Computer Networks

Lecture 2

Circuit Switching and Packet Switching

- There are two fundamental approaches to moving data through a network of links and switches:
  - **circuit switching and**
  - **packet switching.**

Circuit Switching and Packet Switching

- In **circuit-switched networks**, the resources needed along a path (buffers, link transmission rate) to provide for communication between the end systems are *reserved for the duration of the communication session between the end systems.*
- *In* **packet-switched networks**, these resources are *not reserved; a session's messages* use the resources on demand, and as a consequence, may have to wait (that is, queue) for access to a communication link.

Circuit Switching and Packet Switching

- **Traditional telephone networks are examples of circuit-switched networks.**
- Consider what happens when one person wants to send information (voice or facsimile) to another over a telephone network. Before the sender can send the information, the network must establish a connection between the sender and the receiver. This connection is called a circuit. When the network
- establishes the circuit, it also reserves a constant transmission rate in the network's links (representing a fraction of each link's transmission capacity) for the duration of the connection.

Multiplexing in Circuit-Switched Networks

- A circuit in a link is implemented with either-
- **Frequency-division multiplexing(FDM) or**
- **Time-division multiplexing (TDM).**

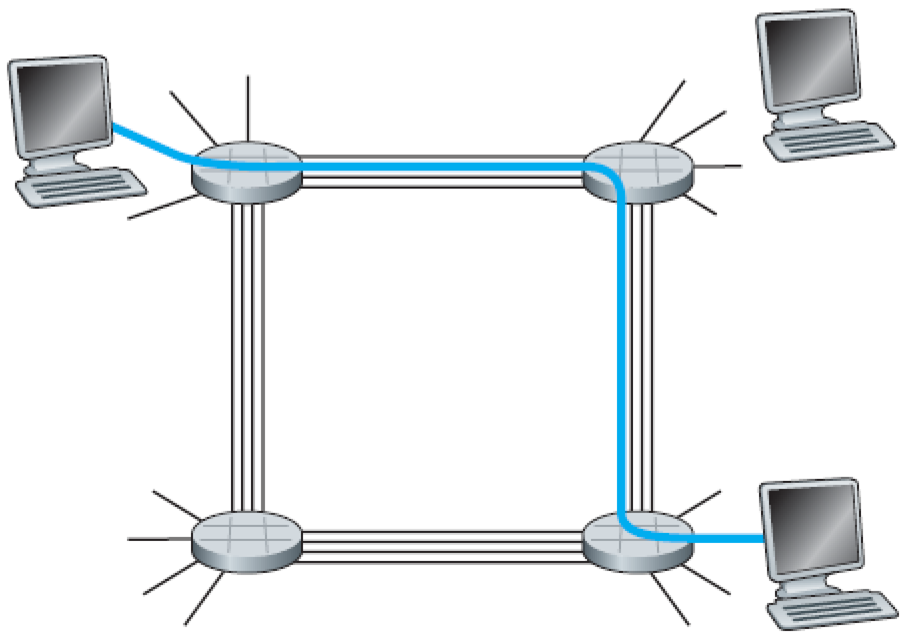


Figure 1.13 ♦ A simple circuit-switched network consisting of four switches and four links

Frequency-division multiplexing(FDM)

- With FDM, the frequency spectrum of a link is divided up among the connections established across the link.
- Specifically, the link dedicates a frequency band to each connection for the duration of the connection.
- In telephone networks, this frequency band typically has a width of 4 kHz (that is, 4,000 hertz or 4,000 cycles per second). The width of the band is called, not surprisingly, the **bandwidth.**
- **FM radio stations also use** FDM to share the frequency spectrum between 88 MHz and 108 MHz, with each station being allocated a specific frequency band.

Time-division multiplexing (TDM)

- For a TDM link, time is divided into frames of fixed duration, and each frame is divided into a fixed number of time slots.
- When the network establishes a connection across a link, the network dedicates one time slot in every frame to this connection.
- These slots are dedicated for the sole use of that connection, with one time slot available for use (in every frame) to transmit the connection’s data.

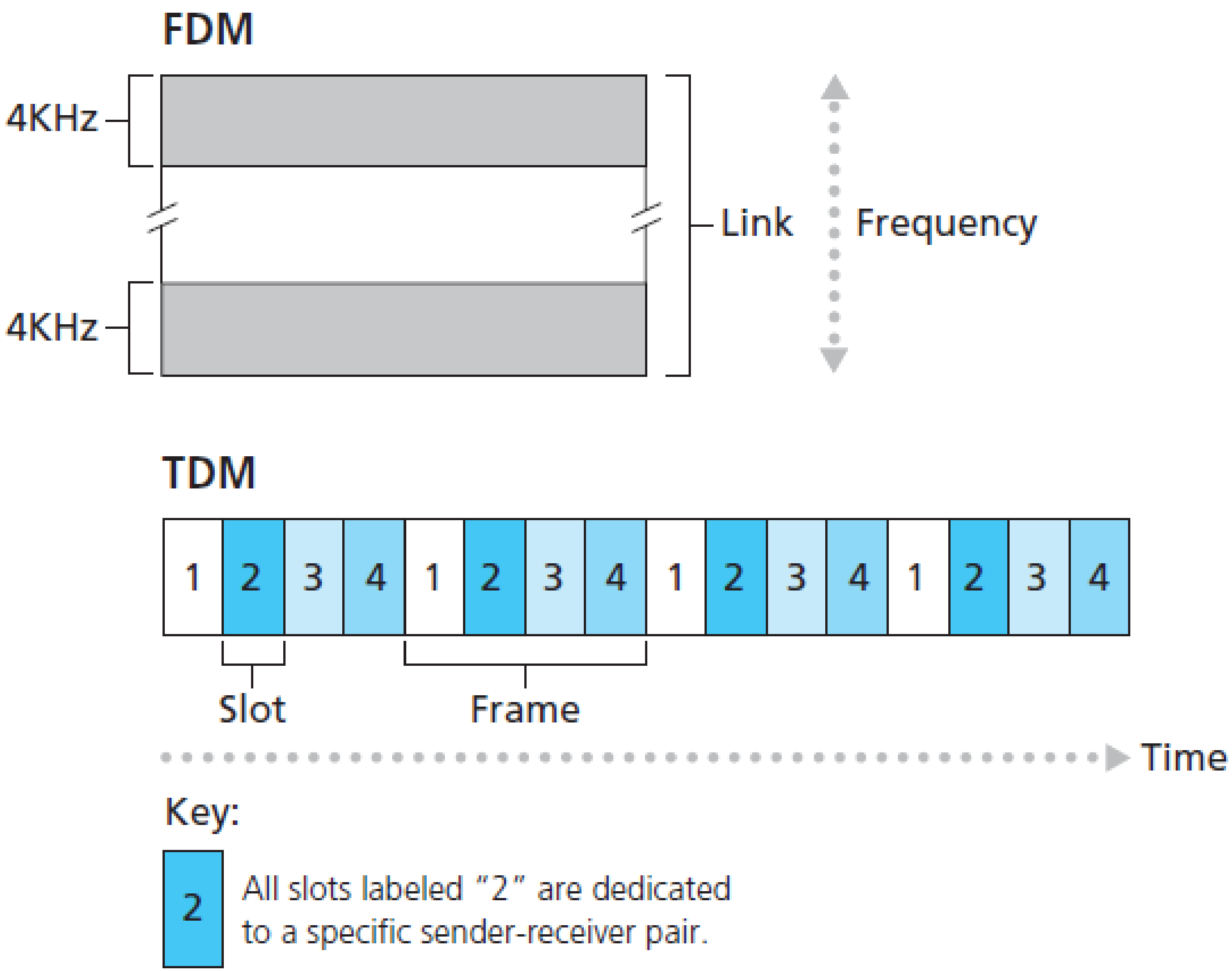


Figure 1.14 ♦ With FDM, each circuit continuously gets a fraction of the bandwidth. With TDM, each circuit gets all of the bandwidth periodically during brief intervals of time (that is, during slots)

Packet Switching Versus Circuit Switching

- Packet switching is not suitable for real-time services (for example, telephone calls and video conference calls) because of its variable and unpredictable end-to-end delays (due primarily to variable and unpredictable queuing delays).
- It offers better sharing of transmission capacity than circuit switching.
- It is simpler, more efficient, and less costly to implement than circuit switching.
- Generally speaking, people who do not like to hassle with restaurant reservations prefer packet switching to circuit switching.

Packet Switching Versus Circuit Switching

- The performance of packet switching can be superior to that of circuit switching.
- In Circuit switching pre-allocates use of the transmission link regardless of demand, with allocated but unneeded link time going unused. Packet switching on the other hand allocates link use *on demand.*

Delay in Packet-Switched Networks

- Recall that a packet starts in a host (the source), passes through a series of routers, and ends its journey in another host (the destination).
- As a packet travels from one node (host or router) to the subsequent node (host or router) along this path, the packet suffers from several types of delays at *each node along the path.*

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 in Packet-Switched Networks

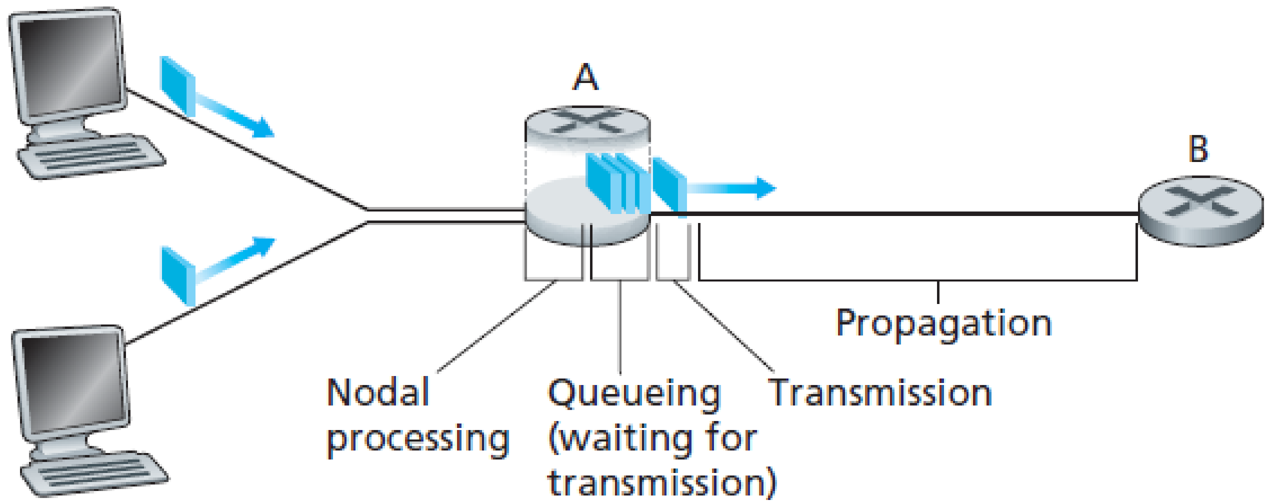


Figure 1.16 ♦ The nodal delay at router A

- The performance of many Internet applications—such as search, Web browsing, email, maps, instant messaging, and voice-over-IP—are greatly affected by network delays.

Processing Delay

- The time required to examine the packet's header and determine where to direct the packet is part of the **processing delay.**
- **The processing delay** can also include other factors, such as the time needed to check for bit-level errors in the packet that occurred in transmitting the packet's bits from the upstream node to router A.
- Processing delays in high-speed routers are typically on the order of microseconds or less.
- After this nodal processing, the router directs the packet to the queue that precedes the link to router B.

Queuing Delay

- At the queue, the packet experiences a **queuing delay as it waits to be transmitted onto** the link.
- The length of the queuing delay of a specific packet will depend on the number of earlier-arriving packets that are queued and waiting for transmission onto the link.
- If the queue is empty and no other packet is currently being transmitted, then our packet's queuing delay will be zero.
- On the other hand, if the traffic is heavy and many other packets are also waiting to be transmitted, the queuing delay will be long.
- Queuing delays can be on the order of microseconds to milliseconds in practice.

Transmission Delay

- Assuming that packets are transmitted in a first-come-first-served manner, as is common in packet-switched networks, our packet can be transmitted only after all the packets that have arrived before it have been transmitted.
- Denote the length of the packet by *L bits, and denote the transmission rate of the link from router A to router* B by *R bits/sec. For example, for a 10 Mbps Ethernet link, the rate is R = 10 Mbps;* for a 100 Mbps Ethernet link, the rate is *R = 100 Mbps. The **transmission delay is** L/R.*
- Transmission delays are typically on the order of microseconds to milliseconds in practice.

Propagation Delay

- Once a bit is pushed into the link, it needs to propagate to router B. The time required to propagate from the beginning of the link to router B is the **propagation delay.**
- The bit propagates at the propagation speed of the link.
- **The propagation** speed depends on the physical medium of the link (that is, fiber optics, twisted-pair copper wire, and so on).

Total nodal delay

- If we let d_{proc}, d_{queue}, d_{trans}, *and* d_{prop} *denote the processing, queuing, transmission,* and propagation delays.
- Then the total nodal delay is given by-

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

Packet Loss

- 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**.
- From an end-system viewpoint, a packet loss will look like a packet having been transmitted into the network core but never emerging from the network at the destination.

End-to-End Delay

- Suppose there are N 1 routers between the source host and the destination host.
- The queuing delays are negligible.
- The processing delay at each router and at the source host is d_{proc},
- The transmission rate out of each router and out of the source host is R bits/sec, and the propagation on each link is d_{prop}. The nodal delays accumulate and give an end-to-end delay:

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

Throughput in Computer Networks

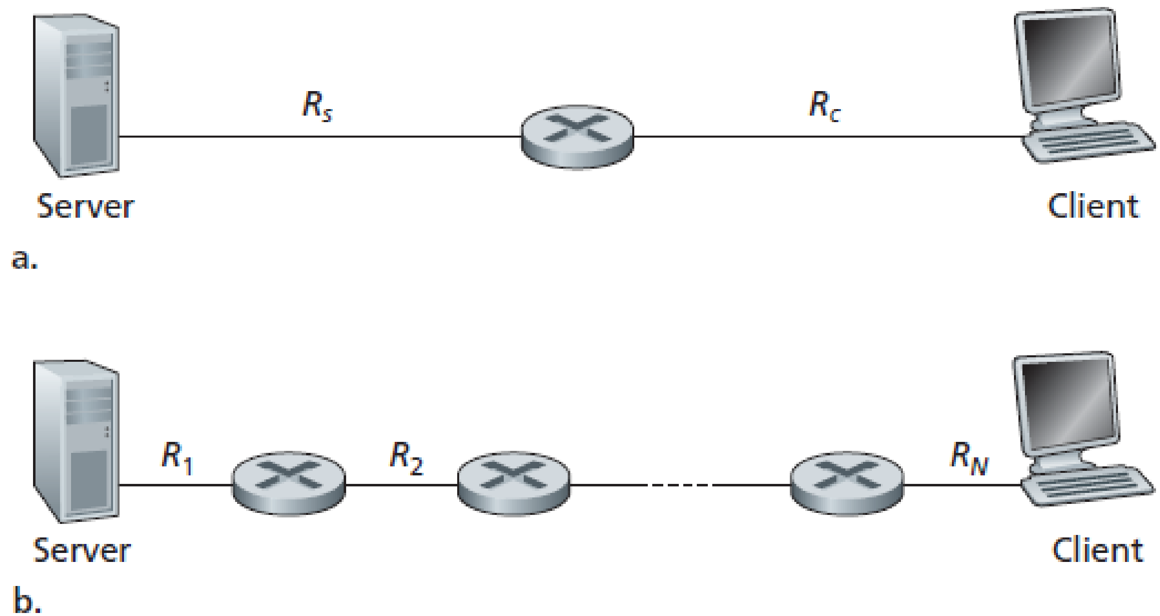


Figure 1.19 ♦ Throughput for a file transfer from server to client

- Let R_s denote the rate of the link between the server and the router; and
- R_c denote the rate of the link between the router and the client.

Throughput in Computer Networks

- The server cannot pump bits through its link at a rate faster than R_s bps; and the route cannot forward bits at a rate faster than R_c bps.
- If $R_s < R_c$, then the bits pumped by the server will "flow" right through the router and arrive at the client at a rate of R_s bps, giving a throughput of R_s bps.
- If, on the other hand, $R_c < R_s$, then the router will not be able to forward bits as quickly as it receives them. In this case, bits will only leave the router at rate R_c, giving an end-to-end throughput of R_c.

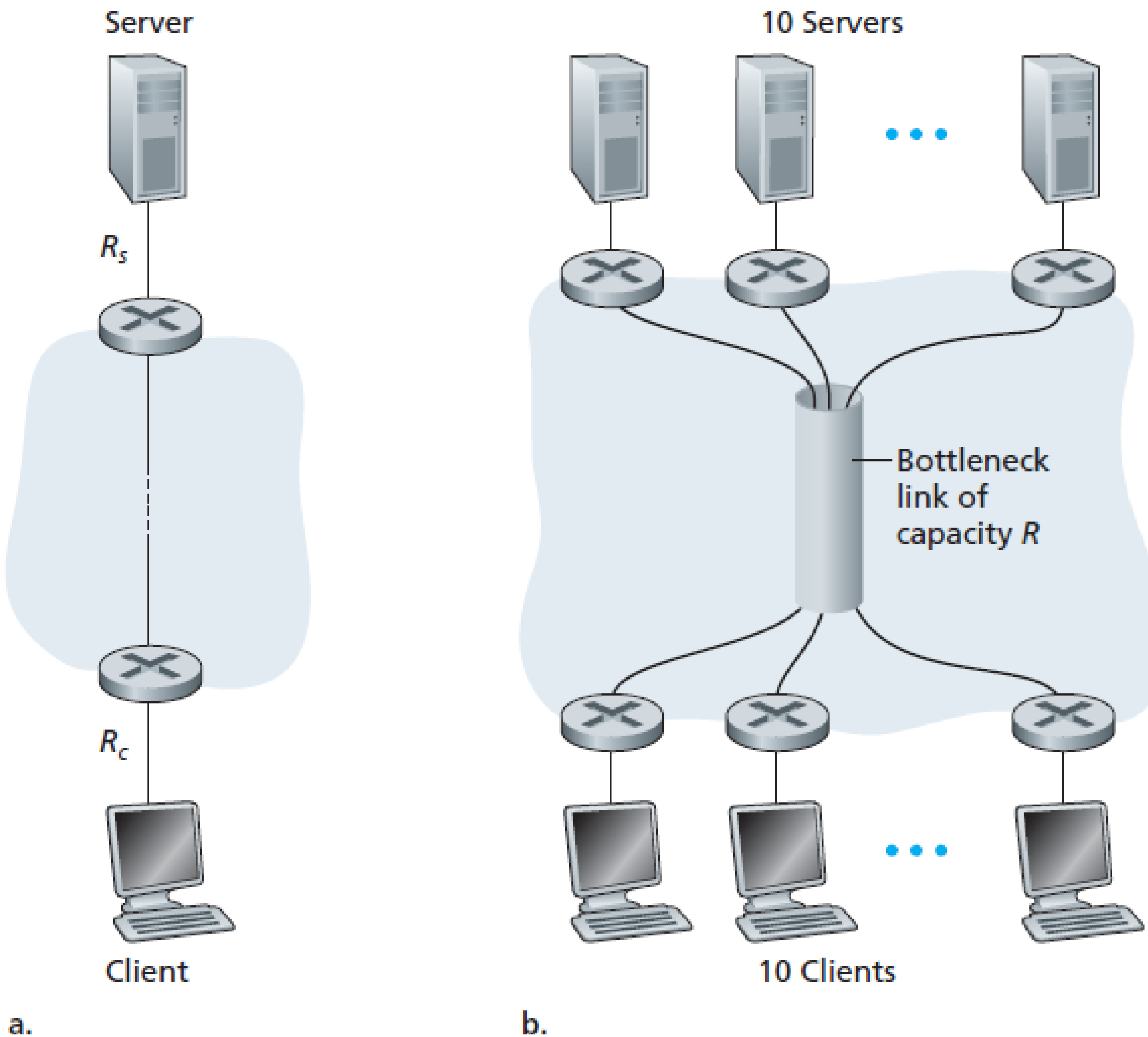


Figure 1.20 ♦ End-to-end throughput: (a) Client downloads a file from server; (b) 10 clients downloading with 10 servers

Layered Architecture

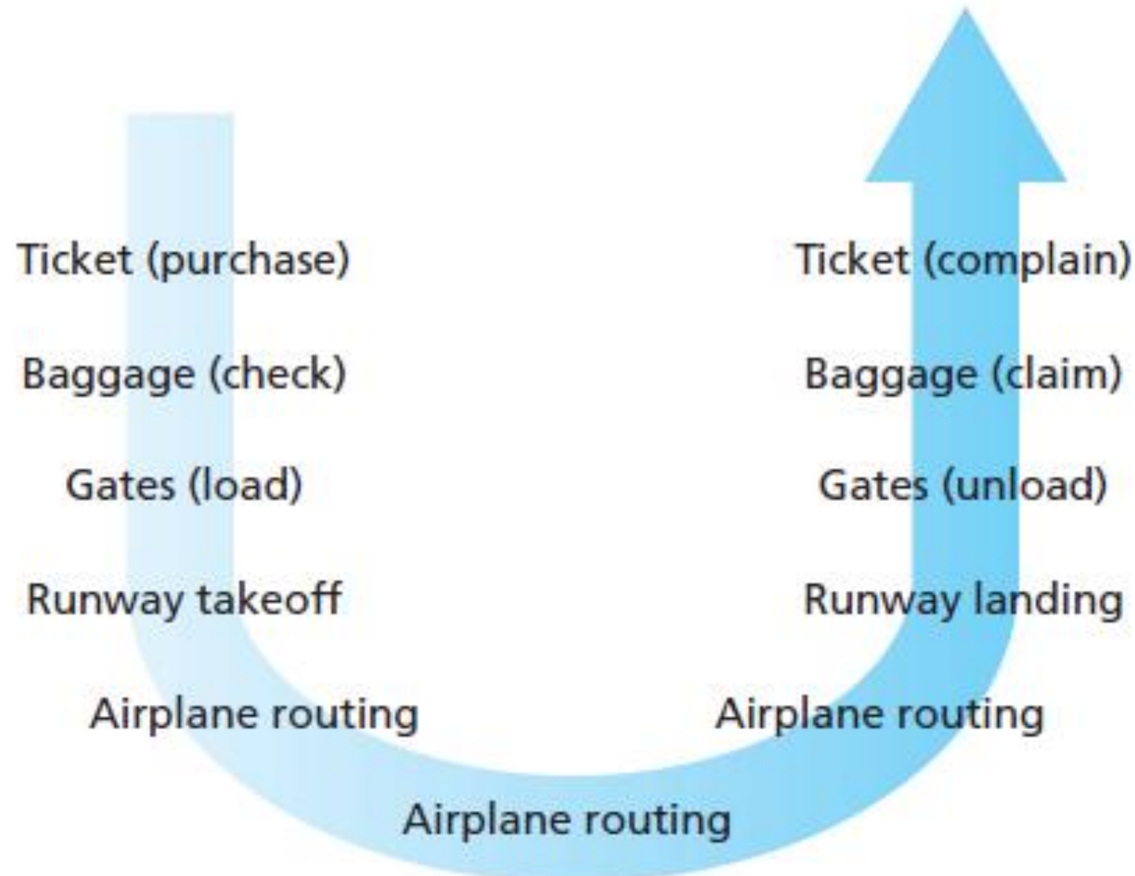


Figure 1.21 ♦ Taking an airplane trip: actions

Layered Architecture

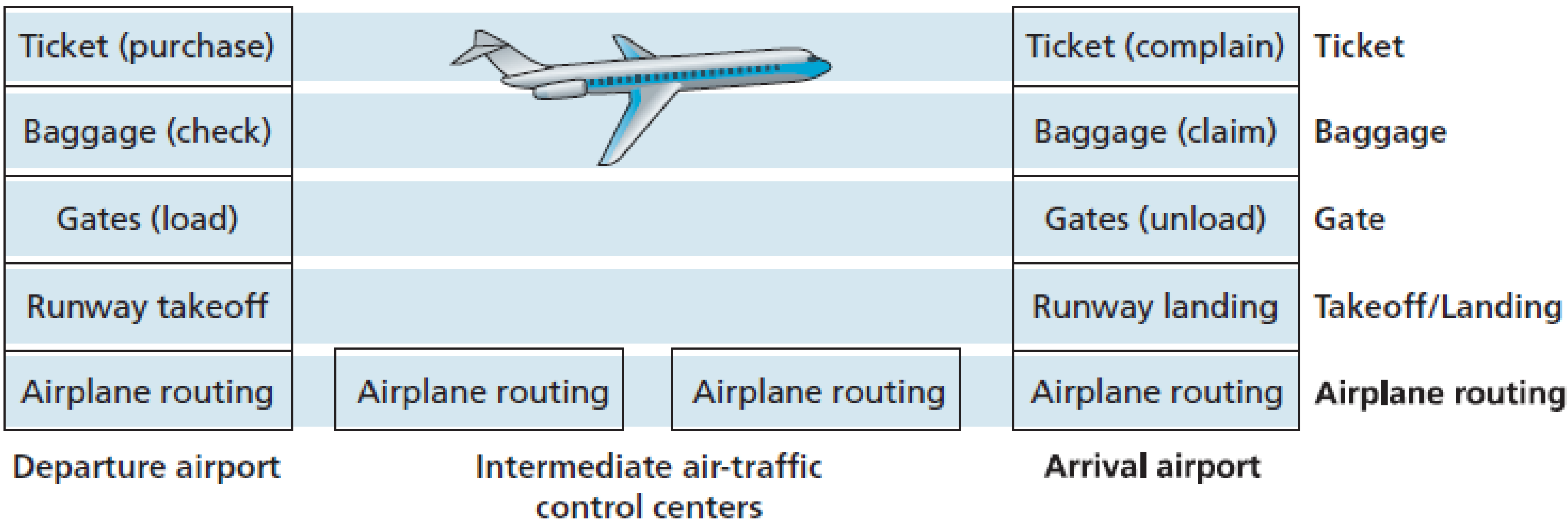
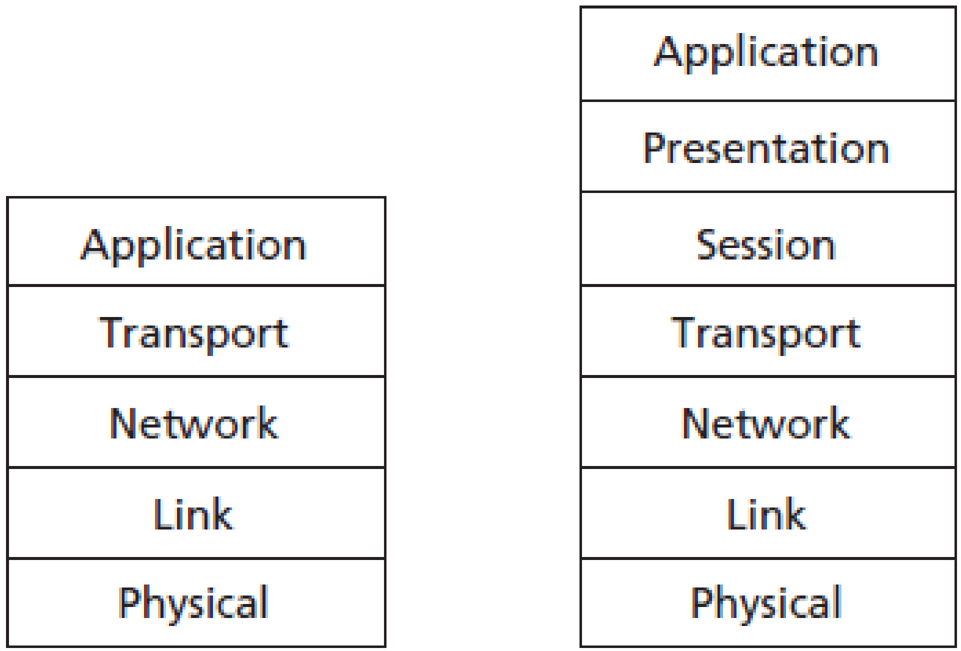


Figure 1.22 ♦ Horizontal layering of airline functionality

Layered Architecture



a. Five-layer Internet protocol stack

b. Seven-layer ISO OSI reference model

Figure 1.23 ♦ The Internet protocol stack (a) and OSI reference model (b)

Encapsulation

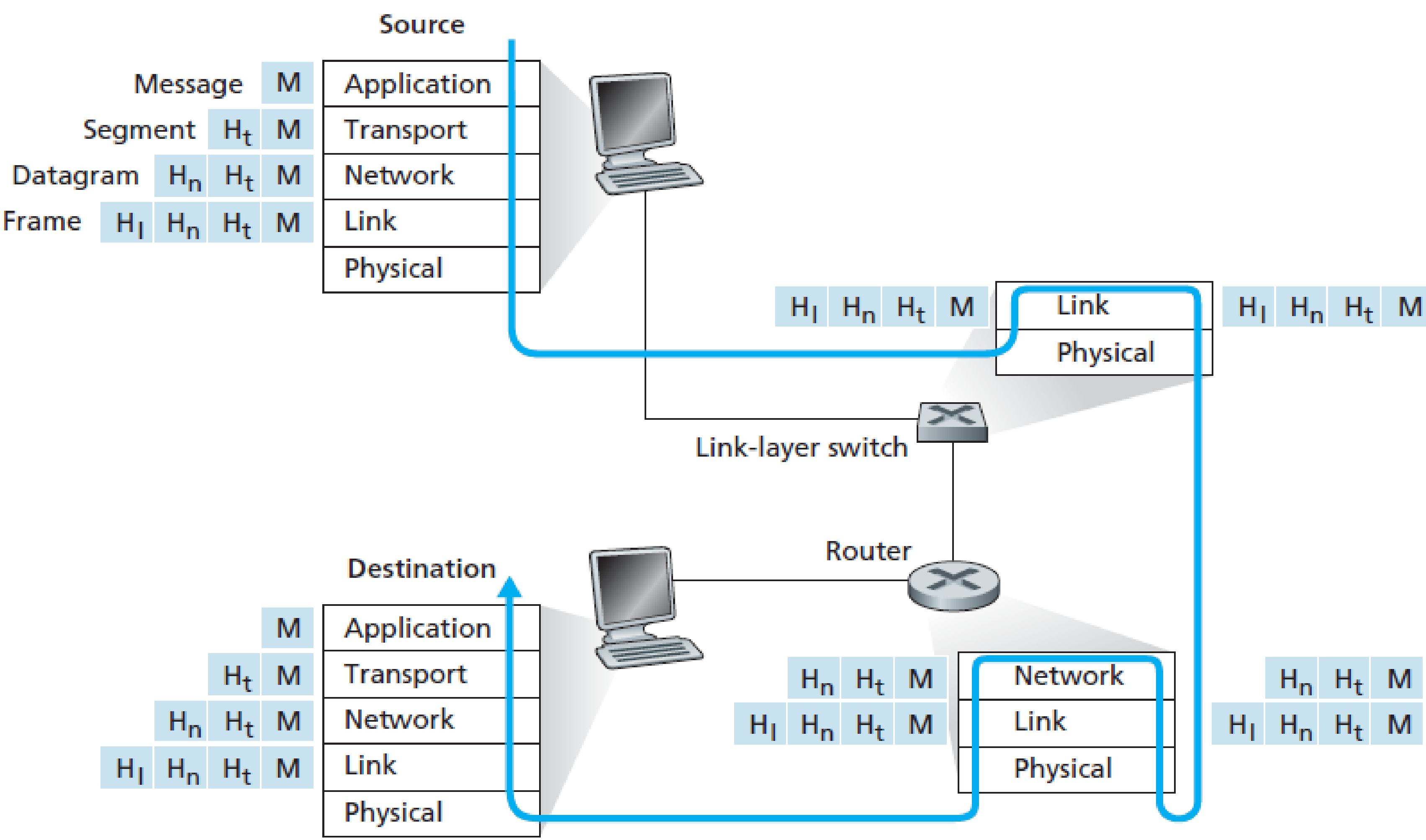


Figure 1.24 ♦ Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality

Encapsulation

- At the sending host, an **application-layer message** (M) is passed to the transport layer.
- The transport layer takes the message and appends additional information (so-called transport-layer header information, H*t*) that will be used by the receiver-side transport layer.
- The application layer message and the transport-layer header information together constitute the **transport-layer segment**.
- The transport layer then passes the segment to the network layer, which adds network-layer header information (H*n*) such as source and destination end system addresses, creating a **network-layer datagram**.

Encapsulation

- The datagram is then passed to the link layer, which will add its own link-layer header information and create a **link-layer frame**.
- A packet has two types of fields: header fields and a **payload field**. The payload is typically a packet from the layer above.

End