

Computer Networks and the Internet



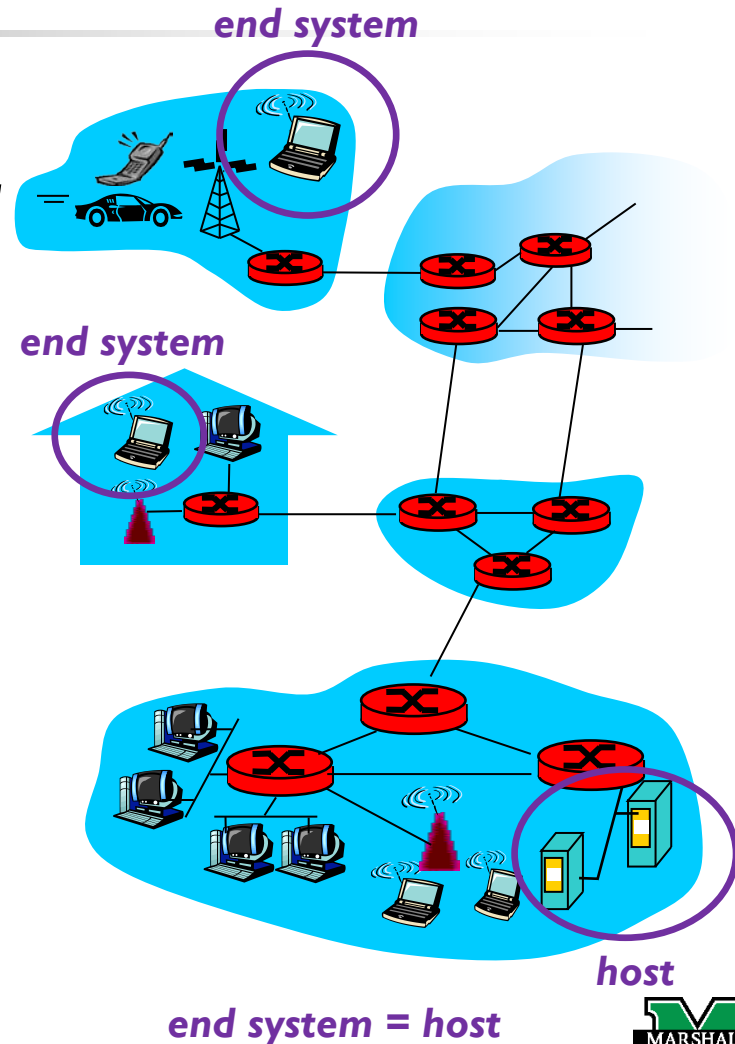
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Lecture 02

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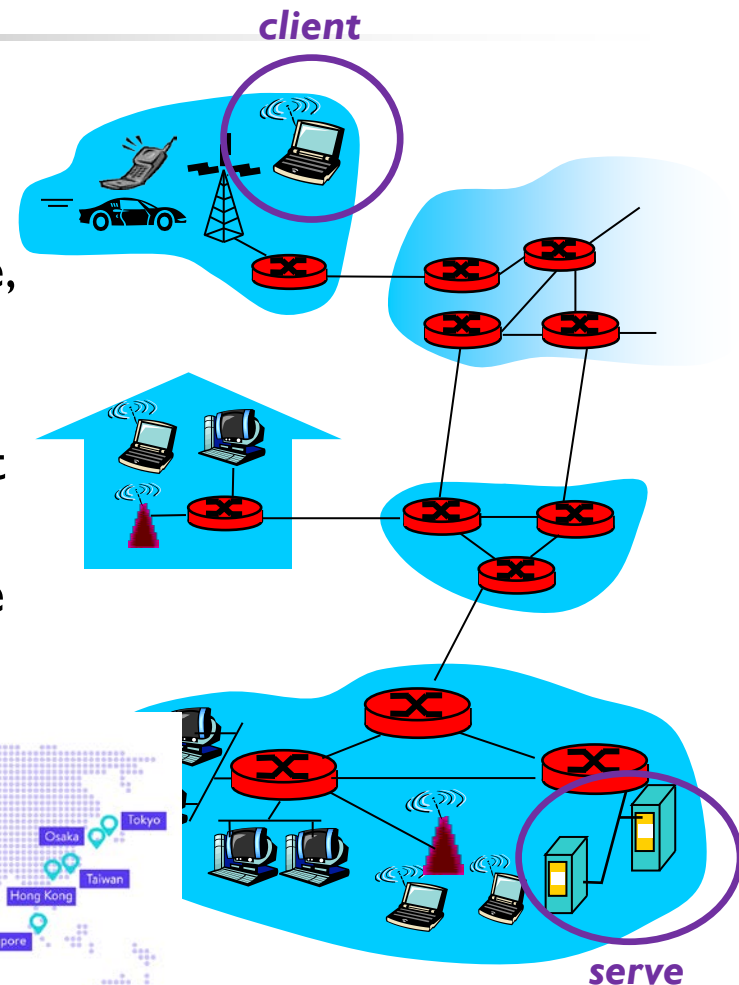
Network Edge

- Computers and other devices connected to the Internet = **end systems**
 - sit at the edge of the Internet
 - including
 - desktop computers
 - servers
 - mobile computers
 - more...
- end system also = hosts
 - because they host application programs
 - web browser program
 - web server program
 - email client and server program



Network Edge

- Hosts can be further divided into
 - **clients**
 - desktop, mobile PC, smartphone, etc
 - **servers**
 - more powerful machine that store and distribute information
- Most of the servers reside in large **data centers**

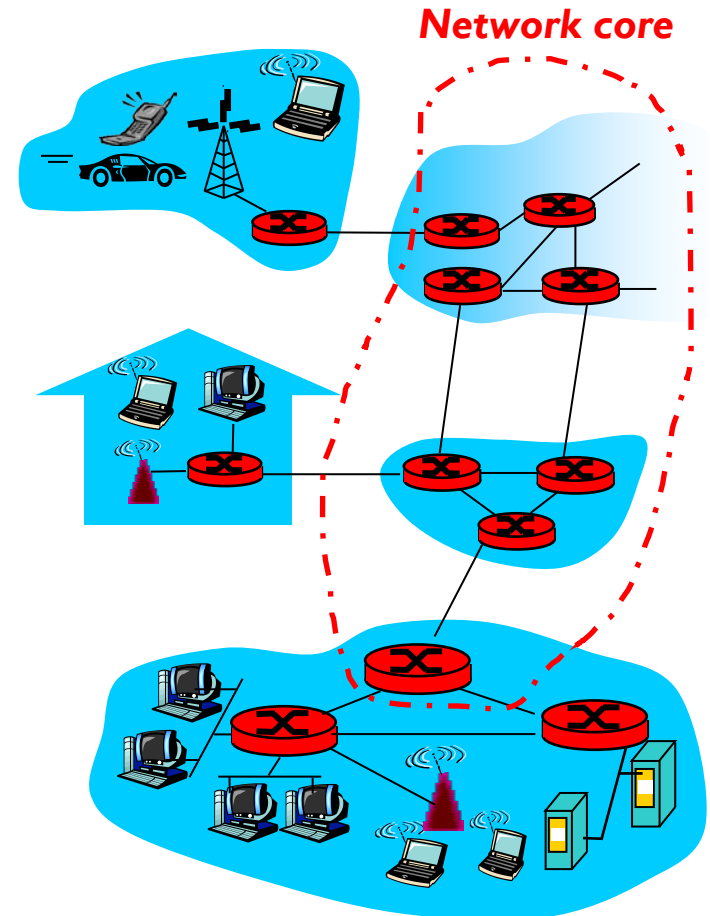


Google data center in Singapore



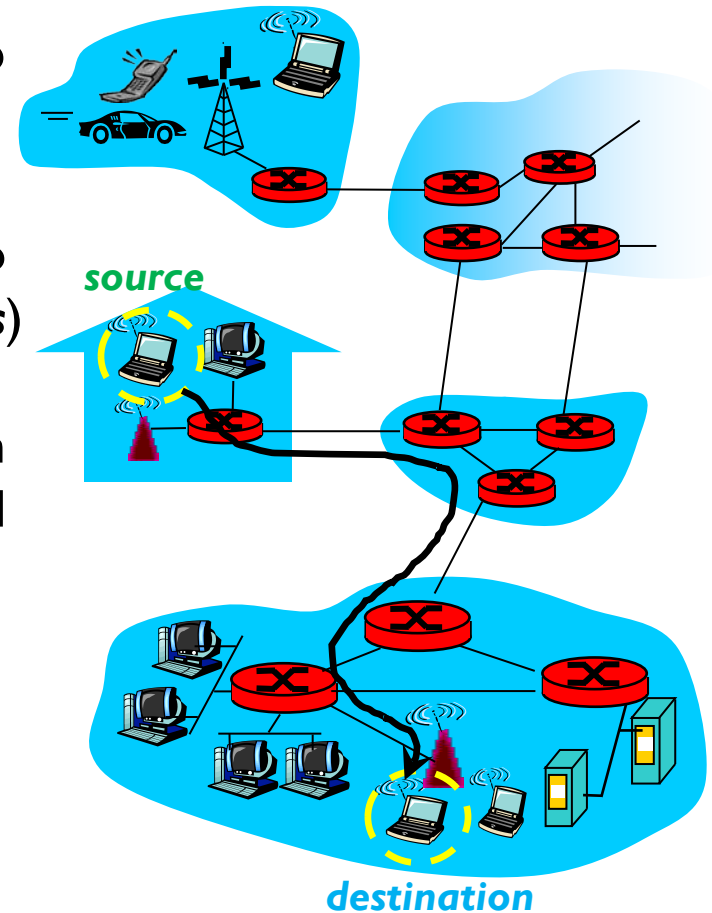
Network Core

- Network core
 - the mesh of **packet switches** and **links** that interconnects the Internet's end systems
- In a network application
 - end systems exchange messages
 - messages can contain anything
 - perform control function
 - contain data



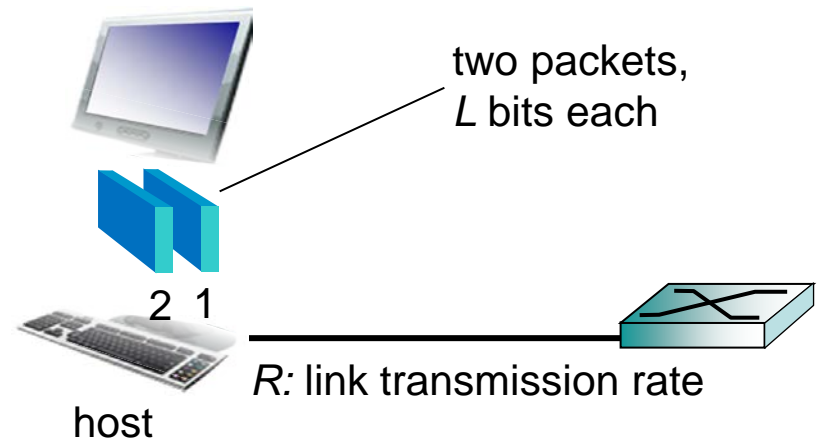
Network Core

- To send a message from source to destination
 - source
 - breaks long messages into smaller chunks of data (**packets**)
 - between source and destination
 - each packet travels through **communication links** and **packet switches**



Network Core

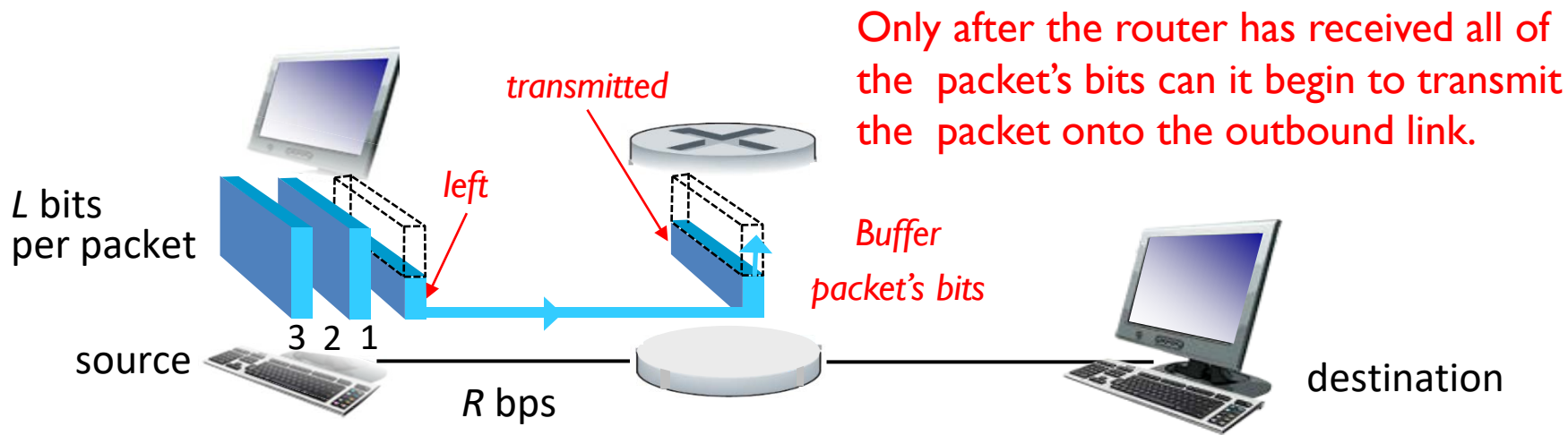
- Packet are transmitted over each communication link at a rate equal to the full transmission rate of the link
 - if a packet has L bits, transmitted over a link with transmission rate R bit/sec
 - then, the time to transmit the packet is L/R seconds



$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

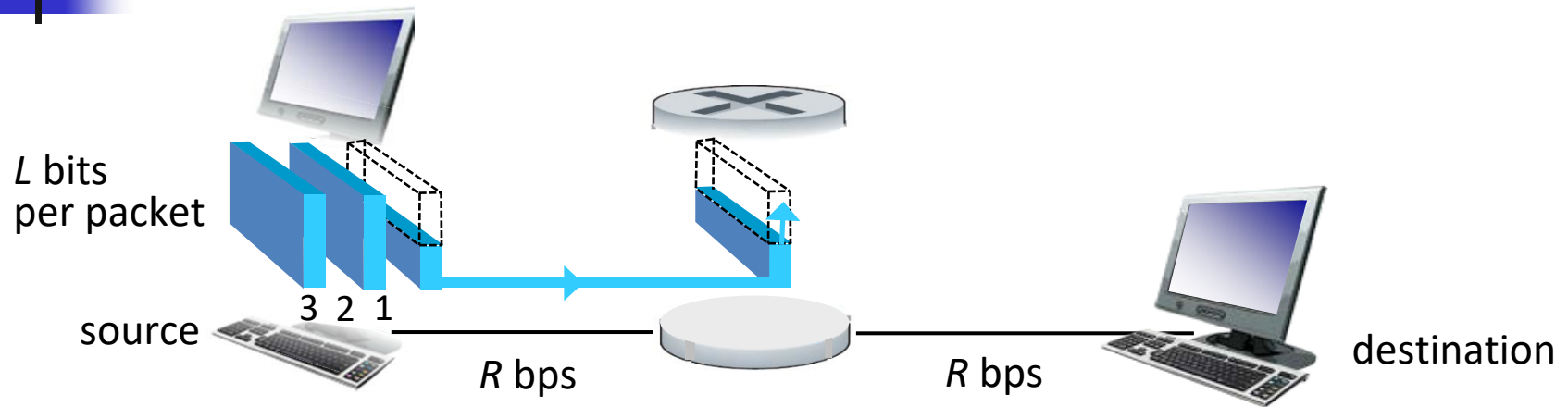
Store-and-Forward Transmission

- Most packet switches use ***Store-and-Forward Transmission*** at the inputs to the links.
 - the packet switch must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link



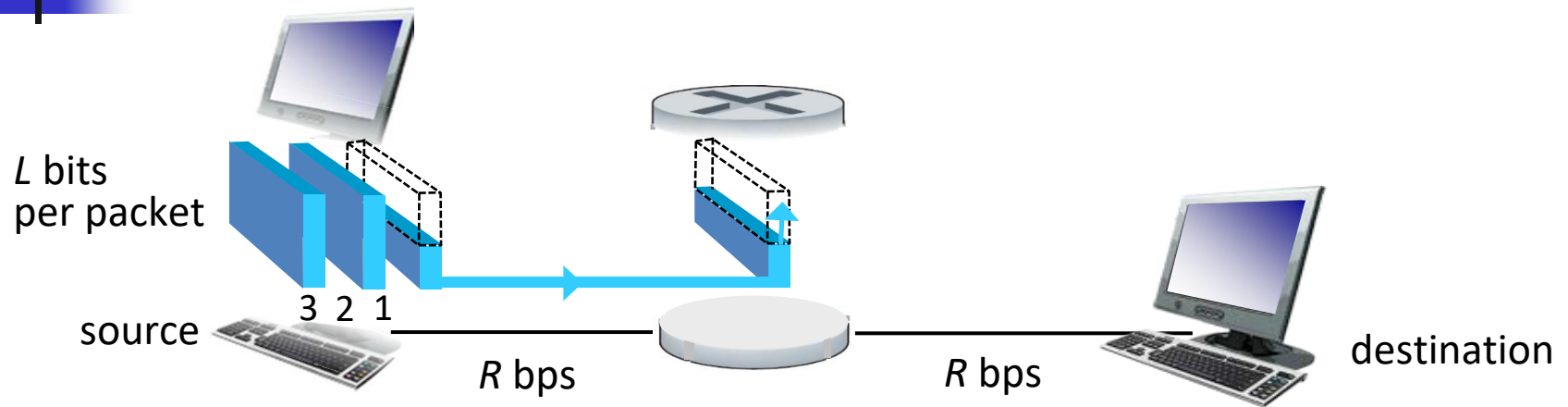
A router typically have many incident links, transferring a packet from one (incoming) link to one (outgoing) link.

Packet Switching: Store-and-Forward



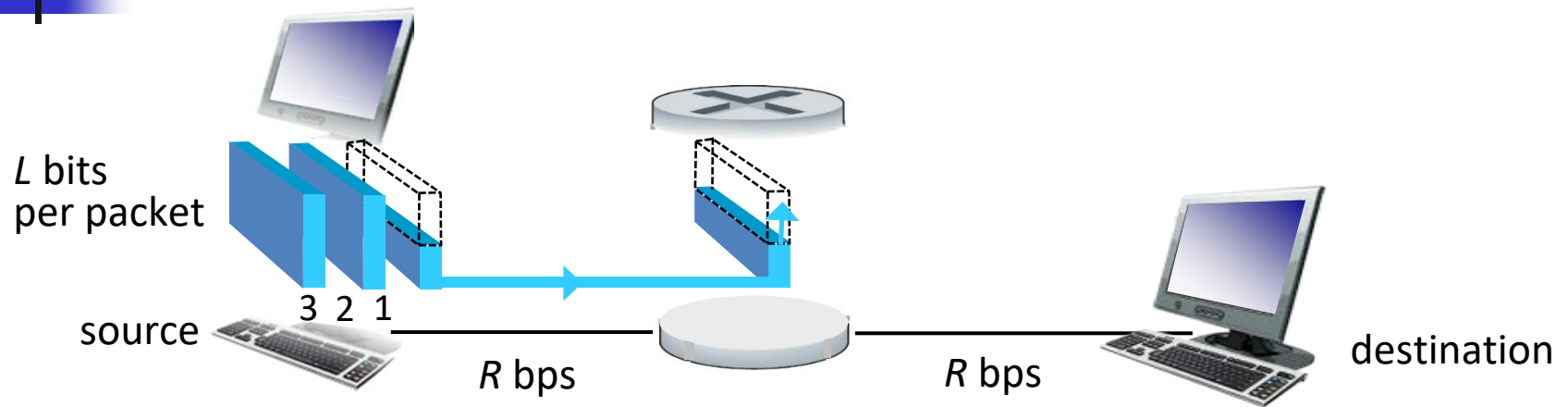
- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
 - *store and forward*: entire packet must arrive at router before it can be transmitted on next link
 - delay that destination receives the entire packet
 - $2L/R$ (assuming zero propagation delay)
- Example:**
- $L = 7.5$ Mbits
 - $R = 1.5$ Mbps
 - transmission delay = 10 sec

Packet Switching: Store-and-Forward



- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- *store and forward*: entire packet must arrive at router before it can be transmitted on next link
- **delay to receive all three packets**
 - $4L/R$

Packet Switching: Store-and-Forward



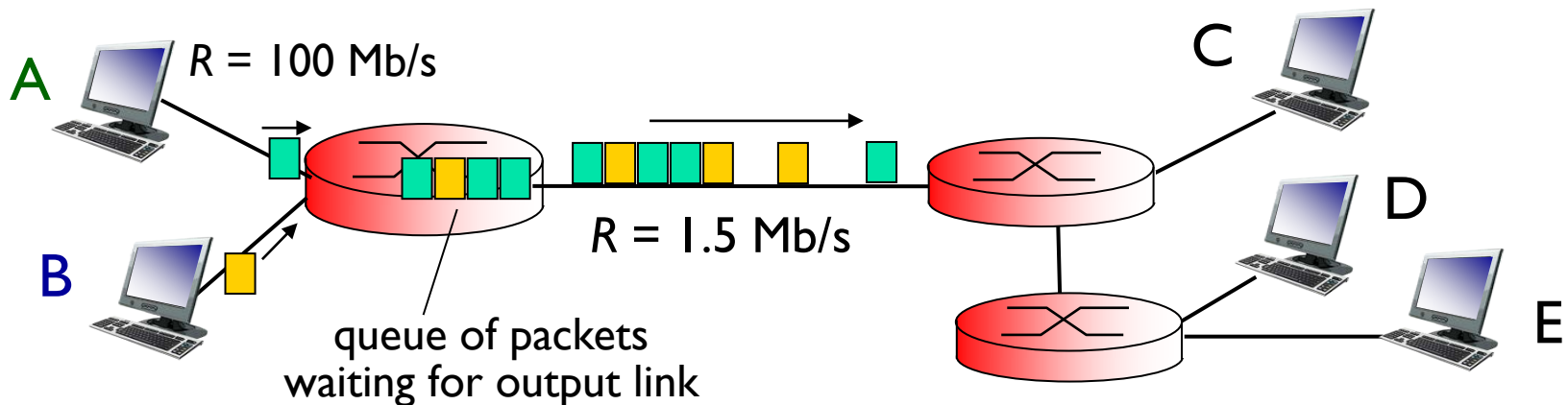
- sending one packet from source to destination over a path consisting of **N** links each of rate R
- the end-to-end delay is: $d_{\text{end-to-end}} = N \frac{L}{R}$



Packet Switching: Queueing Delay and Packet Loss

- Packet switch has multiple links
 - **output buffer** (also called an *output queue*) for each attached link
 - stores packets that the router is about to send into that link
 - If the link busy with the transmission of another packet?
 - packet must **wait** in the output buffer
- In addition to store-and-forward delay, there is an output buffer **queuing delays**
 - these delays are variable and depend on the level of congestion in the network
- The amount of buffer space is **limited**
 - if the buffer is completely full when packet arrives
 - **packet loss**
 - either the arriving packet or one of the already-queued packets will be **dropped**

Packet Switching: Queueing Delay and Packet Loss



queuing and loss:

- ❖ If arrival rate of packets exceeds transmission rate of link (1.5 Mb/s) for a period of time:
 - congestion will occur at the router as
 - packets will be queued in the buffer, wait to be transmitted on link
 - packets can be dropped (lost) if memory (buffer) fills up



Two Key Network-core Functions

- A router takes a packet arriving on one of its attached communication links and forwards that packet onto another one of its attached communication links.
- But how does the router determine which link it should forward the packet onto?
 - Packet forwarding



Two Key Network-core Functions

- Every end system has an address called an IP address.
- When a source end system sends a packet to a destination end system
 - put destination's IP address in the packet's header
 - IP address “=” postal address
 - hierarchical structure
- When a packet arrives at a router
 - examines packet's destination address
 - forwards the packet to an adjacent router
 - **forwarding table**: maps destination addresses to that router's outbound links

When a packet arrives at a router, the router examines the address and searches its forwarding table, using this destination address, to find the appropriate outbound link.



Two Key Network-core Functions

- The end-to-end routing process is analogous to a car driver who does not use maps but instead prefers to ask for directions.
 - Suppose Joe is driving from New York City to 156 Lakeside Drive in Orlando (FL)
 - Joe first drives to point A, where the people tell Joe that he needs to get to point B.
 - So Joe drives to point B, where the people tell Joe that he needs to get to point C.
 - So Joe
 - So Joe drives to point x, where the people tell Joe that he just drives 1 miles east and he will reach 156 Lakeside Drive in Orlando (FL).



Two Key Network-core Functions

- How do forwarding tables get set?
- **routing protocols:** automatically set the forwarding tables
 - E.g., shortest path routing protocol
 - determine the shortest path from each router to each destination and use the shortest path results to configure the forwarding tables in the routers.

Two Key Network-core Functions

routing: determines source-destination route taken by packets

- *routing algorithms*

forwarding: move packets from router's input to appropriate router output

