Computer Networks and the Internet

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Lecture 02

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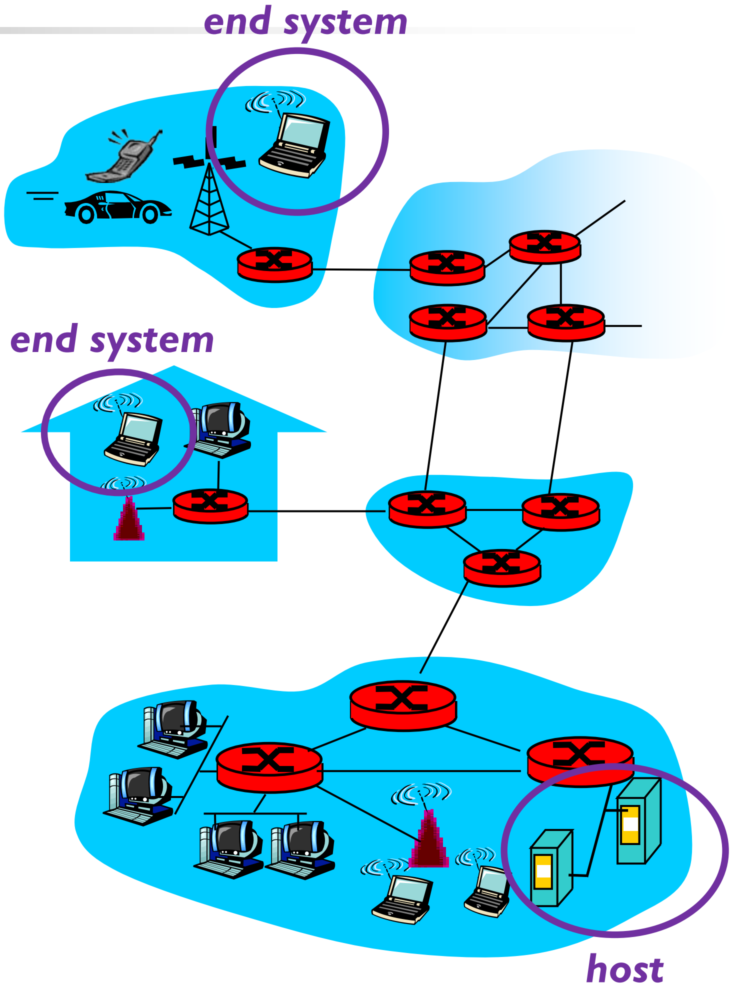
Network Edge

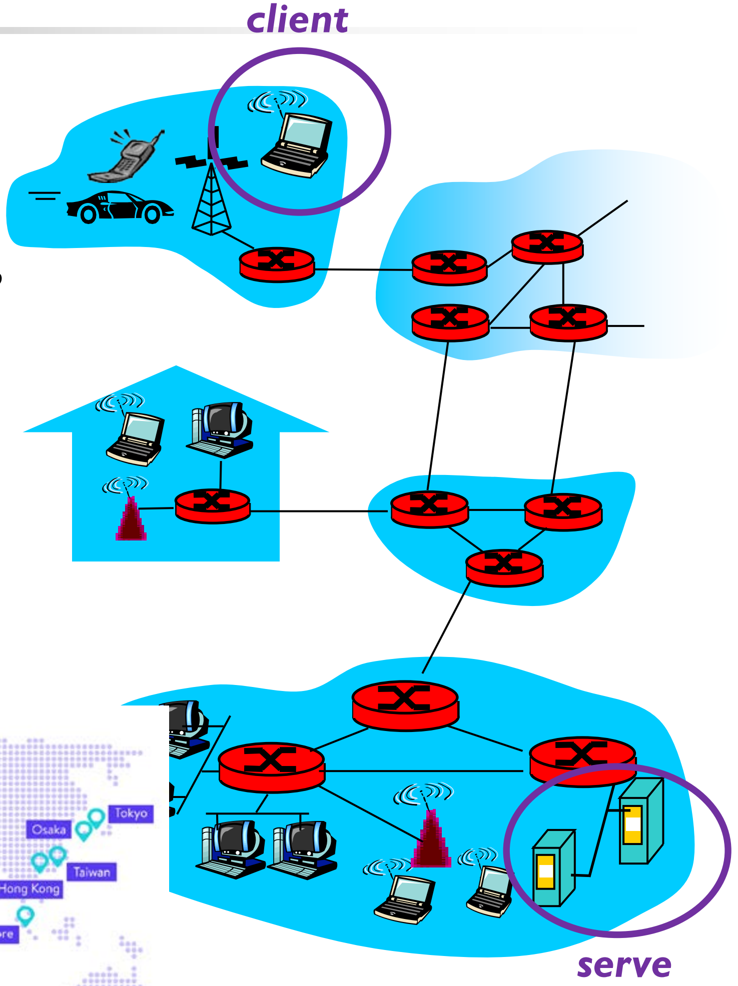
- Computers and other devices connected to the Internet = ***end systems***
  - sit at the edge of the Internet
  - including
    - desktop computers
    - servers
    - mobile computers
    - more…
- end system also = hosts
  - because they host application programs
    - web browser program
    - web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



end system = host

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**

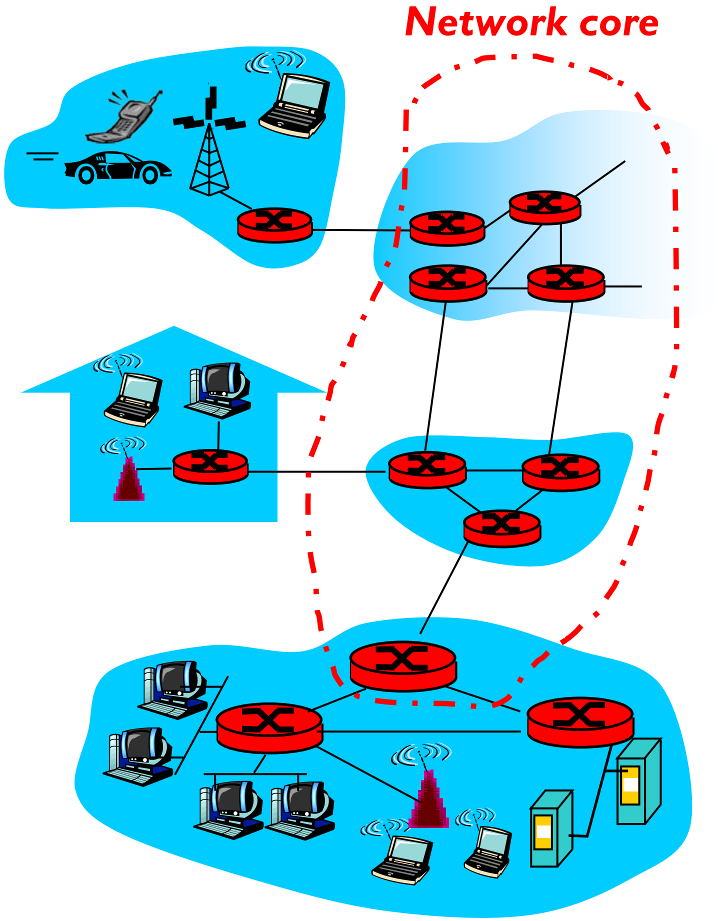


Google data center in Singapore

Oregon
Iowa
Montréal
N Virginia
S Carolina
Los Angeles
London
Netherlands
Hamina
Belgium
Frankfurt
Zürich
Mumbai
Singapore
Hong Kong
Taiwan
Osaka
Tokyo
Sydney
São Paulo
Kinsta
Google Cloud Platform

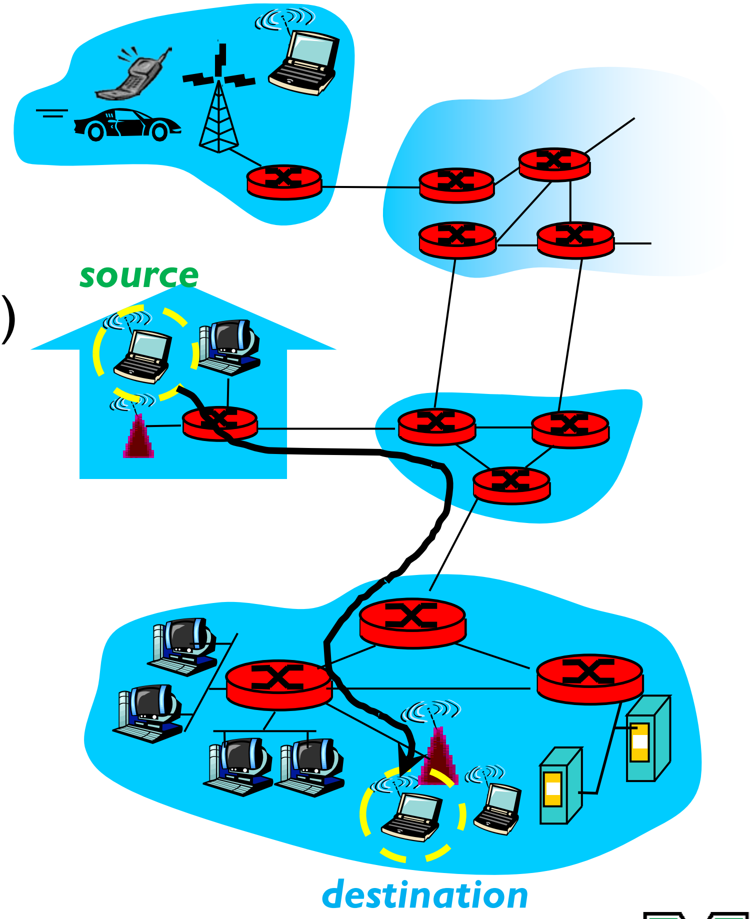
Network Core

- 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



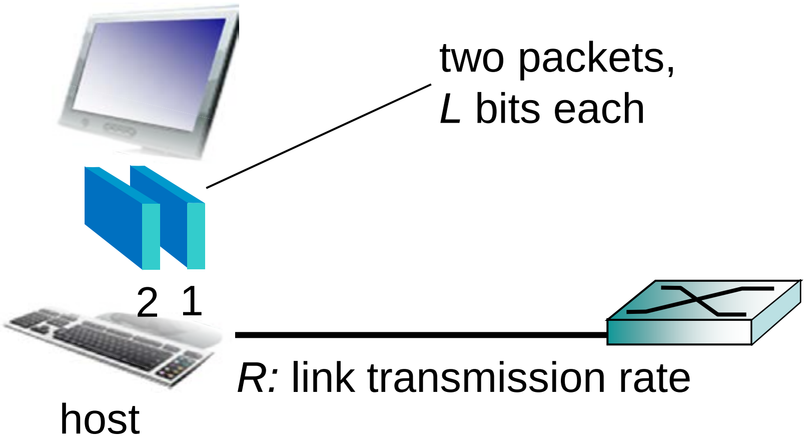
Network Core

- 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

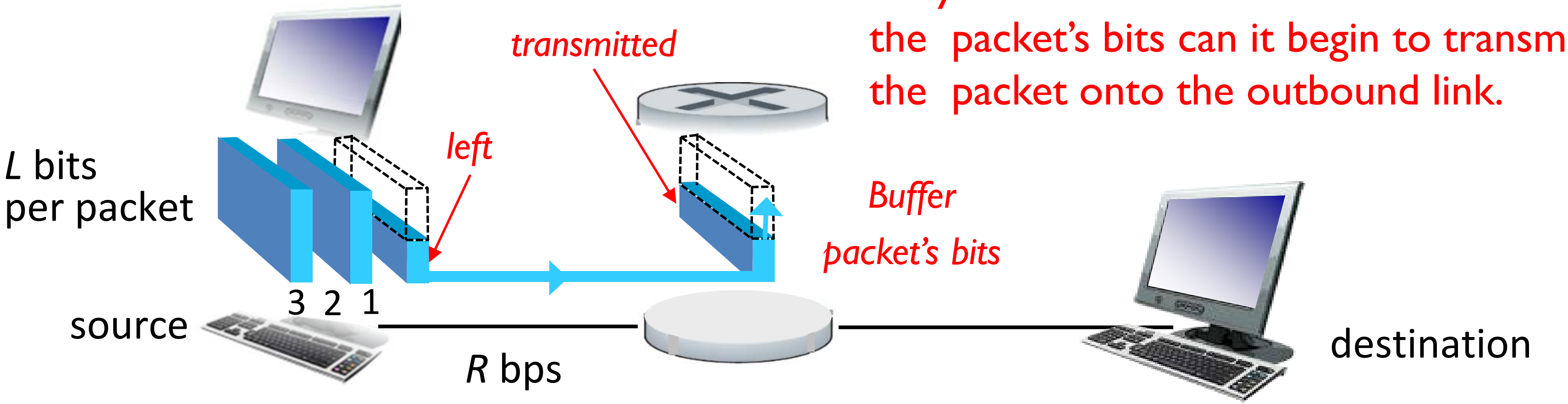
- Packet are transmitted over each communication link at a rate equal to the full transmission rate of the link
  - if a packet has ***L*** bits, transmitted over a link with transmission rate ***R*** bit/sec
  - then, the time to transmit the packet is ***L/R*** seconds



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

Store-and-Forward Transmission

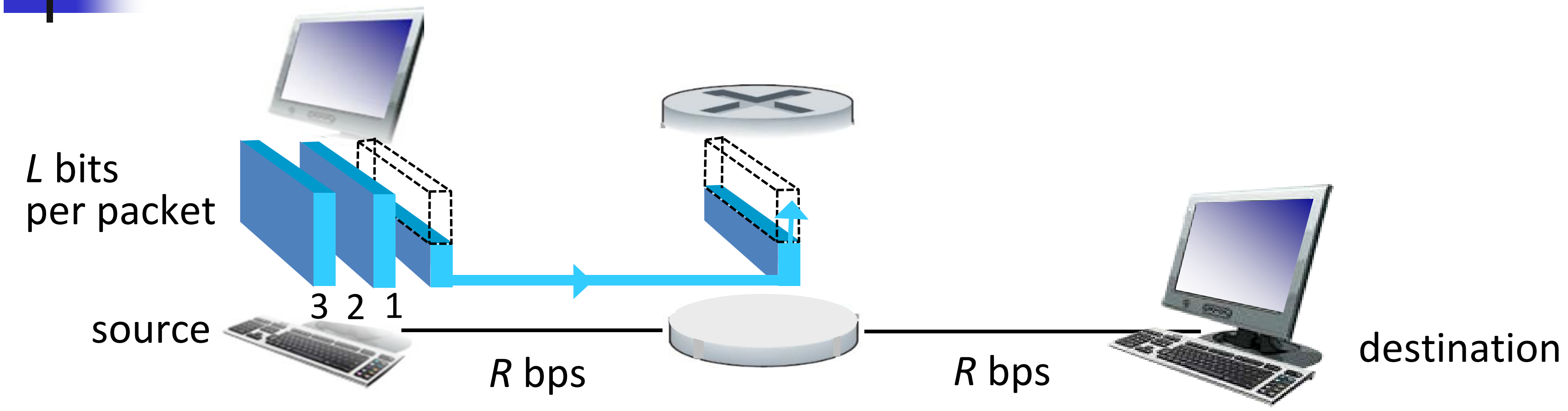
- Most packet switches use ***Store-and-Forward Transmission*** at the inputs to the links.
  - **the packet switch must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link**



Only after the router has received all of the packet's bits can it begin to transmit 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

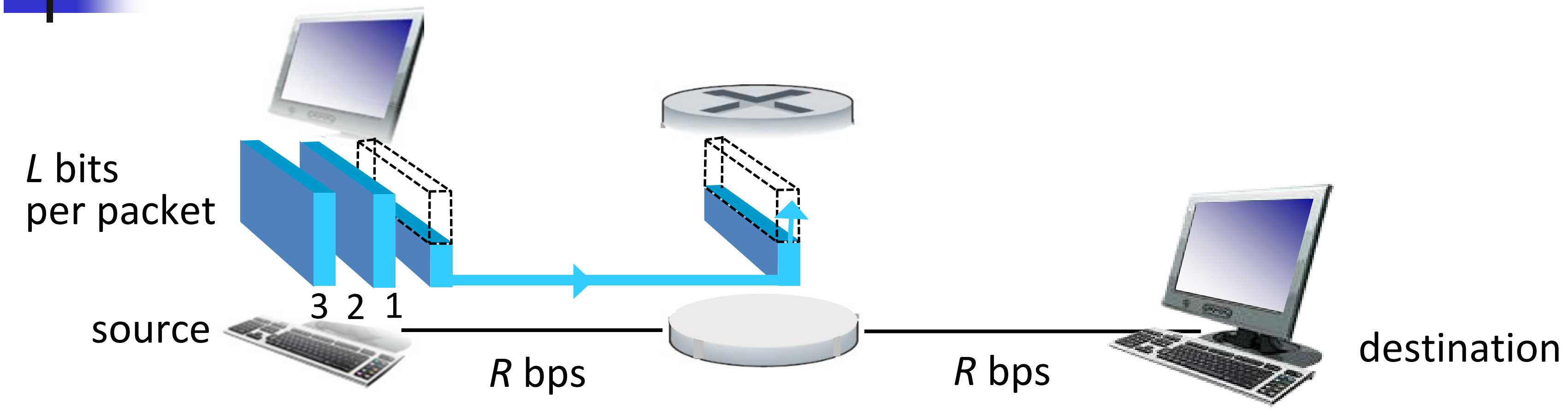


- takes L/R seconds to transmit (push out) packet of L bits on to link at R bps
- *store and forward:* entire packet must arrive at router before it can be transmitted on next link
- delay that destination receives the entire packet
  - 2L/R (assuming zero propagation delay)

Example:

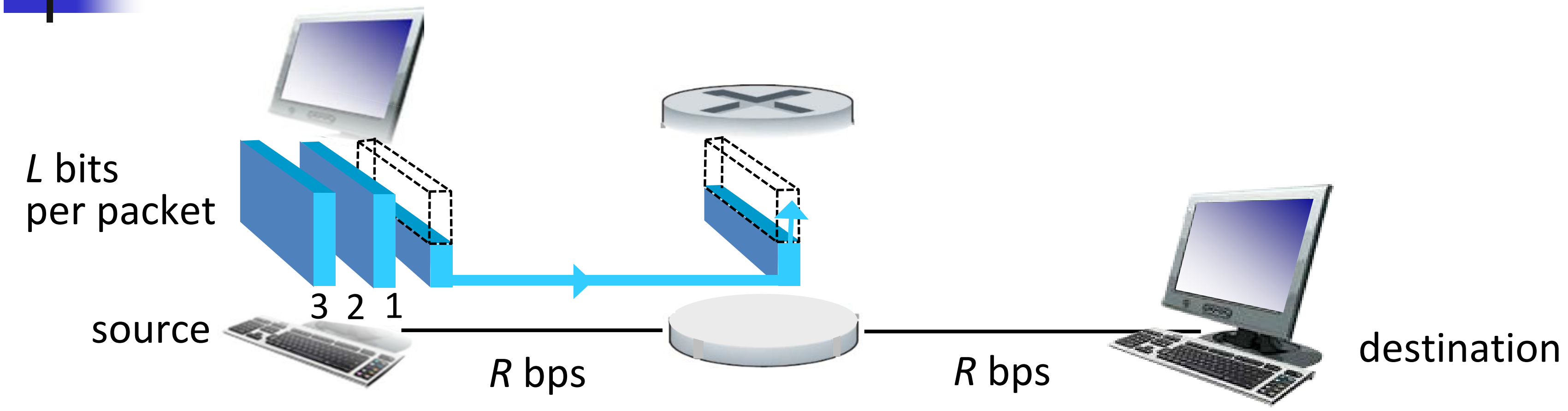
- L = 7.5 Mbits
- R = 1.5 Mbps
- transmission delay = 10 sec

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



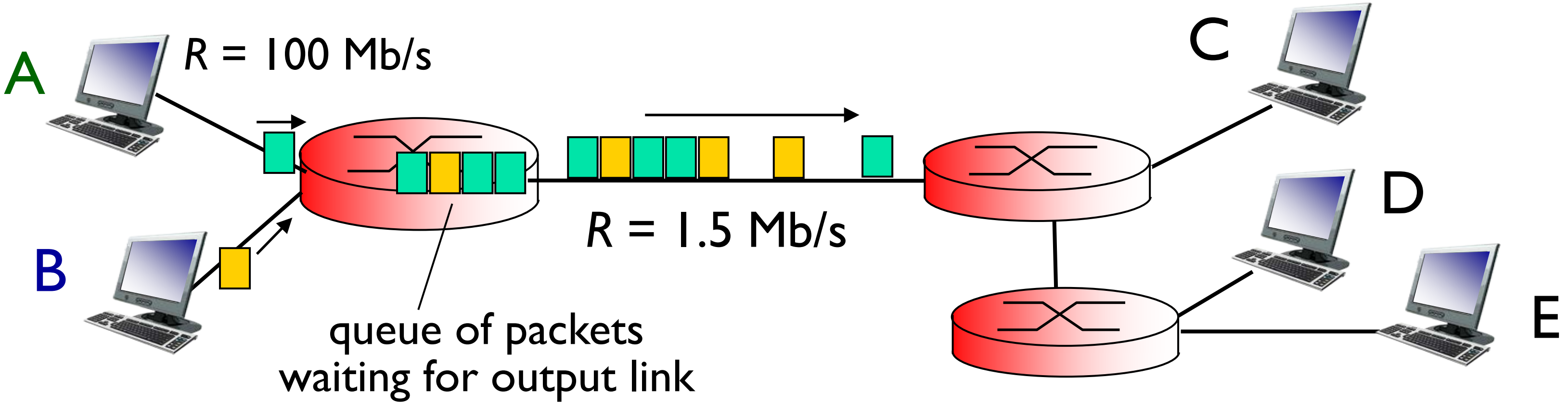
- sending one packet from source to destination over a path consisting of **N** links each of rate R

- 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?

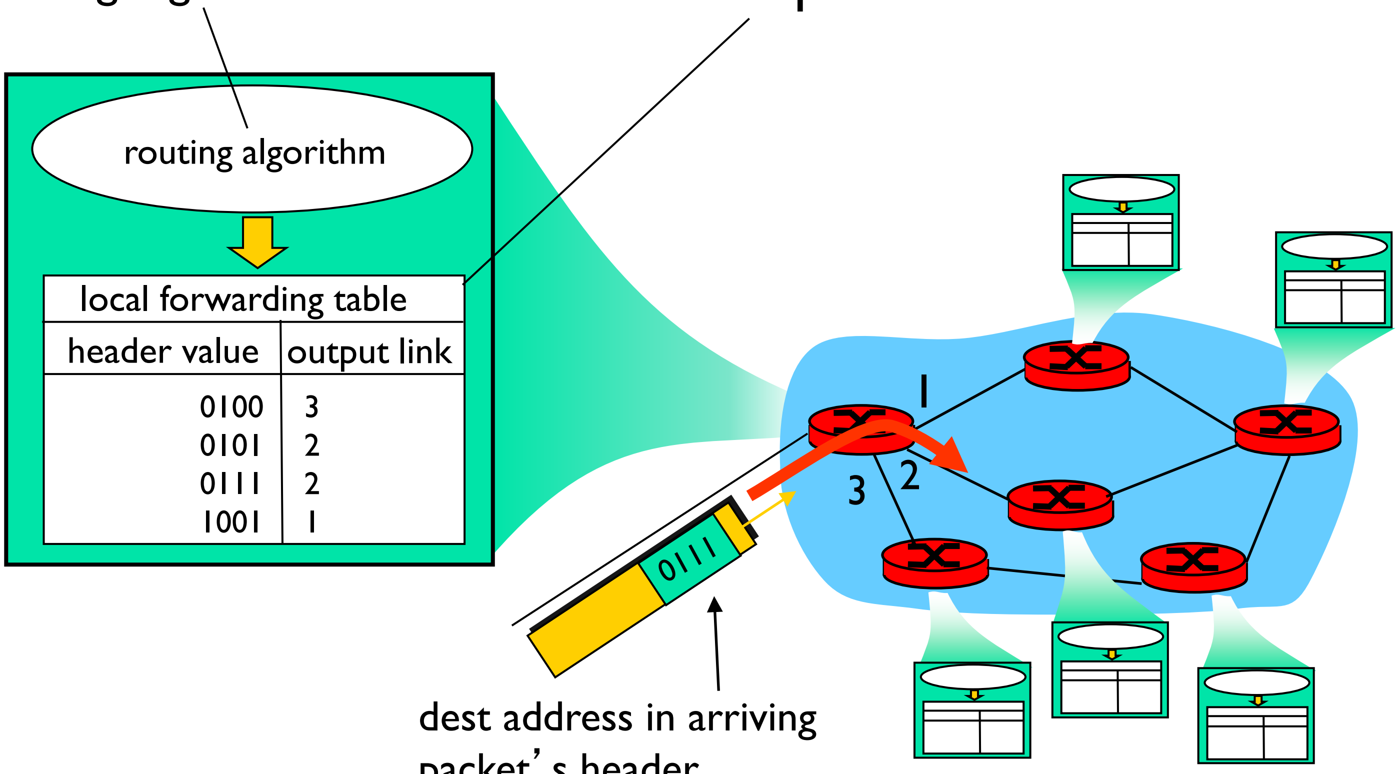
- **routing protocols**: automatically set the forwarding tables
  - E.g., shortest path routing protocol
    - determine the shortest path from each router to each destination and use the shortest path results to configure the forwarding tables in the routers.

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



local forwarding table

header value	output link
0100	3
0101	2
0111	2
1001	1

dest address in arriving packet's header