Lesson 1.2: Introduction & Foundation

CSC450 – COMPUTER NETWORKS | WINTER 2019-20

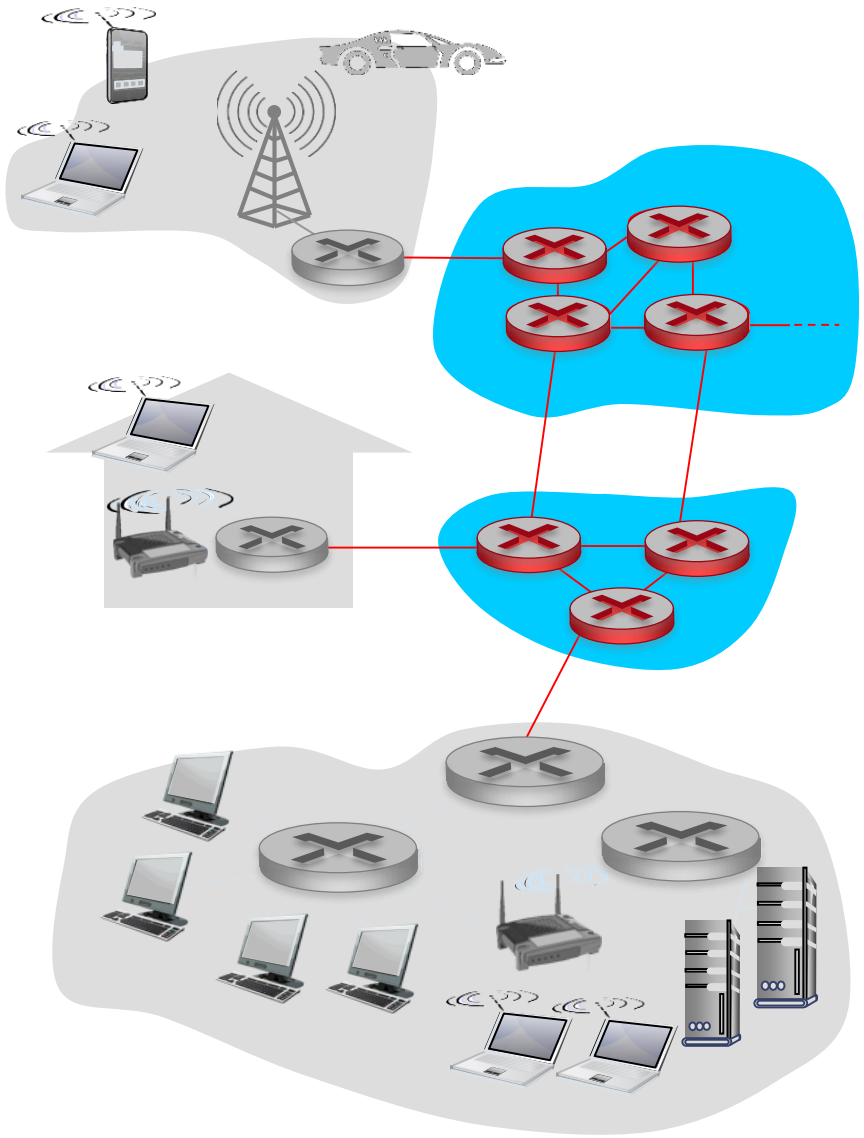
DR. ANDREY TIMOFEYEV

OUTLINE

- Network core.
  - Packet switching.
  - Store-and-forward transmission.
  - Routing & forwarding.
- Performance.
  - Delay.
    - Processing delay.
    - Queueing delay.
    - Transmission delay.
    - Propagation delay.
  - Throughput.

NETWORK CORE

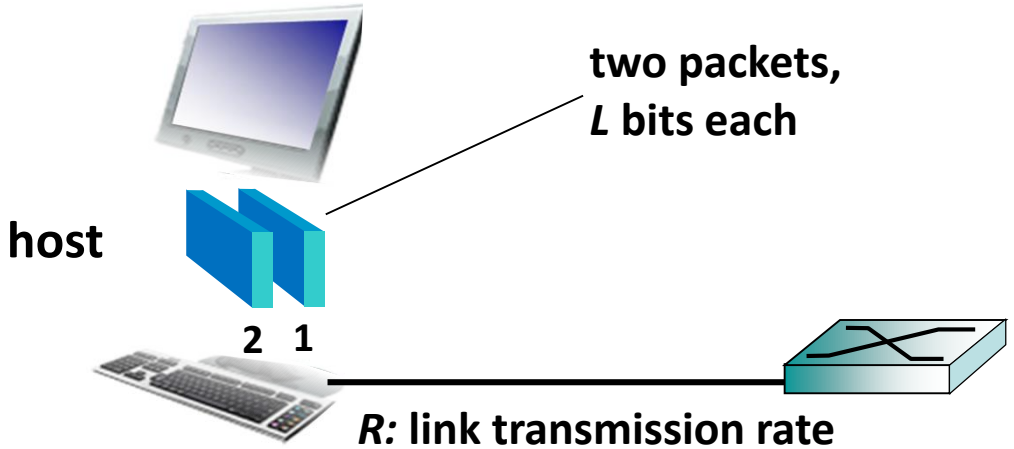
- Network **core**.
  - **Mesh** of interconnected **routers**.
- **Data** can be **moved** through the network in two ways:
  - **Circuit** switching.
  - **Packet** switching.



Interconnection of networks

PACKET SWITCHING

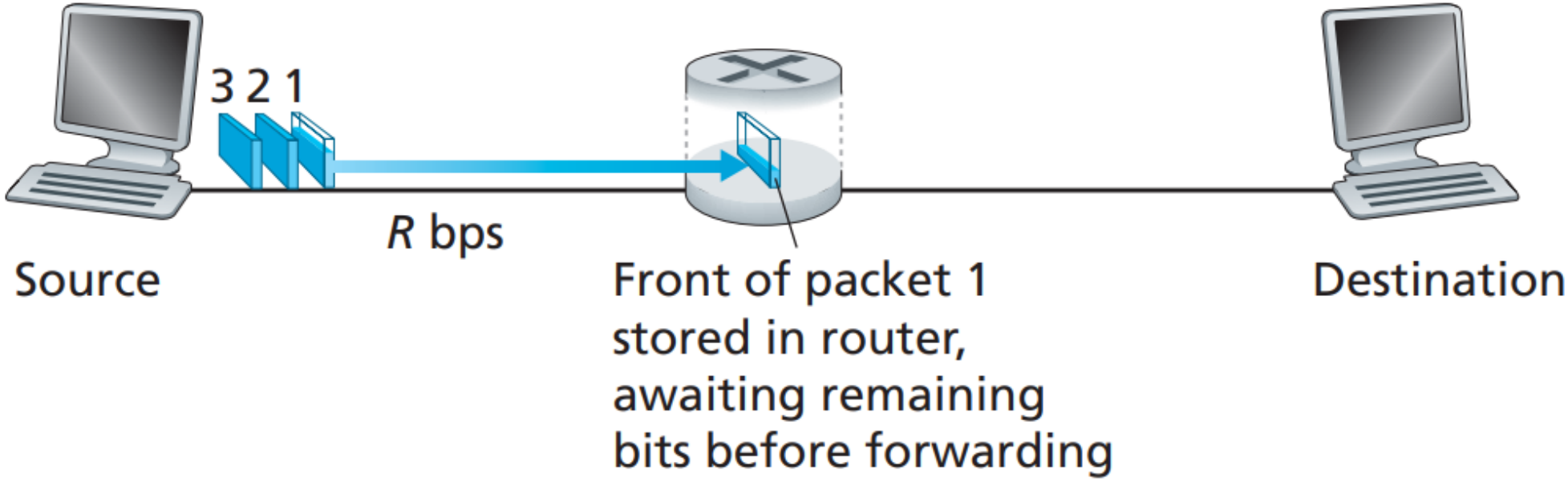
- **Hosts** exchange **messages** with each other.
- **Messages** are broken down into **packets**.
  - Packet size = *L* bits.
- **Packets** travel through **communication links** and **routers/switches**.
- **Communication links** pass packets at a **transmission rate** (*throughput* or *bandwidth*).
  - Transmission rate = *R* bits/sec.
- Packet **transmission time** = *L/R* sec.
  - Time needed to transmit L-bit packet through communication link.



Message broken down into packets

PACKET SWITCHING: STORE-AND-FORWARD

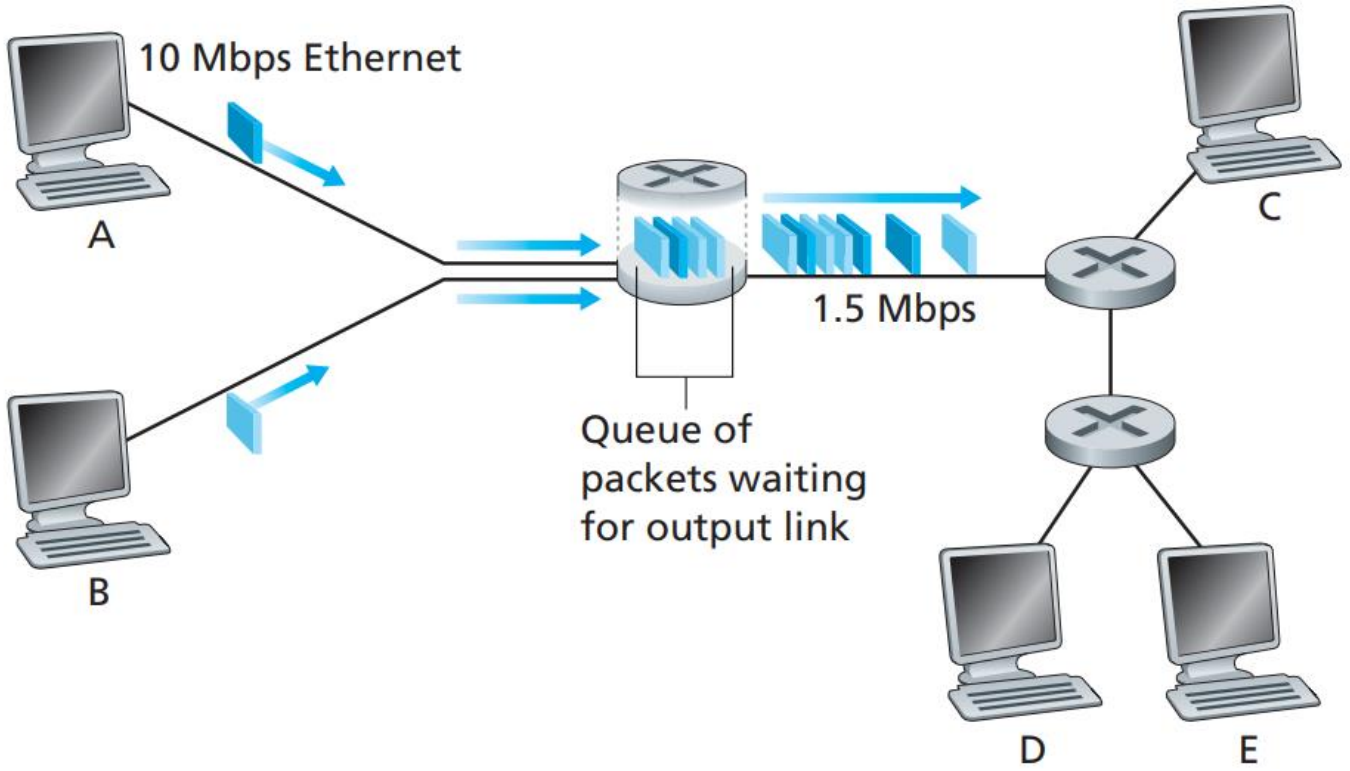
- **Store-and-forward transmission**.
  - **Switch/router** must receive **entire packet** before it can **transmit** first bit onto **outbound link**.
    - **Bits** of a **packet** are **stored** (*"buffered"*) by the **switch/router**.



Store-and-forward packet switching

PACKET SWITCHING: DELAY & PACKET LOSS

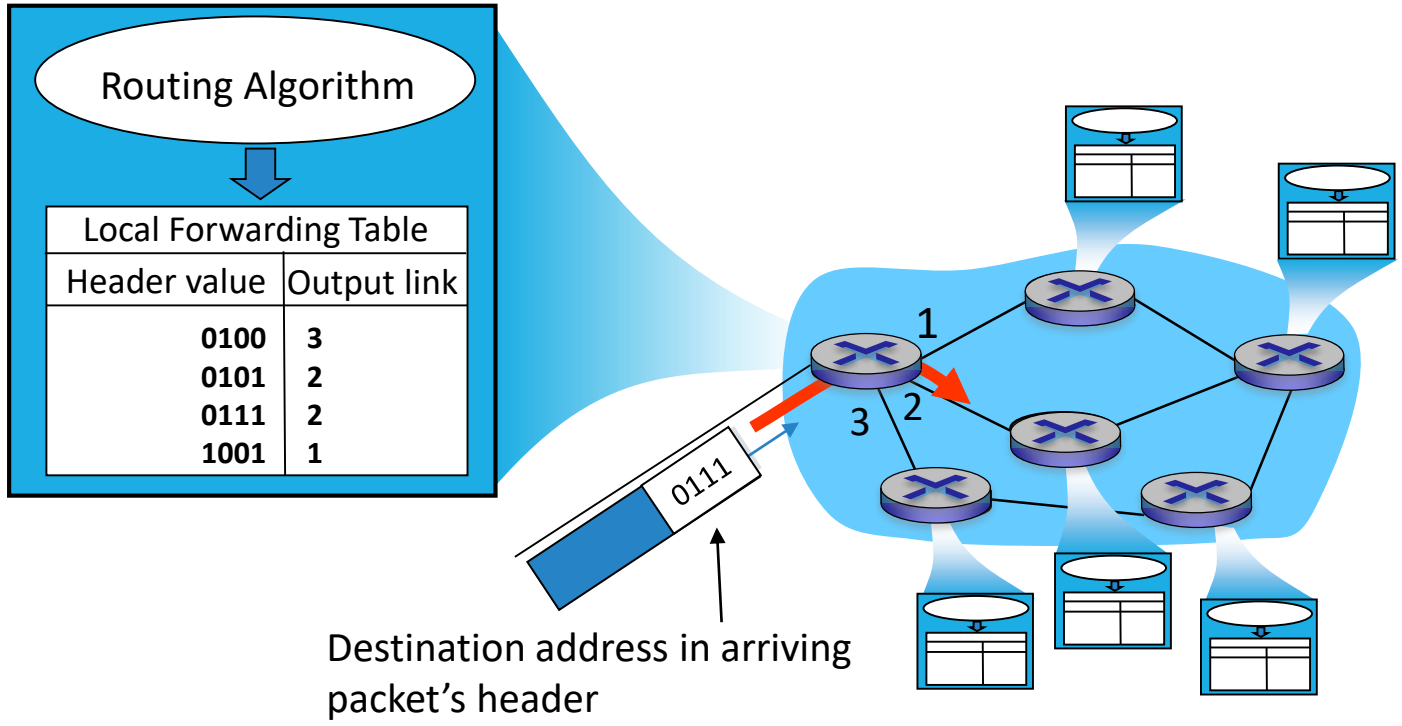
- **Delay** and **packet loss**.
  - If **arrival rate** to link exceeds **transmission rate** of link for a period of time:
    - **Packets** will **queue** and wait to be **transmitted** on link (*queueing delay*);
    - **Packets** will be **dropped** (*packet loss*) if **memory** (*buffer*) **fills** up.



Delay in packet switching

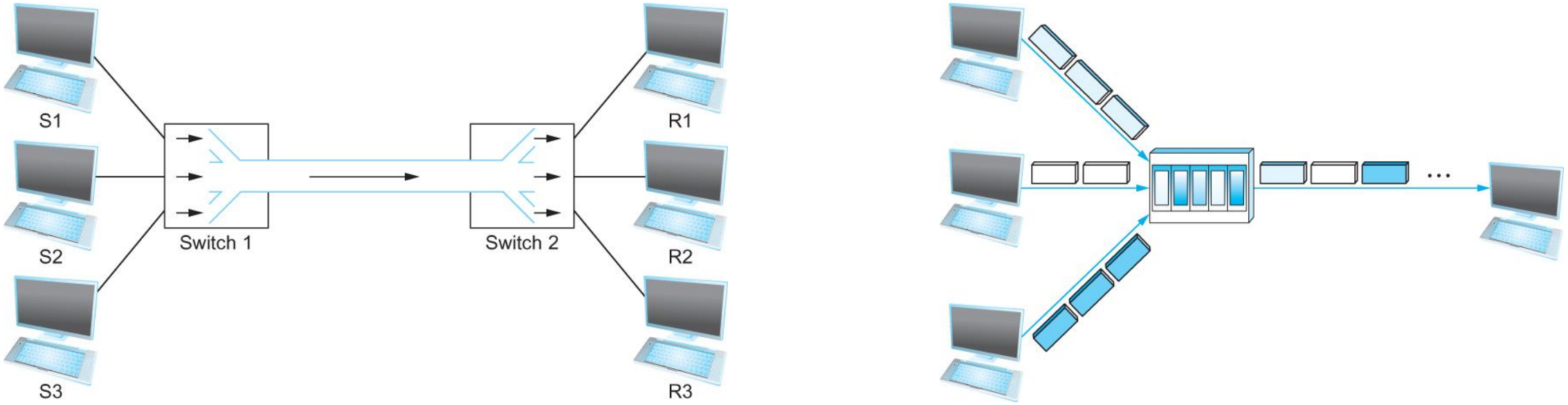
PACKET SWITCHING: ROUTING & FORWARDING

- **Routing** & **forwarding** are the **key** network-core **functions**.
  - **Routing** determines **source-destination route** taken by packets.
    - Generates **forwarding table**.
  - **Forwarding moves** packets from router **input link** to appropriate router **output link**.



PACKET SWITCHING: RESOURCE SHARING (1)

- **Hosts** share **communication links** using **multiplexing/de-multiplexing** process.
  - **Time division** multiplexing.
  - **Frequency division** multiplexing.
  - **Statistical** multiplexing.



Multiplexing data flows over single communication link

PACKET SWITCHING: RESOURCE SHARING (2)

- **Statistical multiplexing**:
  - **Cost-effective** way for multiple hosts to **share** a communication link.
  - Allows hosts to **share** the link **over time**.
  - **Data** is transmitted based on **demands** of each host **data flow**.
  - **Assigns** an **upper limit** for the **size** of data each host can send.

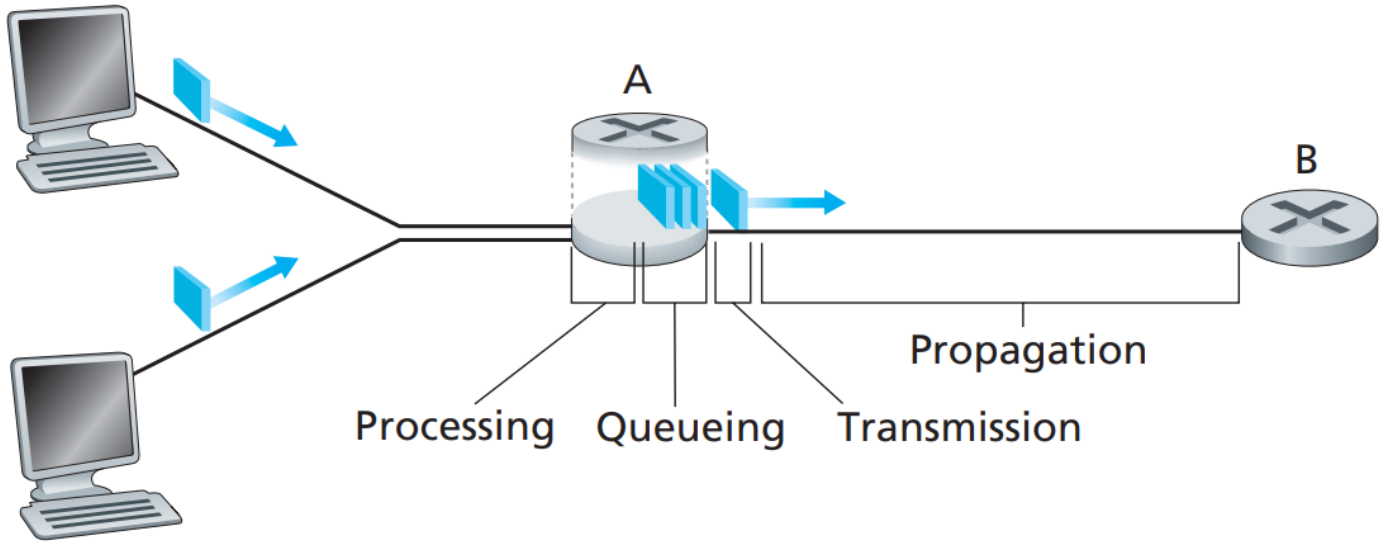
NETWORK PERFORMANCE

- Network **performance** is determined by following measures:
  - **Delay** (*latency*).
    - **How long** it takes a message to **travel** from one end of the network to another.
    - **Round-trip time (RTT)** is frequently used instead of one-way delay.
  - **Throughput** (*bandwidth*).
    - **Amount of data** per second that can be **transferred** by communication link.

DELAY

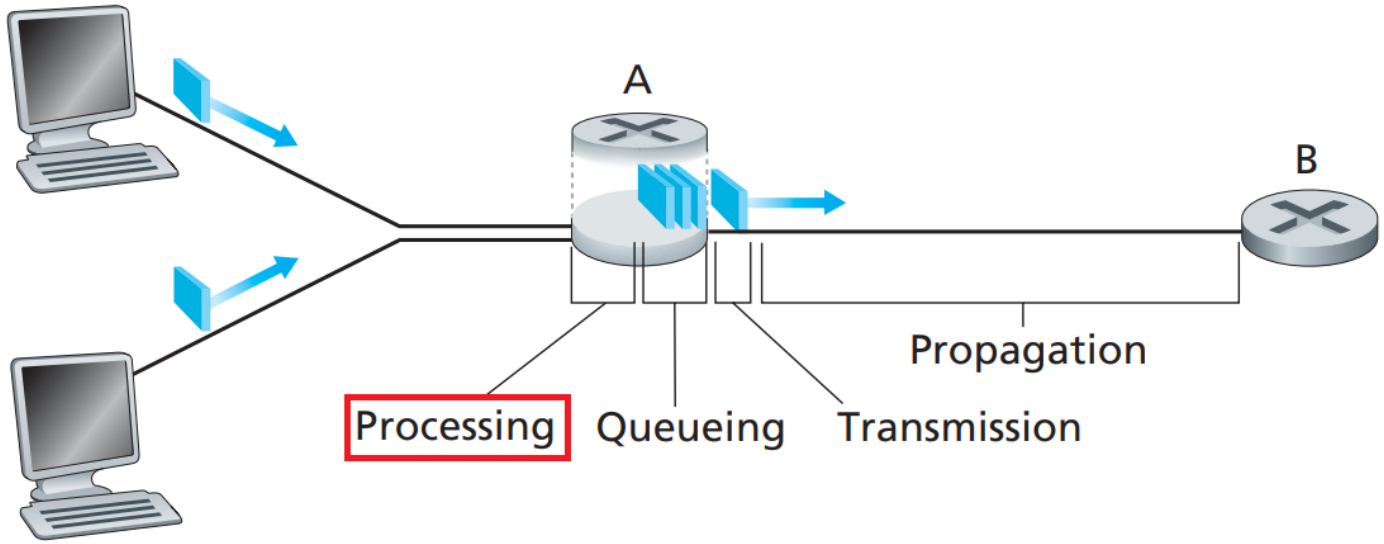
- As a **packet travels** through the network it **suffers** from several **types** of **delays**:
  - **Processing** delay.
  - **Queueing** delay.
  - **Transmission** delay.
  - **Propagation** delay.

- Total **nodal delay** (at single router) $d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$



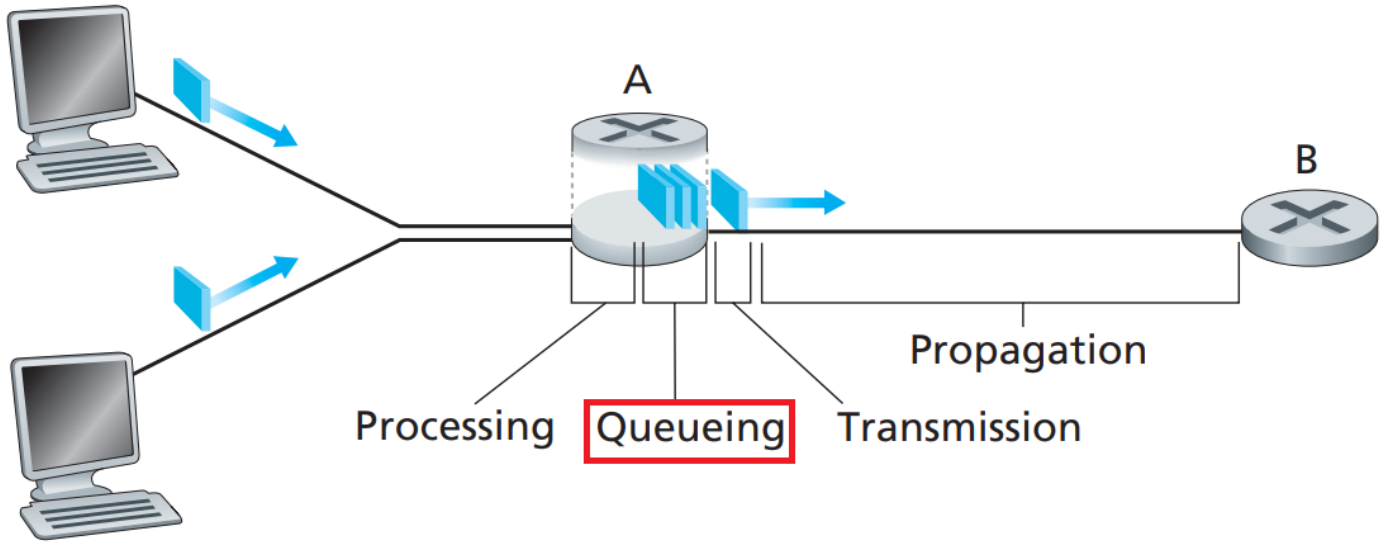
PROCESSING DELAY

- **Processing delay** - time required to **examine** the **packet's header** and determine where to **direct** the **packet**.
  - In addition – time needed to **check** for bit-level **errors**.
- Typically in order of **microseconds** or less in high-speed routers.



QUEUEING DELAY (1)

- **Queueing delay** – time the **packet** has to **wait** in a queue until being **transmitted** onto the link.
  - The **length** depends on the **number** of earlier-arriving packets in the queue.
  - Empty queue = no queueing delay.
- Typically in order of **microseconds** to **milliseconds**.



QUEUEING DELAY (2)

- **Queueing delay** varies packet by packet.
  - **Average** delay, **variance** of delay, **probability** that delay exceeds specified value.
- **Queueing delay time** depends on:
  - **Rate** at which traffic **arrives** at the queue;
  - **Transmission rate** of the link;
  - **Nature** of arriving traffic.
    - **Periodical** or **at bursts**.

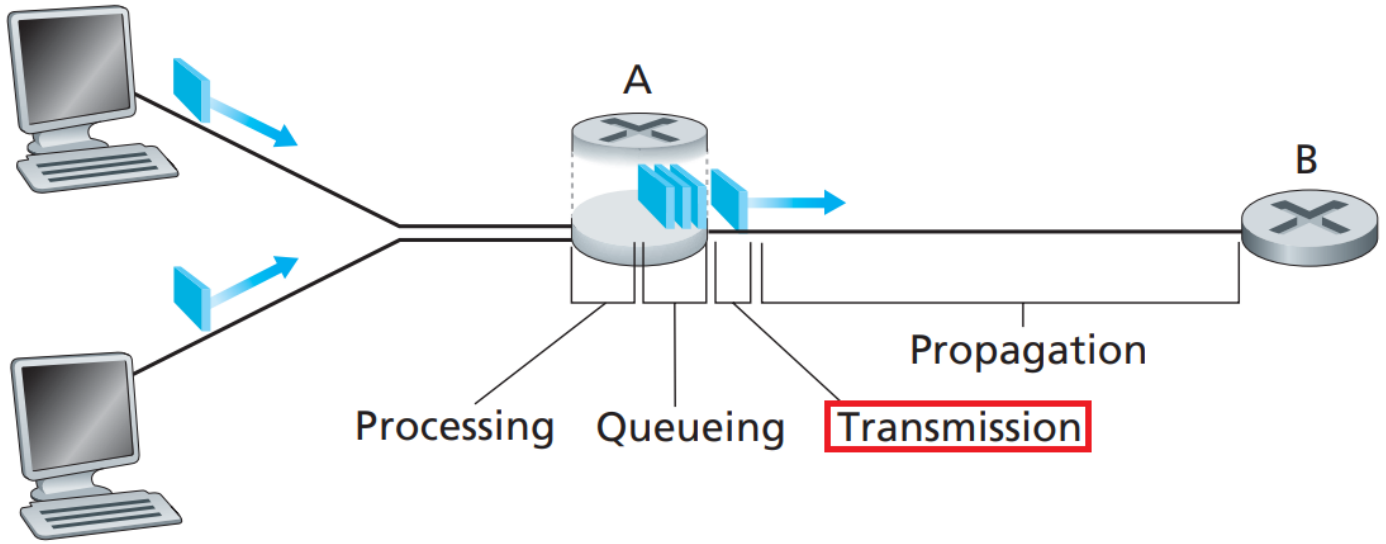
QUEUEING DELAY: TRAFFIC INTENSITY

- **Queueing delay** is estimated by **traffic intensity**.
- **Traffic intensity** = *L*A/R*.
  - L – length of the packet (bits),
  - R – transmission rate of the link (bits/sec),
  - A – average rate at which packets arrive at the queue (packets/sec).
- If **L*A/R > 1**:
  - Queueing delay approaches the **total size** of the **queueing buffer**.
    - Buffer is **full => packet dropped** by the router and is considered **lost**.
- If **L*A/R <= 1**:
  - If traffic arrives **periodically**,
    - **No** queueing **delay**.
  - If traffic arrives at **bursts**,
    - **Significant** average queueing **delay**, but less then the **size** of queueing buffer.

Switch congestion animation

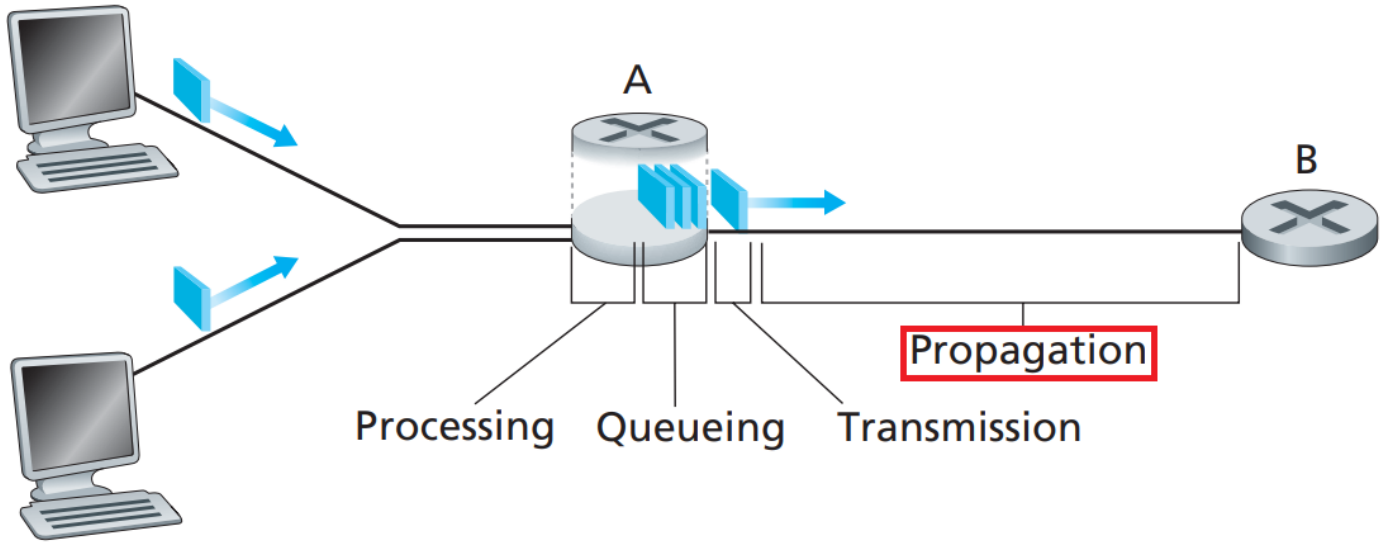
TRANSMISSION DELAY

- **Transmission delay** – time required to **transmit** (*push*) **all** of the packet's **bits** onto the link.
- **Calculated** by *L/R*.
  - L – length of the packet (bits), R – transmission rate of the link (bits/sec).
- Typically in order of **microseconds** to **milliseconds**.



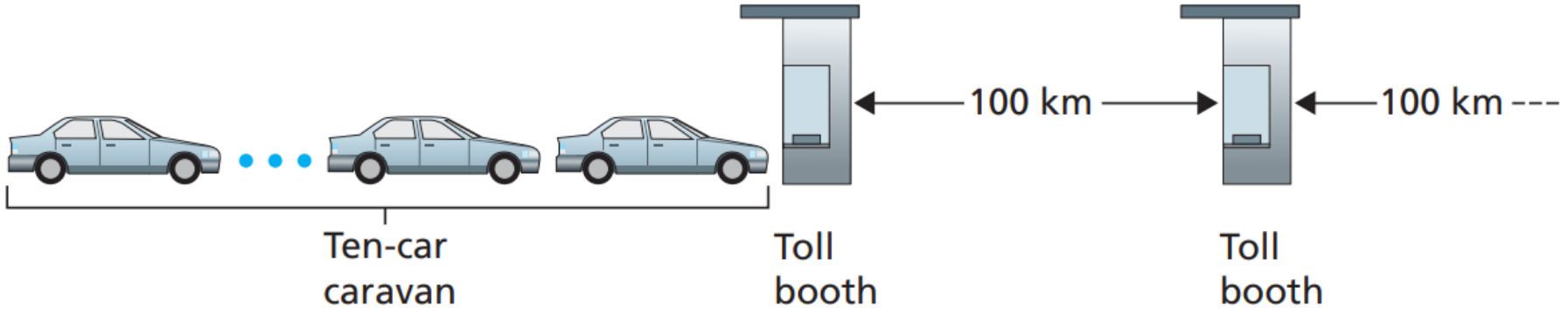
PROPAGATION DELAY

- **Propagation delay** – time required to **propagate** the **bit** from the **beginning** of the link to the **router/host**.
- **Calculated** as *D/S*.
  - D – distance between the routers, S – propagation speed of link.
  - Propagation speed depends on the **physical** medium of the link.
    - In range of $2*10^8 – 3*10^8$ meters/sec.



TRANSMISSION DELAY VS. PROPAGATION DELAY

- **Transmission** delay - time required for the router to push out the packet.
  - Function of **packet's length** (L) and **transmission rate** (R) of the link.
  - Nothing to do with the **distance** (D) between routers/nodes.
- **Propagation** delay - time it takes a bit to propagate from one router/host to next.
  - Function of the **distance** (D) between two routers and **propagation speed** (S) of the link.
  - Nothing to do with **packet's length** (L) and **transmission rate** (R) of the link.

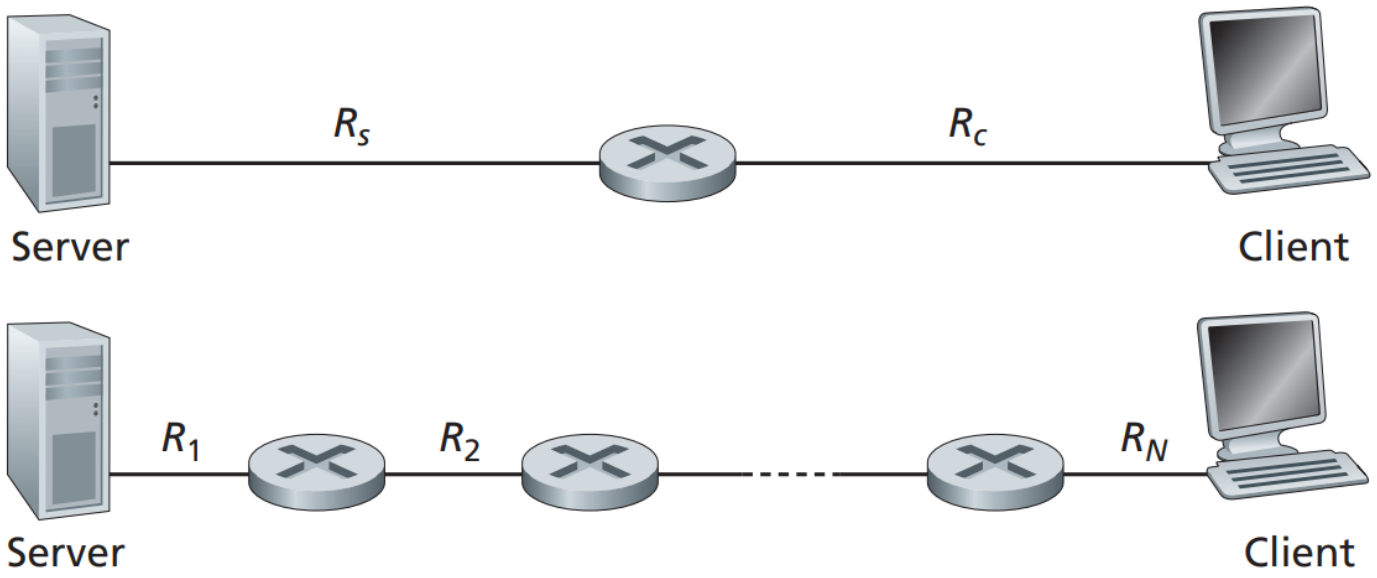


Car caravan example

- Total **end-to-end** delay $d_{end\text{-}end} = N(d_{proc} + d_{queue} + d_{trans} + d_{prop})$

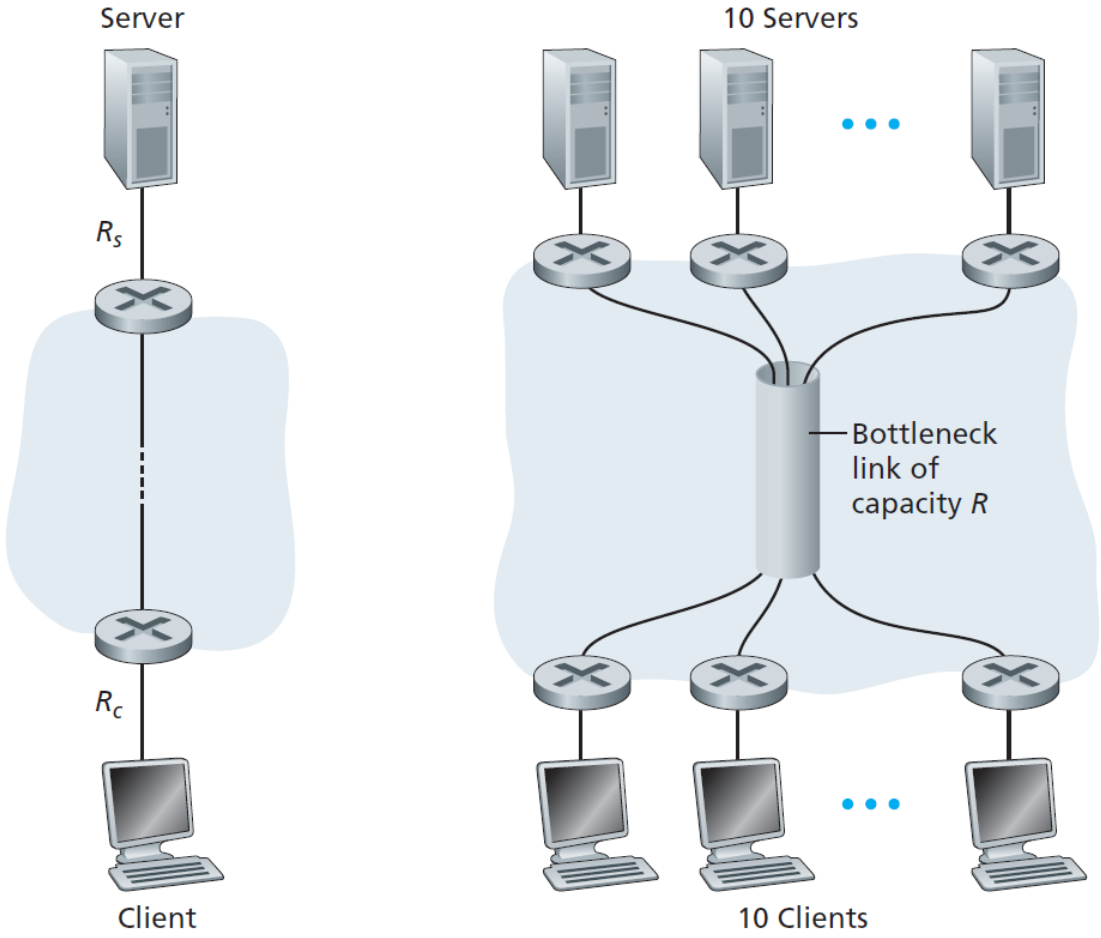
THROUGHPUT (1)

- **Throughput** – **number** of **bits** per **second** that can be transmitted on the **link**.
- For a simple **two-link** network, throughput = $min\{R_c, R_s\}$,
  - R – transmission rate of the link.
- For a network with **N links,** throughput = $min\{R_1, R_2, \ldots, R_n\}$
  - Transmission rate of **bottleneck link**.



THROUGHPUT (2)

- **Throughput** depends on the **transmission rates** of the **links** over which the data flows.
  - **Access network** is a typical **constraining** factor for the throughput.



DELAY VS. THROUGHPUT

- **Relative** importance of **delay** and **throughput** depends on the **application**.
- **Delay-bound**:
  - **Application** is affected **more** by **propagation delay** than **transmission delay**.
  - **Example:** Client sends a 1-byte message to a server and receives a 1-byte message in return.
- **Throughput-bound**:
  - **Application** is affected **more** by **transmission delay** than **propagation delay**.
  - **Example:** Digital library application that fetches a 25-Mbyte image.

SUMMARY

- Packet switching.
- Store-and-forward transmission.
- Queueing delay & packets loss.
- Routing & forwarding.
- Delay.
- Throughput.
- Delay-bound vs. throughput-bound.