University of Manchester
School of Computer Science

CS3282 Digital Communications

Syllabus for 2005-2006

Level: 3, **Course rating**: 10

Teaching arrangements: Two lectures per week for one semester.

Lecturer: Barry Cheetham www.cs.man.ac.uk/barry

Background knowledge needed:

Basic mathematics: (As surveyed in first year Mathematics courses covering: complex numbers, Argand diagram, modulus & argument, differentiation, simple integration, sum of an arithmetic series, factorisation of quadratic equation, De Moivre's Theorem, exponential function and natural logarithms. Sine waves and the Fourier series.)

Computing: Experience with any high-level computer programming language.

Aims:

To gain an understanding of fundamental principles of digital transmission systems as used for applications in fixed and mobile telephony, wired and wireless computer networks, data storage and digital broadcasting. This course is mainly concerned with the physical layer and the different ways in which bit-streams may be transmitted and received over communication links such as a cable or a radio channel. Source and channel coding are briefly considered and also the demands for multiple access to radio channels.

Survey of the course and its objectives:

A 'discrete time' or 'digital' transmission channel is a communication link capable of sending and receiving digitised data. Such a link is generally achieved by placing a "digital transmitter" and a "digital receiver" at the ends of a "real channel" which is invariably analogue in nature. In traditional telephony, the "real channel" may be wire or cable, optical fibre, a radio channel, an infra-red or ultrasound link or perhaps a combination of several of these types. Such channels are also used for transmitting broadcast material for TV and radio and the data generated by computer networks and the Internet. Another form of transmission channel is obtained by magnetic and optical recording devices and their corresponding read-back devices (magnetic disks, tapes, CDROMs, DVDs. Zip-drives, etc.). The similarities between the technical problems of storage and transmission are as striking as the differences between them: e.g. efficient bandwidth utilisation and error concealment raise similar issues in both cases whereas overall delay and cost requirements are considerably different.
This course addresses mainly the "digital transmitter" and "digital receiver" and "real channel" issues arising in digital communications, though we will look at other aspects higher up the chain of "layers" of "protocols" governing telephone and data network communications.
In many ways the digital transmitter is a digital-to-analogue converter converting the stream of binary digits (obtained possibly by digitising analogue speech) into an analogue signal suitable for the channel in question. Similarly, the receiver is a type of analogue-to-digital converter.
To understand digital transmission and the demands of the analogue-digital conversion process, we must have a grounding in the relationship between the shape of an analogue waveform in the time-domain and its frequency-spectrum. Each binary digit will be represented by a segment of such an analogue waveform. So we have a brief section on Fourier transforms and spectral analysis.
It will become apparent that the performance of a digital transmission link is governed by two main factors: channel bandwidth and system noise. We will discuss the design of digital transmitters and receivers with reference to the bandwidth and noise characteristics of the channel and fundamental limitations in what can be achieved in a given situation will be established.

Summary of Objectives & Learning Outcomes:

Specific objectives are that after successful completion of the course, students will be able to:

- describe the requirements and limitations of digital transmission techniques as used for applications in fixed and mobile telephony, wired and wireless computer networks, data storage & digital broadcasting.
- calculate the effect of channel noise, band-limiting and frequency selective fading.
- design matched filtering, pulse shaping & equalisation schemes to meet given specifications.
- determine parameters & calculate expected bit-error rates (per unit of transmitter power) for 'single carrier' amplitude, frequency and phase modulation schemes.
- understand the very latest 'multi-carrier' modulation schemes (OFDM) & their advantages.
- appreciate the technology currently available & participate in its rapid development.

Detailed Syllabus:

Number of lectures Topic

1 Section 1: Introduction:
Definition of a digital communication link and its applications in telephony, computer networks, broadcasting and data storage. Importance of channel bandwidth and system noise. Protocols in telephony and internet communications. Types of channels (twisted pairs, co-axial cable, optical fibre, radio, etc.). Advantages and disadvantages of analogue and digital transmission.

2 Section 2: Notes on the Fourier Transform:
Notation. Analogue Fourier Transform and its inverse. Reminder of Fourier series and its relationship to the Fourier Transform (generalised to encompass certain power signals). Parseval's Theorem, auto-correlation function, Weiner-Khinchine Theorem and random signals. Energy and power of signals. Signal correlation and its significance as a measure of similarity and matching.

2 Section 3: Digitising speech, music and video
Digitising speech for fixed and mobile telephony: waveform coding at 64 & 32 kb/s, and parametric coding at lower bit-rates. 'RPE-LTP' speech coding at 13kb/s for GSM mobile & other standards. Digitising music for broadcasting (DAB), compressed transmission and storage (MP3 etc.). Digitising video for HDTV (MPEG-1&2).

2 Section 4: Introduction to digital transmission
Definition of bit-rate and signalling rate. Asynchronous transmission for low data-rates. Introduction to synchronous transmission. The need for pulse shaping, synchronisation and line-coding at higher data-rates. PCM waveforms (line-codes) in common use, including Manchester coding as used in computer networks. Calculation of bit-error probabilities when the channel is affected by the addition of 'white Gaussian' noise. The need for channel coding. Meaning of the terms: Hamming code, interleaving, block-code and convolutional code.

3 Section 5: Detection of binary signals in band-limited white Gaussian noise
Improving error performance using an "integrate and dump" circuit. Introduction to the concepts of a matched filter and a correlation detector. Schwartz's inequality. Establish formulae for bit-error probability in terms of signalling energy per bit and power spectral density of the noise. Unipolar and bipolar base-band signalling.

2 Section 6: Inter-symbol interference and pulse shaping.

The need for pulse-shaping. Nyquist filter. Raised cosine frequency-response. Pulse shaping combined with matched filtering. Root raised cosine frequency-response. Equalisation by zero-forcing and other adaptive equalisers with decision feedback. .

1 Section 7: The Shannon-Hartley Theorem.
An understanding of the theorem itself and its implications for achievable bit-rates over noisy channels with specified signal-to-noise ratio.

5 Section 8: Carrier modulated (band-pass modulation) for digital transmission
Introduction to single-carrier, multi-carrier and spread-spectrum modulation for digital transmission. Binary and multi-level amplitude-shift keying (ASK), frequency-shift keying (FSK) and phase-shift keying (PSK). Minimum-shift keying (MSK) and Gaussian MSK as used in GSM mobile phones. Coherent and non-coherent demodulation. Vector-modulator and the concept of complex base-band. Constellation diagrams. Differential PSK and quadrature phase shift keying (QPSK). Multi-carrier modulation and orthogonal frequency division multiplexing (OFDM). Applications of OFDM in digital broadcasting (e.g. DAB and DVB-T), wireless computer networks (e.g. IEEE802.11) and ASDL modems.

2 Section 9: Multi-level digital modulation:
Combined amplitude and phase-shift keying (QAM and APK). ITU modem standards. Carrier derivation and symbol timing recovery. 'Early-late' method. Non-coherently and coherently detected M-ary FSK. Advantages of Gray coding for multi-level modulation.

1 Section 10: Multi-user access for wireless communications
Frequency, time & code division multiplex access (FDMA, TDMA & CDMA techniques as currently used in mobile telephony. Multiple access by packet switching as used by Ethernet & wireless computer networks. Frequency hopping. Direct sequence CDMA. Wide-band CDMA for third generation mobile communication systems.

3 Discussion of exercises and problems

Text-books referred to:

"Digital Communications", Glover & Grant, Prentice-Hall, (new ed. due).
"Digital Communications" 2nd ed., B. Sklar, Prentice -Hall, 2001.
"Computer Networks, 4th edition" A.S Tanenbaum, Prentice-Hall, 2003.

Assessment: Two hour written examination.