Contemporary Communication Systems

Chapter 1

Introduction

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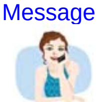
What is Communication?

- Communication is the transfer of information
  - The goal is to reproduce as accurately as possible at the *receiver* a *message* sent from the *transmitter*
- Electrical communication systems convey or transmit information in the form of an electromagnetic signal
- Electrical communication systems enable interaction *at a distance* almost *instantaneously*
  - For example, we can download a Web page with a click of the mouse from anywhere on the globe
- This illustrates the important role that communication systems play in our modern information age

Types of Message Signals

- Speech

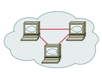


- Music

- Image

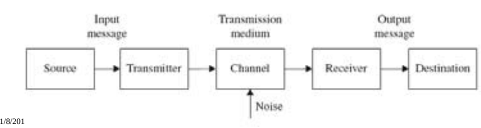
- Video

- Data



Elements of a Communication System

- A typical communication system consists of
  - **Transmitter** – converts the message into a signal that is suitable for transmission over a physical medium or channel
  - **Transmission medium or channel** – conveys the energy of the signal from the transmitter to a receiver
  - **Receiver** – recovers the original message from the attenuated/distorted and noisy received signal



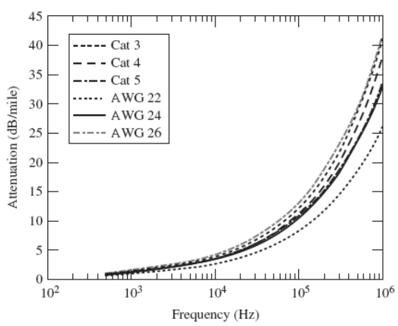
Communication Channels

- For information transfer to occur, we must have a communication channel that conveys the energy of a signal from the transmitter to the receiver
- There are two basic types of communication channels:
  - **Wired media** – the signal energy is contained and guided within a solid medium
    - Provide **point-to-point** connectivity. Users communicate via a point-to-point physical link or channel
    - Examples: Twisted wire pairs, coaxial cable, optical fibers
  - **Wireless media** – the signal energy propagates in the form of unguided electromagnetic waves
    - Examples: radio and infrared light
    - Generally operate in a **broadcast** mode, i.e., the medium is *shared*

Twisted Wire Pair (TWP)

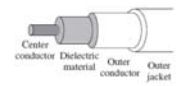
- Two insulated wires (Copper or copper clad steel) twisted in a regular spiral pattern
  - UTP = Unshielded Twisted Pair
  - STP = Shielded Twisted Pair (to reduce interference)
- Various thicknesses, e.g. 0.016 inch (24 gauge)
- Attenuation ranges from 1 – 4 dB/mile @ 1 kHz
  - Increases as a function of frequency on $\sqrt{f}$ basis. Attenuation @ 500 kHz increases to between 10 and 20 dB/km
- Inexpensive compare to coax or fiber
- Dominant transmission medium in the subscriber loop plant of telephone companies – used for POTS, dial-up modem, ISDN and ADSL applications
- Intra-building wiring from telephone closet to desktop

Attenuation vs frequency for TWP



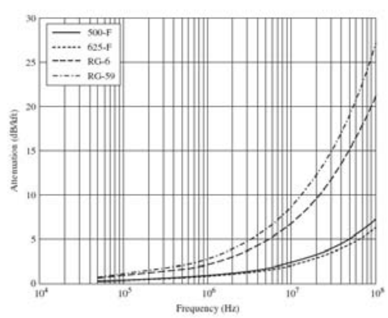
Coaxial Cable

- Solid center conductor located coaxially within a cylindrical outer conductor; separated by a solid dielectric material
- 75-ohm design exclusively deployed in CATV plant. Cables with solid Aluminum outer conductor used for *trunk* and *feeder* applications
- Braided outer conductor design used for *drop* cable application



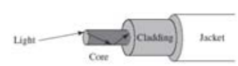
- High bandwidth (~1 GHz) of coaxial cable divided into a large number of lower bandwidth channels (~ 6 MHz) to carry a variety of entertainment programming as well as POTS and high-speed Internet services (using cable modems)
- 50-ohm coax for LAN and military applications
- Excellent noise immunity; but not as immune as fiber

Attenuation vs Frequency for Coaxial Cables

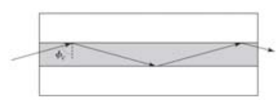


Optical Fibers

- Optical fiber consists of a cylindrical glass *core* surrounded by a concentric layer of glass called *cladding* as shown in Figure

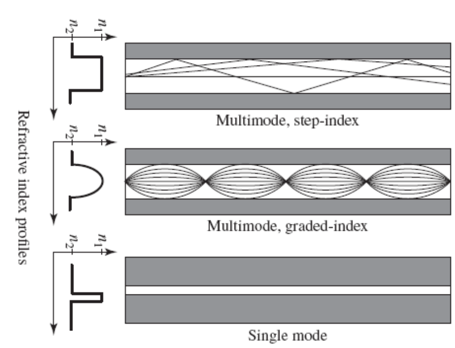


- Light propagates through fiber using *total internal reflection* which is made possible by making refractive index of the core higher than that of cladding



Types of Fiber

- There are three types of optical fiber as shown in Figure
  - Step-Index Multimode
  - Step-Index Single Mode
  - Graded-Index Multimode
- The term *multimode* refers to the fact that multiple modes or rays propagate through the fiber
- *Step-index multimode fiber* has a refractive index profile that undergoes a step change from high to low at the cladding boundary
  - Different rays (“modes”) travel along paths of different lengths ⇒ spreading of the pulse at the output
  - Step-index multimode fiber is used in LAN or campus network applications that require high bandwidth over relatively short distances



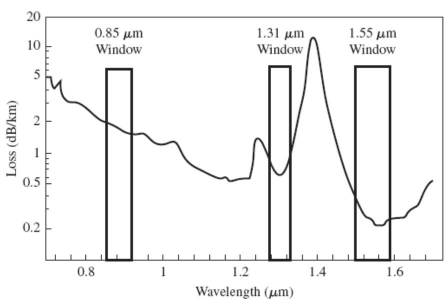
Types of Fiber (contd)

- **Step-index single-mode fiber** allows for only one mode of light (“axial ray”) to travel within the fiber
  - Single-mode fibers are used in applications where low signal loss and high data rates are required, such as on long spans in telecommunication networks
- **Graded Index multimode fiber** offers a higher bandwidth than a step-index multimode fiber by creating a core whose index of refraction varies parabolically from the center towards the cladding
- This has the effect of equalizing the time taken by different rays (modes) as they travel along paths of different lengths
  - For example, the axial ray travels shorter path length but at slower speed because of higher refractive index in the center
  - The other rays travel longer paths but at faster speeds

Types of Fiber (contd)

- Optical fibers are medium of choice in so many applications because of
  - Lower attenuation, as low as 0.2 dB/km at 1550 nm wavelength
  - 25-30 THz optical bandwidth available in 4 transmission windows as shown in Figure
  - Dielectric nature of transmission medium provides total electrical isolation and noise immunity
- **Dense Wavelength Division Multiplexing (DWDM)** allows up to 100 signal streams (each up to 10 Gb/s) to be carried over the same fiber using different wavelengths (colors!)
  - This is 1 Tb/s transmission capacity! (15 million voice conversations on a single strand of glass of the size of human hair)

Attenuation Characteristics of Optical Fibers



Radio Channels

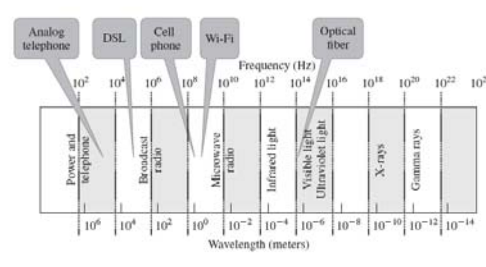
- An attractive option for communication is to use electromagnetic (EM) wave propagation through space, i.e., radio
- Requires the use of frequency spectrum that is very scarce!
- Excellent attenuation characteristics over long distances in specific frequency bands
- The radio frequency (RF) spectrum is allocated on a worldwide basis by the International Telecommunication Union (ITU) for various classes of service
- In United States, the Federal Communications Commission (FCC) is responsible for the allocation and assignment of frequencies in the RF spectrum
- Table 1.1 summarizes the frequency bands in the RF spectrum

RF Spectrum Allocation

Frequency Band	Frequency Range
Very Low Frequency (VLF)	3–30 kHz
Radio navigation	
Fixed maritime mobile communications	
Submarine communications	
Low Frequency (LF)	30–300 kHz
Fixed maritime mobile communications	
Radio navigation	
Medium Frequency (MF)	300–3000 kHz
AM radio broadcasting	530–1700 kHz
Traveler's information service	
High Frequency (HF)	3–30 MHz
Shortwave radio broadcasting	5.95–26.1 MHz
Very High Frequency (VHF)	30–300 MHz
TV channels 2–6	54–88 MHz
FM radio broadcast	88–108 MHz
TV channels 7–13	174–216 MHz
Ultra High Frequency (VHF)	300–3000 MHz
TV channels 14–83	420–890 MHz
Cellular telephony	824–894 MHz
Industrial, scientific, and medical (ISM): Wi-Fi	902–928 MHz
Global positioning system (GPS)	1227.6, 1575.4 MHz
Cellular telephony: Personal communications services (PCS)	1850–1990 MHz
ISM: Wi-Fi	2400–2483.5 MHz
Superhigh (Microwave) Frequencies (SHF)	3–30 GHz
G band: Geostationary satellite communications	4–6 GHz
J band: Geostationary satellite communications	10.7–14.5 GHz
Ka band: Satellite communications	26.5–40 GHz

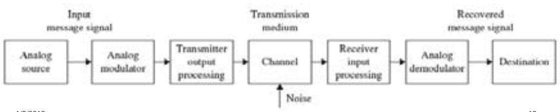
Allocation of Frequency Spectrum

- Figure displays the allocation of the frequency spectrum to various communication applications



Analog Communication Systems

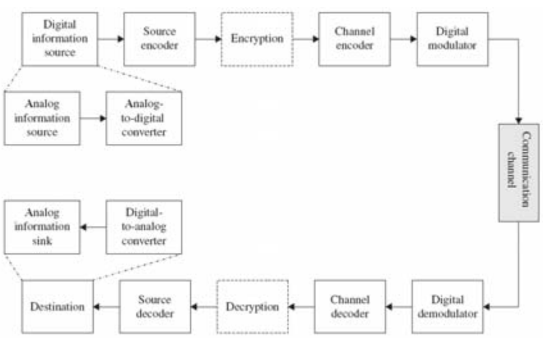
- Convert analog message signals into waveforms suitable for transmission over a communication channel
- Usually involves modulation, i.e., vary the amplitude, phase, or frequency of a high-frequency sinusoidal waveform (called a **carrier**) in accordance with the analog message signal
- At the other end of the channel, the **demodulation** process recovers the original analog message signal
- For example, AM and FM broadcasting
- Performance degraded by noise and other channel impairments



Digital Communication System

- In a digital communication system, the message is a sequence of symbols from a finite alphabet
  - For example, characters from the English or Chinese alphabet, binary symbols from a computer file, etc.
  - If the source is analog, such as a voice signal from a microphone, the output of a sensor, a video waveform, etc., it can be converted into a sequence of binary digits by an **analog-to-digital (A/D) conversion** process
- The block diagram of a typical digital communication system is shown in Figure
  - **Source encoder** – produces efficient representation of source signals as a **sequence of bits** subject to some fidelity measure
    - Removes inherent redundancy in the source

Block Diagram of a Digital Communications System



Digital Communication System (contd)

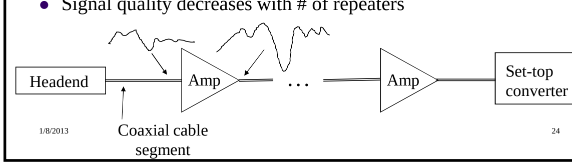
- **Channel encoder** – introduces in a controlled manner some redundancy in the source encoder binary sequence
  - Channel encoder output is a succession of codewords or coded sequences
  - Used at the receiver to overcome the effects of noise and other channel impairments
- **Digital modulator** – serves as the interface to the communication channel
  - Maps a block of channel encoder output bits into a continuous-time waveform suitable for transmission through the channel
- **Digital demodulator** – processes the channel-distorted and noisy received waveform and generates an estimate of the channel encoder output sequence

Digital Communication System (contd)

  - For example, in the case of binary transmission, the demodulator output is a binary 0 or 1 during a bit period
- **Channel decoder –** utilizes the redundancy contained in the received data and attempts error detection and correction
- **Source decoder –** reconstructs a more-or-less faithful replica of the original source output symbol sequence from the channel decoder output (possibly corrupted)
- Encryption is optionally used to assure the security of message transmission, that is, only the intended receiver can understand the message and only the authorized sender can transmit it
  - A decryption stage may decipher the data using the proper decryption key

Analog Transmission

- Consider a coaxial **cable television (CATV)** system
- As the system length increases, the output of the coaxial cable increasingly attenuated, and the shape of the signal distorted
- Each amplifier (repeater) attempts to restore analog signal to its original form
- Restoration is imperfect
  - Distortion is not completely eliminated
  - Noise & interference is only partially removed
- Signal quality decreases with # of repeaters

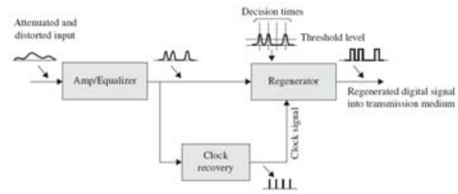


Why Digital Transmission?

- Digital transmission uses **regeneration**, i.e., the regenerator in a digital repeater recovers the original bit sequence and retransmits on next segment along the transmission path
  - Regeneration ⇒ the **rejuvenated** signal is like the first time!
- Amplified and reshaped signal in a regenerative repeater is sampled at the midpoint of each bit period
- The **regenerator** produces a **clean** pulse whenever the magnitude of the sample is above the threshold value in the case of binary signaling ⇒ **no** accumulation of noise
- Error occurs when noise and interference large enough that the received signal sample value crosses the threshold at the sampling point when no pulse is transmitted ⇒ the original symbol can be recovered error free virtually every time

Why Digital Transmission? (contd)

- Note that the job of **regenerative repeater** is simple; it does not need to restore the original shape of the transmitted signal as in the case of an analog transmission
  - It needs to determine only the presence or absence of a pulse ⇒signal can be severely attenuated and distorted. Can go much farther before the need for regeneration



Advantages of Digital Transmission

- Other than ease of regeneration, digital transmission has following advantages
  - **One network for all services** Digital transmission systems can carry all types of information, whether inherently analog or digital, in one network
  - **Lower transmitted power** Digital transmission systems require several orders of magnitude less received power than analog systems for the same user experience or performance (voice or picture quality)
  - **Enhanced capabilities** Digital transmission enables easier implementation of multiplexing, error control coding, and compression techniques
    - These capabilities have made feasible the availability of multimedia services and applications on a global scale

Advantages of Digital Transmission (contd)

- **Security** Encrypting digital data is easier, more secure, and more cost effective. With the tremendous growth of mobile communications and electronic financial transactions, protection of information has become very important
- **Benefits of Moore's law** The silicon chips inside the digital transmission equipment follow Moore's law, which states that the number of transistors on a chip will double about every two years
  - Semiconductor industry has kept that pace for more than 40 years
  - ⇒Decreasing cost and integration of more functions to implement sophisticated error control, compression, equalization, and encryption capabilities

Important Milestones in History of Communications

Year	Event
1820	Oersted shows electric currents create magnetic fields
1830–1840	Henry discovers induction; Faraday and others show changing magnetic fields produce electric fields
1838	Samuel Morse demonstrates telegraph
1844	First commercial telegraph link from Baltimore to Washington
1864	James C. Maxwell predicts electromagnetic radiation
1866	Transatlantic telegraph
1876	Alexander Graham Bell files patent application for the invention of telephone
1878	Alexander Graham Bell installs first telephone exchange in New Haven, Connecticut
1887	Hertz experimentally verifies Maxwell theory
1895	Radio, or "wireless," born when Guglielmo Marconi experiments with wireless telegraphy
1901	First transatlantic radio message by Marconi, United Kingdom to Canada
1904–1906	Fleming announces diode tube; DeForest announces triode
1906	AM radio broadcasting
1918	Edwin Armstrong devises superheterodyne receiver
1920	First modern radio broadcast by KDKA, Pittsburgh, Pennsylvania
1924–1928	Mechanical TV system demonstrations by John Baird, London
1928	Gaussian thermal noise papers of Johnson and Nyquist
	First all-electronic television system demonstrated by Philo Farnsworth, and also independently by Vladimir Zworkin in 1929
1933	Edwin Armstrong invents FM
1936	Commercial TV broadcasting by British Broadcasting Corporation, London

Important Milestones in History of Communications

1937	Alec Reeves patents pulse-code modulation (PCM) in England
1943	D. O. North introduces matched filter for radar detection application
1947	Kotelnikov in Russia introduces signal space concepts to develop theory of optimal reception of digital signals in the presence of noise
1948	Brattain, Bardeen, and Shockley demonstrate transistor in the United States; Claude Shannon publishes *A Mathematical Theory of Communication*
1949	Shannon publishes sampling theorem in the context of communication; Kotelnikov arrived at similar results in 1933 independently
1950–1955	Beginnings of computer software; beginnings of microwave long-haul transmission
1956	First transatlantic telephone cable
1959	Jack Kilby patents integrated circuit
1960s	Error-correcting codes begin rapid development
1960	Theodore Maiman introduces the first working laser in the United States
1962	AT&T introduces T1 digital carrier system, the transmission of voice in digital format
	First communication satellite, Telstar I, launched
1967	Viterbi proposes algorithm for efficient decoding of convolutional codes
1970	Low-loss optical fibers demonstrated
1971	Microprocessor invented
1975	Robert Metcalfe and others file a patent for Ethernet at Xerox PARC
1976	Apple I home computer invented
1979	First commercial citywide cellular network is launched in Japan by NTT
1981	IBM launches its personal computer (PC)
1983	FT3C (90 Mb/s) digital optical fiber system linking Washington D.C. to New York installed
1983	16-bit DSP chips commercially available
1985–1990	Cellular mobile telephones become widespread in Europe

Important Milestones in History of Communications

1987	EDFA optical amplifier invented, a key enabling technology for wavelength-division multiplexing (WDM) systems
1988	Flash memory commercially available (key technology for PDAs, laptop computers, MP3 players, digital cameras, and cellular phones)
1991	Second-generation (digital) cellular system, GSM, begins operation in Europe
1993	Turbo coding invented by C. Berrou and others, approaches Shannon limit
1996	Demonstration of Tbit/sec rate transmission on single-mode fibers using WDM
Late-1990s	Internet proliferates
2001	First commercial launch of third-generation (3G) cellular network in Japan by NTT DoCoMo using WCDMA technology

Key Themes And Drivers

- Shannon's 1948 paper laid the foundation of digital information age
  - Presented concepts, architecture, and fundamental limits on the performance of digital communication systems that can be achieved using complex processing
- It required two additional revolutions to realize Shannon's prophecy:
  - Semiconductor revolution in the form of Moore's law that enabled the development of powerful silicon chips
  - Software revolution beginning with the development of stored-program computer concept by Von Nuemann
    - Complex coding and compression algorithms are implemented in software to run on these silicon chips

Key Themes And Drivers (contd)

- The marriage of communication and computers has produced a paradigm shift in the design of digital communication systems and networks
  - It is the ideas and algorithms rather than the devices and circuits that drive innovations in the twenty-first-century communications industry
- Other significant trends in the communication landscape include
  - **Transition from electrons to photons** – abundant bandwidth and faster speeds
  - **Discrete-time processing** – cost and performance benefits increasingly driven by Moore's law
  - **Mobility** – instant access to all kinds of information through mobile applications anywhere, anytime