A Taxonomy of Communication Networks

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http://zoo.cs.yale.edu/classes/cs433/

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Outline

➢ *Admin and recap*
❑ A taxonomy of communication networks

Admin

□ Please check the Schedule page for links to related readings

Recap

□ A protocol defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission or receipt of a message or other events.

□ Some implications of the past:

   ○ ARPANET is sponsored by ARPA →

               design should survive failures

   ○ The initial IMPs (routers) were made by a small company → keep the network simple

   ○ Many networks →

         internetworking: need a network to connect networks

   ○ Commercialization →

       architecture supporting decentralized, autonomous systems

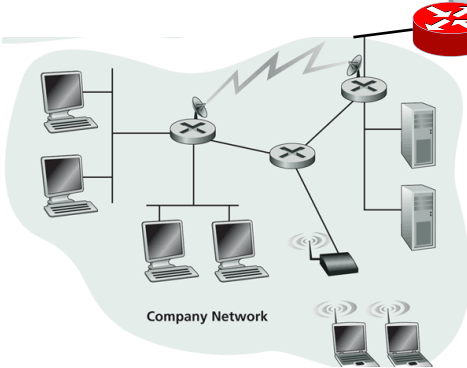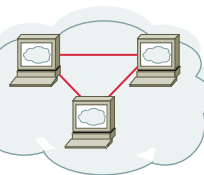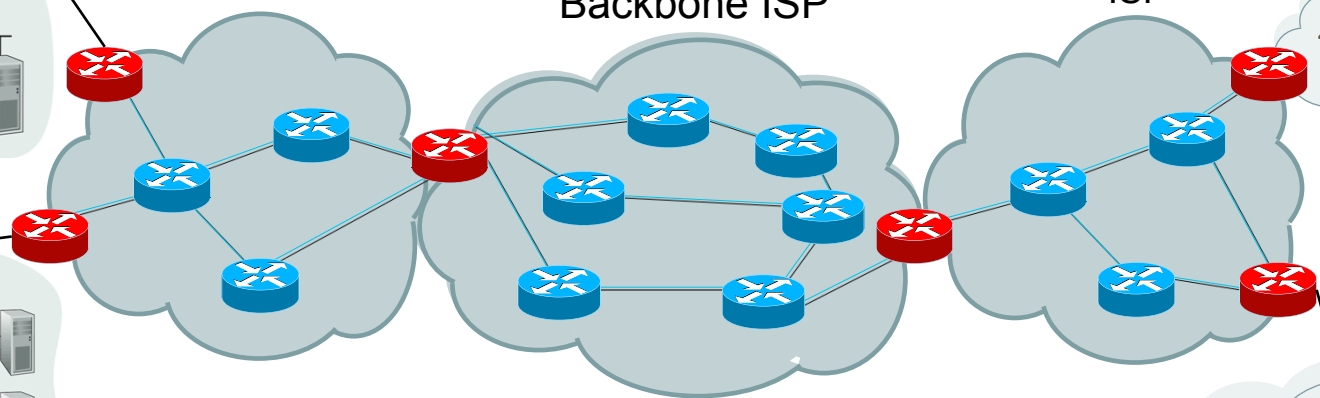# Recall: Internet Physical Infrastructure

Residential access, e.g.,
- Cable, Fiber, DSL, Wireless

ISP

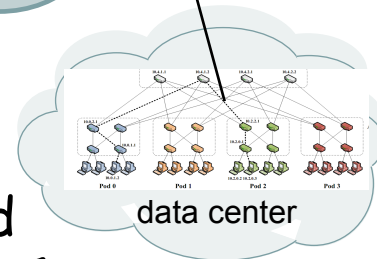Backbone ISP

ISP

Local ISP

Company Network

data center
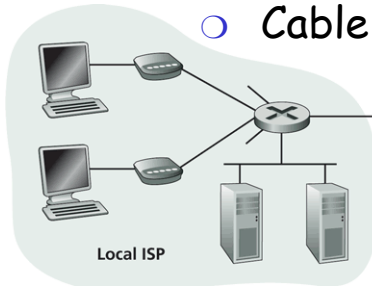
Campus access, e.g.,
- Ethernet, Wireless

□ The Internet is a network of networks

□ Each individually administrated network is called an Autonomous System (AS)

~ 52000 ASes (http://bgp.potaroo.net/as2.0/bgp-active.html)

https://www.google.com/loon/how/

Observing the Internet State

- ❒ Read the manual of traceroute, and try it on a zoo machine

  % /usr/sbin/traceroute <machine_name>

- ❑ Look at the web sites of the routers you see through traceroute

- ❑ Lookup ASN info

  https://www.ultratools.com/tools/asnInfo

- ❑ fixedorbit to look for info (e.g., neighbors) about a network:

  - http://www.fixedorbit.com/search.htm

Roadmap

□ So far we have looked at only the topology and physical connectivity of the Internet: a mesh of computers interconnected via various physical media

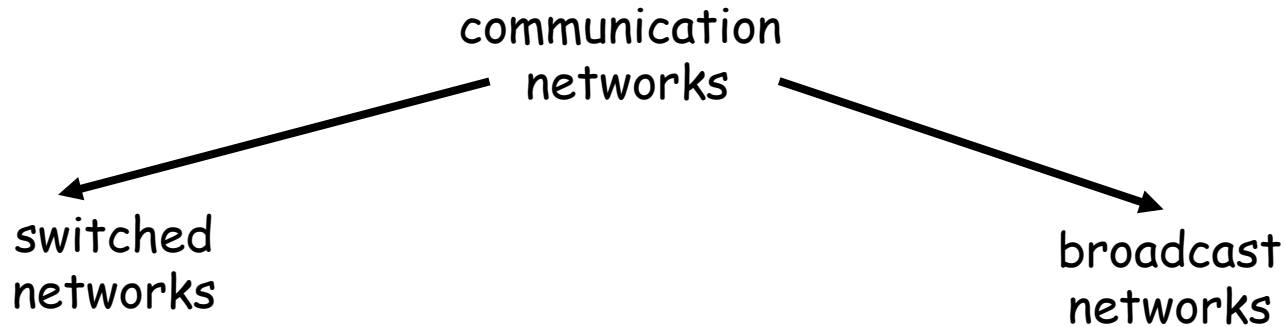□ <u>A</u> fundamental question: how are data (the bits) transferred through communication networks?
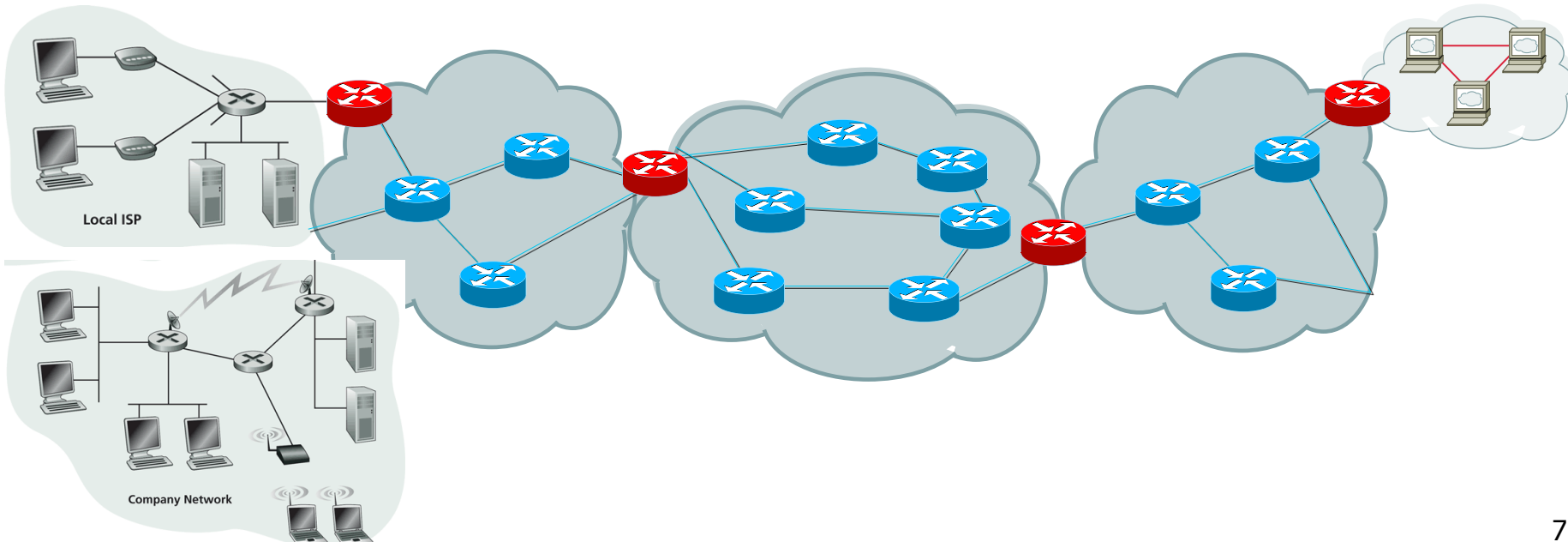
Outline

❑ Admin. and recap

➢ *A taxonomy of communication networks*

Taxonomy of Communication Networks

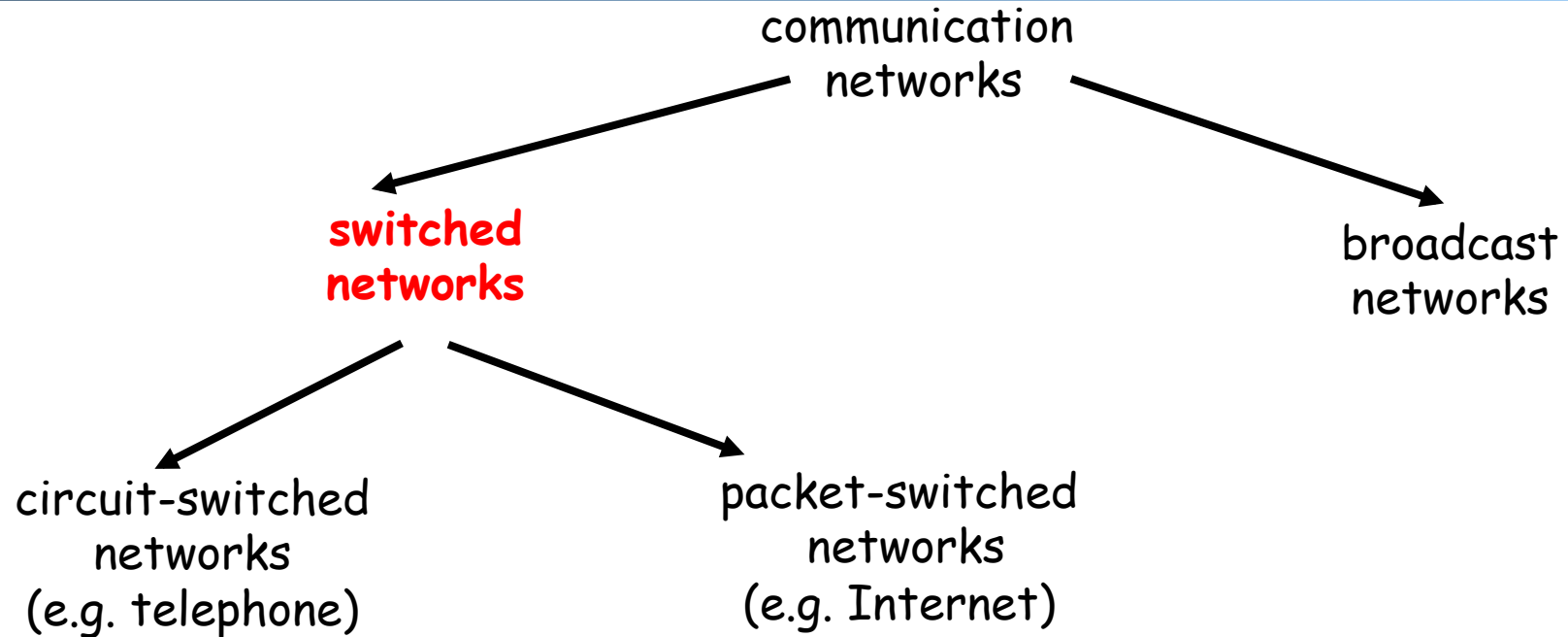communication
networks

switched
networks

broadcast
networks

❒ Broadcast networks
   ○ nodes share a common channel; information transmitted by a node is received by all other nodes in the network
   ○ examples: TV, radio

❒ Switched networks
   ○ information is transmitted to a small sub-set (usually only one) of the nodes
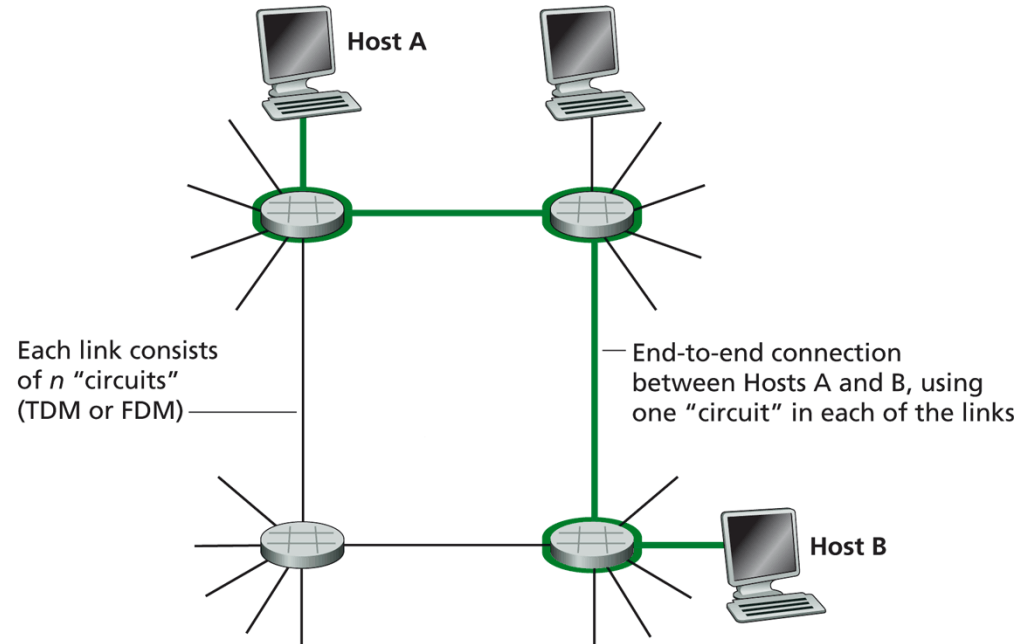
A Taxonomy of Switched Networks

```
                    communication
                       networks
              ↙                        ↘
    switched                              broadcast
    networks                               networks
      ↙           ↘
circuit-switched    packet-switched
   networks            networks
(e.g. telephone)    (e.g. Internet)
```

❑ Circuit switching: dedicated circuit per call/session:
  ○ e.g., telephone, cellular voice
❑ Packet switching: data sent thru network in discrete "chunks"
  ○ e.g., Internet, cellular data

Outline

- ❑ Admin. and review
- ➢ *A taxonomy of communication networks*
  - ➢ *circuit switched networks*

Circuit Switching

□ Each link has a number of "circuits"

　○ sometime we refer to a "circuit" as a channel or a line

□ An end-to-end connection reserves one "circuit" at each link

Host A

Each link consists of *n* "circuits" (TDM or FDM)

End-to-end connection between Hosts A and B, using one "circuit" in each of the links
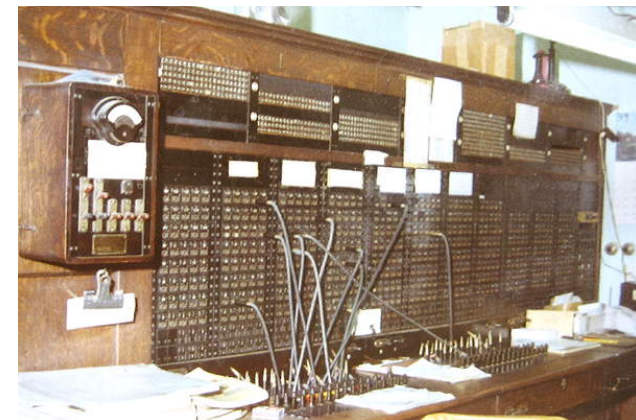
Host B

Key:

Host　Circuit switch

First commercial telephone switchboard was opened in 1878 to serve the 21 telephone customers in New Haven

Circuit Switching: Resources/Circuits (Frequency, Time and others)

- Divide link resource into "circuits"
  - frequency division multiplexing (FDM)
  - time division multiplexing (TDM)
  - others such as code division multiplexing (CDM), color/ lambda division
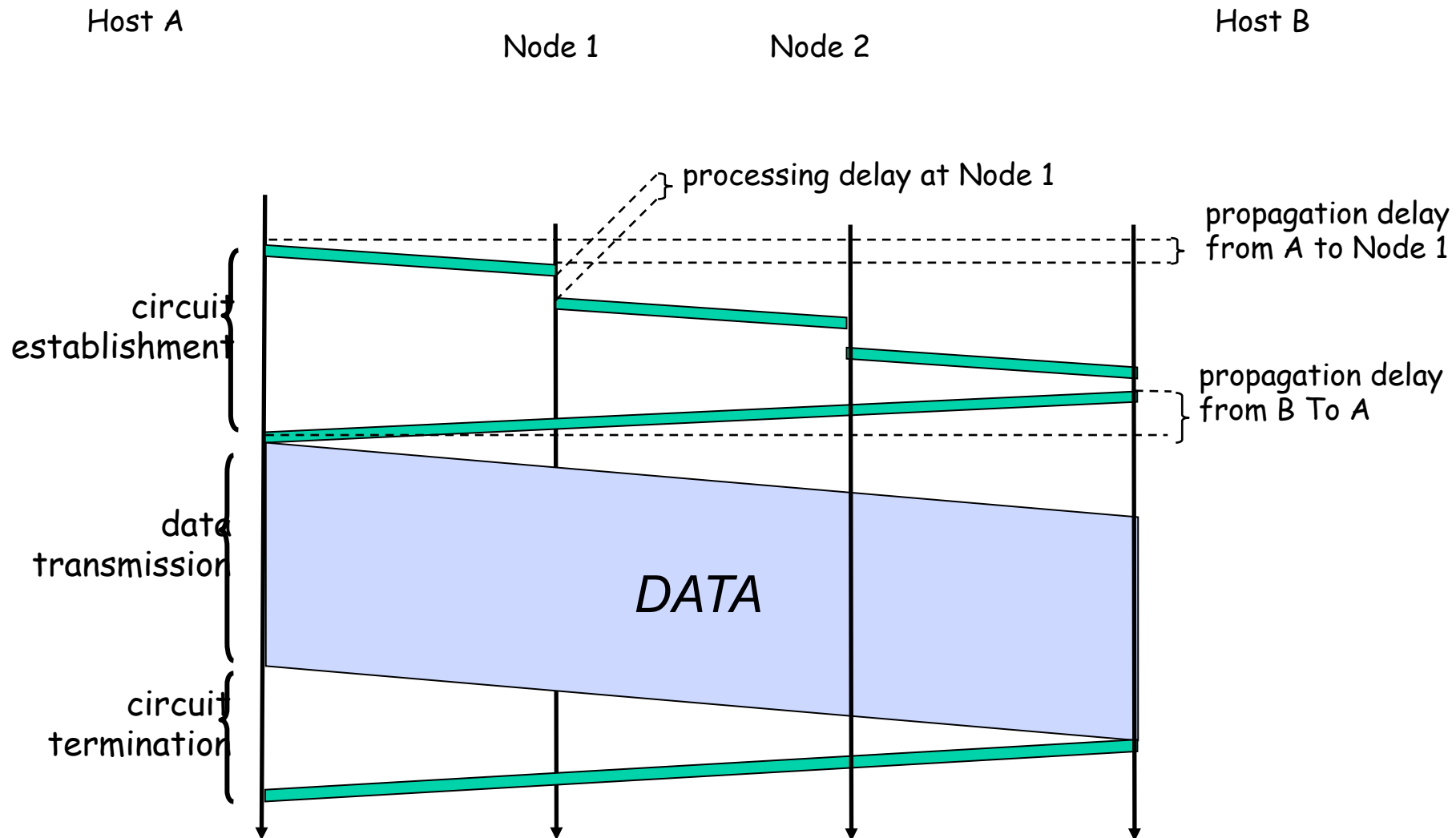
FDM

4KHz

4KHz

Link   Frequency

TDM

| 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |

Slot   Frame

Time
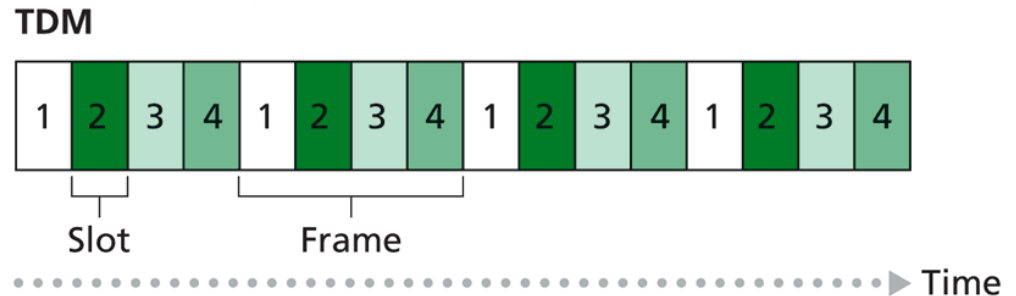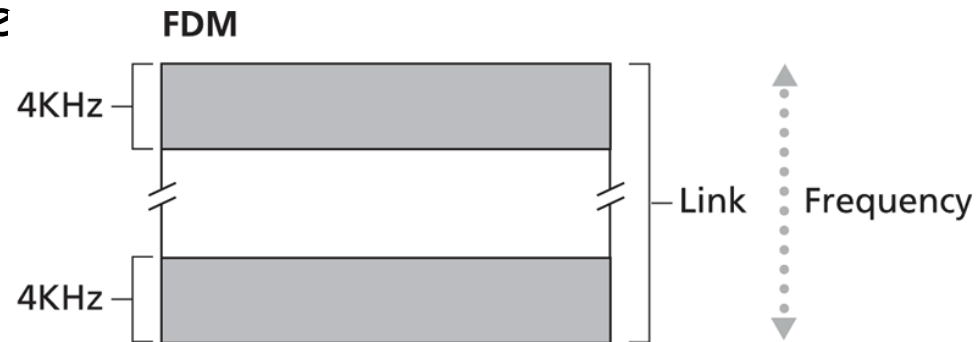
Key:

2   All slots labeled "2" are dedicated to a specific sender-receiver pair.

Circuit Switching: The Process

□ Three phases
1. circuit establishment
2. data transfer
3. circuit termination

Timing Diagram of Circuit Switching

Host A   Node 1   Node 2   Host B

processing delay at Node 1

propagation delay from A to Node 1

circuit establishment

propagation delay from B To A
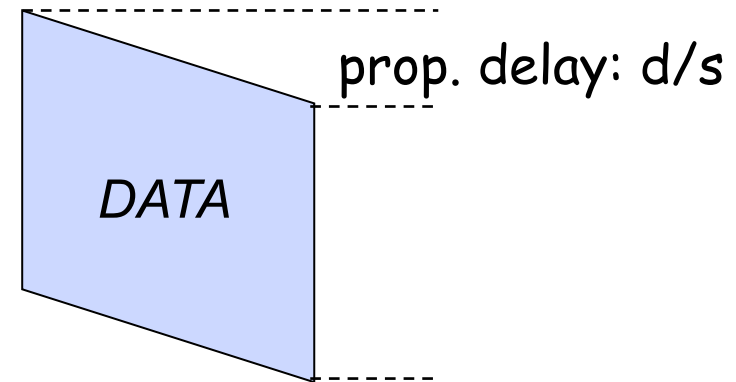
data transmission

DATA

circuit termination

Delay Calculation in Circuit Switched Networks

❐ Propagation delay: delay for the first bit to go from a source to a destination

Propagation delay:
❐ d = length of physical link
❐ s = propagation speed in medium (~2x10^5 km/sec)
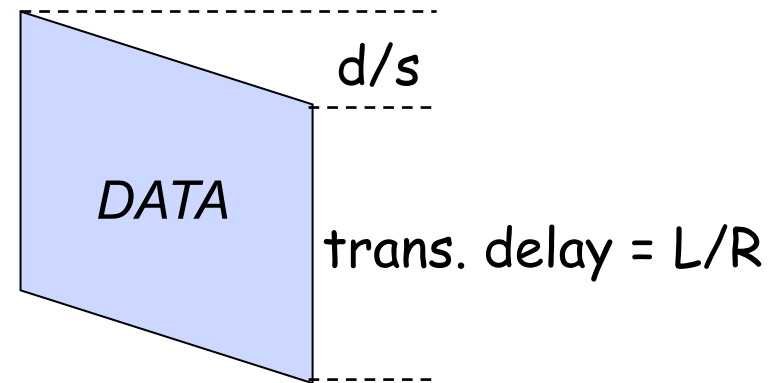

prop. delay: d/s

DATA

Delay Calculation in Circuit Switched Networks

❐ **Transmission delay**: time to pump data onto link at *line* rate

Transmission delay:
❐ R = reserved bandwidth (bps)
❐ L = message length (bits)

DATA

d/s

trans. delay = L/R

An Example

□ Propagation delay

○ suppose the distance between A and B is 4000 km, then one-way propagation delay is:

$$\frac{4000\,km}{200,000\,km\,/\,s} = 20ms$$

□ Transmission delay

○ suppose your iphone reserves a one-slot HSCSD channel
  - each HSCSD frame can transmit about 115 kbps
  - a frame is divided into 8 slots

○ then the transmission delay of using one reserved slot for a message of 1 Kbits:

$$\frac{1kbits}{14kbps} \approx 70ms$$

An Example (cont.)

- ❑ Suppose the setup message is very small, and the total setup processing delay is 200 ms
- ❑ Then the delay to transfer a message of 1 Kbits from A to B (from the beginning until host receives last bit) is:
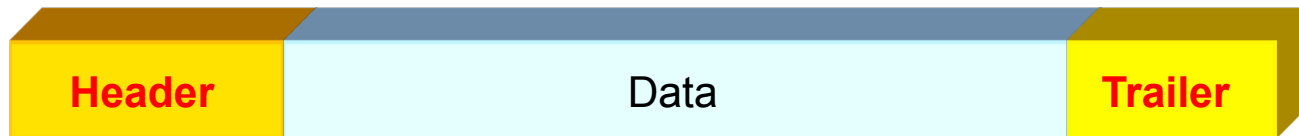
$$20 + 200 + 20 + 20 + 70 = 330ms$$
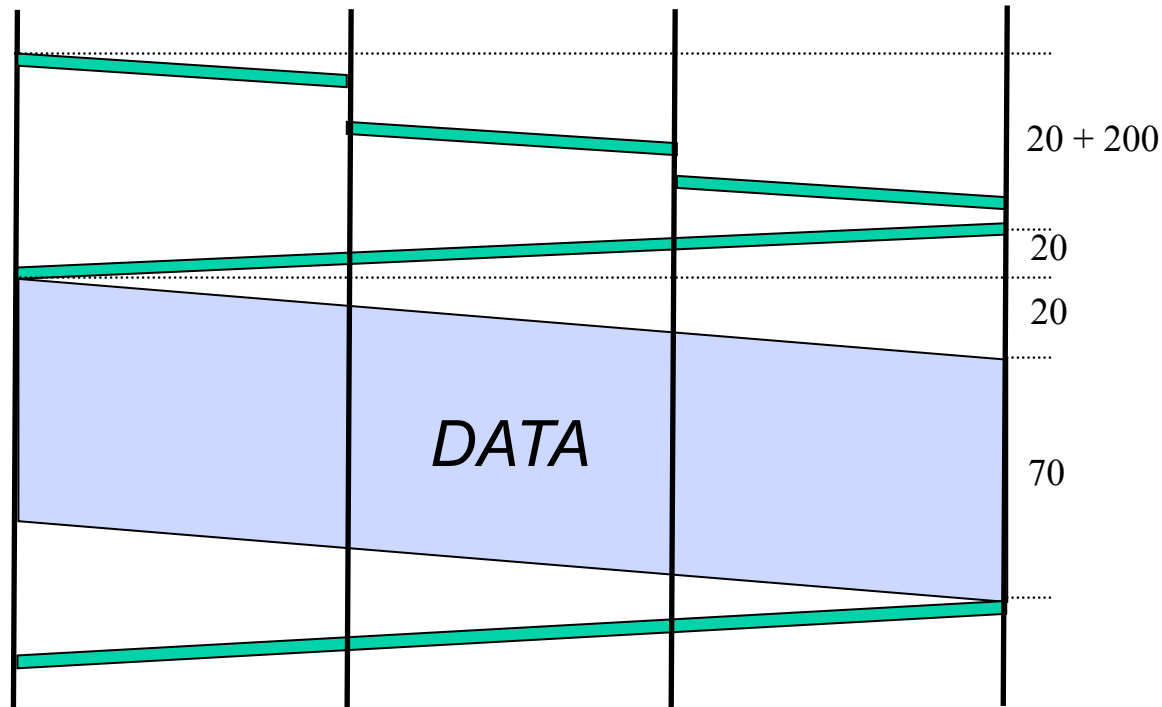
20 + 200

20

20

DATA

70

Outline

❑ Admin. and review

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  ○ circuit switched networks
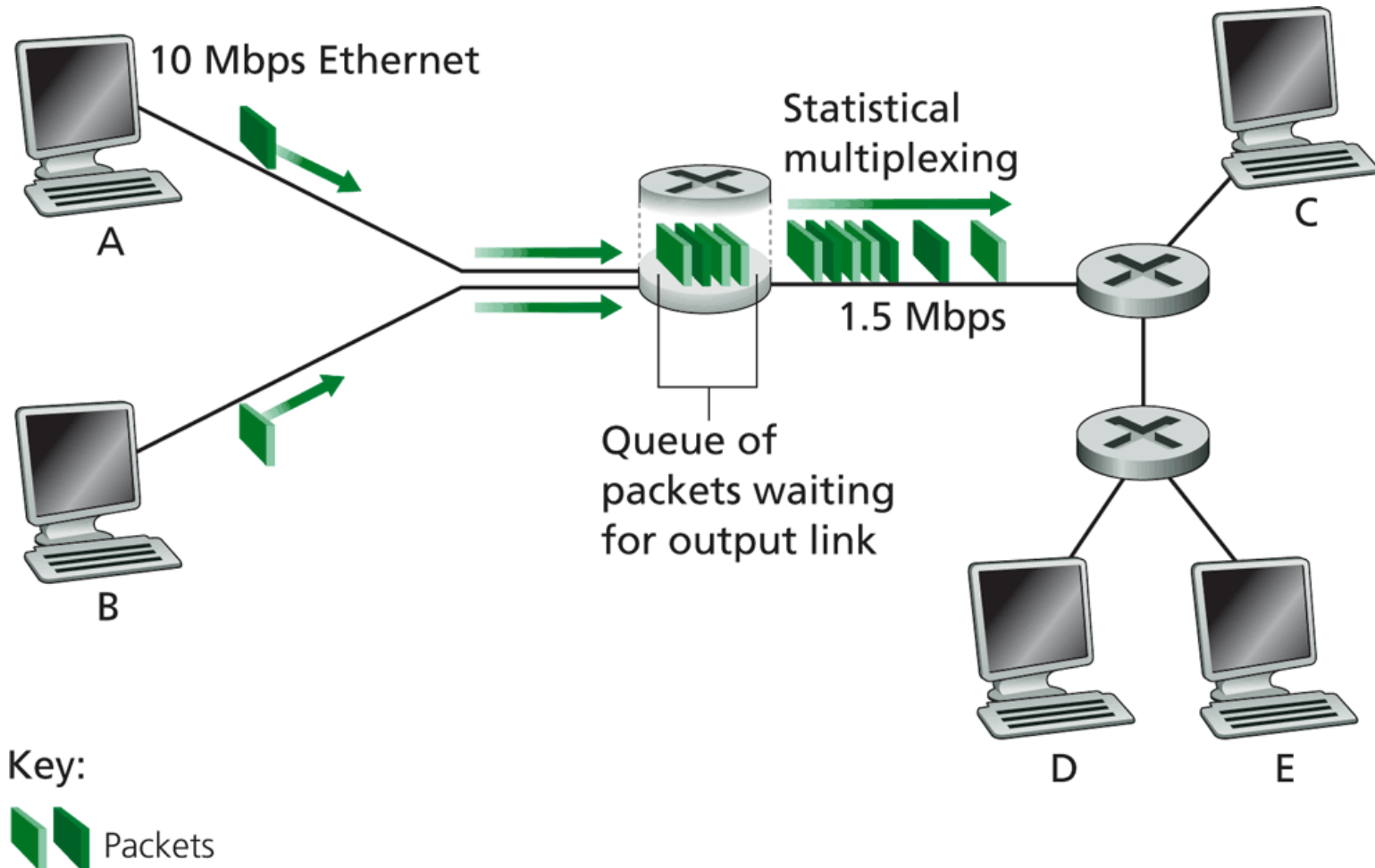
    ➢ *packet switched networks*

Packet Switching

Each end-to-end data **flow** (i.e., a sender-receiver pair) divided into *packets*

❐ Packets have the following structure:

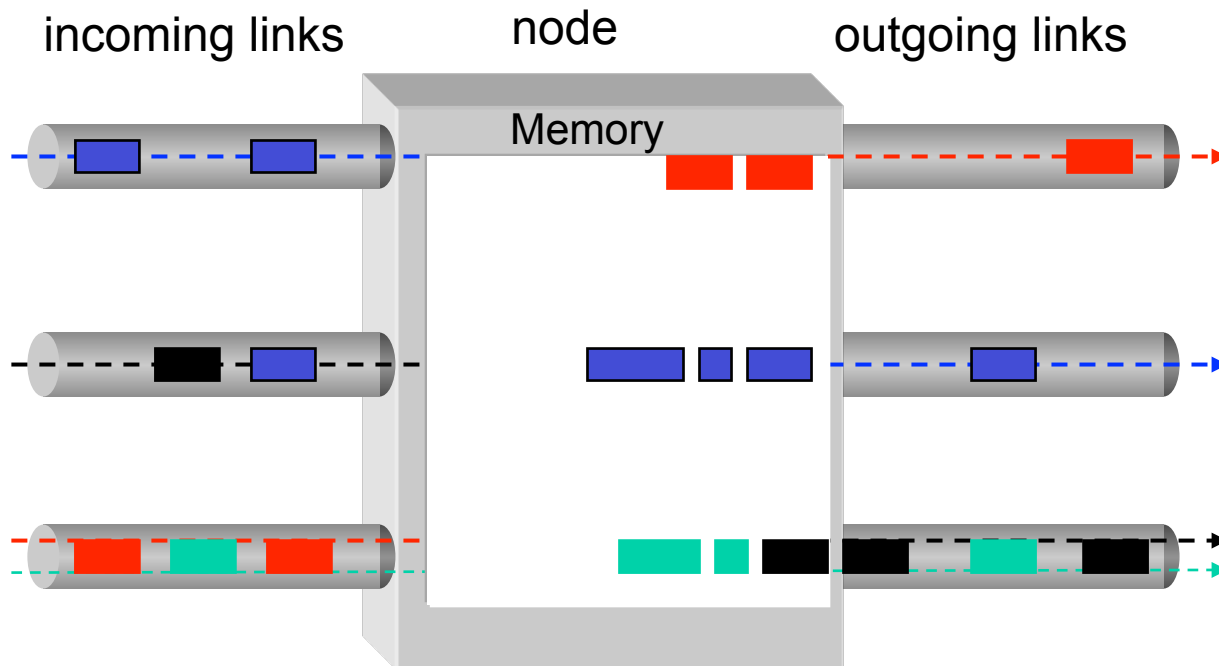| Header	Data	Trailer

- header and trailer carry control information (e.g., destination address, check sum)
- where is the control information for circuit switching?

❐ At each node the entire packet is received, processed (e.g., routing), stored briefly, and then forwarded to the next node; thus packet-switched networks are also called **store-and-forward networks.** On its turn, a packet uses full link bandwidth

Packet Switching

10 Mbps Ethernet

Statistical multiplexing

1.5 Mbps

Queue of packets waiting for output link

A

B

C

D

E

Key:

Packets

An output queueing switch

Outline

❑ Admin. and review

➢ *A taxonomy of communication networks*
  ○ circuit switched networks
  ○ packet switched networks
    ➢ *circuit switching vs. packet switching*

Packet Switching vs. Circuit Switching

❑ The early history of the Internet was a heated debate between Packet Switching and Circuit Switching

   ○ the telephone network was the dominant network

❑ Need to compare packet switching with circuit switching
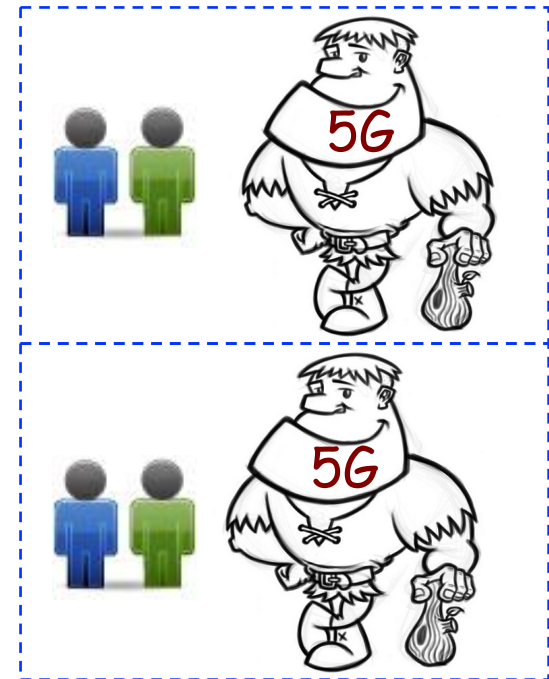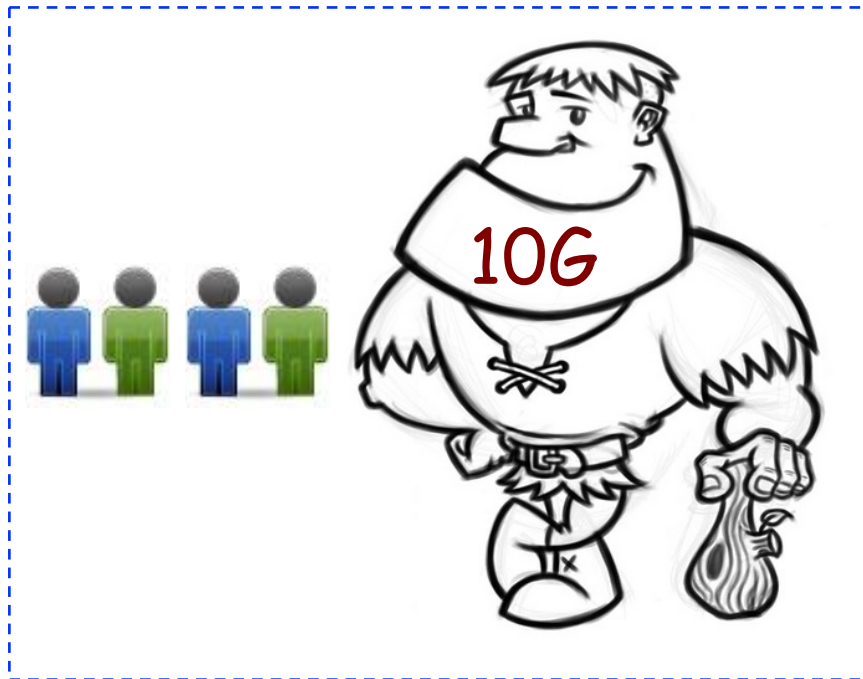
Circuit Switching vs. Packet Switching

	circuit switching	packet switching
resource usage		
reservation/setup		
resource contention		
charging		
header		
fast path processing		

Circuit Switching vs. Packet Switching

	circuit switching	**packet switching**
resource usage	use a single partition bandwidth	use whole link bandwidth
reservation/setup	need reservation (setup delay)	no reservation
resource contention	busy signal (session loss)	congestion (long delay and packet losses)
charging	time	packet
header	no per-pkt header	per packet header
fast path processing	fast	per packet processing

Key Issue to be Settled

□ A key issue: what is the efficiency of resource partition

□ Tool used to analyze the issue: queueing theory
  ○ Some basic results of queueing theory can be quite useful in many systems settings

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  ❍ circuit switched networks

  ❍ packet switched networks

  ❍ circuit switching vs. packet switching

  ➢ *M/M queues and statistical multiplexing*

Queueing Theory

❐ We are not interested in extremely precise modeling, but want quantitative intuition

❐ Strategy:
  ❍ model system state
    • if we know the fraction of time that the system spends at each state, we can get answers to many basic questions: how long does a new request need to wait before being served?

❐ System state changes upon events:
  ❍ introduce state transition diagram
  ❍ focus on equilibrium: state trend neither growing nor shrinking (key issue: how to define equilibrium)

Warm up: Analysis of Circuit-Switching Blocking (Busy) Time

□ Assume a link has only a finite number of N circuits

□ Objective: compute the percentage of time that a new session (call) is blocked

□ Analogy in a more typical real-life scenario?

□ Key parameters?
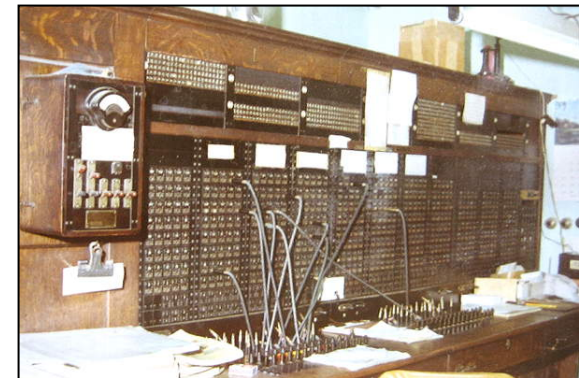
Analysis of Circuit-Switching Blocking (Busy) Time

□ Consider a simple arrival pattern
  ○ client requests arrive at a rate of λ (lambda/second)
  ○ service rate: each call takes on average $1/\mu$ second

□ Arrival and service patterns: memoryless (Markovian)
  ○ During a small interval Δt, the number of expected new arrivals is: $\lambda\Delta t$
  ○ During a small interval Δt, the chance (fraction) of a current call finishes is: $\mu\Delta t$

□ This model is also called an M/M/N model

Analysis of Circuit-Switching Blocking (Busy) Time: State
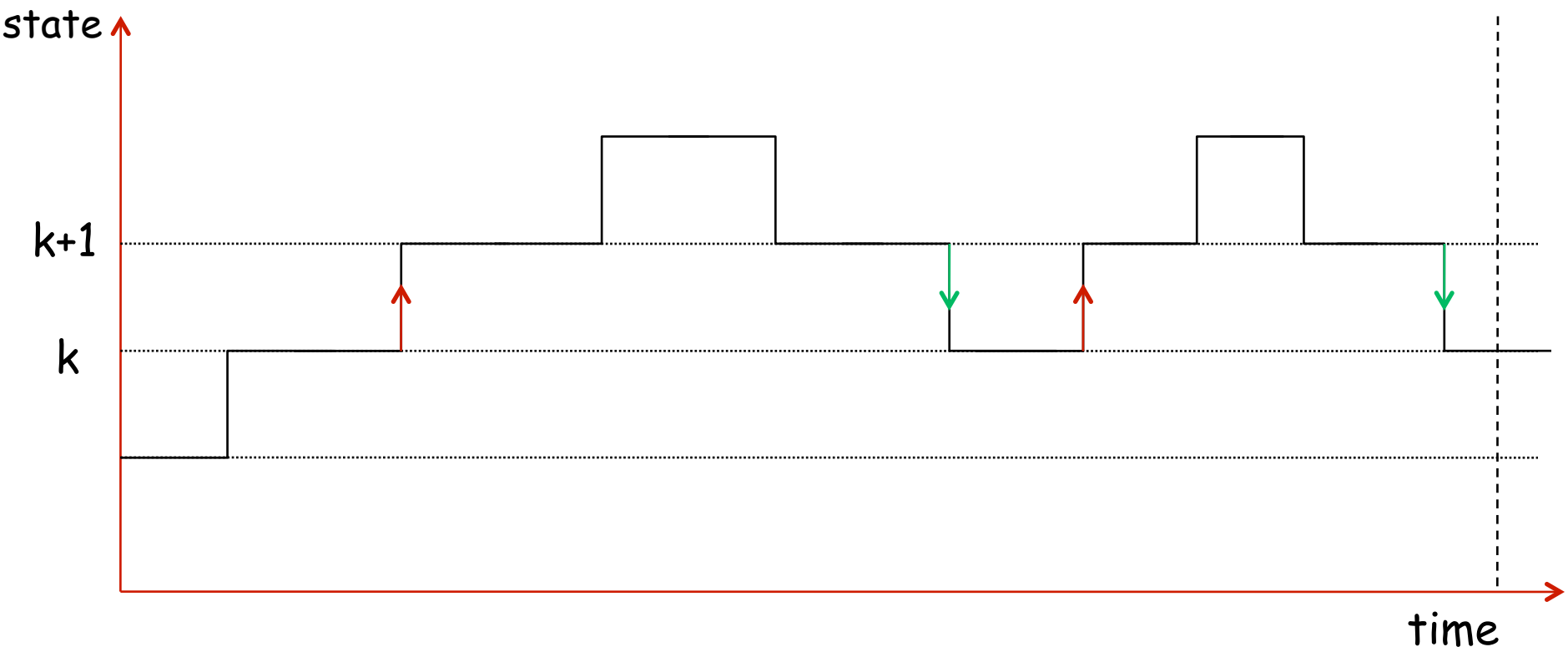
system state: # of busy lines
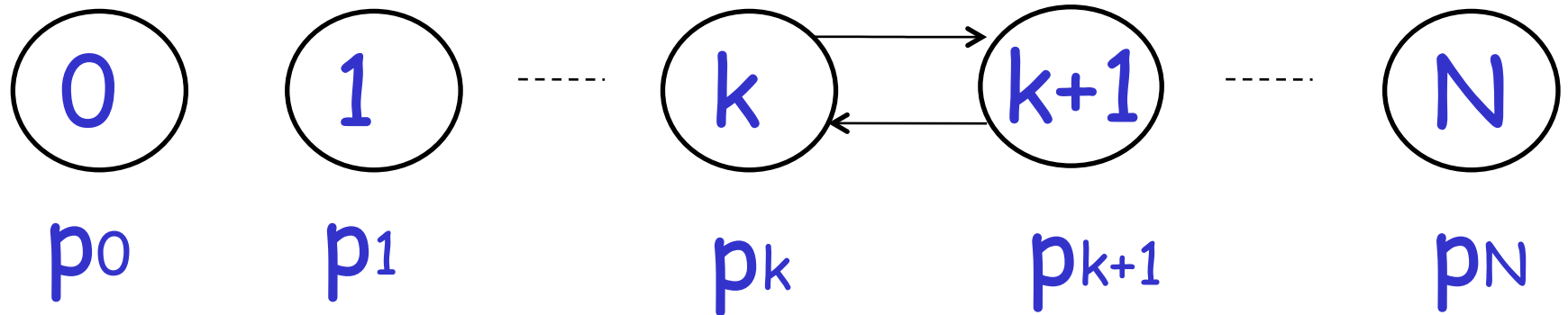
Q: How to characterize equilibrium?

Equilibrium = Time Reversibility [Frank Kelly]

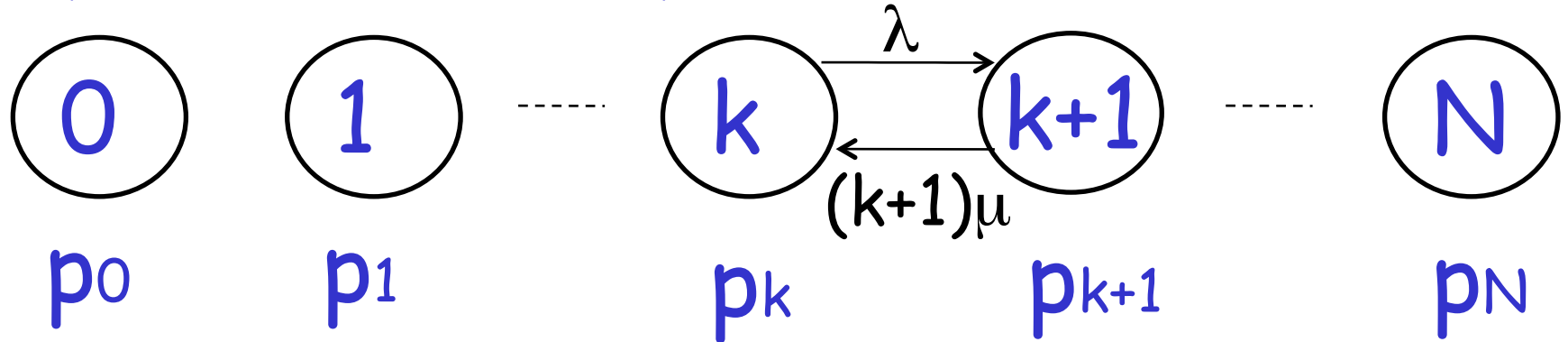☐ Statistically
cannot distinguish

$$\# f_{k\to k+1}, \quad \# f_{k+1\to k}$$

$$\# b_{k\to k+1}, \quad \# b_{k+1\to k}$$

Analysis of Circuit-Switching Blocking (Busy) Time: Sketch

system state: # of busy lines

$$p_0 \qquad p_1 \qquad p_k \qquad p_{k+1} \qquad p_N$$

at equilibrium (time resersibility) in one unit time:
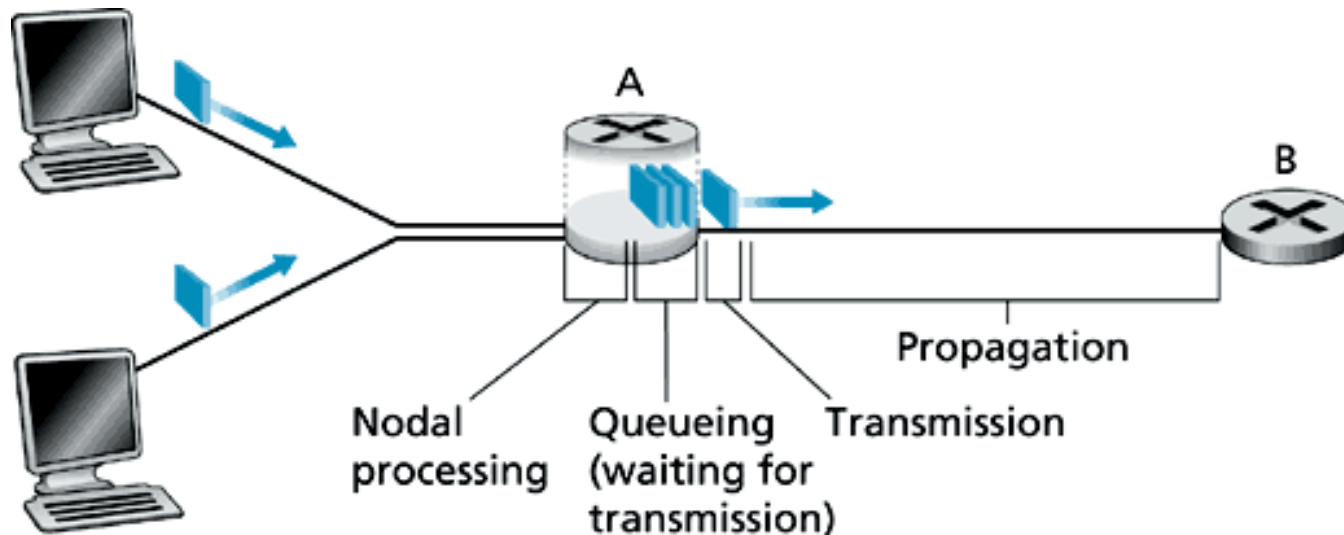
#(transitions k → k+1) = #(transitions k+1 → k)

$$p_k \lambda = p_{k+1}(k+1)\mu$$

$$p_{k+1} = \frac{1}{k+1} \frac{\lambda}{\mu} p_k = \frac{1}{(k+1)!} \left(\frac{\lambda}{\mu}\right)^{k+1} p_0$$

$$p_0 = \frac{1}{1 + \frac{1}{1!}\frac{\lambda}{\mu} + \frac{1}{2!}\left(\frac{\lambda}{\mu}\right)^2 + \ldots + \frac{1}{N!}\left(\frac{\lambda}{\mu}\right)^N}$$
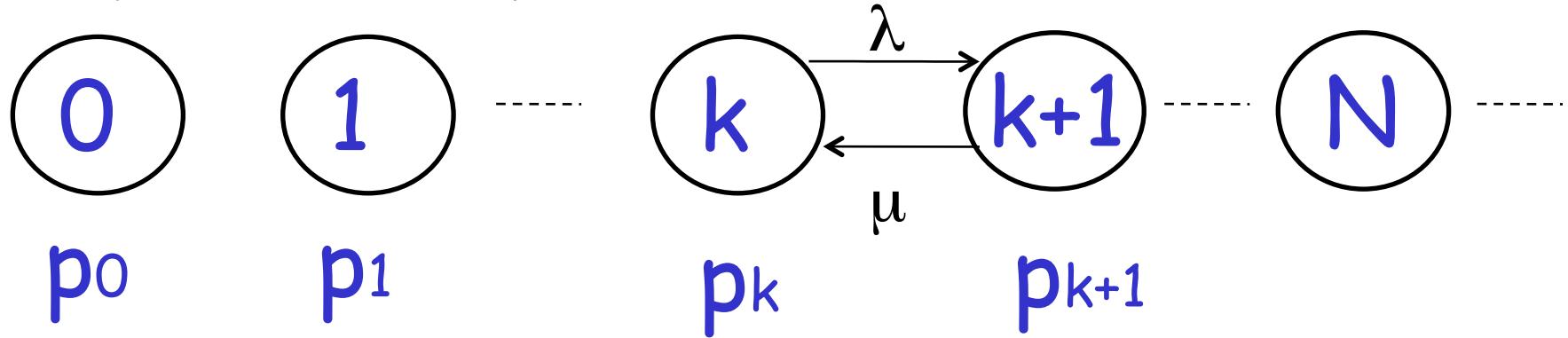
Queueing Analysis: Packet Switching Delay

❑ Four types of delay at each hop
  - ❍ nodal processing delay: check errors & routing
  - ❍ queueing: time waiting for its turn at output link
  - ❍ transmission delay: time to pump packet onto a link at link speed
  - ❍ propagation delay: router to router propagation
- ❍ The focus is on queueing and transmission delay

Packet Switching Delay
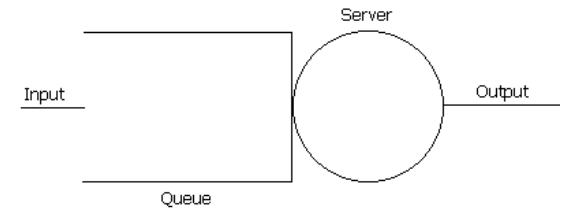
system state: #packets in queue

λ

μ

$$\text{0} \quad \text{1} \quad \text{-----} \quad \text{k} \quad \text{k+1} \quad \text{-----} \quad \text{N} \quad \text{-----}$$

$p_0 \qquad p_1 \qquad\qquad p_k \qquad\qquad p_{k+1}$

at equilibrium (time reversibility) in one unit time:
    #(transitions k → k+1) = #(transitions k+1 → k)