CSC 4350 – Computer Networks

Connection Media, Switching, and ISPs

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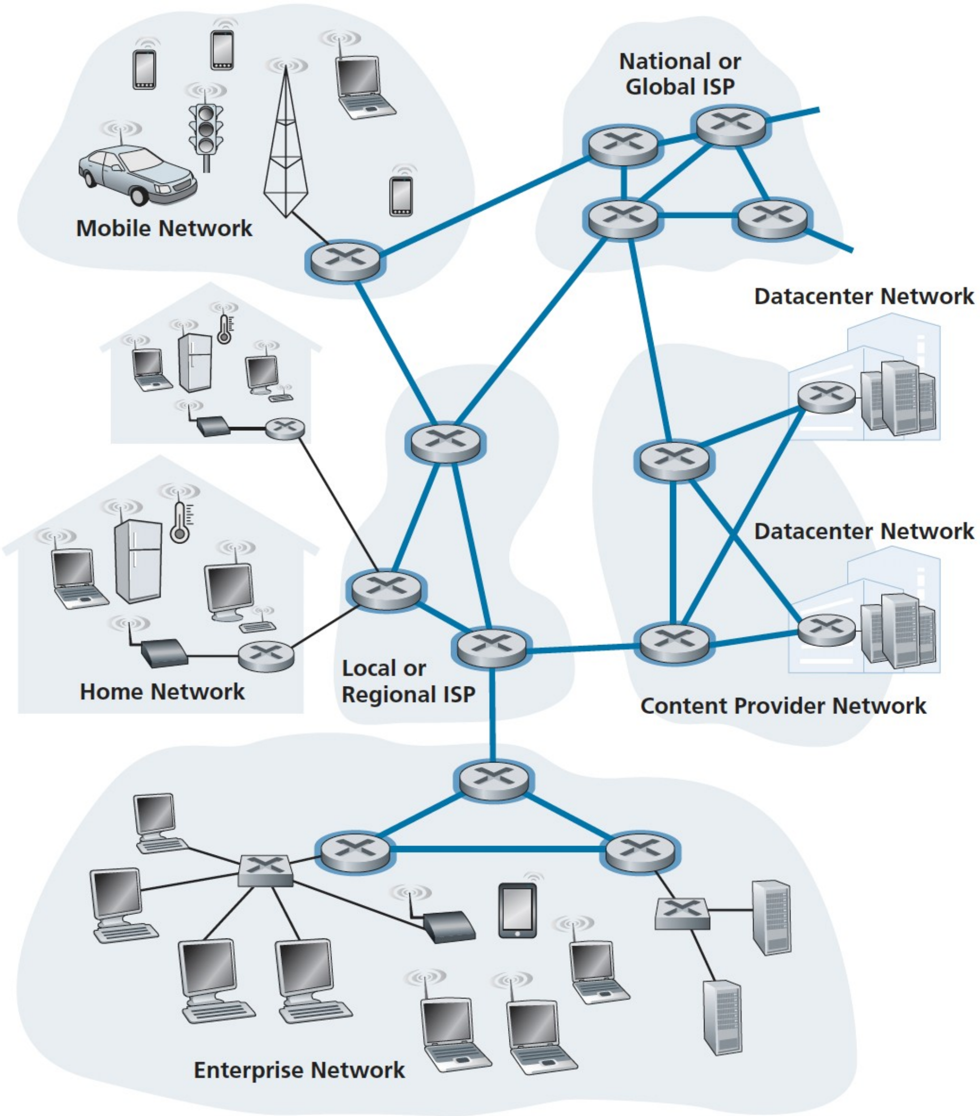
Physical Media

- For each transmitter-receiver pair, the bit is sent by propagating electromagnetic waves or optical pulses across a physical medium
  - Twisted-pair copper wire
  - Coax cable
  - Fiber-optic cable
  - Terrestrial radio spectrum
  - Satellite radio spectrum
- Categories
  - Guided media – guided along a solid medium, like a cable
  - Unguided media – waves are in the atmosphere, outer space, such as a wireless LAN or digital satellite channel

Physical Media

- Progression (good to best)
  - Unshielded twisted pair (UTP) – 10Mbps to 10Gbps
  - Coaxial cable – hundreds of Mbps
    - Used as a guided shared medium
  - Fiber optics
    - Thin, flexible medium that conducts pulses of light, each representing a bit
    - Single optical figure can support up to (perhaps) 10s-100s Gbps
- Others
  - Terrestrial Radio Channels – no wire needed to be installed, can penetrate walls, connectivity for a mobile user
    - Operate over
      - Very short (1-2 meter) distance
      - Local areas (spans 10-100 meters)
      - Wide area (Up to 10+km)
  - Satellite Radio Channels – link two or more Earth-based microwave transmitter/receivers (ground stations)
    - Satellite receives transmissions on one band, regenerates the signal on a repeater, transmits signal on a different frequency
    - Geostationary satellites, low-earth orbiting (LEO) satellites

Figure 1.10 – The Network Core



Packet Switching

- End systems exchange messages with each other
- Messages – contain anything the application designer wants
- To send a message from a source end system to a destination end system, the source breaks long messages into smaller chunks of data (packets)
- Between source and destination – packet travels through communication links and packet switches

Store-and-Forward Transmission

- Means that the packet switch must receive the entire packet before it can begin to transmit the first bit of the packet onto the outbound link
- Router will typically have many links, since its job is to switch an incoming packet onto an outgoing link
- Because router employs store-and-forwarding, the router cannot transmit the bits it has received
  - Must buffer the packet's bits
- Only after router has received all of the packet's bits can it begin to transmit

Figure 1.11 – Store-and-Forward Packet Switching

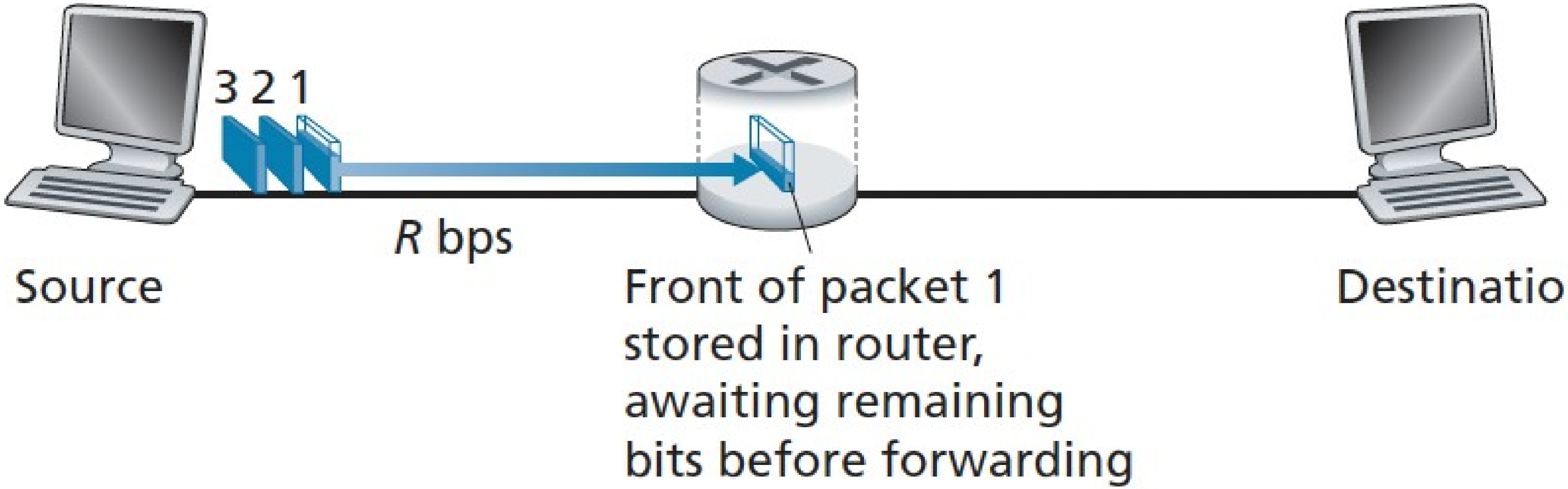


Figure 1.11, Explained

- Source begins to transmit at time 0
- At time L/R seconds, the source has transmitted the entire packet, which has been received and stored at the router
- At time L/R seconds – since the router has just received the entire packet, it can begin to transmit the packet onto the outbound link towards the destination
- At time 2L/R, the router has transmitted the entire packet
    - Entire packet has been received by the destination
- Total delay: 2L/R
- If bits were forwarded as received, the total delay would be L/R

More Generally…

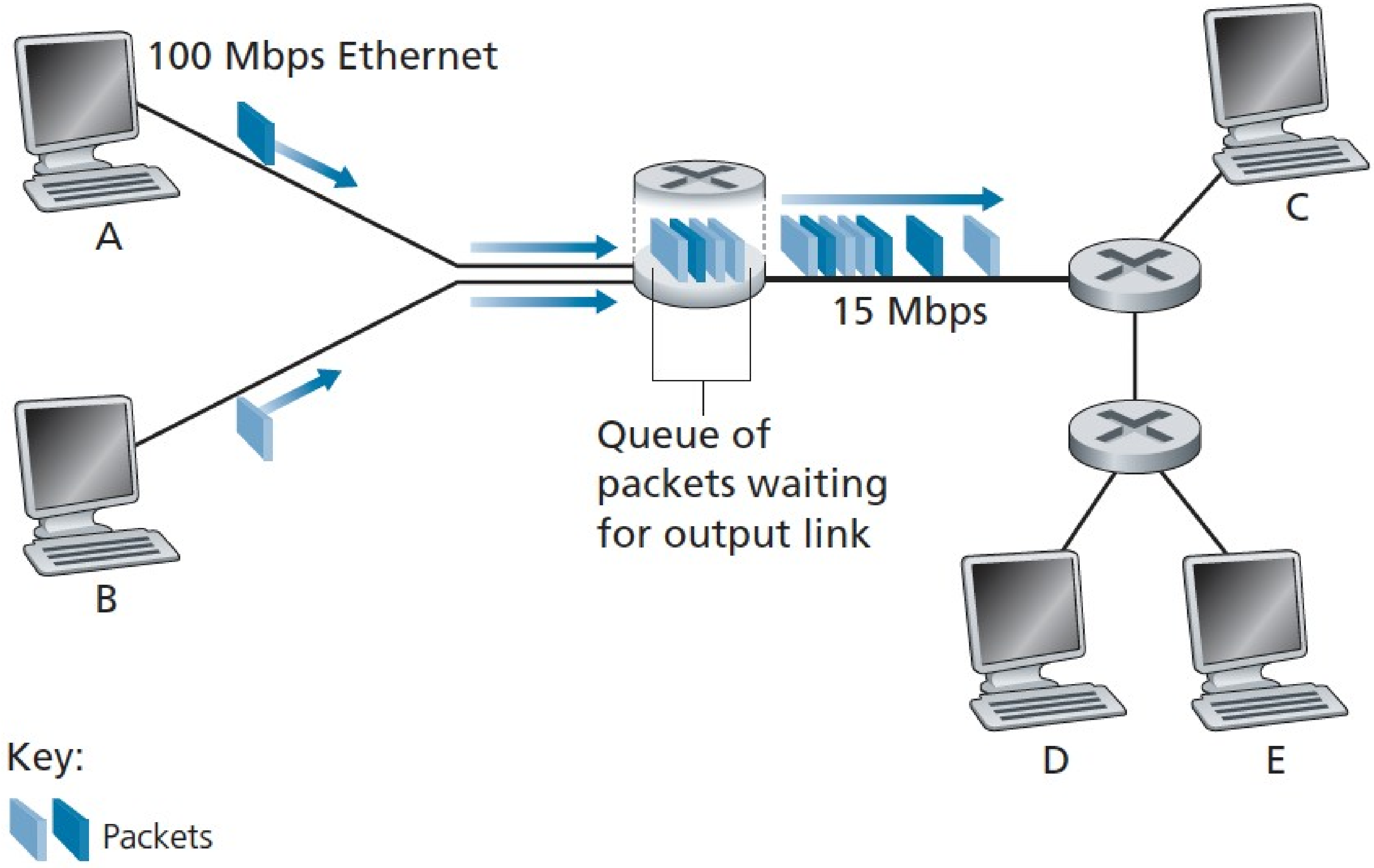
- Send one packet from source to destination over a path consisting of N links each of rate R
  - N-1 routers between src and dest
- End-to-end delay

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

Queuing Delays and Packet Loss

- Each packet switch has multiple links attached to it
  - For each attached link, the packet switch has an output buffer/queue
    - Stores packets that the router is about to send into that link
  - If an arriving packet needs to be transmitted onto a link but finds the link busy with the transmission of another packet, arriving packet must wait in the output buffer
- In addition to store-and-forward delays, packets suffer output buffer queuing delays
  - Variable and depend on the level of network congestion
- An arriving packet may find that the buffer is full with others waiting for transmission
  - Packet loss will occur – arriving packet or an already-queued packet will be dropped

Figure 1.12 – Packet Switching



Packet Switching – Fig. 1.12

- Hosts A and B are sending packets to Host E
- Hosts A and B first send their packets along 100 Mbps ethernet links to the first router
- Router directs the packets to the 15 Mbps link
- If during a period of time the arrival rate of packets to the router exceeds 15 Mbps – congestion will occur at the router as packets queue in the link's output buffer before being transmitted onto the link
- If Host A and B each send a burst of 5 packets back-to-back at the same time, most of these packets will end up waiting in the queue

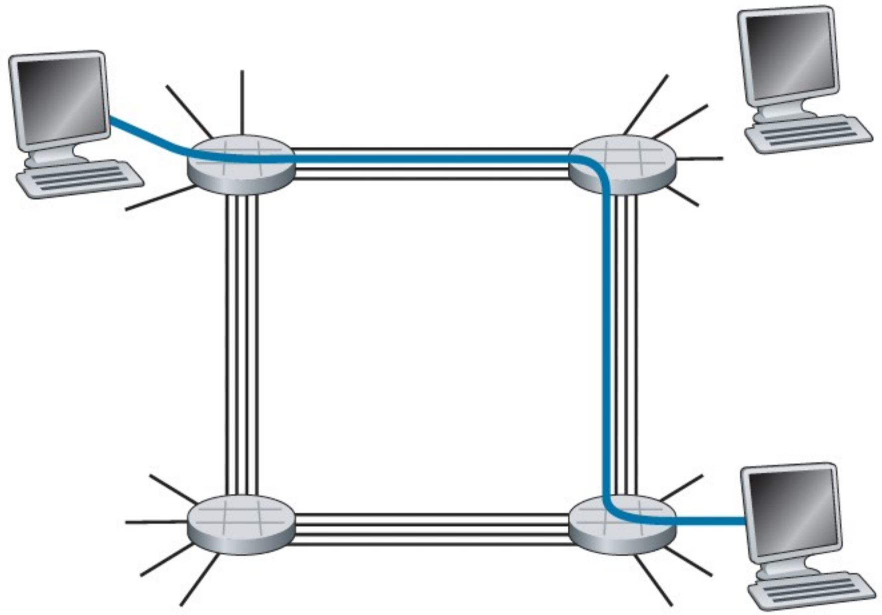
Forwarding Tables and Routing Protocols

- Packet forwarding – done in different ways in different types of computer networks
- Internet – every end system has an IP address
- When source end system wants to send a packet to a destination end system, the source includes the destination's IP address in the packet's header
- When a packet arrives at a router in the network, the router examines a portion of the packet's destination address and forwards the packet to an adjacent router
- Each router has a forwarding table that maps destination addresses to that router's outbound links
- When the packet arrives at a router, the router examines the address and searches its forwarding table with the destination address to find the appropriate outbound link
- Router then directs the packet to this outbound link
- Real-world example: traveling from home to a destination
  - Note: if the authors have ever used a GPS, the example they listed is seriously outdated.

Circuit Switching

- Resources needed along a path to provide communication are reserved for the duration of the communication session
- Packet switching – no reservation (previous topic)
- Session’s messages use the resources on demand; may have to wait for access to a certain communication link
- Before the sender can send the information, the network must establish a connection between sender and receiver
  - Telephony jargon - circuit

Simple Circuit-Switched Network Consisting of Four Switches and Four Links – Fig. 1.13



From Fig. 1.13

- Each link has/is a part of four circuits
  - Link can support four simultaneous connections
- When two hosts want to communicate, network establishes a dedicated end-to-end connection between the two hosts
  - For Host A to communicate with Host B
    - Network must first reserve one circuit on each of two links
- Key takeaway
  - Packet-switched – sends information into the network without a reservation on a link/series of links
  - Circuit-switched – needs the links to/from sender and receiver reserved

Packets Over Circuits

- Proponents of packet-switching
  - It offers better sharing of transmission capacity than circuit switching
  - It is simpler, more efficient, and less costly to implement
  - Used on demand
- Circuit switching
  - Reserves/”pre-allocates” use of transmission link regardless of demand, with allocated but unneeded link time going unused

A Network of Networks

- All kinds of ways to connect to the Internet, but must depend on an access ISP
  - Wired or wireless
  - Lots of different tech to use, perhaps
- Access ISPs must be interconnected between themselves, thus the “network of networks”
- Network Structure 1
  - Connects all of the access ISPs with a single global transit ISP
  - Global transit ISP – network of routers and links that goes all over the world, and has at least one router near each of the hundreds of thousands of ISPs
  - Very costly; would need to charge each access ISP for connectivity, depending on traffic
  - Access ISP – Customer, Global Transit ISP - Provider

A Network of Networks

- Network Structure 2
  - Two-tier hierarchy with global transit providers residing at the top tier
  - Access ISPs at the bottom tier
  - Assumption: global transit ISPs are capable of getting close to each access ISP, but find it economically desirable to do so
  - Realistically
    - No ISP has presence in each and every city in the world
    - In any given region – there must be a regional ISP to which the access ISPs in the region connect
    - Each regional ISP to Tier-1 ISPs
      - Again, these ISPs don't have a presence in every city in the world
      - Roughly 10+ Tier-1 ISPs

Network of Networks

- Each access ISP pays the regional ISP to which it connects
- Each regional ISP pays the Tier-1 ISP to which it connects
- Customer-provider relationship at each level of the hierarchy
- Some regions might have larger regional ISPs
- Must add other pieces
  - Points of presence (PoP)
  - Multi-homing
  - Peering
  - Internet exchange points
- Helps make up Network Structure 3

A Network of Networks

- Network Structure 4
  - PoP – group of one or more routers at the same location in the provider's network where customer ISPs can connect to the provider ISP
    - To connect to a provider's PoP, it can lease a high-speed link from a third-party telecom provider to directly connect one of its routers to a router at the PoP
  - Multi-home – connect two or more provider ISPs
  - A pair of nearby ISPs at the same level of the hierarchy can peer
    - Directly connect networks together so that all the traffic between them passes over the direct connection rather than upstream
  - Internet Exchange Point (IXP) – meeting point where multiple ISPs can peer together
    - Typically in its own building with its own switches

A Network of Networks

- Network Structure 5 – today’s Internet
  - Builds on top of Network Structure 4 by adding content-provider networks
  - Google gets massive props from your authors
- Summary – Today’s Internet
  - Consists of 10+ tier-1 ISPs and many lower-tier ISPs
  - ISPs – diverse in coverage; some span countries, continents, oceans
  - Lower-tier ISPs connect to the higher-tier ISPs and higher-tier ISPS connect with each other
  - Users and content providers are customers of lower-tier ISPs
  - Lower-tier ISPs are customers of higher-tier ISPs

Interconnecting ISPs – Figure 1.15