Computer Networking

Chapter 1:
Data transmission: Switching Techniques

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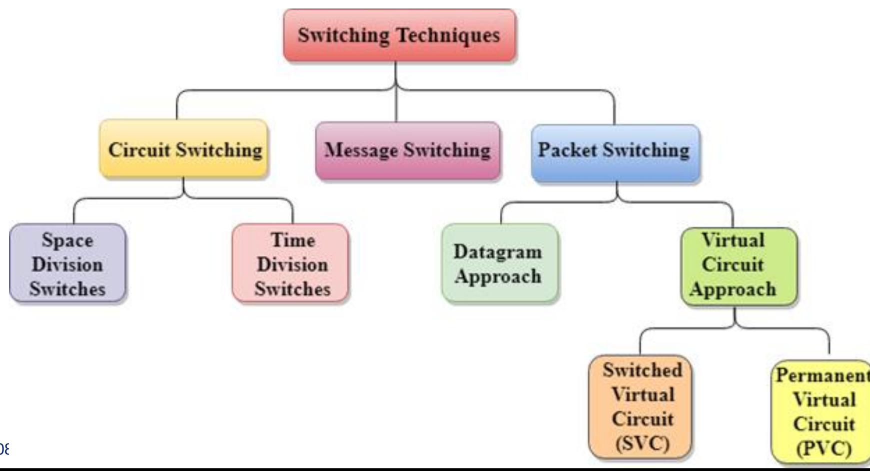
Contents

- History of computer network
- Computer network
- Network topology
- Network protocol
- Network Components
- Internet
- Data transmission: Switching Techniques
- Packet-Switched Networks problems:
  - Delay, Loss, and Throughput in
- Protocol Layers and Their Service Models
- OSI model
- TCP/IP model

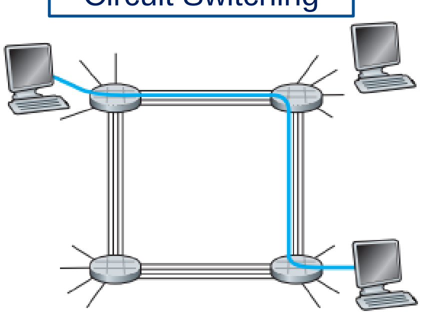
Data transmission: Switching Techniques

- The switching technique will decide the best route for data transmission.

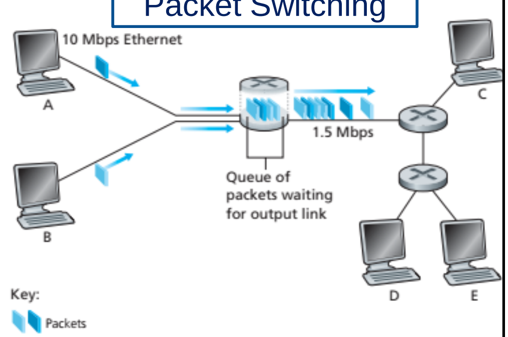


Switching Techniques

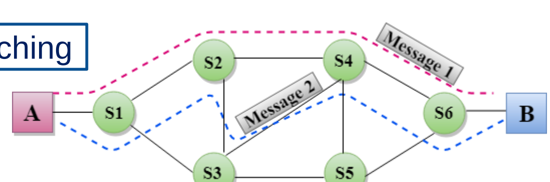
Circuit Switching



Packet Switching



Message Switching



Switching Techniques

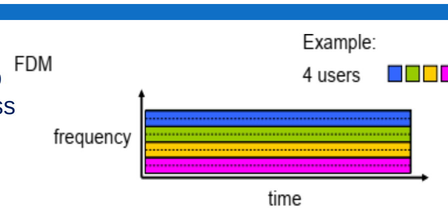
Circuit Switching Vs Packet Switching

Circuit Switching	Packet Switching
Physical path between source and destination	No physical path
All packets use same path	Packets travel independently
Reserve the entire bandwidth in advance	Does not reserve
Bandwidth Wastage	No Bandwidth wastage
No store and forward transmission	Supports store and forward transmission

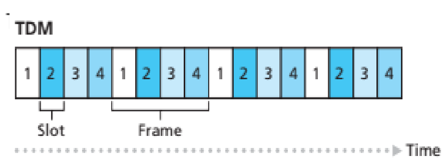
3

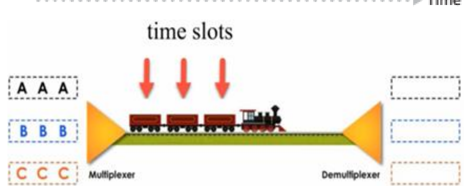
Circuit Switching: FDM and TDM

- FDM (frequency-division multiplexing): the frequency spectrum of a link is divided up among the connections established across the link (with analog signals)
  - Ex: In telephone/tivi networks, FDM=4 kHz (4,000 cycles/s) => **bandwidth**

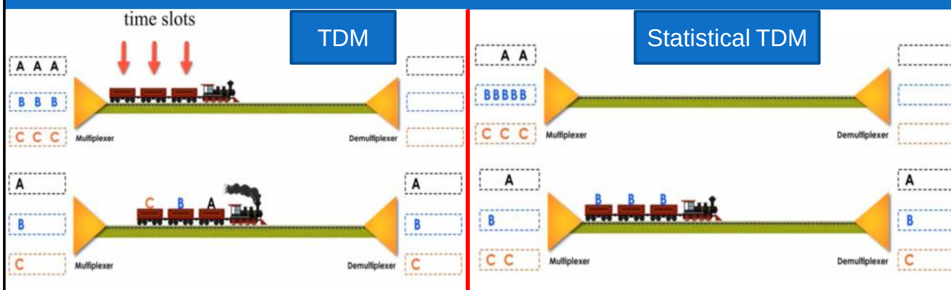


- TDM (time-division multiplexing): time is divided into frames of fixed duration, and each frame is divided into a fixed number of time slots (with analog & digital signals)
  - TDM is efficient, has low conflict
  - Ex: the link transmits 8,000 frames/s and each slot consists of 8 bits, then the transmission rate of a circuit is 64 kbps (8000x8)





Circuit Switching: FDM and TDM



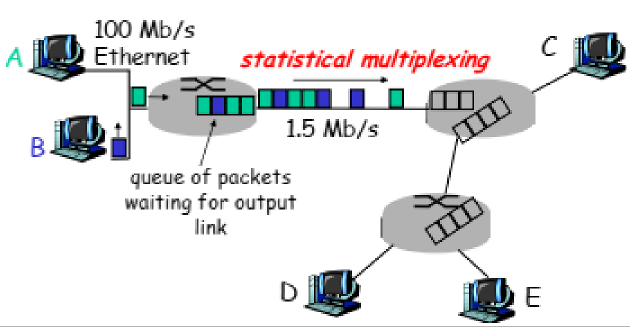
- Ex, How long does it take to send a file of 640,000 bits from host A to host B over a circuit- switched network (TDM)?
  - All links are 1.536 Mbps (link rate)
  - Each link uses TDM with 24 slots/sec
  - 500 msec to establish end-to-end circuit

  Ref: https://www.youtube.com/watch?v=fIZhDl35_XY

1 circuit has transmission rate:
(1.536 Mbps)/24 = 64 kbps
Transmission time:
(640,000 bits)/(64 kbps) = 10 seconds to transmit the file
add the circuit establishment time,
=> 10.5 seconds to send the file

Packet Switching: Statistical Multiplexing

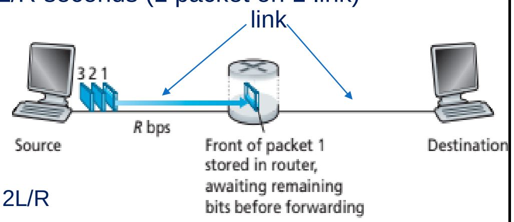
- The message splits into packets that are given a unique number to identify their order at the receiving end.
- Every packet contains some information in its headers such as source address, destination address and sequence numbe
- Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand => **statistical multiplexing**.
- TDM: each host gets same slot in revolving TDM frame



Packet-switching: store-and-forward

- store and forward: entire packet must arrive at router before it can be transmitted on next link
- **a** packet of L bits (**size**) over **a link** with transmission **rate** R bits/sec, then the **time** to transmit the packet is L/R seconds (1 packet on 1 link)

$$T = \frac{L}{R}$$

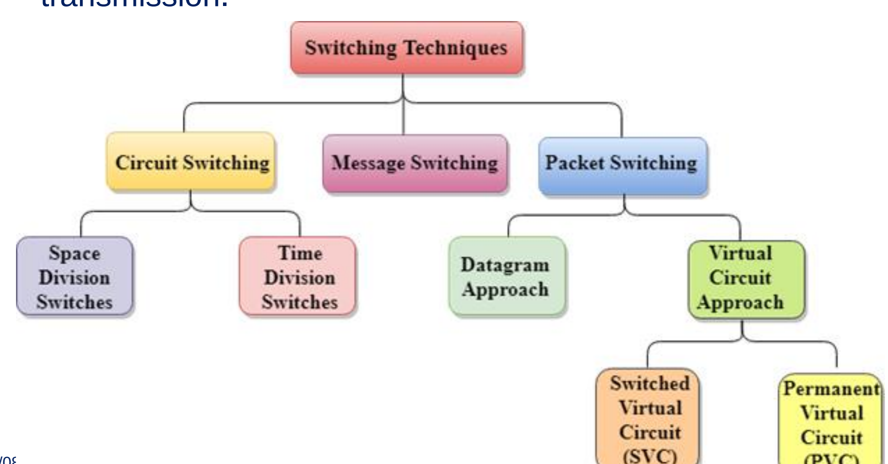


- Example: time (source -> des)
  - L = 7.5 Mbits
  - R = 1.5 Mbps
  - **time** to transmit 1pkt/1link: 5s
  - transmission delay (2links, 1 pkts): 2L/R
  - 3pkts: 4L/R
- the general case of sending one packet from source to destination over a path consisting of *N* links each of rate *R* (using N-1 router) between source and destination

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

Data transmission: Switching Techniques

- The switching technique will decide the best route for data transmission.



Contents

Packet-Switched Networks

- Store and forward:
  - entire packet must arrive at router before it can be transmitted on next link
- Ideally,
  - Internet services need to move as much data as we want between any two end systems, instantaneously, without any loss of data.
- But:
  - computer networks necessarily constraints throughput (the amount of data per second that can be transferred) between end systems, introduce delays between end systems, and can actually lose packets

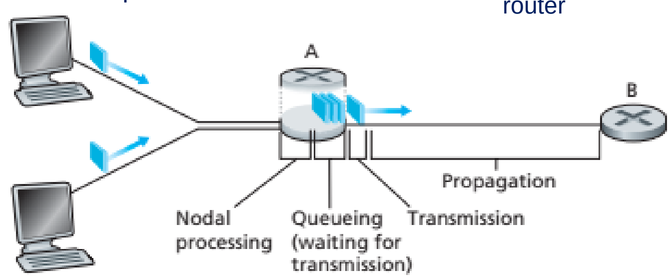
⇒ Problems: Delay, Loss, and Throughput

Delay in Packet-Switched Networks

- Packets experience **delay** on end-to-end path
- **Four** sources of delay at each hop

1. Processing delay:
- The time to examine the packet's header and determine where to direct the packet

2. Queueing delay
- The time waiting to be transmitted onto the link
- Depends on congestion level of router



13

Delay in Packet-Switched Networks

3. Transmission Delay: T

The time required to transmit all of the packet's bits into the link

R = Link bandwidth (bps)

L = Packet length (bits)

T = L/R

Note: *s* and *R* are ***very*** different quantities

4. Propagation Delay: d_{prop}

The time required to propagate from the beginning of the link to router

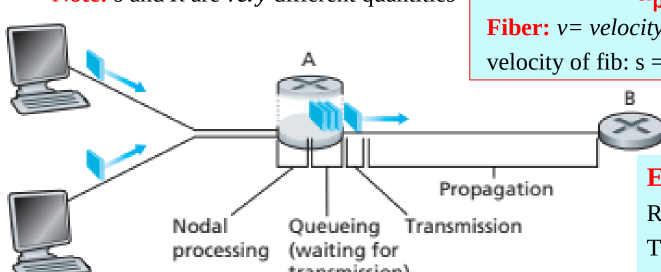
d = Length of physical link

s = propagation speed in medium ($\sim 2 \times 10^8$ m/sec)

$$d_{prop} = d/s$$

Fiber: *v= velocity of light* $=3\text{x}10^8$m/s

velocity of fib: s = *v* x 70%speed



Ex:

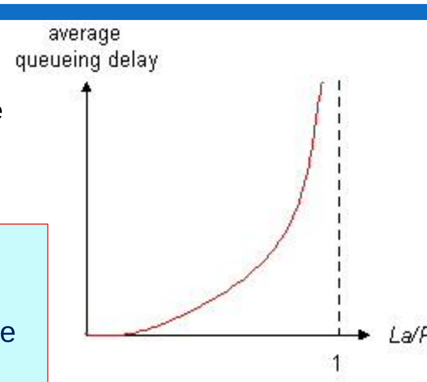
R=1kbps, L=1Kbyte (?bit)

T=?

d=20km, d_{prop} ?

Queueing delay

- d_{queue} is the time it takes for the packet to be transmitted onto the link
- the length of this time is defined by the number of packets that was added to the queue prior to this packet



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* > 1: More "work" arriving than can be serviced, average delay infinite!

Nodal 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_{proc} and d_{queue} depend on the speed of processor
speed of processor is very high, d_{queue} and d_{proc} are less

- d_{trans} = transmission delay: significant for low-speed links
- d_{prop} = propagation delay: a few microsecs to hundreds of msecs

"Real" Internet Delays and Routes

traceroute (or tracert): Routers, round-trip delays on source-dest path
Also: `pingplotter`, various Windows programs

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
```

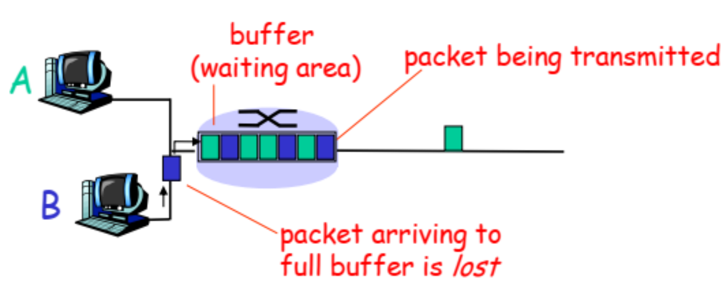
trans-oceanic link

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

17

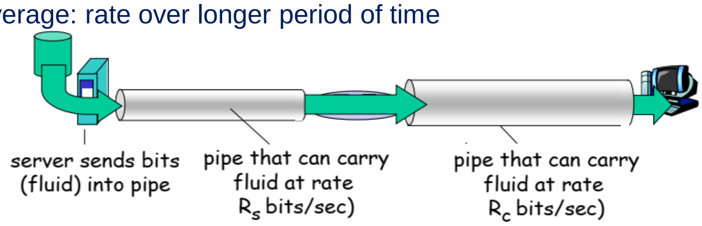
Packet loss

- queue (aka buffer) preceding link in buffer has finite capacity
  - a packet can arrive to find a full queue.
  - With no place to store such a packet, a router will drop that packet; that is, the packet will be lost
- lost packet may be retransmitted by previous node, by source end system, or not at all

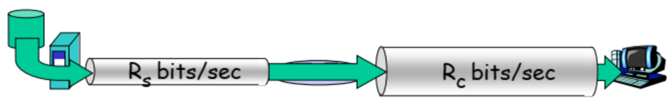


Throughput

- throughput: rate bits transferred between sender/receiver
  - instantaneous: rate at given point in time
  - average: rate over longer period of time



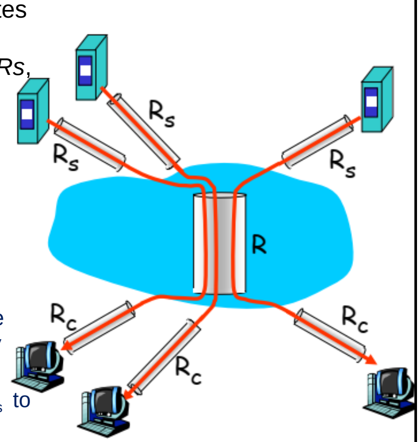
- What is average end-end throughput?
  - $R_s < R_c$
  - $R_s > R_c$



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

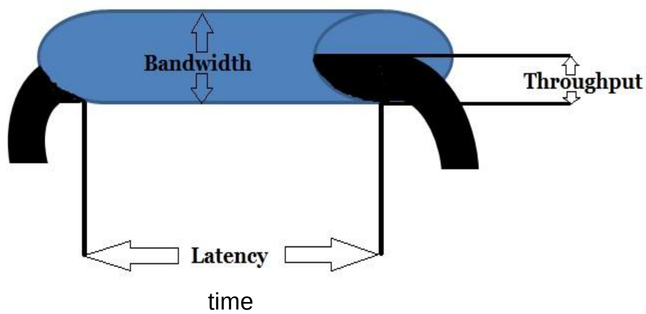
Throughput: Internet scenario

- Let's suppose all R_s have the same rate, R_c have the same rate, and the transmission rates of all the links in the core except the one common link of rate *R* are much larger than *Rs*, *Rc*, and *R*
- *Ex:* 10 connections (fairly) share backbone bottleneck link R bits/sec
  - per-connection end-end throughput: **$\min(R_c,R_s,R/10)$**
- Ex:
  - *Rs* = 2 Mbps, *Rc* = 1 Mbps, *R* = 5 Mbps, and the common link divides its transmission rate equally among the 10 downloads
  - the end-to-end throughput for each download (R_s to R_c) is now reduced to…?



Latency, Throughput, bandwidth

- Latency – The time taken for **a packet** to be transferred across a network. You can measure this as one-way to its destination or as a round trip.
- Throughput – The quantity of data being sent and received within a unit of time
- The **bandwidth** of a network specifies the maximum number of conversations that the network can support



Latency vs Throughput

- The more routers a packet has to travel through the more latency there is because each router has to process the packet
- Throughput is a good way to measure the performance of the network connection because it tells you how many messages are arriving at their destination successfully
- Both network latency and throughput are important because they have an effect on how well your network is performing.
- The bandwidth of your network is limited to the standard of your internet connection and the capabilities of your network devices
- Tools for Measuring Network Throughput, BW
  - **SolarWinds Flow Tool Bundle**
  - speedtest

Excersices

- 1.
  - How long does it take a **packet of length** 1,000 bytes to **propagate** over a **link of distance** 2,500 km, **propagation speed** 2.5 x 10^8 m/s, and **transmission rate 2 Mbps**?
  - More generally, how long does it take a packet of length L to propagate over a link of distance d, propagation speed s, and transmission rate R bps?
  - Does this delay depend on packet length?
  - Does this delay depend on transmission rate?

- 2. Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has **three** links, of rates R_1 = 500 kbps, R_2 = 2 Mbps, and R_3 = 1 Mbps.
  - a. Assuming no other traffic in the network, what is the throughput for the file transfer?
  - b. Suppose **the file is 4 million bytes**. Dividing the file size by the throughput, roughly how long will it take to transfer the file to Host B?
  - c. Repeat (a) and (b), but now with R2 reduced to 100 kbps.