MODERN DIGITAL MODULATION TECHNIQUES

ELEN E6909

Columbia University
Spring Semester-2008

Professor I. Kalet

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Course Website:

http://www.ee.columbia.edu/~jiantan/E6909/ELEN-E6909.htm

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The goal of this course is to acquaint the student with modern digital modulations and multiple access techniques, and with their applications in present and future mobile wireless, broadband wireless, satellite and wireline systems. At the end of the course, you should have enough background to understand both present and future concepts in the field.

We will spend much time at the beginning of the course discussing the channels over which we communicate, with special emphasis in this course, on the Rayleigh multipath fading channel and the twisted-pair channel. The Rayleigh fading channel is the channel model for wireless mobile and cellular communications, and the twisted-pair channel is the one used in ADSL and VDSL. Later on in the course, we will discuss the concept of space diversity or space multiplexing, e.g., MIMO and BLAST. This concept in combination with OFDM and coding is now being used to greatly improve the performance of many wireless communication systems.

As part of the course we will include a discussion of results from Shannon Information Theory. Shannon Theory is the theoretical basis for all communication systems. Information Theory basically tells us what are the bounds on communications. Our discussion of Information Theory will lead us into the topics of Multitone and OFDM modulations. We will discuss the information theory bounds on communications over Rayleigh fading channels, including a discussion of the MIMO concept, and space-time (Alamouti coding).

We will discuss almost all of the modulations presently being used, or being considered for use, in communication systems. Classic modulation techniques such as QAM and MPSK, will be described. We will also investigate multiple access techniques, a topic very closely related to modulation theory. We will place special emphasis on Orthogonal Frequency Division Multiplex Access (OFDMA) and Code Division Multiple Access (CDMA).

We will, as mentioned before, discuss relatively new concepts in modulation, antenna and space diversity, and multiple access techniques such as OFDM and UWB-OFDM. We will discuss the use of iterative decoding (Turbo-coding) to improve communication system performance. We will also describe the concept of adaptive modulation and coding, which is being used in many new communication systems, e.g., IEEE 802.11 (Wi-Fi), IEEE 802.16 (Wi-Max) and 3G-LTE.

We will emphasize the topic of multitone modulations such as DMT and OFDM. Discrete Multitone (DMT) is presently being used in the ADSL and VDSL.

OFDM, based on the multitone concept, is presently being used in broadband wireless access systems, e.g., IEEE 802.11a, IEEE 802.16, 3G-LTE and the UWB-OFDM WiMedia Alliance Standards. OFDM is also a candidate for use in Fourth Generation Mobile Systems.

Time permitting, we will discuss the Viterbi Algorithm. This algorithm may be used in the detection of a number of coding techniques and modulations, such as Trellis Coded Modulation (TCM), and in optimum detection of Continuous Phase Modulations. The Viterbi Algorithm is also used to decode convolutional codes and to overcome intersymbol interference.

We will discuss the topic of Continuous Phase Modulations (CPM). These modulations are used in mobile and satellite communications, e.g., GMSK is used in

GSM, DECT, GPRS and other systems as well. CPM modulations are constant-envelope modulations which allow the use of non-linear power-efficient transmitter amplifiers in cellular and space communications.

Again, we hope that by the end of the course you will have a better understanding of modern digital modulations and multiple access techniques.

I.Kalet
10 January 2008

PREREQUISITES

The student is expected to have studied the Course #ELEN E4702 at Columbia University, or its equivalent, in another university.
Basically this means that the student should have knowledge of the topics of signal space, optimum receiver structure and the matched filter, as presented in ELEN E4702.

If you have any questions about your pre-requisites please contact the instructor, Professor Irving Kalet at either of the two e-mail addresses shown below.
kalet@actcom.co.il
kalet@ee.columbia.edu

REFERENCES

The course has no formal reference book. A list of reference books and articles will be handed out during the first lesson. However, a number of books might be of some interest to the student. These books are listed below.

1. S. Haykin, "Communications Systems", J. Wiley and Sons, New York, Fourth Edition, 2001.

2. H. L. Van Trees, "Detection, Estimation and Modulation Theory -Volume I," McGraw-Hill, New York, 1965.

3. J. Proakis, "Digital Communications", Fifth Edition, McGraw-Hill, New York, 2007.

4. B. Sklar, "Digital Communications: Fundamentals and Applications-Second Edition", Englewood Cliffs, N.J., Prentice-Hall, 2001.

5. M.Schwartz, W.R. Bennett and S. Stein, "Communication Systems and Techniques", McGraw-Hill Co., New York, 1966 (Re-issued by IEEE Press, 1997).

6. A. R. S. Bahai, B. R. Saltzberg and M. Ergen, "Multi-carrier Digital Communications (Theory and Applications of OFDM)", Springer-Verlag, 2005.

The final mark for the course will be determined on the following basis:

Final Mark: Homework Assignments-15% (Required)

Final Project-85%

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Syllabus

Introduction

- A "Bit" of History
- Analog and Digital Modulations
- FDMA, TDMA, FDD, TDD-Definitions
- Major system descriptions-Wireline, Wireless, Satellite
- Tradeoffs

Communication Channels

- Telephone Channel
- Twisted-Pair Channel
- Multipath Fading Channel
  - Rayleigh Fading
  - Delay Spread and Frequency Selective Fading

Brief Review of Signal Space, Optimum Detection and Matched Filter

***Baseband Signaling** (This topic will not be covered in class-Student is expected to have studied this topic- However, some extra pages of notes, will be handed out to students, to help them review this topic!)

- Nyquist Signaling
- Optimum Filtering
- Linear Equalization
- Duobinary Signaling

Classical Modulations

- BPSK, QPSK, MPSK,QAM,BFSK,MFSK
- Definitions
- Optimum Detection
- Probability of Error

Rayleigh fading channel

- **Performance of Modulations on Fading Channel-SISO**
- **Antenna (and) Space Diversity**
- **Classic Antenna Diversity-SIMO**
- **Space Multiplexing**
- **MIMO, BLAST**

Brief survey of information theory

- **Why Code?**
- **The Famous Capacity Equation for a Perfectly Bandlimited Channel**
- **Bandwidth Efficiency versus Power Efficiency**
- **Capacity of the General Channel**
- **Why Multitone systems?**

Multitone Modulation

- **Multitone Concept**
- **Discrete Multitone (DMT) Implementation**

Orthogonal Frequency Division Multiplexing-OFDM

- **Definition**
- **Why use OFDM?**
- **Adaptive Modulation and Coding**
- **IEEE 802.11, 802.16, 3G-LTE-Radio Interfaces**
- **OFDMA**
- **OFDMA-Multiple Access Technique for the Fourth Generation?**

New Information Theory Bounds on Rayleigh Fading Channels

- **SISO, MIMO,SIMO, MISO**
- **Alamouti Coding**
- **Multi-User Diversity**

MSK-type Signaling (This topic has been moved from an earlier date)

- **QPSK, SQPSK and MSK-type Signals**
- **π/4-QPSK, EDGE-8PSK**
- **Adjacent Channel Crosstalk in QPSK, SQPSK, MSK**
- **Nyquist Signaling for BPSK, QPSK, etc**

The Viterbi Algorithm-Time Permitting

Trellis Coded Modulation- Ungerboeck Modulation-Time Permitting

- **WGN channels**
- **Interleaving for the Rayleigh channel**
- **Performance on Rayleigh channel**
- **The ISI channel**

Iterative Techniques (Time Permitting)

- **Turbo-Coding**
- **Iterative decoding for a channel with ISI**

Continuous Phase Modulation-CPM

- **Coherent Detection**
- **GMSK(GSM, DECT, CDPD), TFM, GTFM**
- **Adjacent Channel Crosstalk**
- **Optimum detection -trellis-coding gain**
- **Combined CPM and coding techniques- Iterative decoding**
- **Iterative decoding of CPM**
- **Adjacent channel interference**
- **FM receiver**

CDMA and WCDMA

- **The concepts and some important points**

THE PHYSICAL INTERFACE

- **OF IS-95 AND IMT 2000 WCDMA- Time permitting**

SUMMARY AND THE FUTURE