Signal and Information Processing Laboratory

Prof. Dr. A. Lapidoth, Prof. Dr. H.-A. Loeliger, Dr. K. Heutschi

ANNUAL REPORT

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Research Period 2005

Teaching Period 2004/2005

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Foreword

For many members of our Institute, and for various reasons, 2005 proved taxing at times. In particular, the construction work during the summer brought many inconveniences. However, it also brought us to the mountains: in order to escape the noise and the dust, the Institute was moved for a week to Sedrun (Graubünden), where we had a marvelous time — and productive, too! We also had two visitors there: Ralf Kötter (from Illinois) and Andrew Eckford (from Toronto), whose stimulating presentations completed the perfection of that week.

The inconveniences of the year were particularly felt by our support staff: Francesco Amatore, Thomas Schärer, Max Dünki, Patrik Strebel, and our secretaries, Bernadette Röösli and Marion Brändle. We particularly wish to thank them for doing an excellent job despite the difficulties.

An unusually large number of Ph.D. students finished their dissertations and left us in 2005: in spring, Patrick Merkli and Markus Hofbauer; in summer, Stefan Moser (who had finished his dissertation in 2004); in fall, Sascha Korl; and in December, Daniel Hösli and Justin Dauwels. Only 8 of the 14 Ph.D. students of January 2005 remain! However, we also welcomed two new additions: Jonas Biveroni (from ETH Zurich) and Murti Devarakonda (from India).

A special pleasure in 2005 was Frank Kschischang (from Toronto) and Nikolai Nefedov (from Nokia, Helsinki) spending several months with us.

As in every year, we have learned much, and we look forward to learn more.

April 2006, Hans-Andrea Loeliger

Contents

1. Personnel

Professor for Information Theory:

Prof. Dr. Amos Lapidoth

Professor for Signal Processing:

Prof. Dr. Hans-Andrea Loeliger

Adjunct Lecturer: **Dr. Kurt Heutschi**

Secretaries: **Mrs. Bernadette Röösli**
Mrs. Marion Brändle

Technical Supervisor: **Dr. Max Dünki**

Research Assistants:	**Jonas Biveroni**	Dipl.El.Eng.	since 16.05.05
	Justin Dauwels	Dipl.Phys.Eng.	left on 31.12.05
	Murti Devarakonda	Dipl.El.Eng	since 01.07.05
	Matthias Frey	Dipl.El.Eng.	
	Markus Hofbauer	Dipl.El.Eng.	left on 30.04.05
	Daniel Hösli	Dipl.El.Eng.	left on 31.12.05
	Junli Hu	Dipl.El.Eng.	
	Tobias Koch	Dipl.El.Eng.	
	Volker Koch	Dipl.Eng.	
	Sascha Korl	Dipl.Eng.	left on 31.10.05
	Patrick Merkli	Dipl.Eng.	left on 31.03.05
	Natalia Miliou	Dipl.El.Eng.	
	Stefan Moser	Dipl.El.Eng.	left on 30.06.05
	Maja Ostojic	Dipl.El.Eng.	
	Stephan Tinguely	Dipl.El.Eng.	
	Wigger Michèle	Dipl.El.Eng.	

Technical Staff:	**Francesco Amatore**	
	Thomas Schärer	
	Patrik Strebel	El.Eng.HTL

Academic Guests: (see 6.1 for report of activities)

Prof. Emre Telatar,	EPF Lausanne, Switzerland.	17.01. – 18.02.05
Prof. F. Kschischang	University of Toronto, Toronto, Canada	01.02. – 30.04.05
Dr. Shraga Bross,	Technion, Haifa, Israel	29.06. - 03.07.05
Prof. Allen Lindgren	University of Rhode Island, Kingston, USA	01.07. - 15.08.05
Andrew Eckford	University of Toronto, Toronto, Canada	08.08. – 14.08.05
Dr. Eran London	Hebrew University, Jerusalem, Israel	17.08. - 31.08.05
Dr. Nikolai Nefedov	Nokia Research Center, Helsinki, Finland	16.09. – 31.12.05
Dr. Shraga Bross	Technion, Haifa, Israel	22.11. - 16.12.05
Dr. Jonathan Yedidia	Mitsubishi Electric Research Labs, Cambridge, USA	27.11. - 02.12.05

2. Teaching

2.1 Lectures

Sem.	Instructors	Title	ETH-No.
7th	Prof. H.-A. Loeliger	Signal and Information Processing	227-0427
5th	Prof. H.-A. Loeliger	Stochastic Models and Signal Processing	227-0101
8th	Prof. H.-A. Loeliger	Algebra, Codes, and Signal Processing	227-0416
5/7th	Prof. A. Lapidoth	Applied Digital Information Theory I	227-0417
6th	Prof. A. Lapidoth	Information Transfer	227-0104
8th	Dr. H.P. Schmid	Analog Signal Processing and Filtering	227-0468
7th	Dr. K. Heutschi	Acoustics I	227-0477
8th	Dr. K. Heutschi	Acoustics II	227-0478

2.2 Practica

5/6th	Practica	Laboratory for "Fundamentals in Electrical Engineering"	227-0095
1st/2nd	D. Hösli, M. Wigger	Cellular Automata in Matlab	PPS
3rd/4th	V. Koch, M. Ostojic S. Korl	Practical Signal Processing using a DSP	PPS
2nd/3rd	Th. Schaerer	EMG Biofeedback Device	PPS

2.2 Semester Projects and Diploma Theses

During the winter semester 2004/05 and summer semester 2005, 8 Semester Projects (8 candidates) and 3 Diploma Theses (4 candidates) were carried out.

Candidates	Title	Supervisor
Semester Projects WS 2004/05		
Christian Zimmermann	Entwicklung und Implementierung von A-Priori-Modellen zur Zerlegung von EMG-Signalen	V. Koch
Pascal Wildbolz	Seismosomnography: Heartbeat Detection from Pressure Sensors	V. Koch S. Korl M. Brink/IHA
Markus Wenk	Segmentierung vom EMG-Signalen	V. Koch
Vedran Galijas	Application of Generalized Belief Propagation to LFSR State Estimation	J. Dauwels M. Ostojic
Semester Projects SS 2005 (8th Semester)		
Georg Böcherer	Adaption von Filterkoeffizienten in einem EMG-Zerlegungsprogramm	V.Koch
Wenjie Xu	Firm Lower Bounds on the Capacity of Non-Coherent Fading Channels	T. Koch S. Moser
Yves Kunz	Evaluation verschiedener EMG-Signal-Zerlegungsalgorithmen	V. Koch
Tunc I.M. Parmaksiz	Numerical Examination of an Achievable Rate Region of the Multiple Access Gel'fand-Pinsker Channel	M. Wigger T. Koch
Diploma Theses WS 2004/5		
Marco Diefenbacher Roland Abt	Akustische Verkehrsklassierung	D. Lippuner A. Kälin
Diploma Theses SS 2005		
Johan Peterson	Biomedical Signal Processing: Estimation and Tracking of Filter Coefficients in Eletromyography	V. Koch
Daniel Furrer	Design of a Big Analog Decoder	M. Frey

3. Research

3.1 Research Areas

The Signal and Information Processing Lab focusses on research and teaching in the following areas:

Information Theory

Current topics:

- The capacity of non-coherent multiple-antenna fading channels
- The capacity of single-user and multi-user coherent MIMO Rician fadingchannels
- Multiple-access channels with feedback
- Sending correlated sources over noisy networks
- Multicasting with transmitter side-information
- Multiple-antenna fading broadcast channels
- Duality theory for error exponents
- Numerical computation of information rates and channel capacity for channels with memory

Digital Signal Processing

Current topics:

- Fundamentals and applications of graphical models (factor graphs)
- Decomposition of electromyographic signals
- Channel estimation and equalization in communications receivers
- Clock noise and synchronization in communication receivers

Analog Signal Processing

Current topics:

- Decoding of error correcting codes
- Digital-to-analog conversion and analog-to-digital conversion

3.2 Current Research Projects

Information Theory and Coding

Robust Communication over Fading Channels

We study the robustness of the information theoretic analysis of fading channels with respect to the assumptions on the fading law. Of special interest to us is the pre-log, which is defined as the limiting ratio of channel capacity to the logarithm of the signal-to-noise ratio (SNR).

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Professor: Dr. Amos Lapidoth

Multicasting with Transmitter Side Information

We consider sending a common message to two (or more) receivers. The channels from the transmitter to each of the receiver are controlled by "states" that are all known to the transmitter (but not receivers) a-causally. We investigate the maximal rate at which reliable communication is possible.

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Professor: Dr. Amos Lapidoth

Transmitting a Gaussian Source on the Gaussian Channel

We revisit the classical problem of sending a memoryless Gaussian source over the additive discrete-time Gaussian noise channel. We propose a continuum of asymptotically optimal schemes that include, as special cases, the classical source-channel separation approach and Goblick's uncoded scheme.

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Professor: Dr. Amos Lapidoth

Sending a Bi-Variate Gaussian Source over the Gaussian MAC

We study a distributed communication problem where each component of a bi-variate Gaussian source is observed by a different user. The users communicate to a single receiver via a Gaussian multiple-access channel. We study the optimal achievable distortions. Source-channel separation is sub-optimal.

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On the Robustness of Fading MIMO Broadcast Channels

A fading broadcast channel is considered where the transmitter employs two antennas and each of the two receivers employs a single receive antenna. It is demonstrated that the achievable throughput is greatly reduced if the transmitter only has an approximate estimate of the fading realization.

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Professor: Dr. Amos Lapidoth

On the Feedback Capacity of Discrete-Time Multi-Access Channels

An achievable region for the two-user discrete memoryless multiple-access channel with noiseless feedback is derived. The proposed region includes the Cover-Leung region, with the inclusion being for some channels strict.

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Professor: Dr. Amos Lapidoth

On the Computational Cut-off Rate for Rayleigh and Rician Fading Channel without Receiver Side Information

We demonstrate how duality theory can be used to derive upper bounds on the channel cut-off rate. For the Rician fading channel, we obtain the high signal-to-noise ratio (SNR) expansion of the cut-off rate.

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Professor: Dr. Amos Lapidoth

Duality-based Bounds on Error Exponents

We study a dual expression for the random coding error exponent where the maximization over input distributions is replaced with a minimization over output distributions. Using this technique we can derive UPPER bounds on the random coding error exponent and on the sphere packing exponents.

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Professor: Dr. Amos Lapidoth

On the capacity of Multi-Input Multi-Output Rician Fading Channels with Perfect Side-Information

We prove that the capacity of a MIMO Rician channel with perfect receiver side-information is monotonic in the singular values of the mean matrix. This result is derived for the optimal power allocation scheme and not only for the uniform one.

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Professor: Dr. Amos Lapidoth

Isotropic Gaussian Rates for Multi-Input Multi-Output Rician Fading Channels with Perfect Side-Information

We prove that the mutual information corresponding to an isotropically distributed Gaussian input to a Rician multi-antenna channel with perfect receiver side information is monotonic in the singular values of the mean matrix.

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The Capacity Region of the Poisson Multiple-Access Channel with Noiseless Feedback

The Poisson multiple-access channel (MAC) models a many-to-one optical communication system. Its capacity region has recently been computed by Lapidoth & Shamai. The purpose of the present research is to investigate the gains (in capacity) afforded by noiseless delayless feedback from the receiver to the transmitters.

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On MIMO Rician Fading Channels with Feedback

In this project we study the capacity of a multiple-transmit multiple-receive system operating over Rician fading channels. The transmitter is assumed to employ spatially and temporally white Gaussian inputs, and the receiver is assumed to possess perfect knowledge of the realization of the fading process. We prove that the mutual information corresponding to such scenarios is componentwise monotonic in the vector of the singular-values of the mean matrix. The dependence on the variance of the fading is under current investigation.

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Bounds on the Capacity of Fading Channels

The goal of this project is to obtain accurate estimates of the capacity of fading channels, which are typically encountered in mobile wireless communication. The capacity of such channels serves as the ultimate upper bound on the rates at which reliable communication is possible. Moreover, with the advent of Turbo-codes, one can often approach these rates with practical coding schemes. Since the exact calculation of capacity is intractable, one must resort to upper and lower bounds. To this end we have developed a new technique to derive upper bounds on the capacity of general channels, and we have applied this technique to fading channels. Together with some lower bounds that we have found for such channels, we are now in a position to understand the behavior of the channel capacity for the large family of multi-antenna fading channels with or without memory and with or without side information related to the fading realization. We have further developed the concept of “the capacity achieving input distributions that estimates of channel capacity” and showed how his concept can be used to derive asymptotic estimates of channel capacity. Using this paradigm we were able to derive a high-SNR asymptotic expansion for the capacity of a number of fading models. In particular we have solved the single-input single-output (SISO) case (with memory) as well as the multi-input single-output (MISO) case.

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Digital Signal Processing

Basics of Graphical Models

Most of our research is somehow related to graphical models (factor graphs) and to message passing algorithms on such graphs. We are interested in a wide variety of conceptual and algorithmical issues.

Examples include:

- applied signal processing by message passing algorithms
- adaptation and learning
- local formulation of Kalman filtering, expectation maximization, particle methods, etc.
- improved message passing with structured summaries
- electrical networks and other physical systems as factor graphs
- Fourier and Lagrange duality

Index Terms: graphical models, factor graphs, inference, Kalman filtering, particle filter, Monte Carlo methods, duality.

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Professor: Dr. Hans-Andrea Loeliger

Decoding and More in Analog VLSI

Modern iterative (“turbo”) decoders consist of “probability gates” that can be directly implemented in analog integrated circuits. We are investigating such circuits and their application to decoding and to related signal processing tasks.

Error correcting codes may be represented by factor graphs, and iterative probability propagation decoding operates by message passing along the edges of the graph. Back in 1998, we discovered that the factor graph of many error correcting codes (including trellis codes, turbo codes, and low-density parity check codes) can be translated directly into analog transistor circuits that operate in continuous time and in parallel. Such analog decoders are composed of "probability gates", where currents represent probabilities and voltages represent logarithms of probabilities (or of probability ratios). Such analog decoders might allow the use of error correcting codes in applications where digital decoders would be too slow or would consume too much power.

We have built simple decoder chips as well as a collection of probability gates as individual integrated circuits; the latter allow us to put together and to study several simple decoders on the breadboard level.

More recently, we have extended analog probability propagation to synchronization. We have demonstrated that a clockless continuous-time circuit can synchronize to a properly designed periodic waveform, even in the presence of substantial noise. This work also sheds some light on the connection between statistical state estimation and the subject of "entrainment" of dynamical systems.

Index Terms: analog decoder, nonlinear circuits, factor graphs, joint decoding and equalization, synchronization, entrainment.

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Contact Person 3: Patrick Strebel, Room ETF D109, Phone 044 632 6687, Email: strebel@isi.ee.ethz.ch

Professor: Dr. Hans-Andrea Loeliger

Decomposition of EMG Signals

Muscle contraction produces electrical activity that can be measured and analyzed. An electromyographic (EMG) signal consists of contributions from several sources (motor units) which discharge repeatedly producing spikes called motor unit action potentials (MUAPs). We study the decomposition of EMG signals into their components.

Index Terms: EMG, signal decomposition, source separation, factor graphs.

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In Collaboration with: Dr. T. Läubli, Institut für Hygiene und Arbeitsphysiologie (IHA), ETH Zurich

Professor: Dr. Hans-Andrea Loeliger

Decoding and Equalization

We study iterative ("message passing") methods for joint decoding and equalization.

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Professor: Dr. Hans-Andrea Loeliger

Information Processing by Chaotic Dynamical Systems

We study the use of dynamical systems as error correcting codes and decoders of such codes. We have recently demonstrated clockless analog circuits that lock to a specific pseudo-random periodic signal even if that signal is covered by much noise.
We now aim at the design of dynamical systems (and their realization as electronic circuits) that can act as decoders for error correcting codes. A first goal of the project is to produce families of chaotic systems with high-dimensional state spaces with well-understood properties.

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Professor: Dr. Hans-Andrea Loeliger

3.3 Completed Dissertations

HOFBAUER Markus	Optimal Linear Separation and Deconvolution of Acoustical Convolution Mixtures	
	ETH Diss. Nr. 15989	
	Referee:	Prof. Dr. H.-A. Loeliger
	Co-referees:	Dr. S. Launer, Phonak, Stäfa
		Dr. M. Joho, Phonak, USA
MERKLI Patrick	Message-Passing Algorithms and Analog Electronic Circuits	
	ETH Diss. Nr. 15942	
	Referee:	Prof. Dr. H.-A. Loeliger
	Co-referee:	Prof. Dr. Schlegel, Canada
KORL Sascha	A Factor Graph Approach to Signal Modelling, System Identification and Filtering	
	ETH Diss. Nr. 16170	
	Referee:	Prof. Dr. H.-A. Loeliger
	Co-referees:	Prof. A. Lindgren, USA
		Dr. S. Launer, Phonak, Stäfa
HOESLI Daniel	On the Role of the Line-of-Sight Component in Coherent MIMO Ricean Channels	
	ETH Diss. Nr. 16284	
	Referee:	Prof. Dr. A. Lapidoth
	Co-referee:	Prof. A. Tulino, Italy
DAUWELS Justin	On Graphical Models for Communications and Machine Learning: Algorithms, Bounds and Analog Implementation	
	ETH Diss. Nr. 16365	
	Referee:	Prof. Dr. H.-A. Loeliger
	Co-referees:	Dr. J. Yedidia, MERL
		Prof. Moeneclaey, Gent
		Prof. Shun-ichi Amari, Japan

HOFBAUER Markus

Optimal Linear Separation and Deconvolution of Acoustical Convolutive Mixtures

ETH Diss. Nr. 15989 (Referee: Prof. Dr. H.-A. Loeliger)

This thesis addresses the problem of the optimal inversion of a linear acoustical convolutive mixing process by means of multi-channel linear filtering. In most real world acoustical scenarios, a number of sound emitting sources are encountered, which may be simultaneously active. When perceiving the sound of these sources by direct listening or from microphone recordings, the original undistorted signal of a single source is not accessible, but merely a mixture of the superposed sources. Furthermore the source signals are reverberated due to multipath propagation within the environment. Propagation and mixing of the sources is characterized by a convolutive mixing process.

Reverberation, the superposition of several sources and additive background noise account for a reduced speech intelligibility in case of speech sources, and for a reduced sound fidelity in general. Several algorithms exist which aim at a separation and deconvolution - i.e. dereverberation - of the sources, the most prevalent linear techniques being beamforming- and blind algorithms. However, in adverse and highly reverberant environments the performance of these methods is limited and it is not clear, whether the limitations arise due to the algorithm's insufficiency, or if the setup and environment fundamentally constrains the performance of any linear method to be bounded.

A theoretical and practical “best-case” performance analysis for linear methods in the least-squares (LS) optimal sense is presented in this thesis. The term “best-case” implies that the convolutive mixing process is known, i.e. the set of AIRs are given. Insights gained by the analysis may serve as an upper bound for any practical linear algorithm with less knowledge.

AIRs in real world environments are complex in the sense that they are typically non-minimum phase, with lengths of thousands of taps. A direct single-channel inversion of an AIR requires a non-causal filter of infinite length (IIR), and is not feasible. Hence, it is not apparent that effective inverse filters of finite lengths (FIR) can be determined for real world AIRs, and be reasonably applied.

In this thesis it is demonstrated that in the multi-channel case and under certain conditions, a perfect separation and deconvolution is achievable with FIR filters in theory and praxis, even in adverse environments. In the more applicable general case, a LS-solution still yields a significant source enhancement.

A versatile framework for a “best-case” analysis is developed, to determine the filters which yield a LS-optimal inverse of the convolutive mixing process. Each source is embedded in a block-Toeplitz matrix equation (BTME) according to its propagation model.

A general weighing function allows to control the filtering task: the BTME can be arbitrarily weighted to specify confined problems, and to influence the LS-solution as desired. Lower bounds for the filter lengths and conditions are derived that guarantee an exact deconvolution and separation, or either one at a time.

A measurement system is established, which allows the measurement of the AIRs, and the assessment of the “best-case” performance with a maximum of eight sources and eight sensors, and background noise. The insights of the theoretical analysis are confirmed by real world experiments in representative environments - a quiet office, a noisy cafeteria and a highly reverberant hallway. It is demonstrated that inverse filtering `really works' in adverse real world conditions. Dependencies on important eligible parameters, like the system latency and filter length, are analysed. An AIR sensitivity analysis shows the importance of an accurate AIR estimation.

The presented “best-case” analysis framework and measurement system may be utilized when designing an application or source enhancement algorithm: for a particular setup and environment, parameters can be optimized and results assessed in listening test.

Finally, the analysis framework reveals the complexity of the convolutive mixing process in a particular environment, and imparts a deeper intuitive understanding thereof.

Keywords: convolutive mixtures, block Toeplitz/Sylvester matrix, multi-channel, blind source separation, deconvolution, dereverberation, beamforming, noise suppression, speech enhancement, acoustic impulse-response.

MERKLI Patrick

Message-Passing Algorithms and Analog Electronic Circuits

ETH Diss. Nr. 15942 (Referee: Prof. Dr. H.-A. Loeliger)

Solving decision problems by means of message-passing algorithms defined on graphical models has received increasing attention in recent years. The origin of this approach lies in coding theory and can be traced back to work by Gallager in 1963 and Tanner in 1981. The actual breakthrough though was marked by the discovery of turbo codes in 1993, coinciding with advances by Wiberg in graphical modeling of codes. Subsequently, the idea of algorithms defined on graphs found its way into various fields of signal processing as a systematic and unifying method for deriving detection algorithms.

Often, message-passing algorithms are computationally demanding, and their implementation in hardware requires a considerable amount of resources (both, in terms of power and circuit area). Therefore, the idea emerged to use analog electronic circuits for implementing message-passing algorithms. The hope is that such highly application-specific circuits allow to obtain fast and power-efficient implementations. Amongst other things, this hope is based on a natural mapping of primitives of message-passing algorithms to very simple non-linear transistor circuits.

The present thesis is a collection of new methods and ideas in the vast domain of message-passing algorithms and their implementation as analog electronic circuits. Therefore, the work does not represent a complete discourse, but rather a contribution to an ongoing research effort.

In the first part of this work we start by giving a short review of how to model a decision problem by means of factor graphs, a special type of graphical model. Subsequently, we show that the summary-product algorithm - a very popular message-passing algorithm defined on the factor graph - can be used for solving the underlying problem. It is well known that the summary-product algorithm operating on a cycle-free graph provides the desired results. However, on a graph with cycles the algorithm becomes iterative and gives back only approximate results. It often occurs that the sub-optimal algorithm on a loopy graph shows the crucial advantage of being of much lower complexity compared to the computations required to obtain the optimal solution. On the other hand, the approximations provided by the sub-optimal algorithm can be arbitrarily bad, especially if the graph has short cycles. In a next step, we therefore present two methods for devising message-passing algorithms on a loopy graph, which allow to trade off complexity against accuracy in a flexible way. In this context we propose a message update rule for so-called structured messages, which subsumes the well-known sum-product update rule. The application and the effect of the proposed methods is illustrated by means of an example of synchronization on noisy linear-feedback shift register sequences.

In the second part of this thesis we move on to analog circuits. After a short introduction to well-established basics, we propose a new fundamental building block, which enables the implementation of a division operation. This extension of implementable operations seems to naturally match the intermediate-complexity algorithms mentioned previously. This is because the message update computations for such algorithms can contain division operations. Finally, we

present an extensive collection of measurement results for two analog integrated implementations of message-passing algorithms, built up solely with MOS transistors. Both networks implement decoding algorithms, the first circuit for a binary [8,4,4] extended Hamming code and the second circuit for a binary [16,5,8] Reed-Muller code. Error rate performance curves for both decoders and for various operating conditions are compared to ideal discrete-time simulation results of the corresponding algorithms. Additionally, we offer a detailed characterization of the transistors used for implementing the Hamming code decoding network.

Keywords: Factor graphs, message-passing algorithms, summary-product algorithm, sum-product algorithm, structured summary, structured message, analog non-linear transistor circuits, translinear circuits, multiplication matrix, division/multiplication matrix, analog iterative decoder.

KORL Sascha

A Factor Graph Approach to signal Modelling, System Identification and Filtering

ETH-Diss. Nr. 16170 (Referee: Prof. Dr. H.-A. Loeliger)

This thesis concerns model-based signal processing. In model-based signal processing a class of signals is described by a stochastic state-space model, in general with unknown parameters. The aim of signal estimation (filtering, denoising, parameter estimation, etc.) is to determine the 'best' signal (e.g. the most probable signal) out of that class given a set of observations.

Just a few years ago model-based signal processing was still limited to a restricted class of models. There are models with finite state-space (hidden Markov models) on the one hand and there are linear Gaussian state-space models (Kalman filter and related algorithms) on the other hand. For a multitude of applications those model types are insufficient.

Factor graphs open up new possibilities in this matter. First, factor graphs (and similar graphical models) provide a framework for the systematic and consistent derivation of classic model-based algorithms. Second, factor graphs permit and encourage the combination of different classic approaches for complex models with many unknown parameters; and third, factor graphs provide a framework for the systematic development of completely new algorithms.

A factor graph is used to represent the factorisation of the probability density function of the signal model. Inference is performed by passing messages along the edges of the graph. Messages can be interpreted as summaries of subgraphs, therefore the inference algorithm is called summary-propagation algorithm. We derive different message types justified by different representations of such summaries. In a first step all messages in the graph are Gaussian. Several classic algorithms can be solely represented by Gaussian essages: Kalman filtering and smoothing, linear prediction and recursive least squares adaptive filters.

The more interesting and also more complicated case is when messages appear which are not Gaussian. Different techniques are proposed in this thesis to deal with such messages. For example, complicated messages can be represented with lists of samples of the exact message, which leads to particle-filter-type algorithms, or as gradients of the exact message, which leads to gradient descent (or hill climbing) methods.

The expectation maximisation (EM) algorithm is a powerful parameter estimation algorithm which has been used by many people in different applications. In this thesis we show how the EM algorithm can be stated as message passing on a factor graph. A simple message update rule is given, which allows the development of reusable building blocks. In varying the message update schedule, different new variants of the EM algorithm can be devised. Finally, a local message update rule arising from the combination of the ideas of summary-propagation and EM is given.

The utilisation of the proposed techniques is demonstrated by means of the autoregressive model with unknown coefficients, unknown input noise variance and unknown observation noise variance.

Keywords: Graphical models, factor graphs, summary-propagation algorithm, belief propagation, message passing, expectation maximisation, signal modelling, system identification, autoregressive model, Kalman filter.

HOESLI Daniel

On the role of the Line-of-Sight Component in coherent MIMO Ricean Channels

ETH-Diss. Nr. 16284 (Referee: Prof. Dr. Amos Lapidoth)

This thesis considers a memoryless baseband model of a multiple-input multiple-output (MIMO) flat-fading channel. The fading matrix is assumed to be known at the receiver and has a Ricean distribution, i.e., it is the sum of a random matrix whose entries are independent and identically distributed according to a complex zero-mean unit-variance circularly symmetric Gaussian distribution, and a deterministic matrix D called the line-of-sight (LOS) component. We focus on multivariate zero-mean circularly symmetric Gaussian inputs since they achieve the capacity of such channels under an average input power constraint. These inputs are uniquely determined by their covariance matrix.

In a first part, we analyze optimal input covariance matrices. We show that the eigenvectors of an optimal covariance matrix coincide with those of the Hermitian product D'D. Since no closed-form expression for the eigenvalues are known, we also analyze the performance of an equal input power distribution over the antennae, i.e., isotropic Gaussian inputs. At high signal-to-noise ratios (SNR) such inputs are shown to be asymptotically optimal if the number of transmit antennae does not exceed the number of receive antennae. In the other case, we show that if D is of unit rank, isotropic Gaussian inputs are asymptotically suboptimal as the SNR tends to infinity. We also provide an iterative algorithm to find the optimal input power allocation numerically. This procedure, which is based on the Blahut-Arimoto algorithm, is general in the sense that it finds an optimal input covariance matrix for arbitrary fading distributions. Finally, isotropic Gaussian inputs are proved to achieve the capacity of a MIMO Ricean compound channel where the LOS matrix is from a unitarily unconstrained set but unknown to the transmitter.

The second part of this thesis investigates the dependence of Gaussian input information rates on the LOS matrix. Such rates can be expressed in terms of an expectation with respect to a non-central Wishart matrix---the influence of the LOS component is, however, not obvious from that expression. We demonstrate that for a fixed input covariance matrix the induced mutual information is monotonically increasing with respect to the positive semi-definite ordering on the Hermitian matrix D'D. In fact, this result is a consequence of the monotonicity of the outage probability of the channel and has applications in multiple-access and physically degraded relay channels. The monotonicity result leads to a natural pre-order on MIMO Ricean channels through their LOS matrices. This is also supported by a converse result. Our monotonicity result comes in a particularly appealing form in the special cases of isotropic Gaussian input information rates and channel capacity, which are both shown to be monotonic in the singular values of D.

Keywords: channel capacity, compound channel, fading, isotropic, line of sight, monotonicity, MAC, MIMO, non-central Wishart distribution, outage probability, power allocation, physically degraded, relay, Ricean, signaling directions.

DAUWELS Justin

On Graphical Models for Communications and Machine Learning: Algorithms, Bounds, and Analog Implementation

ETH-Diss. Nr. 16365 (Referee: Prof. Dr. H.-A. Loeliger)

This dissertation is about a specific problem and about general methods. The specific problem is carrier-phase synchronization, which appears in the context of digital communications. The general methods are message-passing algorithms operating on graphical models, in particular, factor graphs. We consider applications of such algorithms in the context of statistical inference (as in communications, signal processing, and machine learning), statistics, information theory, and the theory of dynamical systems (such as analog electronic circuits).

The primary motivation for this work was (1) to analyze the degradation of digital communications systems due to oscillator non-idealities; (2) the development of synchronization algorithms that minimize this performance degradation.

Clocks are ubiquitous in digital communications systems; real-life clocks are noisy, i.e., their signals are not perfectly periodic, which often leads to a significant degradation of the performance of communications systems.

In the early days of communications, this source of degradation was only of secondary concern. Communications systems used to operate far from the ultimate performance bound, i.e., channel capacity. The main concern was therefore to develop error-correcting techniques that could close the gap between the performance of practical communications systems and channel capacity.

With the recent advent of iterative decoding techniques, communications systems nowadays most often operate close to the ultimate performance limits; issues such as synchronization, which were earlier only of secondary importance, have now become the mayor (remaining) bottlenecks in the design of communications systems.

In this dissertation, we focus on carrier-phase synchronization, i.e., the alignment of the phase of the local oscillator in the receiver to the phase of the incoming carrier. The questions we address are:

1. Which physical mechanisms are responsible for phase noise? How can phase noise be modeled?

2. How can carrier-phase estimation algorithms systematically be derived?

3. What are the ultimate limits for communication over channels with phase noise?

In Particular:

3.a. How much does the information rate of a communications channel decrease due to phase noise? 3.b. How well can the (noisy) carrier phase be estimated? In contrast to earlier and parallel work, our aim is not the design and optimization of fully operating communications systems. In this thesis, various tools are developed that lead (or may lead) to an answer to the above questions (and many other related questions).

We give a detailed analysis of phase noise in free-running clocks and PLLs (Question 1). We propose a simple intuitive model for phase noise in free-running oscillators. We describe two simple models for passband communications channels. The models take phase offsets into account between the received carrier and the local carrier in the receiver, but disregard timing offsets. In the first model, the phase is constant, in the second, the phase performs a random walk. We investigate under which conditions the two models are valid. Most methods of this thesis will be illustrated by means of both channel models.

Most methods we propose in this dissertation are based on graphical models, more precisely, factor graphs. Factor graphs are used to visualize the structure of the system at hand. They represent the factorization of multivariate functions. Each edge in the graph corresponds to a variable, each node corresponds to a factor. Factor graphs can represent any function, in particular, probabilistic models, error-correcting codes, block diagrams and other common models in communications, signal processing and beyond. We show how factor graphs can be used as a tool to develop practical estimation and detection algorithms. Our techniques can be applied to model-based signal processing (e.g., phase estimation) and machine learning. In particular, we formulate several standard signal-processing and machine-learning algorithms as message passing on factor graphs, e.g., particle methods, gradient methods, decision-based methods, and expectation maximization. In all those algorithms, local rules are applied at the nodes in a factor graph. In other words, the (global) estimation and detection problem is tackled by a divide-and-conquer strategy: the global computation is carried out by multiple (simple) local computations. The local message update rules may be used as building blocks for novel estimation and detection algorithms. By listing the possible update rules at each node in the factor graph, one can systematically explore novel algorithms. We demonstrate this idea by deriving phase estimation algorithms for the constant-phase model and the random-walk phase model (Question 2). We also show how the back-propagation algorithm for the training of feed-forward neural networks follows by applying generic message-passing rules. We elaborate on thecomputation of kernels in the light of message passing on factor graphs.

We demonstrate how message-passing algorithms for inference can be implemented as dynamical systems, in particular, as clock-free analog electronic circuits. Those systems operate in continuous time, and do not require a digital clock; therefore, they circumvent the problem of timing synchronization.

We present a numerical algorithm to compute the information rate of continuous channels with memory (Question 3.a). The algorithm is an extension of the methods proposed earlier for discrete channels with memory. Also here, factor graphs and the summary-propagation algorithm are key ingredients. We apply the method to the random-walk phase model.

A numerical algorithm is proposed for computing the capacity (or lower bounds on capacity) of continuous memoryless channels (Question 3.a). We present numerical results for the Gaussian channel with average-power and/or peak-power constraints. We outline how the algorithm can be extended to continuous channels with memory (e.g., channels with phase noise) by means of message-passing techniques.

We propose message-passing algorithms to compute Cramér-Rao-type bounds. Cramér-Rao-type bounds are lower bounds on the minimum mean square estimation error; the bounds may be used to asses the performance of practical (message-passing) estimation algorithms, in particular, our phase-estimation algorithms (Question 3.b). The algorithms we propose for computing Cramér-Rao-type bounds open the door to exciting applications of information geometry, such as: 1) natural-gradient-based algorithms; (2) the computation of Fisher kernels.

Keywords: Graphical models, summary-propagation, belief propagation, message passing, expectation maximization, EM, steepest descent, particle filter, MCMC, particle methods, Gibbs sampling, importance sampling, decision-based estimation, iterative conditional modes, ICM, carrier phase estimation, phase noise, clock jitter, synchronization, Blahut-Arimoto algorithm, information rate, channel capacity, Cramér-Rao bound, information matrix, kernel methods, Fisher kernel, product kernel, probabilistic kernel, neural networks, back-propagation algorithm, analog electrical circuits, linear feedback shift register, LFSR.

4. Conferences, Meetings and Committees

4.1 Conference Organization

Prof. Lapidoth

Member of the Technical Program Committee for the 2005 IEEE International Symposium on Information Theory held at Adelaide, Australia from September 4-9, 2005.

Member of the Technical Program Committee for the 2006 International Zurich Seminar held at Zurich, Switzerland from February 22-24, 2006.

Member of the International Advisory Committee of ISITA 2006, Seoul held at Korea from October 29-November 1, 2006.

Prof. Loeliger

Chairman of the 2006 International Zurich Seminar on Communications.

Member of the Technical Program Committee for the 2005 International Symposium on Information Theory, Adelaide, Australia, September 2005.

Member of the Technical Program Committee for the 4th International Symposium on Turbo Codes and Related Topics, Munich, Germany, April 2006.

4.2 Participation in Congresses and Meetings

Dauwels Justin	26th Symposium on Information Theory in the Benelux, Brussels, Belgium, 19.-20.5.2005.
Dauwels Justin	Eight International Symposium on Communication Theory and Applications, Ambleside, UK, 17.-22.7.2005.
Dauwels Justin	2005 IEEE ITSOC Information Theory Workshop on Coding and Complexity, Rotorua, New Zealand, 28.8.-1.9.2005.
Dauwels Justin	2005 IEEE International Symposium on Information Theory, Adelaide, Australia, 4.-9.9.2005.
Dauwels Justin	2005 Neural Information Processing Systems Workshop, Whistler, Canada, 9.-10.12.2005.
Frey Matthias	Analog Modeling with Verilo-A, Munich, Germany, 9.-10.2.2005.
Frey Matthias	Analog Mixed Signal Designer Course, Munich, Germany, 21.-23.3.2005.
Frey Matthias	2005 International Symposium on Circuits and Systems, Kobe, Japan, 23.-26.5.2005.
Biveroni Jonas Frey Matthias	4th Analog Decoding Workshop, Rennes, France, 16.-17.6.2005.
Frey Matthias Loeliger H.-A. Merkli Patrick Strebel Patrick	2005 IEEE Int. Analog VLSI Worskshop, Bordeaux France, 19.-21.10.2005.
Hösli Daniel	Winterschool on Coding and Information Theory, Bratislava, Slovakia, 20.-25. 2.2005.
Hösli Daniel	IEEE International Symposium on Information Theory (ISIT 2005), Adelaide, Australia, 4.-9.9.2005.
Koch Volker	Maschine Learning Summer School 2005, Australian National University, Canberra, Australia, 23.1.-5.2.2005.
Koch Volker	Lecturer at HTA Lucerne, Lucerne, Switzerland, 1.4.-30.9.2005.
Koch Volker	IEEE ICASSP, Philadelphia, USA, 18.3.2005.
Koch Volker	Research stay at RIKEN Brain Science Institute, Saitama, Japan, 6.7.-30.9.2005.
Koch Volker	RIKEN Brain Science Institute, Saitama, Japan, Lecture Course "Neurobiology of Mental Disorder and the Mind", 12.-22.7.2005.
Koch Volker	Workshop "Advances in Computational Biology and Bioinformatics", IEEE EMBC, San Francisco, USA, 1.9.2005.

Koch Volker	Workshop “Advanced Technology for Decomposing the EMG Signal”, ISEK Boston, USA, 18.6.2005.
Korl Sascha	Machine Learning School, Canberra, Australia 24.1.-5.2.2005.
Hösli Daniel	Winterschool on Coding and Information Theory, Bratislava, Slovakia, 20.-25.02.2005.
Hösli Daniel	IEEE International Symposium on Information Theory (ISIT 2005), Adelaide, Australia, 4.-9.9.2005.
Koch Tobias	Winterschool on Coding and Information Theory, Bratislava, Slovakia, 20.-25.02.2005.
Koch Tobias	IEEE International Symposium on Information Theory (ISIT 2005) Adelaide, Australia, 4.-9.9.2005
Lapidoth Amos	IEEE International Symposium on Information Theory (ISIT 2005) Adelaide, Australia, 4.-9.9.2005.
Lapidoth Amos	43rd Annual Allerton Conference on Communication, Control, and Computing, University of Illinois at Urbana-Champaign, Allerton, Illinois, USA, 28.-30.9.2005.
Loeliger Hans-Andrea	IEEE International Symposium on Information Theory (ISIT 2005) Adelaide, Australia, 4.-9.9.2005
Miliou, Natalia Moster Stefan Tinguely Stephan Wigger Michèle	Winterschool on Coding and Information Theory, Bratislava, Slovakia, 20.-25.2.2005.
Wigger Michèle	43rd Annual Allerton Conference on Communication, Control, and Computing, University of Illinois at Urbana-Champaign, Allerton, Illinois, USA, 28.-30.9.2005.

4.3 Service Activities and Society Memberships

Prof. Lapidoth

Fellow of the IEEE

Member of the IMS Institute of Mathematical Statistics, Bethesda, USA

Associate Editor for Shannon Theory, IEEE New York

Research Affiliate in the Research Laboratory of Electronics (RLE) at the Massachusetts Institute of Technology (MIT)

Member of the Center for Communication and Information Technologies (CCIT), Technion, Haifa, Israel

Prof. Loeliger

Fellow of the IEEE

Chairman of the IEEE Switzerland Chapter on Digital Communication Systems

Dr. Heutschi

Member, Acoustical Society of America

Member, Audio Engineering Society

Member, Swiss Acoustical Society (SGA)

Member, German Acoustical Socyety (DEGA)

4.4 Presentations by Institute Members

Dauwels Justin	"Applications of Graphical Models in Signal Processing", RIKEN Brain Science Institute, Wako-shi, Japan, 6.1.2005.
Dauwels Justin	"Numerical Computation of the Capacity of Continuous Memoryless Channels", 26th Symposium on Information Theory in the Benelux, Brussels, Belgium, 19.-20.5.2005.
Dauwels Justin	"Phase Estimation by EM and Steepest Descent", University of Louvain-la-Neuve (DIGICOM), Belgium, 23. & 24.5.2005.
Dauwels Justin	"On Cramér-Rao-Bound Paradoxes (and how to Circumvent them)", University of Gent (DIGCOM), Belgium, 3.6.2005.
Dauwels Justin	"Steepest Descent on Factor Graphs", Eight International Symposium on Communication Theory and Applications, Ambleside, UK, 18.7.2005.
Dauwels Justin	"Expectation Maximization for Phase Estimation", 2005 IEEE ITSOC Information Theory Workshop on Coding and Complexity, Rotorua, New Zealand, 30.8.2005.
Dauwels Justin	"Computing Bayesian Cramér-Rao Bounds", 2005 IEEE International Symposium on Information Theory, Adelaide, Australia 4.-9.9.2005.
Dauwels Justin	"On Various Applications of Message Passing on Factor Graphs", MIT (CSAIL/RLE/LIDS), Cambridge, USA, 13.12.2005.
Dauwels Justin	"On Information-Geometric Aspects of Graphical Models and Kernel Machines", 2005 Neural Information Processing Systems Workshop, Whistler, Canada, 9.-10.12.2005.
Frey Matthias	"Analog Decoding and More at ETH", Analog Decoding Workshop, Rennes, France, 16.6.2005.
Frey Matthias	"Two Experimental Analog Decoders", 2005 IEEE Int. Analog VLSI Workshop, Bordeaux, France, 21.10.2005.
Hösli Daniel	"On the Role of the Line-of-Sight Component in Coherent MIMO Fading Channels", Winterschool on Coding and Information Theory, Bratislava, Slovakia, 24.2.2005.
Hösli Daniel	"Monotonicity Results for Coherent Single-User and Multiple-Access MIMO Rician Channels", IEEE International Symposium on Information Theory (ISIT), Adelaide, Australia, 8.9.2005.

Koch Tobias	“Degrees of Freedom in Non-Coherent Stationary MIMO Fading Channels”, Winterschool on Coding and Information Theory, Bratislava, Slovakia, 24.2.2005.
Koch Tobias	“On the Pre-Log of Gaussian Fading Relay Channels”, IEEE International Symposium on Information Theory (ISIT), Adelaide, Australia, 6.9.2005.
Koch Volker	Poster Presentation: “EMG Signal Decomposition by Loopy Belief Propagation”, 30th IEEE International Conference on Acoustics, Speech, and Signal Processing (IEEE ICASSP 2005), Philadelphia, USA, 23.3.2005.
Koch Volker	Poster Presentation: “EMG Signal Decomposition using an Iterative Message-Passing Algorithm”, RIKEN Summer Program, Saitama, Japan, 20.7.2005.
Koch Volker	“Factor Graphs and the Sum-Product Algorithm: Introduction”, RIKEN Brain Science Institute, Saitama, Japan, 27. & 29.7.2005.
Koch Volker	Poster Presentation: “Blind Source Separation using Iterative Message-Passing Algorithms on Factor Graphs”, RIKEN Summer Program, Saitama, Japan, 25.8.2005.
Koch Volker	“Blind Source Separation (BSS) using Factor Graphs and Loopy Belief Propagation, BSS for EMG Signal Decomposition, Spike Sorting, and Brain-Computer Interfaces”, RIKEN Brain Science Institute, Saitama, Japan, 22.9.2005.
Lapidoth Amos	“The Fading Number and Degrees of Freedom: A Peace Pipe”, Tel Aviv University, Tel Aviv, Israel, 27.3.2005.
Lapidoth Amos	“The Fading Number and Degrees of Freedom: A Peace Pipe”, ETH Zurich, Zurich, Switzerland, 6.4.2005.
Lapidoth Amos	“The Fading Number and Degrees of Freedom in Non-Coherent MIMO Fading Channels: A Peace Pipe”, IEEE International Symposium on Information Theory (ISIT), Adelaide, Australia, 6.9.2005.
Lapidoth Amos	“On the Capacity of Non-Coherent Networks”, MIT, Cambridge, MA, 21.9.2005.
Lapidoth Amos	“On Fading MIMO Broadcast Channels with Imperfect Transmitter Side-Information”, Stanford University, Stanford, CA, 22.9.2005.
Lapidoth Amos	“On the Capacity of Fading MIMO Broadcast Channels with Imperfect Transmitter Side-Information”, 43rd Annual Allerton Conference on Communication, Control, and Computing, University of Illinois at Urbana-Champaign, Allerton, Illinois. 29.9.2005.
Lapidoth Amos	“On Fading MIMO Broadcast Channels with Imperfect Transmitter Side-Information”, Technion, Haifa, Israel, 15.11.2005.

Loeliger Hans-Andrea	“Expectation Maximization as Message Passing”, 2005 IEEE International Symposium on Information Theory, Adelaide, Australia, 5.9.2005.
Miliou Natalia	“Reliable Communication over an Unknown Channel”, Winterschool on Coding and Information Theory, Bratislava, Slovakia, 24.2.2005.
Miliou, Natalia	“Duality Bounds on the Cut-Off Rate with Applications to Rician Fading”, Laboratory of Information and Decision Systems, MIT, Cambridge, MA, USA, 3.10.2005.
Moser Stefan M.	“Duality-Based Bounds on Channel Capacity”, FTW Vienna, Austria, 14.1.2005.
Moser Stefan M.	“Fading Channels and Feedback”, Winterschool on Coding and Information Theory, Bratislava, Slovakia, 24.2.2005.
Wigger Michèle	“Bounds on the Capacity of Free-Space Optical Intensity Channels”, Winterschool on Coding and Information Theory, Bratislava, Slovakia, 24.2.2005.

4.5 Organization of Lectures, Seminars, and Colloquia

Colloquium Speakers for the Colloquium "Electronics and Communications" were:

Invited by Prof. Lapidoth:

20.07.05 **Prof. Shlomo Shamai (Shitz),** Technion – Israel Institute of Technology, Haifa, Israel
"Downlink Multi-Cell Processing: An Information Theoretic View".

13.07.05 **Ashish Khisti,** Massachusetts Institut of Technology (MIT), Cambridge, USA
"Multicasting in Wireless Networks".

15.08.05 **Prof. Alfred M. Bruckstein,** Technion – Israel Institute of Technology, Haifa, Israel
"The Variatonal Principles of Image Analysis".

16.12.05 **Prof. Sekhar Tatikonda,** Yale University, New Haven, USA
"An MDP Approach to Computing Feedback Capacity".

Invited by Prof. Loeliger:

22.03.05 **Prof. Joachim Rosenthal,** University of Zurich, Zurich, Switzerland
"CRD Codes, List Decoding and Factoring of Integers".

11.04.05 **Prof. R. Kschischang,** University of Toronto, Toronto, Canada
"On EXIT charts and LDPC codes".

28.04.05 **Dr. Nikolai Nefedov,** Nokia Research Center, Helsinki, Finland
"Generalized Zigzag Codes".

14.07.05 **Prof. Martin Hänggi,** University of Notre Dame, Notre Dame, USA
"Outage and Throughput Bounds for Stochastic Wireless Networks".

29.11.05 **Dr. Jonathan Yedidia,** Mitsubishi Electric Research Labs, Cambridge, USA
"Understanding Belief Propagation and its Connection to Statistical Physics".

30.11.05 **Dr. Stefan Launer,** Phonak AG, Stäfa, Switzerland
"Technische Herausforderungen in der Hörgerätetechnik".

30.11.05 **Dr. Jonathan Yedidia,** Mitsubishi Electric Research Labs, Cambridge, USA
"The Slepian-Wolf Idea: Syndrome Codes and Their Application to Distributed Video Coding and Secure Biometrics".

16.12.05 **Dr. Pascal Vontobel,** MIT, Cambride, USA
"An Explicit Construction of Universally Decodable Matrices for Space-Time Coding".

Invited by Dr. Heutschi,

25.05.05 **Davide Caprioli**, Rieter Automotive Management AG, Winterthur, Switzerland
"Shape and damping vibro-acoustical optimization of automotive structural panels".

22.06.05 **Sascha Spors,** Lehrstuhl für Multimediakommunikation und Signalverarbeitung, Universität Erlangen-Nürnberg, Germany
"Wellenfeldsynthese: Grundlagen und Perspektiven".

14.12.05 **Prof. Dr. Jörg Sennheiser,** Sennheiser Electronic, Wedemark, Germany
"Mikrophonprinzipien für die Multimediawelt".

5. Publications

Dauwels J., Korl S., Loeliger H.-A.	"Phase Estimation by Expectation Maximization", Proceedings Eight International Symposium on Communication Theory and Applications, 2005.
Dauwels J., Korl S., Loeliger H.-A.	"Steepest Descent as Message Passing", IEEE Information Theory Workshop on Coding and Complexity, 2005.
Frey Matthias, Loeliger Hans-Andrea, Merkli Patrick, Strebel Patrik	"Two experimental analog decoders", Proc. 2005 IEEE Int. Analog VLSI Workshop, Bordeaux, France, Oct. 19-21, 2005.
Hoesli Daniel, Lapidoth Amos	"Monotonicity Results for Coherent Single-User and Multiple-Access MIMO Rician Channels", Proceedings 2005 IEEE International Symposium on Information Theory (ISIT), 2005.
Hösli D., Kim Y.-H., Lapidoth A.	"Monotonicity results for coherent MIMO Rician Channels", IEEE Transactions on Information Theory, vol. IT-51, no. No. 12, pp. pp. 4334-4339, December, 2005.
Khisti Ashish, Erez Uri, Lapidoth Amos, Wornell Gregory W.	"Carbon Copying Onto Dirty Paper", arXiv: cs.IT/0511095, November 28, http://www.arxiv.org/pdf/cs.IT/0511095, 2005.
Koch Tobias, Kramer Gerhard	"On the Pre-Log of Gaussian Fading Relay Channels", in Proceedings 2005 IEEE International Symposium on Information Theory (ISIT), Adelaide, Australia, 2005.
Koch Tobias, Lapidoth Amos	"Degrees of Freedom in Non-Coherent Stationary MIMO Fading Channels", Proceedings 2005 Winterschool on Coding and Information Theory, Bratislava, Slovakia, Feb. 20-25, 2005.
Koch Tobias, Lapidoth Amos	"The Fading Number and Degrees fo Freedom in Non-Coherent MIMO Fading Channels: A Peace Pipe", in Proceedings 2005 IEEE International Symposium on Information Theory (ISIT), Adelaide, Australia, 2005.
Koch V. M., Loeliger H.-A.	"EMG Signal Decomposition by Loopy Belief Propagation", Proc. of the 30th IEEE International Conference on Acoustics, Speech, and Signal Processing (IEEE ICASSP 2005), pp. 397-400, Philadelphia, PA, USA, March 18-23, 2005.
Lapidoth Amos	"On the Asymptotic Capacity of Stationary Gaussian Fading Channels", IEEE Transactions on Information Theory, vol. 51, no. 2, pp. 437-446, February, 2005.
Lapidoth Amos	"On the High-SNR Capacity of Noncoherent

	Networks”, IEEE Transactions on Information Theory, vol. IT-51, no. No. 9, pp. pp. 3025-3036, September, 2005.
Lapidoth Amos, Miliou Natalia	“Duality Bounds on the Cut-Off Rate with Applications to Ricean Fading”, arXiv:cs.IT/0503019, March, 14, 2005.
Lapidoth Amos, Moser Stefan M.	“On Non-Coherent Fading Channels with Feedback”, Proceedings 2005 Winter School on Coding and Information Theory, Bratislava, Slovakia, Feb. 20-25, 2005.
Ott T., Dauwels J., Stoop R.	“Sequential Clustering by Loopy Belief Propagation”, Proceedings of the European Conference on Circuit Theory and Design, 2005.
Zemen Thomas, Moser Stefan M.	“Asymptotic Capacity Results for Non-Stationary Time-Variant Channels Using Subspace Projections”, arXiv:cs.IT/0505020, May 10, 2005.

6. Guests, Visitors

6.1 Activities of Academic Guests at the Institute

Guests of Prof. Lapidoth:

Prof. Emre Telatar
EPF Lausanne, Switzerland.
Collaboration with Prof. Lapidoth 17.01. – 18.2.2005

Dr. Shraga Bross
Technion, Haifa, Israel.
Collaboration with Prof. Lapidoth, and presentation of a talk on "Achievable Rates for Partial Feedback Configurations of the Discrete Memoryless Relay Channel" 29.06. - 03.07.2005

Dr. Eran London
Hebrew University, Jerusalem, Israel.
Collaboration with Prof. Lapidoth 17.08. - 31.08.2005

Dr. Shraga Bross
Technion, Haifa, Israel.
Collaboration with Prof. Lapidoth 22.11. - 16.12.2005

Guests of Prof. Loeliger:

Prof. Frank Kschischang
University of Toronto, Toronto, Canada
Collaboration with Prof. Loeliger and Justin Dauwels;
Co-referee for Ph.D. thesis of Patrick Merkli.
talk "On EXIT charts and LDPC codes" 01.02. – 30.04.2005

Prof. Allen Lindgren
University of Rhode Island, Kingston, USA
Collaboration with Sascha Korl and Prof.Loeliger,
Co-referee for Ph.D. thesis of Sascha Korl 01.07. – 15.08.2005

Andrew Eckford
University of Toronto, Canada
Collaboration with Justin Dauwels, Sascha Korl and Prof. Loeliger on Expectation Maximization as message passing 08.08. – 14.08.2005

Dr. Nikolai Nefedov
Nokia Research Center, Helsinki, Finland

Collaboration with group of Prof. Loeliger on topics
in analog processing 16.09. – 31.12.2005

Dr. Jonathan Yedidia
Mitsubishi Electric Research Labs, Cambridge, USA
Co-referee for Ph.D. thesis of Justin Dauwels. Held talks on "Understanding Belief Propagation and its connection to Statistical Physics", and " The Slepian-Wolf Idea: Syndrome Codes and their Application to distributed Video Coding and Secure Biometrics" 27.11. - 02.12.2005