Communication Systems

Courtesy of Dr. Francis Lau
Communication Systems

- Introduction
- Electrical Communication System
- Analog Communication System
- Digital Communication System
- Mathematical Models for Communication Channels
- Summary
- Reference
Introduction

• Telegraphy
  – Morse code invented by Samuel Morse in 1837

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>. . .</td>
<td>N</td>
<td>. .</td>
<td>1</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>. . . .</td>
<td>O</td>
<td>. . .</td>
<td>2</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>. . . .</td>
<td>P</td>
<td>. . .</td>
<td>3</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>. . .</td>
<td>Q</td>
<td>. . . .</td>
<td>4</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>. . .</td>
<td>R</td>
<td>. . .</td>
<td>5</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>. . .</td>
<td>S</td>
<td>. . .</td>
<td>6</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>. . .</td>
<td>T</td>
<td>. . .</td>
<td>7</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>. . . .</td>
<td>U</td>
<td>. . .</td>
<td>8</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>. . . .</td>
<td>V</td>
<td>. . .</td>
<td>9</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>. . . . .</td>
<td>W</td>
<td>. . .</td>
<td>0</td>
<td>. . . . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>. . . .</td>
<td>X</td>
<td>. . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>. . . .</td>
<td>Y</td>
<td>. . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>. . .</td>
<td>Z</td>
<td>. . . .</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Introduction

• Telegraphy
  – Morse code
    
<table>
<thead>
<tr>
<th>Character</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period (.)</td>
<td>......</td>
</tr>
<tr>
<td>Comma (,)</td>
<td>———</td>
</tr>
<tr>
<td>Interrogation (?)</td>
<td>..··</td>
</tr>
<tr>
<td>Quotation Mark (&quot;)</td>
<td>···</td>
</tr>
<tr>
<td>Colon (:)</td>
<td>———</td>
</tr>
<tr>
<td>Semicolon (;)</td>
<td>———</td>
</tr>
<tr>
<td>Parenthesis ( )</td>
<td>———</td>
</tr>
<tr>
<td>Wait sign (AS)</td>
<td>......</td>
</tr>
<tr>
<td>Double dash (break)</td>
<td>———</td>
</tr>
<tr>
<td>Error sign</td>
<td>····</td>
</tr>
<tr>
<td>Fraction bar (/)</td>
<td>———</td>
</tr>
<tr>
<td>End of message (AR)</td>
<td>··—</td>
</tr>
<tr>
<td>End of transmission (SK)</td>
<td>·——</td>
</tr>
</tbody>
</table>

Punctuation and Special Characters

– binary digital communication system

– letters of the English alphabet were efficiently encoded into corresponding variable-length code words having binary elements
Introduction

• Telegraphy
  – in 1875, Emile Baudot developed the Baudot code for telegraphy
  – each letter was encoded into fixed-length binary code words of length 5
Introduction

• Telephony
  – Alexander Graham Bell invented the telephone in 1876
  – invention of the amplifier by Lee DeForest in 1906
  – automatic switch, developed by Strowger in 1897, was an electromechanical step-by-step switch
Introduction

• Telephony
  – digital switch was placed in service in 1960
  – fiber optic are replacing copper wire and coaxial cables in the telephone system
  – development of fax machine, modem etc.
  – computer-telephony integration (CTI)
Introduction

- **Wireless Communications**
  - James C. Maxwell in 1864 predicted the existence of electromagnetic radiation and formulated the basic theory (Maxwell's equations)
  - Maxwell's theory was verified experimentally by Hertz in 1887
Introduction

• **Wireless Communications**
  – On December 12, 1901, Guglielmo Marconi successfully received a radio signal at Signal Hill in Newfoundland, North America, which was transmitted from Cornwall, England—a distance of about 1700 miles
  – Marconi is credited with the development of wireless telegraphy
Introduction

• **Wireless Communications**
  – amplitude modulation (AM) broadcast was started in 1920
  – in 1933, Edwin Armstrong built and demonstrated the first frequency modulation (FM) communication system
Introduction

• Wireless Communications
  – first television system was built in the United States by Vladimir Zworykin and demonstrated in 1929
  – commercial television broadcasting began in London in 1936 by the British Broadcasting Corporation (BBC)
  – colour TV in late 1960'
  – digital TV, high-definition TV
Introduction

• Wireless Communications
  – satellite named Telstar 1 was launched in 1962 and used to relay TV signals between Europe and the United States
  – commercial satellite communication services began in 1965 with the launching of the Early Bird satellite
Introduction

• **Wireless Communications**
  – first global mobile satellite communication system (Iridium) in operation in 1999
  – mobile cellular systems developed since 1980'
    • analog (TACS, AMP)
    • digital (GSM, CDMA, D-AMP)
    • third generation (wideband CDMA)
Introduction

• Computer
  – Standalone PC
  – local area network (LAN)
  – metropolitan area network (MAN)
  – intranet
  – internet
Electrical Communication System

• designed to send messages or information from a source that generates the messages to one or more destinations

Functional block diagram of a communication system
Electrical Communication System

- information source
  - voice (speech source)
  - picture (image source)
  - plain text in some particular language, such as English, Japanese, German, French, etc
  - output is described in probabilistic terms, that is the output of a source is not deterministic
Electrical Communication System

• input transducer
  – convert the output of a source into an electrical signal that is suitable for transmission
  – a microphone serves as the transducer that converts an acoustic speech signal into an electrical signal
  – a video camera converts an image into an electrical signal
Electrical Communication System

• **transmitter**
  - converts the electrical signal into a form that is suitable for transmission through the physical channel or transmission medium
  - in radio and TV broadcast, the Office Of the Telecommunication Authority (OFTA) specifies the frequency range for each transmitting station
Electrical Communication System

• **transmitter**

  – the transmitter must translate the information signal to be transmitted into the appropriate frequency range that matches the frequency allocation assigned to the transmitter

  – signals transmitted by multiple radio stations do not interfere with one another
Electrical Communication System

- **transmitter**
  - similar functions are performed in telephone communication systems, where the electrical speech signals from many users are transmitted over the same wire
  - in general, the transmitter performs the matching of the message signal to the channel by a process called **modulation**, e.g AM, FM
Electrical Communication System

- **channel**
  - physical medium used to send the signal from the transmitter to the receiver
Electrical Communication System

- channel
  - wireline channel
    - twisted-pair
  - coaxial cable
  - optical fiber
Electrical Communication System

• channel
  – wireless channel
    • normally atmosphere (free space)
    • electromagnetic energy is coupled to the propagation medium by an antenna which serves as the radiator
Electrical Communication System

• channel

  – underwater acoustic channels
    • electromagnetic waves do not propagate over long distances under water except at extremely low frequencies
    • acoustic signals propagate over distances of tens and even hundreds of km
Electrical Communication System

• channel
  – storage channels
    • magnetic tape
    • digital audio tape
    • magnetic disk
    • VCD
    • DVD
Electrical Communication System

- receiver
  - recover the message signal contained in the received signal
  - if the message signal is transmitted by carrier modulation, the receiver performs carrier demodulation to extract the message from the sinusoidal carrier
Electrical Communication System

• **output transducer**
  
  – convert the electrical signals that are received into a form that is suitable for the use; e.g., acoustic signals, images, etc.
Analog Communication System

• **analog signals**
  – continuous-time signal waveforms

• **analog sources**
  – information sources that produce analog signals

• **analog communication systems**
  – analog signals transmitted directly via carrier modulation over the communication channel and demodulated accordingly at the receiver

• **e.g. AM, FM**
Digital Communication System

- digital signals are transmitted via digital modulation and demodulated as a digital signal at the receiver

Basic elements of a digital communication system
Digital Communication System

• information source
  – analog signal
    • e.g. audio or video signal
  – digital (discrete) signal
    • e.g. output of a keyboard
Digital Communication System

- source encoder
  - converts the output of either an analog or a digital source into a sequence of binary digits
  - represent the source output (message) by as few binary digits as possible
  - data compression
Digital Communication System

• channel encoder

  – introduces in a controlled manner some redundancy in the binary information sequence from the source encoder
  – increases the reliability of the received data and improves the fidelity of the received signal
Digital Communication System

- digital modulator
  - serves as the interface to the communications channel
  - maps the binary information sequence into signal waveforms
    - e.g. '0' $\rightarrow$ waveform $s_0(t)$; '1' $\rightarrow$ waveform $s_1(t)$
Digital Communication System

- channel

- introduces noise and distortion to the transmitted waveform
Digital Communication System

- digital demodulator

- processes the channel-corrupted transmitted waveform and reduces each waveform to a single number that represents an estimate of the transmitted data symbol (binary or M-ary)
Digital Communication System

- channel decoder

  - attempts to reconstruct the original information sequence from knowledge of the code used by the channel encoder and the redundancy contained in the received data
Digital Communication System

- **source decoder**

  - accepts the output sequence from the channel decoder and attempts to reconstruct the original signal from the source
  
  - difference between the original signal and the reconstructed signal is a measure of the distortion introduced by the digital communications system
Mathematical Models for Communication Channels

• construct mathematical models that reflect the most important characteristics of the transmission medium

• use the mathematical model for the channel in the design of the channel encoder and modulator at the transmitter and the demodulator and channel decoder at the receiver
Mathematical Models for Communication Channels

• additive noise channel
  – arises from electronic components and amplifiers at the receiver of the communication system
  – arises from interference encountered in transmission as in the case of radio signal transmission
Mathematical Models for Communication Channels

- additive noise channel

\[ r(t) = \alpha s(t) + n(t) \]

- if the signal undergoes attenuation in transmission through the channel,

\[ r(t) = \alpha s(t) + n(t) \]

- \( \alpha \): attenuation factor

\( s(t) \): transmitted signal

\( n(t) \): additive random noise process

\( r(t) \): received signal
Mathematical Models for Communication Channels

• linear filter channel
  – in some physical channels, filters are used to ensure that the transmitted signals do not exceed specified bandwidth limitations and thus do not interfere with one another
    • e.g. wireline telephone channels
Mathematical Models for Communication Channels

- **linear filter channel**

\[ r(t) = s(t) \ast h(t) + n(t) \]

- \( h(t) \): impulse response of the linear filter
- \( \ast \): convolution
Mathematical Models for Communication Channels

• **linear time-variant filter channel**
  
  – channel results in time-variant multipath propagation of the transmitted signal
  
  – \( h(\tau; t) \): time-variant channel impulse response
  
  • response of the channel at time \( t \) due to an impulse applied at time \( (t - \tau) \)
Mathematical Models for Communication Channels

- linear time-variant filter channel

\[ r(t) = s(t) \ast h(\tau; t) + n(t) \]

\[ = \int_{-\infty}^{+\infty} h(\tau; t)s(t - \tau) \, d\tau + n(t) \]
Mathematical Models for Communication Channels

- **linear time-variant filter channel**
  - for multipath signal propagation through physical channels
  - e.g. ionosphere (at frequencies below 30 MHz) and mobile cellular radio channels

\[ h(\tau; t) = \sum_{k=1}^{L} a_k(t) \delta(\tau - \tau_k) \]

- \( \{a_k(t)\} \): possibly time-variant attenuation factors for the \( L \) multipath propagation paths
Mathematical Models for Communication Channels

• linear time-variant filter channel
  – received signal

\[ r(t) = \sum_{k=1}^{L} a_k(t)s(t - \tau_k) + n(t) \]

• consists of \( L \) multipath components
• each component is attenuated by \( \{a_k(t)\} \) and delayed by \( \{\tau_k\} \)
Summary

• development of communications
• components in a communication system
Summary

- analog communication system
- components in a digital communication system
Summary

• channel models
  – additive noise
  – linear filter
  – linear time-variant filter
Reference