Contemporary Communication Systems

Chapter 1

Introduction

M.F. Mesiya

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 √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
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

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

<table>
<thead>
<tr>
<th>Wavelength (μm)</th>
<th>Loss (dB/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>20</td>
</tr>
<tr>
<td>1.0</td>
<td>10</td>
</tr>
<tr>
<td>1.2</td>
<td>5</td>
</tr>
<tr>
<td>1.4</td>
<td>2</td>
</tr>
<tr>
<td>1.6</td>
<td>1</td>
</tr>
</tbody>
</table>

### 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

### Allocation of Frequency Spectrum

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>Allocation</th>
</tr>
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<tbody>
<tr>
<td>300-600 MHz</td>
<td>AM broadcast</td>
</tr>
<tr>
<td>530-1700 kHz</td>
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</tr>
<tr>
<td>530-1700 MHz</td>
<td>TV channels</td>
</tr>
<tr>
<td>100-300 MHz</td>
<td>FM broadcast</td>
</tr>
<tr>
<td>100-300 MHz</td>
<td>TV channels</td>
</tr>
<tr>
<td>30-60 MHz</td>
<td>AM broadcast</td>
</tr>
<tr>
<td>902-928 MHz</td>
<td>ISM bands</td>
</tr>
<tr>
<td>1710-1755 MHz</td>
<td>Cellular services</td>
</tr>
<tr>
<td>1805-1880 MHz</td>
<td>Broadband services</td>
</tr>
<tr>
<td>2015-2110 MHz</td>
<td>Local Loop services</td>
</tr>
<tr>
<td>2170-2230 MHz</td>
<td>Fixed wireless services</td>
</tr>
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</table>

### RF Spectrum Allocation

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**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

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

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
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.

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 transmitted 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.

Important Milestones in History of Communications

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1835</td>
<td>General Morse patents pole-and-wire telegraph (US) in England.</td>
</tr>
<tr>
<td>1854-1866</td>
<td>Henry罐cky Liverpool and Manchester; the Mail Races.</td>
</tr>
<tr>
<td>1876</td>
<td>Alexander Graham Bell invents telephone.</td>
</tr>
<tr>
<td>1901</td>
<td>First transatlantic radio message from Marconi, United Kingdom to Canada.</td>
</tr>
<tr>
<td>1945-1946</td>
<td>Fleming announces a tube, the “infant electron tube.”</td>
</tr>
<tr>
<td>1956</td>
<td>All radio broadcasting.</td>
</tr>
<tr>
<td>1956</td>
<td>Edwin Kenneth donates his first portable transmitter.</td>
</tr>
<tr>
<td>1962</td>
<td>First transatlantic telephone calls.</td>
</tr>
<tr>
<td>1975</td>
<td>Transistor power transistors.</td>
</tr>
<tr>
<td>1981</td>
<td>First connecting four types of equipment.</td>
</tr>
<tr>
<td>1990</td>
<td>Frederick McClure invents the first high-speed laser in the United States.</td>
</tr>
<tr>
<td>1996</td>
<td>ARF introduces Ti digital carier system, the revolution of voice in digital format.</td>
</tr>
<tr>
<td>1997</td>
<td>World’s first digital broadband (3G).</td>
</tr>
<tr>
<td>1998</td>
<td>Wireless communication satellite, Globalstar.</td>
</tr>
<tr>
<td>1999</td>
<td>Integrated digital broadband.</td>
</tr>
<tr>
<td>2003</td>
<td>Introduction of Wi-Fi.</td>
</tr>
<tr>
<td>2004</td>
<td>Introduction of WiMAX.</td>
</tr>
</tbody>
</table>

Important Milestones in History of Communications (contd)

- 1837 | Bell's telephone patented. |
- 1843 | The Photographic Alphabet. |
- 1876 | The invention of the telephone. |
- 1901 | The transatlantic telephone. |
- 1956 | The first transatlantic radio. |
- 1960 | The invention of the first laser. |
- 1976 | The invention of the transistors. |
- 1981 | The first connecting four types of equipment. |
- 1990 | The invention of the first high-speed laser in the United States. |
- 1996 | ARF introduces Ti digital carier system, the revolution of voice in digital format. |
- 1997 | World’s first digital broadband (3G). |
- 1998 | Wireless communication satellite, Globalstar. |
- 1999 | Integrated digital broadband. |
- 2003 | Introduction of Wi-Fi. |
- 2004 | Introduction of WiMAX. |
Important Milestones in History of Communications

1947 - EDFA, optical amplifier invented, a key enabling technology for wavelength-division multiplexing (WDM) systems
1948 - Shannon’s 1948 paper laid the foundation of digital information age
1951 - Second-generation (digital) cellular systems, GSM, begins operation in Europe
1960 - Tasto coding invented by C. Bovee and others, approaches Shannon limit
Late 1980s - Demonstration of Tbit/sec rate transmission on single-mode fiber using WDM
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 Neumann
- 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