Guided and Unguided Transmission Media

Physical Media

- A bit, when traveling from source to destination, passes through a series of **transmitter-receiver pairs.**
- For each transmitter-receiver pair, the bit is sent by **propagating electromagnetic waves or optical pulses across a physical medium.**
- Physical media fall into two categories: **Guided Media and Unguided Media.**
- With **guided media**, the waves are guided along a solid medium, such as a **fiber-optic cable**, a **twisted-pair copper wire**, or a **coaxial cable**.
- With **unguided media**, the waves propagate in the **atmosphere** and in **outer space**, such as in a wireless LAN or a digital satellite channel.

Guided and Unguided Transmission Media

Access Network

Physical Media

- The actual **cost** of the physical link (copper wire, fiber-optic cable, and so on) is often **relatively minor** compared with other networking costs.

- **Twisted-Pair Copper Wire**
  - **Least expensive and most commonly used guided transmission medium by telephone networks.**
  - Consists of two insulated copper wires, each about 1 mm thick, arranged in a regular spiral pattern.
  - Twisted to reduce the electrical interference from similar pairs close by.
  - A number of pairs are bundled together in a cable by wrapping the pairs in a protective shield.

Guided and Unguided Transmission Media

Access Network

Physical Media

- **Twisted-Pair Copper Wire**
  - Unshielded twisted pair (UTP) is commonly used for **computer networks within a building, that is, for LANs.**
  - Data rates for LANs using twisted pair today range from **10 Mbps to 10 Gbps.**
  - The data rates that can be achieved depend on the **thickness** of the wire and the **distance** between transmitter and receiver.
  - **Twisted pair has emerged as the dominant solution for high-speed LAN networking.**

Guided and Unguided Transmission Media

Access Network

Physical Media

- **Coaxial Cable**
  - It consists of **two copper conductors**, but the two conductors are **concentric** rather than parallel.
  - With this construction and special insulation and shielding, coaxial cable can achieve **high data transmission rates.**
  - Quite common in **cable television systems.**
  - Transmitter shifts the digital signal to a **specific frequency band.**

Guided and Unguided Transmission Media

Access Network

Physical Media

- **Fiber Optics**
    - **An optical fiber is a thin, flexible medium that conducts pulses of light, with each pulse representing a bit.**
    - Supports bit rates, up to **tens or even hundreds of gigabits per second.**
    - They are immune to **electromagnetic interference, have very low signal attenuation up to 100 kilometers, and are very hard to tap.**
    - **High cost** of optical devices—such as transmitters, receivers, and switches—has hindered their deployment for short-haul transport.
    - The Optical Carrier (OC) standard link speeds range from **51.8 Mbps to 39.8 Gbps.**

Guided and Unguided Transmission Media

Access Network

Physical Media

- **Terrestrial Radio Channels**
  - Radio channels carry signals in the **electromagnetic spectrum.**
  - Require **no physical wire** to be installed, can **penetrate walls**, provide **connectivity to a mobile user**, and can potentially carry a signal for **long distances.**
  - Depend significantly on the **propagation environment** and the **distance** over which a signal is to be carried.
  - **Shadow Fading, Multipath Fading and Interference.**
  - Broadly classified into three groups: those that operate over very **short distance**, those that operate in **local areas**, those that operate in the **wide area**.

Guided and Unguided Transmission Media

Access Network

Physical Media

- **Satellite Radio Channels**
  - **A communication satellite links two or more Earth-based microwave transmitter/ receivers, known as ground stations.**
  - The satellite receives transmissions on one frequency band, regenerates the signal using a repeater and transmits the signal on another frequency.
  - Types: **Geostationary Satellites** and **Low-Earth Orbiting Satellites.**
  - **Geostationary Satellites** are placed in orbit at **36,000 kilometers** above Earth's surface with propagation delay of **280 milliseconds**.
  - Can operate at speeds of **hundreds of Mbps**, are often used in areas without access to DSL or cable-based Internet access.

Guided and Unguided Transmission Media

Access Network

Physical Media

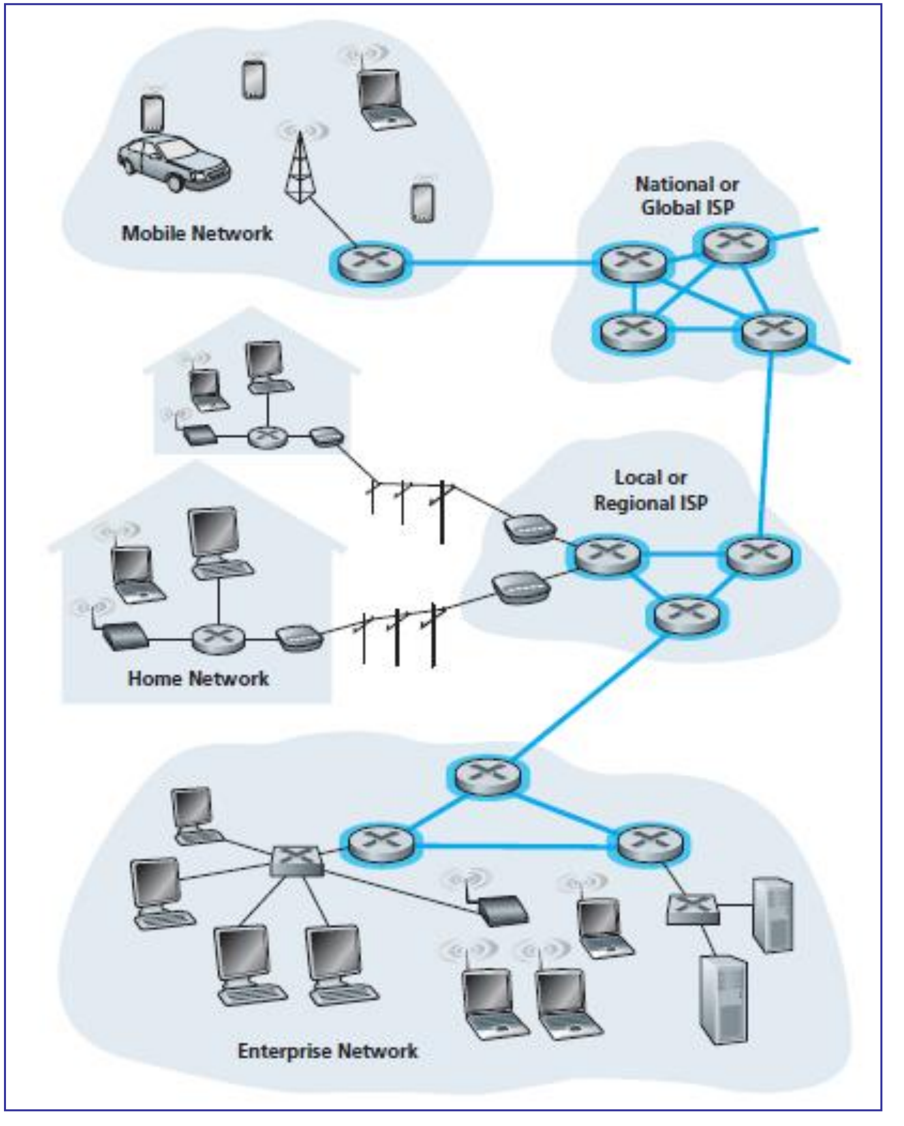
- **Satellite Radio Channels**
  - **LEO** satellites are placed **much closer to Earth.**
  - May communicate with **each other**, as well as with **ground stations.**
  - LEO satellite technology may be used for Internet access sometime in the future.

The Network Core

Mesh of packet switches and links that interconnects the Internet's end systems.

Two fundamental approaches to moving data through a network of links and switches:

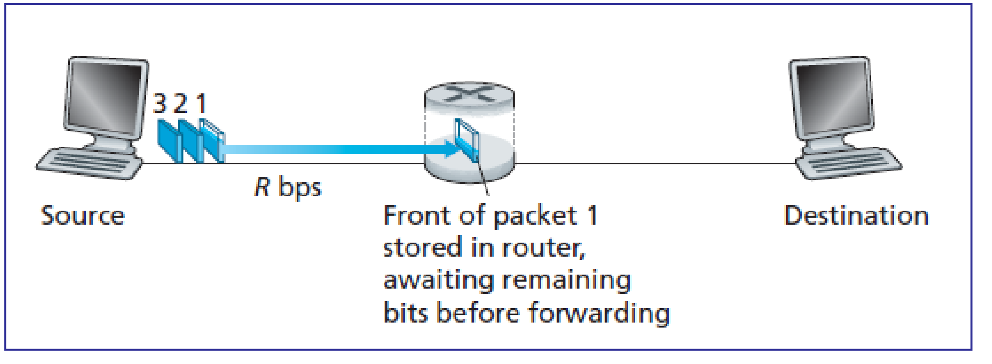
1. **Circuit switching**
2. **Packet switching**



The Network Core

Packet Switching

- End systems exchange **Messages** with each other.
- Source breaks long messages into smaller chunks of data known as **Packets.**
- Packet travels through **Communication Links and Packet Switches.**
- Packets are transmitted over each communication link at a rate equal to the **full transmission rate of the link.**
- **Store-and-Forward Transmission :** the packet switch must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link.



The Network Core

Packet Switching

- **Store-and-Forward Transmission:**
  - The total delay for transmission of one packet is **2L/R** for Store-and-Forwarding transmission. If the switch instead forwarded bits as soon as they arrive then the total delay would be **L/R.**
  - The amount of time that elapses from when the source begins to send the first packet until the destination has received all three packets would be **4L/R.**
  - Sending one packet from source to destination over a path consisting of **N links** each of **rate R**, **end-to-end delay is;**

$$\boxed{d_{\text{end-to-end}} = N\frac{L}{R}}$$

The Network Core

Packet Switching

- **Store-and-Forward Transmission:**

  Queuing Delays and Packet Loss

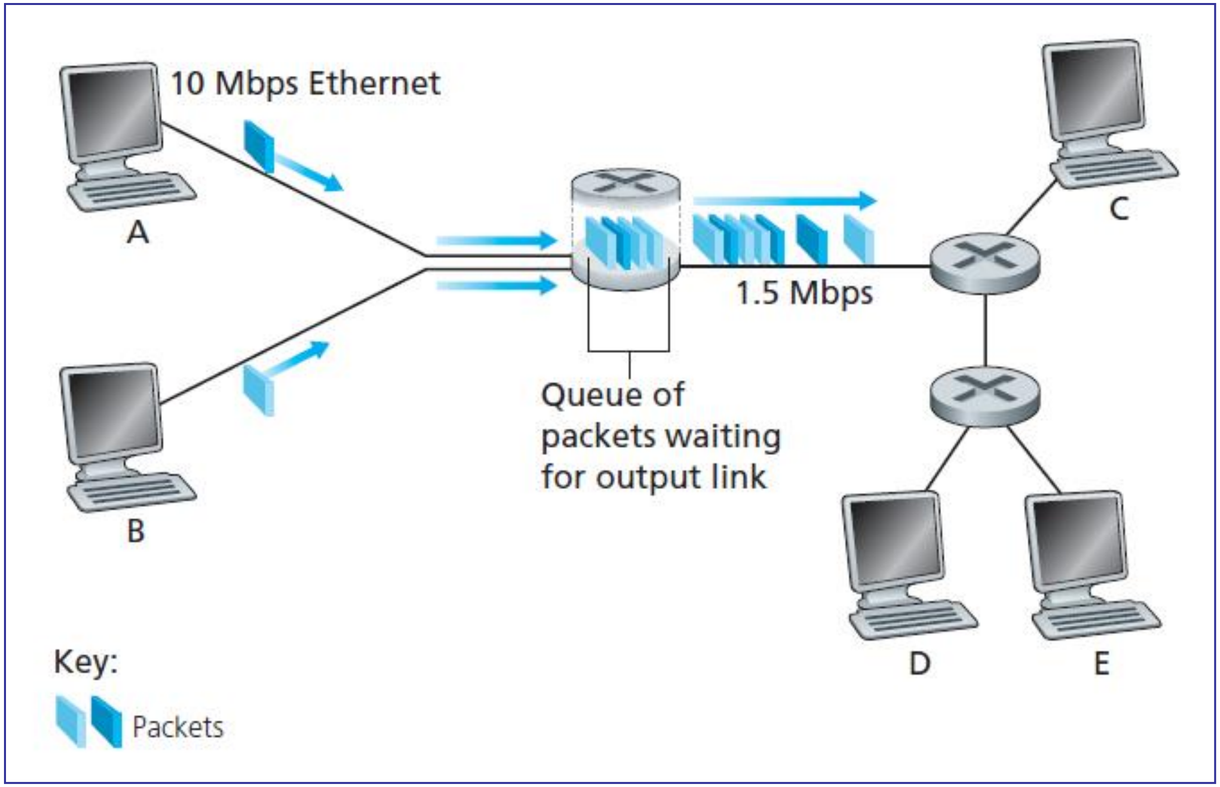
  - For each attached link, the packet switch has an **output buffer** (output queue), which stores packets that the router is about to send into that link.
  - In addition to the store-and-forward delays, packets suffer **output buffer queuing delays.**
  - **Variable and depend on the level of congestion in the network.**
  - **packet loss** will occur.

The Network Core

Packet Switching

- **Store-and-Forward Transmission:**

  Queuing Delays and Packet Loss



The Network Core

Packet Switching

- **Store-and-Forward Transmission:**

  Forwarding Tables and Routing Protocols

  - In the Internet, every end system has an address called an **IP address.**
  - Each router has a **forwarding table** that maps destination addresses (or portions of the destination addresses) to that router's outbound links.
  - **A router uses a packet's destination address to index a forwarding table and determine the appropriate outbound link.**
  - How do forwarding tables get set?
  - **Routing Protocol** automatically set the forwarding tables.
  - Determine the **shortest path** from each router to each destination and use the shortest path results to **configure the forwarding tables** in the routers.

The Network Core

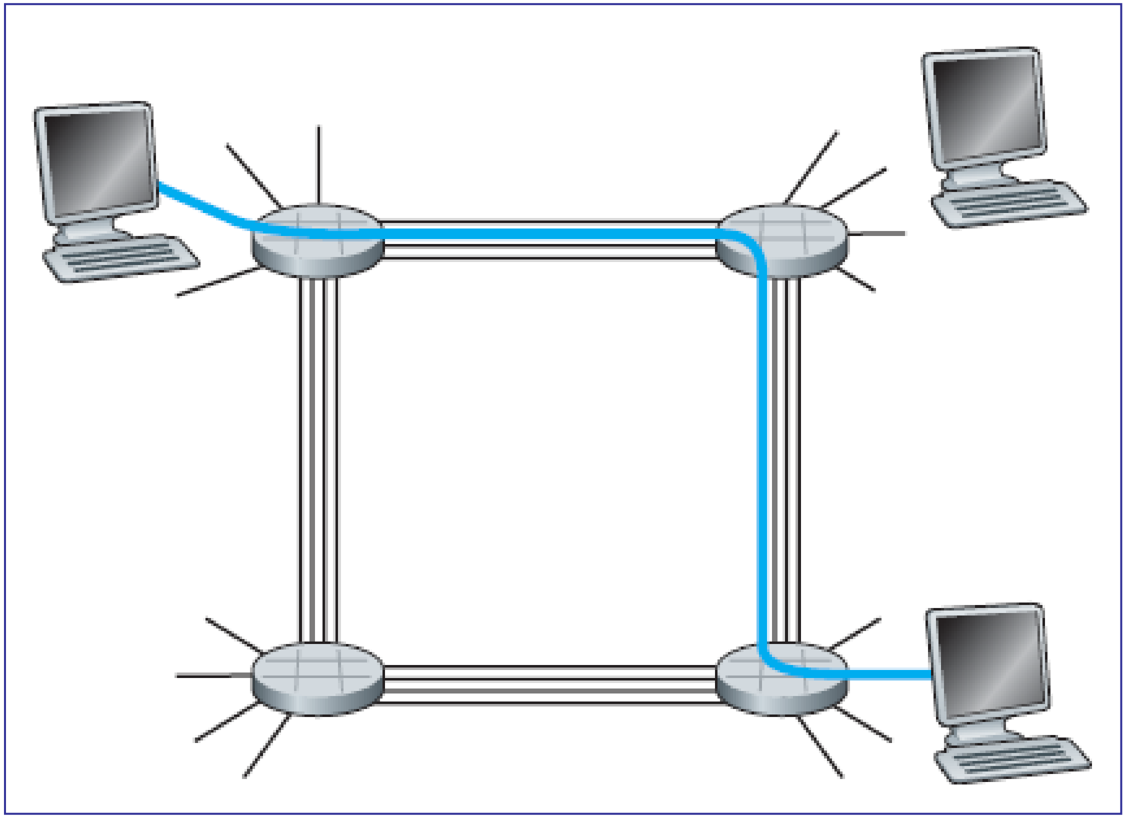
Circuit Switching

- **Resources are reserved** for the duration of the communication session between the end systems.
- May have to **wait** for access to a communication link.
- **Example:** Traditional telephone networks
- connection is called a **circuit.**
- Sender can transfer the data to the receiver at the **guaranteed constant rate.**
- **Example:** Each link has four circuits, use end-to-end connection, the connection gets one fourth of the link's total transmission capacity for the duration of the connection.
- The **Internet** makes its best effort to deliver packets in a timely manner, but it **does not make any guarantees.**

The Network Core

Circuit Switching

A simple circuit-switched network consisting of four switches and four links



The Network Core

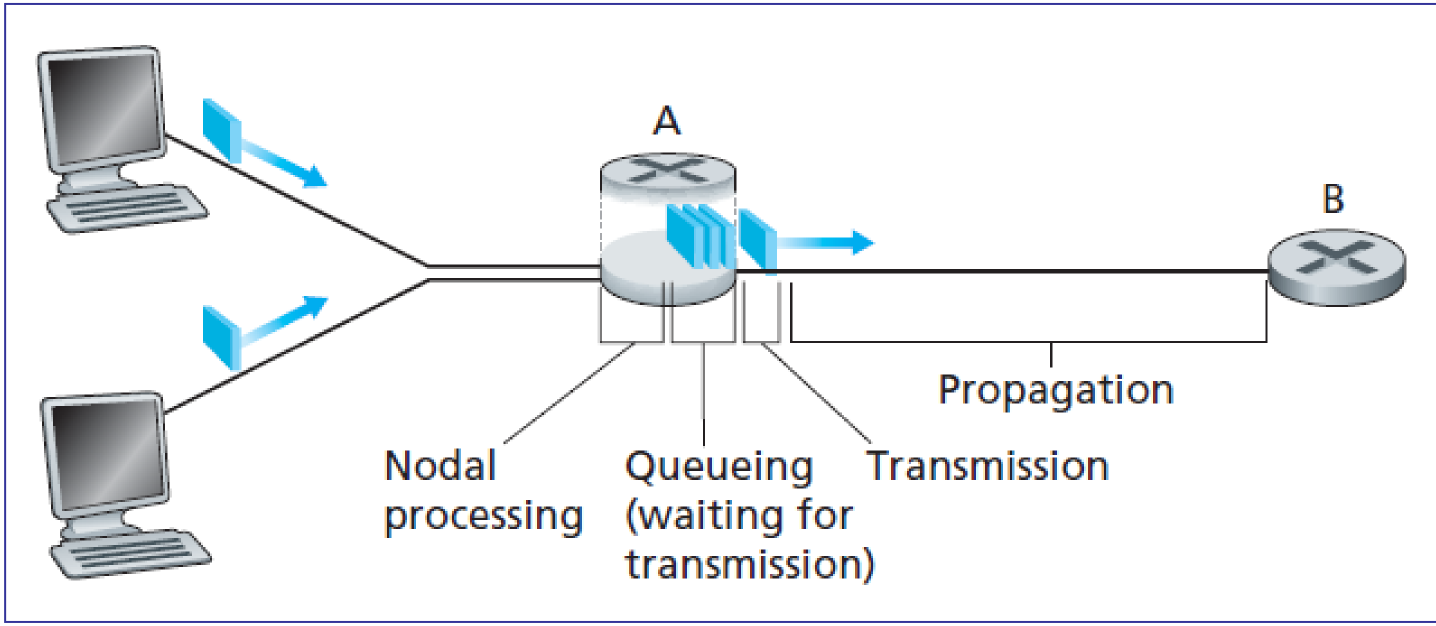
Packet Switching Versus Circuit Switching

- Supporters of packet switching have always argued that **circuit switching is wasteful** because the dedicated circuits are idle during **silent periods.**
    - It offers better sharing of transmission capacity.
    - It is simpler, more efficient, and less costly to implement.

- Critics of **Packet switching** have often argued that packet switching is not suitable for real-time services.

Delay, Loss, and Throughput in Packet-Switched Networks

Overview of Delay in Packet-Switched Networks



The most important of these delays are the **Nodal Processing Delay**, **Queuing Delay**, **Transmission Delay**, and **Propagation Delay**; together, these delays accumulate to give a **Total Nodal Delay.**

Delay, Loss, and Throughput in Packet-Switched Networks

Overview of Delay in Packet-Switched Networks

- **Processing Delay:**
  - Time required to **examine the packet's header** and determine where to **direct the packet**. Can also include **other factors.**
  - Typically on the order of **microseconds or less.**

- **Queuing Delay:**
  - The packet experiences a queuing delay as it waits to be transmitted onto the link.
  - Depend on the number of **earlier-arriving packets** that are queued and waiting for transmission onto the link.
  - On the order of **microseconds to milliseconds.**

Delay, Loss, and Throughput in Packet-Switched Networks

Overview of Delay in Packet-Switched Networks

- **Transmission Delay:**
  - Amount of time required to **push all of the packet's bits into the link.**
  - Typically on the order of **microseconds to milliseconds** in practice.
  - If length of the packet is L bits, Transmission rate of the link is R bits/sec than transmission delay is L/R.

- **Propagation Delay :**
  - The propagation delay is the **distance between two routers divided by the propagation speed.**
  - That is, the propagation delay is d/s, where d is the distance and s is the propagation speed of the link.
  - propagation speed is in the range of $2x10^8$ meters/sec to $3x10^8$ meters/sec.
  - propagation delays are on the order of **milliseconds.**

Delay, Loss, and Throughput in Packet-Switched Networks

Comparing Transmission and Propagation Delay

- The Transmission Delay is the amount of time required for the router to push out the packet; it is a function of the **packet's length** and **the transmission rate of the link**, but has **nothing to do with the distance between the two routers.**

- The propagation delay, on the other hand, is the time it takes a bit to propagate from one router to the next; it is a function of the **distance between the two routers**, but has nothing to do with the **packet's length or the transmission rate of the link.**

Delay, Loss, and Throughput in Packet-Switched Networks

If we let $\mathbf{d_{proc}}$, $\mathbf{d_{queue}}$, $\mathbf{d_{trans}}$, and $\mathbf{d_{prop}}$ denote the **processing**, **queuing**, **transmission** and **propagation delays**, then the total nodal delay is given by;

$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

Delay, Loss, and Throughput in Packet-Switched Networks

Queuing Delay and Packet Loss

- The most complicated and interesting component of nodal delay is the **queuing delay**, as it vary from packet to packet.
- **Average queuing delay**, **variance of queuing delay**, and the **probability that the queuing delay exceeds some specified value.**
- Queuing delay depends on the rate at which **traffic arrives at the queue**, **the transmission rate of the link**, and the **nature of the arriving traffic.**
  - ***a*** – average rate at which packets arrive at the queue (packets/sec).
  - ***R*** - transmission rate (bits/sec).
  - All packets consist of ***L*** bits.
  - Then the average rate at which bits arrive at the queue is ***La bits/sec.***

Delay, Loss, and Throughput in Packet-Switched Networks

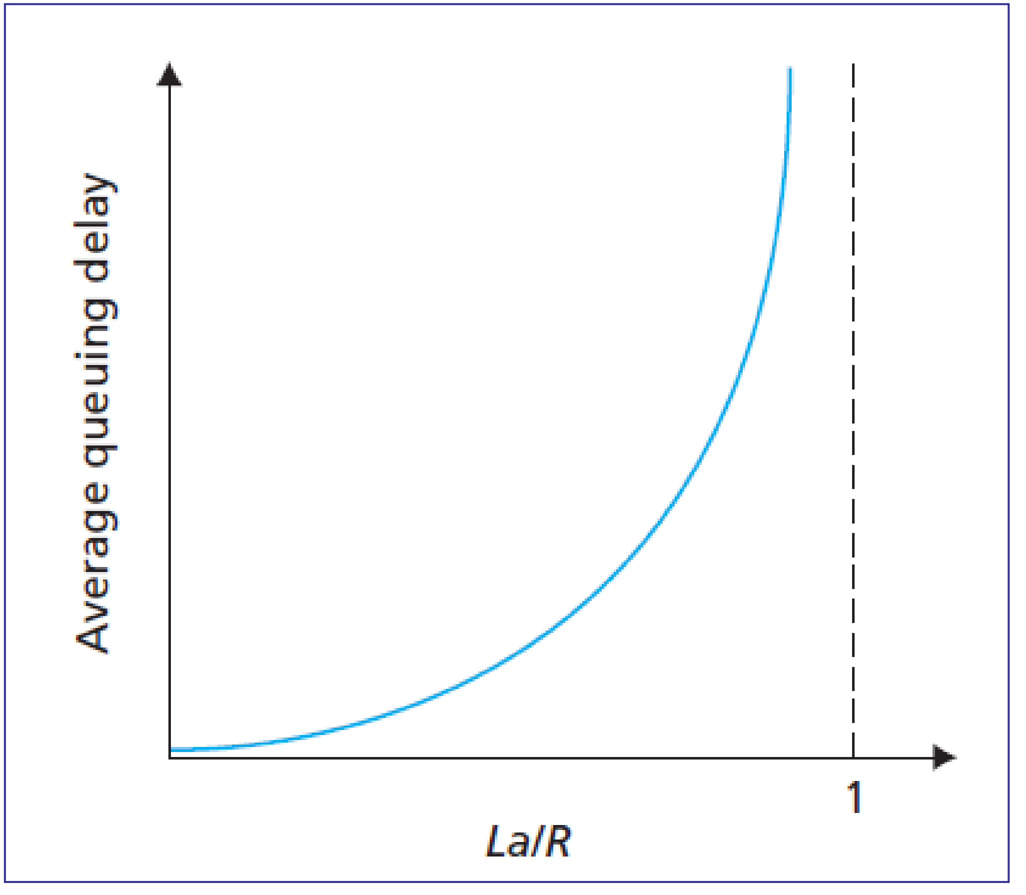
Queuing Delay and Packet Loss

- The ratio ***La/R***, called the **traffic intensity.**
- If ***La/R > 1***, than the queue will tend to increase without bound and the queuing delay will approach infinity!
- **Design your system so that the traffic intensity is no greater than 1.**
- If ***La/R ≤ 1,*** than the nature of the arriving traffic impacts the queuing delay.
- if the **traffic intensity is close to 0**, then it is unlikely that an arriving packet will find another packet in the queue.
- if the **traffic intensity is close to 1**, a queue will form during these periods of time.

Delay, Loss, and Throughput in Packet-Switched Networks

Queuing Delay and Packet Loss

Dependence of average queuing delay on traffic intensity



Delay, Loss, and Throughput in Packet-Switched Networks

Packet Loss

- Queue preceding a link has **finite capacity**, greatly depends on the router design and cost.
- Because the queue capacity is finite, packet delays do not really approach infinity as the traffic intensity approaches 1. Instead, a **packet can arrive to find a full queue.**
- With no place to store such a packet, a router will drop that packet; that is, the **packet will be lost.**
- **Performance at a node is often measured not only in terms of delay, but also in terms of the probability of packet loss.**

Delay, Loss, and Throughput in Packet-Switched Networks

End-to-End Delay

- Suppose there are ***N - 1*** **routers** between the source host and the destination host.
- Suppose the network is **uncongested.**
- **Processing delay** at each router and at the source host is d_{proc}.
- **Transmission rate** out of each router and out of the source host is ***R bits/sec***
- Propagation on each link is d_{prop}.
- The ***nodal delays*** accumulate and give an end-to-end delay,

$$d_{end\text{-}end} = N\,(d_{proc} + d_{trans} + d_{prop})$$

- Once again, $d_{trans} = L/R$, where ***L*** is the packet size.

Delay, Loss, and Throughput in Packet-Switched Networks

Throughput in Computer Networks

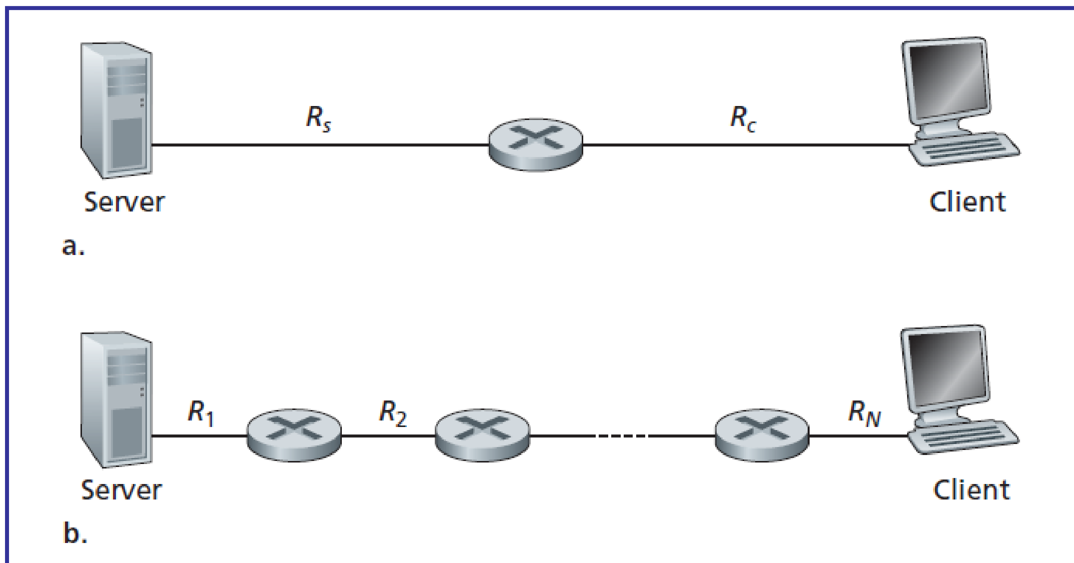
- Another **critical performance measure is end-to-end throughput.**
- Ex. Host A is transferring large file to Host B across a computer network.
- **The instantaneous throughput at any instant of time is the rate (in bits/sec) at which Host B is receiving the file.**
- If the file consists of ***F bits*** and the transfer takes ***T seconds*** for Host B to receive all F bits, then the **average throughput of the file transfer is *F/T bits/sec.***
- Different applications have different requirements in terms of **delays** and **throughput.**

Delay, Loss, and Throughput in Packet-Switched Networks

Throughput in Computer Networks

- Consider the throughput for a file transfer from the server to the client.
- R_s - rate of the link between the server and the router. R_c - rate of the link between the router and the client. **What is the server to client throughput?**

Throughput for a file transfer from server to client



Delay, Loss, and Throughput in Packet-Switched Networks

Throughput in Computer Networks

- If $R_s < R_c$, it gives a throughput of R_s ***bps.***
- If $R_c < R_s$, it gives a throughput of R_c ***bps.***
- Thus, for this simple two-link network, the throughput is $\min\{R_c, R_s\}$, that is, it is the transmission rate of the **bottleneck link.**
- For a network with **N links**, throughput for a file transfer from server to client is $\min\{R_1, R_2, \ldots, R_N\}$, which is once again the **transmission rate of the bottleneck link along the path between server and client.**
- **The constraining factor for throughput in today's Internet is typically the access network.**
- *Example: if* R_s = 2 Mbps, R_c = 1 Mbps, R = 5 Mbps, what will be the throughput value?

Delay, Loss, and Throughput in Packet-Switched Networks

Throughput in Computer Networks

End-to-end throughput: (a) Client downloads a file from server; (b) 10 clients downloading with 10 servers