

Networking Chapter 1

Chapter 1 Computer Networks and the Internet

1.1 What Is the Internet?

1.1.1 A Nuts-and-Bolts Description

All devices connected to the internet are called **hosts** or **end-systems**

There are different communication links that connect these hosts including **fiber**, **copper**, **coax**, and **radio** spectrum all of which transmit at different transmission rates (measured in bits/second)

End systems access the internet via (low tier) ISPs and there are different types of ISPs such as Home (Copper, Cable (TV) Modem, and DSL) University, Corporate WiFi ISPs and Cellular ISPs

- These lower tier ISPs connect to higher-tier ISPs with higher speed routers connected by fiber and the upper-tier ISPs are connected to each other
- the computers and other devices connected to the Internet are often referred to as end systems (including servers, laptops, etc.). They are referred to as end systems because they sit at the edge of the Internet.

In order for devices to be able to communicate with each other, a standardized protocol must be used across all different types of systems

These standards are outlined by the **IETF** as **RFCs** however for internet standards the **IEEE** specifies **Ethernet** and **WiFi** standards think **802.3** Ethernet and **802.11** WiFi

1.1.2 A Services Description

Instead of looking at the internet in a 'technical' description with routers and end-systems, we can look at the internet as the infrastructure that provides services to applications. Think about email or text, or even web surfing. These apps need an infrastructure for data to get from point A --> point B. These apps also include mobile apps.

- The applications that run on end systems are said to be **Distributed** Applications because they involve multiple **end-systems** exchanging data with each other. Think

about a video conferencing app with 10 people, all those **end-systems** of those 10 users are exchanging VoIP data with each other.

- These apps run on end systems NOT the network core (routers & switches)
- Although (routers & switches) facilitate the exchange of data they're **NOT** concerned with the application data whatsoever (unless it's a NGFW which does application-layer inspection)

How does one program running on one end system instruct the Internet to deliver data to another program running on another end system? **A Socket** as well as defining **How** one program should send the data

1.1.3 What Is a Protocol?

What is a protocol? What does a protocol do?

*A protocol is a rule set for how host A should send **some type** of data (HTTP, TCP, STP) to host B.* So all a protocol does is define **what messages** should be sent between two hosts using **A** protocol and how each host should respond to those messages. Take the TCP protocol and its three-way handshake to establish a connection SYN -> SYN ACK -> ACK

Book Definition: A protocol defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other event.

1.2 The Network Edge

This section focuses on the components at the **edge** of the internet namely, the computers, smartphones, etc.

Throughout this book we will use the terms hosts and end systems interchangeably; that is, host = end system. They're called hosts because they **host** some application such as a browser.

1.2.1 Access Networks

the access network is the network that connects to an edge router which connects to the internet

For Broadband connection to the internet for residential access the two most common types are digital subscriber line (DSL)(Telephone) and cable (TV).

Home Access: DSL, Cable, FTTH, and 5G Fixed Wireless

DSL

-- DSL Modem -> CO -- INSIDE CO -> DSLAM ---> Internet

- each customer's DSL modem uses the existing telephone line exchange data with the **Digital-Subscriber-Line-Access-Multiplexer**(DSLAM) located in the telco's **Central Office (CO)**
- Takes the internet digital data and converts it into high-frequency tones (which are sent across the telephone line) and converts it back into internet digital data by the teleco company's DSLAM that then connects to the internet. *Yes Hundreds or even thousands of households connect to a single DSLAM.*

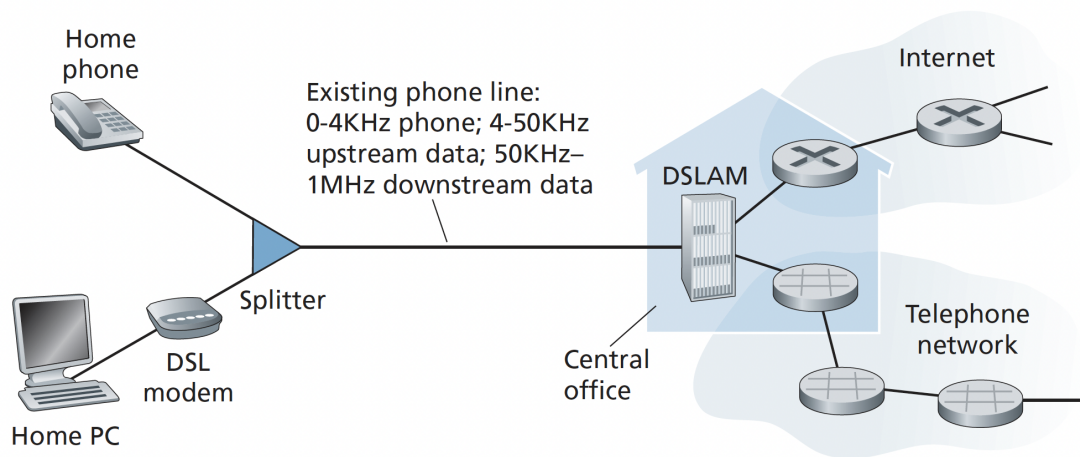


Figure 1.5 ♦ DSL Internet access

- The residential telephone line carries both data and traditional telephone signals simultaneously, which are encoded at different frequencies. This approach makes the single DSL link appear as if there were **three separate links**. this is related to FDM and TDM.
 - A high-speed downstream channel, in the 50 kHz to 1 MHz band
 - A medium-speed upstream channel, in the 4 kHz to 50 kHz band
 - An ordinary two-way telephone channel, in the 0 to 4 kHz band
- **DSLAM Transmission Rates**
 - Because the downstream and upstream transmission rates are different DSL access is said to be **asymmetric**
 - Transmission rates are negatively impacted by distance and electrical interference
 - downstream transmission rates 24 Mbs and 52 Mbs,
 - upstream rates of 3.5 Mbps and 16 Mbps;
 - the newest standard provides for aggregate upstream plus downstream rates of 1 Gbps [ITU 2014]

Cable

Uses TV cable lines. Home has **Cable Modem** which converts the digital internet data to

analog signals, and the CMTS inside the ISP's Cable Head End does the reverse before sending it to the internet.

House -- COAX Connection (Analog Signals) --> -- Fiber nodes -> --(FIBER Connection)--> Cable Head End --(Inside cable end) --> Cable Modem Termination System

You can think of the **Cable Head End** the same as the teleco's Central Office and the Cable Modem Termination System (CMTS) as the DSLAM

*Because this network utilizes both Fiber **AND** Coax this home connection is referred to as Hybrid Fiber Coax (HFC)*

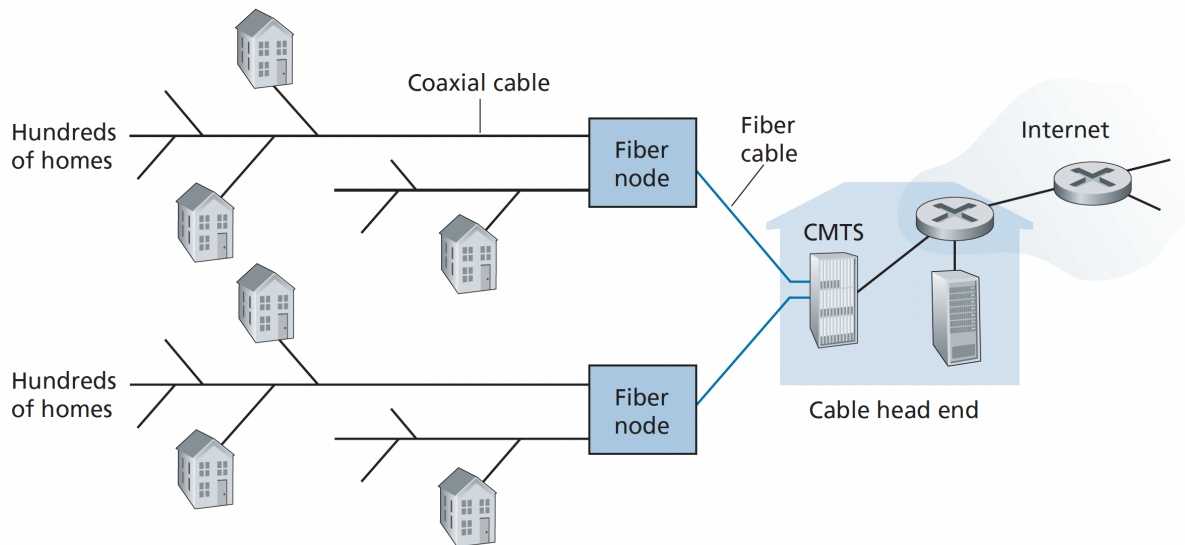


Figure 1.6 ♦ A hybrid fiber-coaxial access network

- **Data Over Cable Service Interface Specification (DOCSIS) Transmission Rates**
 - Also Asymmetric
 - **DOCSIS 2.0** 40 Mbps (down) 30 Mbps (up)
 - **DOCSIS 3.0** 1.2 Gbps (down) and 100Mbps (up)
 - As in the case of DSL networks, the maximum achievable rate may not be realized due to lower contracted data rates _or media impairments.
 - travels downstream on every link to every home and every packet sent by a home travels on the upstream channel to the head end
- **fiber to the home (FTTH)** This provides fiber from the CO directly to the home

Optical Distribution Network Types

- Direct Fiber (Connection between CO and splitter is shared, but between Homes and the splitter, individual fiber lines are linked to each home)
- **Optical Distribution Network Architecture Types** (Two types of network architectures that perform this splitting)
 - Active Optical Networks (AONs) --> switched Ethernet

- Passive Optical Networks (PONs) -->
- Each home has an connects their 'edge router' to their Optical Network Terminator
- Homes individual fiber lines are connected to one line via a Optical Splitter
- The Single fiber line between the splitter and CO is terminated by the **Optical Line Terminator**
- all packets sent from OLT to the splitter are replicated at the splitter
- PON Distribution Architecture

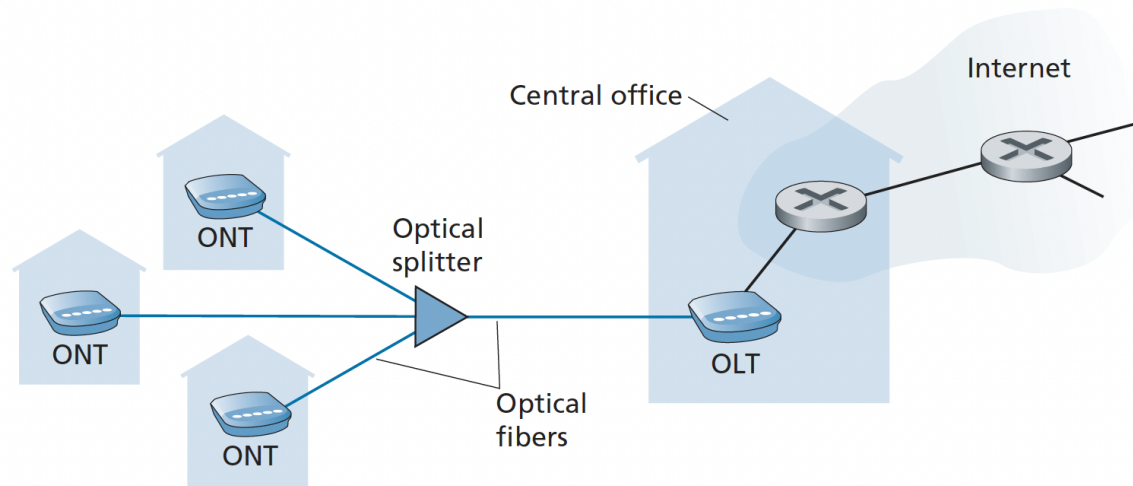


Figure 1.7 ♦ FTTH Internet access

5G Wireless

Beam-forming technology (radio spectrum) and data is sent wirelessly from the provider's base station to the a modem in the home. A WiFi wireless router is connected to the modem

Access in the Enterprise (and the Home): Ethernet and WiFi

- Ethernet -> Wired connection via switches
- WiFi -> Data sent to/from Wireless Access Point (which connects to the internet via Wired ethernet)

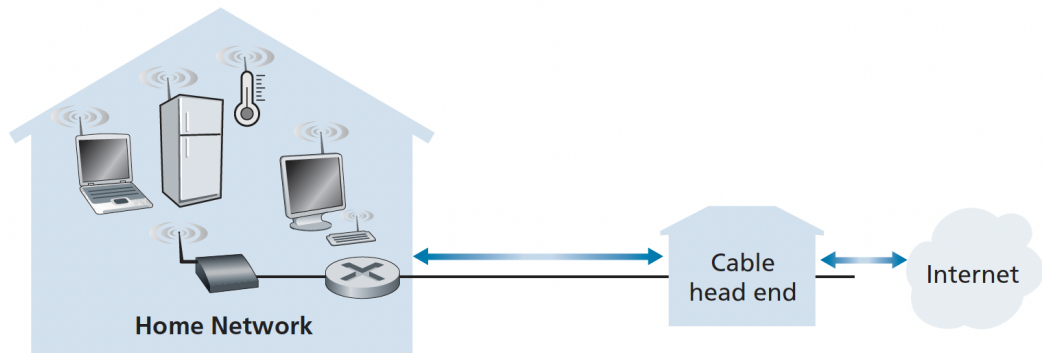


Figure 1.9 ♦ A typical home network

Wide-Area Wireless Access: 3G and LTE 4G and 5G

These devices employ the same wireless infrastructure used for cellular telephony to send/receive packets through a base station that is operated by the cellular network provider.

1.2.2 Physical Media

Data is sent through a series of sender and receiver pairs connected by some physical medium. These **DO NOT** have to be the same between pairs only within (think about HFC)

Types of Physical Media

- Guided Media --> Waves are **guided** along a **physical** medium (fiber, copper, coax)
- Unguided Media --> Waves propagate in the atmosphere and in outer space (WiFi, Satellite)

Interestingly it's NOT the medium, but rather the **Work needed for Installation** that costs the most

Twisted-Pair Copper Wire

- *Most common transmission media*
- Exactly as it sounds *pairs* of copper wire are twisted to reduce Electro Magnetic Interference (EMI)

Coaxial Cable

- 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.

- the modem shifts the digital signal to a specific frequency band, and the resulting analog signal is sent from the transmitter to one or more receivers.
- Shared medium where multiple end systems can directly connect to the cable

Fiber Optics

- Uses pulses of light, with each pulse representing a bit
- tens or even hundreds of gigabits per second.
- Immune to EMI
- Very low signal attenuation up to 100 kilometer
- **Optical Carrier (OC-*n*) Transmission Rates**
 - **link speed equals $n * 51.8 \text{ Mbps}$**
 - OC-1
 - OC-3
 - OC-12
 - OC-24
 - OC-48
 - OC-96
 - OC-192
 - OC-768

Terrestrial Radio Channels

- Radio channels carry signals in the electromagnetic spectrum
- They require no physical wire to be installed, can penetrate walls

Environmental considerations

- path loss and shadow fading (which decrease the signal strength as the signal travels over a distance and around/through obstructing objects)
- multipath fading (due to signal reflection off of interfering objects)
- interference (due to other transmissions and electromagnetic signals)

Terrestrial Radio Channels Types

- Short range (1-2m) (med devices & bluetooth, NFC)
- Medium range (10-[1,2,3,4]00m) (WiFi)
- Long range spanning tens of kilometers (cellular)

Satellite Radio Channels

-The satellite receives transmissions on one frequency band, regenerates the signal using a repeater and transmits the signal on another frequency.

- substantial signal propagation delay (280 ms)
- only used if DSL and cable are not an option

Two Types of Satellites used

- geostationary satellites --> permanently remain above the same spot on Earth
- low-earth orbiting (LEO) satellites --> Many satellites orbiting earth
 - Not used for internet connectivity

1.3 The Network Core

The core of the internet is made up of packet switches (**routers**)

FROM NOW ON PACKET SWITCHES = ROUTERS (This is just my personal preference)

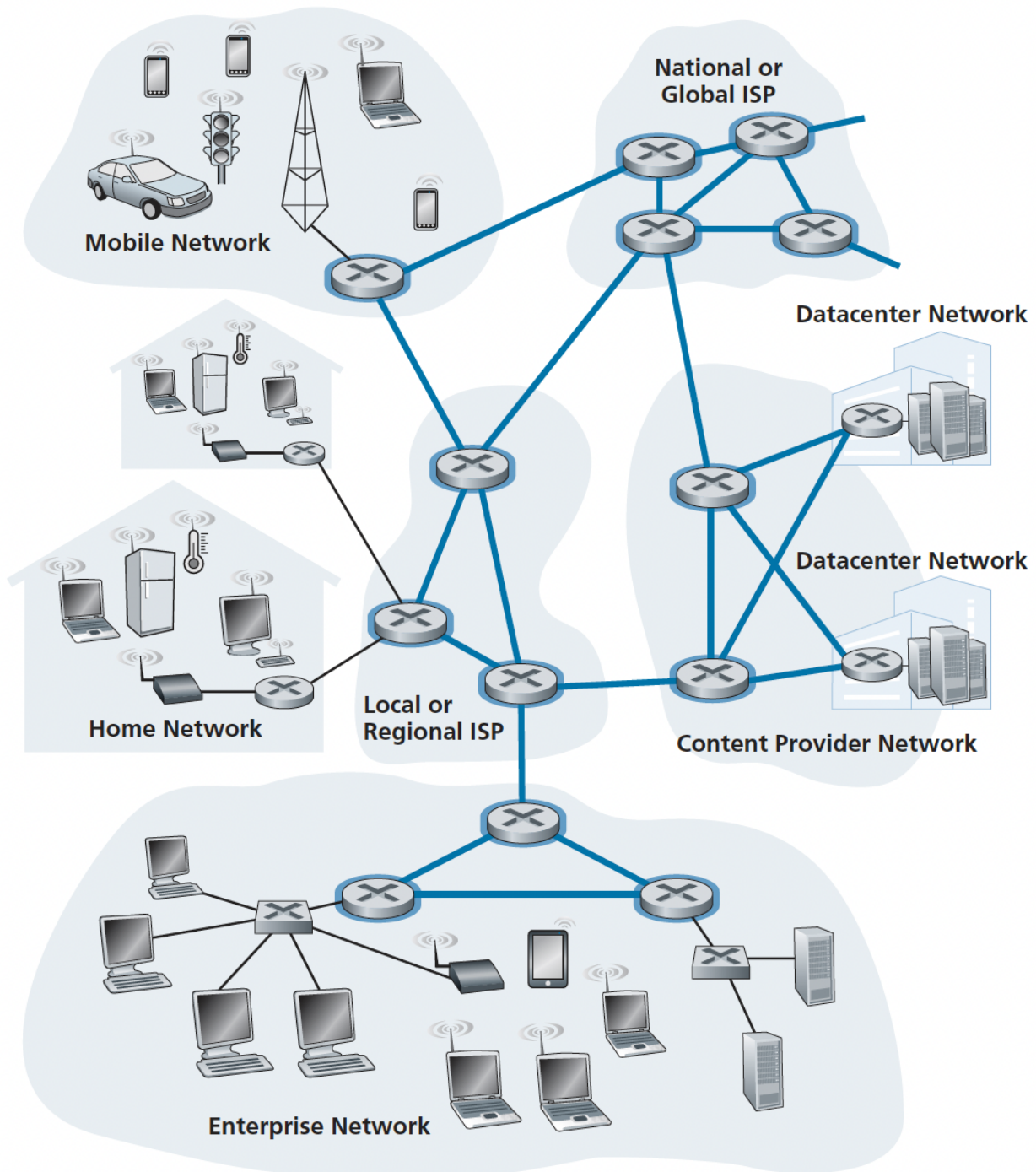


Figure 1.10 ♦ The network core

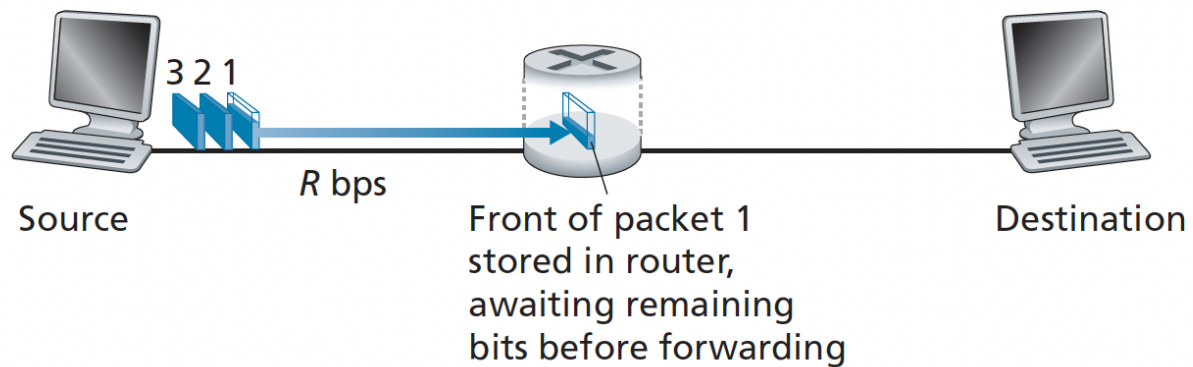
1.3.1 Packet Switching

App data is broken into "**packets**" and travel across a physical medium from one *Packet Switch*(L3 switch or Router) to another

Packets are transmitted over each communication link at a rate equal to the full transmission rate of the link (L (# of bits) * R (bits/sec) = L/R seconds)

Store-and-Forward Transmission

Store-and-Forward Transmission means that the ENTIRE packet must be received BEFORE the first bit of that packet can be sent (bits of packet stored in buffer)



Given L/R seconds between each device the following happens

Time	nthPacket on Router	nthPacket on Des
L/R	Packet 1	N/A
$2L/R$	Packet 2	Packet 1
$3L/R$	Packet 3	Packet 1 & Packet 2
$4L/R$	Packet 4	Packet 1 & Packet 2 & Packet 3

End to End Delay

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

Queuing Delays and Packet Loss

for each link connected to the router has an **output queue** (buffer) which stores the packets
 If the link is busy (some other packets are in front) the packet has to wait **queuing delay**
 (baed on the congestion level of the network)

- If the buffer for the queue (output buffer) is full and another packet arrives **packet loss** occurs

Forwarding Tables and Routing Protocols

Skipped for brevity but the idea is that for a routers to send the packet to the next destination it uses a "**routing table**" which answers the following

To send the packet to destination X send it to next hop (next host) Y out of interface Z

There are also different types of **routing protocols (RIP, EIGRP, OSPF)** which govern *how* the router learns routes to destination networks and we'll (hopefully) go very in-depth on this topic

1.3.2 Circuit Switching

In a circuit switched network, the links and buffers are *reserved* for the duration of the communication session *this is NOT the case in packet switched networks (hence the queue)* Traditional telephone networks are examples of circuit-switched networks.

- the switches on the path between the sender and receiver maintain connection state for that connection. This is known as a **circuit**
- When circuit is established it reserves (guarantees) a constant transmission rate
- number of links = number of simultaneous connections
- $\text{Transmission Capacity of One Link} = \text{Capacity} / N_{\text{links}}$
 - If each link between adjacent switches has a transmission rate of 1 Mbps, then each end-to-end circuit-switch connection gets 250 kb
- must first reserve one circuit on each of two links.
 - Notice the first link is used then the second

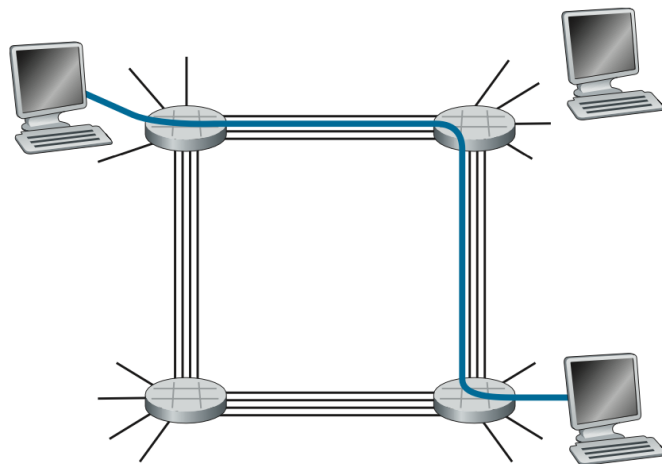


Figure 1.13 ♦ A simple circuit-switched network consisting of four switches and four links

Multiplexing in Circuit-Switched Networks

Circuit-Switched Implementation Types

multiplexing is specifically a solution for sharing one physical medium among multiple

users/connections via establishing circuits. We can separate out these circuits on one physical medium in two ways

- frequency-division multiplexing (FDM) the link dedicates a frequency band to each connection. Think about radio they share a specific frequency spectrum, similarly each the link dedicates a frequency band to each connection within its own frequency spectrum (in the above case there would be 4)
- time-division multiplexing (TDM) Each circuit gets it's own time slice within a physical link

Weaknesses of Circuit Switching

- circuit switching can be wasteful because the dedicated circuits are idle during **silent periods** (nobody's talking, so nobody is using the link, but it still can't be used to transmit other data (unlike packet switching))
- establishing end-to-end circuits and reserving end-to-end transmission capacity is complicated and requires complex signaling software to coordinate the operation of the switches along the end-to-end path.

Packet Switching Versus Circuit Switching

Packet switching is not suitable for real-time services (phone calls, video conference calls) b/c of its end-to-end delays

Counter Argument

- it offers better sharing of transmission capacity than circuit switching
- it is simpler, more efficient, and less costly to implement than circuit switching.

Why is packet switching more efficient?

It's hard for me to wrap my head around this but here is the breakdown (partly from AI but I've inspected and validated its correctness)

Example 1

- Setup:
 - Total link capacity: 1 Mbps
 - Each active user needs: 100 kbps
 - Users are only active 10% of the time
 - When active, they generate data at a constant rate
- Circuit Switching Analysis:
 - Each user gets a dedicated slice of bandwidth (100 kbps) whether they use it or not
 - Maximum number of users = $1 \text{ Mbps} \div 100 \text{ kbps} = 10 \text{ users}$

- This is inefficient because 90% of the time, each user's allocated bandwidth is wasted
- Packet Switching Analysis:
 - Bandwidth is allocated dynamically based on who's actually sending data
 - When 10 or fewer users are active (99.96% of time):
 - Each active user can get up to 100 kbps or more depending on how many others are active
 - If only 5 users are active, they could each get 200 kbps
 - Each user has 0.1 (10%) probability of being active at any time
 - The system can support 35 users with very little risk of congestion
 - Why? Because probability of having 11+ active users (which would exceed capacity) is only 0.0004 (0.04%)
 - This means 99.96% of the time, the system works as well as circuit switching

Because the probability of having more than X simultaneously active users is minuscule in this example, packet switching provides essentially the same performance as circuit switching, but does so while allowing for more than three times the number of users.

Example 2 (Pasted from book)

Let's now consider a second simple example. Suppose there are 10 users and that one user suddenly generates one thousand 1,000-bit packets, while other users remain quiescent and do not generate packets. Under TDM circuit switching with 10 slots per frame and each slot consisting of 1,000 bits, the active user can only use its one time slot per frame to transmit data, while the remaining nine time slots in each frame remain idle. It will be 10 seconds before all of the active user's one million bits of data has been transmitted. In the case of packet switching, the active user can continuously send its packets at the full link rate of 1 Mbps, since there are no other users generating packets that need to be multiplexed with the active user's packets.

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.

1.3.3 A Network of Networks

Yes Homes, Companies etc, connect to ISPs but ISPs themselves must connect with each other

- One naive approach would be to have each access ISP directly connect with every other access ISP.

- Network Structure 1, interconnects all of the access ISPs with a single global transit ISP
 - Since the access ISP pays the global transit ISP, the access ISP is said to be a **customer** and the global transit ISP is said to be a **provider**.
- Network Structure 2, consists of the hundreds of thousands of access ISPs and multiple global transit ISPs (two tier)
 - Smaller ISPs can now choose among the competing global transit providers as a function of their pricing and services
 - The global ISPs must connect with each other otherwise access ISPs connected to one of the global transit providers would not be able to communicate with access ISPs connected to the other global transit providers.

Network Structure 2 (preferred) has a caveat, no global ISP has presence in each and every city in the world to connect to the access ISP thus there is an intermediary **regional ISP**. (three-tier network) this becomes *Network Structure 3*

- **Network Structure 3**
 - regional ISP to which the access ISPs in the region connect
 - Each regional (access) ISP connects to the their **Tier-1** (global) ISP

Network Structure 3 also contains Points of Presence (PoPs)

- group of one or more routers (at the same location) in the provider's network where customer ISPs can connect into the provider ISP

Network Structure 3 also has ISPs who **multi-home**

- Any ISP (except for tier-1 ISPs) connects to two or more provider ISPs.
 - A access ISP may multi-home with two regional ISPs
 - A regional ISP may multi-home with multiple tier-1 ISPs.
 - When an ISP multi-homes, it can continue to send and receive packets into the Internet even if one of its providers has a failure.

Network Structure 4

Customer ISPs pay their provider ISPs to obtain global Internet interconnectivity which is based on the amount of data transfer. To dodge this, lower-tier ISPs connect with each other, so that traffic doesn't need to go upstream to the provider ISP (regional or tier-1 (global)), so it doesn't count towards their bill. When two ISPs **peer** with each other

- Along these same lines, a third-party company can create an Internet Exchange Point (IXP), which is a meeting point where multiple ISPs can peer together.

Network Structure 4 = access ISPs, regional ISPs, tier-1 ISPs, PoPs, multi-homing, peering, and IXPs (Not Network Structure 3)

Network Structure 5 (don't worry this is the last one)

builds on top of Network Structure 4 by adding content-provider networks.

Google has it's own private network that, while does connect to tier-1 ISPs, and pays those ISPs for the traffic it exchanges with them, reduces its payments to upper-tier ISPs and has greater control of how its services are ultimately delivered to end users, by connect to lower tier ISPs and IXP

The Internet Core

Connection between two regional ISPs (not through IXPs) is a **multi-home**

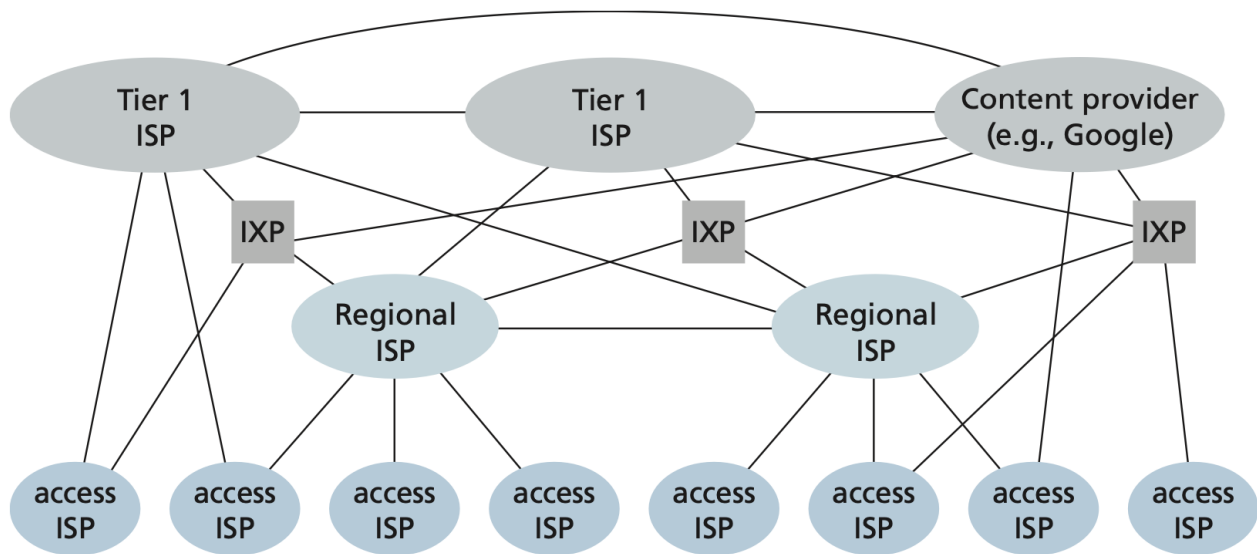


Figure 1.15 ♦ Interconnection of ISPs

1.4 Delay, Loss, and Throughput in Packet-Switched Networks

1.4.1 Overview of Delay in Packet-Switched Networks

A packet moving from one destination to another experiences the following delays (together they accumulate the **total nodal delay**)

Nodal Processing Delay --> Time required to inspect L3 Header and checksums and decide where to send the packet next

Queuing Delay --> The wait for packet to be transmitted onto the link

Transmission Delay --> Time required to push (that is, transmit) all of the packet's bits into the link $L(\text{size of data in bits})/R(\text{bits/sec})$ (transmission speed)

Propagation Delay --> Time required for one bit to travel from one end of the link to the other

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

Difference between 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.

- Link speed (transmission rate) = how fast the router can push out bits
- Propagation speed = how fast those bits travel through the cable/fiber/medium once they've left the router

1.4.2 Queuing Delay and Packet Loss

The ratio $(a = \text{packets/sec}) L$ (length of packet in bits) a (rate at which packets arrive at the queue) $/ R$ (bits/sec), called the traffic intensity,

If $La/R > 1$, then the average rate at which bits arrive at the queue exceeds the rate at which the bits can be transmitted from the queue. Thus it's imperative to follow this *golden rule*

Design your system so that the traffic intensity is no greater than 1

Packet Loss

Again if the output queue (buffer for packets) is full, the router will start dropping packets

1.4.3 End-to-End Delay

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

Traceroute

As these packets work their way toward the destination, they pass through a series of routers. When a router receives one of these special packets, it sends back to the source a short message that contains the name and address of the router

Suppose there are $N - 1$ routers between the source and the destination. Then the source will send N special packets into the network, with each packet addressed to the ultimate destination.

Traceroute actually repeats the experiment just described three times, so the source actually sends $3 \cdot N$ packets to the destination.

The output has six columns: the first column is the n value described above, that is, the number of the router along the route; the second column is the name of the router; the third column is the address of the router (of the form xxx.xxx.xxx.xxx); the last three columns are the round-trip delays for three experiments packet losses are marked with an asterisk

```
1 gw-vlan-2451.cs.umass.edu (128.119.245.1) 1.899 ms 3.266 ms 3.280 ms
2 j-cs-gw-int-10-240.cs.umass.edu (10.119.240.254) 1.296 ms 1.276 ms
  1.245 ms
3 n5-rt-1-1-xe-2-1-0.gw.umass.edu (128.119.3.33) 2.237 ms 2.217 ms
  2.187 ms
4 core1-rt-et-5-2-0.gw.umass.edu (128.119.0.9) 0.351 ms 0.392 ms 0.380 ms
5 border1-rt-et-5-0-0.gw.umass.edu (192.80.83.102) 0.345 ms 0.345 ms
  0.344 ms
6 nox300gw1-umass-re.nox.org (192.5.89.101) 3.260 ms 0.416 ms 3.127 ms
7 nox300gw1-umass-re.nox.org (192.5.89.101) 3.165 ms 7.326 ms 7.311 ms
8 198.71.45.237 (198.71.45.237) 77.826 ms 77.246 ms 77.744 ms
9 renater-lb1-gw.mx1.par.fr.geant.net (62.40.124.70) 79.357 ms 77.729
  79.152 ms
10 193.51.180.109 (193.51.180.109) 78.379 ms 79.936 80.042 ms
11 * 193.51.180.109 (193.51.180.109) 80.640 ms *
12 * 195.221.127.182 (195.221.127.182) 78.408 ms *
13 195.221.127.182 (195.221.127.182) 80.686 ms 80.796 ms 78.434 ms
14 r-upmcl.reseau.jussieu.fr (134.157.254.10) 78.399 ms * 81.353 ms
```

There are a number of free software programs that provide a graphical interface to Traceroute; one of our favorites is PingPlotter [PingPlotter 2020].

End System, Application, and Other Delays

Application Delay : An end system may purposefully delay its transmission as part of its application protocol

Packetization Delay : In VoIP, the sending side must first fill a packet with encoded digitized speech before passing the packet to the Internet

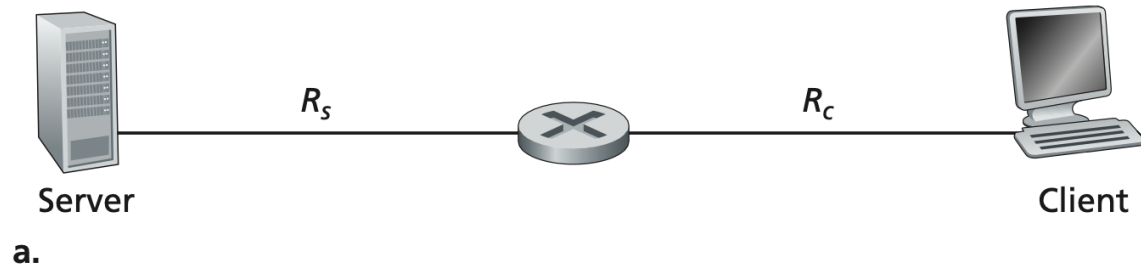
1.4.4 Throughput in Computer Networks

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.

$R_s < R_c$ (bits "flow") at a rate of R_s bps and giving a throughput of R_s bp

$R_c < R_s$, bits will only leave the router at rate R_c , giving an end- to-end throughput of R_c

Thus, for this simple two-link network, the throughput is $\min\{R_c, R_s\}$ - any additional delay

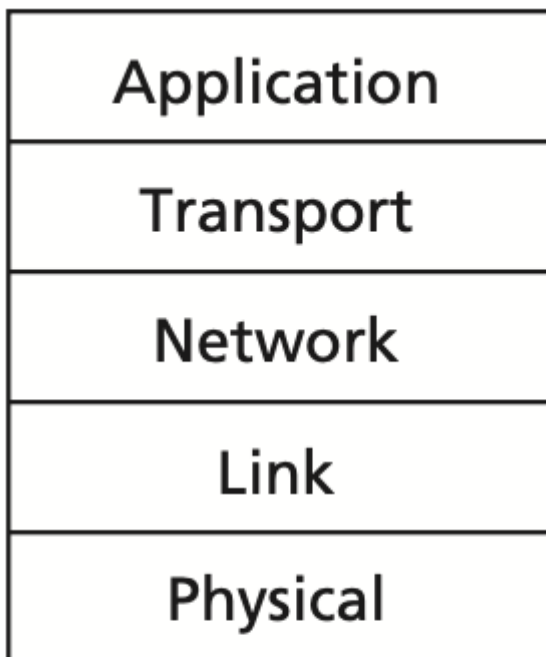


the constraining factor for throughput in today's Internet is typically the access network

1.5 Protocol Layers and Their Service Models

1.5.1 Layered Architecture

Protocol Layering



Five-layer Internet protocol stack

Layer	PDU	Protocol Examples or Medium
Application	Message	HTTP, SMTP, FTP
Transport	Segment	TCP, UDP
Network	Datagrams	IP

Layer	PDU	Protocol Examples or Medium
Link	Frame	Ethernet, WiFi, and the cable access network's DOCSIS protocol
Physical	Bits	Twisted-pair copper wire, single-mode fiber optics

Data is encapsulated with its corresponding layer which is eventually sent over a medium as bits, and is then de-encapsulated

1.5.2 Encapsulation

Figure 1.24 shows the physical path that data takes down a sending end system's protocol stack, up and down the protocol stacks of an intervening link-layer switch

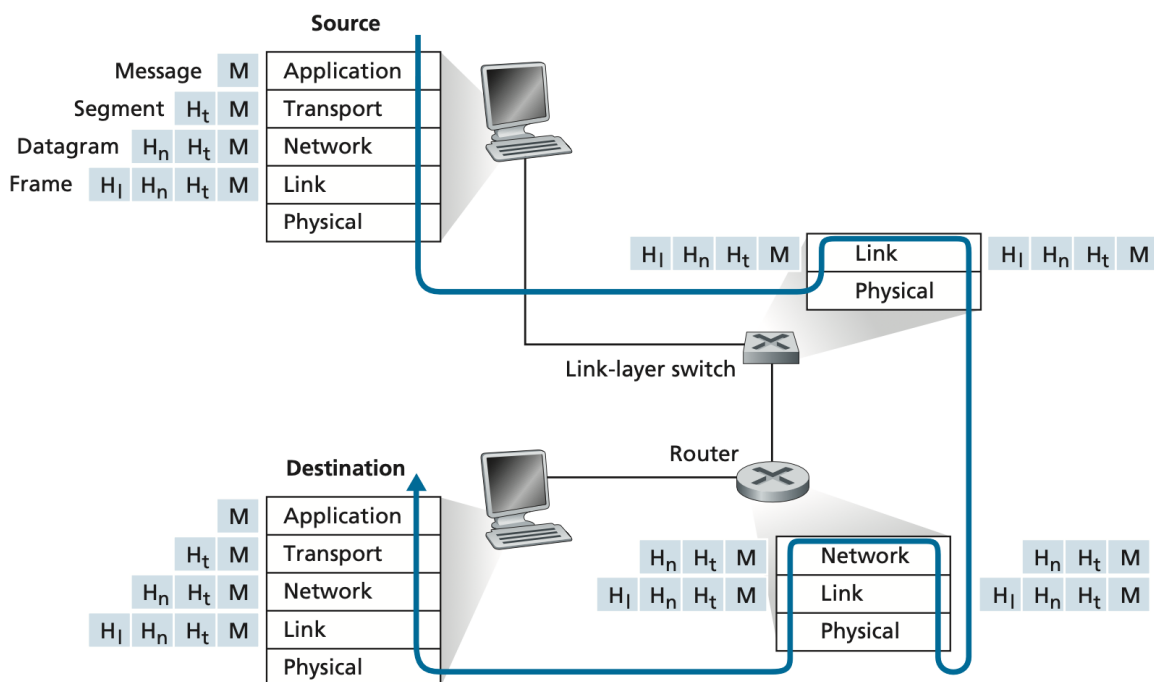


Figure 1.24 ♦ Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality

1.5.2 Encapsulation

Skipped for brevity

1.6 Networks Under Attack

Skipped for brevity

1.7 History of Computer Networking and the Internet

Skipped for brevity

SECTION 1.1

1. R1. What is the difference between a host and an end system? List several different types of end systems. Is a Web server an end system?

Not all hosts are endsystems, but all endsystems are hosts

2. R2. The word protocol is often used to describe diplomatic relations. How does Wikipedia describe diplomatic protocol?

3. R3. Why are standards important for protocols?

If there was no agreed standard

SECTION 1.2

The DSL standards define multiple transmission rates, including downstream transmission rates of 24 Mbps and 52 Mbps, and upstream rates of 3.5 Mbps and 16 Mbps; the newest standard provides for aggregate upstream plus downstream rates of 1 Gbps [ITU 2014].

1.2.2

Examples of physical media include twisted-pair copper wire, coaxial cable, multimode fiber-optic cable, terrestrial radio spectrum, and satellite radio spectrum. 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.

1.3 The Network Core

Intactive optical networks (AONs) and passive optical networks (PONs).

1.3.1

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.

Remember packet switching happens in parallel

Queuing Delays and Packet Loss

If an arriving packet needs to be transmitted onto a link but finds the link busy with the transmission of another packet, the arriving packet must wait in the output buffer

Since the amount of buffer space is finite, an arriving packet may find that the buffer is completely full with other packets waiting for transmission. In this case, packet loss will occur—either the arriving packet or one of the already-queued packets will be dropped.

Multiplexing in Circuit-Switched Networks

4. R4. List four access technologies. Classify each one as home access, enterprise access, or wide-area wireless access.

- DSL
- Ethernet
- Wifi
- HFC (Fiber to the home)

5. R5. Is HFC transmission rate dedicated or shared among users? Are collisions possible in a downstream HFC channel? Why or why not?

Yes it's a share medium, and yes because it's a shared medium

6. R6. List the available residential access technologies in your city. For each type of access, provide the advertised downstream rate, upstream rate, and monthly price.

7. R7. What is the transmission rate of Ethernet LANs?

10,100,1000

8. R8. What are some of the physical media that Ethernet can run over?

9. R9. HFC, DSL, and FTTH are all used for residential access. For each of these access technologies, provide a range of transmission rates and comment on whether the transmission rate is shared or dedicated.

10. R10. Describe the most popular wireless Internet access technologies today. Compare and contrast them.

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SECTION 1.3

11. R11. Suppose there is exactly one packet switch between a sending host and a receiving host. The transmission rates between the sending host and the switch and between the switch and the receiving host are R_1 and R_2 , respectively. Assuming that the switch uses store-and-forward packet switching, what is the total end-to-end delay to send a packet of length L ? (Ignore queuing, propagation delay, and processing delay.)

12. R12. What advantages does a circuit-switched network have over a packet-switched network? What advantages does TDM have over FDM in a circuit-switched network?

13. R13. Suppose users share a 2 Mbps link. Also suppose each user transmits continuously at 1 Mbps when transmitting, but each user transmits only 20 percent

of the time. (See the discussion of statistical multiplexing in Section 1.3.)

1. When circuit switching is used, how many users can be supported?

2. For the remainder of this problem, suppose packet switching is used. Why will there be essentially no queuing delay before the link if two or fewer users transmit at the same time? Why will there be a queuing delay if three users transmit at the same time?

3. Find the probability that a given user is transmitting.
4. Suppose now there are three users. Find the probability that at any given time, all three users are transmitting simultaneously. Find the fraction of time during which the queue grows.
5. R14. Why will two ISPs at the same level of the hierarchy often peer with each other? How does an IXP earn money?
6. R15. Some content providers have created their own networks. Describe Google's network. What motivates content providers to create these networks?

SECTION 1.4

16. R16. Consider sending a packet from a source host to a destination host over a fixed route. List the delay components in the end-to-end delay. Which of these delays are constant and which are variable?
17. R17. Visit the Transmission Versus Propagation Delay interactive animation at the companion Web site. Among the rates, propagation delay, and packet sizes available, find a combination for which the sender finishes transmitting before the first bit of the packet reaches the receiver. Find another combination for which the first bit of the packet reaches the receiver before the sender finishes transmitting.
18. R18. How long does it take a packet of length 1,000 bytes to propagate over a link of distance 2,500 km, propagation speed 2.5×10^8 m/s, and transmission rate 2 Mbps? More generally, how long does it take a packet of length L to propagate over a link of distance d , propagation speed s , and transmission

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rate R bps? Does this delay depend on packet length? Does this delay depend on transmission rate?

19. R19. Suppose Host A wants to send a large file to Host B. The path from Host A to Host B has three links, of rates $R_1 = 500$ kbps, $R_2 = 2$ Mbps, and $R_3 = 1$ Mbps.
 1. Assuming no other traffic in the network, what is the throughput for the file transfer?
 2. Suppose the file is 4 million bytes. Dividing the file size by the throughput, roughly how long will it take to transfer the file to Host B?
 3. Repeat (a) and (b), but now with R_2 reduced to 100 kbps.
20. R20. Suppose end system A wants to send a large file to end system B. At a very high level, describe how end system A creates packets from the file. When one of these packets arrives to a router, what information in the packet does the router use to determine the link onto which the packet is forwarded? Why is packet switching in the

Internet analogous to driving from one city to another and asking directions along the way?

21. R21. Visit the Queuing and Loss interactive animation at the companion Web site. What is the maximum emission rate and the minimum transmission rate? With those rates, what is the traffic intensity? Run the interactive animation with these rates and determine how long it takes for packet loss to occur. Then repeat the experiment a second time and determine again how long it takes for packet loss to occur. Are the values different? Why or why not?

SECTION 1.5

22. R22. List five tasks that a layer can perform. Is it possible that one (or more) of these tasks could be performed by two (or more) layers?
23. R23. What are the five layers in the Internet protocol stack? What are the principal responsibilities of each of these layers?
24. R24. What is an application-layer message? A transport-layer segment? A network-layer datagram? A link-layer frame?
25. R25. Which layers in the Internet protocol stack does a router process? Which layers does a link-layer switch process? Which layers does a host process?

SECTION 1.6

26. R26. What is self-replicating malware?
27. R27. Describe how a botnet can be created and how it can be used for a DDoS attack.
28. R28. Suppose Alice and Bob are sending packets to each other over a computer network. Suppose Trudy positions herself in the network so that she can capture all the packets sent by Alice and send whatever she wants to Bob; she can also capture all the packets sent by Bob and send whatever she wants to Alice. List some of the malicious things Trudy can do from this position.

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Problems

1. P1. Design and describe an application-level protocol to be used between an automatic teller machine and a bank's centralized computer. Your protocol should allow a user's card and password to be verified, the account balance (which is maintained at the centralized computer) to be queried, and an account withdrawal to be made (that is, money disbursed to the user). Your protocol entities should be able to handle the all-too-common case in which there is not enough money in the account to cover the withdrawal. Specify your protocol by listing the messages exchanged and the action taken by the automatic teller machine or the bank's centralized computer on transmission and receipt of messages. Sketch the operation of your protocol for the case of a simple withdrawal with no errors, using a diagram similar to that in Figure 1.2. Explicitly state the assumptions made by your protocol about the underlying end-to-end transport service.

2. P2. Equation 1.1 gives a formula for the end-to-end delay of sending one packet of length L over N links of transmission rate R . Generalize this formula for sending P such packets back-to-back over the N links.

3. P3. Consider an application that transmits data at a steady rate (for example, the sender generates an N -bit unit of data every k time units, where k is small and fixed). Also, when such an application starts, it will continue running for a relatively long period of time. Answer the following questions, briefly justifying your answer:

1. Would a packet-switched network or a circuit-switched network be more appropriate for this application? Why?

2. Suppose that a packet-switched network is used and the only traffic in this network comes from such applications as described above. Furthermore, assume that the sum of the application data rates is less than the capacities of each and every link. Is some form of congestion control needed? Why?

4. P4. Consider the circuit-switched network in Figure 1.13. Recall that there are four circuits on each link. Label the four switches A, B, C, and D, going in the clockwise direction.

1. What is the maximum number of simultaneous connections that can be in progress at any one time in this network?

2. Suppose that all connections are between switches A and C. What is the maximum number of simultaneous connections that can be in progress?

3. Suppose we want to make four connections between switches A and C, and another four connections between switches B and D. Can we route these calls through the four links to accommodate all eight connections?

5. P5. Review the car-caravan analogy in Section 1.4. Assume a propagation speed of 100 km/hour.

1. Suppose the caravan travels 175 km, beginning in front of one tollbooth, passing through a second tollbooth, and finishing just after a third toll-booth. What is the end-to-end delay?

2. Repeat (a), now assuming that there are eight cars in the caravan instead of ten.

6. P6. This elementary problem begins to explore propagation delay and transmission delay, two central concepts in data networking. Consider two hosts, A and B, connected by a single link of rate R bps. Suppose that the two hosts are separated by m meters, and suppose the propagation speed along the link

is s meters/sec. Host A is to send a packet of size L bits to Host B.

1. Express the propagation delay, d_{prop} , in terms of m and s .

2. Determine the transmission time of the packet, d_{trans} , in terms of L and R .

3. Ignoring processing and queuing delays, obtain an expression for the end-to-end delay.

4. Suppose Host A begins to transmit the packet at time $t = 0$. At time $t = d_{\text{trans}}$, where is the last bit of the packet?

5. Suppose d_{prop} is greater than d_{trans} . At time $t = d_{\text{trans}}$, where is the first bit of the packet?

6. Suppose d_{prop} is less than d_{trans} . At time $t = d_{\text{trans}}$, where is the first bit of the packet? # 8

VideoNote

Exploring propagation delay and transmission delay

g. Suppose $s = 2.5$

distance m so that d_{prop} equals d_{trans} .

10 , $L = 1500$ bytes, and $R = 10$ Mbps. Find the

7. P7. In

over a packet-switched network (VoIP). Host A converts analog voice to a digital 64 kbps bit stream on the fly. Host A then groups the bits into 56-byte packets. There is one link between Hosts A and B; its transmission rate is

10 Mbps and its propagation delay is 10 msec. As soon as Host A gathers a packet, it sends it to Host B. As soon as Host B receives an entire packet, it converts the packet's bits to an analog signal. How much time elapses from the time a bit is created (from the

original analog signal at Host A) until the bit is decoded (as part of the analog signal at Host B)?

8. P8. Suppose users share a 10 Mbps link. Also suppose each user requires 200 kbps when transmitting, but each user transmits only 10 percent of the time. (See the discussion of packet switching versus circuit switching in Section 1.3.)

1. When circuit switching is used, how many users can be supported?
2. For the remainder of this problem, suppose packet switching is used. Find the probability that a given user is transmitting.

this problem, we consider sending real-time voice from Host A to Host B

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- c. Suppose there are 120 users. Find the probability that at any given time, exactly n users are transmitting simultaneously. (Hint: Use the binomial distribution.)

- d. Find the probability that there are 51 or more users transmitting simultaneously.

9. P9. Consider the discussion in Section 1.3 of packet switching versus circuit switching in which an example is provided with a 1 Mbps link. Users are generating data at a rate of 100 kbps when busy, but are busy generating data only with probability $p = 0.1$. Suppose that the 1 Mbps link is replaced by a 1 Gbps link.

1. What is N , the maximum number of users that can be supported simultaneously under circuit switching?
2. Now consider packet switching and a user population of M users. Give a formula (in terms of p , M , N) for the probability that more than N users are sending data.

10. P10. Consider a packet of length L that begins at end system A and travels over three links to a destination end system. These three links are connected by two packet switches. Let d_i , s_i , and R_i denote the length, propagation speed, and the transmission rate of link i , for $i = 1, 2, 3$. The packet switch delays each packet by d_{proc} . Assuming no queuing delays, in terms of d_i , s_i , R_i ,

($i = 1, 2, 3$), and L , what is the total end-to-end delay for the packet? Suppose now the packet is 1,500 bytes, the propagation speed on all three links is 2.5×10^8 m/s, the transmission rates of all three links are 2.5 Mbps, the packet switch processing delay is 3 msec, the length of the first link is 5,000 km, the length of the second link is 4,000 km, and the length of the last link is 1,000 km. For these values, what is the end-to-end delay?

11. P11. In the above problem, suppose $R_1 = R_2 = R_3 = R$ and $d_{\text{proc}} = 0$. Further suppose that the packet switch does not store-and-forward packets but instead

immediately transmits each bit it receives before waiting for the entire packet to arrive. What is the end-to-end delay?

12. P12. A packet switch receives a packet and determines the outbound link to which the packet should be forwarded. When the packet arrives, one other packet is halfway done being transmitted on this outbound link and four other packets are waiting to be transmitted. Packets are transmitted in order of arrival. Suppose all packets are 1,500 bytes and the link rate is 2.5 Mbps. What is the queuing delay for the packet? More generally, what is the queuing delay when all packets have length L , the transmission rate is R , x bits of the currently-being-transmitted packet have been transmitted, and n packets are already in the queue?
13. P13. (a) Suppose N packets arrive simultaneously to a link at which no packets are currently being transmitted or queued. Each packet is of length L and the link has transmission rate R . What is the average queuing delay for the N packets?

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(b) Now suppose that N such packets arrive to the link every LN/R seconds.

What is the average queuing delay of a packet?

14. P14. Consider the queuing delay in a router buffer. Let I denote traffic intensity; that is, $I = \lambda a / R$. Suppose that the queuing delay takes the form $IL/R(1 - I)$ for $I < 1$.
1. Provide a formula for the total delay, that is, the queuing delay plus the transmission delay.
 2. Plot the total delay as a function of L/R .
15. P15. Let λ denote the rate of packets arriving at a link in packets/sec, and let μ denote the link's transmission rate in packets/sec. Based on the formula for the total delay (i.e., the queuing delay plus the transmission delay) derived in the previous problem, derive a formula for the total delay in terms of λ and μ .
16. P16. Consider a router buffer preceding an outbound link. In this problem, you will use Little's formula, a famous formula from queuing theory. Let N denote the average number of packets in the buffer plus the packet being transmitted. Let λ denote the rate of packets arriving at the link. Let d denote the average total delay (i.e., the queuing delay plus the transmission delay) experienced by a packet. Little's formula is $N = \lambda d$. Suppose that on average, the buffer contains 100 packets, and the average packet queuing delay is 20 msec. The link's transmission rate is 100 packets/sec. Using Little's formula, what is the average packet arrival rate, assuming there is no packet loss?

17. P17. a. Generalize Equation 1.2 in Section 1.4.3 for heterogeneous processing rates, transmission rates, and propagation delays.
- b. Repeat (a), but now also suppose that there is an average queuing delay of d_{queue} at each node.
18. P18. Perform a Traceroute between source and destination on the same continent

at three different hours of the day.

1. Find the average and standard deviation of the round-trip delays at each of the three hours.
2. Find the number of routers in the path at each of the three hours. Did the paths change during any of the hours?
3. Try to identify the number of ISP networks that the Traceroute packets pass through from source to destination. Routers with similar names and/ or similar IP addresses should be considered as part of the same ISP. In your experiments, do the largest delays occur at the peering interfaces between adjacent ISPs?
4. Repeat the above for a source and destination on different continents. Compare the intra-continent and inter-continent results.