Introduction to Digital Communications Engineering I

Lectures No. 1 and 2

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Overview

These lectures look at the following:

- Course introduction
- History of Communications
- Communications system
- Communication modes
- Methods of data communication
- Time constraints
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- Transmission modes
- Analogue versus digital
- Baseband and bandpass
- Digital communications transceiver
- Conclusion
- Acknowledgement
Introduction

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Course Introduction

- **Course Code:** COMM2108
- **Assessment:** 70 % Exam 30 % Lab
- **Lectures:** 2 hours/week
- **Labs:** 2 hours per week
Module Objectives

This module is designed to give an appreciation of the principles of digital communications engineering. After completing this module you should:

• Be able to identify the main elements of a digital communications system.

• Understand source formatting, in particular, sampling, quantisation, signal to quantisation noise ratio.

• Be able to quantify the performance of baseband digital
systems in terms of bandwidth requirements, intersymbol interference and bit-error rates.
Syllabus

- Introduction to digital communications
- Source formatting
- Multiplexing
- Baseband communication: generation, transmission, detection
Textbooks

Recommended Reading:

- ‘Digital Communications: Fundamentals and Applica-
Lectures No. 1 and 2: *Introduction to Digital Communications Engineering I*

History of Communications

The highlights of the inventions which have lead to communications as we know it today are listed below:

- **1440**: Printing press - Gutenberg
- **1826**: Ohm’s law - Ohm
- **1837**: Line telegraphy invention - Gauss, Weber
- **1844**: Line telegraphy patent - Morse
- **1858**: 1st transatlantic cable (fails after 26 days)
- **1864**: Electromagnetic radiation predicted - Maxwell
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• 1866: Successful transatlantic telegraph cable (Valentia to Newfoundland)
• 1875: Telephone invented - Bell
• 1877: Phonograph invented - Edison
• 1887: Detection of radio waves - Hertz
• 1894: Wireless communication over 150 yards - Lodge
• 1895: Wireless telegraphy - Marconi
• 1897: Automatic telephone exchange - Strowger
• 1901: Transatlantic radio transmission - Marconi
1904: Diode valve - Fleming
1905: Wireless transmission of speech and music - Fesseden
1906: Triode valve - de Forest
1907: Regular radio broadcasts
1915: Trans. USA telephone line - Bell System
1918: Superheterodyne radio receiver - Armstrong
1919: Commercial broadcast radio - KDKA Pittsburg
1920: Sampling applied to communications - Carson
1926: Television invented - Baird (UK), Jenkins (USA)
• 1928: All electronic television - Farnsworth
• 1928: Theory of transmission of telegraph - Nyquist
• 1928: Information theory - Hartley
• 1933: FM demonstrated - Armstrong
• 1934: Radar - Kuhnold
• 1937: PCM (pulse code modulation) proposed - Reeves
• 1939: Commercial TV broadcasting - BBC
• 1943: Microwave radar used
• 1944: Statistical methods to describe noise and extract
signals - Rice

- **1945**: Geostationary satellites proposed - Clarke
- **1946**: ARQ (automatic repeat request) proposed - Du-uren
- **1948**: Mathematical theories of communication - Shannon
- **1948**: Invention of transistor - Shockley, Bardeen, Brat-tain
- **1953**: Transatlantic telephone cable
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- **1955**: Invention of laser - Townes, Schawlow
- **1961**: Stereo FM transmission
- **1962**: Satellite communication - TELSTAR
- **1963**: Touch tone telephone - Bell System
- **1963**: Geostationary communications satellite - SYN-COM II
- **1963**: Error correction codes developed
- **1964**: First electronic telephone exchange
- **1965**: Commercial communications satellite - Early Bird
• 1966: optical fibre proposed - Kao, Hockman
• 1968: Cable TV
• 1970: Medium scale data networks - ARPA/TYMNET
• 1970: LAN, MAN, WAN
• 1971: ISDN proposed - CCITT
• 1972: First cellular mobile phone
• 1974: The Internet - Cerf, Kahn
• 1978: Cellular radio
• 1978: Navstar GPS (global positioning system)
• **1980**: Fibre optic communications system developed - Bell System

• **1980**: OSI 7 layer reference model - ISO

• **1981**: HDTV (high-definition television) demonstrated

• **1985**: ISDN basic rate access introduced - UK

• **1986**: SDH introduced (SONET in USA)

• **1991**: GSM (global system for mobile communications) - Europe

• **1999**: WAP (wireless application protocol)
There have been many many more inventions since 1999. As an exercise use the Internet to find as many recent telecommunications inventions as you can.
Communications System

In its simplest form a telecommunications system consists of a transmitter, a channel, a receiver and two transducers.
Transducer

- Converts the input message into an electrical signal. Examples of transducers include:
  - Microphone – converts sound to electrical signal
  - Camera – converts image to electrical signal

- A transducer is also used to convert electrical signals to an output message (or approximation of the input message), e.g., sound, images etc.
Transmitter

- Converts electrical signal to a form that is suitable for transmission through the transmission medium or channel.

- Generally matching of signal to channel is done by modulation.

- Modulation uses the information (message signal) to vary the amplitude, frequency or phase of a sinusoidal carrier, e.g. amplitude/frequency modulation AM/FM.

- The transmitter also filters and amplifies the signal.
Receiver

- Recovers the message contained in the received signal
- Receiver demodulates the message signal
- Receiver filters signal and suppresses noise
Communication Modes

There are a few basic modes of communication:

- **Point-to-Point**: where one user wishes to communicate with one other user, or with a small group of nominated users. Examples include the telephone network or email. Communication is normally two-way.

- **Broadcast**: Where one sender communicates with all capable receivers who cannot respond. The communication is therefore normally one-way.

- **Multicast**: One sender communicates with a nominated
set of receivers who cannot respond.
Methods of Data Transmission

There are a few basic methods of data transmission:

- **Simplex**: Data is transmitted in one direction only. The receiver cannot communicate with the sender.

- **Duplex**: Data transmission can take place in both directions simultaneously.

- **Half-Duplex**: Data transmission can take place in both directions but not at the same time.
Time Constraints

There are generally two sets of time restraints; real-time or time-lapse:

- **Real-Time**: Real-time communication is instant and data must be sent and received simultaneously. An example of this is the telephone network or two-way radio.
communications. If a conversation is to be maintained there must be immediate interaction between the talkers. Delays will make the conversation difficult or impossible.

- **Time-Lapse:** Data may be received at any time after having been sent. Examples include email, radio and TV broadcasts. The time of receipt is not important.

Consider the case of radio and TV in more detail. It does not matter when a particular program is transmitted - time lapse is possible. However, once transmission begins it must be continuous and at a constant rate -
during reception it appears as real-time.

There are also cases where time delay is not critical unless it is excessive e.g. downloading a file from a central server or from the Internet. A delay of a few seconds or even minutes is acceptable, but a delay of several hours is not acceptable.

In addition, components of a message should be received in the sequence in which they are sent (otherwise speech will be garbled). This may require that packets of data
must be re-sequenced at the receiver end.
Transmission Modes

All transmission is analogue, in the sense that physical quantities (voltage, current, electromagnetic radiation) must vary in a smooth way. However, the representation of the underlying signals may be either analogue or digital.
Analogue versus Digital

Analogue

In the past most signals were generated, transmitted and received in analogue form i.e. as a sine wave or as a more complex signal which could be made up from a series of sine waves. This was done because speech is an analogue signal and it was easier to implement analogue electronic circuitry than digital. In a very simple system it is still easier to build in analogue. However, analogue has the following disadvantages:
- It is inflexible, in that to make any changes to the system all of the changes have to be made in hardware. This becomes more difficult and expensive as the system grows in size.

- It is prone to noise and distortion.

- Control and manipulation of signals is difficult.

The mathematical treatment of analogue signals is relatively straightforward. An analogue signal is considered to have the form of a sine wave, or a combination of sine waves, the treatment of which is well established.
Digital

Computers deal in ‘1s’ and ‘0s’. Therefore communication between computers is a matter of transferring digital sequences between machines. The next step is to convert speech and other analogue signals into a digital format to permit a combined network. These days digital electronic circuitry is cheaper than analogue circuitry for the implementation of complex functions. Digital has the following advantages:

- Normally large scale digital systems are software controlled so that it is possible to make changes to the system
in software and remotely.

• It is less prone to noise or distortion, a ‘1’ remains a ‘1’ and will not be mistaken for a ‘0’, unless there is an extreme level of distortion.

• If noise or distortion does occur, methods exist to determine that this has happened, and if appropriate to correct the error which has occurred.

• It is relatively easy to manipulate signals.

The mathematical treatment is not as straightforward as that for analogue.
Baseband and Bandpass

Bit representation can be:

- Sent directly e.g. voltage pulses
- **Modulated** in some way first e.g. amplitude/frequency modulation, AM/FM

In the first instance we are dealing with *baseband* communication, in the second case *bandpass* communication.
Digital Communications Transceiver

The components of a hypothetical digital communications transceiver (transmitter/receiver) are shown below. For explanation purposes, the transceiver includes all the elements commonly found in digital transceivers, however, not all transceivers will contain all of these elements.
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CODECs

At its simplest a transceiver CODEC (coder/decoder) consists of an ADC (analogue to digital converter) in the transmitter, which converts an analogue signal into digital pulses, and a DAC (digital to analogue converter) in the receiver, which converts these digital pulses back into an analogue signal.

ADCs will generally consist of a sampling circuit, a quantiser and a pulse code modulator. The sampling circuit provides
discrete voltage samples taken, at regular intervals of time, from the analogue signal. The quantiser approximates these voltages to the nearest one of an allowed set of voltage levels. Indeed, it is the quantisation process that converts the analogue signal to a digital one. The PCM encoder converts each quantised level to a binary codeword, i.e., digital ones and zeros. An anti-aliasing filter is sometimes included prior to sampling in order to reduce distortion that can occur due to the sampling process.

In the receiver’s DAC received binary voltages are converted
to quantised voltage levels by a PCM decoder which is then smoothed by a low pass filter to reconstruct the original, analogue, signal.

Source, Security and Error Control Coding

In addition to PCM encoding and decoding a CODEC may have up to 3 additional functions:

- Firstly, in the transmitter it may reduce the number of digital pulses (bits) required to convey a message. This is called source coding and can be thought of as removing redundant or surplus bits.
• Secondly, it may encrypt the source coded digits using a cipher for security. This ensures security when passing private information.

• Finally, the CODEC may add extra digits to the (possibly source coded and encrypted) PCM signal which can be used at the receiver to detect, and possibly correct, errors made during signal detection. This is known as channel coding.

The source, security and error control decoding operations in the receiver are the inverse of those in the transmitter.
Multiplexers

In digital communications, multiplexing, to accommodate several simultaneous transmissions, usually means time division multiplexing (TDM). Time division multiplexers interleave either PCM codewords, or individual PCM bits, to allow more than one information link to share the same physical transmission medium. This can be cable, optical fibre or a radio frequency channel.

Demultiplexers split the received composite bit stream back
into its component PCM signals.

**MODEMs**

MODEMs (modulators/demodulators) change digital pulse streams so that they can be transmitted over a given physical medium, at a given rate, in a specified or allocated frequency band. Typically the modulator shapes, or filters, the pulses to restrict their bandwidth. The input to a modulator is thus a baseband signal, while the output is often a bandpass waveform.
Multiple Accessing

Multiple accessing refers to those techniques, and/or rules, which allow more than one transceiver pair to share a common transmission medium (e.g. one optical fibre, one satellite transponder or one piece of coaxial cable). Several different types of multiple accessing are currently in use, each type having its own advantages and disadvantages. The multiple accessing problem is essentially one of efficient and equitable sharing of the limited resource represented by the transmission medium.
Signal Transmission

The communications path from transmitter to receiver may use lines or free space. Examples of the former are wire pairs, coaxial cables and optical fibres. The most important use of the latter is radio, although in some situations infrared and optical free space links are also possible. (e.g. remote controls for TV, video and hi-fi equipment and also some security systems). Whatever the transmission medium, it is at this point that much of the attenuation, distortion, interference and noise is encountered.
Line Transmission: The essential advantages of line transmission are:

1. Path loss is modest.

2. Signal energy is confined and interference between systems is therefore negligible.

3. Path characteristics (e.g. attenuation and distortion) are usually stable and relatively easy to compensate for.

The disadvantages of line transmission include:

1. Laying cables in the ground or constructing overhead is expensive.
2. Planning permission may be needed for underground cables and overhead wires.

3. A physical connection to the network is required for each subscriber.

4. Mobile communications cannot be provided.

5. Networks cannot easily be added to or subtracted from.

The table below summarises the nominal frequency range of selected types of line and typical repeater (used to compensate for attenuation) spacings. The useful bandwidths of lines, which determine the maximum information transmis-
sion rate they can carry are often determined by their attenuation characteristics. Twisted wire pairs, for example, are normally limited to (line coded PCM) data rates of 2 Mbit/s. Coaxial cables generally carry 140 or 155 Mbit/s PCM signals but can handle rates several times greater. Optical fibres have very large bandwidth potential but may be limited to a fraction of this by factors such as the spectral characteristics of optical sources and dispersion effects. Nevertheless, optical fibre PCM bitrates of Gbit/s are possible.
**Radio Transmission:** The advantages of radio transmission are:

<table>
<thead>
<tr>
<th>Type</th>
<th>Frequency Range</th>
<th>Repeater Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead Line</td>
<td>0–160 kHz</td>
<td>40 km</td>
</tr>
<tr>
<td>Twisted Pairs</td>
<td>0–1 MHz</td>
<td>2 km</td>
</tr>
<tr>
<td>Coaxial Cables</td>
<td>0–500 MHz</td>
<td>1–9 km</td>
</tr>
<tr>
<td>Optical Fibres</td>
<td>(\lambda=1610 – 810) nm</td>
<td>100s of km</td>
</tr>
</tbody>
</table>
1. It is cheap and quick to implement.

2. Planning permission is only needed for the erection of towers to support repeaters and terminal stations.

3. It has an inherent broadcast potential.

4. It has an inherent mobile communications potential.

5. Networks can be quickly configured and extra terminals or nodes easily introduced or removed.

The principal disadvantages of radio are:

1. Path loss is generally large due to the tendency of the
transmitted signal energy to spread out, most of this energy effectively missing the receive antenna.

2. The spreading of signal energy makes interference between systems a problem.

3. Path characteristics (i.e. attenuation and distortion) tend to vary in time, often in an unpredictable way making equalisation more difficult.

4. The time varying nature of the channel can result in anomalous propagation of signals to locations well outside their normal range. This may cause unexpected interfer-
ence between widely spaced systems.
Conclusion

These lectures have looked at the following:

• Course introduction
• History of communications
• Communications system
• Communication modes
• Methods of data communication
• Time constraints
• Transmission modes
• Analogue versus digital
• Baseband and bandpass
• Digital communications transceiver
Acknowledgement

These lecture notes refer to material obtained from Mr. Lorcan MacManus and Mr. Sean O’Fearghail.