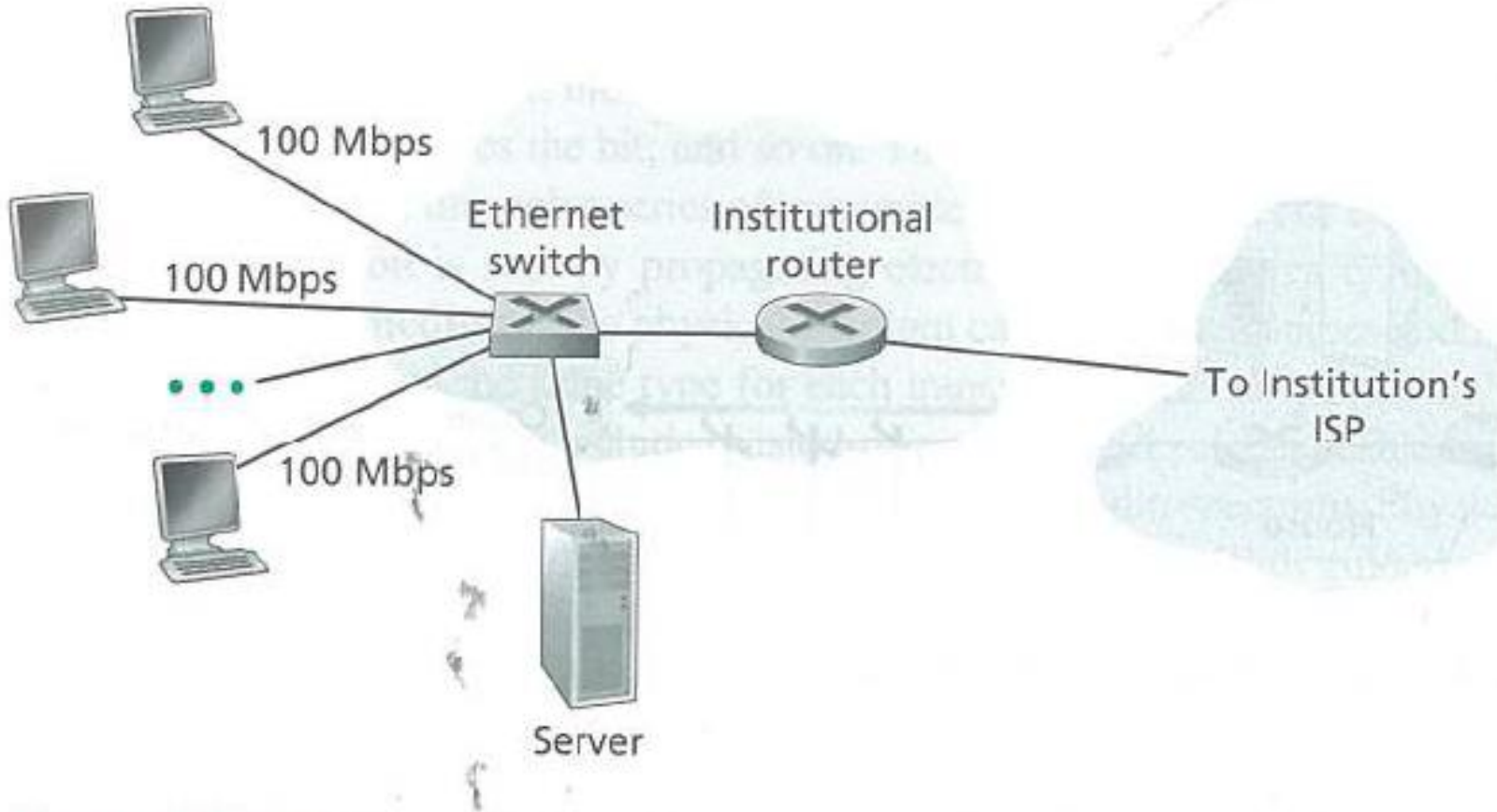


Figure 1.8 ♦ Ethernet Internet access

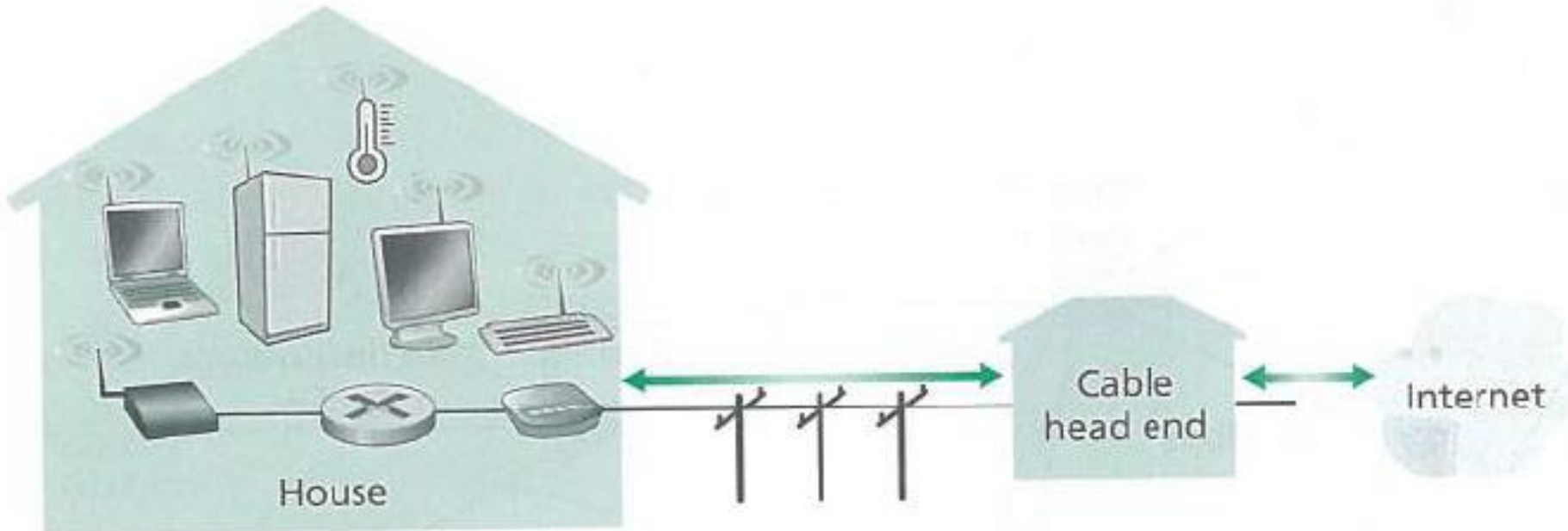


Figure 1.9 ♦ A typical home network

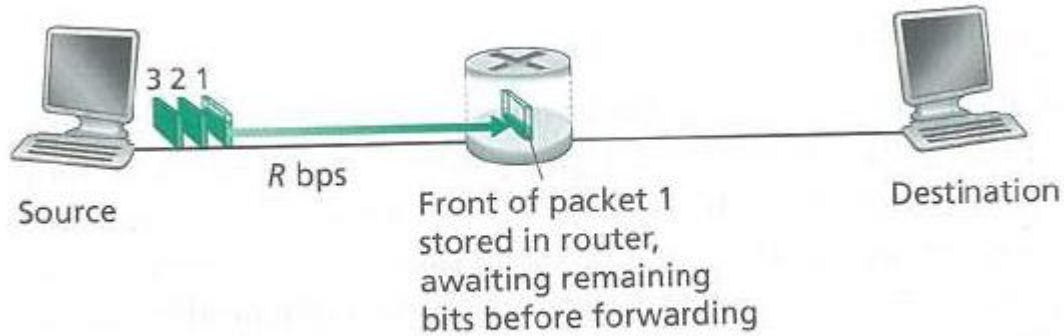


Figure 1.11 ♦ Store-and-forward packet switching

Let's now consider the general case of sending one packet from source to destination over a path consisting of N links each of rate R (thus, there are N-1 routers between source and destination). Applying the same logic as above, we see that the end-to-end delay is:

$$d_{\text{end-to-end}} = N\frac{L}{R} \tag{1.1}$$

You may now want to try to determine what the delay would be for P packets sent over a series of N links.

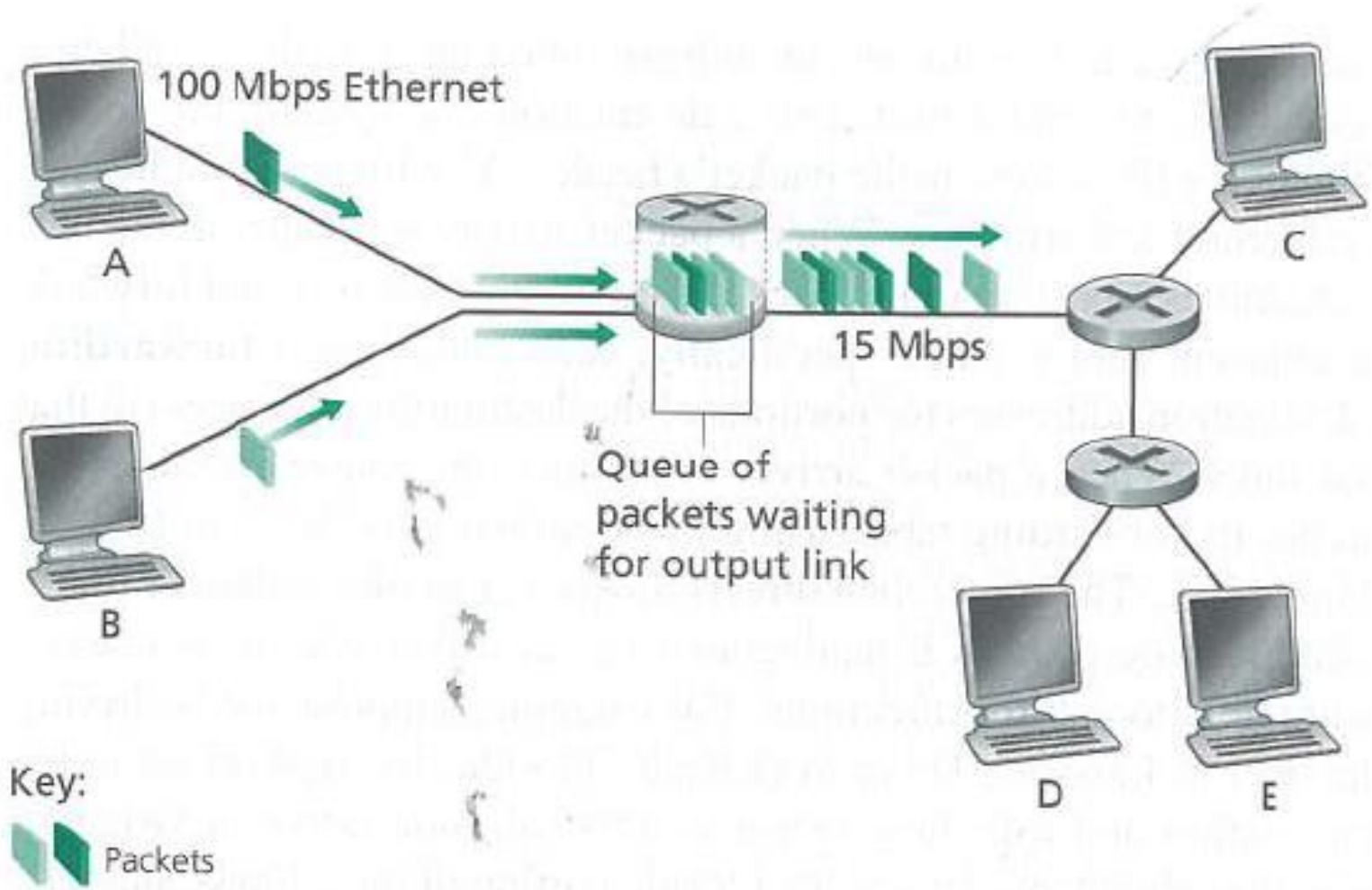


Figure 1.12 ♦ Packet switching

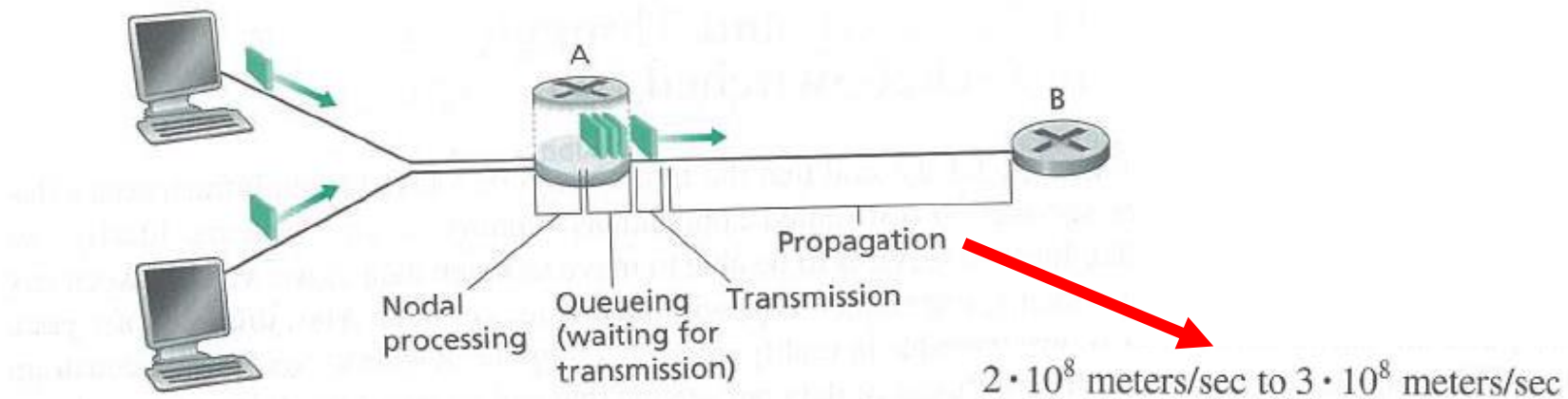


Figure 1.16 ♦ The nodal delay at router A

Nodal processing = given (unpacking of L2, L3 processing + Forwarding decision + packing L3 and L2)
Queueing delay = given
Transmission = Length of packets in bits / Bandwidth in bits per second.
Propagation = distance /speed of propagation

1.4.3 End-to-End Delay

Our discussion up to this point has focused on the nodal delay, that is, the delay at a single router. Let's now consider the total delay from source to destination. To get a handle on this concept, suppose there are $N - 1$ routers between the source host and the destination host. Let's also suppose for the moment that the network is uncongested (so that queuing delays are negligible), the processing delay at each router and at the source host is d_{proc}, the transmission rate out of each router and out of the source host is R bits/sec, and the propagation on each link is d_{prop}. The nodal delays accumulate and give an end-to-end delay,

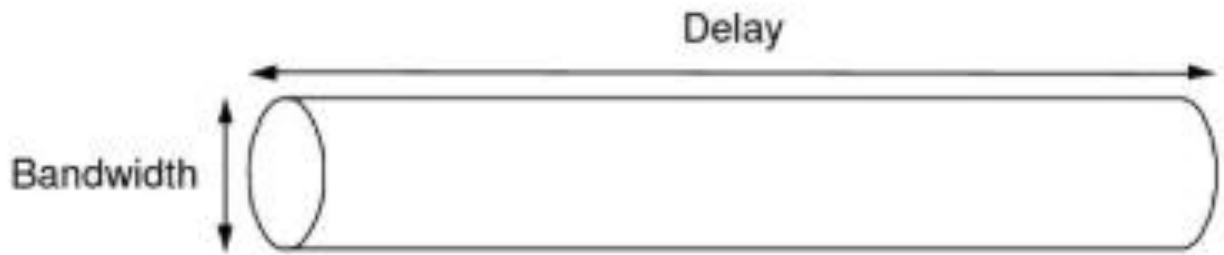
$$d_{\text{end-end}} = N(d_{\text{proc}} + d_{\text{trans}} + d_{\text{prop}}) \tag{1.2}$$

where, once again, $d_{\text{trans}} = L/R$, where L is the packet size. Note that Equation 1.2 is a generalization of Equation 1.1, which did not take into account processing and propagation delays. We leave it to you to generalize Equation 1.2 to the case of heterogeneous delays at the nodes and to the presence of an average queuing delay at each node.

Bandwidth x Delay Product

The amount of data (bits or bytes) "in the pipe"

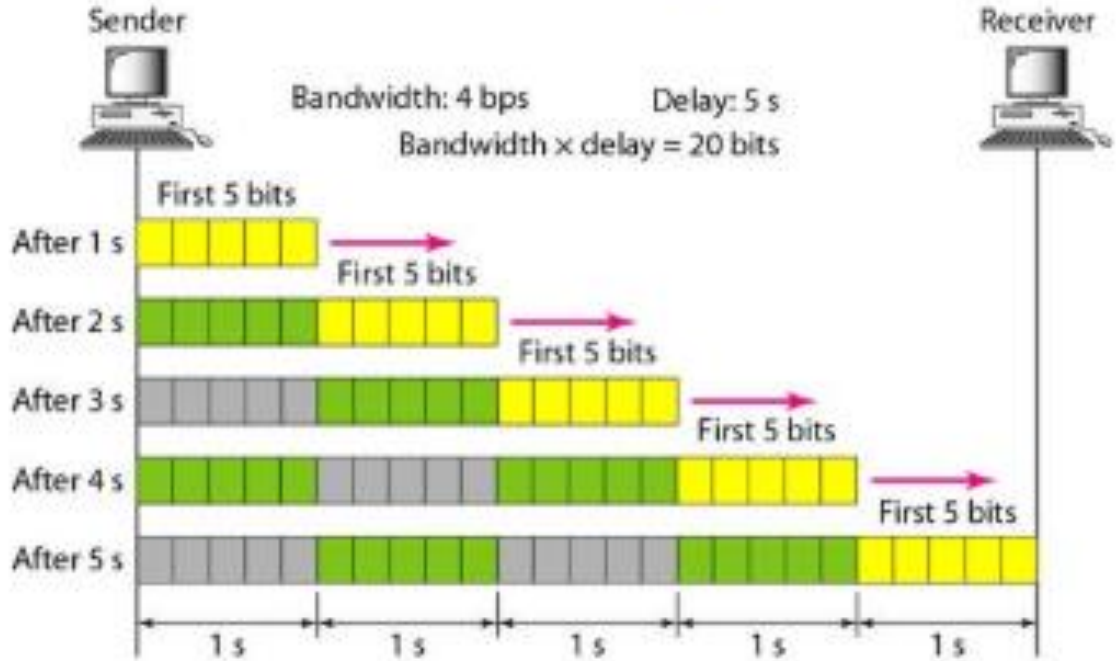
Example: 100Mbps x 10ms = 1 Mbit



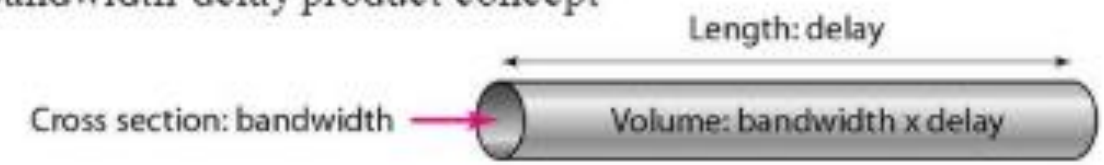
The amount of data sent before first bit arrives

Usually use RTT as delay: amount of data before a reply from a receiver arrives to the sender

Bandwidth-Delay Product



Bandwidth-delay product concept

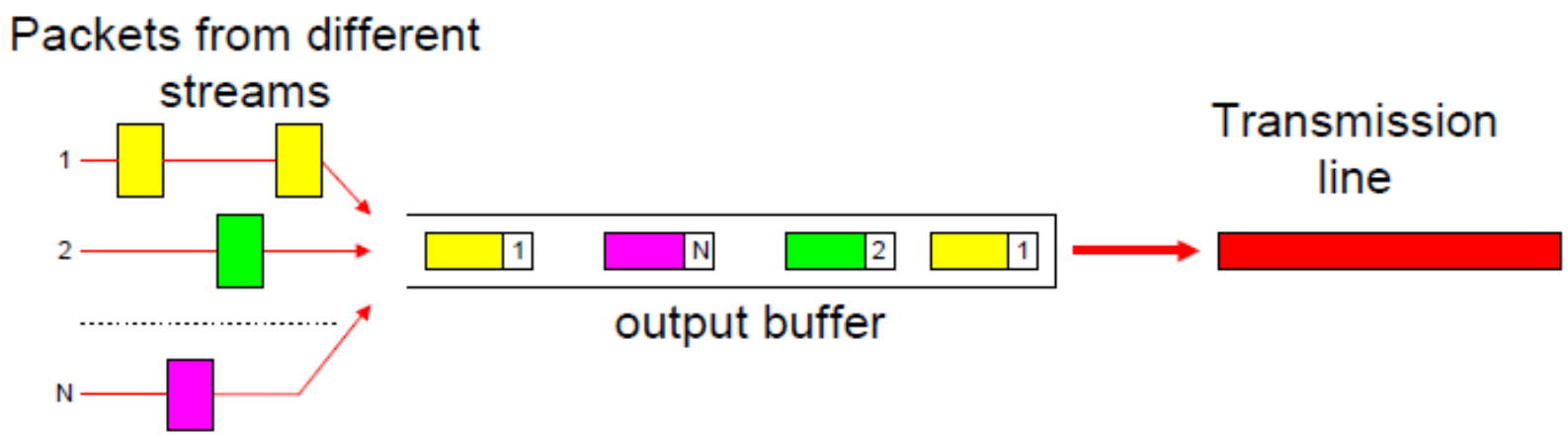


The bandwidth-delay product defines the number of bits that can fill the link.

Statistical Multiplexing

Packet transmission on a link is referred to as **statistical multiplexing**

- There is no fixed allocation of packet transmissions
- Packets are multiplexed as they arrive



Comparison

Circuit Switching

- Dedicated transmission path
- Continuous transmission
- Path stays fixed for entire connection
- Call setup delay
- Negligible transmission delay
- No queueing delay
- Busy signal overloaded network
- Fixed bandwidth for each circuit
- No overhead after call setup

Datagram Packet Switching

- No dedicated transmission path
- Transmission of packets
- Route of each packet is independent
- No setup delay
- Transmission delay for each packet
- Queueing delays at switches
- Delays increase in overloaded networks
- Bandwidth is shared by all packets
- Overhead in each packet

VC Packet Switching

- No dedicated transmission path
- Transmission of packets
- Path stays fixed for entire connection
- Call setup delay
- Transmission delay for each packet
- Queueing delays at switches
- Delays increase in overloaded networks
- Bandwidth is shared by all packets
- Overhead in each packet

Lecture # 8

```
PS C:\WINDOWS\system32> tracert oracle.com

Tracing route to oracle.com [137.254.120.50]
over a maximum of 30 hops:

  1    14 ms     2 ms     2 ms  192.168.0.1
  2     3 ms     3 ms     3 ms  wtl.worldcall.net.pk [111.88.105.1]
  3     3 ms     4 ms     4 ms  192.168.20.2
  4     7 ms     5 ms     7 ms  static.connect.net.pk.249.120.221.in-addr.arpa [221.120.249.233]
  5     6 ms     5 ms     3 ms  119.159.240.165
  6     6 ms     6 ms     7 ms  rwp44.pie.net.pk [221.120.251.213]
  7     6 ms     6 ms     7 ms  static.khi77.pie.net.pk [202.125.128.151]
  8   133 ms   143 ms   146 ms  te0-0-0-14.ccr21.mrs01.atlas.cogentco.com [149.14.125.225]
  9   144 ms   141 ms   144 ms  be2314.rcr21.mil01.atlas.cogentco.com [130.117.50.94]
 10   532 ms   135 ms   133 ms  130.117.14.154
 11   259 ms   262 ms   258 ms  xe-1-2-0.cr6-dal3.ip4.gtt.net [213.254.215.166]
 12   249 ms   249 ms   248 ms  ip4.gtt.net [69.174.9.174]
 13   242 ms   265 ms   245 ms  dal-iar-rtr-1-ae0.oracle.com [209.17.5.201]
 14   250 ms   249 ms   254 ms  adcq7-tar-rtr-1-xe-2-0-0.oracle.com [209.17.0.65]
 15   251 ms   266 ms   261 ms  adcq7-itr-rtr-4-xe-5-0-1.oracle.com [141.146.0.230]
 16   248 ms   247 ms   249 ms  vp-ocoma-cms-adc.oracle.com [137.254.120.50]

Trace complete.
PS C:\WINDOWS\system32>
```

```
PS C:\WINDOWS\system32> tracert oracle.com

Tracing route to oracle.com [137.254.120.50]
over a maximum of 30 hops:

  1    11 ms    48 ms    48 ms  172.16.56.1
  2     *        *        *     Request timed out.
  3     *        *        *     Request timed out.
  4     *
PS C:\WINDOWS\system32>
```

```
PS C:\WINDOWS\system32> tracert ethz.ch

Tracing route to ethz.ch [129.132.128.139]
over a maximum of 30 hops:

  1     3 ms     2 ms    15 ms  192.168.0.1
  2     4 ms     4 ms     7 ms  wtl.worldcall.net.pk [111.88.105.1]
  3     3 ms     3 ms     3 ms  192.168.20.2
  4     5 ms     3 ms     3 ms  static.connect.net.pk.249.120.221.in-addr.arpa [221.120.249.233]
  5     6 ms     4 ms     4 ms  119.159.240.165
  6    11 ms     7 ms     4 ms  khi275.p01.pie.net.pk [221.120.251.209]
  7     5 ms     6 ms     7 ms  static.khi77.pie.net.pk [202.125.128.151]
  8   100 ms   100 ms   102 ms  te0-7-0-7.ccr21.mrs01.atlas.cogentco.com [149.14.126.9]
  9   124 ms   130 ms   137 ms  be3080.ccr51.zrh02.atlas.cogentco.com [130.117.49.2]
 10   115 ms   114 ms   114 ms  te0-0-1-0.rcr11.bsl01.atlas.cogentco.com [130.117.2.146]
 11   140 ms   138 ms   138 ms  149.6.34.6
 12   143 ms   137 ms   139 ms  swiBS1-100GE-0-0-0-0.switch.ch [130.59.37.34]
 13   138 ms   137 ms   137 ms  swiZH1-100GE-0-1-0-5.switch.ch [130.59.36.170]
 14   152 ms   150 ms   149 ms  swiEZ3-100GE-0-1-0-4.switch.ch [130.59.38.109]
 15   136 ms   136 ms   136 ms  rou-gw-lee-tengig-to-switch.ethz.ch [192.33.92.1]
 16   136 ms   159 ms   136 ms  rou-fw-rz-rz-gw.ethz.ch [192.33.92.169]
 17     *        *        *     Request timed out.
 18     *        *        *     Request timed out.
 19     *        *        *     Request timed out.
 20     *        *        *     Request timed out.
 21     *        *        *     Request timed out.
 22     *        *        *     Request timed out.
 23     *        *        *     Request timed out.
 24     *        *        *     Request timed out.
 25     *        *        *     Request timed out.
 26     *        *        *     Request timed out.
 27     *        *        *     Request timed out.
 28     *        *        *     Request timed out.
 29     *        *        *     Request timed out.
 30     *        *        *     Request timed out.

Trace complete.
PS C:\WINDOWS\system32>
```

```
PS C:\WINDOWS\system32> tracert data.gov

Tracing route to data.gov [34.193.244.109]
over a maximum of 30 hops:

  1     3 ms     2 ms     2 ms  192.168.0.1
  2     6 ms     3 ms     3 ms  wtl.worldcall.net.pk [111.88.105.1]
  3     3 ms     3 ms     3 ms  192.168.20.2
  4     4 ms     5 ms     4 ms  static.connect.net.pk.249.120.221.in-addr.arpa [221.120.249.233]
  5     7 ms     4 ms     7 ms  119.159.240.165
  6     9 ms     5 ms     7 ms  rwp44.pie.net.pk [221.120.251.213]
  7     7 ms     5 ms     6 ms  static.khi77.pie.net.pk [202.125.128.171]
  8   106 ms   100 ms   100 ms  te0-7-0-7.ccr21.mrs01.atlas.cogentco.com [149.14.126.9]
  9   124 ms   129 ms   135 ms  be3092.ccr41.par01.atlas.cogentco.com [130.117.49.153]
 10   213 ms   211 ms   207 ms  be3627.ccr41.jfk02.atlas.cogentco.com [66.28.4.197]
 11   185 ms   188 ms   186 ms  be3495.ccr31.jfk10.atlas.cogentco.com [66.28.4.182]
 12   188 ms   183 ms   183 ms  38.140.106.162
 13   310 ms   309 ms   304 ms  52.93.31.45
 14   388 ms   385 ms   391 ms  52.93.4.12
 15     *        *        *     Request timed out.
 16     *        *
PS C:\WINDOWS\system32>
```

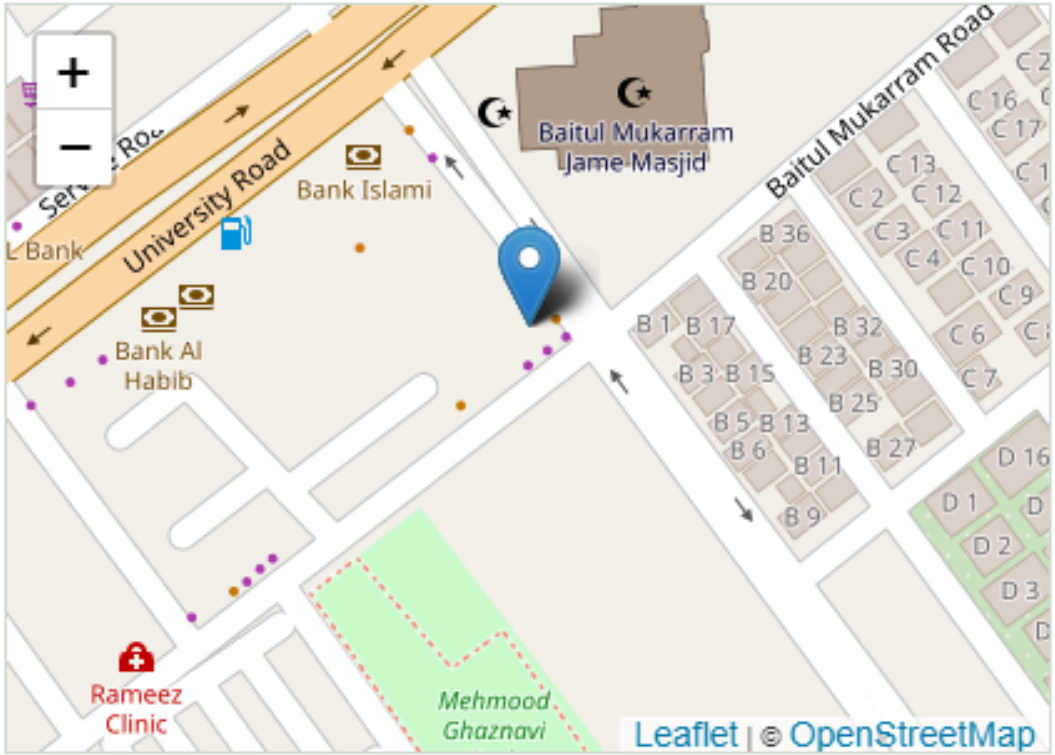
```
PS C:\WINDOWS\system32> tracert pakistan.gov.pk

Tracing route to pakistan.gov.pk [203.101.184.121]
over a maximum of 30 hops:

  1     2 ms     2 ms     2 ms  192.168.0.1
  2     5 ms     3 ms     4 ms  wtl.worldcall.net.pk [111.88.105.1]
  3     8 ms     4 ms     4 ms  192.168.20.2
  4     4 ms     3 ms     3 ms  static.connect.net.pk.249.120.221.in-addr.arpa [221.120.249.233]
  5     4 ms     3 ms     4 ms  119.159.240.165
  6     7 ms     6 ms     6 ms  rwp44.pie.net.pk [221.120.251.213]
  7     7 ms     6 ms     6 ms  rwp44.pie.net.pk [221.120.248.45]
  8  1153 ms   129 ms   222 ms  te0-4-0-17.ccr21.mrs01.atlas.cogentco.com [149.14.125.241]
  9   110 ms   111 ms   109 ms  130.117.15.62
 10   127 ms   128 ms   128 ms  ae-10.r24.frnkge08.de.bb.gin.ntt.net [129.250.4.71]
 11   200 ms   173 ms   179 ms  ae-1.r04.frnkge08.de.bb.gin.ntt.net [129.250.3.218]
 12   134 ms   128 ms   128 ms  ae-0.a01.frnkge03.de.bb.gin.ntt.net [129.250.6.112]
 13   178 ms   179 ms   202 ms  212.119.27.178
 14   277 ms   167 ms   169 ms  po111.bs-a.sech-fra.netarch.akamai.com [72.52.48.194]
 15   212 ms   206 ms   211 ms  po572-10.bs-a.sech-ams.netarch.akamai.com [72.52.1.171]
 16   235 ms   263 ms   218 ms  ae120.access-a.sech-fra.netarch.akamai.com [72.52.48.197]
 17   317 ms   287 ms   281 ms  93.191.173.61
 18     *        *        *     Request timed out.
 19     *        *        *     Request timed out.
 20     *        *        *     Request timed out.
 21     *
PS C:\WINDOWS\system32>
```

```
PS C:\WINDOWS\system32> tracert sindh.gov.pk

Tracing route to sindh.gov.pk [203.101.184.122]
over a maximum of 30 hops:

  1     2 ms     2 ms     2 ms  192.168.0.1
  2     5 ms     2 ms     3 ms  wtl.worldcall.net.pk [111.88.105.1]
  3    27 ms     6 ms     5 ms  192.168.20.2
  4     4 ms     4 ms     3 ms  static.connect.net.pk.249.120.221.in-addr.arpa [221.120.249.233]
  5     4 ms     4 ms     4 ms  119.159.240.165
  6     9 ms     6 ms     7 ms  rwp44.pie.net.pk [221.120.251.213]
  7     5 ms     7 ms     8 ms  khi494.nxa.2c.ptcl.com.pk [221.120.248.5]
  8   108 ms   108 ms   109 ms  te0-0-0-9.ccr21.mrs01.atlas.cogentco.com [149.14.125.217]
  9   109 ms   108 ms   112 ms  130.117.15.62
 10   127 ms   129 ms   126 ms  ae-10.r24.frnkge08.de.bb.gin.ntt.net [129.250.4.71]
 11   136 ms   142 ms   136 ms  ae-1.r04.frnkge08.de.bb.gin.ntt.net [129.250.3.218]
 12   128 ms   129 ms   127 ms  ae-0.a01.frnkge03.de.bb.gin.ntt.net [129.250.6.112]
 13   130 ms   130 ms   131 ms  212.119.27.178
 14   131 ms   130 ms   130 ms  po111.bs-a.sech-fra.netarch.akamai.com [72.52.48.194]
 15   135 ms   134 ms   133 ms  po576-10.bs-a.sech-ams.netarch.akamai.com [72.52.1.179]
 16   172 ms   165 ms   167 ms  ae120.access-a.sech-fra.netarch.akamai.com [72.52.48.197]
 17   149 ms   148 ms   149 ms  93.191.173.18
 18     *        *        *     Request timed out.
 19     *        *
PS C:\WINDOWS\system32>
```

111.68.108.121 - your IP

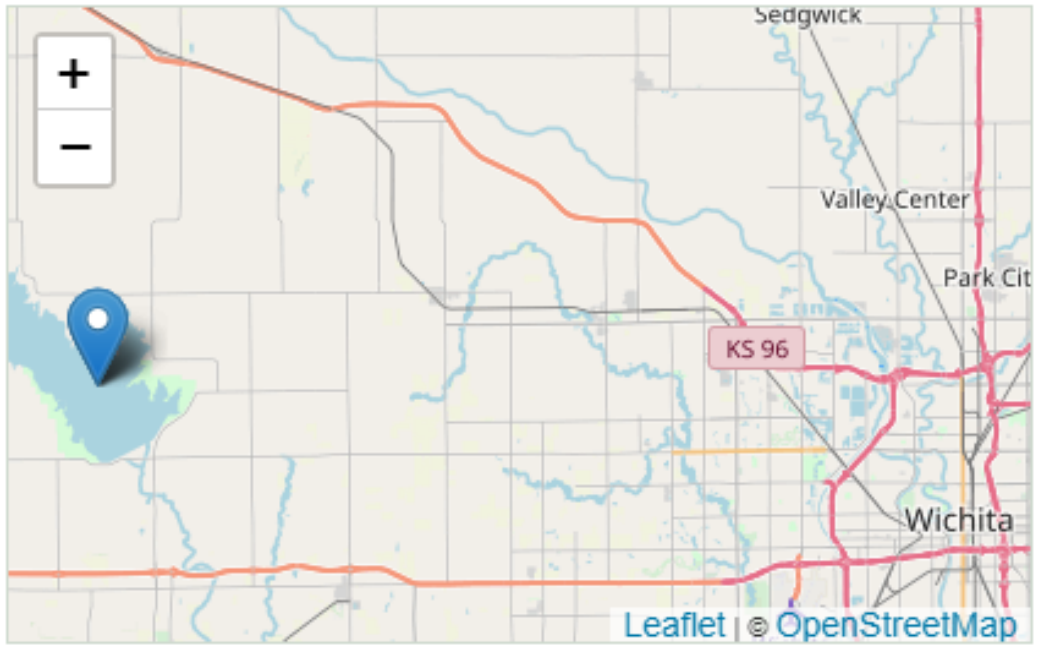
FIND

Your IP address	**111.68.108.121**
Latitude	24.9056
Longitude	67.0822
Country	Pakistan
Region	Sindh
City	Karachi
Organization	PERN AS Content Servie Provider, Islamabad, Pakist



129.250.4.71 FIND

IP address	**129.250.4.71**
Latitude	37.751
Longitude	-97.822
Country	United States
Region	
City	
Organization	NTT America



```
1   cs-gw (128.119.240.254) 1.009 ms 0.899 ms 0.993 ms
2   128.119.3.154 (128.119.3.154) 0.931 ms 0.441 ms 0.651 ms
3   -border4-rt-gi-1-3.gw.umass.edu (128.119.2.194) 1.032 ms 0.484 ms 0.451 ms
4   -acr1-ge-2-1-0.Boston.cw.net (208.172.51.129) 10.006 ms 8.150 ms 8.460 ms
5   -agr4-loopback.NewYork.cw.net (206.24.194.104) 12.272 ms 14.344 ms 13.267 ms
6   -acr2-loopback.NewYork.cw.net (206.24.194.62) 13.225 ms 12.292 ms 12.148 ms
7   -pos10-2.core2.NewYork1.Level3.net (209.244.160.133) 12.218 ms 11.823 ms 11.793 ms
8   -gige9-1-52.hsipaccess1.NewYork1.Level3.net (64.159.17.39) 13.081 ms 11.556 ms 13.297 ms
9   -p0-0.polyu.bbnplanet.net (4.25.109.122) 12.716 ms 13.052 ms 12.786 ms
10  cis.poly.edu (128.238.32.126) 14.080 ms 13.035 ms 12.802 ms
```

End System, Application, and Other Delays

In addition to processing, transmission, and propagation delays, there can be additional significant delays in the end systems. For example, an end system wanting to transmit a packet into a shared medium (e.g., as in a WiFi or cable modem scenario) may *purposefully* delay its transmission as part of its protocol for sharing the medium with other end systems; we'll consider such protocols in detail in Chapter 6. Another important delay is media packetization delay, which is present in Voice-over-IP (VoIP) applications. In VoIP, the sending side must first fill a packet with encoded digitized speech before passing the packet to the Internet. This time to fill a packet—called the packetization delay—can be significant and can impact the user-perceived quality of a VoIP call. This issue will be further explored in a homework problem at the end of this chapter.

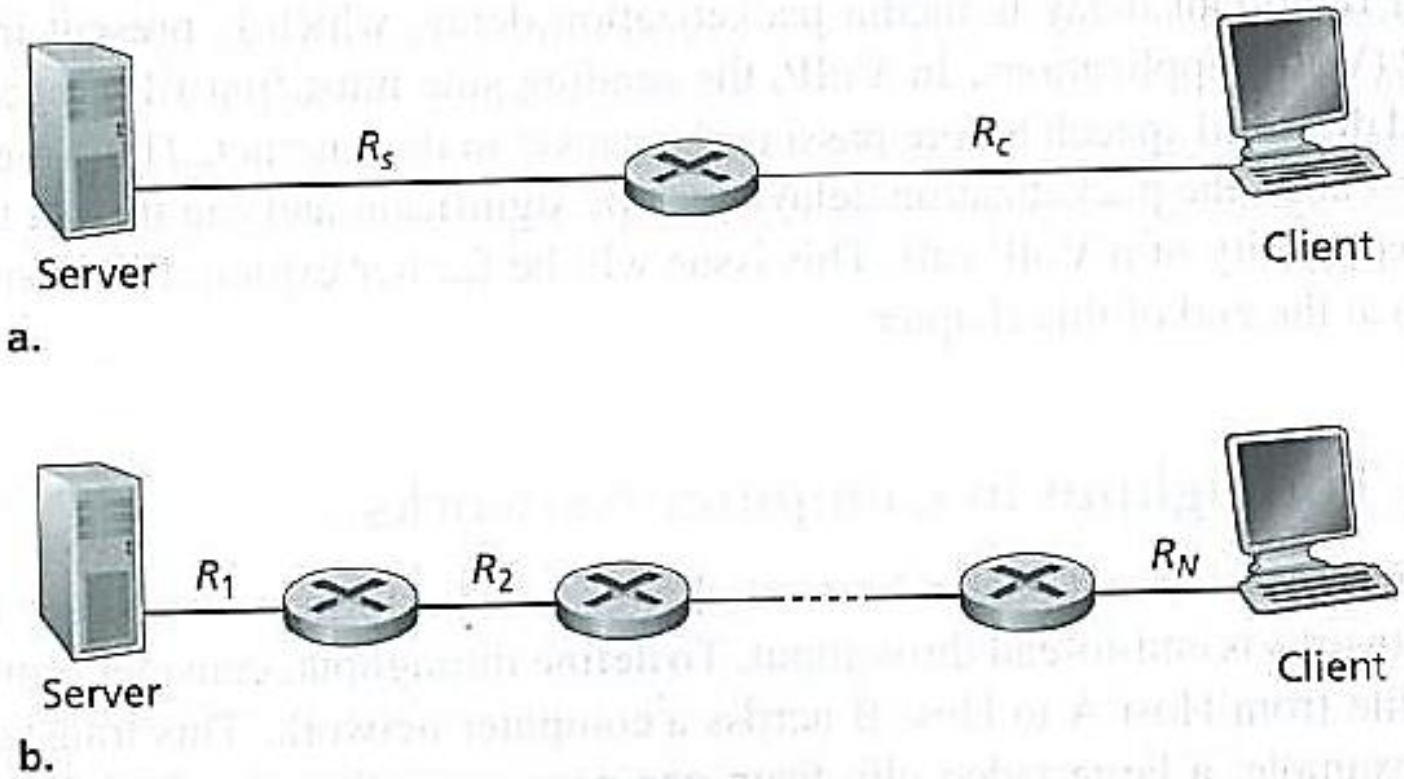


Figure 1.19 ♦ Throughput for a file transfer from server to client

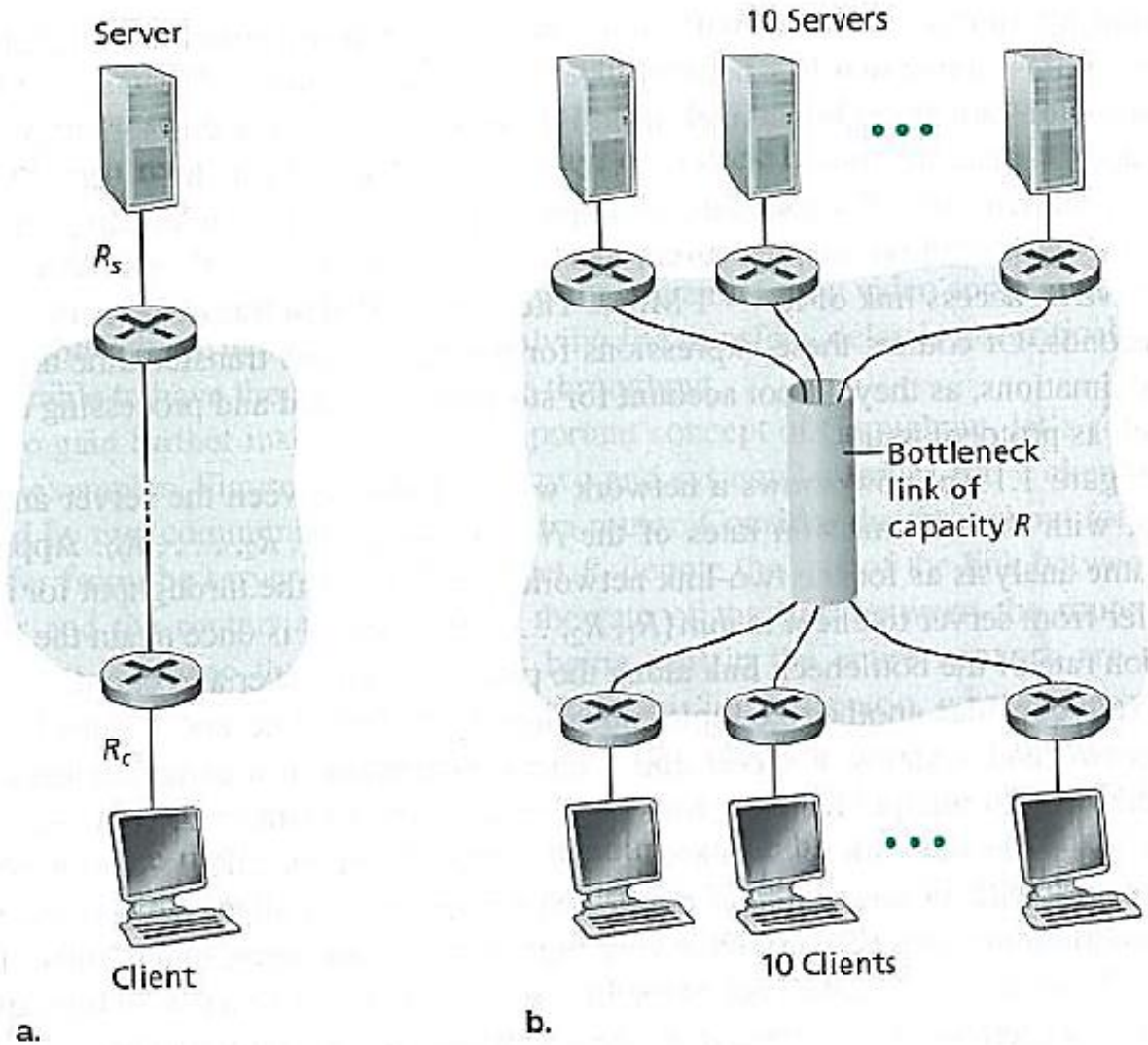


Figure 1.20 ♦ End-to-end throughput: (a) Client downloads a file from server; (b) 10 clients downloading with 10 servers