Course Description

Course Responsible: Elisabeth Uhlemann
E-mail: elisabeth.uhlemann@hh.se, Phone: +46 35 167 195, Room: E306
www.hh.se/staff/bettan/CodDigCom.htm

This course is included as an elective course in the International Master’s Program in Embedded and Intelligent Systems at the School of Information Science, Computer and Electrical Engineering. The course is a core course in the specialization “communication systems” and a broadening course for other specializations. The main area is electrical engineering.

The course focuses on digital communications and how to efficiently transmit information from a source to a destination. If you have taken courses in mathematical statistics, digital signal processing and computer programming previously, it will facilitate the task of assimilating the course content, but a review of the most important tools will be given.

Primary Course Contents
The course contains an introduction on how to evaluate the quality of the received information, as well as what factors limit and determine the performance of a communication system. The following topics are covered:

- Review of signals and random processes.
- Sampling and quantization.
- Description of some modulation and demodulation techniques.
- Definition of some noise and channel models.
- Matched filter and optimum detection.
- Error performance and bandwidth efficiency.
- Overview of channel capacity and coding.
- Linear block and convolutional codes.
- Code properties and error performance.
- Modulation and coding trade-offs.

Goals
After completing the course you should be able to analyze and evaluate a digital communication system. Further, you should be able to elaborate on trade-offs between various parameters, such as bandwidth and signal power, based on system requirements, design limitations and requested error performance. Finally, you should be able to construct optimal receivers, describe some channel codes and apply and estimate the performance of the most common decoding algorithms.

Teaching Formats
Teaching consists of 12 lectures presenting the course content, 8 exercises at which theoretical problems are solved using methods presented at the lectures, and 2 home assignments where you implement different communication systems in Matlab in order to simulate and evaluate their performance. The home assignments are carried out in groups of two students and documented in written reports. Matlab is needed for solving the task. A tutorial on Monte-Carlo simulation of a simple communications system using Matlab is given.
Course Literature

- Lecture slides available through the course homepage.
- Exercises and solutions available through the course homepage.

The course book describes the entire course content covered by the lectures as well as additional topics not treated in the course. References to the appropriate sections in course book are given in conjunction to each lecture below. It is recommended to buy the book (e.g. at http://www.adlibris.se/) and you will be allowed to bring it with you to the exam.

Detailed Lecture Plan

A digital communication system can be described by the following system model, where the transmitter transports the information from the source, through the box marked Source Encoder, via the Channel Encoder to the Modulator, where it is finally transmitted over the Channel. The receiver contains corresponding boxes: Demodulator, Channel Decoder and Source Decoder.

All digital communication systems always include the boxes Modulator, Channel and Demodulator and thus these boxes are treated in the first half of the course. The modulation procedure can be divided into two parts: baseband modulation and bandpass modulation. Baseband modulation is always present in any communication system, whereas bandpass modulation is usually only present for wireless communications. Both methods are treated in the course.

Most communication systems also include the boxes Channel Encoder and Channel Decoder. These boxes are treated in the second half of the course. Channel coding can roughly be divided into three categories: block codes, convolutional codes and concatenated codes. All these categories are treated in the course.

The source encoder and source decoder have the task of compressing the information to a more compact format. They are present in some communications systems, but are not treated in this course. However, some type of information formatting, which may take place inside the source encoder or before the channel encoder, is usually required – and this topic is treated in the course.

Below follows a detailed plan of the contents of each lecture, an orientation its topic in the above figure together with suggested sections to read in the course book:

Topic: Course information, Introduction to digital communications, Review of signals and probability theory, Simple communication example.
Orientation: Covers simplified models of the Modulator, Channel and Demodulator boxes.
Suggested reading: Sklar 1.1–1.5.1, Appendix B.
Lecture #2. **Date:** March 27, 2008. **Time:** 10.15 – 12.00. **Place:** D415.
**Topic:** Formatting information, Sampling, PAM, Quantization, PCM, Baseband modulation, Random processes, Additive white Gaussian noise.
**Orientation:** Covers formatting, the Modulator (baseband modulation) and the Channel boxes.
**Suggested reading:** Sklar 2.1–2.8, 1.5.2–1.8, Appendix A.

Lecture #3. **Date:** March 31, 2008. **Time:** 8.15 – 10.00. **Place:** D415.
**Topic:** Matched filter receiver, Correlator receiver, Signal space, Base functions, Vector channel model.
**Orientation:** Covers the Demodulator (baseband modulation) box.
**Suggested reading:** Sklar 3.1–3.2.3, Appendix C.

Lecture #4. **Date:** April 2, 2008. **Time:** 10.15 – 12.00. **Place:** D415.
**Topic:** Vector channel model cont’d, MAP detection, ML detection, Error performance for binary signaling, Union bound.
**Orientation:** Covers the Modulator (baseband modulation), Channel and Demodulator (baseband demodulation) boxes and their performance.
**Suggested reading:** Sklar 3.2.4–3.2.5.

Lecture #5. **Date:** April 8, 2008. **Time:** 13.15 – 15.00. **Place:** D415.
**Topic:** Bandpass modulation with coherent detection: modulation methods, constellations, detection, mappings, symbol and bit energy, error performance.
**Orientation:** Covers the Modulator and the Demodulator (bandpass modulation and demodulation) boxes.
**Suggested reading:** Sklar 4.1–4.4, 4.7.1, 4.7.3. 4.8–4.10.

Lecture #6. **Date:** April 9, 2008. **Time:** 10.15 – 12.00. **Place:** D415.
**Topic:** Bandpass modulation with non-coherent detection, Intersymbol interference, Pulse shaping, Equalization.
**Orientation:** Covers the Modulator and the Demodulator (bandpass modulation and demodulation) boxes and also the Channel box (a more advanced model of the channel).
**Suggested reading:** Sklar 4.5–4.6, 4.7.2, 4.7.4–4.7.6, 3.3–3.5.

Lecture #7. **Date:** April 15, 2008. **Time:** 10.15 – 12.00. **Place:** D415.
**Topic:** Channel models, Channel capacity, Linear block codes: generator and parity check matrix, syndrome decoding, error detection and correction for the BSC.
**Orientation:** Covers the Channel Encoder and Channel Decoder (block codes) box as well as their performance.
**Suggested reading:** Sklar 6.2–6.5.

Lecture #8. **Date:** April 16, 2008. **Time:** 10.15 – 12.00. **Place:** D415.
**Topic:** Hard and soft decision decoding, Error detection versus error correction, MLSD and MAP decoding, Cyclic codes, Hamming codes.
**Orientation:** Covers the Channel Encoder and Channel Decoder (block codes) box as well as their performance.
**Suggested reading:** Sklar 6.6–6.9.

Lecture #9. **Date:** April 22, 2008. **Time:** 13.15 – 15.00. **Place:** D415.
**Topic:** Convolutional codes: connection representation, state diagram, tree diagram, trellis, the Viterbi algorithm.
**Orientation:** Covers the Channel Encoder and Channel Decoder (convolutional codes) box.
**Suggested reading:** Sklar 7.1–7.3.
Topic: Convolutional codes: free distance, transfer function, error performance, systematic codes, Interleaving, Decoding strategies.
Orientation: Covers the Channel Encoder and Channel Decoder (convolutional codes) box as well as their performance.
Suggested reading: Sklar 7.4–7.6, 8.2.

Topic: Design goals for communication systems, Modulation and coding trade-offs, Trellis coded modulation.
Orientation: Covers all the boxes treated in the course (including concatenated codes and coded modulation) and their trade-offs and performance.
Suggested reading: Sklar 9.1–9.11.

Topic: Course summary.
Orientation: Covers all the boxes treated in the course.
Suggested reading: Lecture slides.

Exercises:
When evaluation the performance of a digital communication system, closed form expressions or theoretical bounds can often be found. The exercises are opportunities to derive these and to solve other theoretical problems presented and described in the lectures. The exercises also help you to verify that you have understood the course content.

Note that the knowledge and understanding required from the lectures to solve the problems described in the exercises can be obtained either by attending the lectures or by reading the course book, but preferably by doing both.

Exercise #1. Date: March 27, 2008. Time: 15.15 – 17.00. Place: D415.
Topic: Review of signals and probability theory.
Prerequisites: Lecture #1 and Lecture #2.

Topic: Sampling, Quantization, Baseband modulation, Base functions, Receiver structure.
Prerequisites: Lecture #3.

Topic: Matched filter, Correlator, Signal space, Error performance, MAP and ML detection, Union bound.
Prerequisites: Lecture #4 and Lecture #5.

Topic: Bandpass modulation and detection.
Prerequisites: Lecture #6.

Topic: Intersymbol interference, Equalization, Linear block codes.
Prerequisites: Lecture #7.

Topic: Linear block codes, Convolutional codes.
Prerequisites: Lecture #8, Lecture #9 and Lecture #10.
Topic: Convolutional codes, Coding and modulation trade-offs, Trellis coded modulation.
Prerequisites: Lecture #11.

Topic: Review of the most important exercises as tools for performance evaluation of communication systems. Case: design of a communication system.
Prerequisites: All lectures.

Assignments:
Other times, the only way to establish the performance of a digital communication system, is to simulate it. The home assignments lets you implement different communication systems in Matlab in order to simulate and evaluate their performance.

Again the prerequisites can be fulfilled by attending the lectures or by reading the course book, but it is recommended to do both. A Matlab tutorial will be given to facilitate the home assignments.

Tutorial
Topic: How to evaluate the performance of a communication system using Monte-Carlo simulation in Matlab.

Topic: Simulation of a communications system using BPSK and QPSK modulation over an AWGN channel.
Prerequisites: Lecture #2, Lecture #3 and Lecture #4.

Topic: Simulation of a communications system using a Hamming (7,4) code and different decoding methods.
Prerequisites: Assignment #1, Lecture #7 and Lecture #8.

Examination
After completing the course you should be able to analyze and evaluate the performance of a digital communication system. This can be done by means of theoretical analysis or simulation. Both these things are evaluated in the examination of the course. The first through a written exam and the second through two approved home assignments.

Further, you should be able to elaborate on trade-offs between various parameters, such as bandwidth and signal power, based on system requirements, design limitations and requested error performance. This is tested mainly through the written exam, but also through the written report commenting the simulation results in the first home assignment.

Finally, you should be able to construct optimal receivers, describe some channel codes and apply and estimate the performance of the most common decoding algorithms. This is again tested mainly through the written exam, but also through the written report commenting the simulation results in the second home assignment.

The name of the course is Coding and Digital Communications and it is indeed divided into two parts, the first being digital communications and the second channel coding and decoding. The two home assignments correspond to these two parts as does the written exam.
The goal of the written exam is to test if you have understood the course content with enough depth to be able to apply it and use the theory to solve problems similar to those given during the exercises. Therefore you are allowed to bring the course book and print-outs of all the lecture slides to the exam – but not exercises or solutions.

Consequently:

- Examination is done in the form of a final written exam, as well as requirements on completed and approved home assignments.
- The course is graded based on the written exam using Fail, 3, 4, or 5 where the grade 3 is equivalent to a Pass.