Elex 7710 - Communication Networks

TextBook: Tenth Edition by William Stallings

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“The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point”

- *The Mathematical Theory of Communication*,

Claude Shannon

Notable Trends

Trend toward faster and cheaper, in both computing and communication

- More powerful computers supporting more demanding applications
- The increasing use of optical fiber and high-speed wireless has brought transmission prices down and greatly increased capacity

Today's networks are more "intelligent"

- Differing levels of quality of service (QoS)
- Variety of customizable services in the areas of network management and security

The Internet, the Web, and associated applications have emerged as dominant features for both business and personal network landscapes

- "Everything over IP"
- Intranets and extranets are being used to isolate proprietary information

Mobility

- iPhone, Droid, and iPad have become drivers of the evolution of business networks and their use
- Enterprise applications are now routinely delivered on mobile devices
- Cloud computing is being embraced

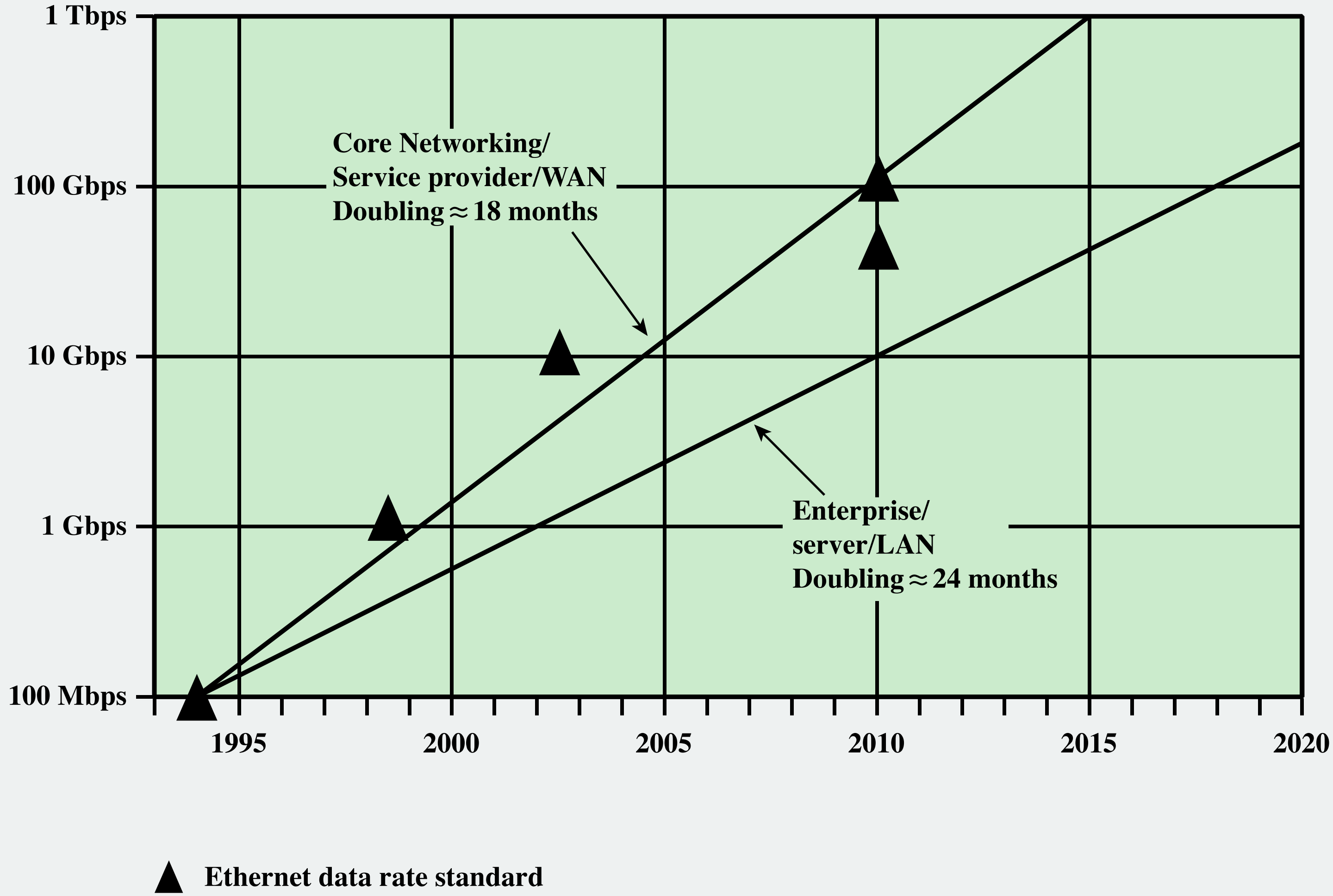


Figure 1.2 Past and Projected Growth in Ethernet Data Rate Demand Compared to Existing Ethernet Data Rates

Changes in Networking Technology

* Emergence of high-speed LANs

* Corporate WAN needs

* Digital electronics

Emergence of High-Speed LANs

- Personal computers and microcomputer workstations have become an essential tool for office workers

Two significant trends altered the requirements of the LAN

Explosive growth of speed and computing power of personal computers

LANs have been recognized as a viable and essential computing platform

- Examples of requirements that call for higher-speed LANs:
  - Centralized server farms
  - Power workgroups
  - High-speed local backbone

Corporate Wide Area Networking Needs

Changes in corporate data traffic patterns are driving the creation of high-speed WANs	Growing use of telecommuting
	Nature of the application structure has changed
	Intranet computing
	More reliance on personal computers, workstations, and servers
	More data-intensive applications
	Most organizations require access to the Internet
	Traffic patterns have become more unpredictable
	Average traffic load has risen
	More data is transported off premises and into the wide area

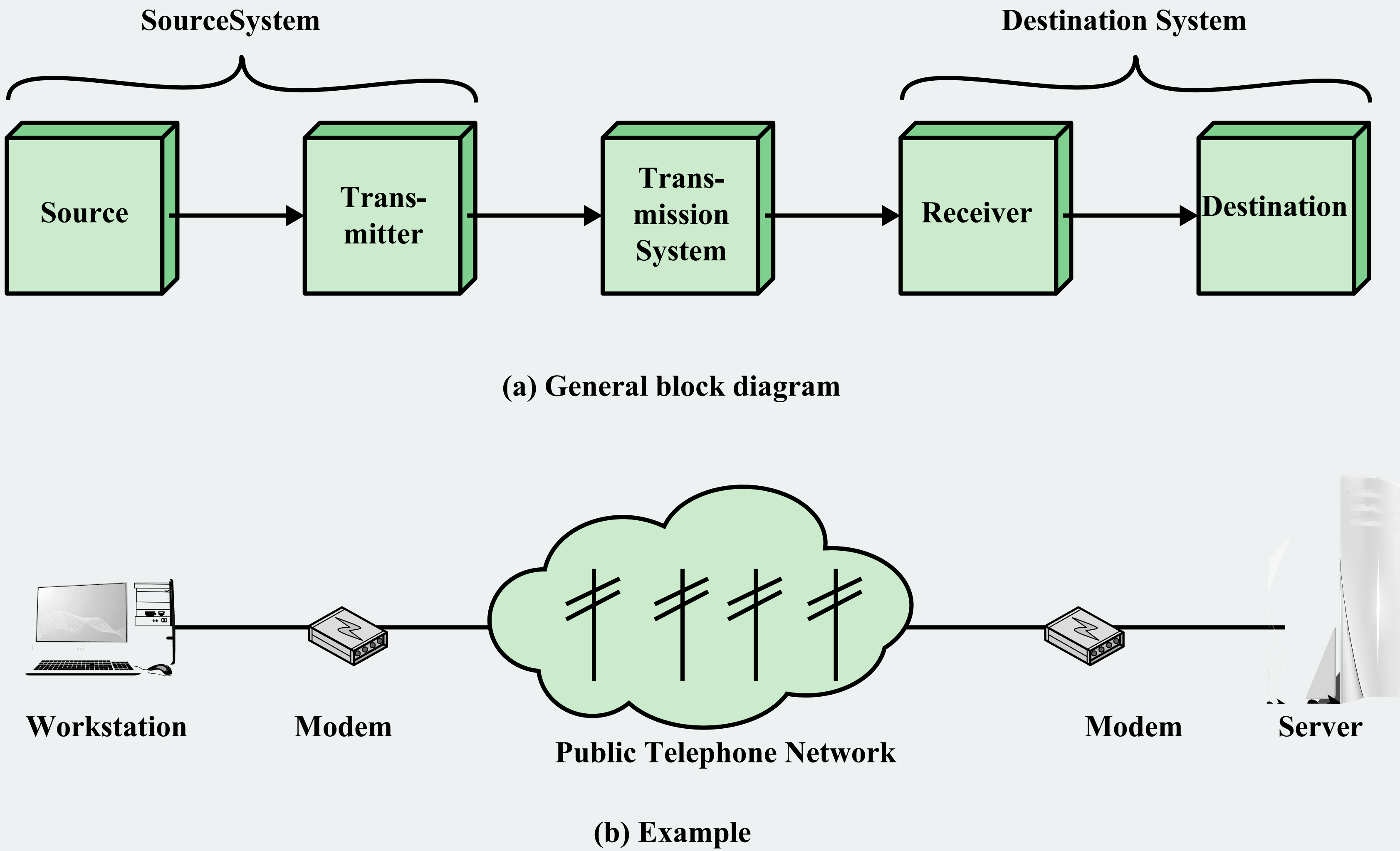


Figure 1.3 Simplified Communications Model

Table 1.1 Communications Tasks

Transmission system utilization	Addressing
Interfacing	Routing
Signal generation	Recovery
Synchronization	Message formatting
Exchange management	Security
Error detection and correction	Network management
Flow control	

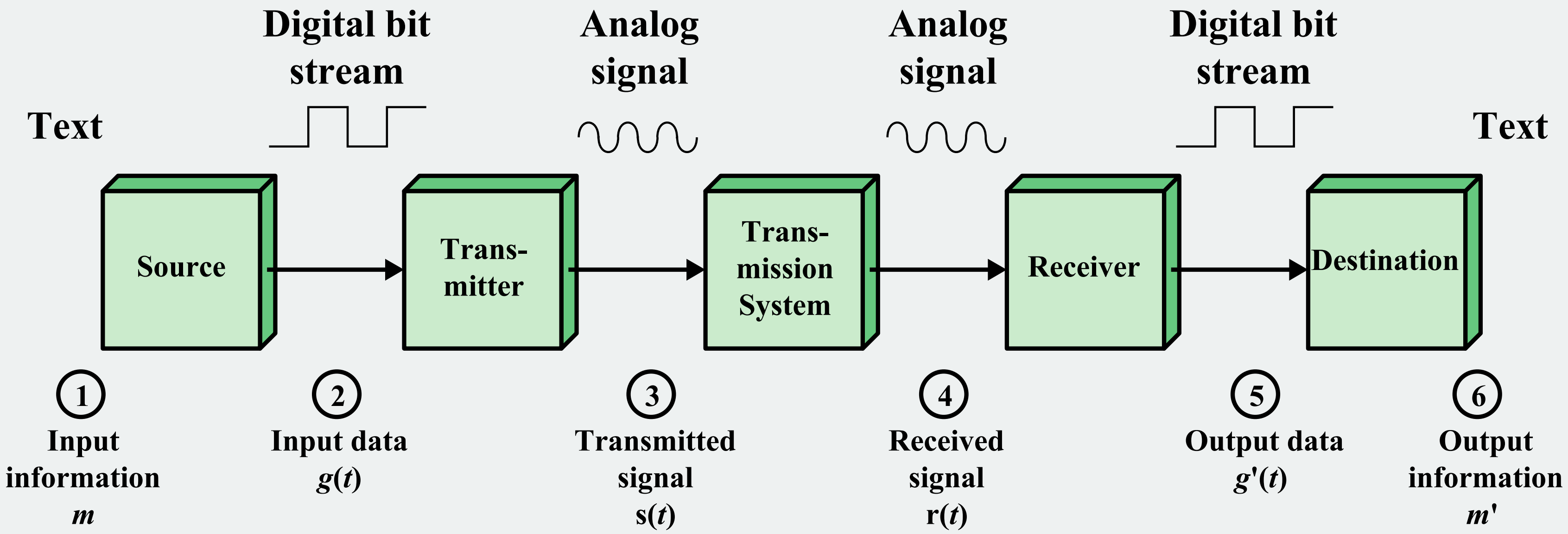
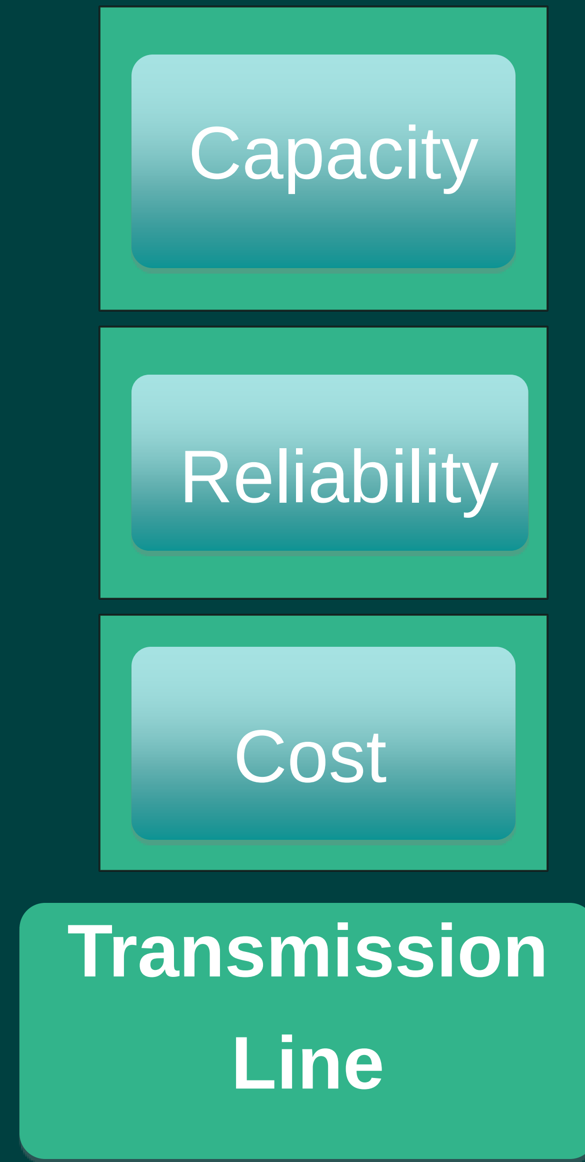


Figure 1.4 Simplified Data Communications Model

Transmission Lines

The basic building block of any communications facility is the transmission line

The business manager is concerned with a facility providing the required capacity, with acceptable reliability, at minimum cost



Transmission Mediums

- *Other than Copper* - Two mediums currently driving the evolution of data communications transmission are:

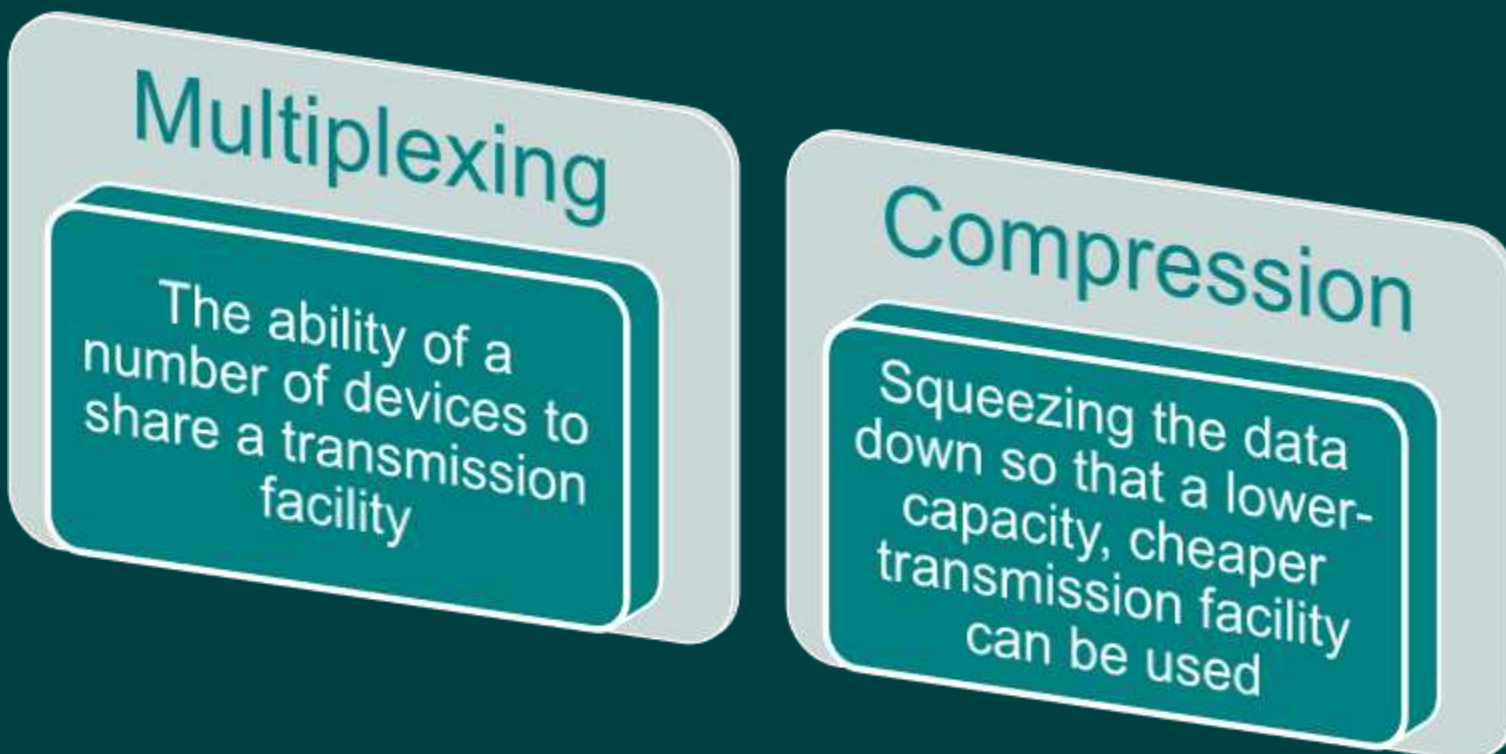
Fiber optic transmissions

and

Wireless transmissions

Transmission Services

- Remain the most costly component of a communications budget
- Two major approaches to greater efficiency:

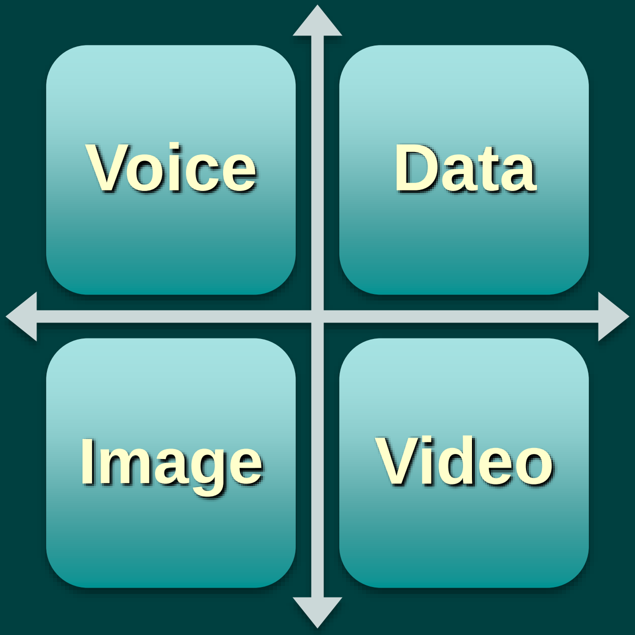


Networks

- It is estimated that by 2016 there will be over 20 billion fixed and mobile networked devices
  - This affects traffic volume in a number of ways:
    - It enables a user to be continuously consuming network capacity
    - Capacity can be consumed on multiple devices simultaneously
    - Different broadband devices enable different applications which may have greater traffic generation capability

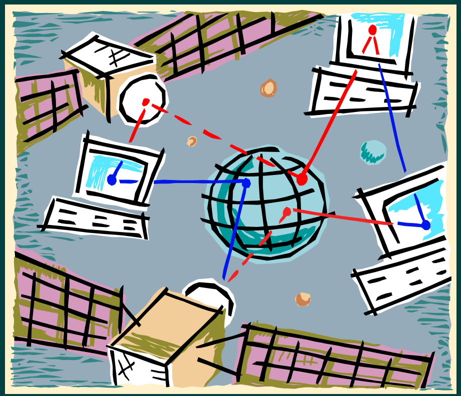
Networking

Advances in technology have led to greatly increased capacity and the concept of integration, allowing equipment and networks to work simultaneously



Wide Area Networks (WANs)

- Span a large geographical area
- Require the crossing of public right-of-ways
- Rely in part on common carrier circuits
- Typically consist of a number of interconnected switching nodes



Wide Area Networks

Alternative technologies used include:

- Circuit switching
- Packet switching
- Frame relay
- Asynchronous Transfer Mode (ATM)

Circuit Switching

- Uses a dedicated communications path
- Connected sequence of physical links between nodes
- Logical channel dedicated on each link
- Rapid transmission
- The most common example of circuit switching is the telephone network

Packet Switching

- Data are sent out in a sequence of small chunks called packets
- Packets are passed from node to node along a path leading from source to destination
- Packet-switching networks are commonly used for terminal-to-terminal computer and computer-to-computer communications

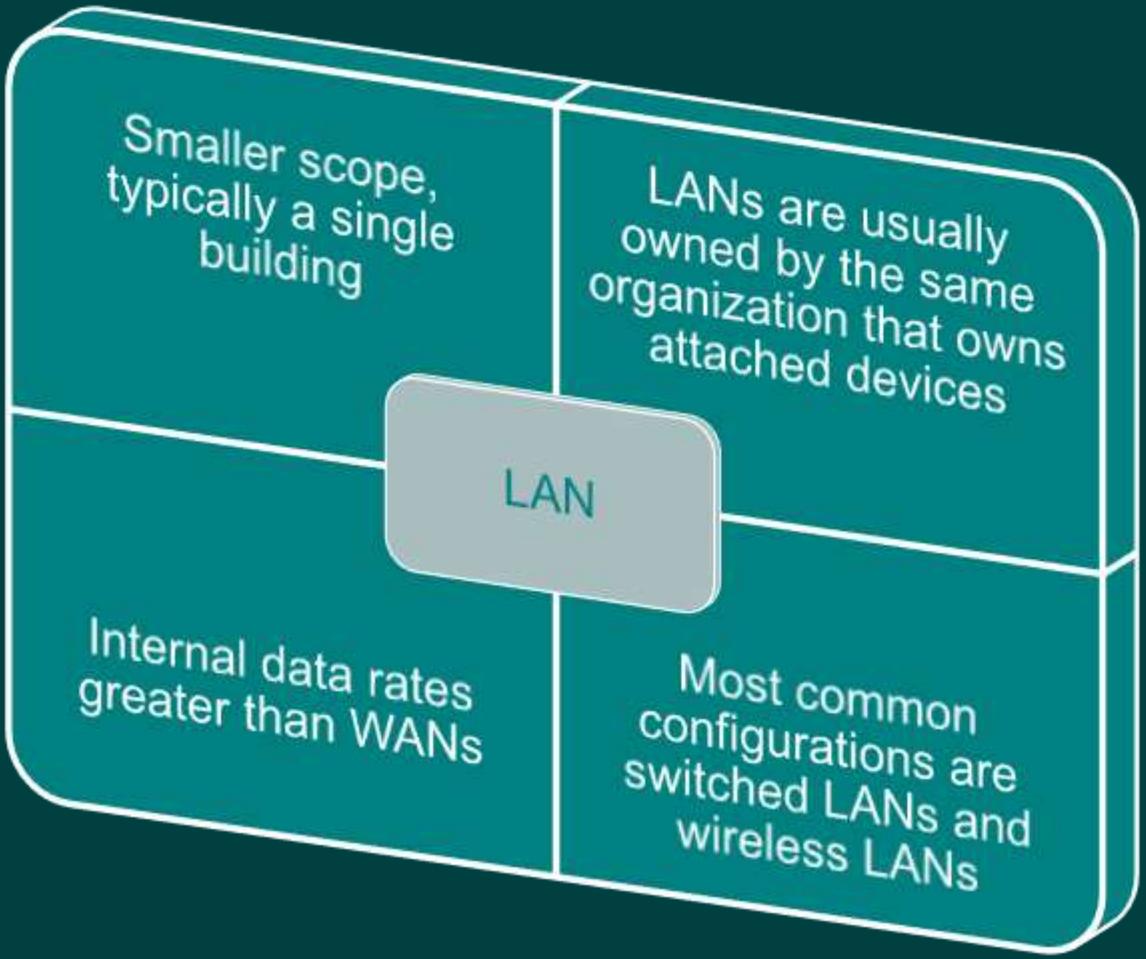
Frame Relay

- Developed to take advantage of high data rates and low error rates
- Operates at data rates of up to 2 Mbps
- Key to achieving high data rates is to strip out most of the overhead involved with error control

Asynchronous Transfer Mode (ATM)

- Referred to as cell relay
- Culmination of developments in circuit switching and packet switching
- Uses fixed-length packets called cells
- Works in range of 10s and 100s of Mbps and in the Gbps range
- Allows multiple channels with the data rate on each channel dynamically set on demand

Local Area Networks (LAN)



The Internet

- Internet evolved from ARPANET
- Developed to solve the dilemma of communicating across arbitrary, multiple, packet-switched networks
- Foundation is the TCP/IP protocol suite

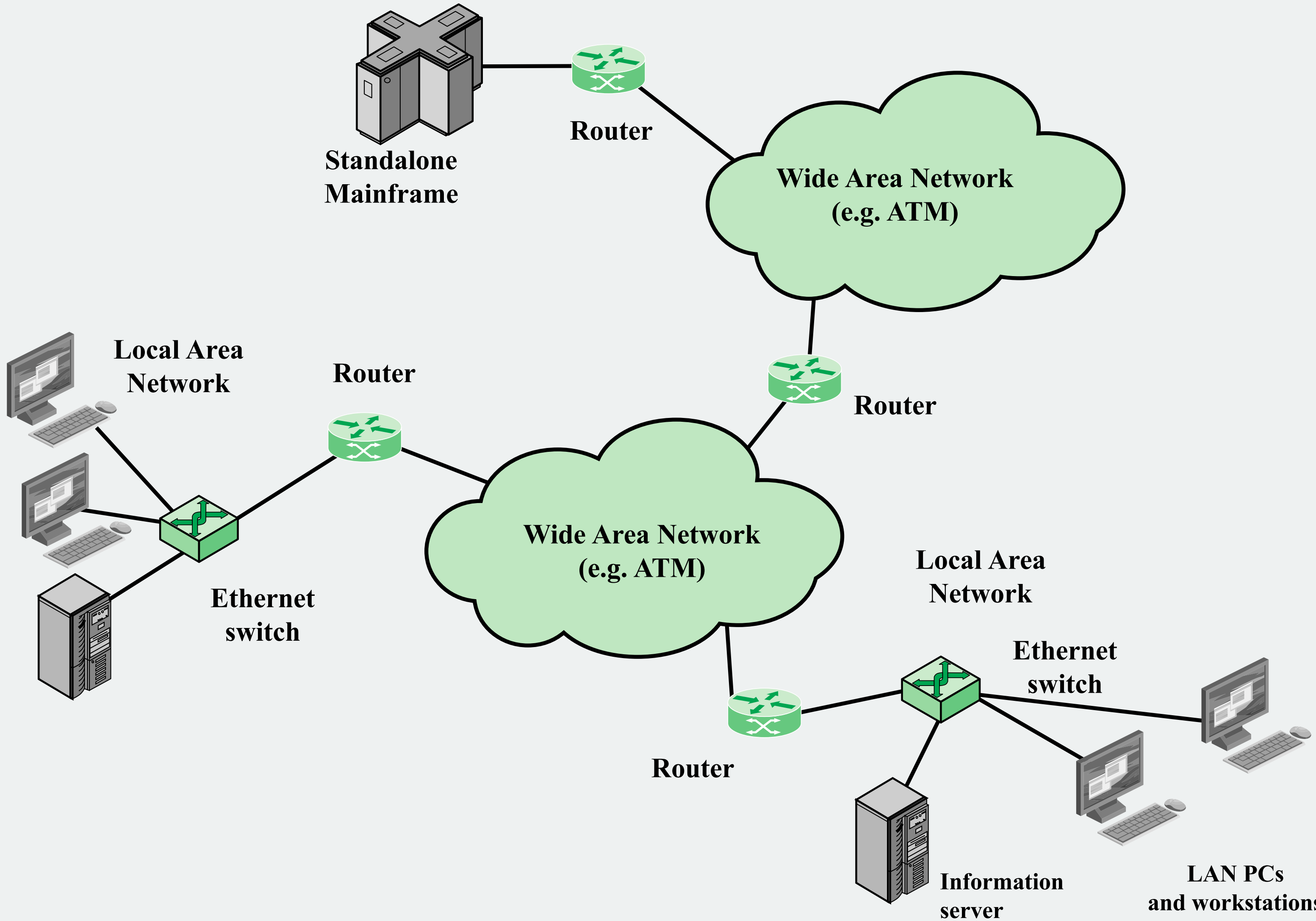


Figure 1.5 Key Elements of the Internet

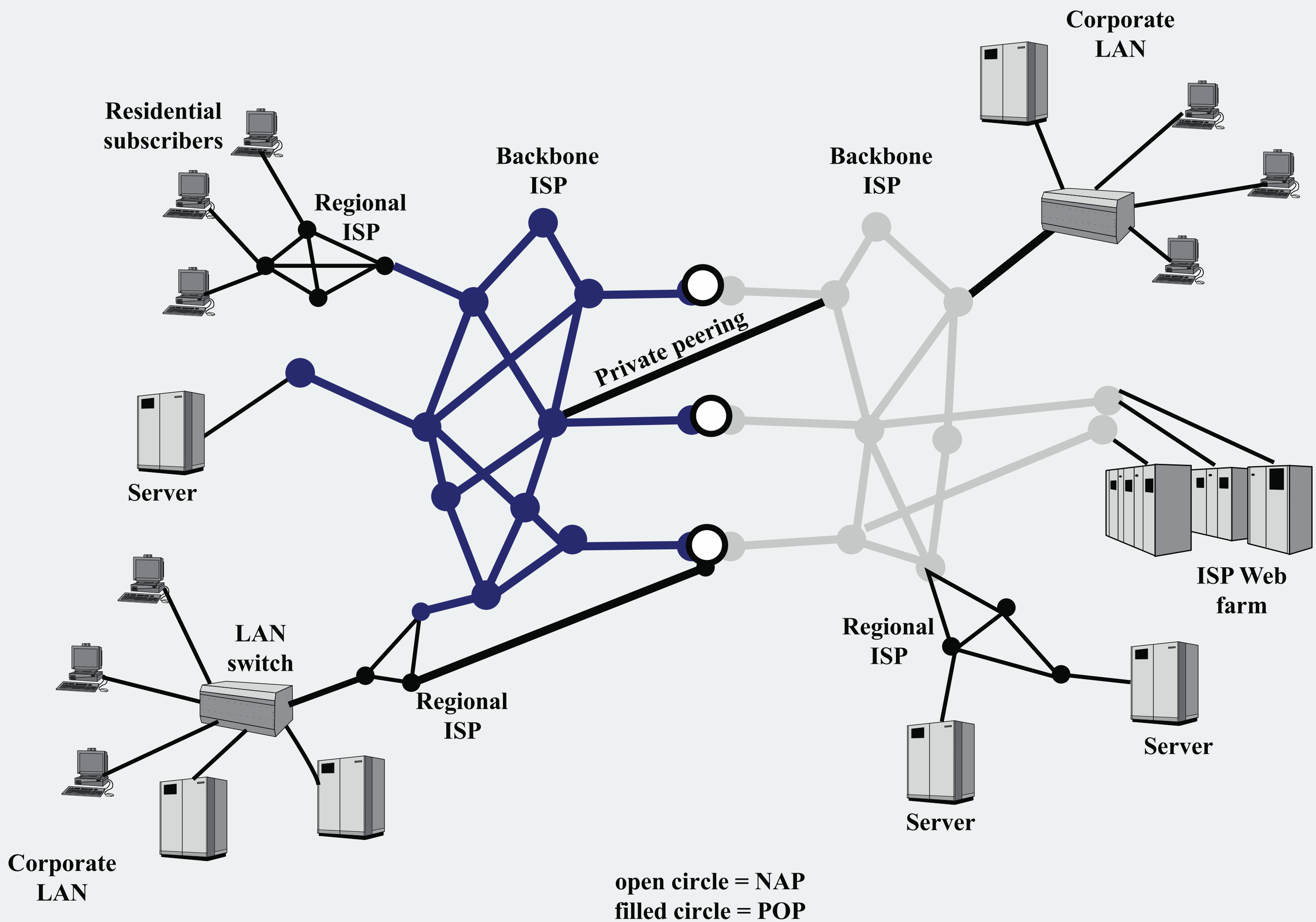


Figure 1.6 Simplified View of Portion of Internet

Table 1.2
Internet Terminology

- Central Office (CO)
  - The place where telephone companies terminate customer lines and locate switching equipment to interconnect those lines with other networks
- Customer Premises Equipment (CPE)
  - Telecommunications equipment that is located on the customer's premises
- Internet Service Provider (ISP)
  - A company that provides other companies or individuals with access to, or presence on, the Internet
- Network Access Point (NAP)
  - One of several major Internet interconnection points that serve to tie all the ISPs together
- Network Service Provider (NSP)
  - A company that provides backbone services to an Internet service provider (ISP)
- Point of Presence (POP)
  - A site that has a collection of telecommunications equipment, usually refers to ISP or telephone company sites

(Table can be found on page 27 in textbook)

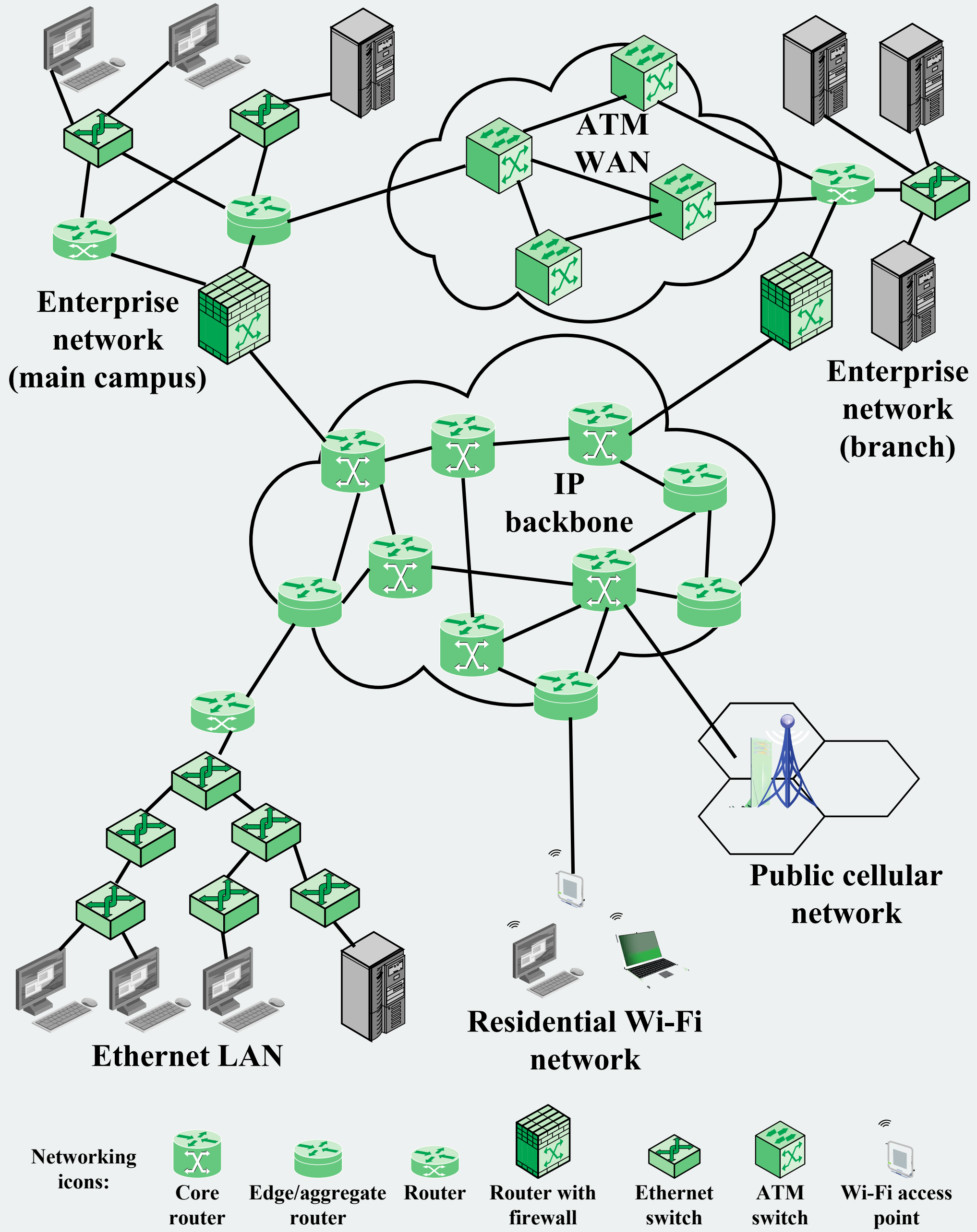


Figure 1.7 A Networking Configuration

Protocol Architecture, TCP/IP, and Internet-Based Applications

The Need for a Protocol Architecture

1.) The source must either activate the direct communications path or inform the network of the identity of the desired destination system

2.) The source system must ascertain that the destination system is prepared to receive data

To transfer data several tasks must be performed:

3.) The file transfer application on the source system must ascertain that the file management program on the destination system is prepared to accept and store the file for this particular user

4.) A format translation function may need to be performed by one or the other system if the file formats used on the two systems are different

Functions of Protocol Architecture

- Breaks logic into subtask modules which are implemented separately
- Modules are arranged in a vertical stack
  - Each layer in the stack performs a subset of functions
  - Relies on next lower layer for primitive functions
  - Provides services to the next higher layer
  - Changes in one layer should not require changes in other layers

Key Features of a Protocol

A protocol is a set of rules or conventions that allow peer layers to communicate

The key features of a protocol are:

Syntax
- Format of data blocks

Semantics
- Control information for coordination and error handling

Timing
- Speed matching and sequencing

A Simple Protocol Architecture

Agents involved:
- Applications
- Computers
- Networks

Examples of applications include file transfer and electronic mail

These execute on computers that support multiple simultaneous applications

Communication Layers

Communication tasks are organized into three relatively independent layers:

- Network access layer
  - Concerned with the exchange of data between a computer and the network to which it is attached
- Transport layer
  - Collects mechanisms in a common layer shared by all applications
- Application layer
  - Contains logic to support applications

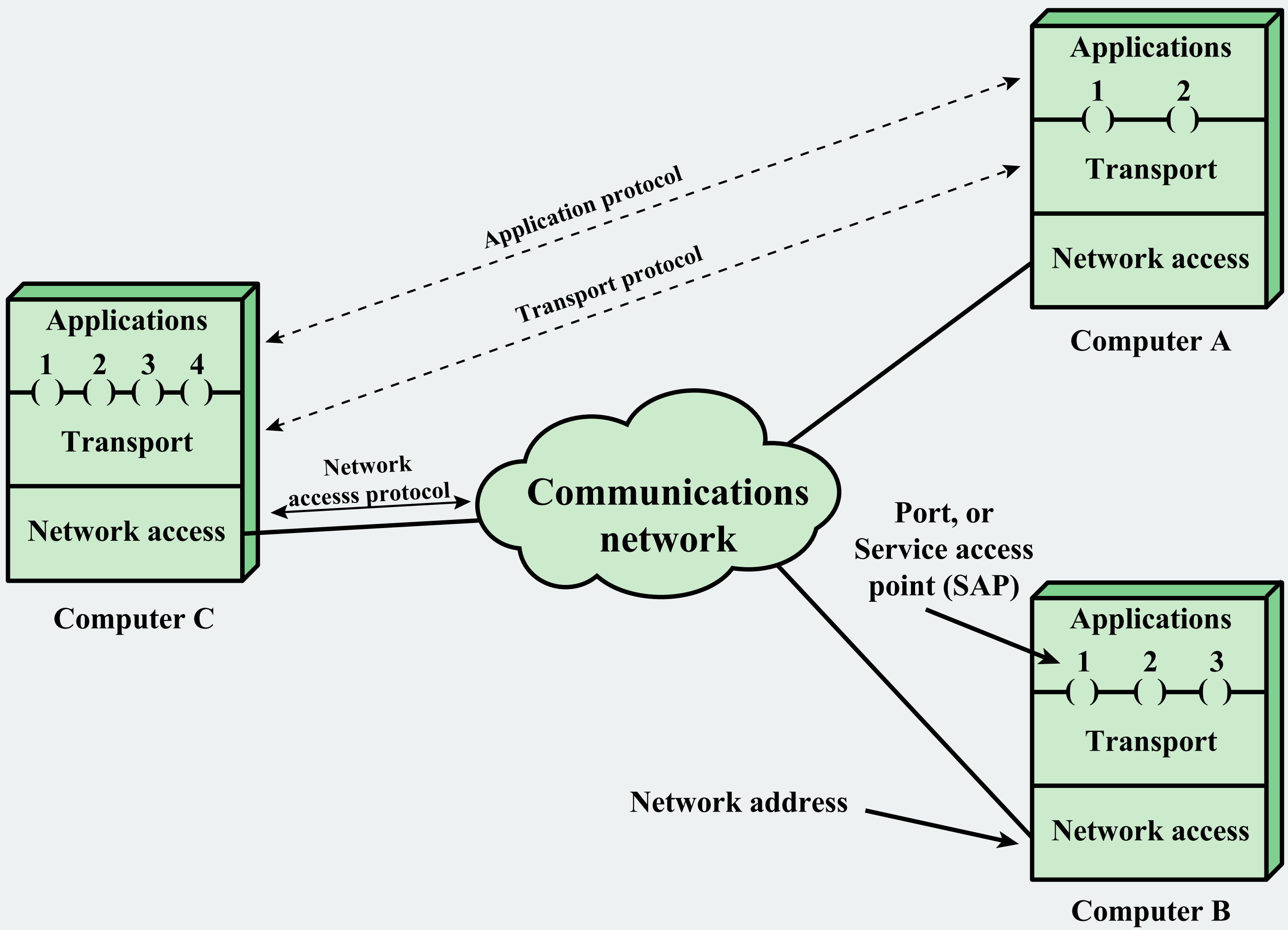


Figure 2.1 Protocol Architectures and Networks

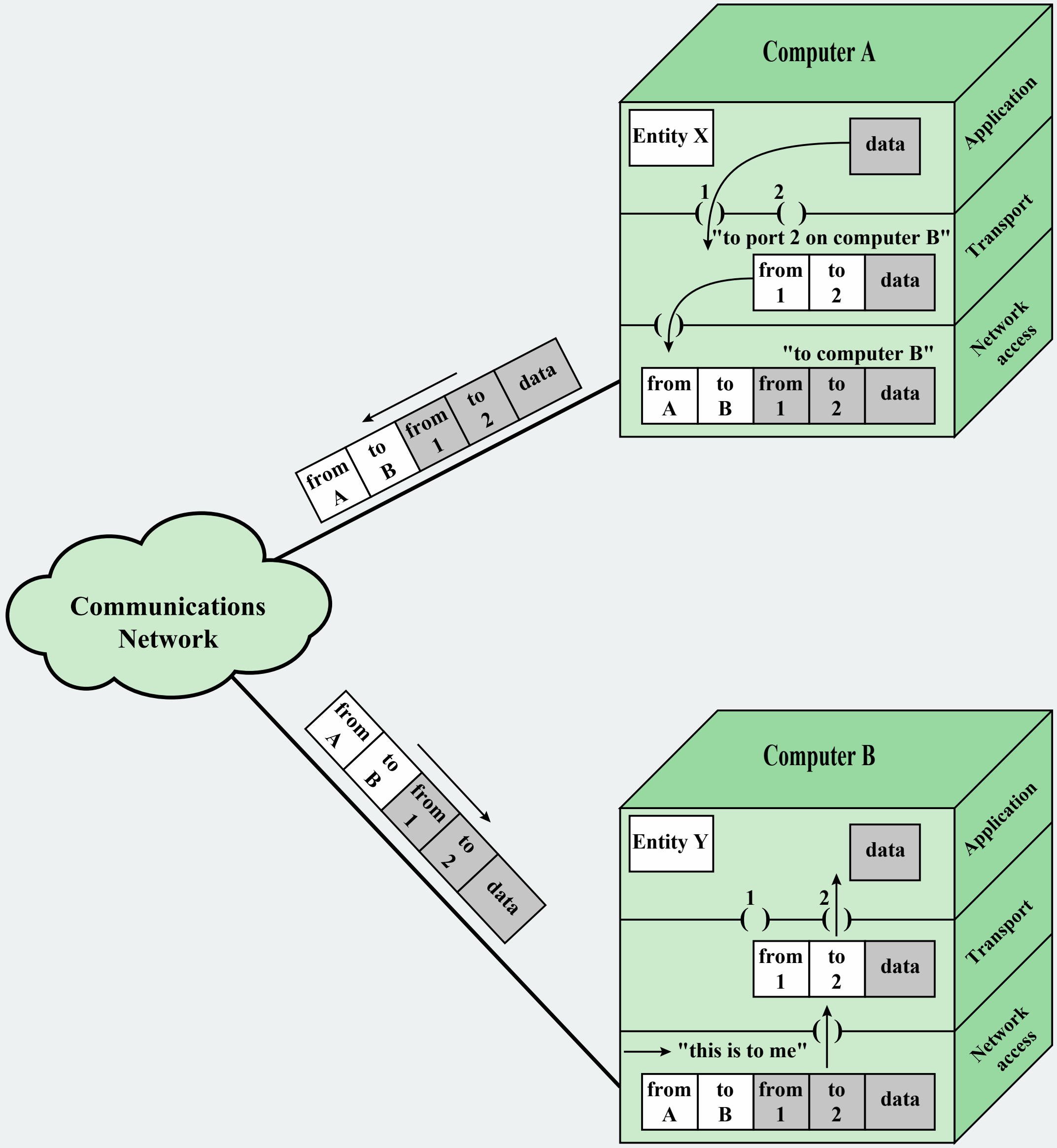


Figure 2.2 Protocols in a Simplified Architecture

TCP/IP Protocol Architecture

TCP/IP Protocol Architecture

- Result of protocol research and development conducted on ARPANET
- Referred to as TCP/IP protocol suite
- TCP/IP comprises a large collection of protocols that are Internet standards

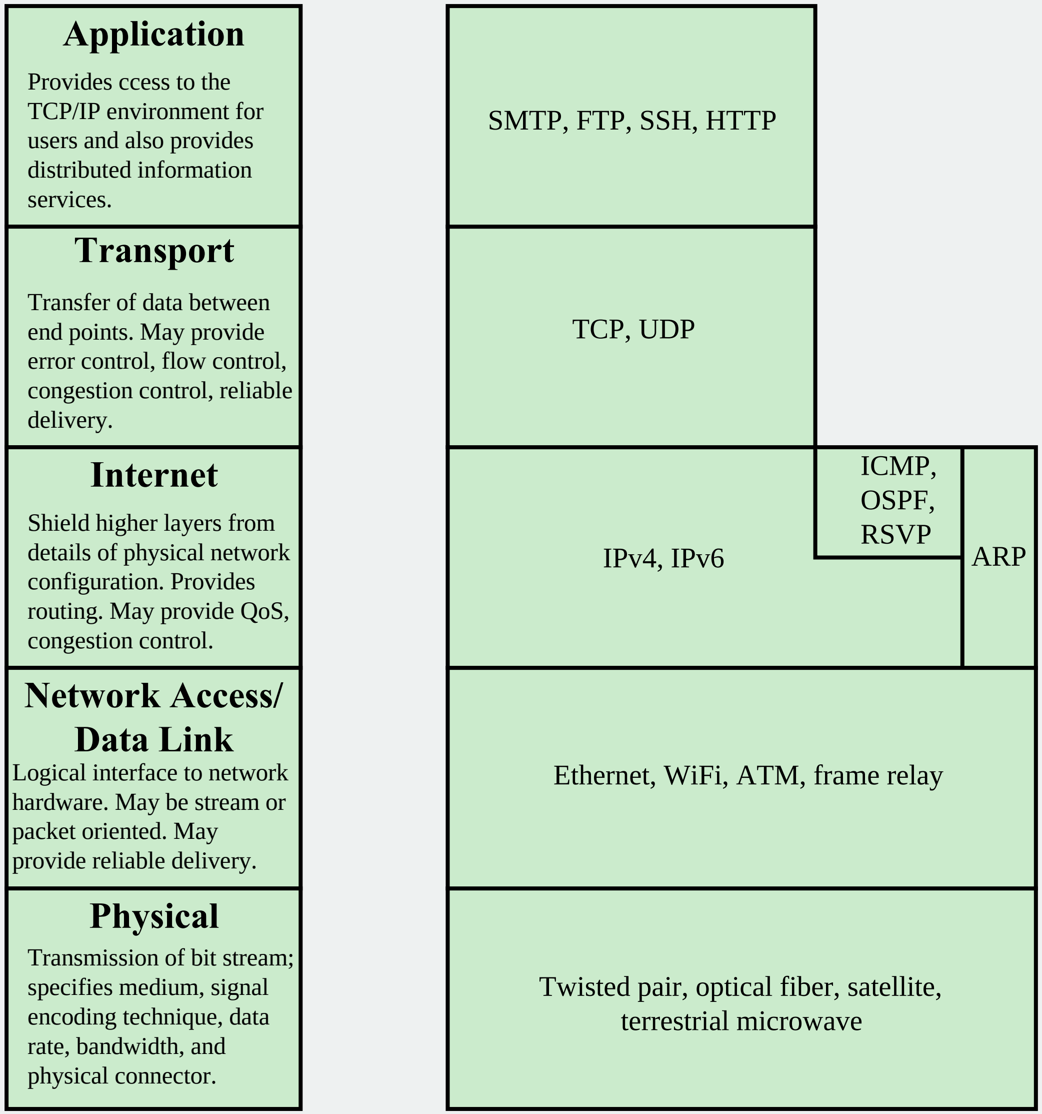
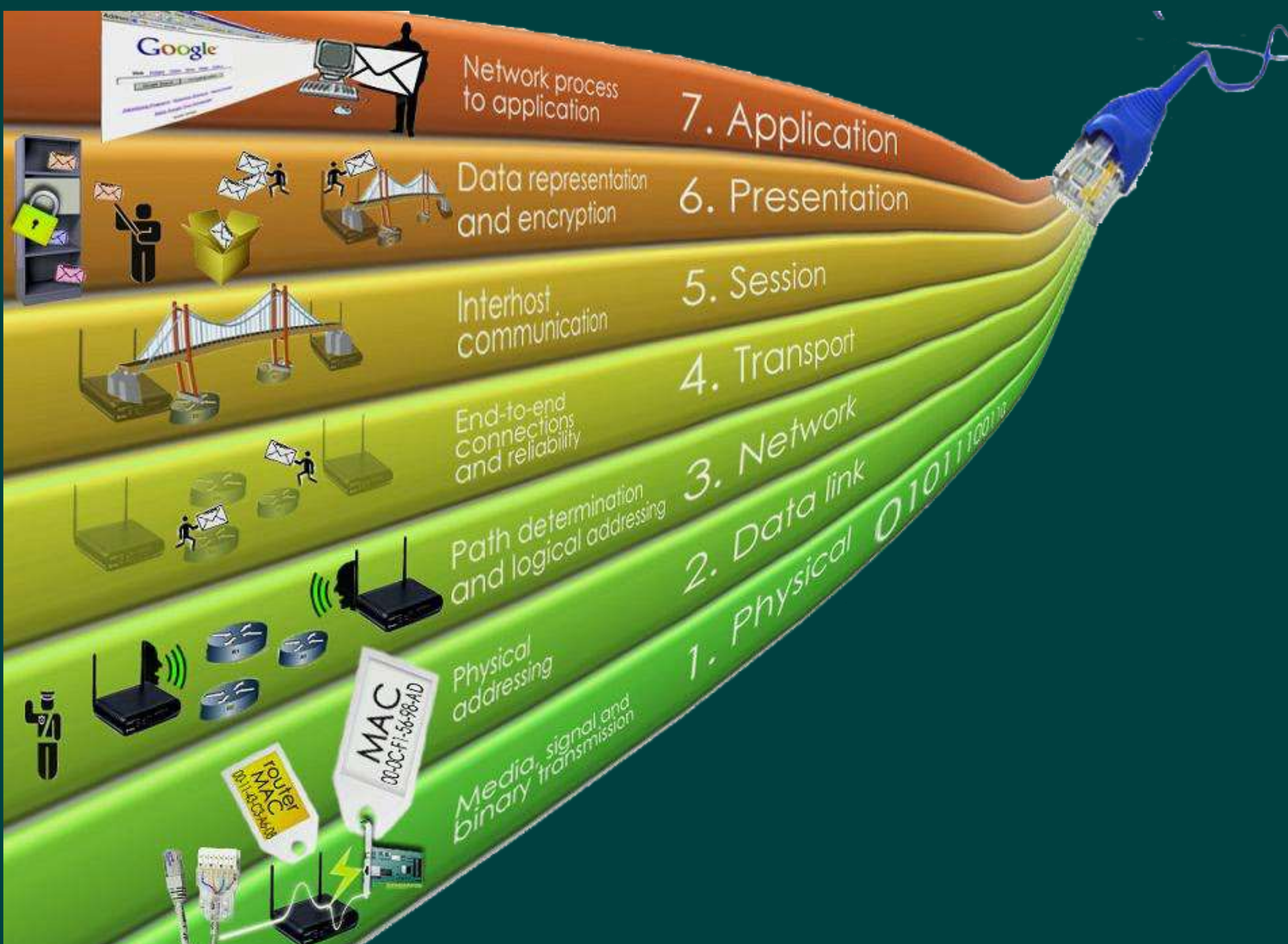
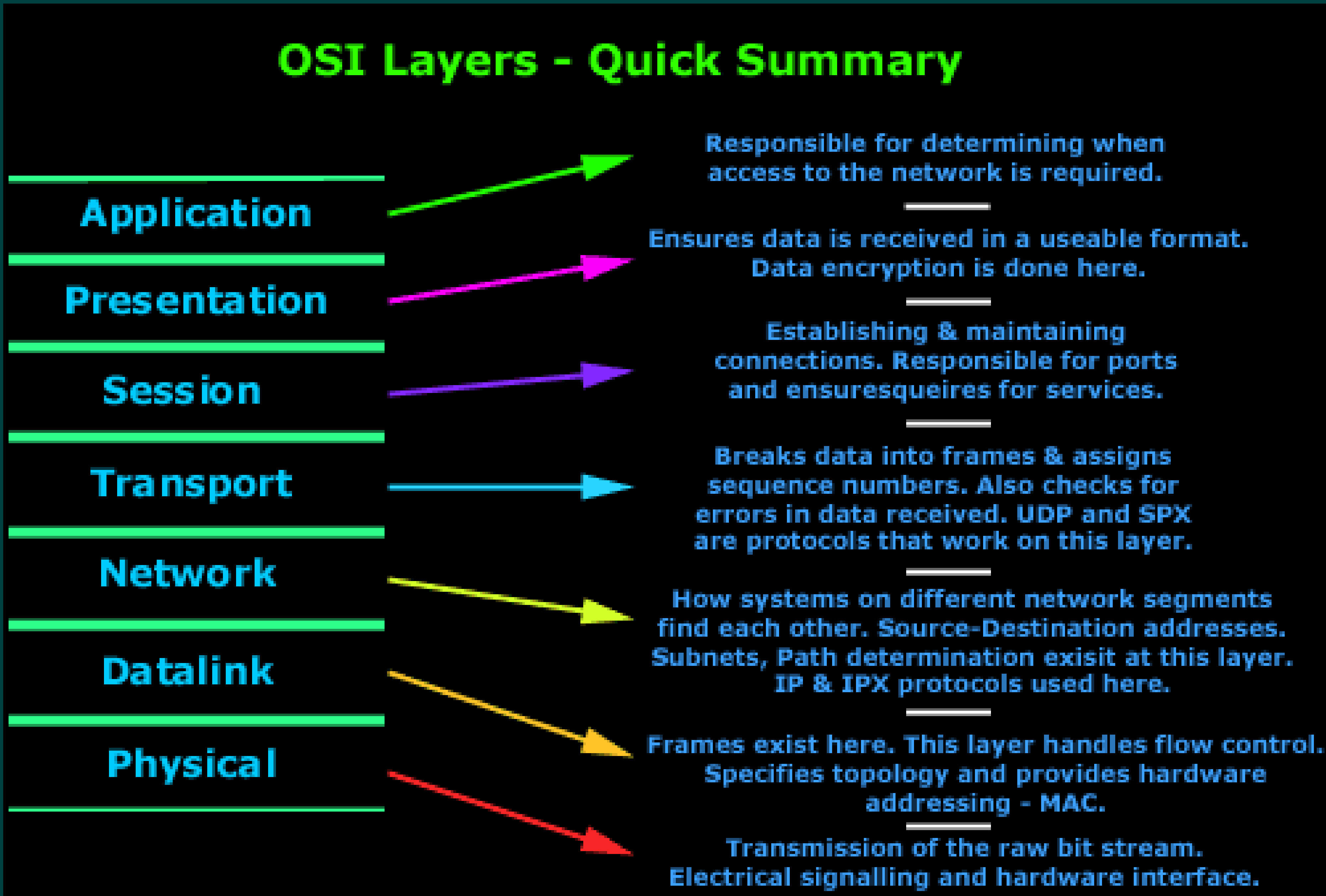


Figure 2.3 The TCP/IP Layers and Example Protocols


Network process
to application
7. Application
Data representation
and encryption
6. Presentation
Interhost
communication
5. Session
End-to-end
connections
and reliability
4. Transport
Path determination
and logical addressing
3. Network
Physical
addressing
2. Data link
Media, signal and
binary transmission
1. Physical
MAC
router
MAC
Google

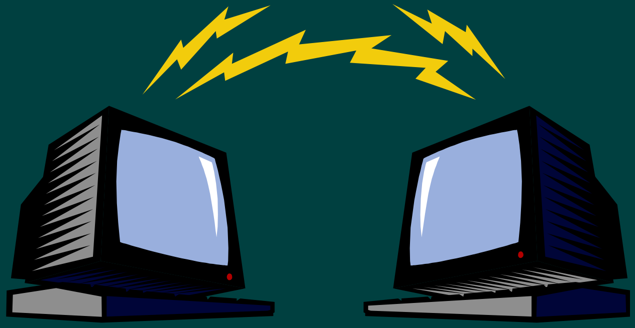

OSI Layers - Quick Summary
Application
Presentation
Session
Transport
Network
Datalink
Physical
Responsible for determining when access to the network is required.
Ensures data is received in a useable format. Data encryption is done here.
Establishing & maintaining connections. Responsible for ports and ensuresqueires for services.
Breaks data into frames & assigns sequence numbers. Also checks for errors in data received. UDP and SPX are protocols that work on this layer.
How systems on different network segments find each other. Source-Destination addresses. Subnets, Path determination exisit at this layer. IP & IPX protocols used here.
Frames exist here. This layer handles flow control. Specifies topology and provides hardware addressing - MAC.
Transmission of the raw bit stream. Electrical signalling and hardware interface.

Physical Layer

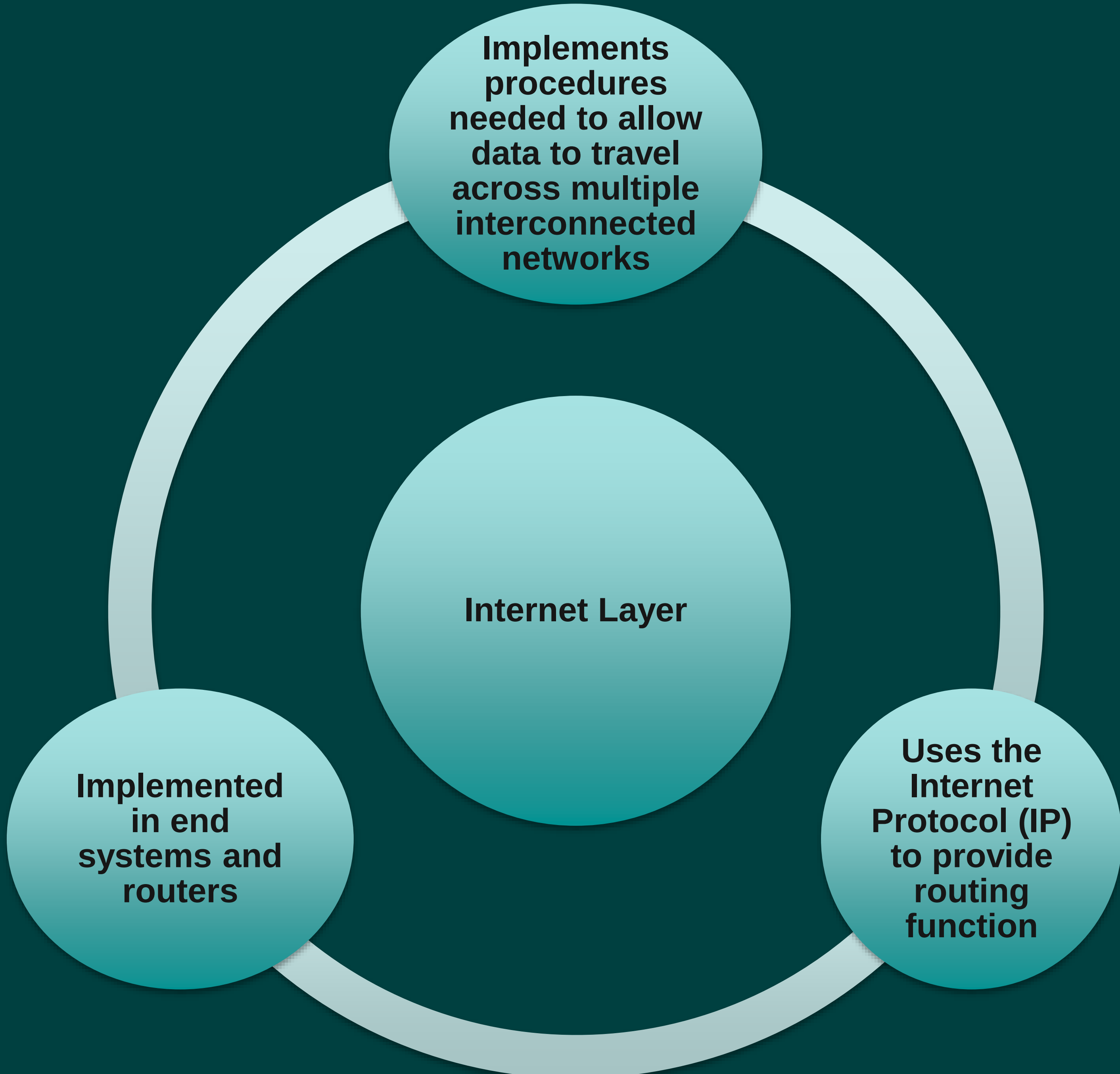
- Covers the physical interface between computer and network
- Concerned with issues like:
  - Characteristics of transmission medium
  - Nature of the signals
  - Data rates

Network Access/Data Link Layer

- Covers the exchange of data between an end system and the network that it is attached to
- Concerned with:
  - Access to and routing data across a network for two end systems attached to the same network



Internet Layer



Host-to-Host (Transport) Layer

- May provide reliable end-to-end service or merely an end-to-end delivery service without reliability mechanisms

Transmission Control Protocol

TCP

- Most commonly used protocol to provide this functionality

Application Layer

- Contains the logic needed to support the various user applications
- A separate module is needed for each different type of application that is peculiar to that application

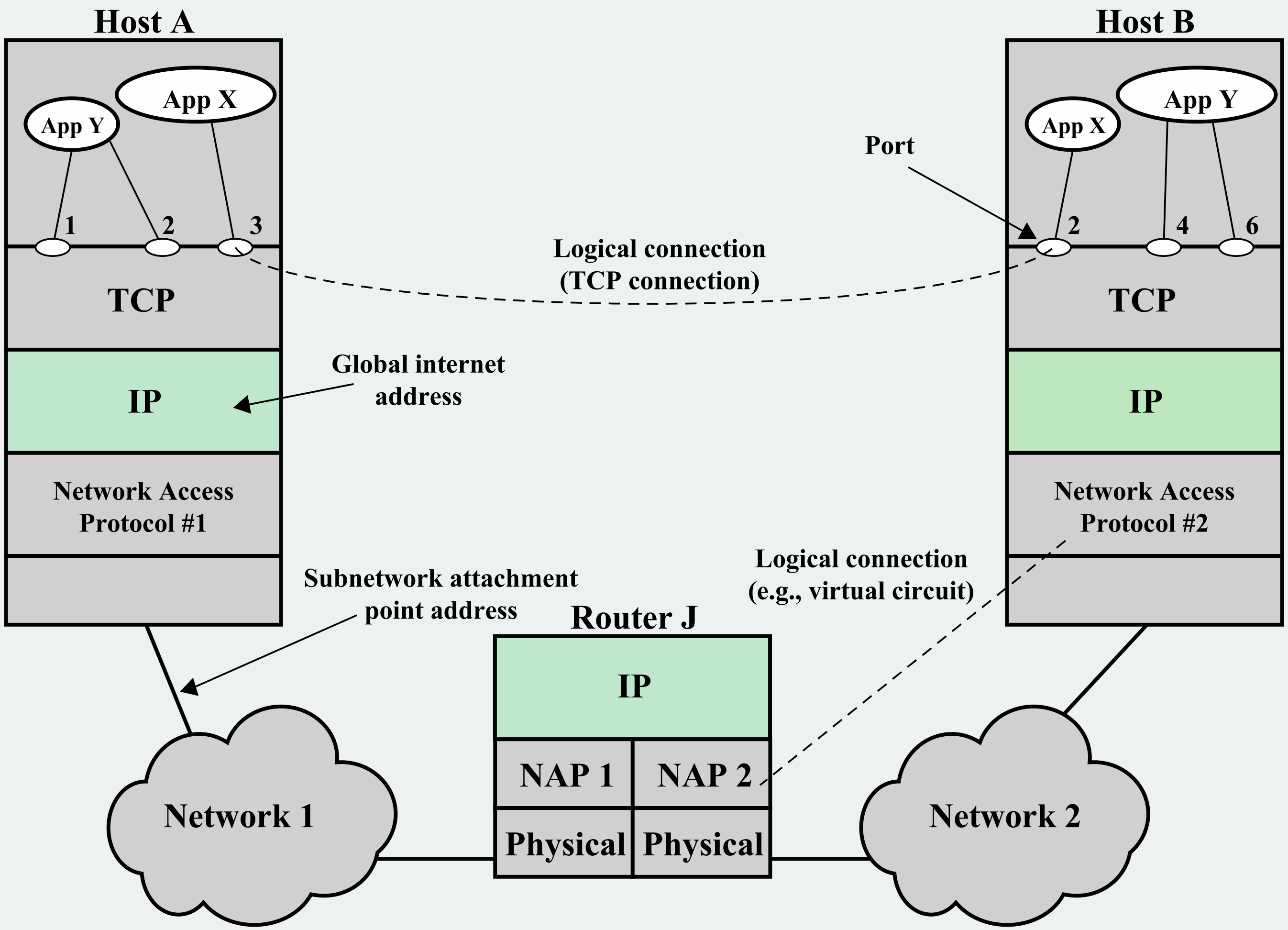


Figure 2.4 TCP/IP Concepts

TCP/IP Address Requirements

Two levels of addressing are needed:

- Each host on a subnetwork must have a unique global internet address
- Each process with a host must have an address (known as a port) that is unique within the host

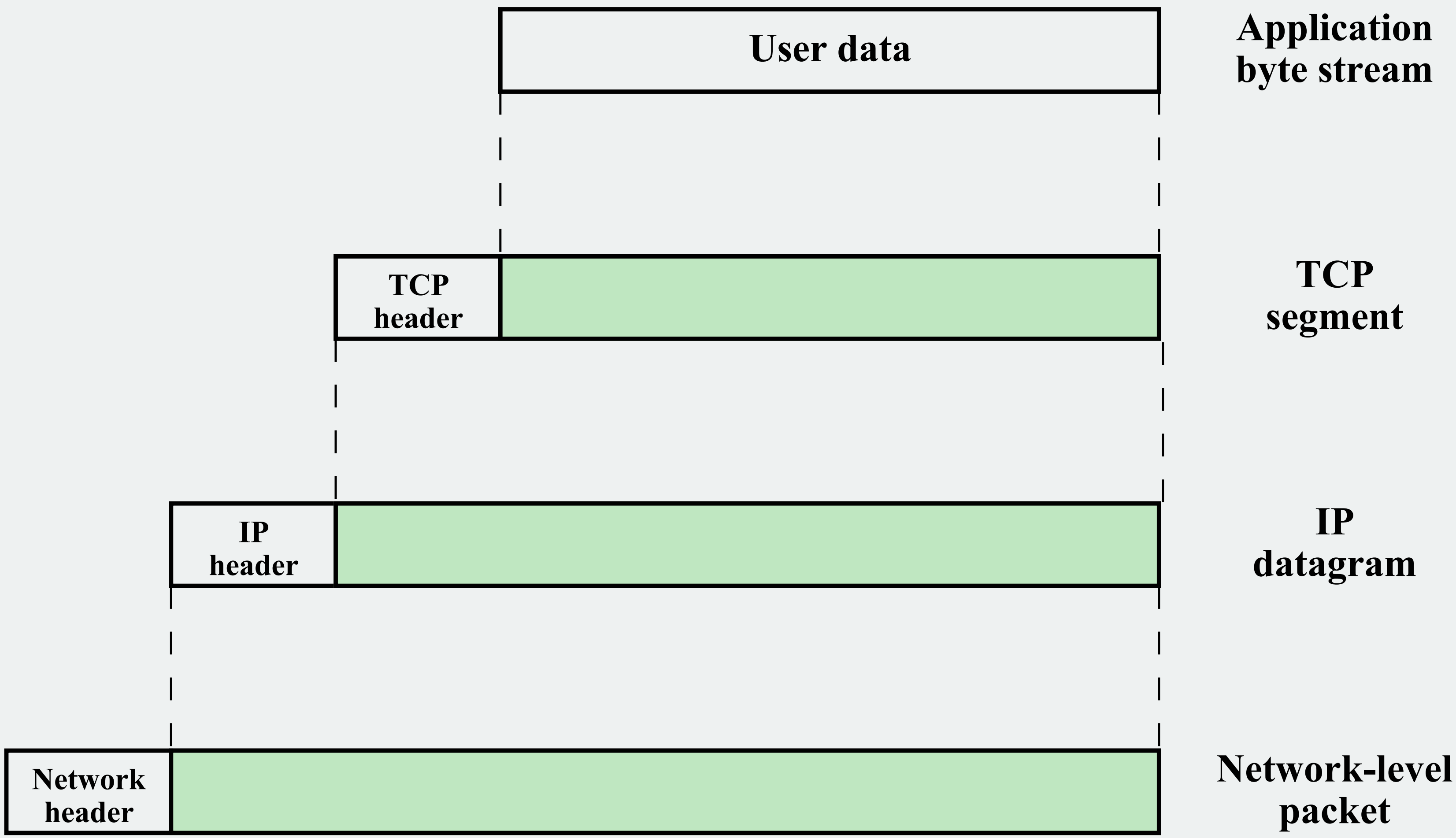


Figure 2.5 Protocol Data Units (PDUs) in the TCP/IP Architecture

Transmission Control Protocol (TCP)

- TCP is the transport layer protocol for most applications
- TCP provides a reliable connection for transfer of data between applications
- A TCP segment is the basic protocol unit
- TCP tracks segments between entities for duration of each connection

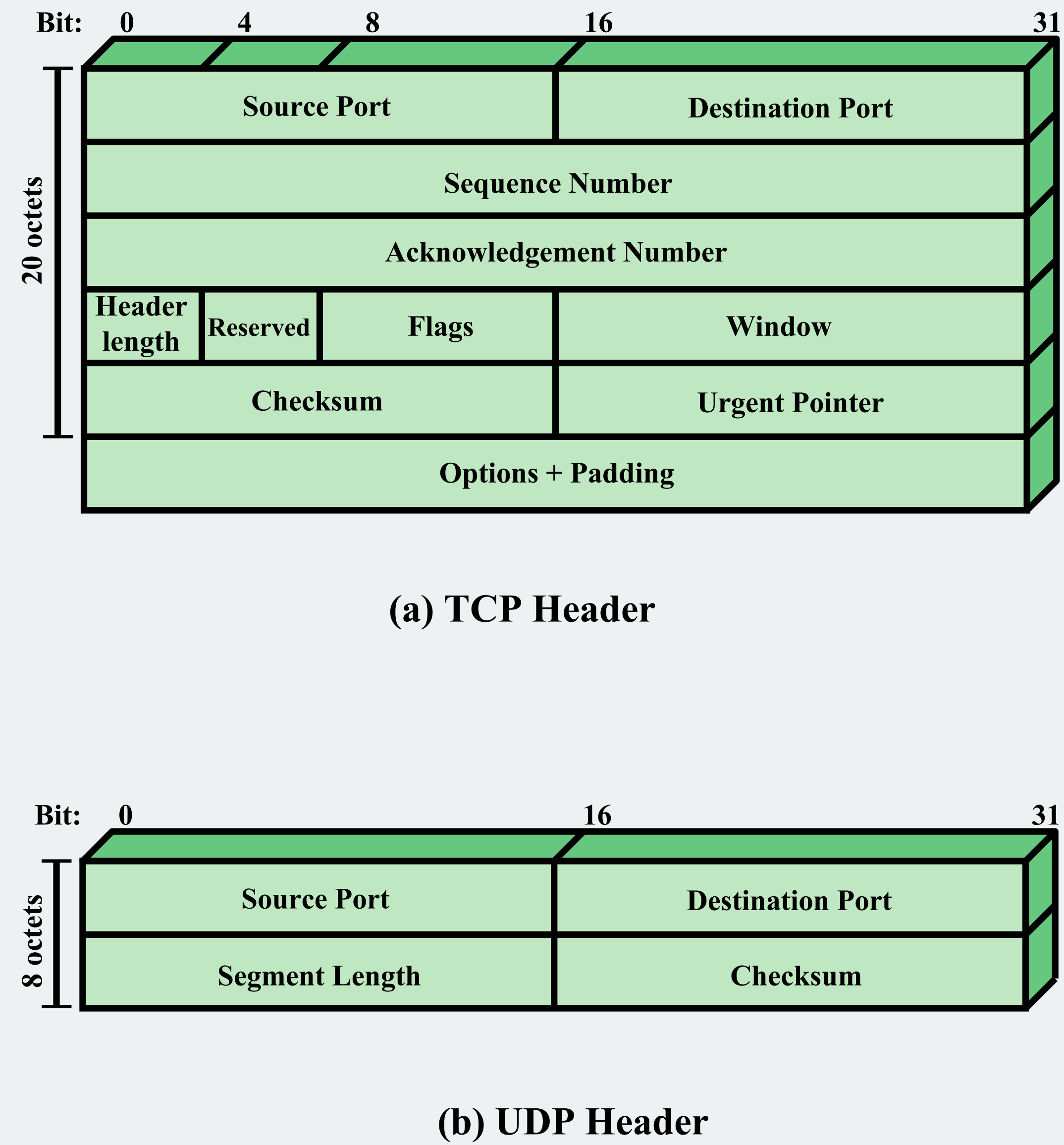
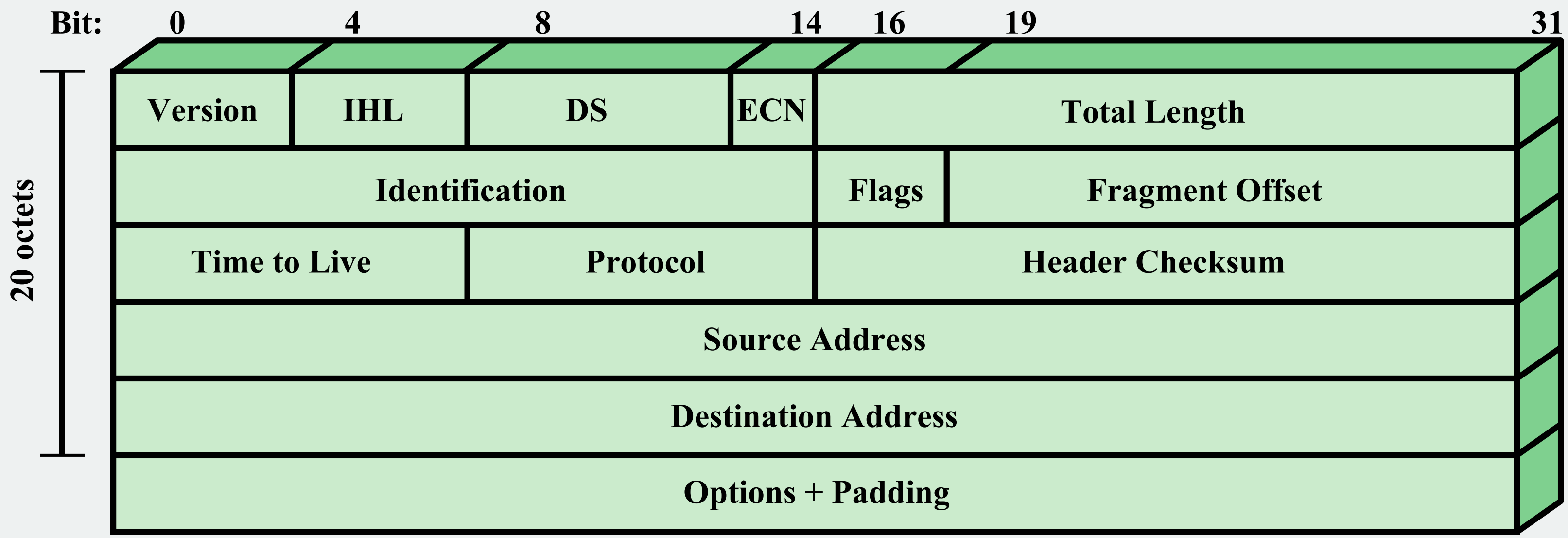


Figure 2.6 TCP and UDP Headers

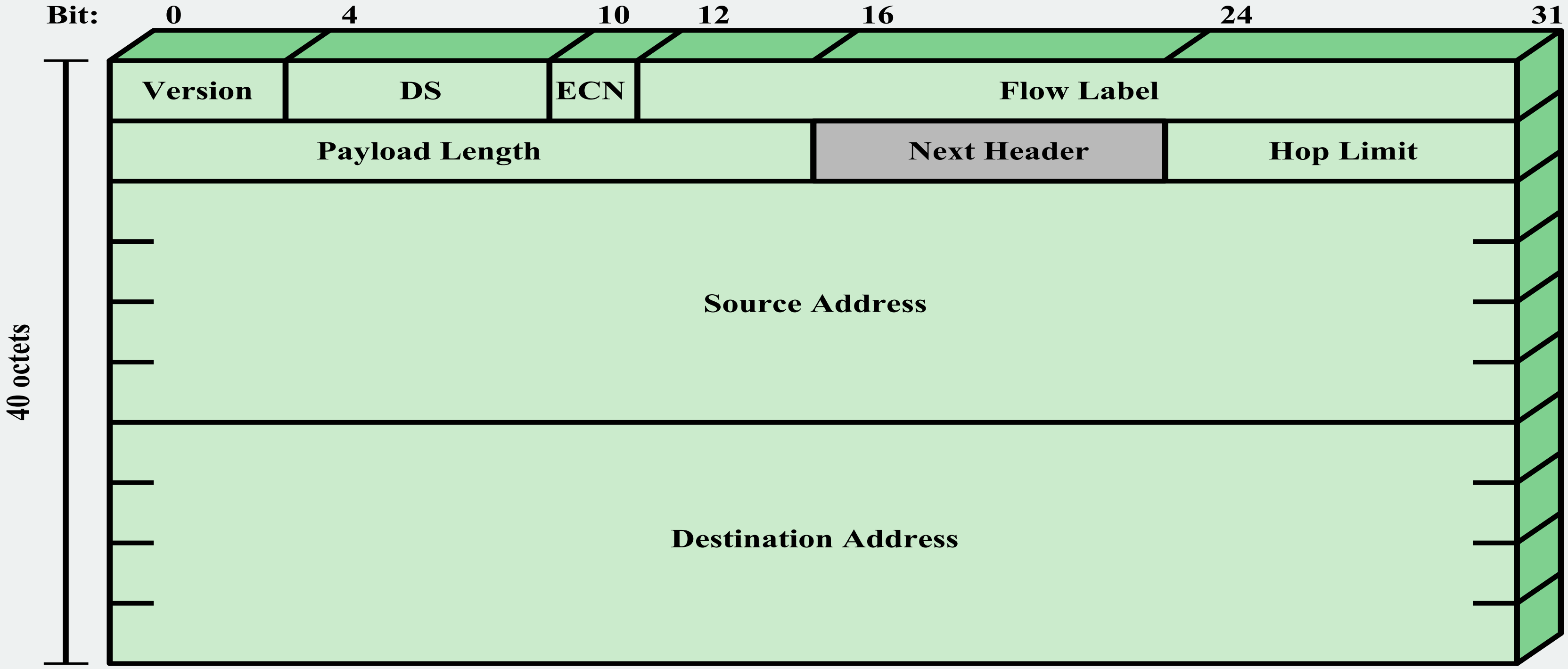
User Datagram Protocol - UDP

- Alternative to TCP
- Does not guarantee delivery, preservation of sequence, or protection against duplication
- Enables a procedure to send messages to other procedures with a minimum of protocol mechanism
- Adds port addressing capability to IP
- Used with Simple Network Management Protocol (SNMP)
- Includes a checksum to verify that no error occurs in the data



(a) IPv4 Header

Number of IP Addresses in 32-bits: 4,294,967,296



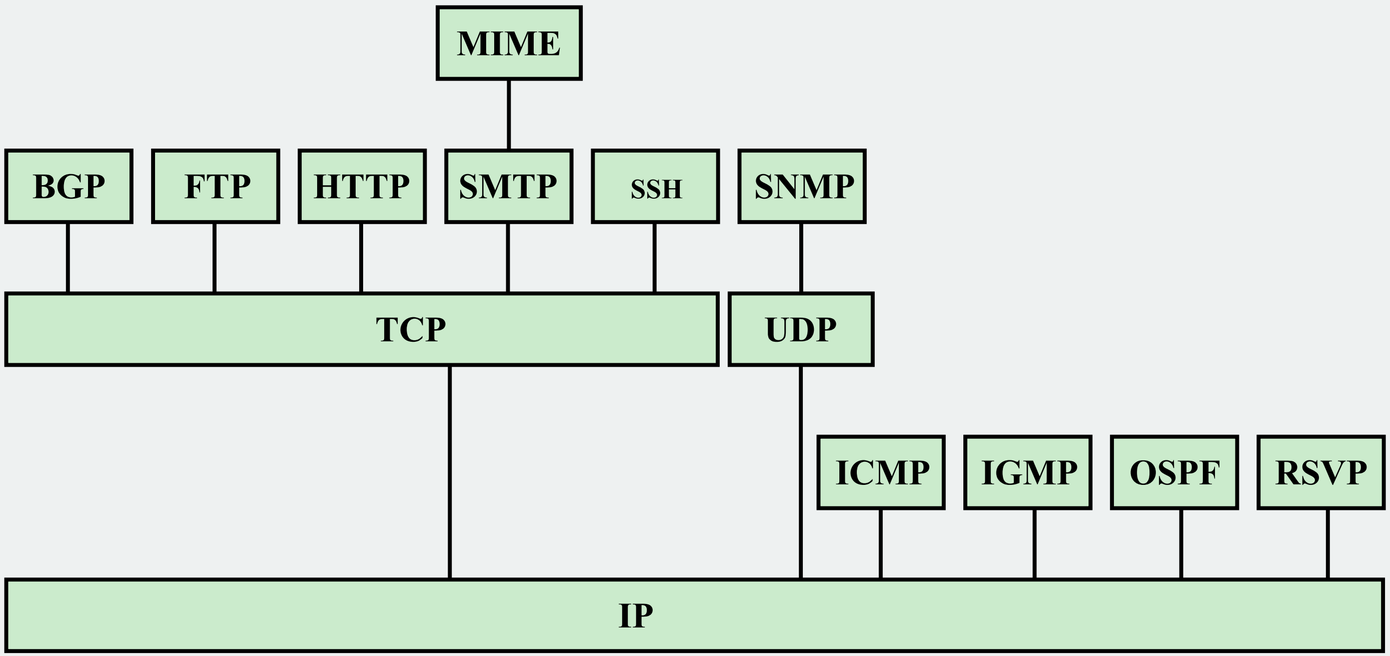
(b) IPv6 Header

DS = Differentiated services field
ECN = Explicit congestion notification field

Note: The 8-bit DS/ECN fields were formerly known as the Type of Service field in the IPv4 header and the Traffic Class field in the IPv6 header.

Figure 2.7 IP Headers

ipV6 – Addresses: 340,282,366,920,938,463,463,374,607,431,768,211,456



BGP = Border Gateway Protocol
FTP = File Transfer Protocol
HTTP = Hypertext Transfer Protocol
ICMP = Internet Control Message Protocol
IGMP = Internet Group Management Protocol
IP = Internet Protocol
MIME = Multipurpose Internet Mail Extension
OSPF = Open Shortest Path First
RSVP = Resource ReSerVation Protocol
SMTP = Simple Mail Transfer Protocol
SNMP = Simple Network Management Protocol
SSH = Secure Shell
TCP = Transmission Control Protocol
UDP = User Datagram Protocol

Figure 2.8 Some Protocols in the TCP/IP Protocol Suite

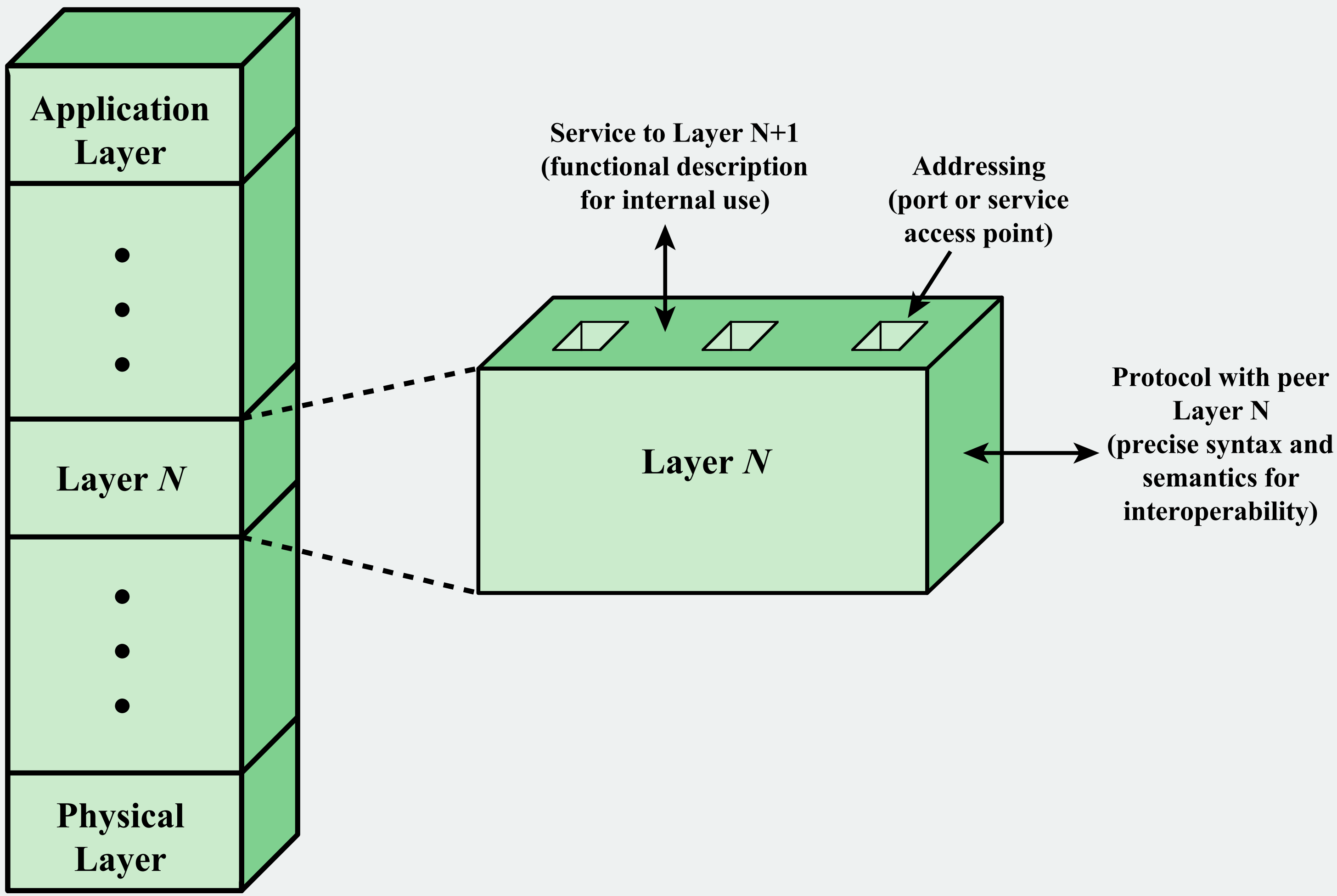


Figure 2.9 A Protocol Architecture as a Framework for Standardization

Service Primitives and Parameters

- Services between adjacent layers
- Expressed as:
  - **Primitives**
    - Specify the function to be performed
  - **Parameters**
    - Used to pass data and control information

Primitive Types

REQUEST	A primitive issued by a service user to invoke some service and to pass the parameters needed to specify fully the requested service
INDICATION	A primitive issued by a service provider either to 1. indicate that a procedure has been invoked by the peer service user on the connection and to provide the associated parameters, or 2. notify the service user of a provider-initiated action
RESPONSE	A primitive issued by a service user to acknowledge or complete some procedure previously invoked by an indication to that user
CONFIRM	A primitive issued by a service provider to acknowledge or complete some procedure previously invoked by a request by the service user

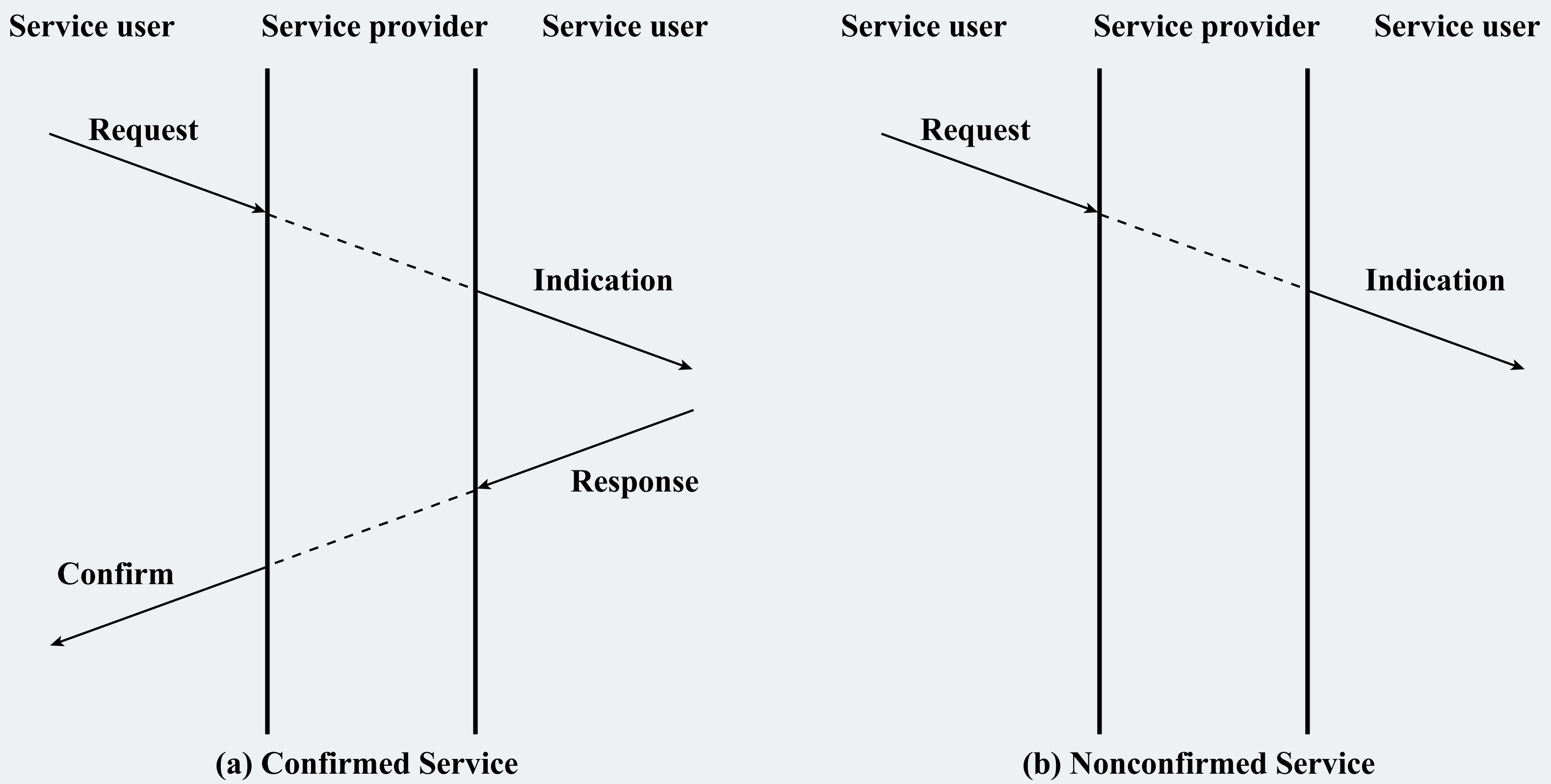


Figure 2.10 Time Sequence Diagrams for Service Primitives

Traditional Internet-Based Applications

- Three common applications that have been standardized to operate on top of TCP are:

Simple Mail Transfer Protocol (SMTP)

- Provides a mechanism for transferring messages among separate hosts

File Transfer Protocol (FTP)

- Used to send files from one system to another under user command
- Both text and binary files are accommodated

Secure Shell (SSH)

- Provides a secure remote logon capability

Table 2.2 : Multimedia Terminology

Media

Refers to the form of information and includes text, still images, audio, and video.

Multimedia

Human-computer interaction involving text, graphics, voice and video. Multimedia also refers to storage devices that are used to store multimedia content.

Streaming media

Refers to multimedia files, such as video clips and audio, that begin playing immediately or within seconds after it is received by a computer from the Internet or Web. Thus, the media content is consumed as it is delivered from the server rather than waiting until an entire file is downloaded.

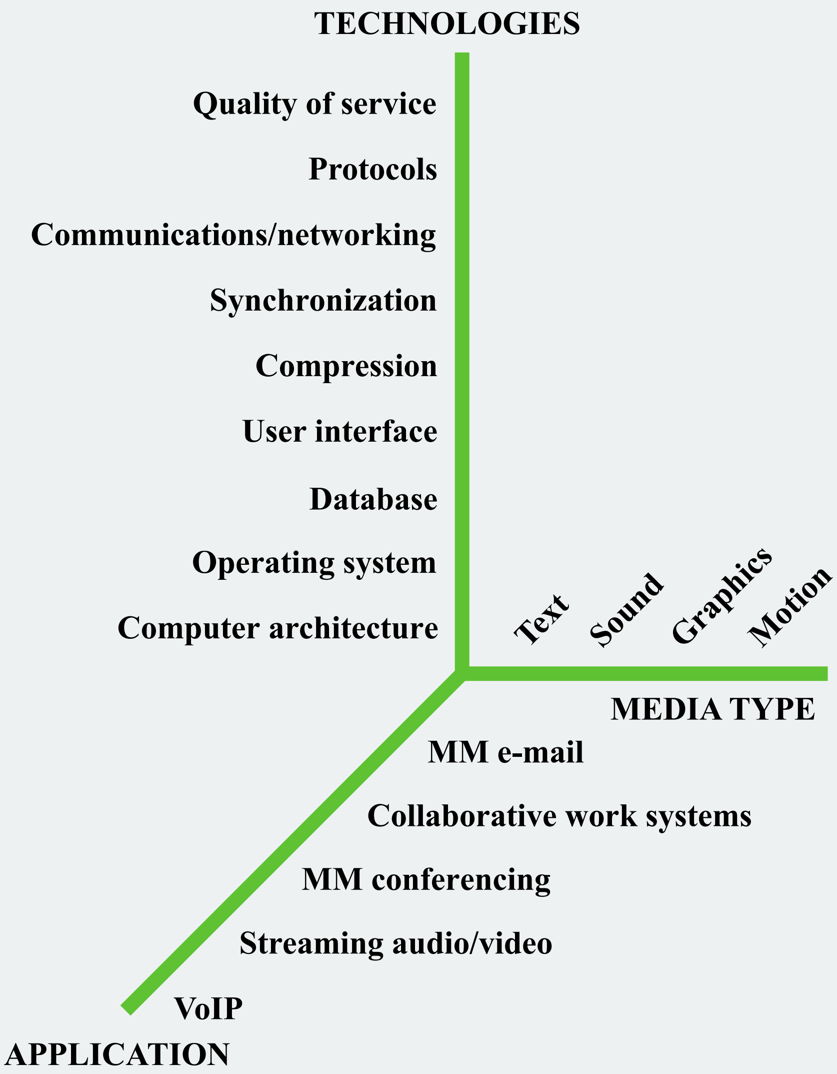
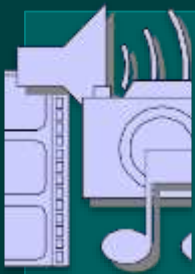


Figure 2.11 A Multimedia Taxonomy

Media Types



audio generally encompasses sounds that are produced by the human speech mechanism

image supports the communication of individual pictures, charts, or drawings

video service carries sequences of pictures in time

text is information that can be entered via a keyboard and is directly readable and printable

Table 2.3

Domains of Multimedia Systems and Example Applications

Domain	Example Application
Information management	Hypermedia, multimedia-capable databases, content-based retrieval
Entertainment	Computer games, digital video, audio (MP3)
Telecommunication	Videoconferencing, shared workspaces, virtual communities
Information publishing/delivery	Online training, electronic books, streaming media

Multimedia Applications

Information systems

- Information kiosks, electronic books that include audio and video, and multimedia expert systems

Communication systems

- Support collaborative work, such as videoconferencing

Entertainment systems

- Computer and network games and other forms of audiovisual entertainment

Business systems

- Business-oriented multimedia presentations, video brochures, and online shopping

Educational systems

- Electronic books with a multimedia component, simulation and modeling applets, and other teaching support systems

Multimedia Technologies

- Some technologies that are relevant to the support of multimedia applications are:

Compression
- JPG for still images
- MPG for video

Communications/networking
- Refers to the transmission and networking technologies that can support high-volume multimedia traffic

Protocols
- RTP
- SIP

Quality of service (QoS)
- Can deal with priority, delay constraints, delay variability constraints, and other similar requirements

Sockets Programming

- Concept was developed in the 1980s in the UNIX environment as the Berkeley Sockets Interface
  - De facto standard application programming interface (API)
  - Basis for Window Sockets (WinSock)
- Enables communication between a client and server process
- May be connection oriented or connectionless

The Socket

- Formed by the concatenation of a port value and an IP address
  - Unique throughout the Internet
- Used to define an API
  - Generic communication interface for writing programs that use TCP or UDP
- Stream sockets
  - All blocks of data sent between a pair of sockets are guaranteed for delivery and arrive in the order that they were sent
- Datagram sockets
  - Delivery is not guaranteed, nor is order necessarily preserved
- Raw sockets
  - Allow direct access to lower-layer protocols

Table 2.4

Core Socket Functions

(Table can be found on page 54 in textbook)

Format	Function	Parameters
`socket( )`	Initialize a socket	**domain** Protocol family of the socket to be created (AF_UNIX, AF_INET, AF_INET6) **type** Type of socket to be opened (stream, datagram, raw) **protocol** Protocol to be used on socket (UDP, TCP, ICMP)
`bind( )`	Bind a socket to a port address	**sockfd** Socket to be bound to the port address **localaddress** Socket address to which the socket is bound **addresslength** Length of the socket address structure
`listen( )`	Listen on a socket for inbound connections	**sockfd** Socket on which the application is to listen **queuesize** Number of inbound requests that can be queued at any time
`accept( )`	Accept an inbound connection	**sockfd** Socket on which the connection is to be accepted **remoteaddress** Remote socket address from which the connection was initiated **addresslength** Length of the socket address structure
`connect( )`	Connect outbound to a server	**sockfd** Socket on which the connection is to be opened **remoteaddress** Remote socket address to which the connection is to be opened **addresslength** Length of the socket address structure

`send( )`
`recv( )`
 	
`read( )`
`write( )`
	Send and receive data on a stream socket (either send/recv or read/write can be used)	**sockfd** Socket across which the data will be sent or read
		data Data to be sent, or buffer into which the read data will be placed
		datalength Length of the data to be written, or amount of data to be read

`sendto( )` `recvfrom( )`	Send and receive data on a datagram socket	**sockfd** Socket across which the data will be sent or read **data** Data to be sent, or buffer into which the read data will be placed **datalength** Length of the data to be written, or amount of data to be read
`close( )`	Close a socket	**sockfd** Socket which is to be closed

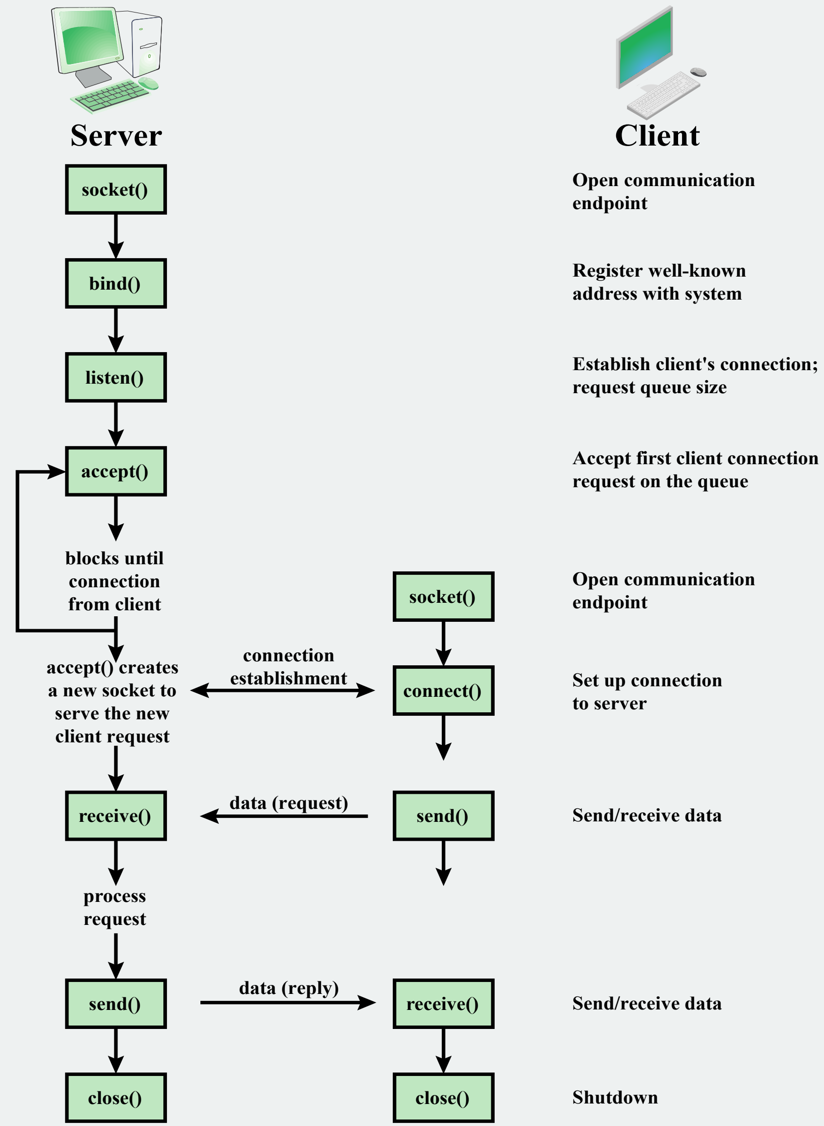


Figure 2.12 Socket System Calls for Connection-Oriented Protocol

```c
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>

void error(char *msg)
{
    perror(msg);
    exit(1);
}

int main(int argc, char *argv[])
{
     int sockfd, newsockfd, portno, clilen;
     char buffer[256];
     struct sockaddr_in serv_addr, cli_addr;
     int n;
     if (argc < 2) {
         fprintf(stderr,"ERROR, no port provided\n");
         exit(1);
     }
     sockfd = socket(AF_INET, SOCK_STREAM, 0);
     if (sockfd < 0)
        error("ERROR opening socket");
     bzero((char *) &serv_addr, sizeof(serv_addr));
     portno = atoi(argv[1]);
     serv_addr.sin_family = AF_INET;
     serv_addr.sin_port = htons(portno);
     serv_addr.sin_addr.s_addr = INADDR_ANY;
     if (bind(sockfd, (struct sockaddr *) &serv_addr,
              sizeof(serv_addr)) < 0)
              error("ERROR on binding");
     listen(sockfd,5);
     clilen = sizeof(cli_addr);
     newsockfd = accept(sockfd, (struct sockaddr *) &cli_addr, &clilen);
     if (newsockfd < 0)
          error("ERROR on accept");
     bzero(buffer,256);
     n = read(newsockfd,buffer,255);
     if (n < 0) error("ERROR reading from socket");
     printf("Here is the message: %s\n",buffer);
     n = write(newsockfd,"I got your message",18);
     if (n < 0) error("ERROR writing to socket");
     return 0;
}
```

Figure 2.13 Sockets Server

(Figure 2.13 can be found on page 57 in textbook)

```c
#include <stdio.h>
#include <sys/types.h>
#include <sys/socket.h>
#include <netinet/in.h>
#include <netdb.h>

void error(char *msg)
{
    perror(msg);
    exit(0);
}

int main(int argc, char *argv[])
{
  int sockfd, portno, n;
  struct sockaddr_in serv_addr;
  struct hostent *server;
  char buffer[256];
  if (argc < 3) {
     fprintf(stderr,"usage %s hostname port\n", argv[0]);
     exit(0);
  }
  portno = atoi(argv[2]);
  sockfd = socket(AF_INET, SOCK_STREAM, 0);
  if (sockfd < 0)
      error("ERROR opening socket");
  server = gethostbyname(argv[1]);
  if (server == NULL) {
      fprintf(stderr,"ERROR, no such host\n");
      exit(0);
  }
  bzero((char *) &serv_addr, sizeof(serv_addr));
  serv_addr.sin_family = AF_INET;
  bcopy((char *)server->h_addr,
       (char *)&serv_addr.sin_addr.s_addr,
       server->h_length);
  serv_addr.sin_port = htons(portno);
  if (connect(sockfd,(struct sockaddr *)&serv_addr,sizeof(serv_addr)) < 0)
      error("ERROR connecting");
  printf("Please enter the message: ");
  bzero(buffer,256);
  fgets(buffer,255,stdin);
  n = write(sockfd,buffer,strlen(buffer));
  if (n < 0)
       error("ERROR writing to socket");
  bzero(buffer,256);
  n = read(sockfd,buffer,255);
  if (n < 0)
       error("ERROR reading from socket");
  printf("%s\n",buffer);
  return 0;
}
```

Figure 2.14 Sockets Client

(Figure 2.14 can be found on page 58 in textbook)

Data Transmission and Terminology

Data Transmission and Terminology

Data transmission occurs between transmitter and receiver over some transmission medium

Communication is in the form of electromagnetic waves

Guided media

- Twisted pair, coaxial cable, optical fiber

Unguided media (wireless)

- Propagation through air, vacuum, and seawater

Transmission Terminology

Direct link

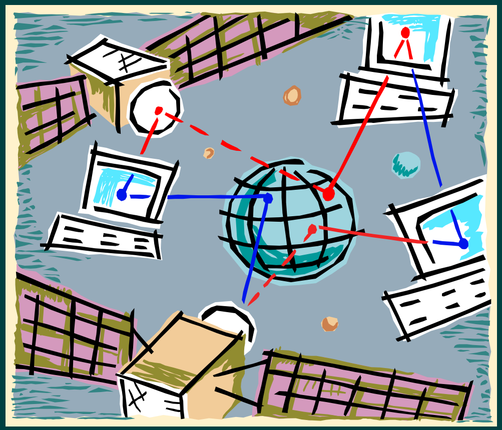
- No intermediate devices other than amplifiers or repeaters used to increase signal strength

Point-to-point

- Direct link between two devices
- Are the only 2 devices sharing medium

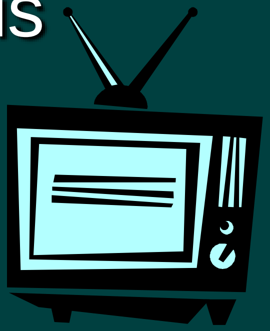
Multi-point

- More than two devices share the same medium

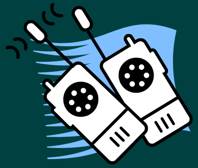


Transmission Terminology

- **Simplex**
  - Signals are transmitted in only one direction
  - One station is transmitter and the other is receiver



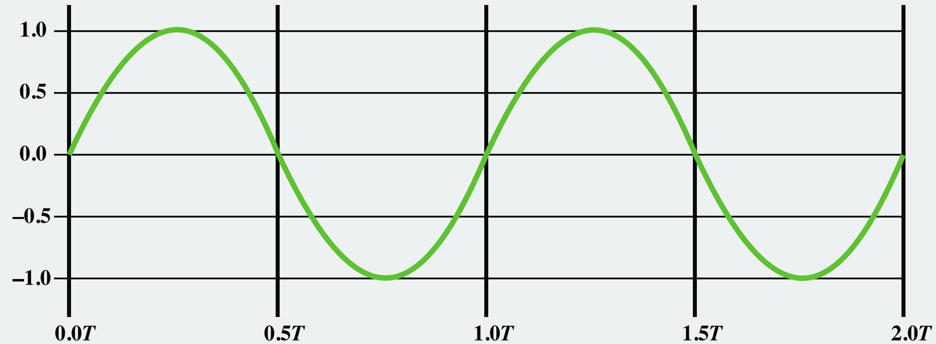
- **Half duplex**
  - Both stations transmit, but only one at a time



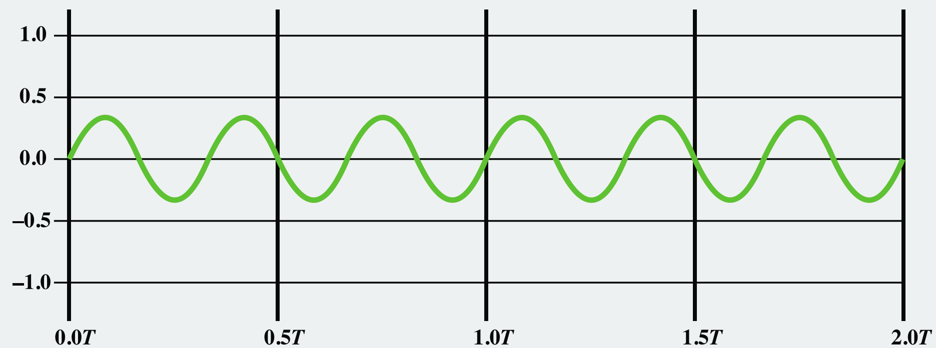
- **Full duplex**
  - Both stations may transmit simultaneously
  - The medium is carrying signals in both directions at the same time

Frequency Domain Concepts

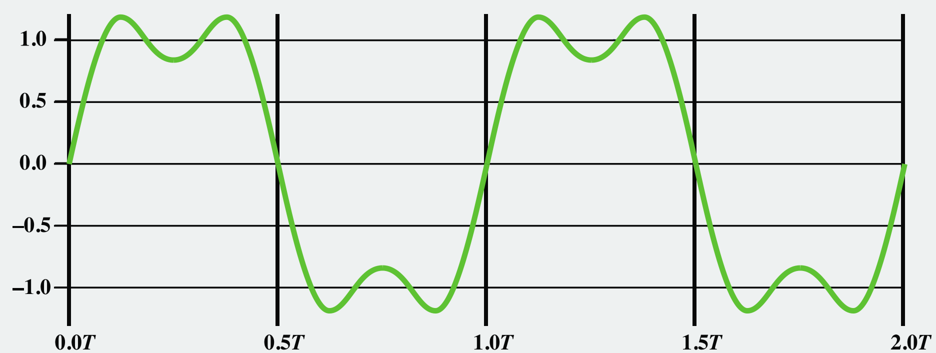
- Signals are made up of many frequencies
- Components are sine waves
- Fourier analysis can show that any signal is made up of components at various frequencies, in which each component is a sinusoid
- Can plot frequency domain functions



(a) sin ($2\pi ft$)



(b) (1/3) sin ($2\pi(3f)t$)



(c) ($4/\pi$) [sin ($2\pi ft$) + (1/3) sin ($2\pi(3f)t$)]

Figure 3.4 Addition of Frequency Components ($T = 1/f$)

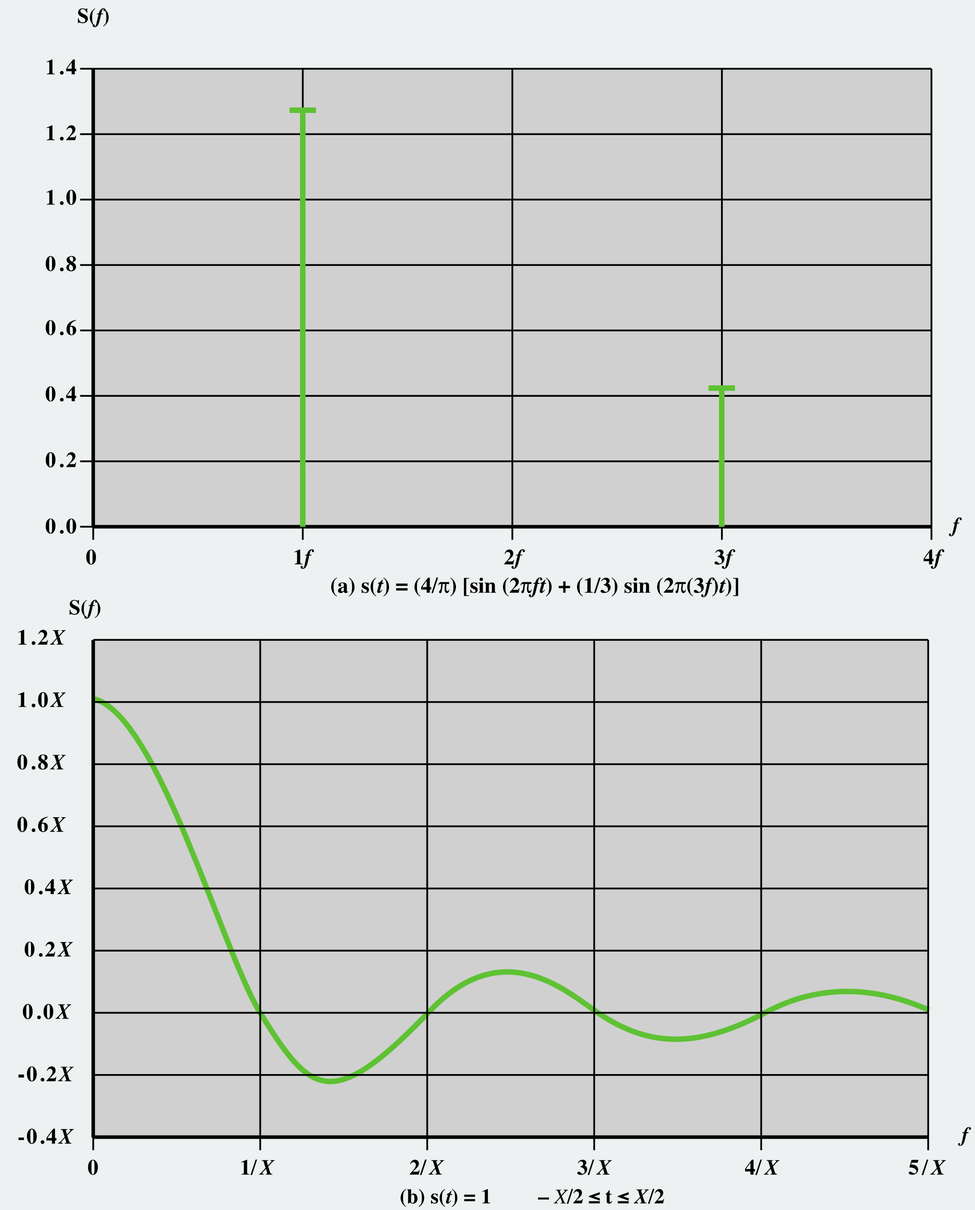


Figure 3.5 Frequency-Domain Representations

Spectrum and Bandwidth

Spectrum

- *Range of frequencies contained in signal*

Absolute bandwidth

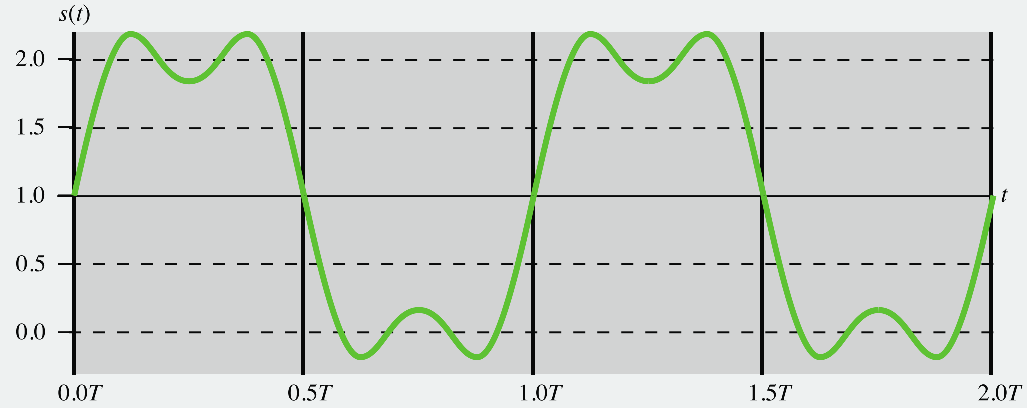
- *Width of spectrum*

Effective bandwidth (or just *bandwidth*)

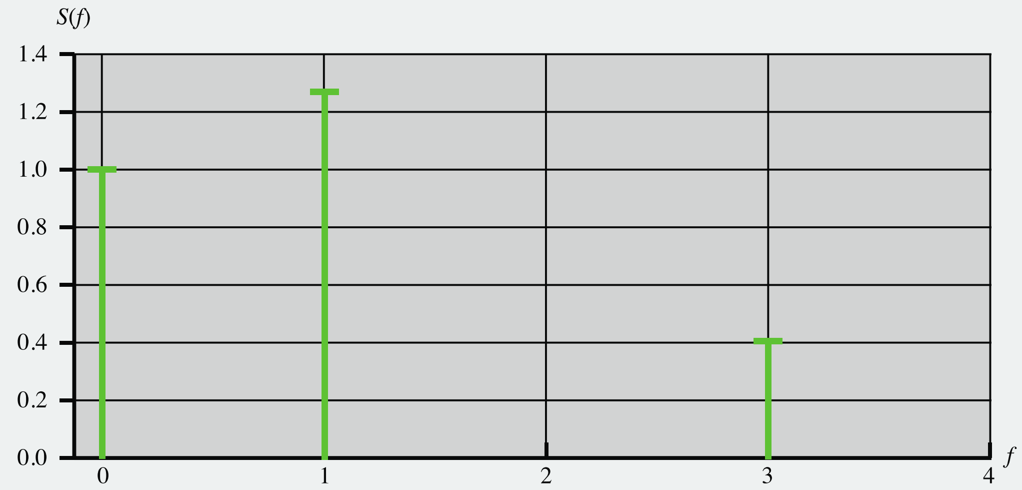
- *Narrow band of frequencies containing most energy*

Dc component

- *Component of zero frequency*



(a) s(*t*) = 1 + (4/π) [sin (2π*ft*) + (1/3) sin (2π(3*f*)*t*)]



(b) S(*f*)

Figure 3.6 Signal with dc Component

Data Rate and Bandwidth

Any transmission system has a limited band of frequencies

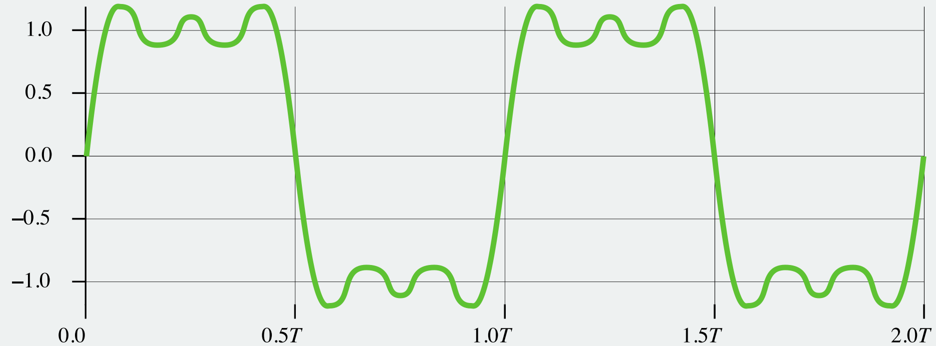
This limits the data rate that can be carried on the transmission medium

Square waves have infinite components and hence an infinite bandwidth

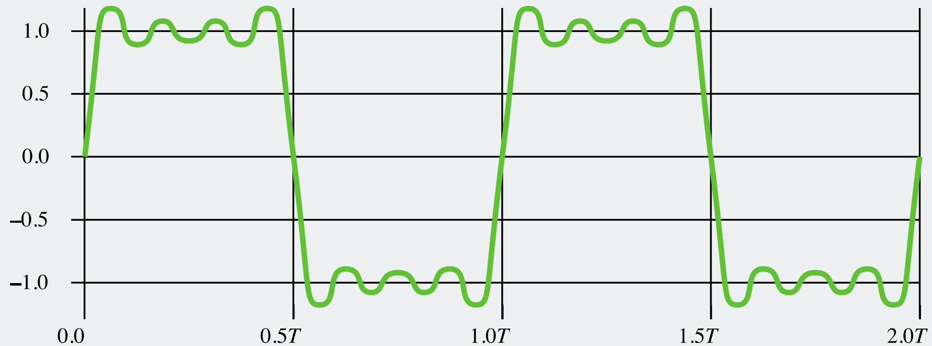
Most energy in first few components

Limiting bandwidth creates distortions

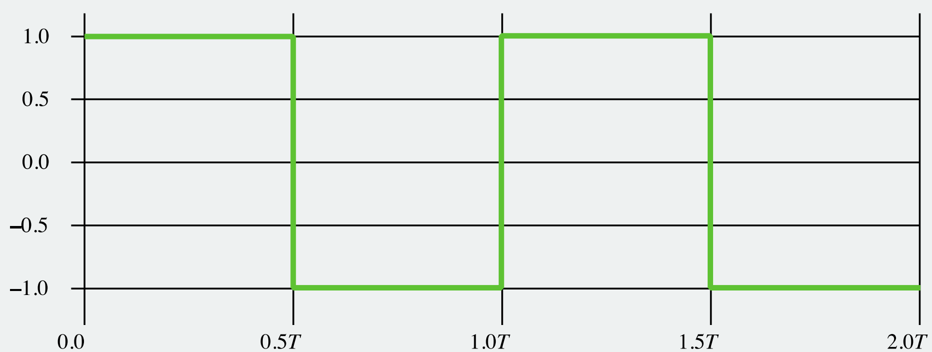
There is a direct relationship between data rate and bandwidth



(a) $(4/\pi)\ [\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$



(b) $(4/\pi)\ [\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$



(c) $(4/\pi)\ \sum(1/k)\sin(2\pi(kf)t)$, for k odd

Figure 3.7 Frequency Components of Square Wave ($T = 1/f$)

Analog and Digital Data Transmission

Data	Signals	Signaling	Transmission
Entities that convey information	Electric or electromagnetic representations of data	Physical propagation of the signal along a suitable medium	Communication of data by the propagation and processing of signals

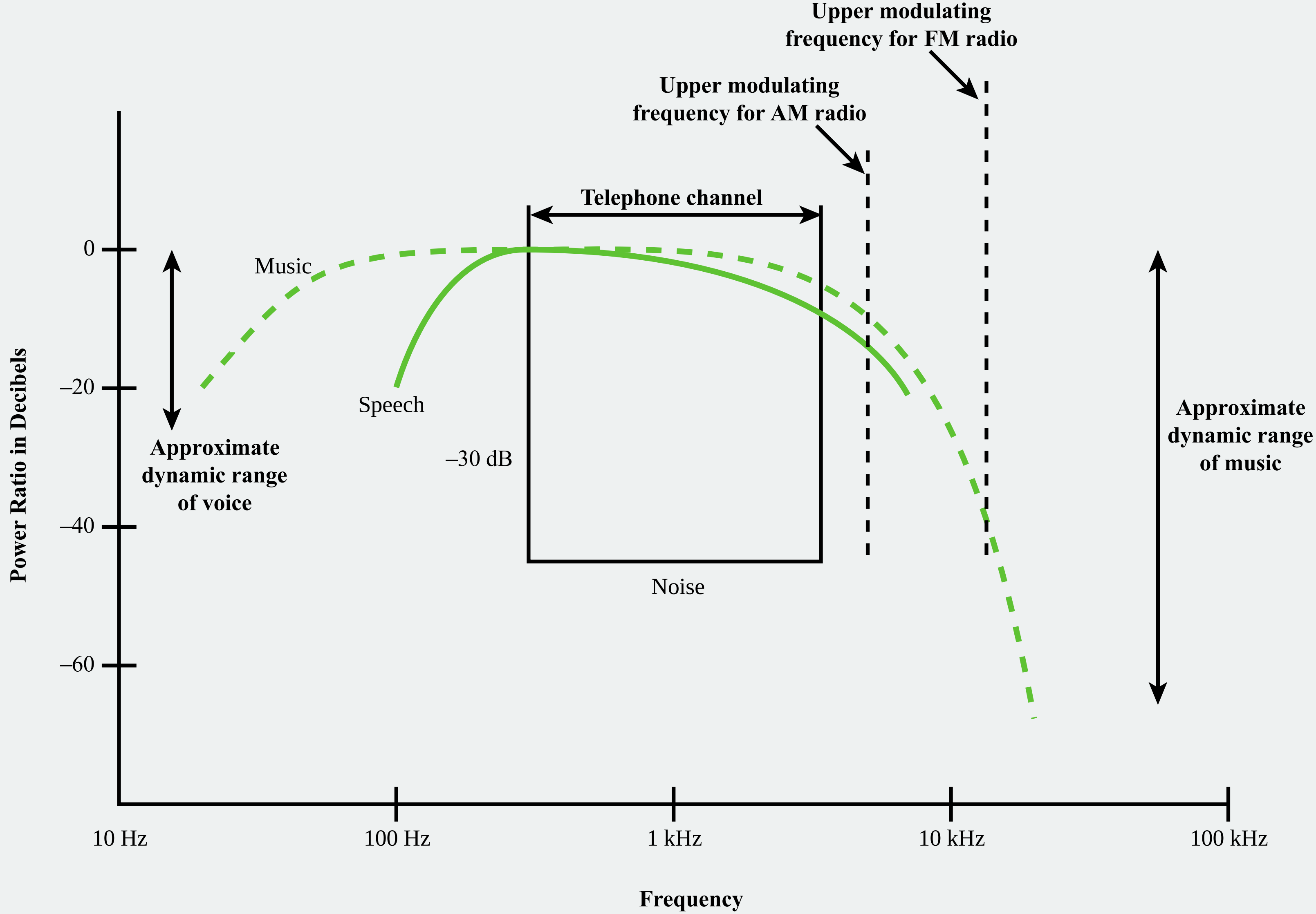


Figure 3.9 Acoustic Spectrum of Speech and Music [CARN99]

Digital Data

Examples:

- Text
- Character strings
- IRA

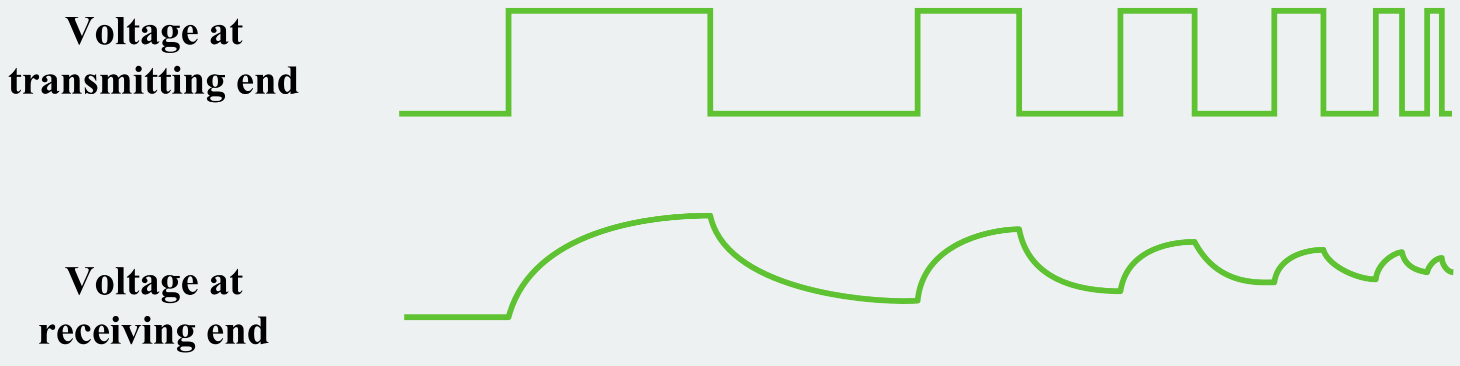
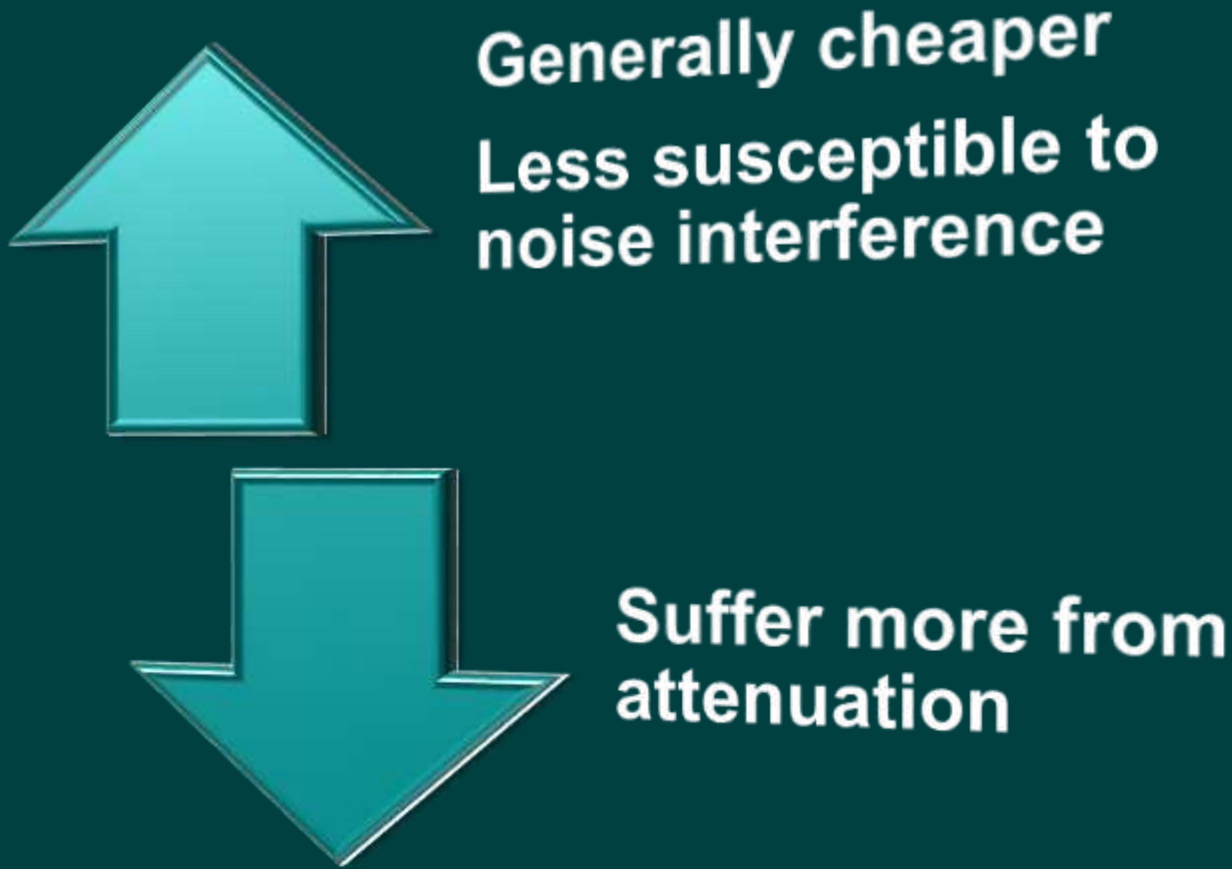
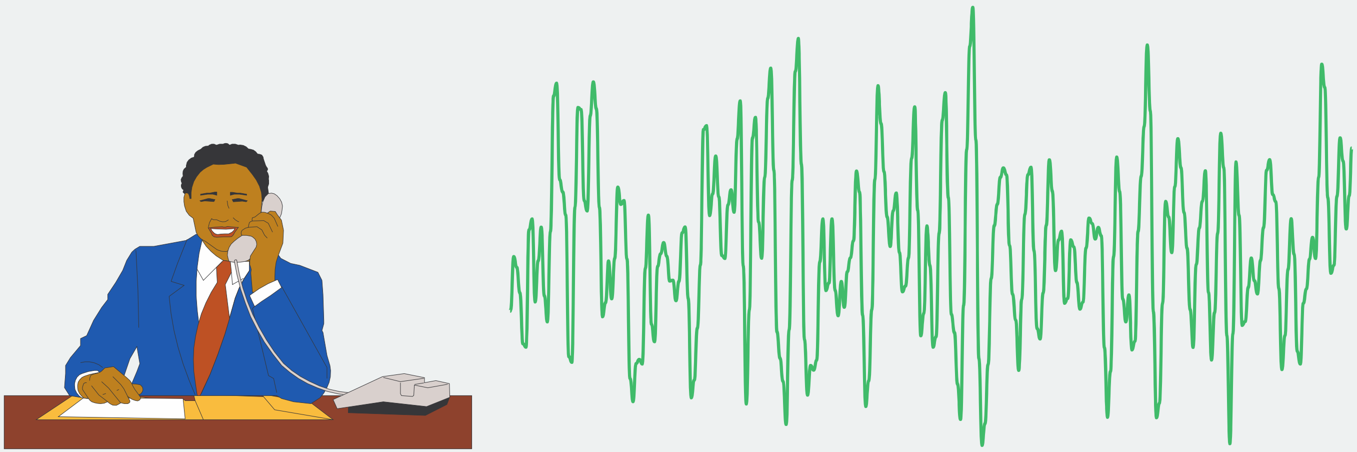


Figure 3.10 Attenuation of Digital Signals

Advantages and Disadvantages of Digital Signals

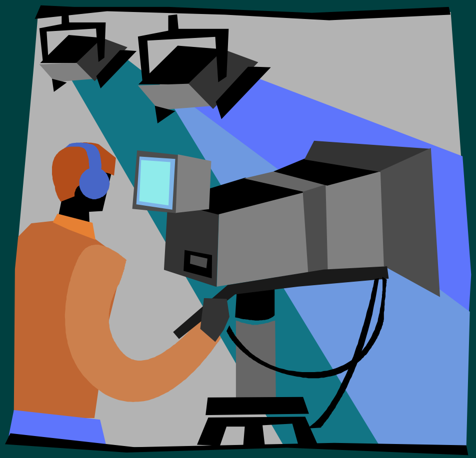




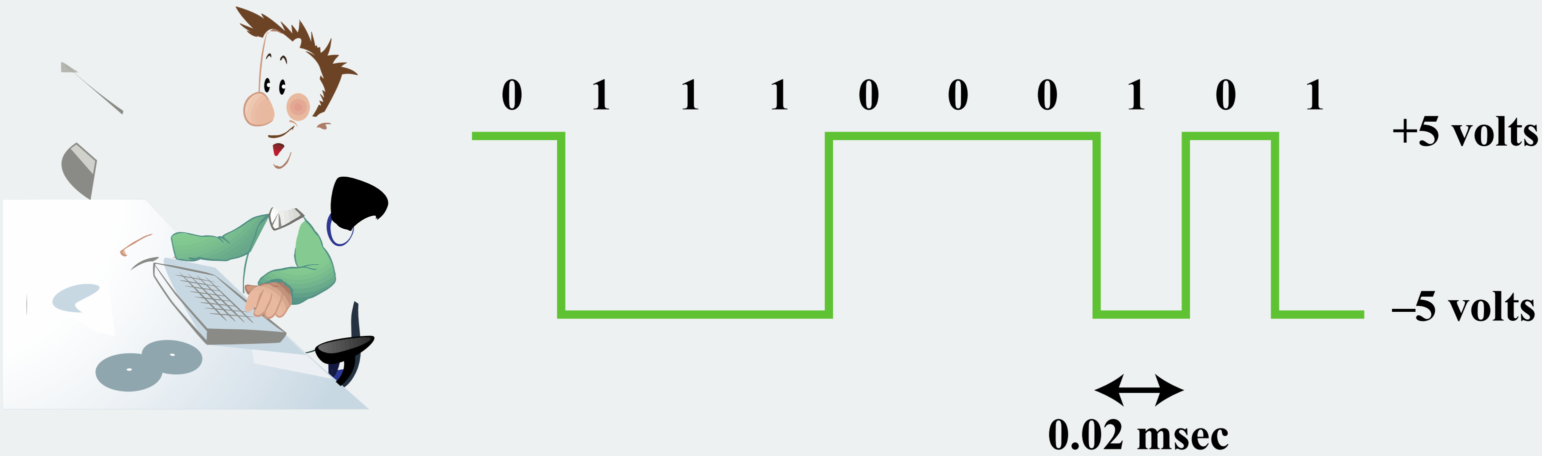
In this graph of a typical analog voice signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

Figure 3.11 Conversion of Voice Input to Analog Signal

Video Signals



- To produce a video signal a TV camera is used
- USA standard is 483 lines per frame, at a rate of 30 complete frames per second
  - Actual standard is 525 lines but about 42 are lost during vertical retrace
- Horizontal scanning frequency is 525 lines x 30 scans = 15750 lines per second
- Max frequency if line alternates between black and white as rapidly as possible



User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by –5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

Figure 3.12 Conversion of PC Input to Digital Signal

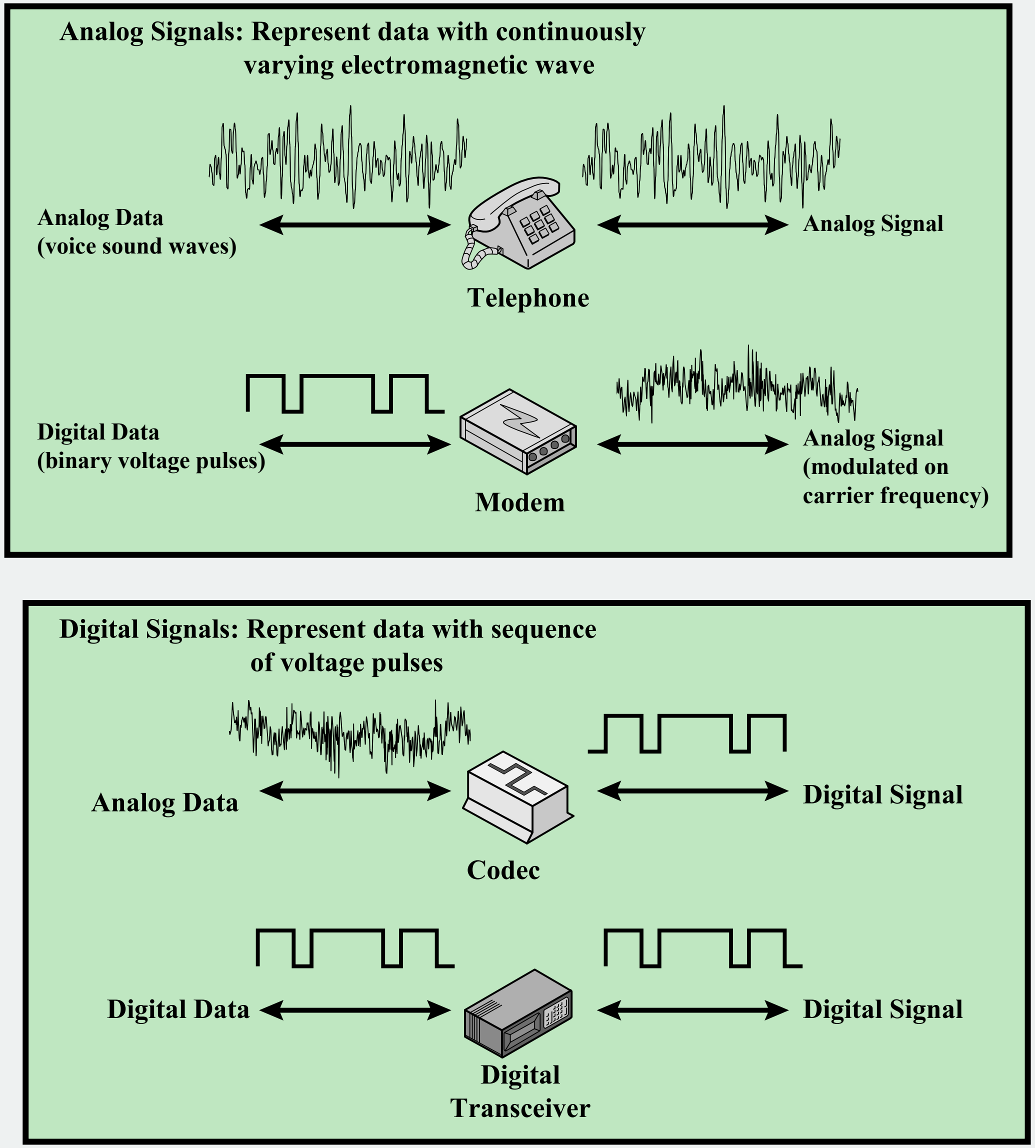


Figure 3.13 Analog and Digital Signaling of Analog and Digital Data

Table 3.1

Analog and Digital Transmission

(a) Data and Signals

	Analog Signal	Digital Signal
Analog Data	Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum.	Analog data are encoded using a codec to produce a digital bit stream.
Digital Data	Digital data are encoded using a modem to produce analog signal.	Two alternatives: (1) signal consists of two voltage levels to represent the two binary values; (2) digital data are encoded to produce a digital signal with desired properties.

(b) Treatment of Signals

	Analog Transmission	Digital Transmission
Analog Signal	Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.	Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal.
Digital Signal	Not used	Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal.

Move to Digital

- Digital technology
  - LSI and VLSI technology has caused a continuing drop in the cost and size of digital circuitry
- Data integrity
  - The use of repeaters has made it possible to transmit data longer distances over lower quality lines while maintaining the integrity of the data
- Capacity utilization
  - It has become economical to build transmission links of very high bandwidth, including satellite channels and optical fiber, and a high degree of multiplexing is needed to utilize such capacity effectively
- Security and privacy
  - Encryption techniques can be readily applied to digital data and to analog data that have been digitized
- Integration
  - Economies of scale and convenience can be achieved by integrating voice, video, and digital data

Asynchronous and Synchronous Transmission

- Asynchronous
  - Strategy is to avoid the timing problem by not sending long, uninterrupted streams of bits
  - Data are transmitted one character at a time, where each character is 5 to 8 bits in length
  - Timing or synchronization must only be maintained within each character
  - The receiver has the opportunity to resynchronize at the beginning of each new character

- Synchronous
  - A block of bits is transmitted in a steady stream without start and stop codes
  - Block may be many bits in length
  - To prevent timing drift between transmitter and receiver, their clocks must somehow be synchronized
    - Provide a separate clock line between transmitter and receiver
    - Embed the clocking information in the data signal
  - Frame
    - Data plus preamble, postamble, and control information

Transmission Impairments

- Signal received may differ from signal transmitted causing:
  - Analog - degradation of signal quality
  - Digital - bit errors
- Most significant impairments are
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise

Equalize attenuation across the band of frequencies used by using loading coils or amplifiers

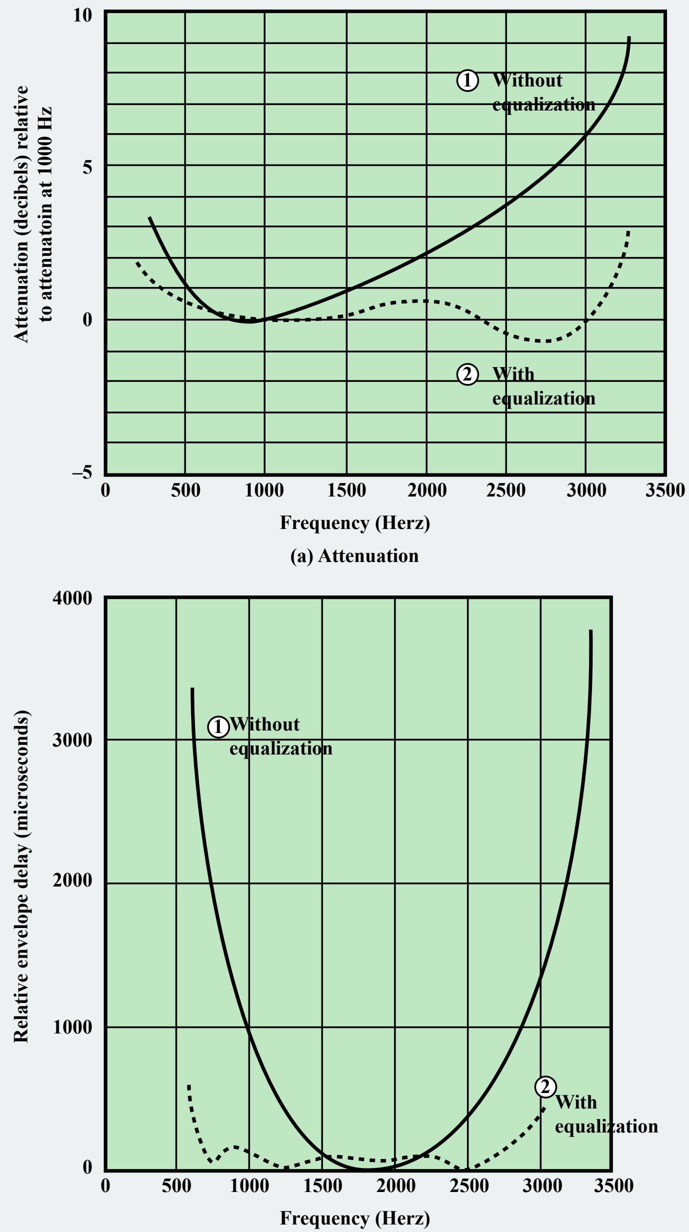
Received signal strength must be:

- Strong enough to be detected
- Sufficiently higher than noise to be received without error

Strength can be increased using amplifiers or repeaters

ATTENUATION

- **Signal strength falls off with distance over any transmission medium**
- **Varies with frequency**



(a) Attenuation

(b) Delay distortion

Figure 3.14 Attenuation and Delay Distortion Curves for a Voice Channel

Delay Distortion

- Occurs in transmission cables such as twisted pair, coaxial cable, and optical fiber
  - Does not occur when signals are transmitted through the air by means of antennas
- Occurs because propagation velocity of a signal through a guided medium varies with frequency
- Various frequency components arrive at different times resulting in phase shifts between the frequencies
- Particularly critical for digital data since parts of one bit spill over into others causing intersymbol interference

Noise

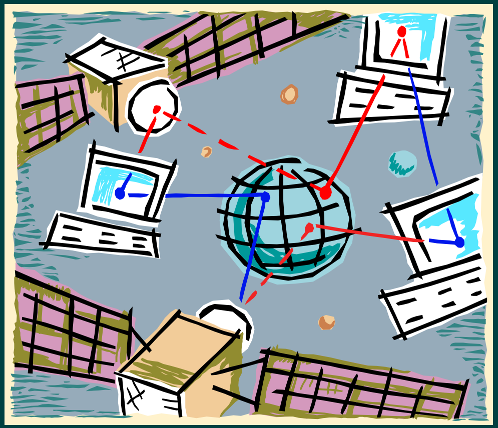
Unwanted signals inserted between transmitter and receiver

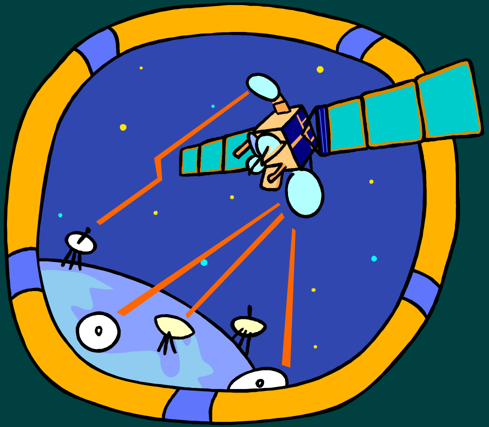
Is the major limiting factor in communications system performance

Categories of Noise

Thermal noise

- Due to thermal agitation of electrons
- Uniformly distributed across bandwidths
- Referred to as white noise





Intermodulation noise

- Produced by nonlinearities in the transmitter, receiver, and/or intervening transmission medium
- Effect is to produce signals at a frequency that is the sum or difference of the two original frequencies

Categories of Noise

Impulse Noise:

- Caused by external electromagnetic interferences
- Noncontinuous, consisting of irregular pulses or spikes
- Short duration and high amplitude
- Minor annoyance for analog signals but a major source of error in digital data

Crosstalk:

- A signal from one line is picked up by another
- Can occur by electrical coupling between nearby twisted pairs or when microwave antennas pick up unwanted signals

Channel Capacity

Maximum rate at which data can be transmitted over a given communications channel under given conditions

<u>Data rate</u> **The rate, in bits per second (bps) at which data can be communicated**	**<u>Bandwidth</u>** **The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or hertz**	**<u>Noise</u>** **The average level of noise over the communications path**	**<u>Error rate</u>** **The rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted**	**The greater the bandwidth of a facility, the greater the cost**	**The main constraint on achieving efficiency is noise**

Nyquist Bandwidth

In the case of a channel that is noise free:

- The limitation of data rate is simply the bandwidth of the signal
  - If the rate of signal transmission is *2B* then a signal with frequencies no greater than *B* is sufficient to carry the signal rate
  - Given a bandwidth of *B*, the highest signal rate that can be carried is 2*B*
- For binary signals, the data rate that can be supported by *B* Hz is 2*B* bps
- With multilevel signaling, the Nyquist formula becomes: $C = 2B \log_2 M$
- Data rate can be increased by increasing the number of different signal elements
  - This increases burden on receiver
  - Noise and other impairments limit the practical value of *M*

Shannon Capacity Formula

- Considering the relation of data rate, noise and error rate:
  - Faster data rate shortens each bit so bursts of noise corrupts more bits
  - Given noise level, higher rates mean higher errors
- Shannon developed formula relating these to signal to noise ratio (in decibels)
- SNR_{db}=10 $\log_{10}$ (signal/noise)
- Capacity $C = B \log_2(1+SNR)$
  - Theoretical maximum capacity
  - Get much lower rates in practice

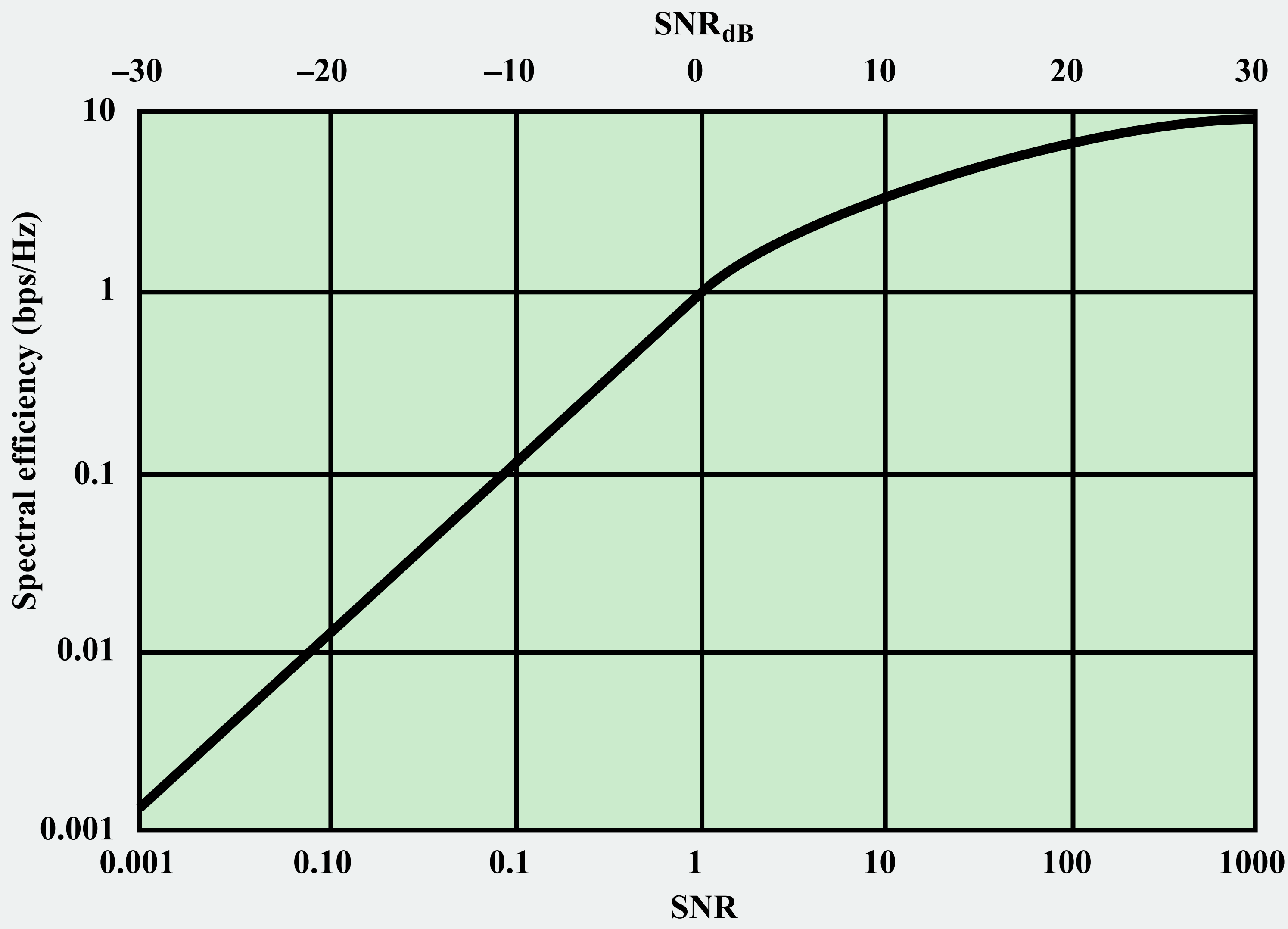
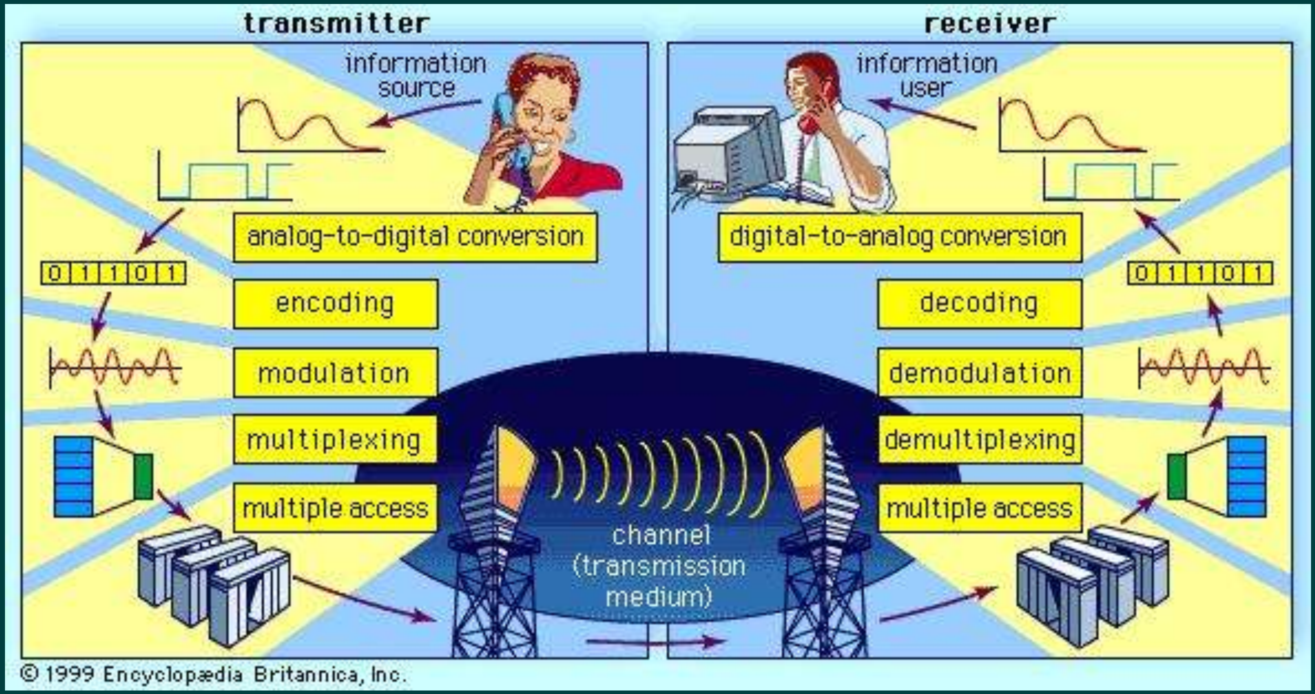
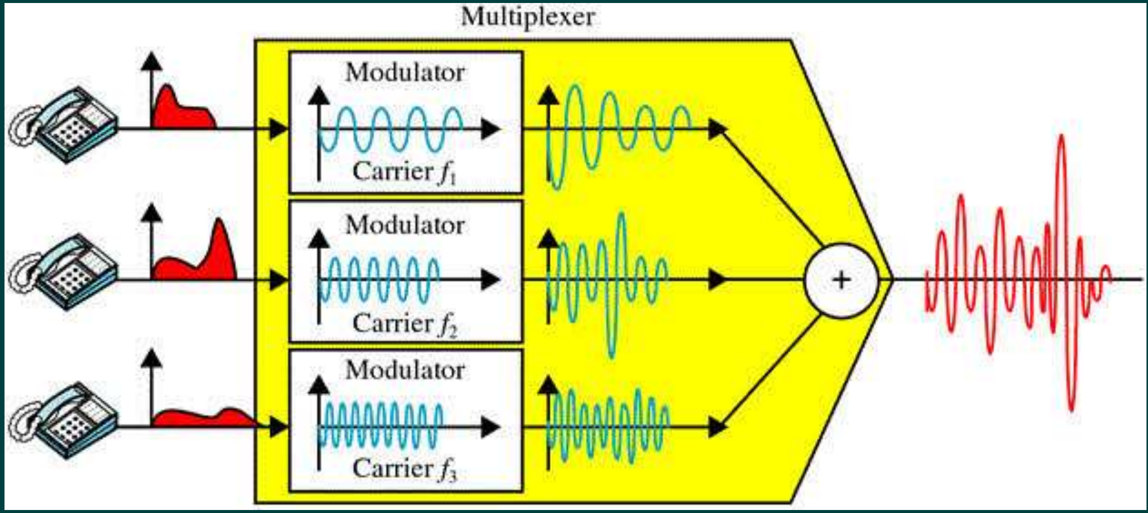


Figure 3.16 Spectral Efficiency versus SNR

Transmission Media and Communication Channels





Design Factors Determining Data Rate and Distance

Bandwidth

- Higher bandwidth gives higher data rate

Transmission impairments

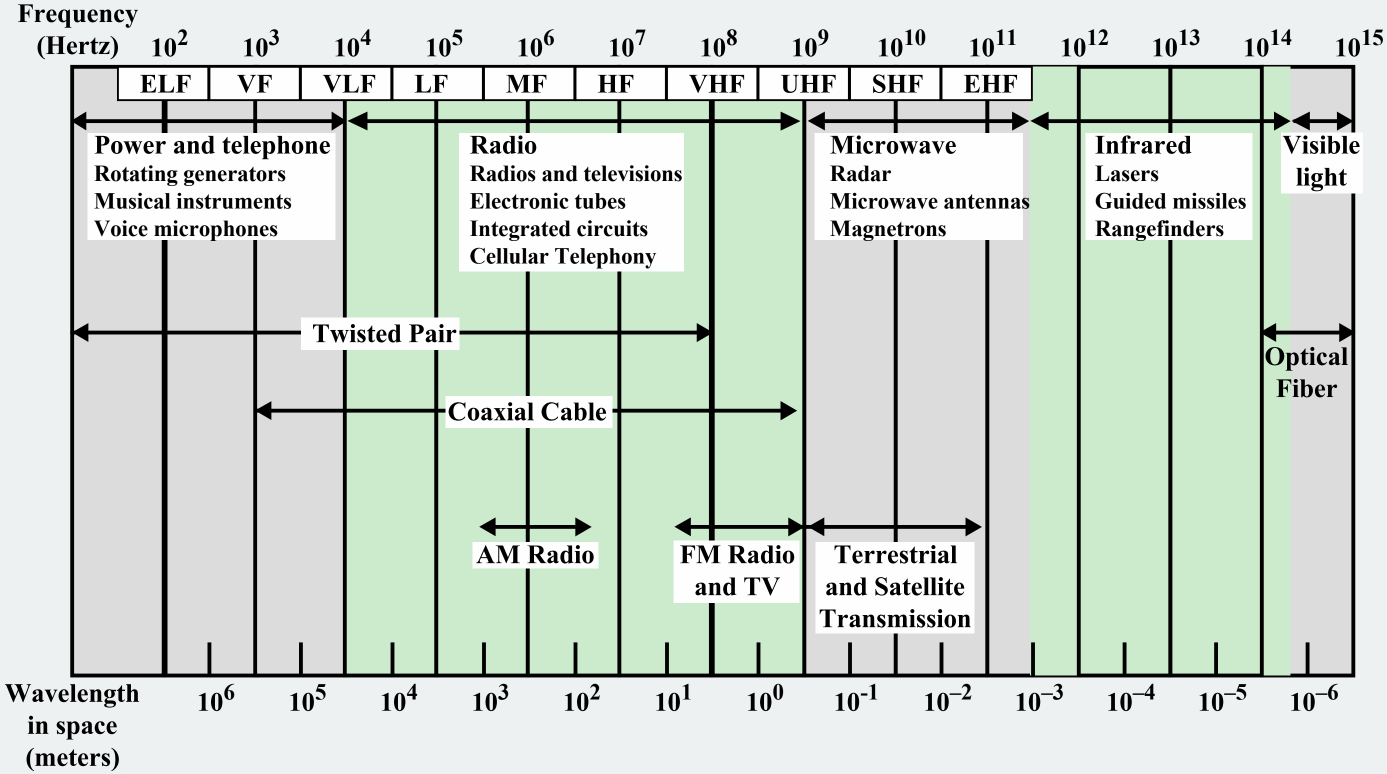
- Impairments, such as attenuation, limit the distance

Interference

- Overlapping frequency bands can distort or wipe out a signal

Number of receivers

- More receivers introduces more attenuation



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

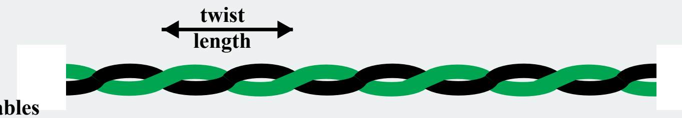
Figure 4.1 Electromagnetic Spectrum for Telecommunications

Table 4.1

Point-to-Point Transmission Characteristics of Guided Media

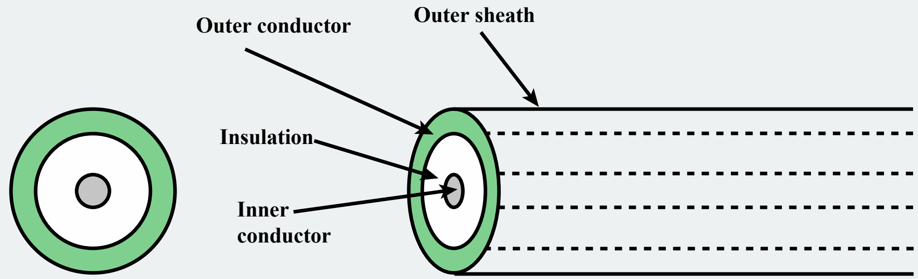
	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 µs/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 µs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 µs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 µs/km	40 km

THz = terahertz = 10^{12} Hz



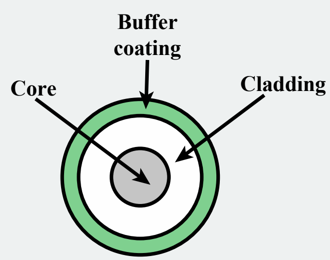
—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building during construction

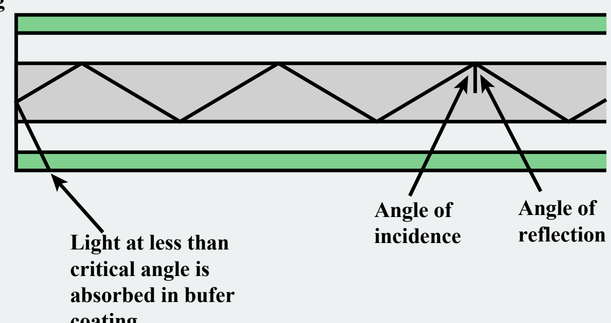
(a) Twisted pair



—Outer conductor is braided shield
—Inner conductor is solid metal
—Separated by insulating material
—Covered by padding

(b) Coaxial cable



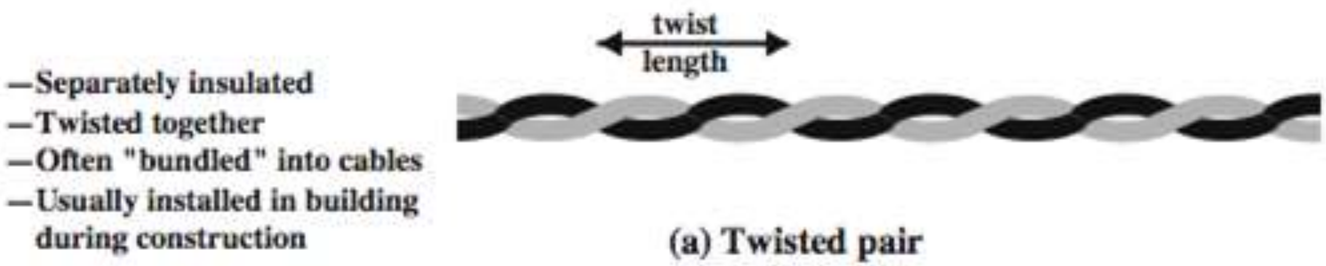


—Glass or plastic core
—Laser or light emitting diode
—Small size and weight

(c) Optical fiber

Figure 4.2 Guided Transmission Media

Twisted Pair



(a) Twisted pair

Twisted pair is the least expensive and most widely used guided transmission medium

- Consists of two insulated copper wires arranged in a regular spiral pattern
- A wire pair acts as a single communication link
- Pairs are bundled together into a cable
- Most commonly used in the telephone network and for communications within buildings

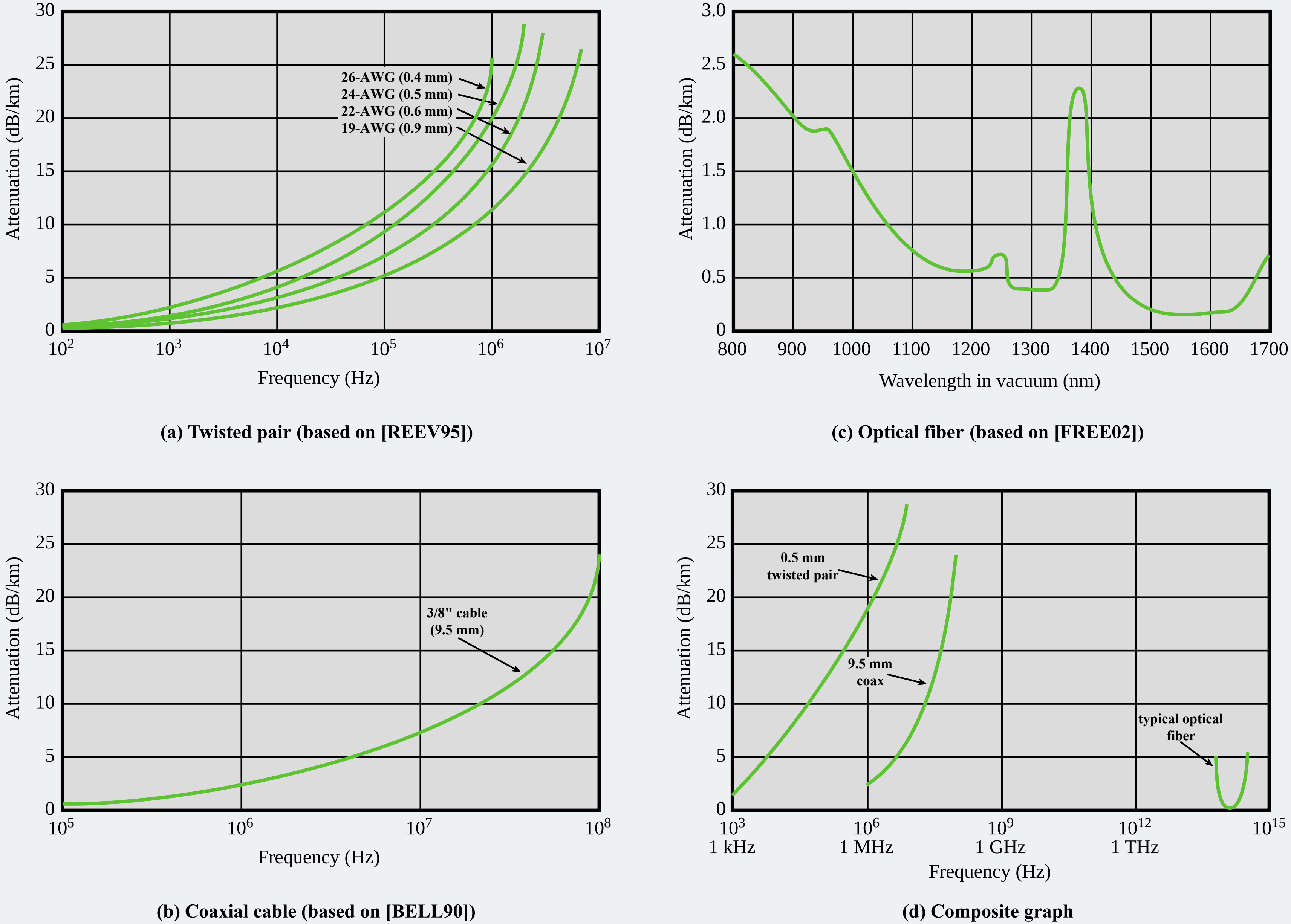


Figure 4.3 Attenuation of Typical Guided Media

Unshielded and Shielded Twisted Pair

Unshielded Twisted Pair (UTP)

- Consists of one or more twisted-pair cables, typically enclosed within an overall thermoplastic jacket which provides no electromagnetic shielding
- Ordinary telephone wire
- Subject to external electromagnetic interference
- The tighter the twisting, the higher the supported transmission rate and the greater the cost per meter

Shielded Twisted Pair (STP)

- Has metal braid or sheathing that reduces interference
- Provides better performance at higher data rates
- More expensive

Table 4.2

Twisted Pair Categories and Classes

	Category 5e Class D	Category 6 Class E	Category 6A Class E_A	Category 7 Class F	Category 7_A Class F_A
Bandwidth	100 MHz	250 MHz	500 MHz	600 MHz	1,000 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	S/FTP	S/FTP
Insertion loss (dB)	24	21.3	20.9	20.8	20.3
NEXT loss (dB)	30.1	39.9	39.9	62.9	65
ACR (dB)	6.1	18.6	19	42.1	44.1

UTP = Unshielded twisted pair
FTP = Foil twisted pair
S/FTP = Shielded/foil twisted pair

Near-End Crosstalk (NEXT)

- Coupling of signal from one pair of conductors to another
  - Conductors may be the metal pins in a connector or wire pairs in a cable
- Near end refers to coupling that takes place when the transmit signal entering the link couples back to the receive conductor pair at that same end of the link
- Greater NEXT loss magnitudes are associated with less crosstalk noise

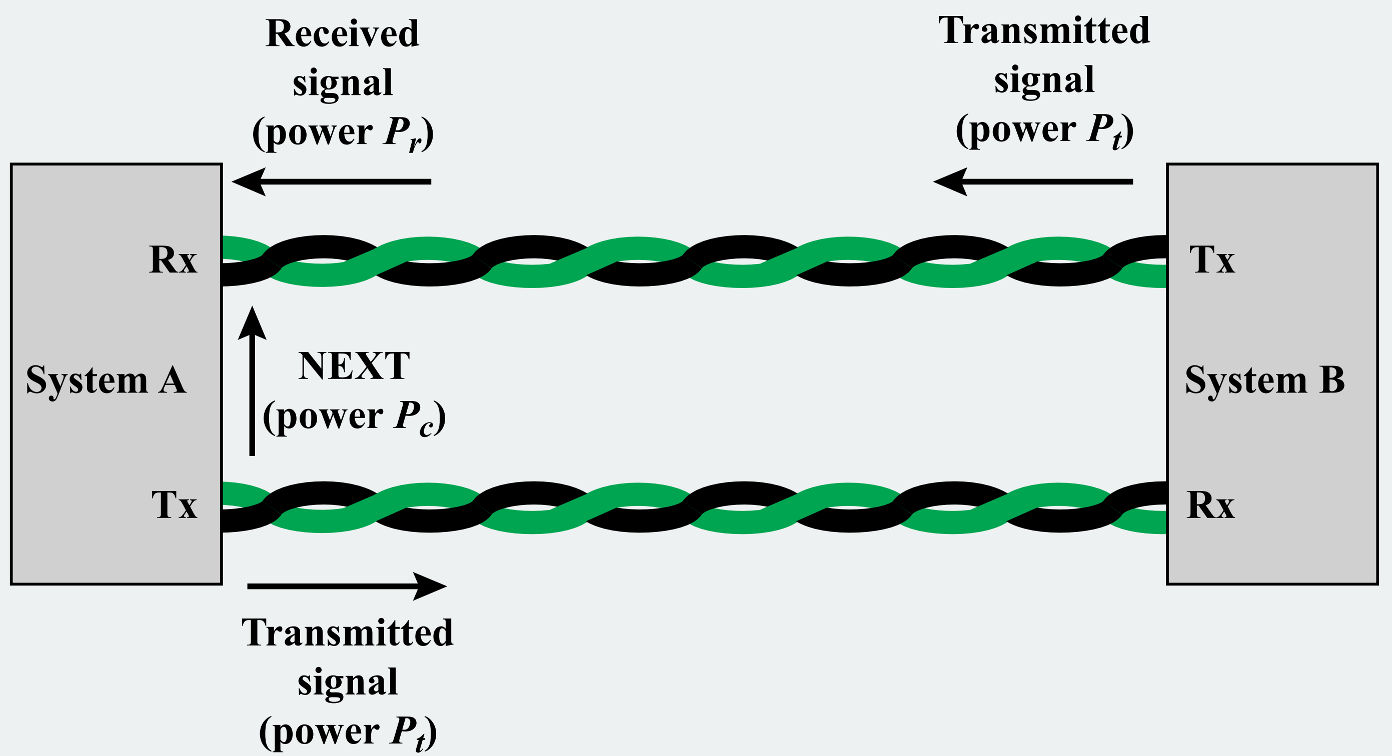
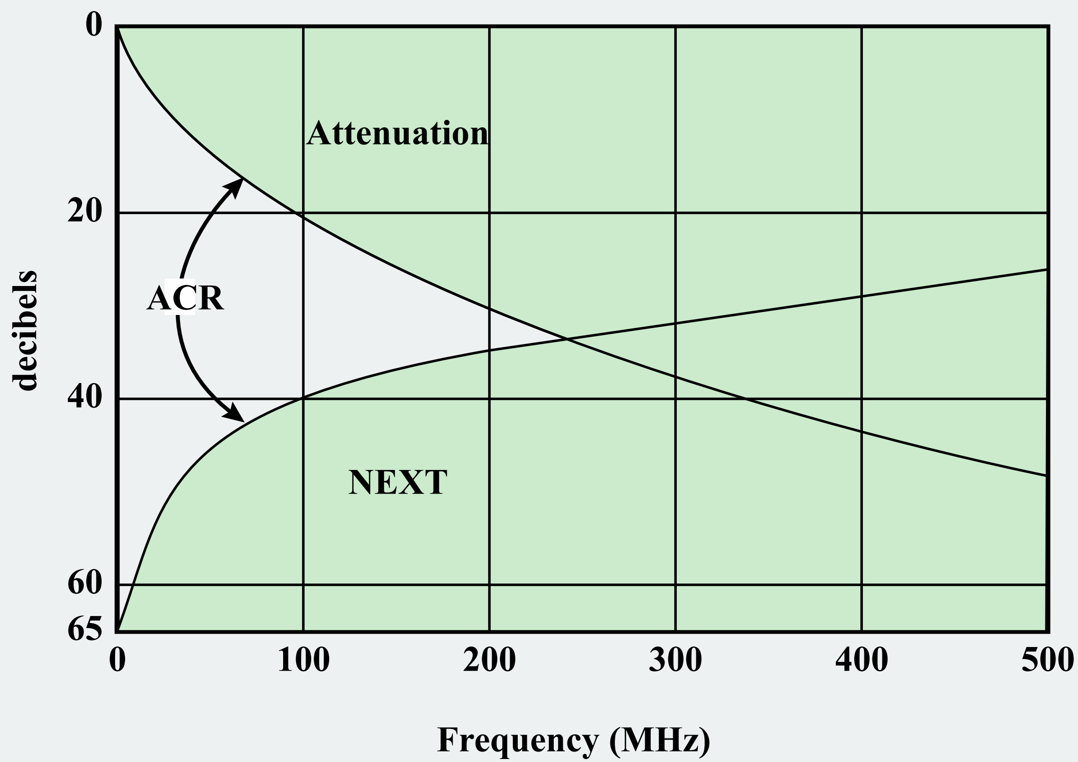


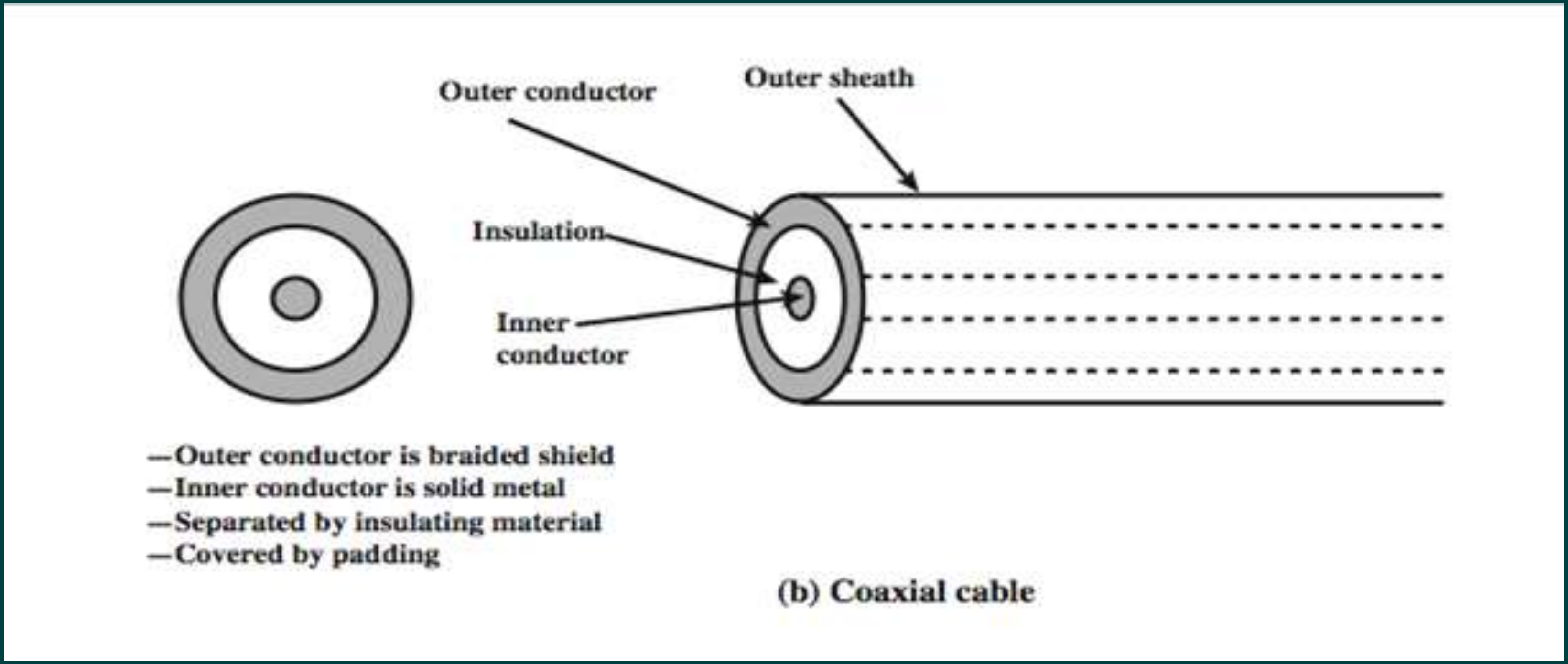
Figure 4.4 Signal Power Relationships (from System A viewpoint)



NEXT = near-end crosstalk
ACR = attenuation-to-crosstalk ratio

Figure 4.5 Category 6A Channel Requirements

Coaxial Cable



Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair

- Consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor
- Is a versatile transmission medium used in a wide variety of applications
- Used for TV distribution, long distance telephone transmission and LANs

Coaxial Cable - Transmission Characteristics

Frequency characteristics superior to twisted pair

Performance limited by attenuation and noise

Analog signals	Digital signals
• Amplifiers are needed every few kilometers - closer if higher frequency • Usable spectrum extends up to 500MHz	• Repeater every 1km - closer for higher data rates

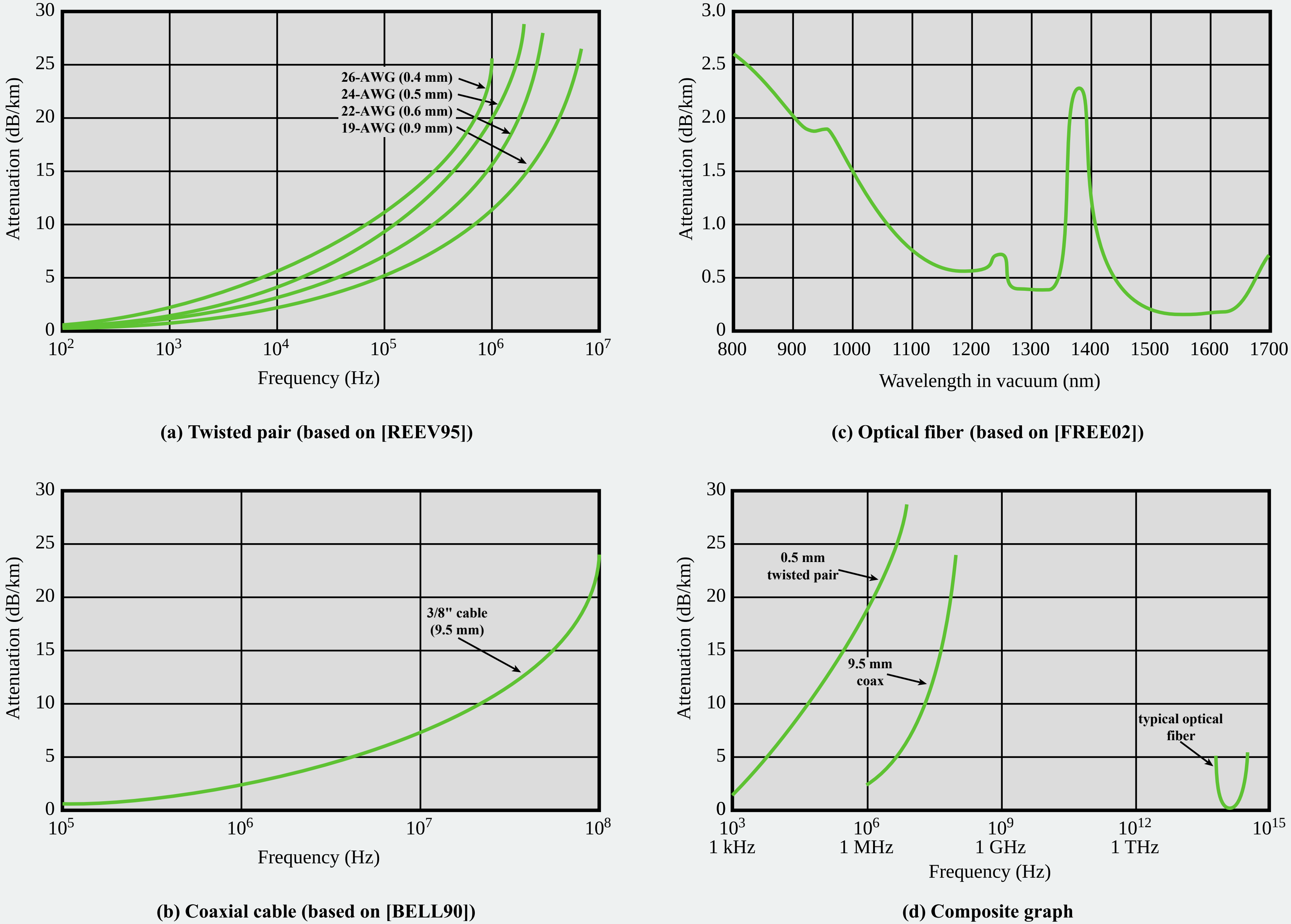
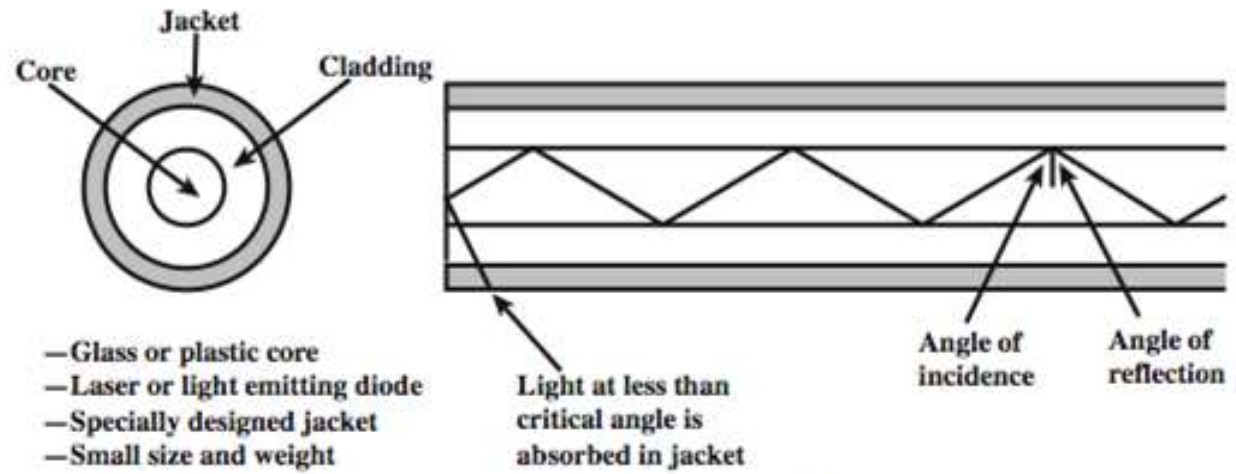


Figure 4.3 Attenuation of Typical Guided Media

Optical Fiber



(c) Optical fiber

Optical fiber is a thin flexible medium capable of guiding an optical ray

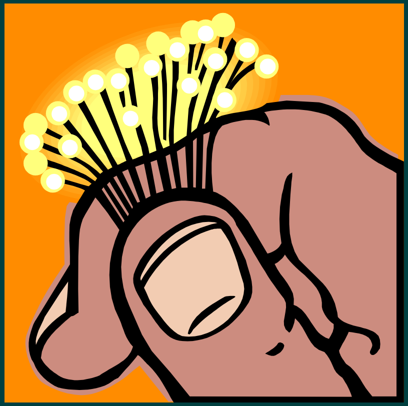
- Various glasses and plastics can be used to make optical fibers
- Has a cylindrical shape with three sections – core, cladding, jacket
- Widely used in long distance telecommunications
- Performance, price and advantages have made it popular to use

Optical Fiber - Benefits

- Greater capacity
  - Data rates of hundreds of Gbps over tens of kilometers have been demonstrated
- Smaller size and lighter weight
  - Considerably thinner than coaxial or twisted pair cable
  - Reduces structural support requirements
- Lower attenuation
- Electromagnetic isolation
  - Not vulnerable to interference, impulse noise, or crosstalk
  - High degree of security from eavesdropping
- Greater repeater spacing
  - Lower cost and fewer sources of error

Categories of Application

- Five basic categories of application have become important for optical fiber:
  - Long-haul trunks
  - Metropolitan trunks
  - Rural exchange trunks
  - Subscriber loops
  - Local area networks



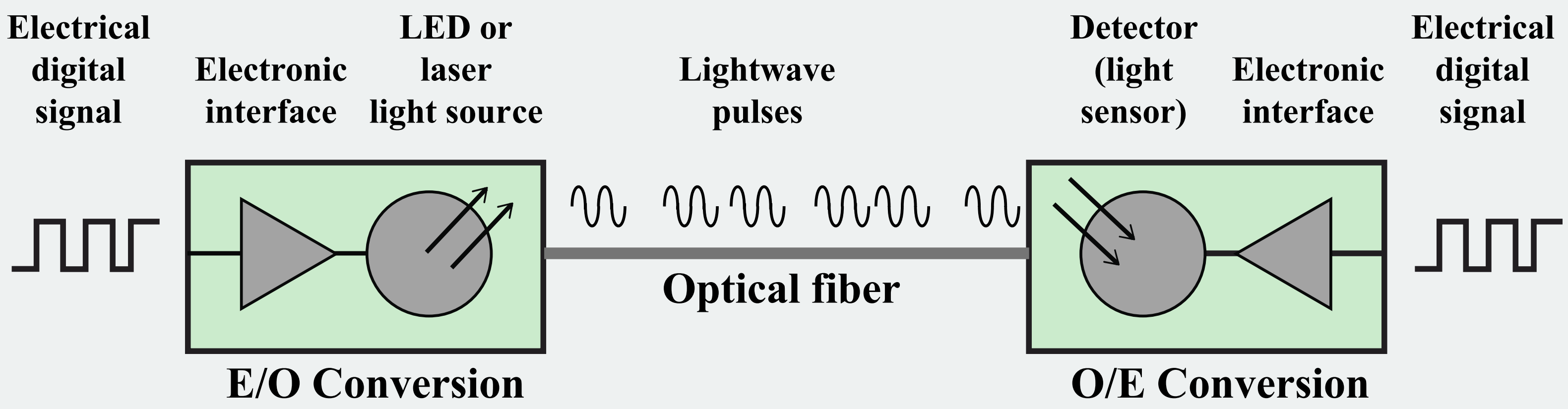


Figure 4.6 Optical Communication

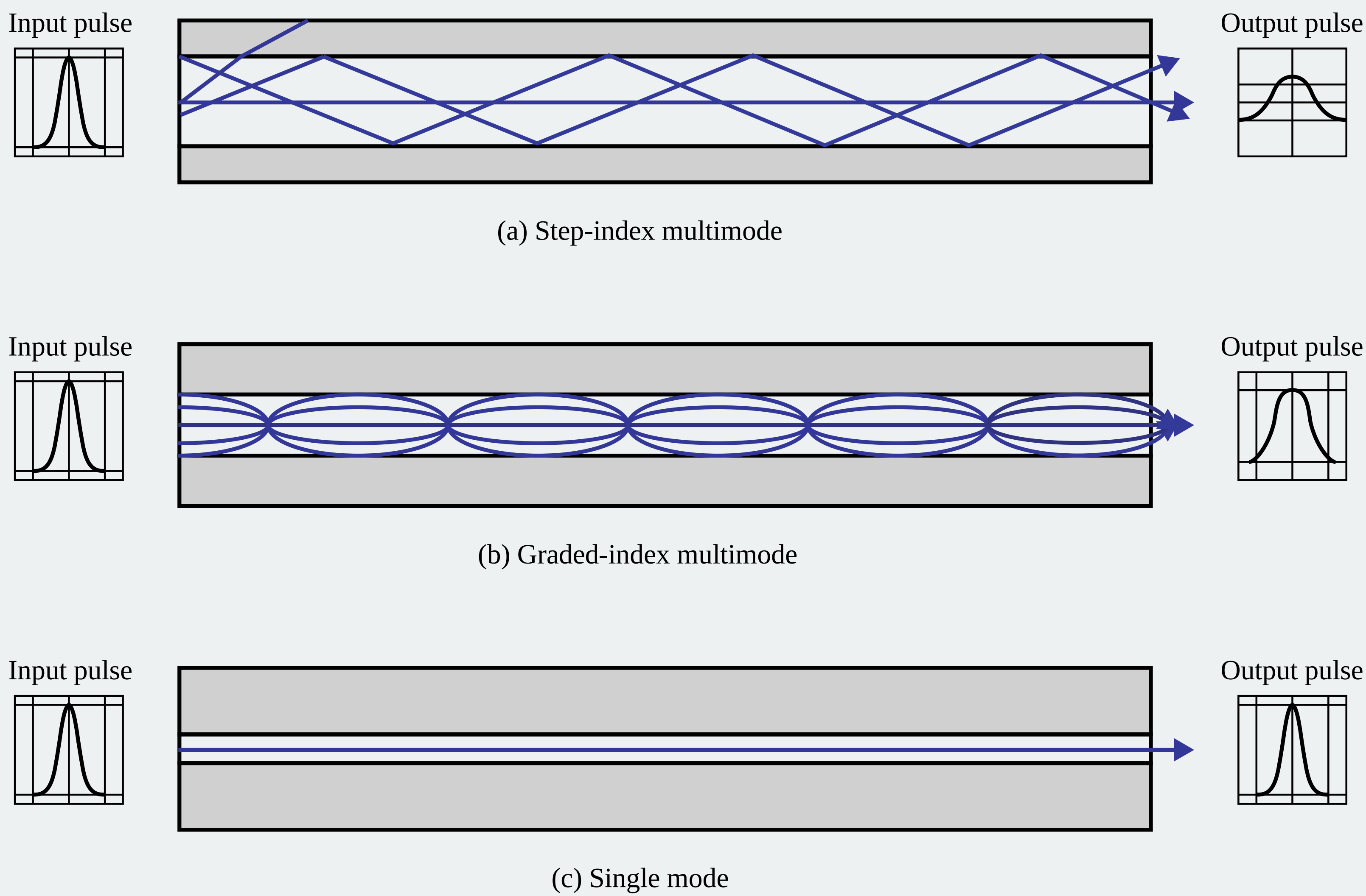


Figure 4.7 Optical Fiber Transmission Modes

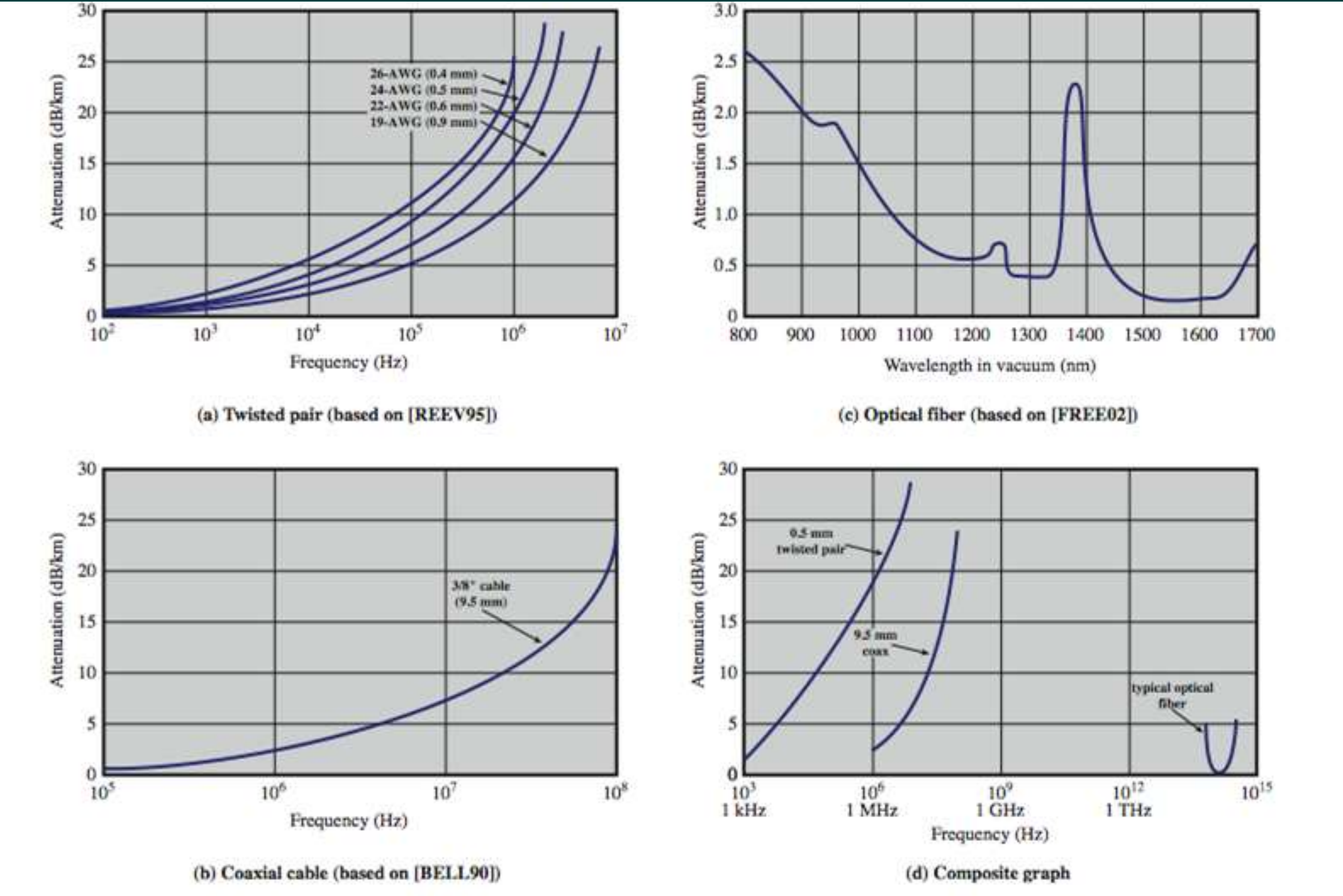
Table 4.3

Frequency Utilization for Fiber Applications

Wave length (in vacuum) range (nm)	Frequency Range (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	192 to 185	L	Single mode	WDM

WDM = wavelength division multiplexing

Attenuation in Guided Media



Wireless Transmission Frequencies

1GHz to 40GHz

- Referred to as microwave frequencies
- Highly directional beams are possible
- Suitable for point to point transmissions
- Also used for satellite communications

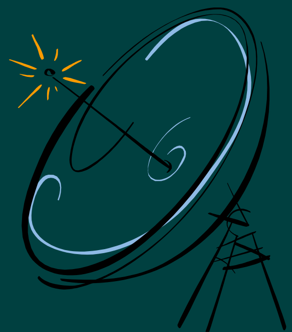
30MHz to 1GHz

- Suitable for omnidirectional applications
- Referred to as the radio range

3×10^{11} to 2×10^{14}

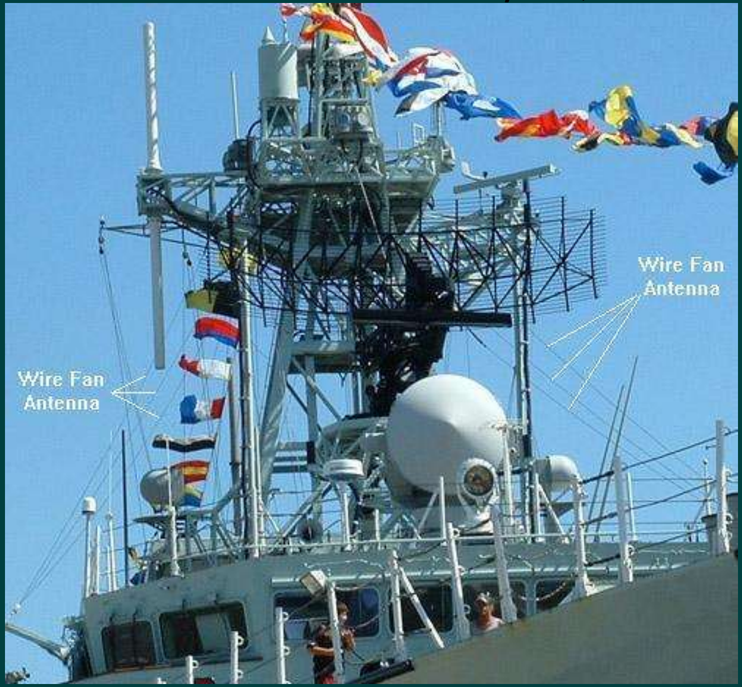
- Infrared portion of the spectrum
- Useful to local point-to-point and multipoint applications within confined areas

Antennas



- Electrical conductor or system of conductors used to radiate or collect electromagnetic energy

- Radio frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment

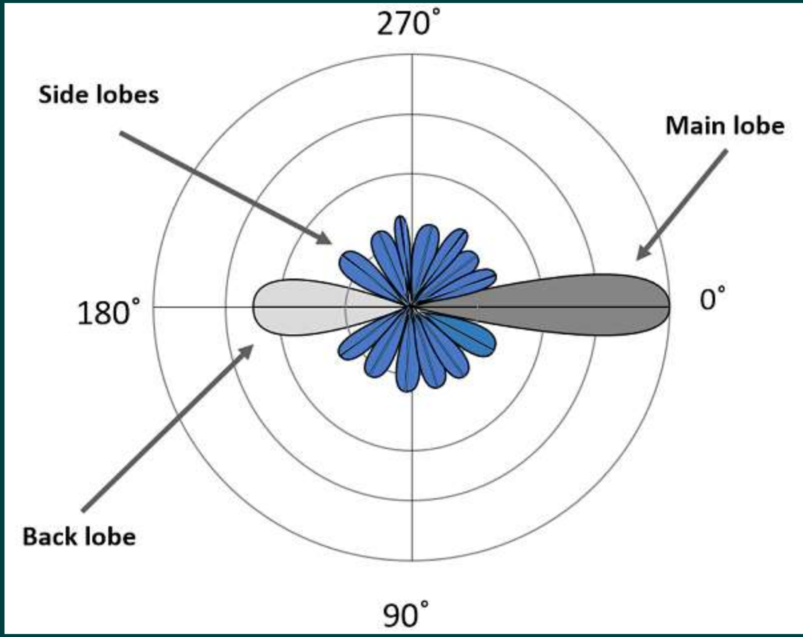


- Reception occurs when the electromagnetic signal intersects the antenna

- In two way communication, the same antenna can be used for both transmission and reception

Radiation Pattern

- Power radiated in all directions
  - Does not perform equally well in all directions
- Radiation pattern
  - A graphical representation of the radiation properties of an antenna as a function of space coordinates
- Isotropic antenna
  - A point in space that radiates power in all directions equally
  - Actual radiation pattern is a sphere with the antenna at the center



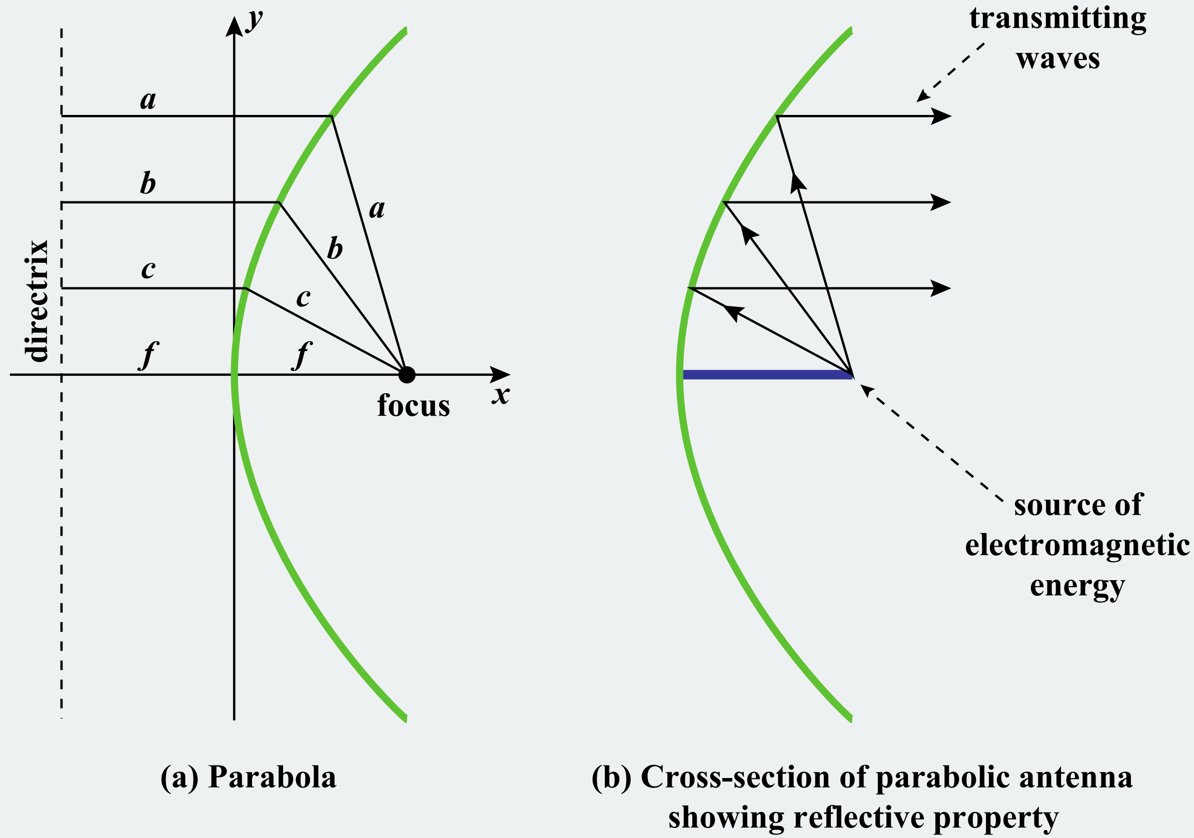


Figure 4.8 Parabolic Reflective Antenna

Antenna Gain

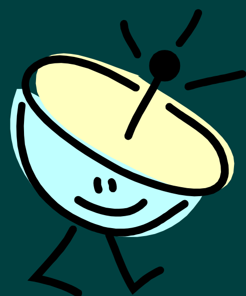
A measure of the directionality of an antenna

Defined as the power output in a particular direction versus that produced by an isotropic antenna

Measured in decibels (dB)

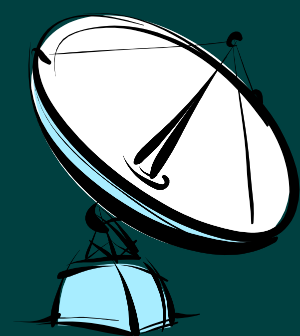
The increased power radiated in a given direction is at the expense of other directions

Effective area of an antenna is related to the physical size of the antenna and to its shape



Terrestrial Microwave

- Most common type is the parabolic "dish"
- Typical size is about 3 m in diameter
- Antenna is fixed rigidly and focuses a narrow beam to achieve line-of-sight transmission to the receiving antenna
- Usually located at substantial heights above ground level
- A series of microwave relay towers is used to achieve long-distance transmission



Terrestrial Microwave Applications

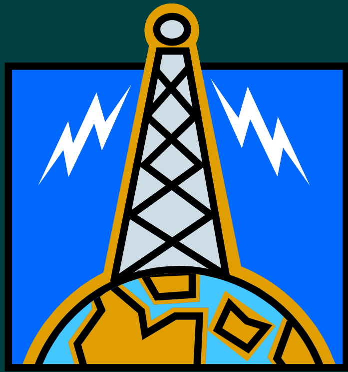
- Used for long haul telecommunications service as an alternative to coaxial cable or optical fiber
- Used for both voice and TV transmission
- Fewer repeaters but requires line-of-sight transmission
- 1-40GHz frequencies, with higher frequencies having higher data rates
- Main source of loss is attenuation caused mostly by distance, rainfall and interference

Table 4.4
Typical Digital Microwave Performance

Band (GHz)	Bandwidth (MHz)	Data Rate (Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

Satellite Microwave

- A communication satellite is in effect a microwave relay station
- Used to link two or more ground stations
- Receives transmissions on one frequency band, amplifies or repeats the signal, and transmits it on another frequency
  - Frequency bands are called transponder channels



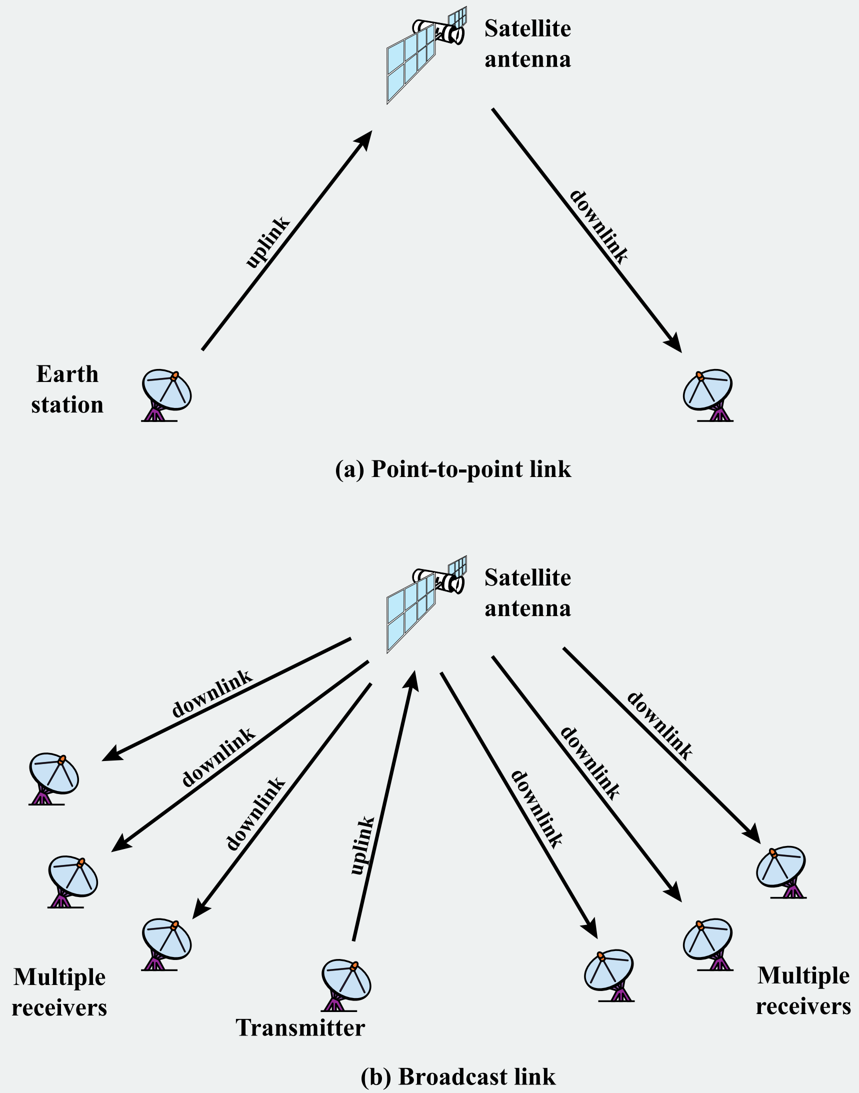


Figure 4.9 Satellite Communication Configurations

Satellite Microwave Applications

- Most important applications for satellites are:

Long-distance telephone transmission
- Is the optimum medium for high-usage international trunks

Private business networks
- Satellite providers can divide capacity into channels and lease these channels to individual business users

Global positioning
- Navstar Global Positioning System (GPS)

Television distribution
- Programs are transmitted to the satellite then broadcast down to a number of stations which then distribute the programs to individual viewers
- Direct Broadcast Satellite (DBS) transmits video signals directly to the home user

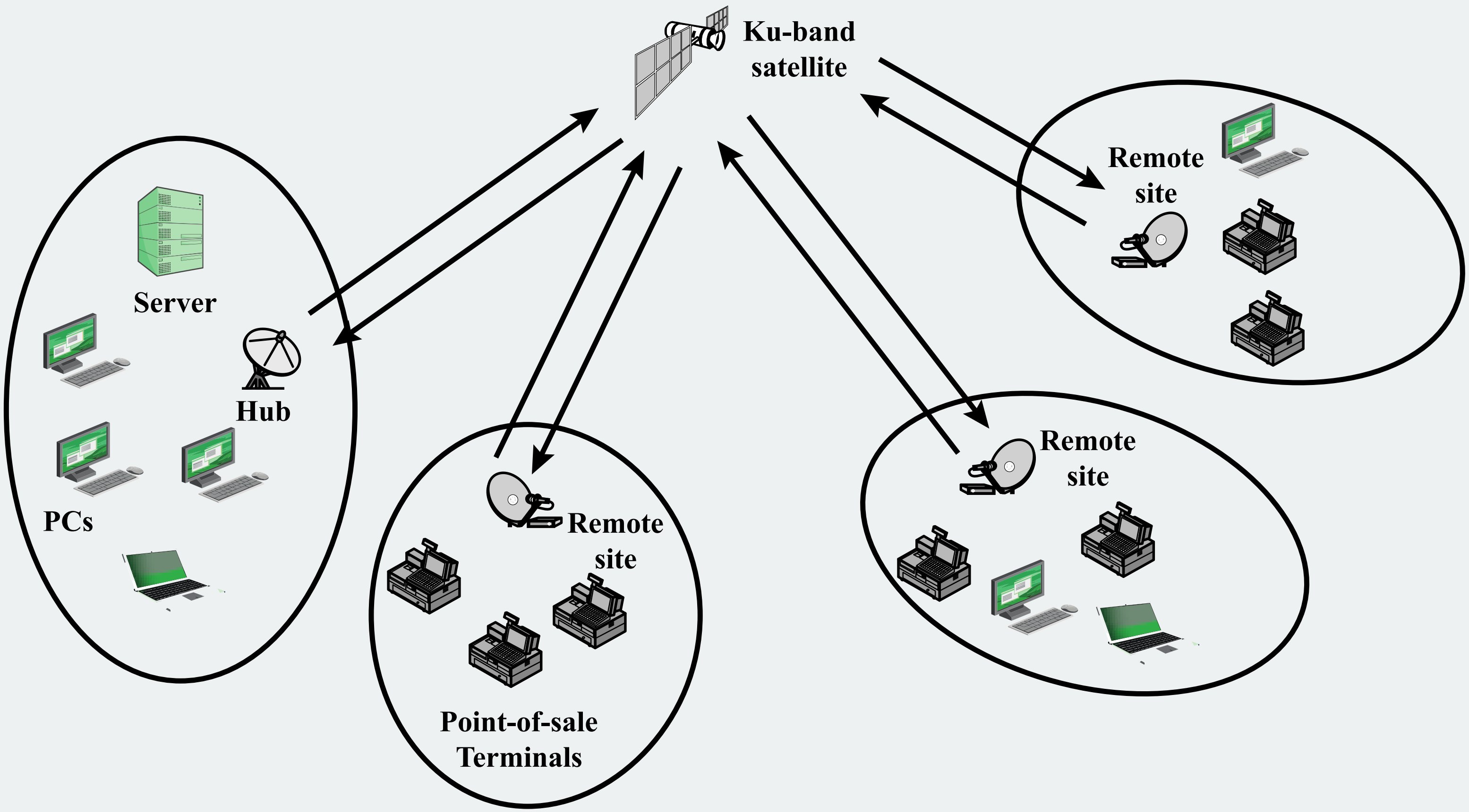


Figure 4.10 Typical VSAT Configuration

Transmission Characteristics

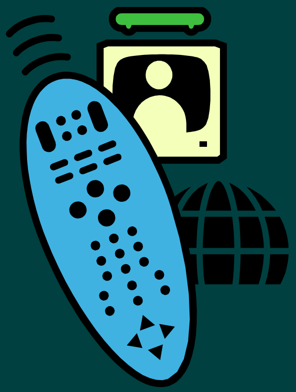
- The optimum frequency range for satellite transmission is 1 to 10 GHz
  - Below 1 GHz there is significant noise from natural sources
  - Above 10 GHz the signal is severely attenuated by atmospheric absorption and precipitation
- Satellites use a frequency bandwidth range of 5.925 to 6.425 GHz from earth to satellite (uplink) and a range of 3.7 to 4.2 GHz from satellite to earth (downlink)
  - This is referred to as the 4/6-GHz band
  - Because of saturation the 12/14-GHz band has been developed

Broadcast Radio

- Broadcast radio is omnidirectional and microwave is directional
- **Radio** is the term used to encompass frequencies in the range of 3kHz to 300GHz
- **Broadcast radio** (30MHz - 1GHz) covers:
  - FM radio and UHF and VHF television band
  - Data networking applications
- Limited to **line of sight**
- Suffers from **multipath interference**
  - Reflections from land, water, man-made objects

Infrared

- Achieved using transceivers that modulate noncoherent infrared light
- Transceivers must be within line of sight of each other directly or via reflection
- Does not penetrate walls
- No licensing is required
- No frequency allocation issues

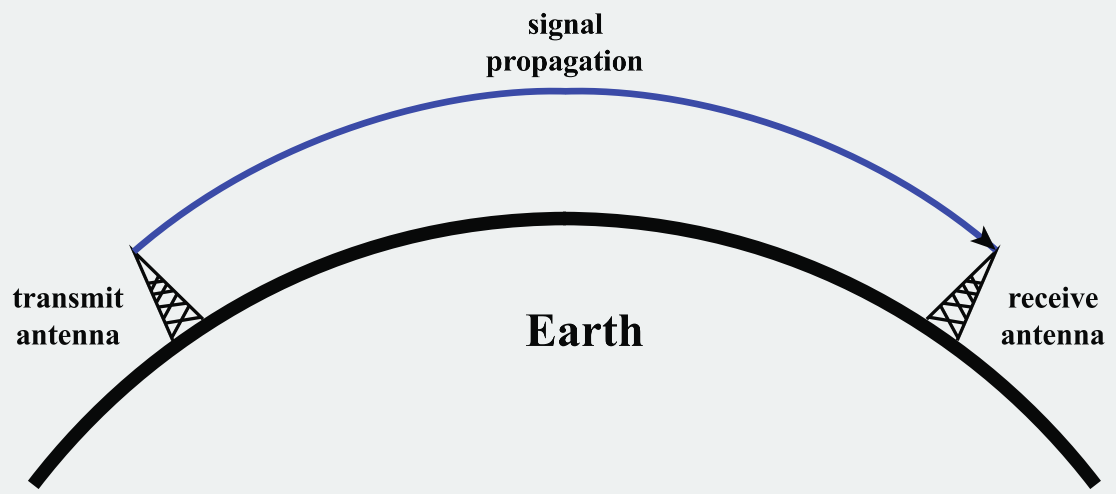


Band	Frequency Range	Free-Space Wavelength Range	Propagation Characteristics	Typical Use
ELF (extremely low frequency)	30 to 300 Hz	10,000 to 1000 km	GW	Power line frequencies; used by some home control systems.
VF (voice frequency)	300 to 3000 Hz	1000 to 100 km	GW	Used by the telephone system for analog subscriber lines.
VLF (very low frequency)	3 to 30 kHz	100 to 10 km	GW; low attenuation day and night; high atmospheric noise level	Long-range navigation; submarine communication
LF (low frequency)	30 to 300 kHz	10 to 1 km	GW; slightly less reliable than VLF; absorption in daytime	Long-range navigation; marine communication radio beacons
MF (medium frequency)	300 to 3000 kHz	1,000 to 100 m	GW and night SW; attenuation low at night, high in day; atmospheric noise	Maritime radio; direction finding; AM broadcasting.
HF (high frequency)	3 to 30 MHz	100 to 10 m	SW; quality varies with time of day, season, and frequency.	Amateur radio; military communication
VHF (very high frequency)	30 to 300 MHz	10 to 1 m	LOS; scattering because of temperature inversion; cosmic noise	VHF television; FM broadcast and two-way radio, AM aircraft communication; aircraft navigational aids
UHF (ultra high frequency)	300 to 3000 MHz	100 to 10 cm	LOS; cosmic noise	UHF television; cellular telephone; radar; microwave links; personal communications systems
SHF (super high frequency)	3 to 30 GHz	10 to 1 cm	LOS; rainfall attenuation above 10 GHz; atmospheric attenuation due to oxygen and water vapor	Satellite communication; radar; terrestrial microwave links; wireless local loop
EHF (extremely high frequency)	30 to 300 GHz	10 to 1 mm	LOS; atmospheric attenuation due to oxygen and water vapor	Experimental; wireless local loop; radio astronomy
Infrared	300 GHz to 400 THz	1 mm to 770 nm	LOS	Infrared LANs; consumer electronic applications
Visible light	400 THz to 900 THz	770 nm to 330 nm	LOS	Optical communication

Table 4.5

Frequency Bands

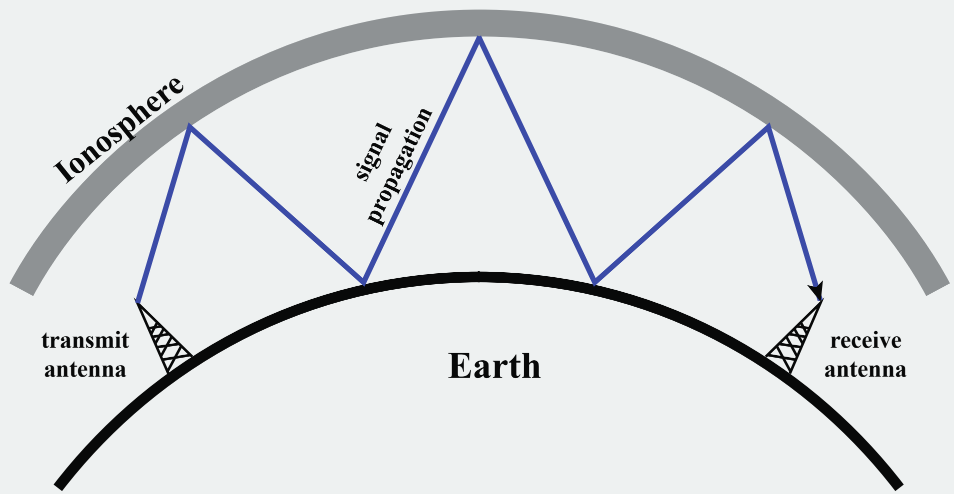
(Table can be found on page 136 in textbook)



(a) Ground-wave propagation (below 2 MHz)

Figure 4.11 Wireless Propagation Modes

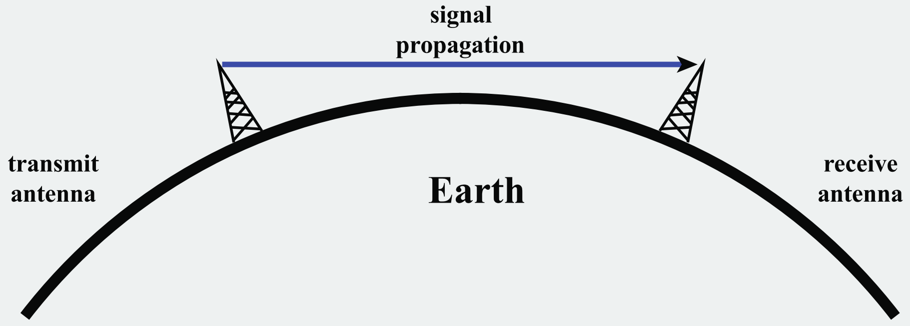
- Ground wave propagation follows the contour of the earth and can propagate distances well over the visual horizon
- This effect is found in frequencies up to about 2MHz
- The best known example of ground wave communication is AM radio



(b) Sky-wave propagation (2 to 30 MHz)

Figure 4.11 Wireless Propagation Modes

- Sky wave propagation is used for amateur radio and international broadcasts such as *BBC* and *Voice of America*
- A signal from an earth based antenna is reflected from the ionized layer of the upper atmosphere back down to earth
- Sky wave signals can travel through a number of hops, bouncing back and forth between the ionosphere and the earth's surface



(c) Line-of-sight (LOS) propagation (above 30 MHz)

Figure 4.11 Wireless Propagation Modes

- **Ground and sky wave propagation modes do not operate above 30 MHz - - communication must be by line of sight**

Refraction

- Occurs because the velocity of an electromagnetic wave is a function of the density of the medium through which it travels
  - 3×10^8 m/s in a vacuum, less in anything else
- The speed changes with movement between a medium of one density to a medium of another density
- Index of refraction (refractive index)
  - The sine of the angle of incidence divided by the sine of the angle of refraction
  - Is also equal to the ratio of the respective velocities in the two media
  - Varies with wavelength
- Gradual bending
  - Density of atmosphere decreases with height, resulting in bending of radio waves toward the earth

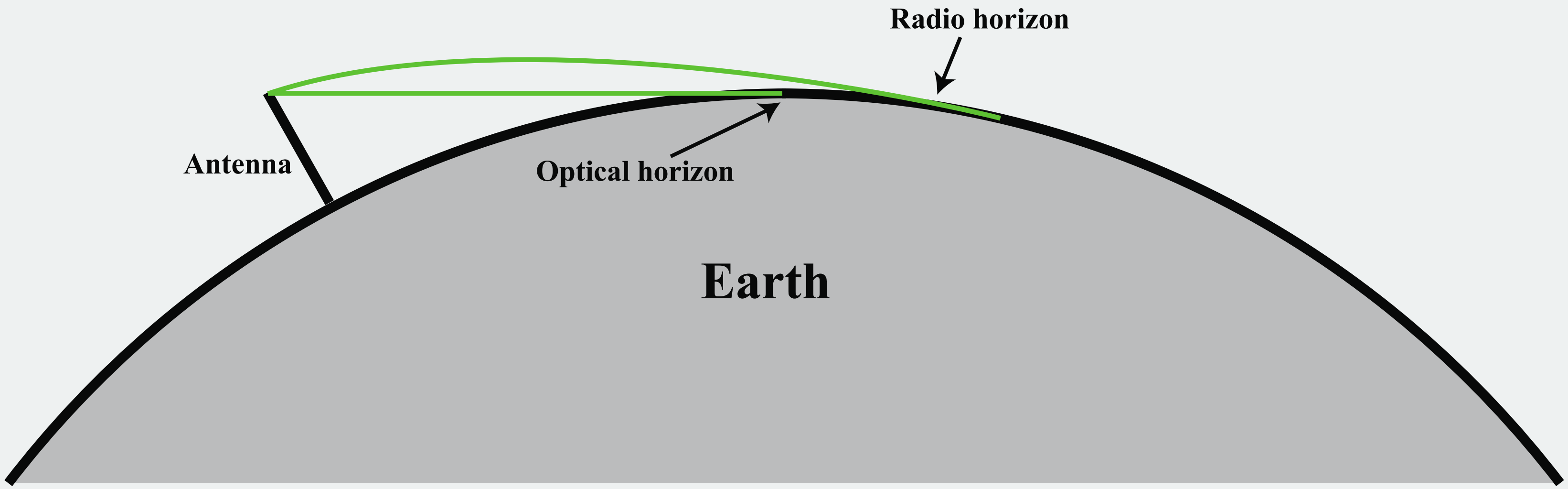


Figure 4.12 Optical and Radio Horizons

Line-of-Sight Transmission

Free space loss

- Loss of signal with distance

Atmospheric Absorption

- From water vapor and oxygen absorption

Multipath

- Multiple interfering signals from reflections

Refraction

- Bending signal away from receiver

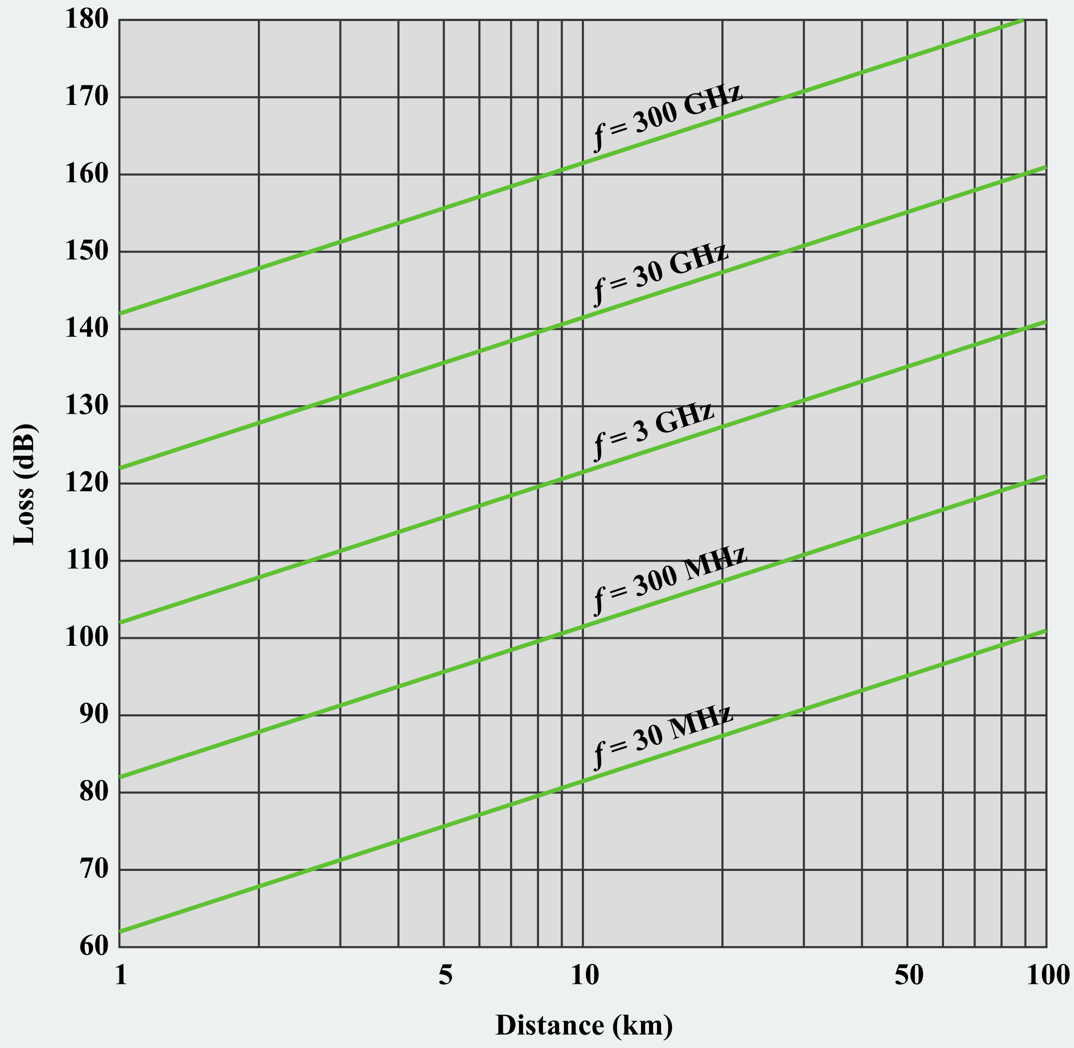
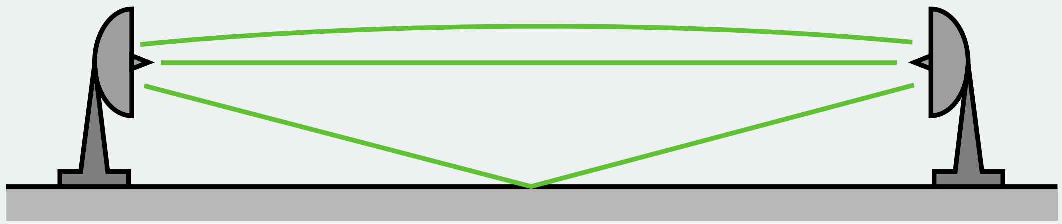
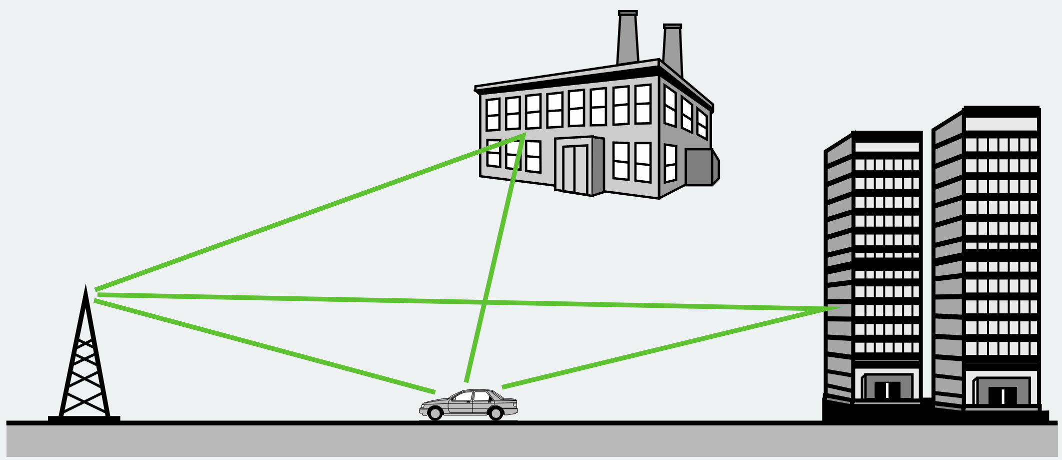


Figure 4.13 Free Space Loss



(a) Microwave line of sight



(b) Mobile radio

Figure 4.14 Examples of Multipath Interference