A Taxonomy of Communication Networks

Reading: KR 1.3, 1,4

Outline

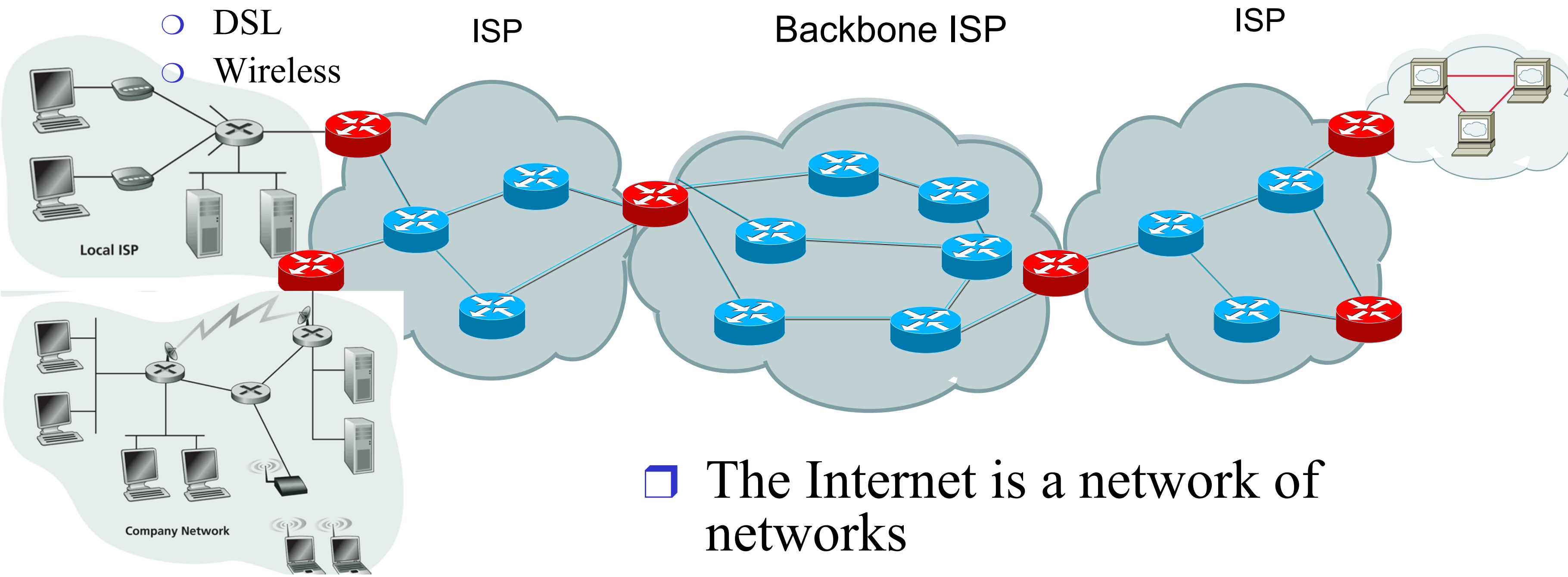
- *Recap*
- A taxonomy of communication networks
- Summary

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 distributed, autonomous systems

Recap: Current Internet Physical Infrastructure

Residential access
- Cable
- Fiber
- DSL
- Wireless



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

- The Internet is a network of networks
- Each individually administrated network is called an Autonomous System (AS)

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A Taxonomy of Communication Networks

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

- *The* fundamental question: how is data (the bits) transferred through a communication network?

Broadcast vs. Switched Communication Networks

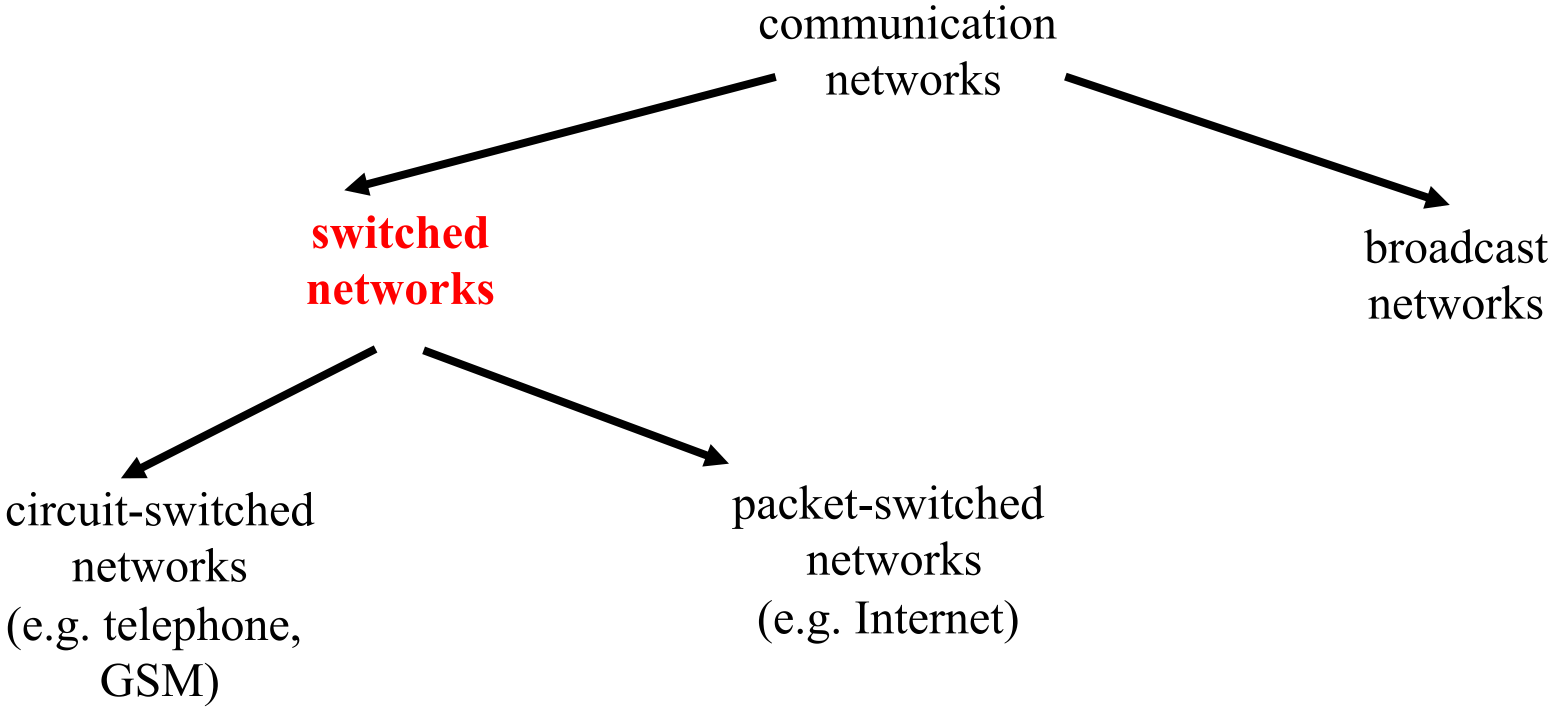
communication networks

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



- Circuit switching: dedicated circuit per call/session:
  - E.g., telephone, GSM High-Speed Circuit-Switched Data (HSCSD)
- Packet switching: data sent through network in discrete “chunks”
  - E.g., Internet, General Packet Radio Service (GPRS)

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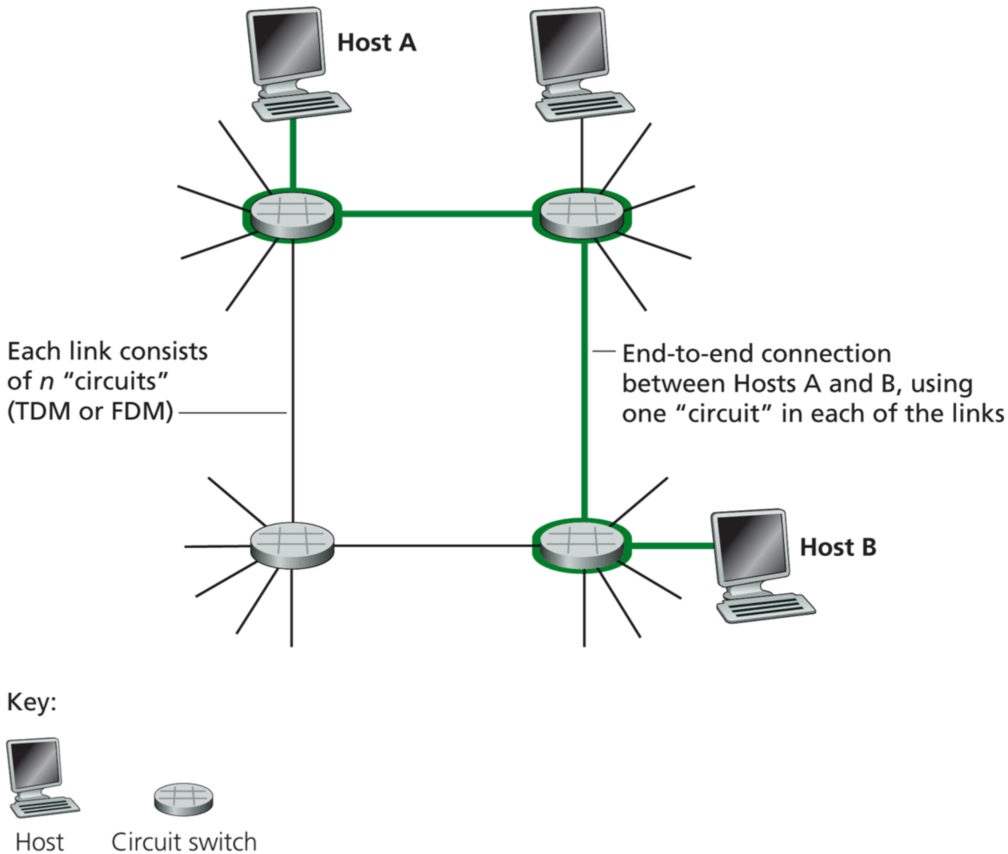
- Recap
- *A taxonomy of communication networks*
  - *Circuit switched networks*
  - Packet switched networks
  - Circuit switching vs. packet switching
  - Datagram switching vs. virtual circuit switching
- Summary

Circuit Switching

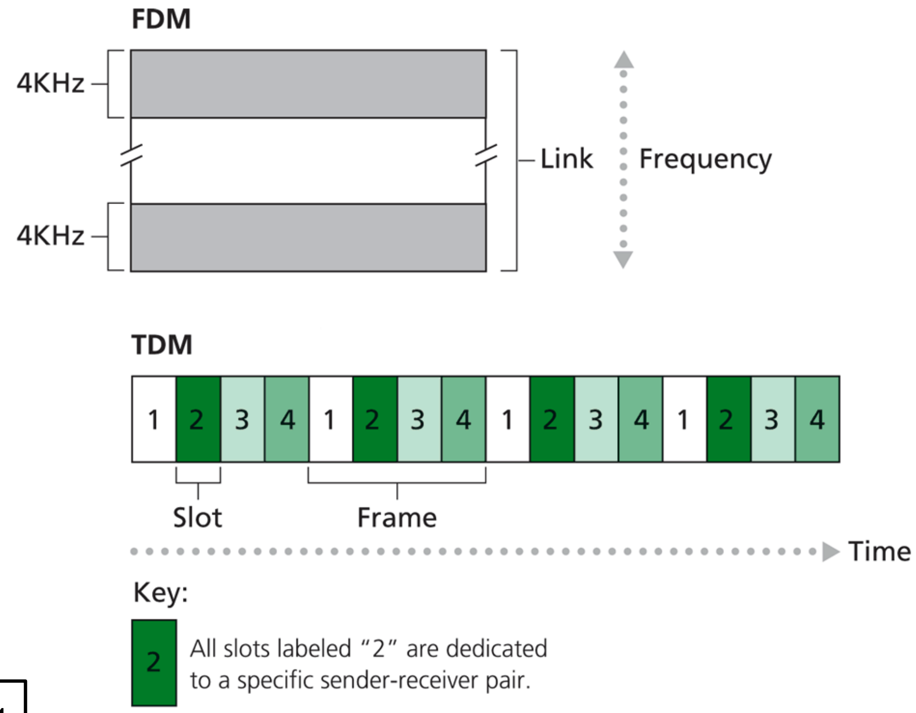
- Each link has a number of "circuits"
  - Sometime we refer to a "circuit" as a channel or a line
- An end-to-end connection reserves one "circuit" at each link

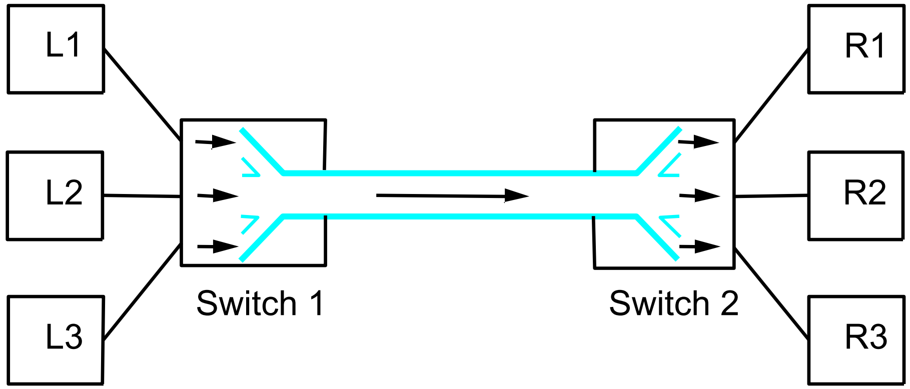


First commercial telephone switchboard was opened in 1878 to serve the 21 telephone customers in New Haven, Connecticut

Multiplexing for Sharing Resources

- Time-Division Multiplexing (TDM)
- Frequency-Division Multiplexing (FDM)
- Others, e.g., code division multiplexing (CDM), color/lambda division

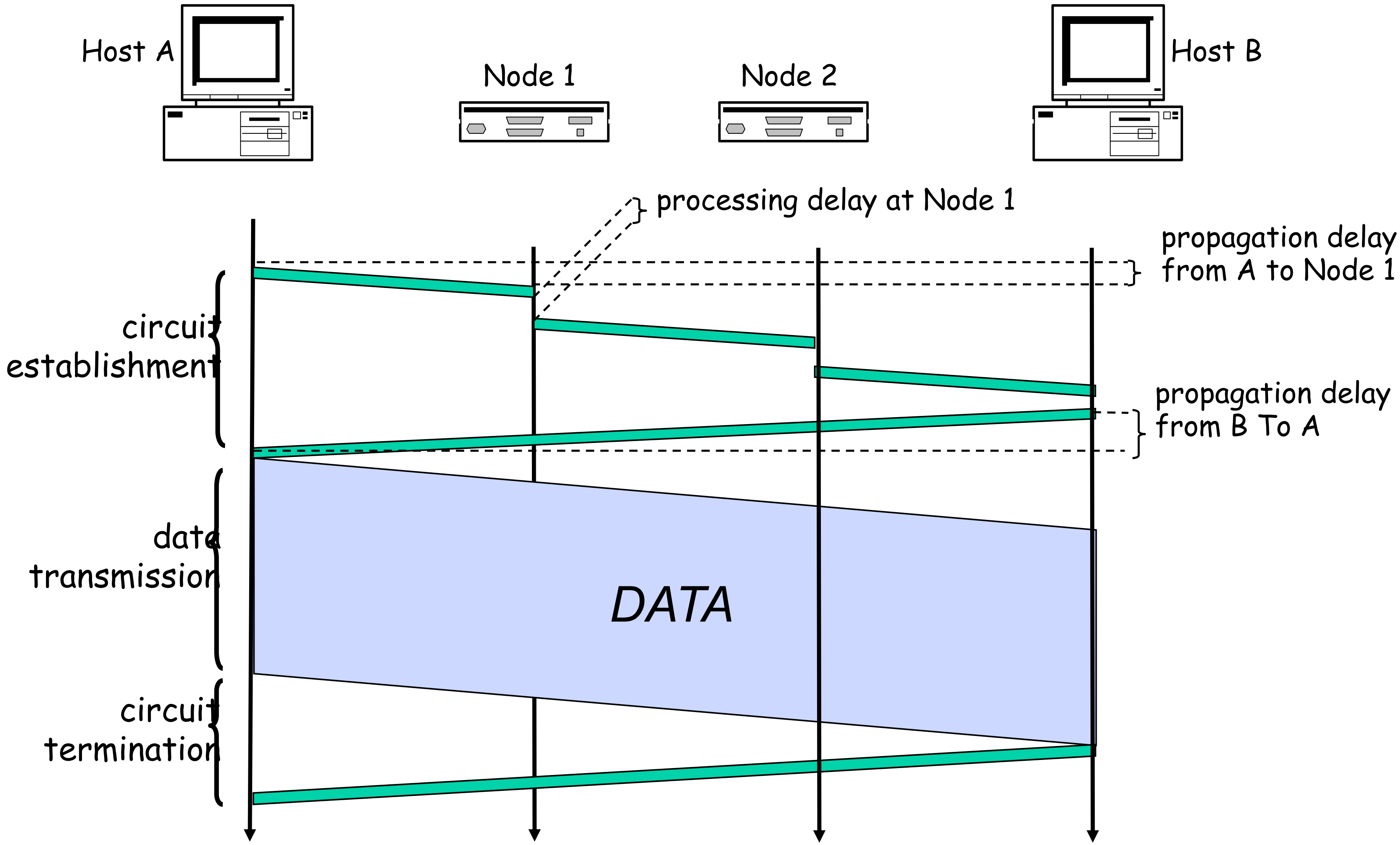




Circuit Switching: The Process

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

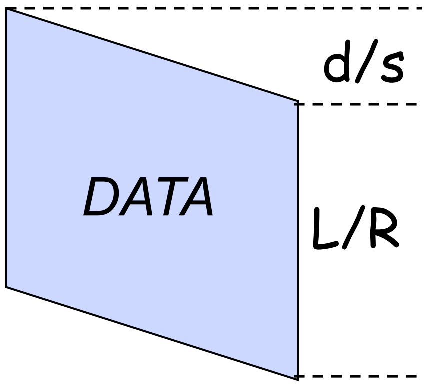
Timing Diagram of Circuit Switching



Delay Calculation in Circuit Switched Networks

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

- Transmission delay: time to pump data onto link at *reserved* rate



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

Transmission delay:
- R = reserved bandwidth (bps)
- L = message length (bits)
- time to send a packet into link = L/R

An Example

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

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

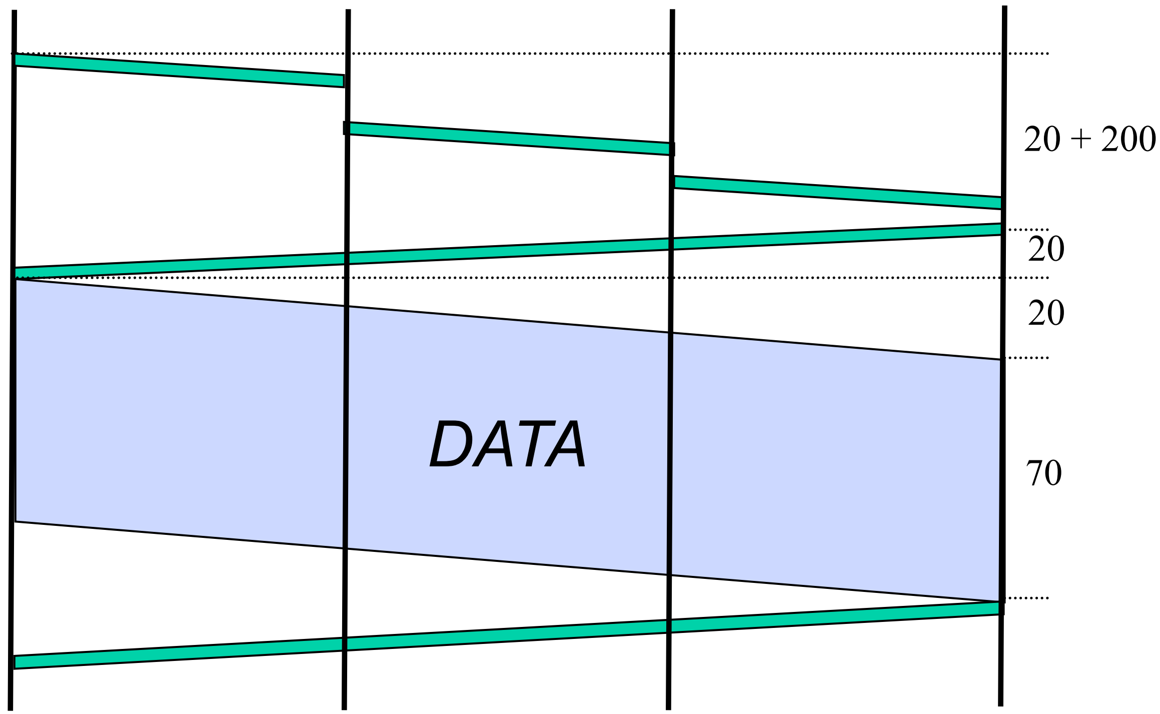
- Transmission delay
  - Suppose we reserve a one slot HSCSD channel
    - Each HSCSD frame can transmit about 115 kbps
    - A frame is divided into 8 slots, each is about 14 kbps
  - Then the transmission delay of using one reserved slot for a message of 1 Kbits:

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

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:

$$20 + 200 + 20 + 20 + 70 = 330ms$$



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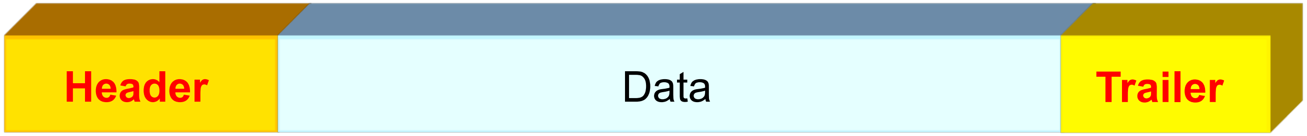
  - *Packet switched networks*

Packet Switching

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

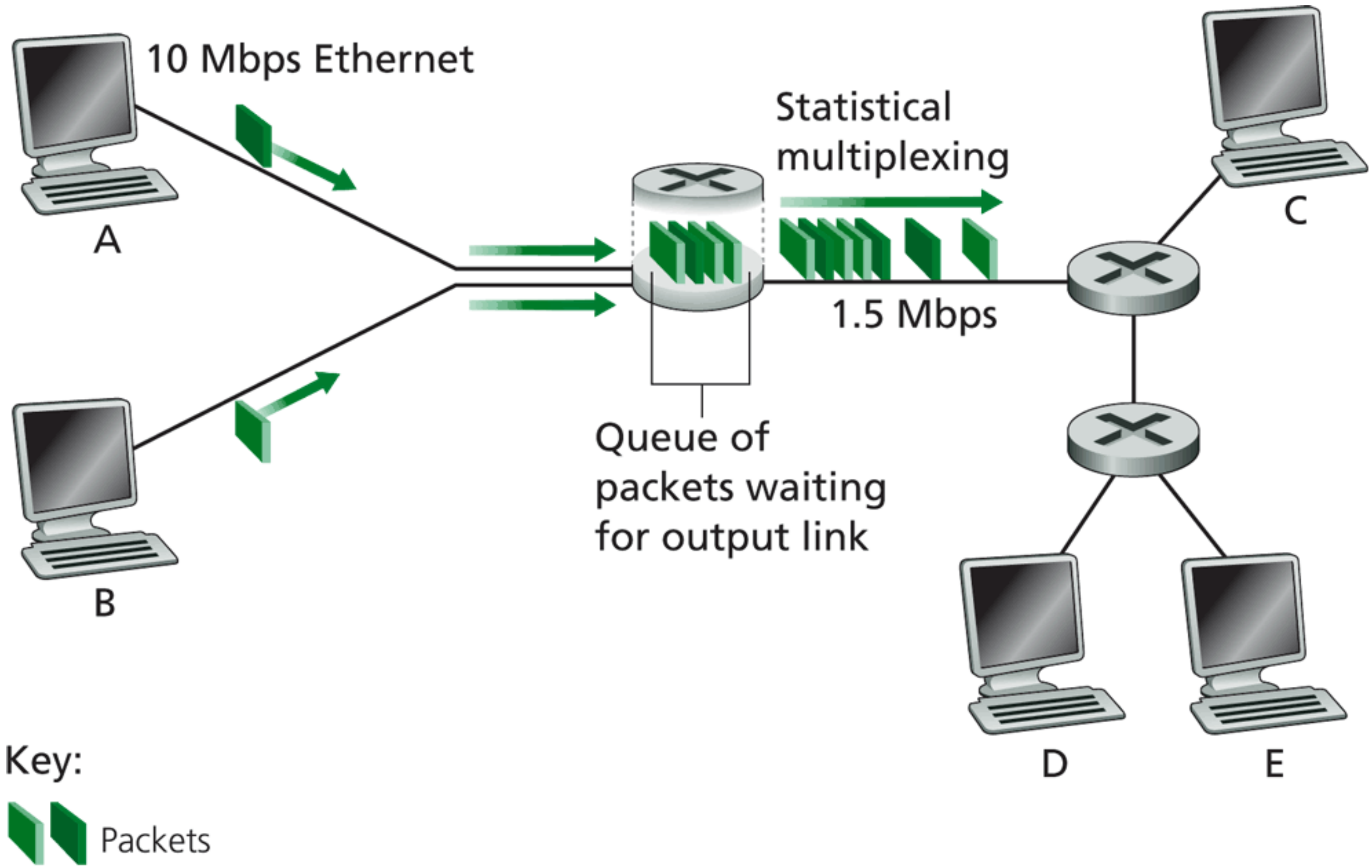
- Packets have the following structure:



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

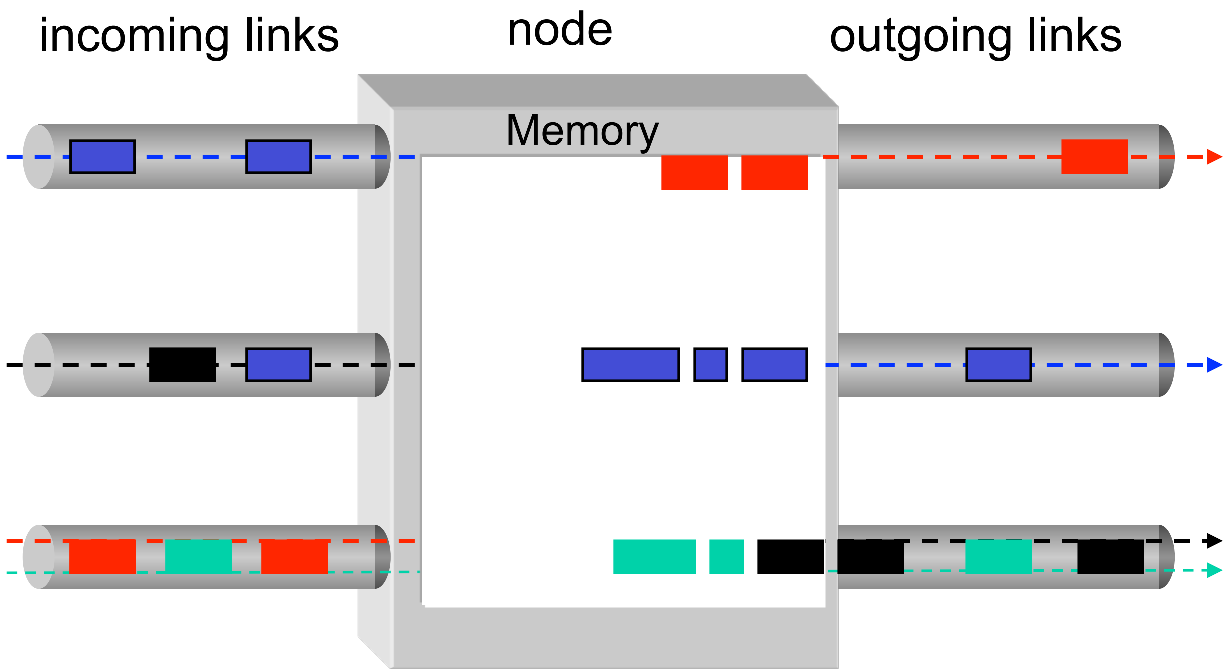
- At each node the entire packet is received, processed (e.g., routing), stored briefly, and then forwarded to the next node; thus packet-switched networks are also called **store-and-forward networks**

Packet Switching



Inside a Packet Switching Router

An output queueing switch



Packet Switching: Resources

- Resources used *as **needed***
- On its turn, a packet uses full link bandwidth

Outline

- Admin. and review
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  - 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
  - Telephone network was the dominant network

- Need to compare packet switching with circuit switching

Circuit Switching vs. Packet Switching

	circuit switching	packet switching
resource		
when using resource		
reservation/ setup		
resource contention		
service guarantee		
charging		
header		
fast path processing		

Circuit Switching vs. Packet Switching

	circuit switching	packet switching
resource	partitioned	not partitioned
when using resource	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)
service guarantee	yes	no
charging	time	packet
header	no header	per packet header
fast path processing	fast	per packet processing

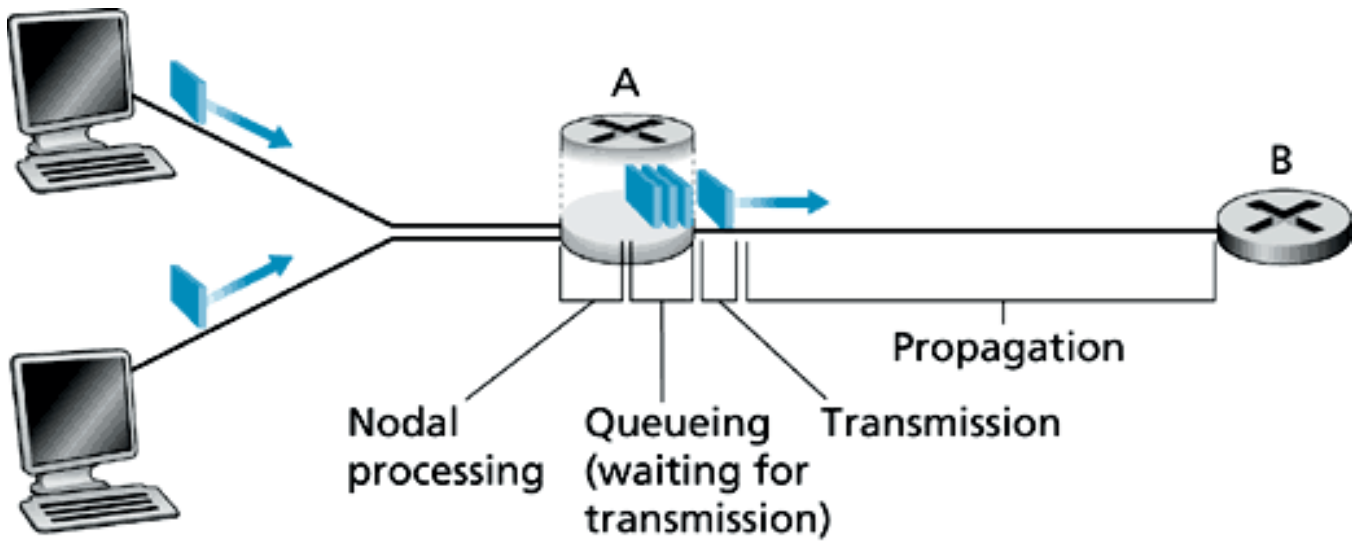
Key Issue to be Settled

- All the other comparisons are easy to understand, a key debating issue was whether resource partition would be inefficient.

- Tool used to analyze the issue: queueing theory

Analysis of Message Delay at a Link

- 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



A Key Question: To Partition or not to Partition?

Assume:

R = link bandwidth (bps)

L = average packet length (bits)

a = average packet arrival rate (pkt/sec)

R/L = packet service rate (pkt/sec)

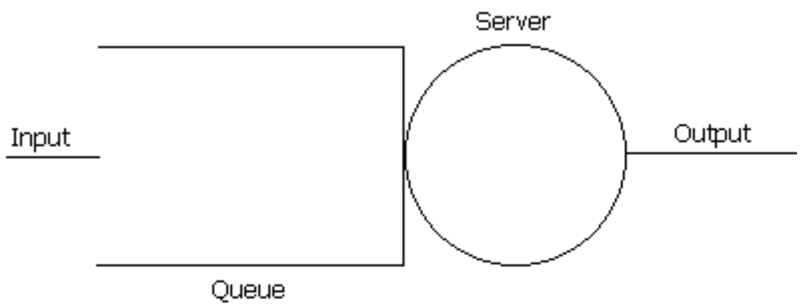
Setup: n streams; each stream has an arrival rate of a/n

Comparison: each stream reserves 1/n bandwidth or not

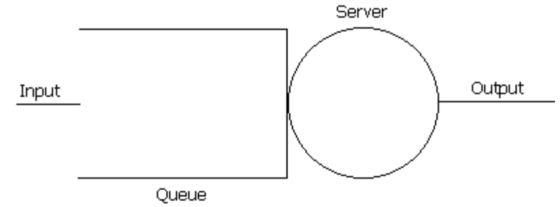
- Case 1 (not reserve): all arrivals into *a single link* with rate R, what is the queueing delay + transmission delay?
- Case 2 (reserve): the arrivals are divided into *n links* with rate R/n each, what is the queueing delay + transmission delay?

Packet Switch: Analysis of Queueing + Transmission Time

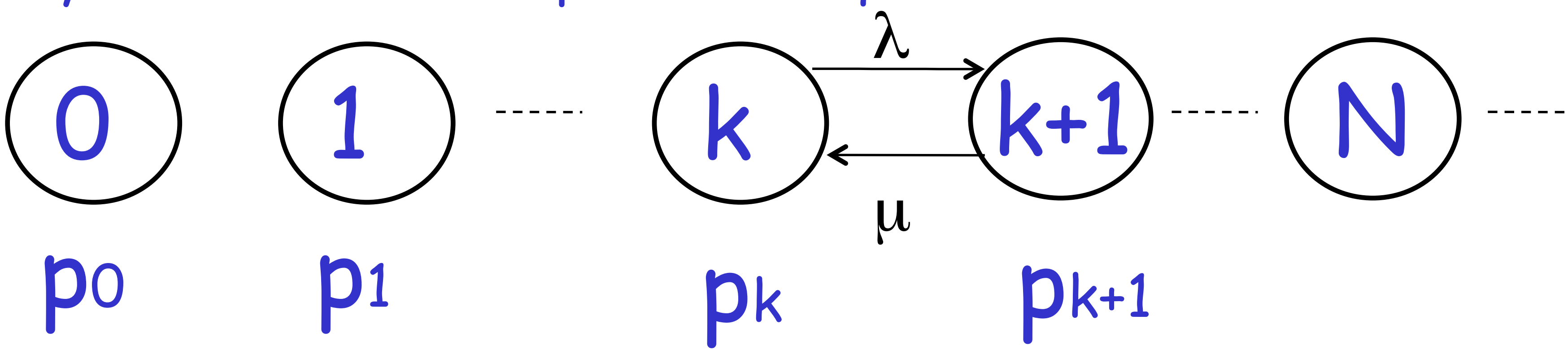
- Consider a single queue
  - Packet arrival rate: λ per second
  - Packet service rate: μ per second
  - What is the queueing + transmission time of each packet?



Analysis of Queueing Delay: Sketch



system state: # of packets in queue



at equilibrium (time resersibility) in one unit time:

#(transitions k → k+1) = #(transitions k+1 → k)

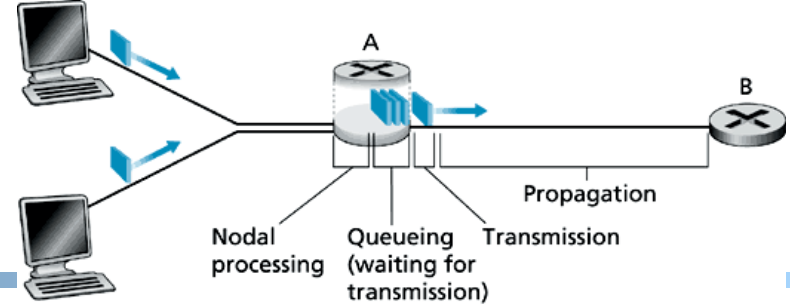
$$\boxed{p_k \lambda = p_{k+1} \mu}$$

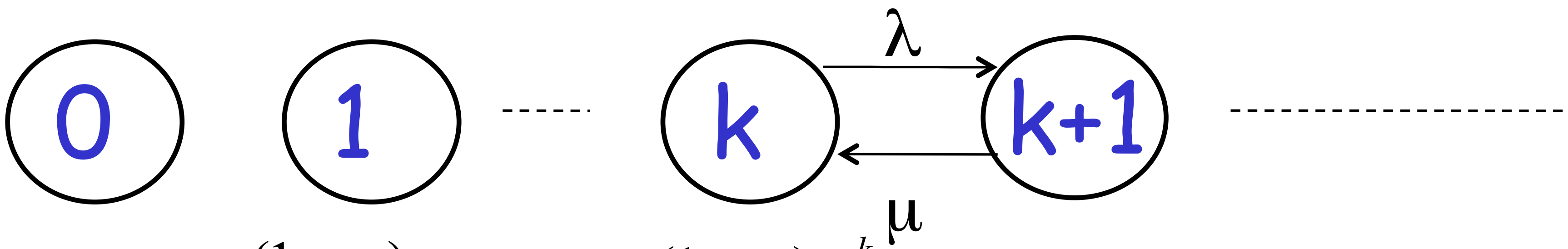
$$\boxed{\rho = \frac{\lambda}{\mu}}$$

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

$$\boxed{p_0 = 1 - \rho}$$

Analysis of Delay (cont')





$1-\rho$ $(1-\rho)\rho$ $(1-\rho)\rho^k$

- Average queue size: $\mathrm{E}(Q) = \sum_{i=0}^{\infty} i\pi_i = (1-\rho)\sum_{i=0}^{\infty} i\rho^i = \frac{\rho}{1-\rho}$
- Average queueing delay: $w = \frac{L}{R}\frac{\rho}{1-\rho}$
- Transmission delay: $\frac{L}{R}$
- Queueing + transmission: $\frac{L}{R}\frac{\rho}{1-\rho} + \frac{L}{R} = \frac{L}{R}\frac{1}{1-\rho}$

Delay: M/M/1 Model

Assume:

R = link bandwidth (bps)

L = average packet length (bits)

a = average packet arrival rate (pkt/sec)

R/L = packet service rate (pkt/sec)

$$utilization: \rho = \frac{a}{R/L} = \frac{La}{R}$$

$$\text{average queueing delay}: \ w = \frac{L}{R}\frac{\rho}{1-\rho}$$

$$queueing + trans = \frac{L}{R}\frac{\rho}{1-\rho} + \frac{L}{R} = \frac{L}{R}\frac{1}{1-\rho}$$

For a demo of M/M/1, see:
http://www.dcs.ed.ac.uk/home/jeh/Simjava/queueing/mm1_q/mm1_q.html

Queueing Delay as A Function of Utilization

Assume:

R = link bandwidth (bps)

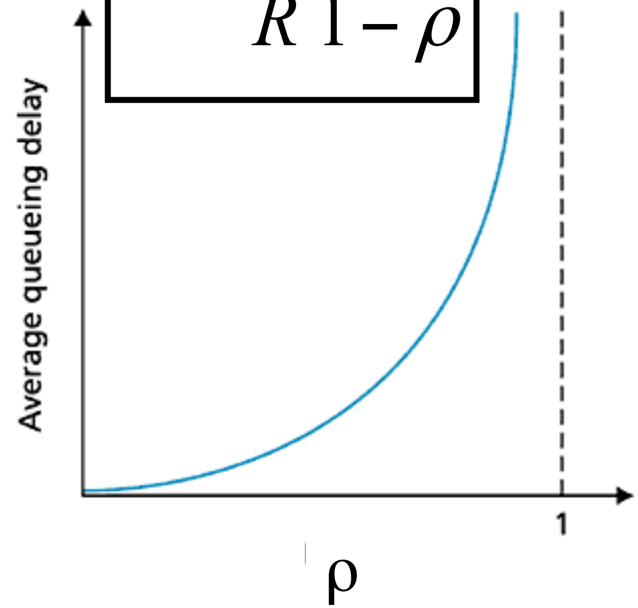
L = average packet length (bits)

a = average packet arrival rate (pkt/sec)

R/L = packet service rate (pkt/sec)

$$utilization: \rho = \frac{a}{R/L} = \frac{La}{R}$$

$$w = \frac{L}{R}\frac{\rho}{1-\rho}$$

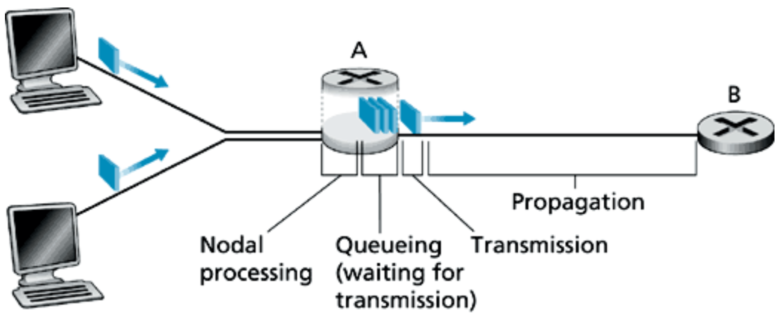


- $\rho \sim 0$: average queueing delay small
- $\rho \to 1$: delay becomes large
- $\rho > 1$: more "work" arriving than can be serviced, average delay infinite !

Statistical Multiplexing

A simple model to compare bandwidth efficiency of

- Reservation/dedication (aka circuit-switching) and
- No reservation (aka packet switching) setup
- A single bottleneck link with rate R
- n flows; each flow has an arrival rate of a/n



- No reservation: all arrivals into the single link with rate R, the queueing delay + transmission delay:

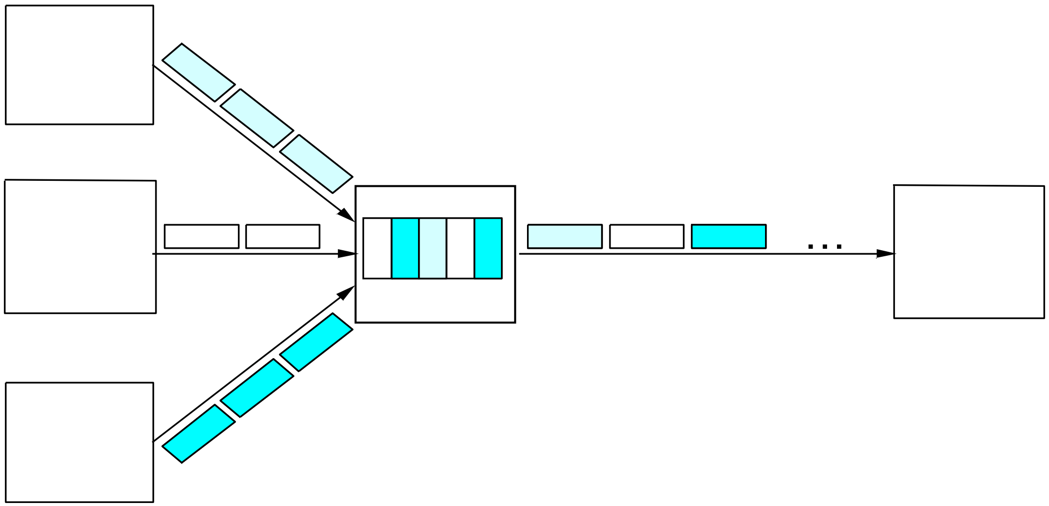
$$\frac{L}{R}\frac{1}{1-\rho}$$

- Reservation: each flow uses its own reserved (sub)link with rate R/n, the queueing delay + transmission delay:

$$n\frac{L}{R}\frac{1}{1-\rho}$$

Statistical Multiplexing

- On-demand time-division
- Schedule link on a per-*packet* basis
- Packets from different sources interleaved on link
- Buffer packets that are *contending* for the link
- Buffer (queue) overflow is called *congestion*



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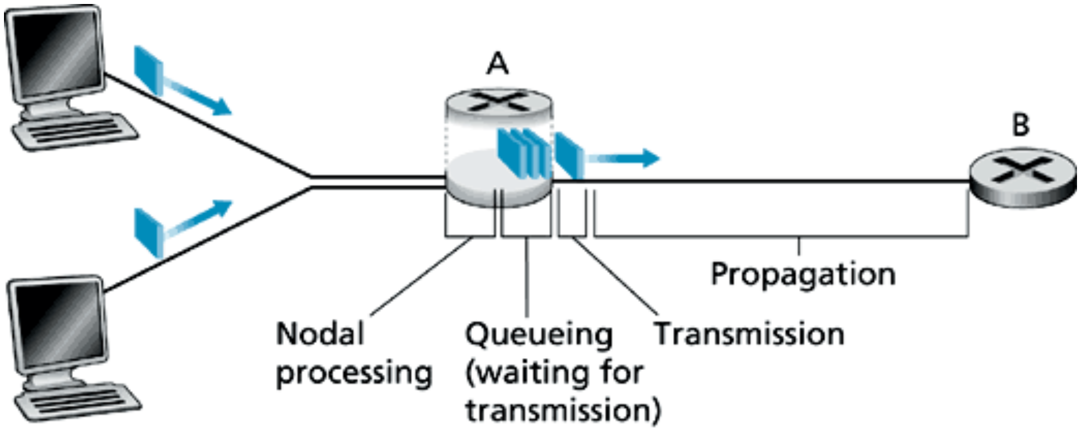
  - circuit switched networks
  - packet switched networks
  - circuit switching vs. packet switching
  - *datagram and virtual circuit packet switched networks*

A Taxonomy of Packet-Switched Networks According to Routing

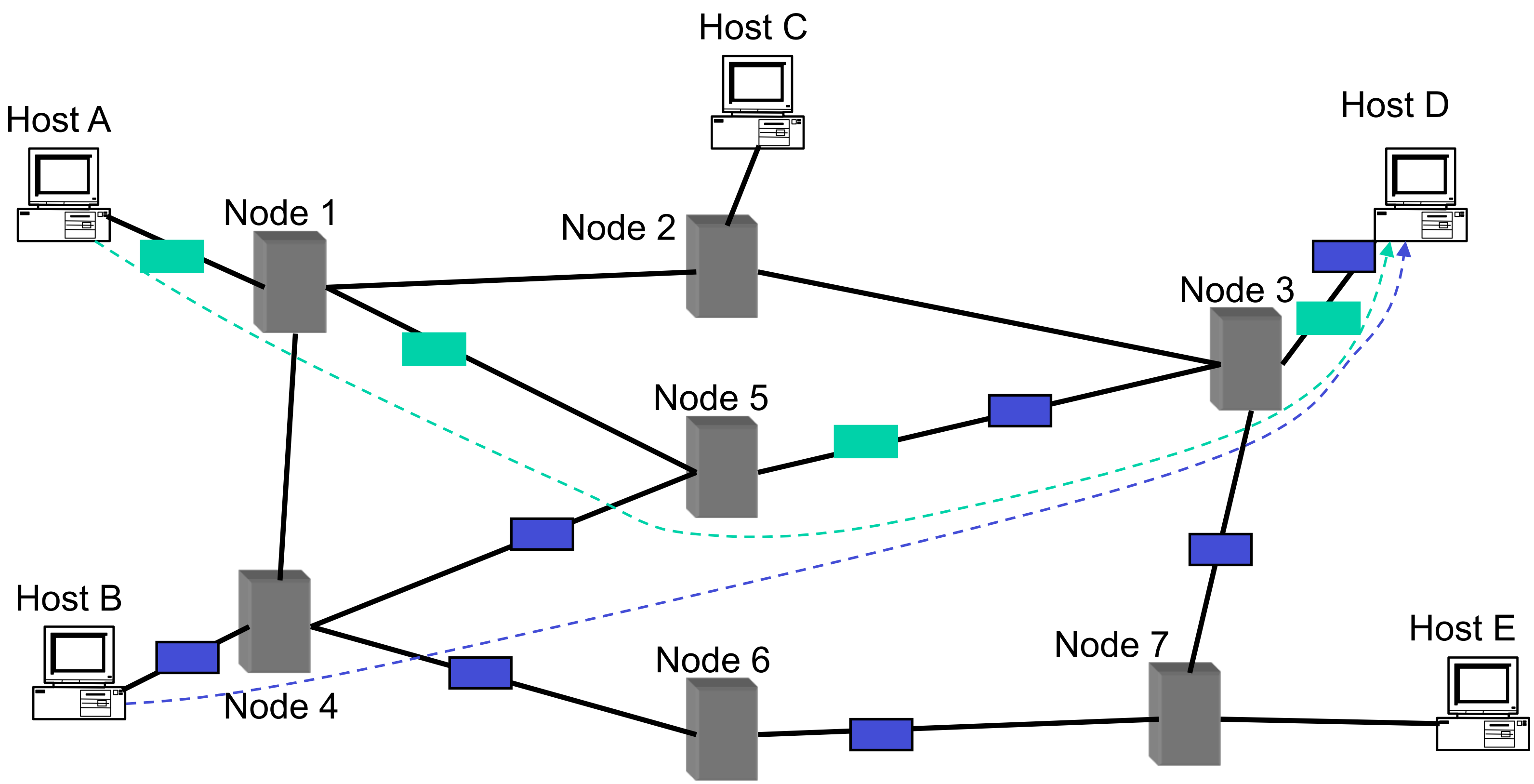
- *Goal:* move packets among routers from source to destination
  - We'll study routing algorithms later in the course
- Two types of packet switching
  - Datagram network
    - Each packet of a flow is switched **independently**
  - Virtual circuit network:
    - All packets from one flow are sent along a **pre-established** path (= virtual circuit)



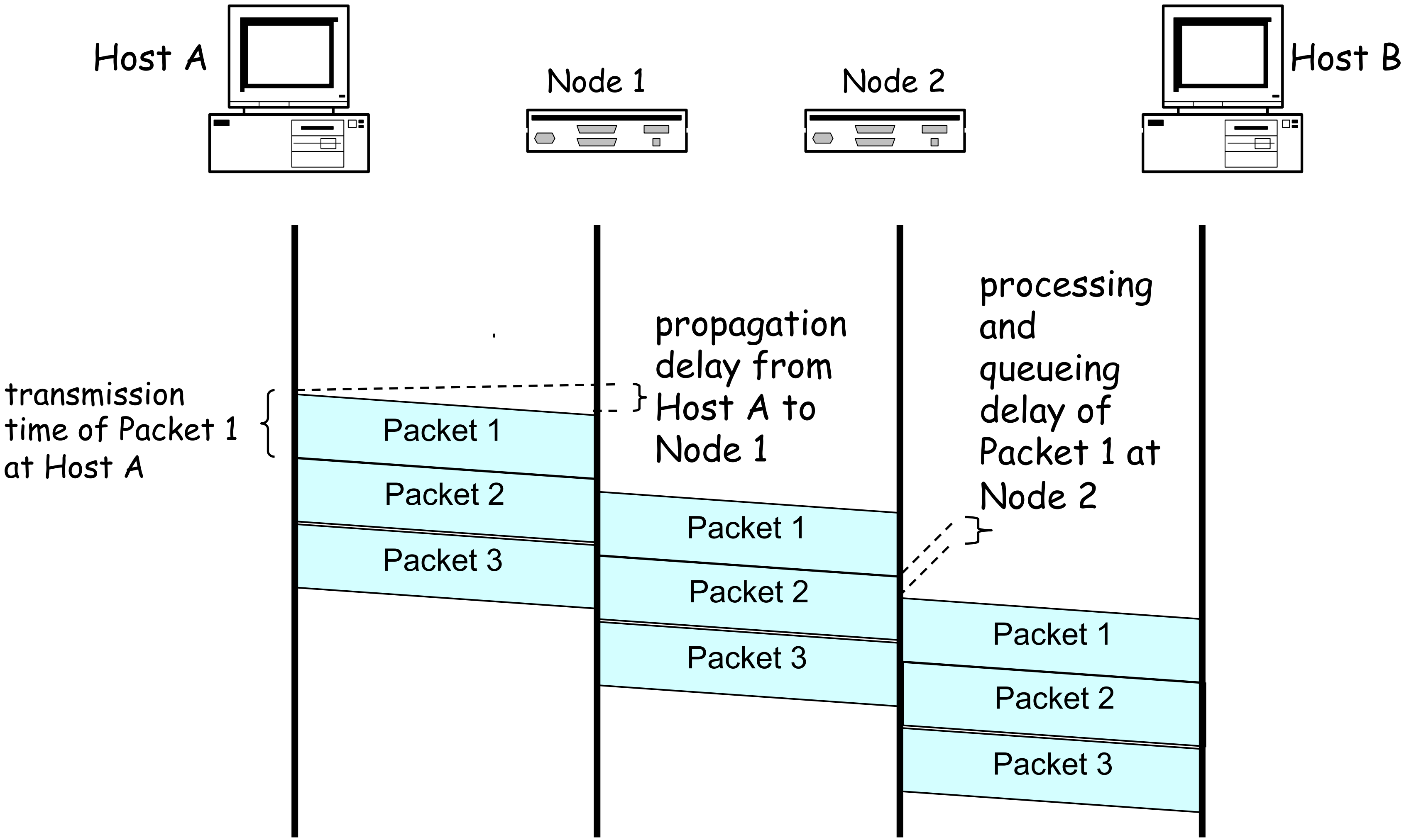
Datagram Packet Switching

- Commonly, when we say packet switching we mean datagram switching
  - E.g., IP networks
- Each packet is independently switched
  - Each packet header contains complete destination address
  - Receiving a packet, a router looks at the packet's destination address and searches its current routing table to determine the possible next hops, and pick one
- Analogy: postal mail system

Datagram Packet Switching



Timing of Datagram Switching



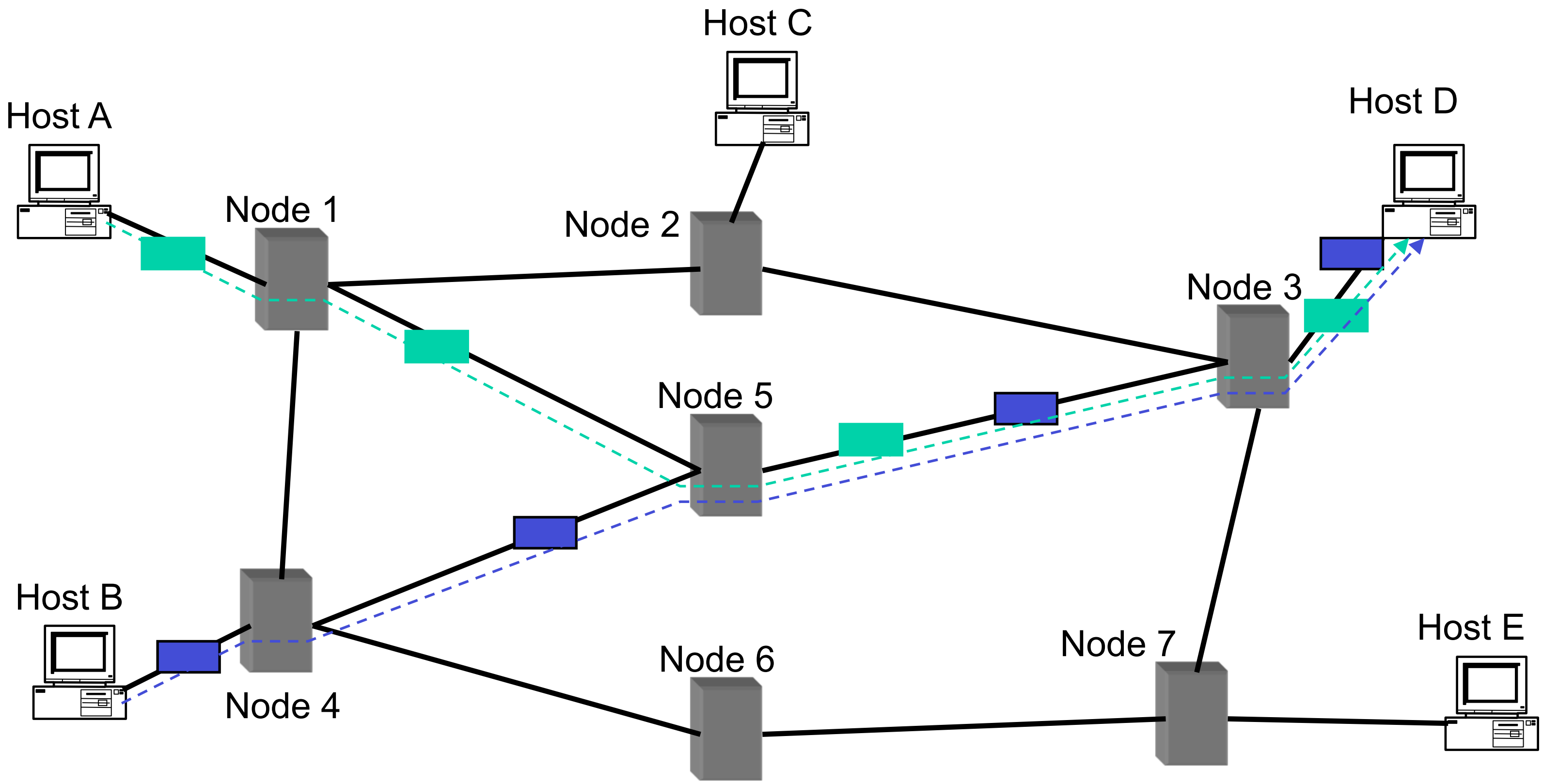
Virtual-Circuit Packet Switching

- Example: Multiple Label Packet Switching (MPLS) in IP networks
- Hybrid of circuit switching and datagram switching
  - Fixed path determined at *virtual circuit setup time*, remains fixed thru flow
  - Each packet carries a short tag (virtual-circuit (VC) #); tag determines next hop

Incoming VC#	Outgoing Interface	QoS
12	2	
16	3	
20	3	
…		

- Question:
  - How big is the lookup table at each router?
  - How about datagram?

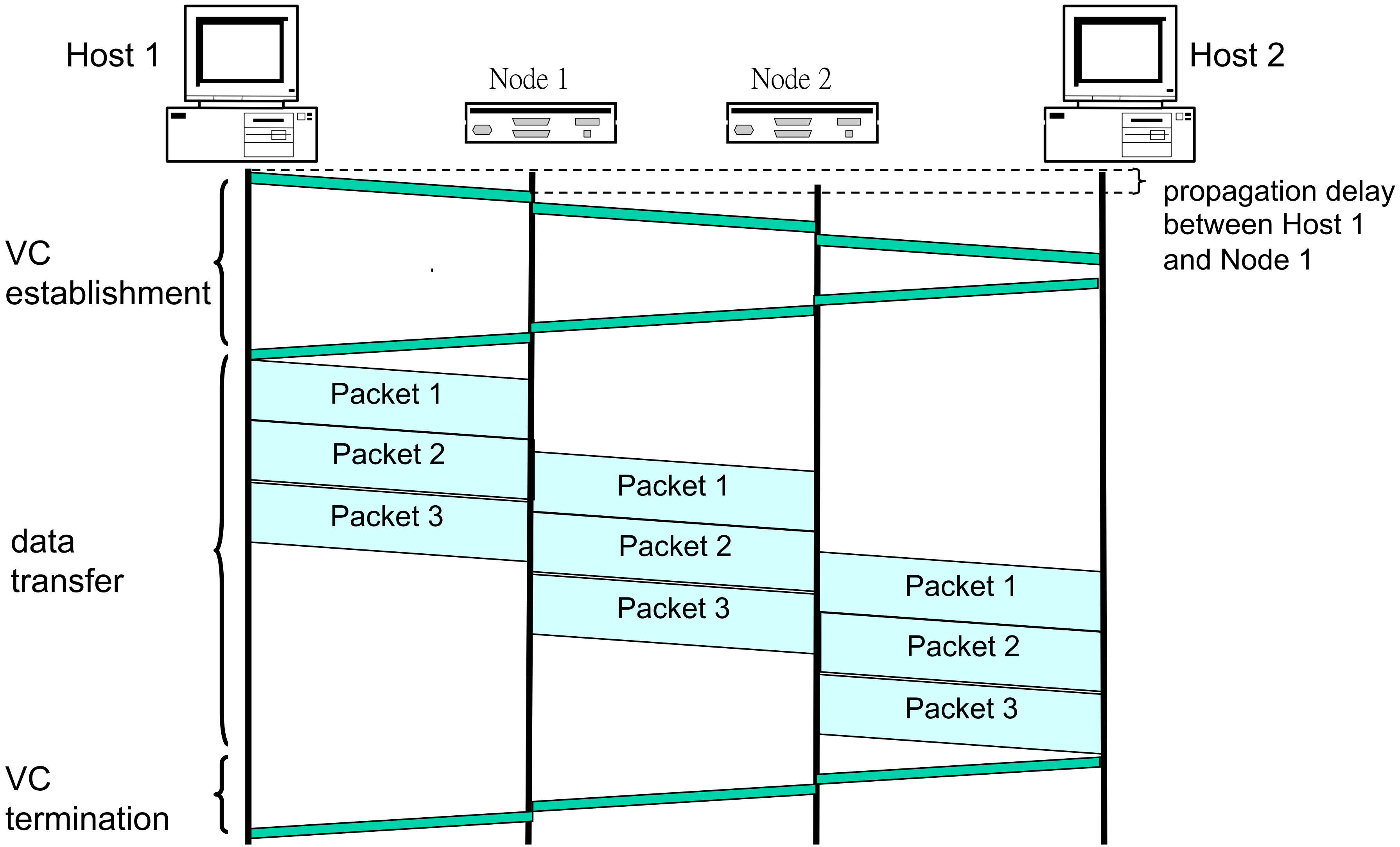
Virtual-Circuit Switching



Virtual-Circuit Packet Switching

- Three phases
  1. VC establishment
  2. Data transfer
  3. VC disconnect

Timing Diagram of Virtual-Circuit Switching



Discussion: Datagram Switching vs. Virtual Circuit Switching

- What are the benefits of datagram switching over virtual circuit switching?

- What are the benefits of virtual circuit switching over datagram switching?

Summary of the Taxonomy of Communication Networks