# CI0121 Computer Networks

## Network taxonomy and packet transmission

Profesores ECCI

# Communications networks

**<u>Communication networks</u>**

**Switched networks**

end nodes send to one (or more) end nodes

**Circuit switching**

Dedicated circuit per call
(telephone, ISDN)
(physical)

**Packet switching**

Data sent in discrete portions
(the Internet)

**Datagram networks**

Each packet switched independently

**Virtual circuit networks**

Pre-established path
(logical)

**Broadcast networks**

End nodes share a common channel (TV, radio…)

# Circuit switching

- A dedicated communication path **(**sequence of links**-circuit)** is established between the two end nodes through the nodes of the network

- Bandwidth: A circuit occupies a fixed capacity of each link for the entire lifetime of the connection. Capacity unused by the circuit cannot be used by other circuits.

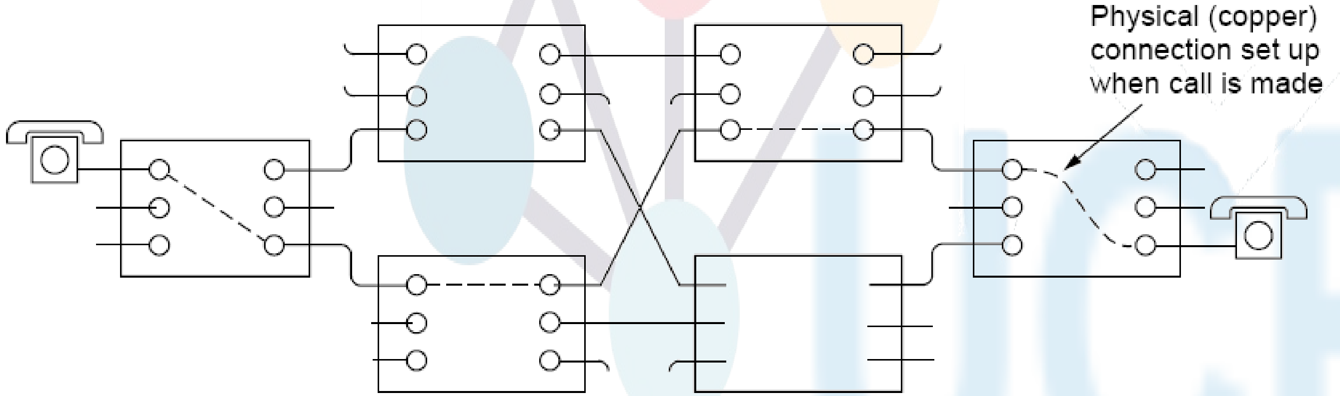
- Latency: Data is not delayed at switches

# Circuit switching (cnt'd)

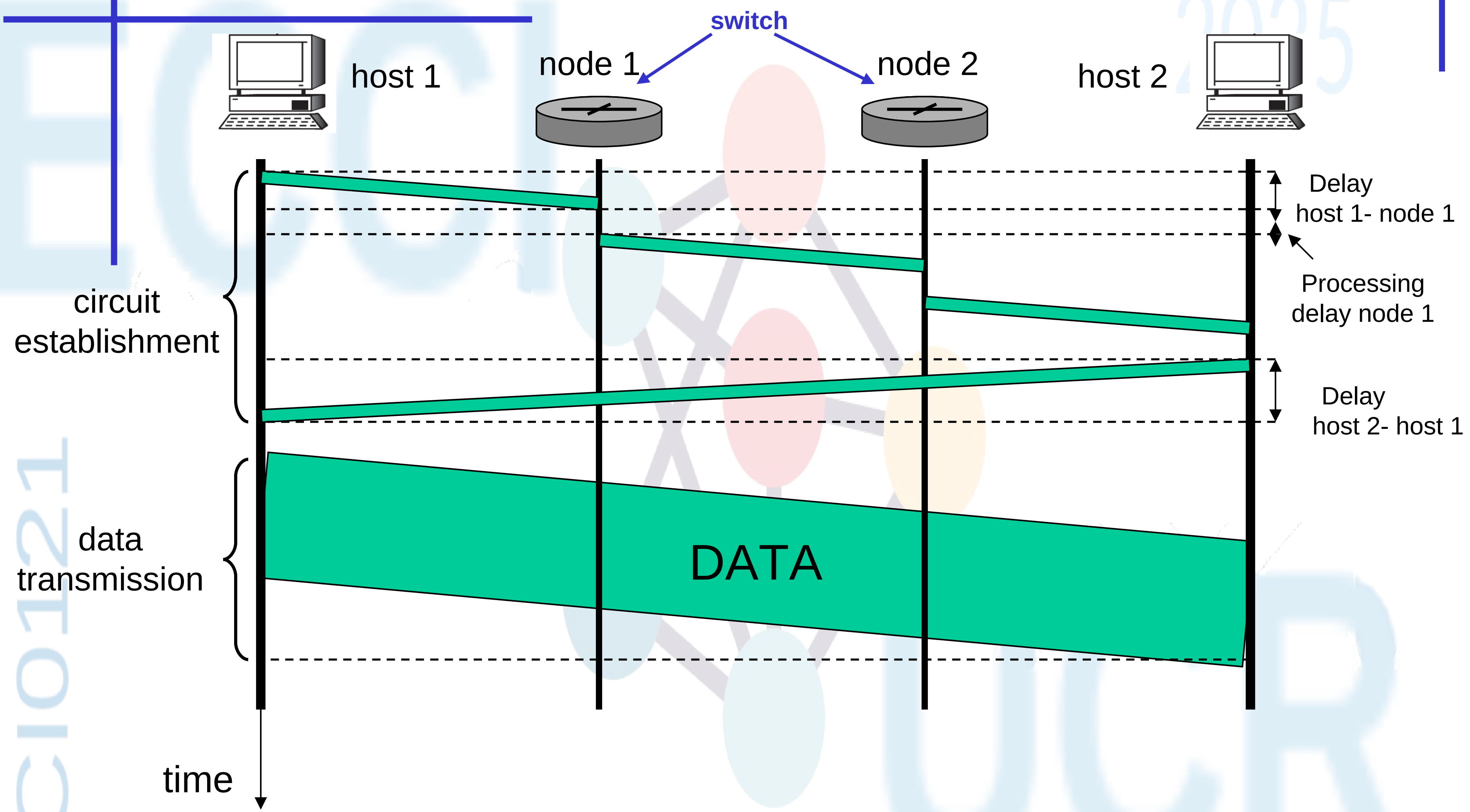
Three phases involved in communication process:

1. Establish the circuit
2. Transmit data
3. Terminate circuit

If circuit not available: busy signal (congestion)



# Time diagram of circuit switching



# Delay calculation

Total delay: $d_{proc} + d_{prop} + d_{trans}$

- Processing delay: $d_{proc}$
- Propagation delay: $d_{prop}$
  - time required for transmission of the first bit of the data packet from its source to its ultimate destination
  - $d_{prop} = \frac{l}{c}$
    - $l$: length of the physical link [m]
    - $c$: propagation speed in medium [m/s]
- Transmission delay: $d_{trans}$
  - time required to push a complete data packet into a network
  - $d_{trans} = \frac{p}{r}$
    - $p$ – packet length [bits]; $r$ – transmission rate [bps]

# Delay calculation

- Analogy with *transmission* and *propagation delay*
  - Toll booths on the highway
    - Toll booth – router
    - A highway between 2 toll booths – link
- Imagine a caravan of cars, traveling as a group in a fixed order that is entering the highway segment, crossing the first toll both
- The time required to push out the cars onto the highway by the tollbooth is analogous to the transmission delay in the communication network
- The time taken by the cars to traverse the highway segment is analogous to the propagation delay in the network

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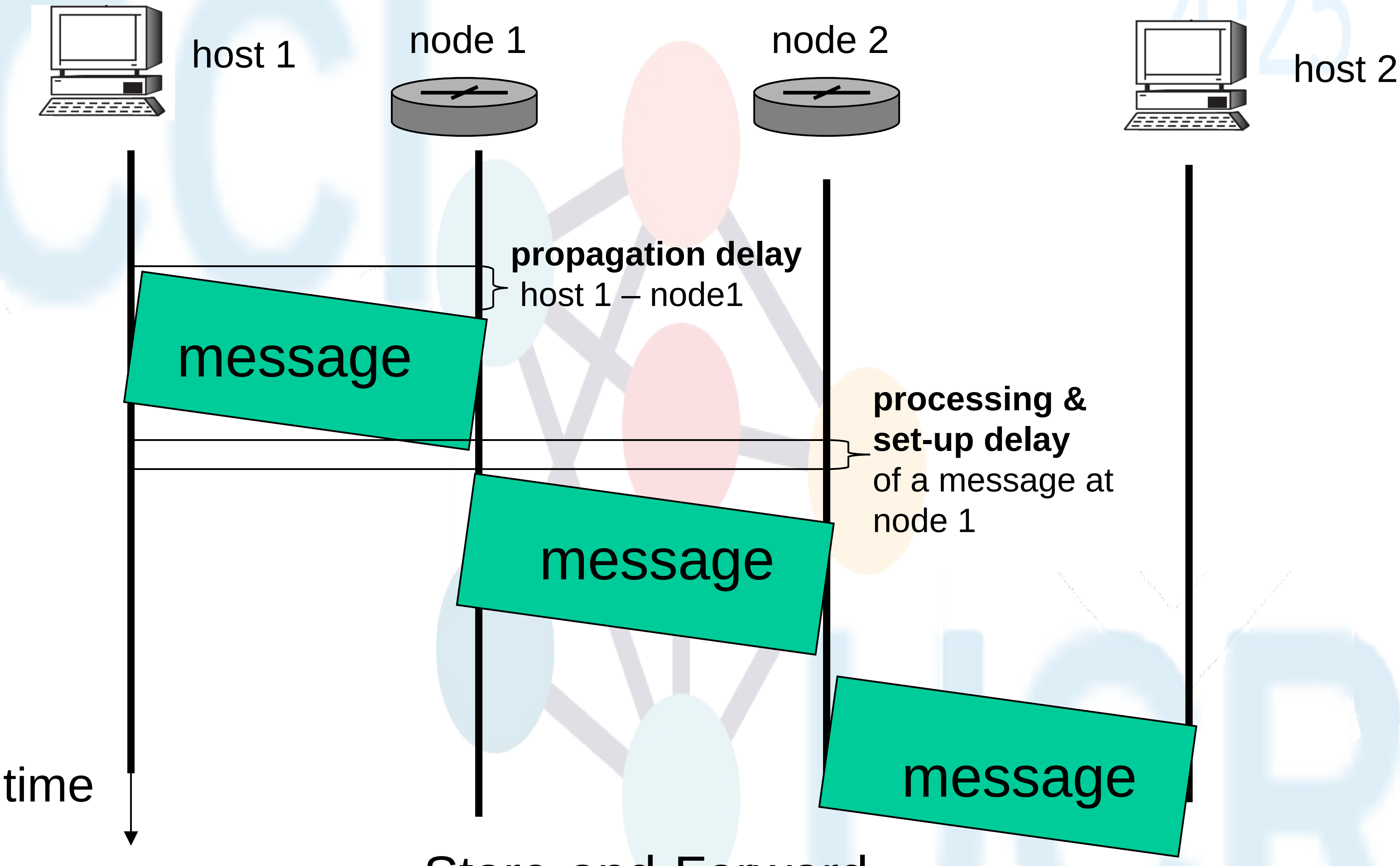
# Packet switching

## Why not message switching?




Store-and-Forward

# Why not message switching?

Message size *M* [bits]

Address info, size *A* [bits]; *A* should be << *M*

Setting up a communication delay *s* [s]

Number of hops *m*

Channel throughput R [bps]

– transmission delay: $m \times \left( s + \frac{(A+M)}{R} \right)$

– bad latency: $(m-1) \times \left( s + \frac{(A+M)}{R} \right)$

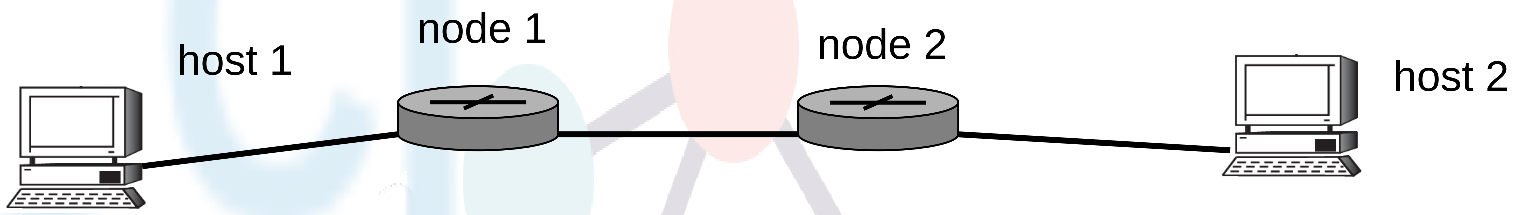
– excessive buffer requirements

*Latency:*

1. The time it takes for a packet to cross a network connection,from sender to receiver.

# Message switching

EXAMPLE




$M$=7.5 Mb

$R$=1.5 Mbps

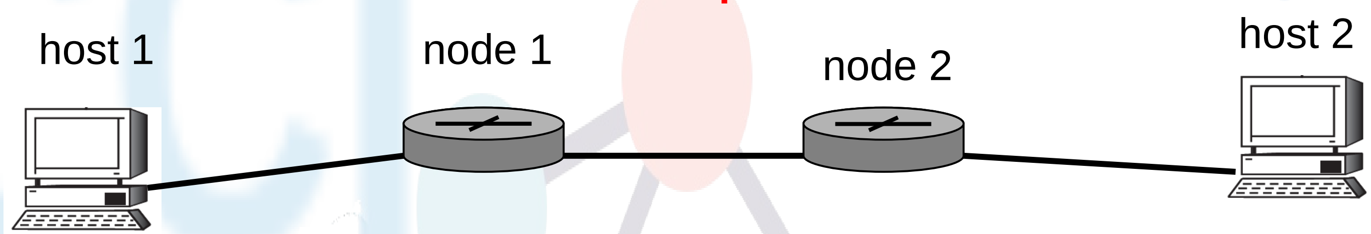
*transmission delay:*

$$3 \cdot \frac{M}{R} = 15[s]$$

*Store complete message and than forward*

# Message switching versus packet switching

## Example

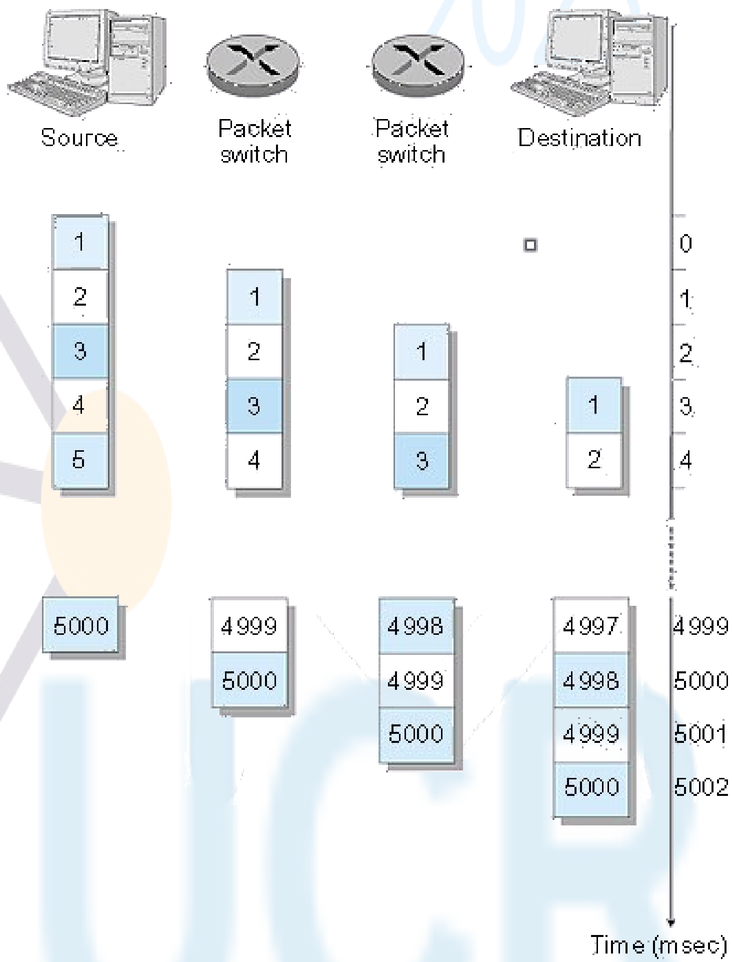



- For simplicity ignore processing and propagation delays
- Split the message into 5000 packets each 1500 bites long
- Store only 1 packet and then forward it

- 1 ms to transmit packet on 1 link
- **Pipelining:** each link works in parallel

- **Delay reduced from 15 s to 5.002 s!!!`**

# Message switching versus packet switching




– transmission delay:

$$(m-1)\times\left(s+\frac{A+P}{R}\right)+\frac{M}{P}\times\left(s+\left(\frac{A+P}{R}\right)\right)$$

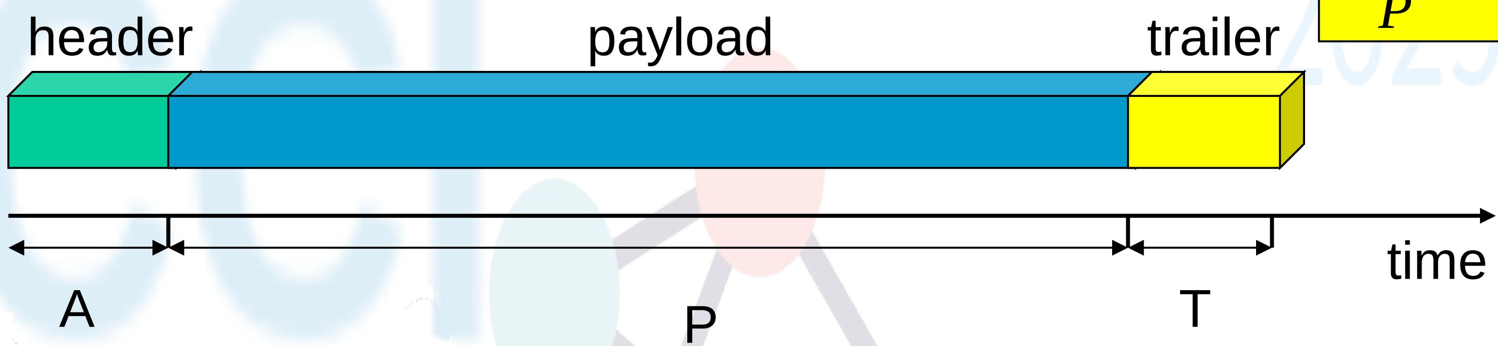
- **Note**: *M+mP  rather than Mm*

– latency:

$$(m-1)\times\left(\frac{A+P}{R}\right)$$

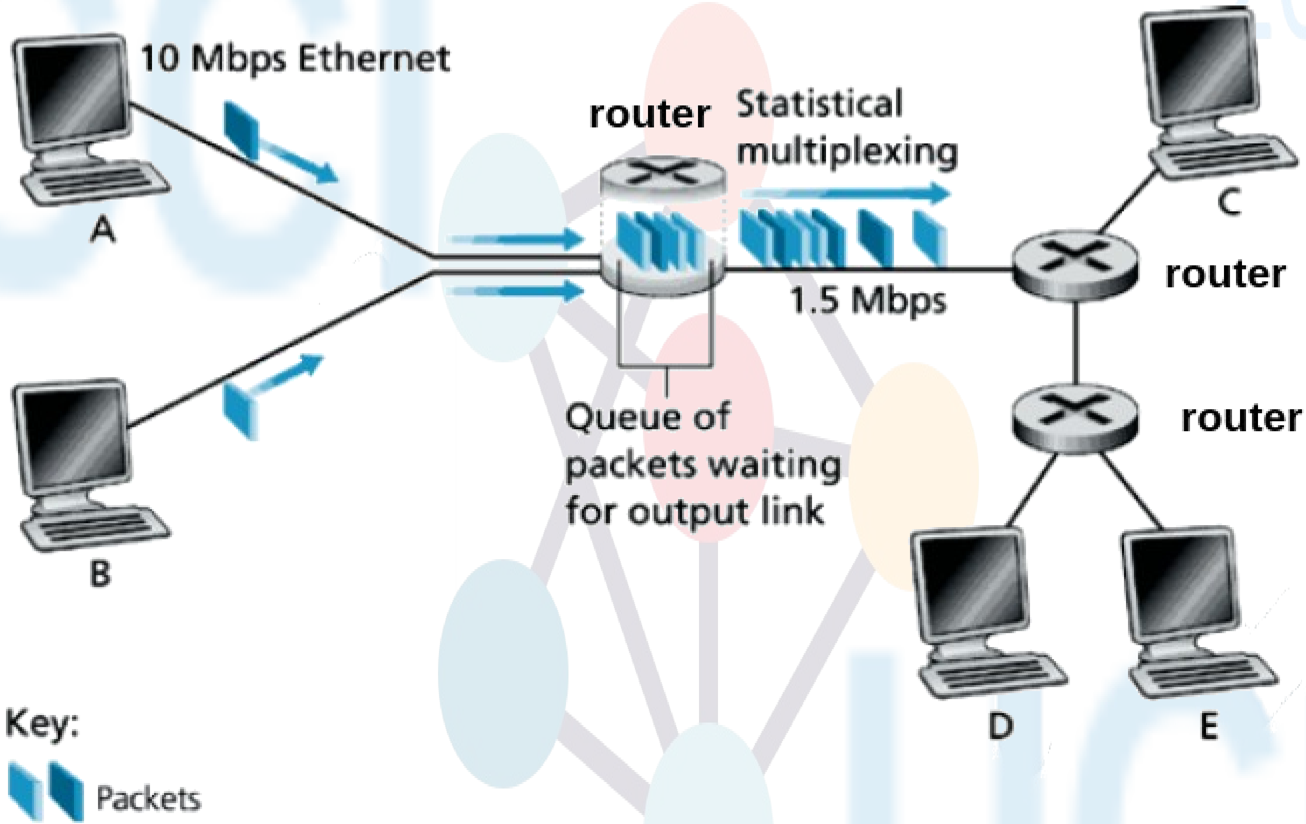
# Packet switching

$$\frac{A+T}{P} << 1$$



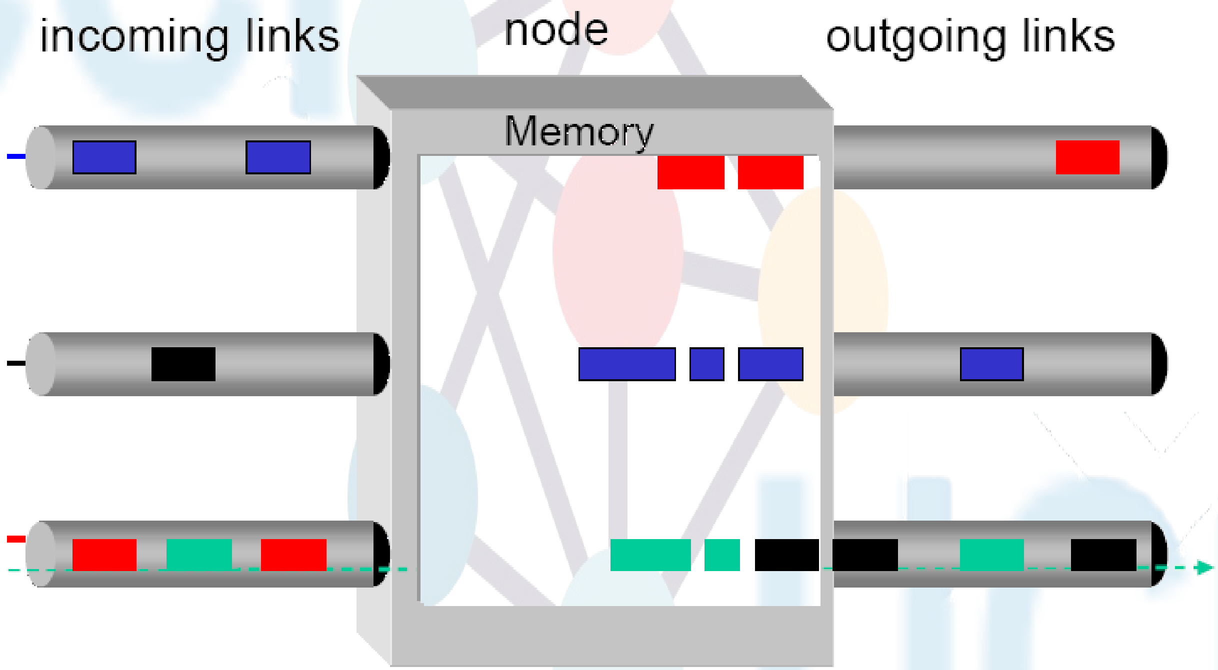

- End-to-end (e2e) data flow transmission divided in packets
- header + trailer carry control information for switching (the source and the final destination addresses, etc.)
- Each packet is transmitted through the network independently from the others. It follows a certain path between the nodes (routers)
- QUESTION: *Where is the control information in circuit switching?*

# Packet switching



# Inside the packet switching router

A node in packet switching network



# Packet switching: resources

1. Each packet waits for its turn at the output link
2. On its turn, a packet uses full link bandwidth
   - Resources used as needed (pro)
   - Aggregate resource demand can exceed amount available (con)

Congestion: packets queue, wait for link use

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# Datagram switching

- Example: IP network (the Internet)
- Each packet (datagram) is switched independently

- Packet header contains a complete destination address
- Receiving a packet, a router looks at the packet's destination address and searches its current routing table to determine the next hop
- Routes may change during session
- Routers do not keep any state about a flow

# Datagram switching

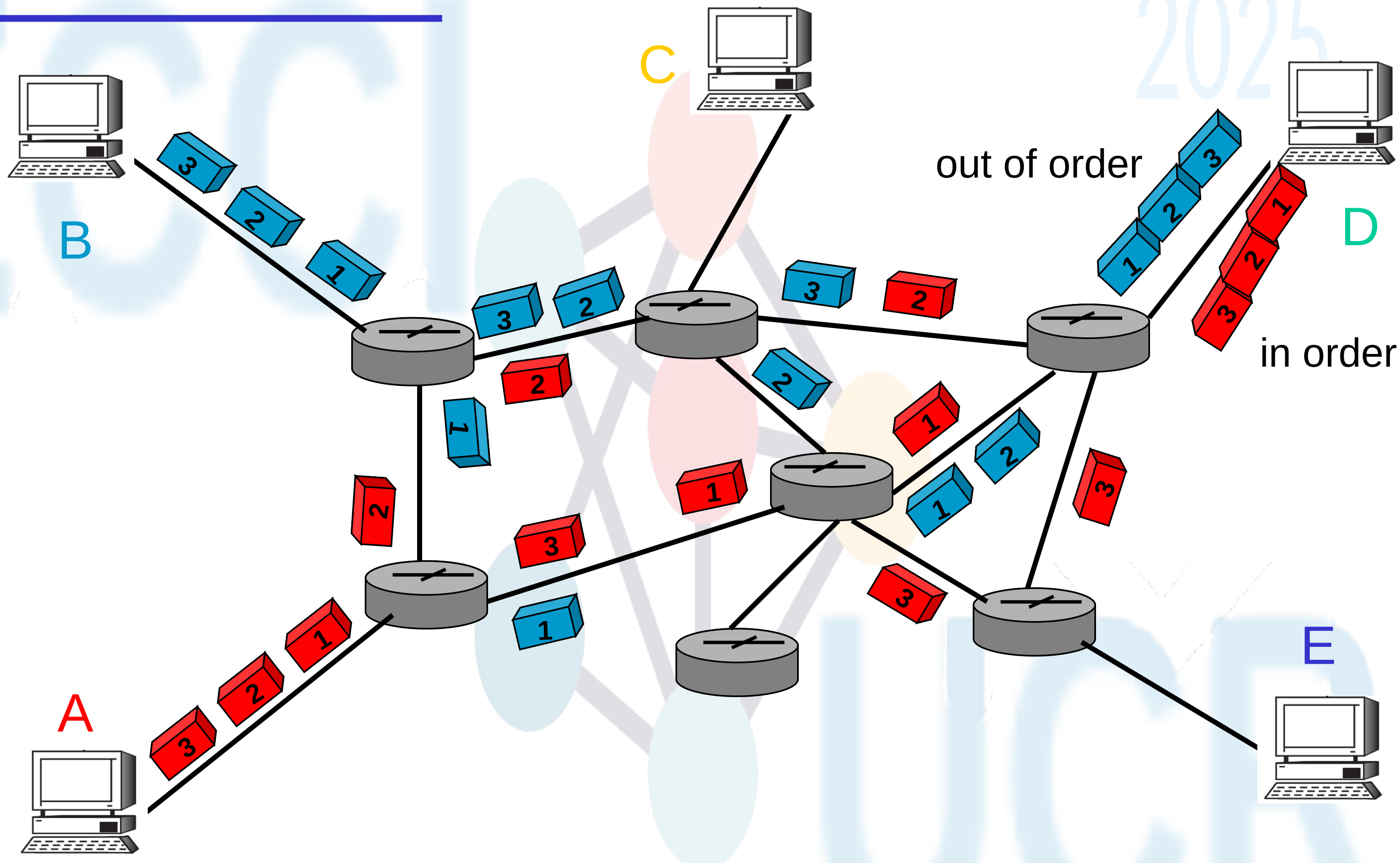
The network nodes process each packet independently

**When host A sends several packets to host B over a datagram packet network, the network cannot tell that the packets belong together. In fact, the packets can take different routes.**

**Implications of datagram packet switching:**

1. A sequence of packets can be received in a different order than it was sent
2. Each packet header must contain the full address of the destination

# Example



# Delays in packet switching networks

A packet experiences delay at each hop

- 4 types of delays at each hop

1. nodal *Processing delay*: checks errors & routing
2. *Queuing delay:* time waiting for its turn at the output link
3. *Transmission delay:* time to pump packet onto a link at a link speed
4. *Propagation delay:* router to router propagation

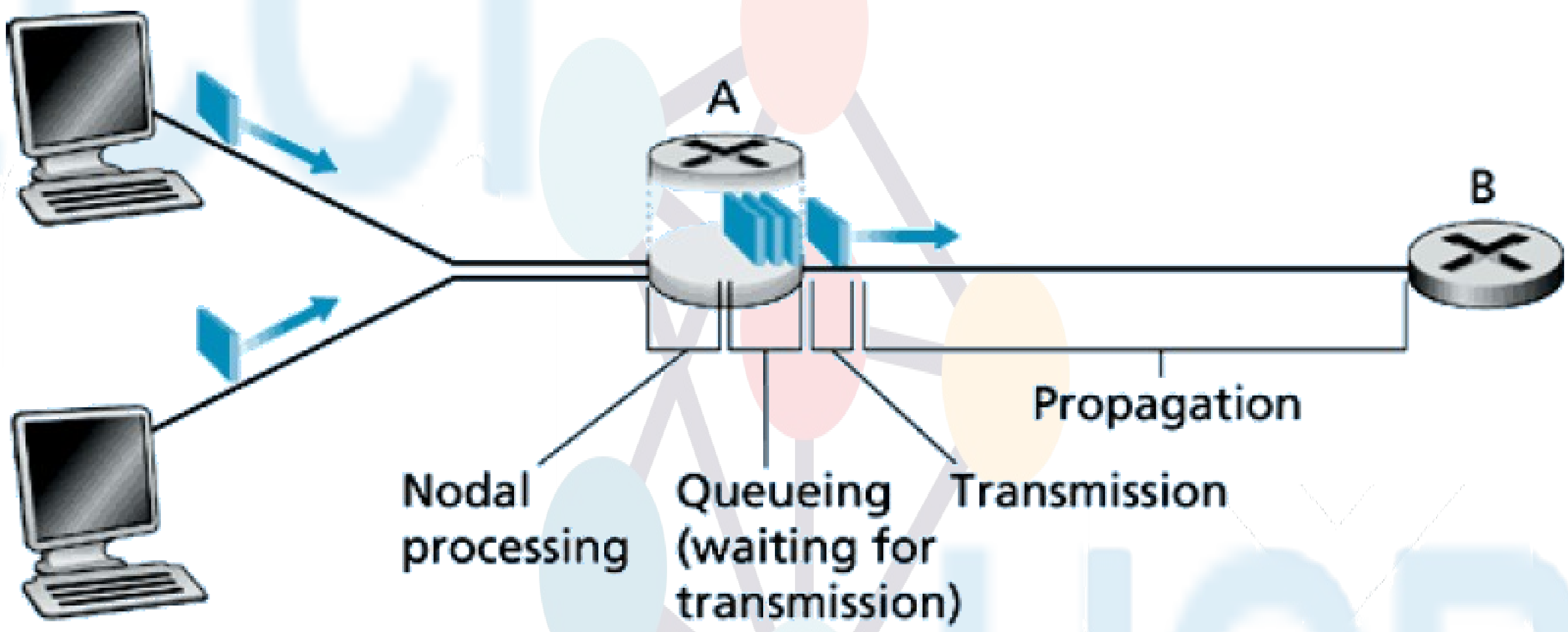
A packet is waiting to be transmitted onto the link

Queuing delay depends on # of packets already waiting in the queue

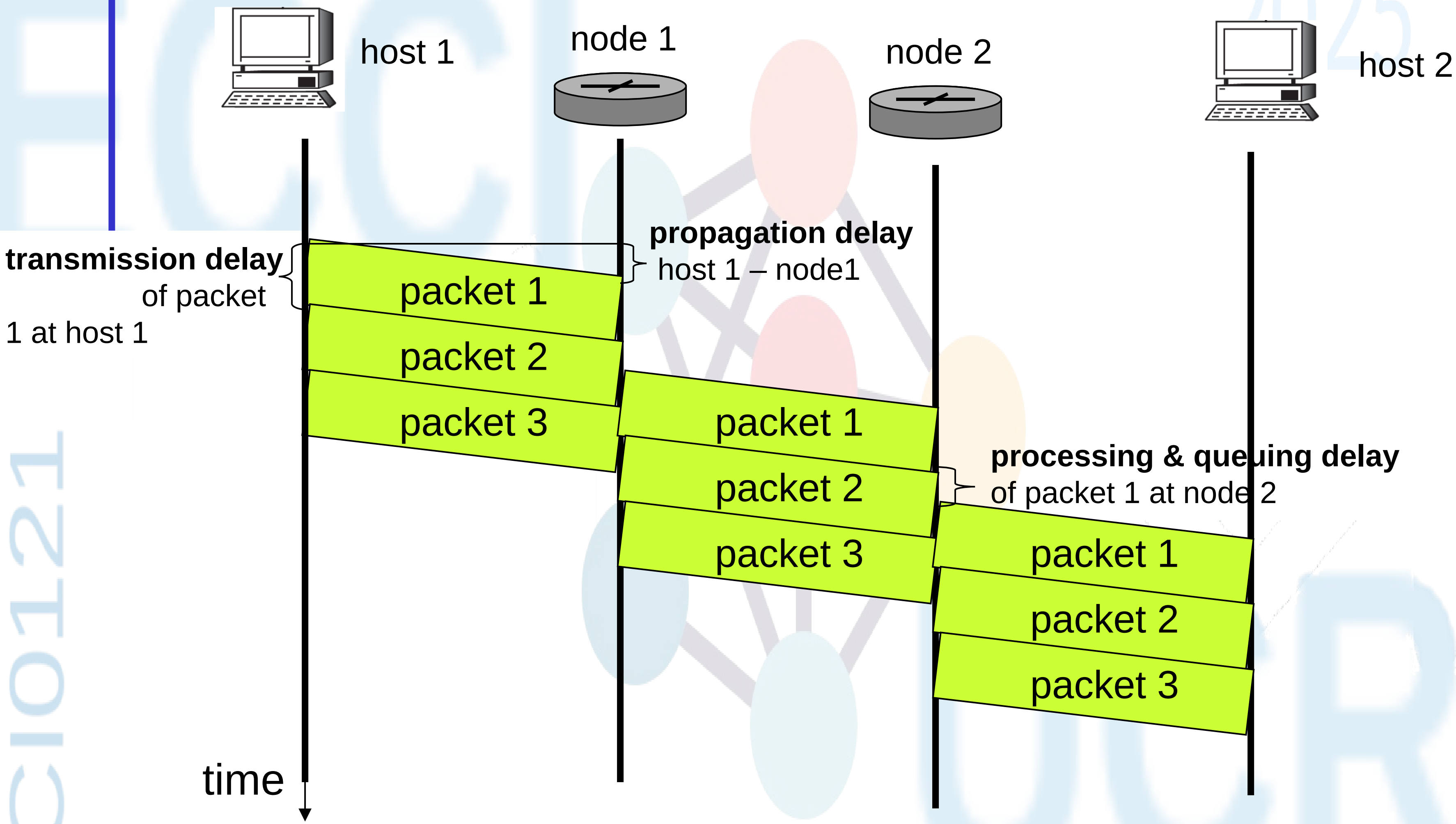
Introduce buffers

- The larger the buffer the larger the # of stored packets
- If the buffer is full than drop the packet

# Delays in packet switching networks



# Delays in datagram networks



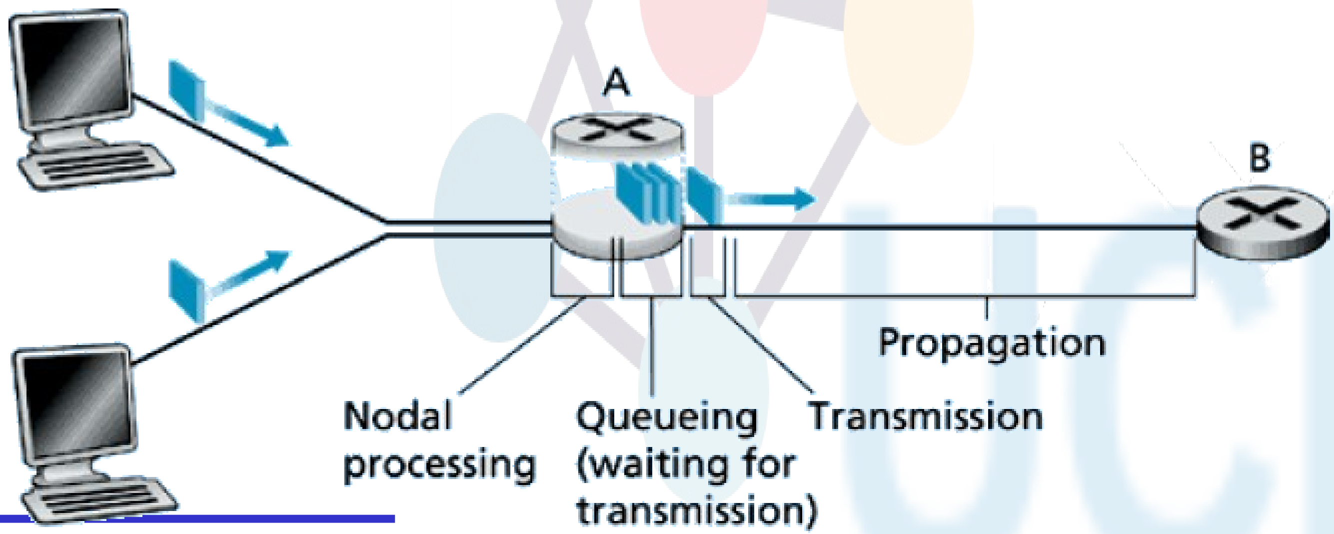
# Delay calculation

R = link bandwidth (bps)

L = packet length (bits)

$\lambda$ = average packet arrival rate (pkt/sec)

L $\lambda$ = average bits arrival rate (b/sec)



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# Virtual circuit networks

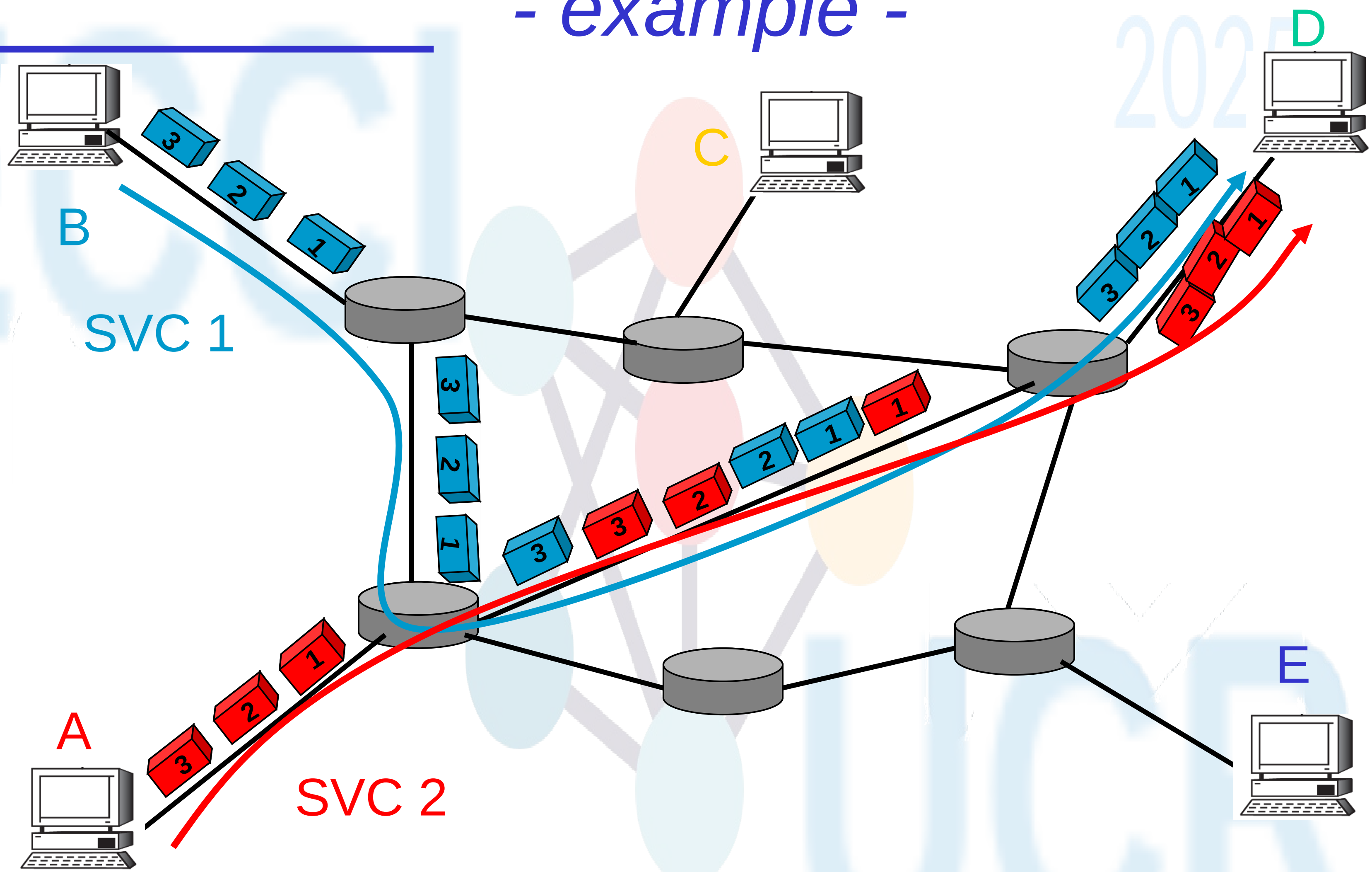
- Combination of *circuit-switched* and *packet-switched* networks
- All the packets are transmitted along the pre-established path

- A switched virtual circuit is a virtual circuit in which a connection session is set up for a user only for the duration of a connection
- The two hosts can communicate *as though* they have a dedicated connection

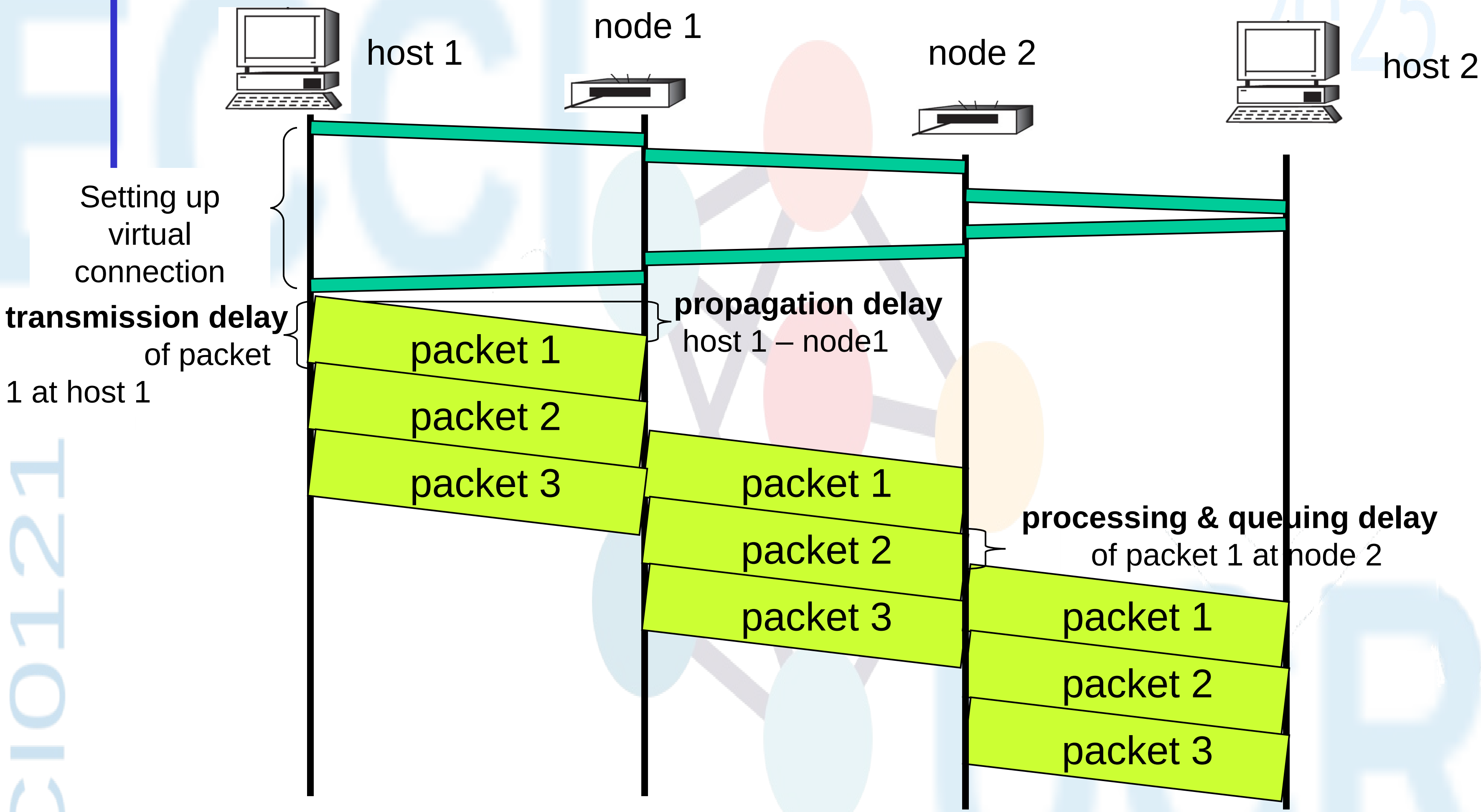
- An example: X.25 connection, Asynchronous Transfer Mode **(ATM)**

- Guarantees in-sequence delivery of packets
- **However**: Packets from different virtual circuits may be interleaved

# Virtual circuit networks
## *- example -*



# Virtual circuit networks
## *- timing diagram -*



# Virtual circuit networks

Note: Packet headers don’t need to contain the full destination address of the packet - only contain *virtual circuit identifier* (VCI)

# Packet switching vs. circuit switching

Packet switching allows more users to use network!

**1 Mb link**

- each user:
  - 100 kbps when “active”
  - active 10% of time
- circuit-switching:
  - 10 users
- packet switching:
  - with 35 users, probability > 10 active less than .0004

# Packet switching versus circuit switching (cnt'd)

- **Advantages** of packet switching over circuit switching
  - Statistical multiplexing, and therefore efficient bandwidth usage
  - Simple to implement

- **Disadvantages** of packet switching over circ. switching
  - Excessive congestion: packet delay and high loss
  - Protocols needed for reliable data transfer, congestion control
  - Packet header overhead
  - Provides no transparency to a user
    - Analogy: a road versus a railroad

# The Internet versus ATM

## The Internet

- data exchange among computers
- no strict timing requirements
- “smart” end systems (computers)
- can adapt, perform control, error recovery
- simple inside network, complexity at “the edge”

## ATM

- evolved from telephony
- human conversation:
  - strict timing
  - reliability requirements
- need for guaranteed service
- “dumb” end systems
  - telephones
    - complexity inside network

# A reminder

## Bandwidth

**1.** telecommunications: **range of radio frequencies:** a range of radio frequencies used in radio or telecommunications transmission and reception

**2.** computing: **communications capacity:** the capacity of a communications channel, for example, a connection to the Internet, often measured in bits per second

3. a data transmission rate; the maximum amount of information (bits/second) that can be transmitted along a channel

## Latency

A synonym for *delay,* is an expression of how much time it takes for a *packet* of data to get from one designated point to another (single transaction).

The contributors to network latency include:

1. propagation
2. transmission
3. node processing
4. queuing

Where is latency important ?

Example:

internet interactive games

video conferencing

# Bandwidth-Latency

*Telephone modems*

9 600 bps: smaller bandwidth, lower latency

56 000 bps: larger bandwidth, higher latency

more complex modulation techniques require longer processing time

QUESTION:

For downloading large files what is more important
1. larger bandwidth, or
2. smaller latency?

# Homework assignment

- A server sends 1024 Mb of data to a client over a 16.4 Mbps link with 2.5% of packet loss.  The server sends the data in packets of 8 Mb and after sending a packet awaits to receive an acknowledgment packet of 8 bytes from the client before sending the next packet. If it takes 10 minutes to complete the transfer of data, determine the **latency** of the link.

- Explain the logic behind the phrase:

  "You can buy more bandwidth, but you cannot buy less delay."
  Exemplify and motivate your answer.

- Compare *Datagram* to the *Virtual Circuit* networks with respect to:
  - circuit setup; addressing scheme; routing; router failure; Quality of Service;

# Homework assignment (cnt'd)

Calculate the total delay to transfer a 10 Mb file from the host 1 to the host 2 (from the beginning until the host 2 receives the last bit of the file) using circuit switching, message switching and datagram switching networks. Datagram size is 75 kb. The following is known:

The *distance* between the two hosts is 2000 km.

There are 3 routers (nodes) at the same distance in between the hosts.

*Propagation speed* is 200 000 km/s.

Transmission *bandwidth* is 1 Mbps.

Node *processing delay* is 100 ms.

Neglect processing delays in hosts.

Comment on the obtained results.