Digital Communication and Signal Processing

Spring Semester 2020

Course number: 227-0436-00L
Prof. Dr. Armin Wittneben (wittneben@nari.ee.ethz.ch)

Exercise session: Wednesday 08:15 – 10:00
Lecture: Wednesday 10:15 – 12:00

Assistants: Henry Schulten (schulten@nari.ee.ethz.ch)
Robert Heyn (heyn@nari.ee.ethz.ch)
Bharat Bhatia (bhatia@nari.ee.ethz.ch)

1. Course Summary

Digital communication systems are characterized by ever increasing requirements on data rate, spectral efficiency and reliability. Due to the huge advances in very large scale integration (VLSI) we are now able to implement extremely complex digital signal processing algorithms to meet these challenges. As a result, the physical layer (PHY) of digital communication systems has become the dominant function in most state-of-the-art system designs. In this course, we discuss the major elements of PHY implementations in a rigorous theoretical fashion and present important practical examples to illustrate the application of the theory. In Part I we treat discrete time linear adaptive filters, which are a core component to handle multiuser and inter-symbol-interference in time-variant channels. Part II is presented in form of a seminar, designed to give the students hands-on experience in modern cooperative wireless communication techniques. Based on different relaying strategies, we develop a theoretical and simulative analysis of multiuser networks. In Part III we cover parameter estimation and synchronization. Based on the classical discrete detection and estimation theory we develop digital algorithms for symbol timing and frequency synchronization.

2. Goals of the Course

A comprehensive presentation of modern modulation, detection and synchronization schemes and relevant aspects of signal processing enables the student to analyze, simulate, implement, and research the physical layer of advanced digital communication schemes. The course both covers the underlying theory (lectures) and provides problem solving and hands-on experience (seminar block and exercises).

3. References

[1] Oppenheim, A. V., Schafer, R. W., "Discrete-time signal processing", Prentice-Hall, ISBN 0-13-754920-2.

[2] Haykin, S., "Adaptive filter theory", Prentice-Hall, ISBN 0-13-090126-1.

[3] Van Trees, H. L., "Detection, estimation and modulation theory", John Wiley&Sons, ISBN 0-471-09517-6.

[4] Meyr, H., Moeneclaey, M., Fechtel, S. A., "Digital communication receivers: synchronization, channel estimation and signal processing", John Wiley&Sons, ISBN 0-471-50275-8.

4. Documentation

- Lecture slides
- Supplementary summary for each lecture (self-contained)
- In the lecture we will use the blackboard intensively for derivations and examples
- Most of the books are available as e-books; purchase of the books is not necessary

5. Exercises

In the exercises, we will primarily treat interesting practical applications of the theory.

6. Central Element

ATTENTION: The student presentations in Part II are graded on a pass/fail basis. To be admitted to the final oral exam of the course it is required to have passed the seminar once (i.e. if a student fails in the final exam it is not necessary to once more pass the seminar).

7. Exam

The exam is oral and lasts 30 minutes. It can be taken in English or German.

8. Detailed Course Schedule and Overview

Each week is split up into two blocks by default:

- 08:15 – 10:00: Interactive discussion of last week's exercise
- 10:15 – 12:00: Lecture

The course will deviate from this scheme where necessary, e.g. for the seminar.

Part I: Linear Adaptive Filters for Digital Communication

Part II: Seminar Block - The Relaying Challenge

Part III: Parameter Estimation and Synchronization

Week	Time	Session	Topic
Week 1 19.02.	8 am - 10 am	**Lec.1**	**Introduction** Course outline and motivating examples
	10 am - 12 pm	**Lec.2/1**	**FIR filter design**
Week 2 26.02.	8 am - 10 am	**Ex.0**	**Basics of Digital Communications**
	10 am - 12 pm	**Lec.2/2**	**2 hours: FIR filter for temporal and spectral shaping** Oppenheim/Schafer: discrete time signal processing; chapter 7 (filter design techniques), pp. 465-501 design by windowing Kaiser window method optimum approximations of FIR filters: the Parks-McClellan algorithm
Week 3 04.03	8 am - 10 am	**Ex.A**	**FIR filter design**
	10 am - 12 pm	**Lec.3**	**Wiener filters: Haykin chapter 2; pp 94-126** principle of orthogonality Wiener-Hopf equation linearly constrained minimum-variance filter generalized sidelobe cancellers
Week 4 11.03.	8 am - 10 am	**Ex.B**	**Wiener filter**
	10 am - 12 pm	**Lec.4**	**Method of steepest descent: Haykin chapter 4; pp. 203-223** steepest-descent algorithm applied to Wiener filter stability transient behaviour
Week 5 18.03.	8 am - 10 am	**Ex.C**	**Method of steepest descent**
	10 am - 12 pm	**Lec.5**	**Least mean square adaptive filters** Haykin chapter 5; pp. 231-238; 257-274 LMS algorithm normalized LMS example: generalized sidelobe canceller statistical LMS theory

Week	Time	Session	Topic
Week 6 25.03.	8 am - 10 am	**Ex.D**	**Least mean square adaptive filters**
	10 am - 11 pm	**Lec.6**	**Seminar Introduction Lecture** Basic concepts of amplify-and-forward (AF) relaying
	11 am - 12 pm	-	**Introduction of project tasks 1 and 2**
Week 7 01.04.	8 am - 9 am	-	**Tasks 1+2: wrap up**
	9 am - 10 am	**Lec.7**	**Introduction of Advanced Tasks** a) Multiple AF relays b) Two-Way relaying c) Decode-and-forward (DF) relaying **Assignment of students to tasks**
	10 am - 12 pm	-	**Individual Work and Q&A**
Week 8 08.04.	8 am - 12 pm	-	**Individual Work and Q&A**
Week 9 15.04.		-	**Easter holidays**
Week 10 22.04.	8 am - 12 pm	-	**Student presentations** 15 min each
Week 11 29.04.	8 am - 12 pm	-	**Spare time for presentations**
		Lec.8	**Discrete detection theory** (van Tree chapter 2); pp.19-52 Bayes criterion; likelihood ratio test Neyman-Pearson criterion receiver operating characteristic M hypotheses
Week 12 06.05.	8 am - 10 am	**Ex.E**	**Detection theory**
	10 am - 12 pm	**Lec.9**	**Discrete estimation theory** (van Tree chapter 2); pp. 52-74 Bayes estimation of random parameters nonrandom parameter estimation, Cramer-Rao bound

Week	Time	Session	Topic
Week 13 13.05.	8 am - 10 am	**Ex.F**	**Estimation theory**
	10 am - 12 pm	**Lec.10**	**Synthesis of synchronization algorithms** (Meyr, chapter 5); pp.271-311 (compressed) derivation of ML synchronization algorithms: decision directed, non data aided; Maximum search algorithms, error feedback systems NDA timing parameter estimation DD timing parameter estimation, timing error feedback systems
Week 14 20.05.	8 am - 10 am	**Ex.G**	**Timing estimation**
	10 am - 12 pm	**Lec.11**	**Frequency estimation** (Meyr, chapter 8); pp. 445-472 classification of frequency estimation algorithms frequency estimator operating independently of timing information: spectrum analysis, phase increments frequency error feedback systems, tracking analysis
Week 15 27.05.	8 am - 10 am	**Ex.H**	**Frequency estimation**
	10 am - 12 pm	**Lec.12**	**Summary**