Information and Coding Theory

The **research activities** of the Information and Coding Theory group (ICT) of the University of Kiel are in the general area of wireless digital communications. Simply speaking, ICT is designing new digital transmission schemes and developing corresponding software algorithms. The proposed transmission schemes are motivated by insights from applied information theory. Among our goals is to serve more users in future cellular radio systems, to increase data rates, and to reduce transmission power and signal bandwidth.

The main expertise is in the area of channel coding (Turbo codes, low-density parity check codes, decoding with reliability information, space-time codes), applied information theory, digital modulation schemes (adaptive modulation and channel coding, superposition modulation, orthogonal frequency-division multiplexing), joint communication and navigation, and development of modern receiver algorithms (equalization, channel estimation, synchronisation, interference rejection). Among the applications are cellular radio systems (GSM and UMTS enhancements, WLAN, LTE, LTE-Advanced), underwater communications, satellite radio, and terrestrial broadcasting systems.

Concerning **teaching**, we offer lectures and exercises on channel coding, information theory, wireless communications and advanced wireless communications with emphasis on digital signal processing, partly in English within the international master program on "Digital Communications". A lecture on system identification (with focus on underwater communications) and a lecture on time series analysis (with focus on medical applications) are offered in form of teaching assignments. Furthermore, several seminars and labs are provided for our students.

Results

Joint Communication and Navigation (Rebecca Adam, Kathrin Schmeink) Recently, joint communication and navigation is gaining more and more interest in research. The advantages and applications cover a wide range. In particular, there are many synergy effects that can be exploited. One major application is the automated localization of emergency calls. However, it is a challenging task to combine communication and navigation because the requirements of both techniques are quite different. ICT tries to face this problem with a system concept based on multi-layer interleave-division multiple access (ML-IDMA). The core part of the concept is joint channel and parameter estimation. A maximum-likelihood approach has been investigated, which leads to a nonlinear optimization problem. Different optimization algorithms like the Levenberg-Marquardt method, particle swarm optimization or simulated annealing have been applied. In addition to finding the global optimum of the nonlinear metric, one major task has been to obtain soft information concerning the parameter estimates. Soft information corresponds to the variance of a parameter estimate and is a measure of reliability. The soft infomation can be exploited in a weighted positioning algorithm in order to improve the positioning accuracy. Different methods to obtain soft information were proposed and analyzed.

Channel Estimation for MIMO-OFDM (Christopher Knievel, Zhenyu Shi) Multi-user multiple-input multiple-output (MIMO) transmission techniques in combination with orthogonal frequency-division multiplexing (OFDM) promise to provide the desired performance of next-generation cellular radio systems. MIMO-OFDM has been selected as a key technology for the IEEE 802.11n wireless local area network (WLAN) standard and for 3GPP Long Term Evolution (LTE), which is the successor of third generation cellular radio systems (such as UMTS). The successor of LTE, called LTE-Advanced (LTE-A), is expected to close the gap between stationary and mobile communications by supporting high data rates.

Channel estimation in multi-antenna scenarios is a challenging task. ICT developed a graph-based iterative receiver, which utilizes correlation in time, frequency, and space in order to improve channel estimation and data detection quality. This graph-based receiver has lower computational complexity, expands the restriction of training symbols, and shows very good performance when compared to iterative as well as non-iterative state-of-the-art algorithms like SAGE and Wiener filtering.

Superposition Modulation (Dapeng Hao, Meelis Noemm, Tianbin Wo) Superposition modulation (SM) is a novel digital modulation scheme that can be used in high-rate mobile communications. The signal points of SM are derived by linearly superimposing binary antipodal symbols with proper power and phase allocation. Unlike conventional PSK/QAM modulation, the signal points of SM are quasi-Gaussian distributed instead of being designed. A special case of SM is interleave-division multiplexing (IDM). IDM can be used as a coded modulation scheme or as a multiplexing scheme. It is particularly suitable for hierarchical signalling.

Power and phase allocation is an important issue for superposition modulation. The constellation diagram and the maximum achievable mutual information are highly influenced by the applied power and phase allocation. Different power and phase allocation schemes were investigated and compared, and we observed that conventional rectangular QAM modulation could be derived by SM with unequal power and orthogonal phase allocation. In the low-to-moderate signal-to-noise region, SM with equal power and uniform phase allocation shows higher potential to achieve the Shannon capacity than other power and phase allocation schemes.

Besides extensive investigations on power and phase allocation of SM, information theoretical properties of SM were investigated. By means of an extensive analysis, the pros and cons of SM have been clarified, and also its potential in the sense of approaching the capacity of the Gaussian channel is now well understood. Theoretical limits for coded as well as uncoded SM systems were derived, which serve as guidelines for practical system design.

The most important result is in finding reasons for the previously known limit on the bandwidth efficiency of coded SM systems. Based on this finding, new coding schemes have been investigated to further improve the system performance. With sophisticated channel coding, we are less than 1 dB away from channel capacity even for large bandwidth efficiencies, which is currently being the world record.

Graph-based Channel Estimation and Data Detection (Christopher Knievel, Zhenyu Shi, Tianbin Wo) Additional effort has been spent on graph-based soft channel estimation (GSCE) and data detection, as reported in the Almanach 2008. The algorithm is now able to support higher-order modulation formats, such as PSK/QAM. Furthermore, it is found that the most suitable code structure for GSCE is to use a parity-check code as the outer code and a repetition code as the inner code.

Further work includes an extension of the graph-based estimator to MIMO-OFDM systems via multi-dimensional estimation, its performance improvement for higher-order modulation schemes in conjunction with channel coding, and its implementation in a cellular environment. 3GPP LTE-A is treated as a special application.

Time Series Analysis (A. Galka) The work of A.Galka deals with the development and application of new tools for the analysis of time series from neuroscience, such as electroencephalograms (EEG) and functional magnetic resonance imaging (FMRI) data sets. In most cases the analysis is based on state space modelling within a Kalman filtering and maximum likelihood framework. Tasks such as artefact removal, noise reduction, decomposition into physiological components, source analysis and estimation of task- or stimulus-related activations can be approached by this analysis.

Underwater Communications (Ivor Nissen, Christian Schroeder) In contrast to wireless RF communications, underwater communications (UWC) typically do not use electromagnetic waves as a carrier. This is because of the strong absorption of EM-waves in water. Only for very low frequencies (below 20 kHz) or at optical frequencies may these waves propagate over small distances. Therefore, acoustic waves are used, which are less subject to absorption and can travel further (hundreds of kilometers in the deep sound channel). This leaves only three frequency regions for wireless data transmission (as depicted in the figure).

However, using acoustic waves comes with several drawbacks. One is the lower propagation speed (around 1500 m/s), which varies with temperature, depth and salinity. This causes large latencies and also makes the signals more vulnerable to Doppler influence than in RF transmission, which is determined by the relation of user speed to wave propagation speed. The Doppler is induced by the almost inevitable drift of the communication nodes in the water and also by the random

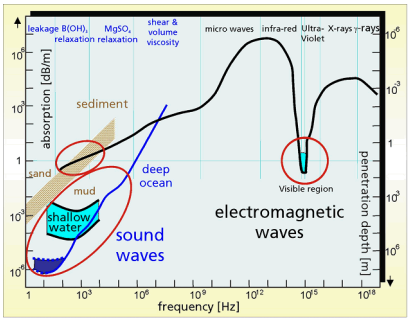

Fig. 1: Absorption of EM and acoustic waves in water.

movement of the reflecting sea surface. Due to the channel geometry there a many reflections from the surface and the seabed resulting in an increasing number of multi-path components at the receiver causing long delay spreads and, hence, inter-symbol interference. The long propagation delay does not allow the assumption of a constant channel during one transmission frame. Moreover, due to the non-constant sound velocity profile in the water column, the propagation is not direct but is affected by refraction. The usable acoustic bandwidth for UWC is rather limited to some tens of kHz (strongly depending on the desired range, which increases with lowering the frequency) and does not allow data rates known from current RF networks.

Since Kiel is a centre for marine research and technology, research in the fields of underwater communications is more than obvious. Hence, there is intensive cooperation with other institutes and companies working on this topic, especially with the *Research Department for Underwater Acoustics and Marine Geophysics (FWG) of the Bundeswehr Technical Centre 71*. In conjunction with this a special lecture on UWC is offered in the international study course on Digital Communications.

Currently, two system approaches are under investigation for underwater acoustic communication, designed for different kinds of application. The first uses a multi-carrier system with non-orthogonal pulse shaping for high data rates (i.e., in the range of some kbps). The second system is designed for small data packets used for example for command & control links to underwater vessels. This uses very short bursts over almost the whole available bandwidth. The benefit is the mitigation of inter-symbol interference due to the short duration and small payload. This might later be used to deploy an underwater network between several mobile nodes or sensors.

The need for underwater mobile communications arises in several fields, from military applications (e.g. communication with submarines) through industrial use (e.g. exploration of natural resources and deep sea-mining) to marine research (geology, oceanography etc.).

Personnel

Head of the group: Prof. Dr.-Ing. P. A. Höher; Secretary: S. Schuchardt (50%)
Technical Staff: Dipl.-Ing. T. Rabsch

Scientific Staff:

Dipl.-Ing. R. Adam Joint Navigation and Communication	01.04.2009-31.12.2010	DFG
Dr. rer. nat. A. Galka Time Series Analysis	01.06.2009-31.12.2010	Lecturer
Dipl.-Ing. M. Gregory Free-space Optical MIMO Communications	01.01.-31.12.2010	External PhD Student

M.Sc. Dapeng Hao	01.01.2007-31.12.2010	DFG
Interleave-Division Multiplexing (IDM), PITAS		
Dipl.-Ing. Ch. Knievel	15.03.2009-31.12.2010	CAU
3GPP LTE-A		
Dr. rer. nat. I. Nissen	01.10.2008-31.12.2010	Lecturer
Acoustical Underwater Communications		
M.Sc. M. Noemm	01.06.2009-31.12.2010	Industry
Interleave-Division Multiplexing (IDM)		
Dipl.-Ing. K. Schmeink	01.04.2007-31.12.2010	CAU
Joint Navigation and Communication		
Dipl.-Ing. Ch. Schröder	01.10.2008-31.12.2010	FWG
Accoustical Underwater Communications		
M.Sc. Z. Shi	01.01.2009-31.12.2010	Industry
3GPP LTE-A		
M.Sc. T. Wo	01.11.2004-31.12.2010	DFG
Superposition Modulation and Graph-based Channel Estimation		
M.Sc. H. Wu	01.12.2006-10.09.2010	External PhD Student
3GPP Long-Term Evolution (LTE)		
Dipl.-Ing. V. Zeiger	01.01.-31.12.2010	External PhD Student
Underwater Navigation		

Lectures, Seminars, and Laboratory Course Offers

Winter 2009/2010

Kanalcodierung, 2 (+ 1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

Information Theory and Coding I, 2 (+ 1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

Wireless Communications II, 2 (+ 1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

System Identification, 2 (+ 1) hrs Vorlesung (+ Exercises)/Week,
I. Nissen

Communications Lab, 4 hrs Praktikum/Week,
P.A. Höher (+ U. Heute, W. Rosenkranz, und Mitarbeiter)

Advanced Topics Lab, 4 hrs Praktikum/Week,
P.A. Höher (+ U. Heute, W. Rosenkranz, und Mitarbeiter)

Informationstechnik und Codierung, 1 hrs Seminar/Week,
P.A. Höher

Summer 2010

Theoretische Grundlagen der Informationstechnik, 2 (+1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

Information Theory and Coding II, 2 (+1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

Wireless Communications (DSP), 2 (+1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

Digital Communications, 4 hrs Seminar/Week,
P.A. Höher (+ U. Heute, W. Rosenkranz, und Mitarbeiter)

Informationstechnik und Codierung, 1 hrs Seminar/Week,
P.A. Höher

Time Series Analysis, 2 (+1) hrs Lecture (+ Exercises)/Week,
A. Galka

Seminar on Topics in Digital and Optical Communications, 2 hrs Seminar/Week,
P.A. Höher (+ und Kollegen)

Projekt, 3 hrs Seminar/Week,
P.A. Höher (+ und Kollegen)

Winter 2010/2011

Grundlagen der Kanalcodierung, 2 (+1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

Information Theory and Coding I, 2 (+1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

Advanced Wireless Communications (DSP), 2 (+1) hrs Vorlesung (+ Exercises)/Week,
P.A. Höher (+ und Mitarbeiter)

System Identification, 2 (+1) hrs Vorlesung (+ Exercises)/Week,
I. Nissen

Communications Lab, 4 hrs Praktikum/Week,
P.A. Höher (+ U. Heute, W. Rosenkranz, und Mitarbeiter)

Advanced Topics Lab, 4 hrs Praktikum/Week,
P.A. Höher (+ U. Heute, W. Rosenkranz, und Mitarbeiter)

Informationstechnik und Codierung, 1 hrs Seminar/Week,
P.A. Höher

Third-Party Funds

DFG, *Multi-Antenna Multi-Layer Interleave-Division Multiple Access (HO 2226/10-1)*, 01.07.2007-30.06.2010 (185468 EUR)
DFG, *Joint Navigation and Communication based on Interleave-Division Multiple Access (HO 2226/11-1)*, 15.03.2009-14.03.2012 (180590 EUR)
DFG, *Multi-Layer Interleave-Division Multiple Access (HO 2226/9-2)*, 01.02.2009-30.07.2010 (95704 EUR)
FWG (WTD-71), *Acoustical Underwater Communications*, 01.07.2008-30.06.2011 (270835 EUR)
Industry, *3GPP LTE-A*, 01.10.2008-30.09.2010 (160000 EUR)
Industry, *Interleave-Division Multiplexing*, 01.11.2009-31.01.2011 (87500 EUR)

Industry, *3GPP LTE-A*, 01.10.2010-30.09.2012 (160000 EUR)
BMWi, *PITAS (Pirate Defence)*, 01.09.2010-31.08.2013 (ca. 240000 EUR ICT contingent)

Further Cooperation, Consulting, and Technology Transfer

Besides cooperation with other universities, the Information and Coding Theory Lab has collaborations with numerous companies and research institutes, including

- German Aerospace Research Establishment (DLR), Oberpfaffenhofen
- DoCoMo Euro Labs, Munich
- L-3 Communications ELAC Nautik GmbH, Kiel
- Raytheon Anschütz, Kiel
- Research Institute of the Armed Forces on Underwater Sound and Geophysics (FWG), Kiel
- Fraunhofer Institute for Integrated Circuits (IIS), Erlangen
- Huawei Technologies, Shanghai
- Nokia Siemens Networks (NSN), Munich
- Toshiba Telecommunications Research Laboratory (TRL), Bristol.

Diploma, Bachelor and Master Theses

X. Wang, *Channel Coding for Superposition Mapping*, 29.03.2010
Y. Zheng, *Frequency Offset and Phase Noise Compensation for BICM*, 04.05.2010
A. Hafeez, *Channel Modelling and Beamforming for Multi-User MIMO OFDM*, 16.06.2010
S. Ghamari, *Optimization Methods for Joint Channel and Parameter Estimation*, 26.11.2010
R. Odugoudar, *Ad-hoc Network Emulation Framework for Underwater Communication Applications*, 08.11.2010
K. Shahab, *Iterative Soft Decoding of Reed-Solomon Turbo Product Codes*, 17.11.2010
N. Ul Hassan, *Channel Coding for Superposition Modulation*, 18.11.2010

Dissertations / Postdoctoral Lecture Qualifications

H. Wu, *Adaptive Multi-user MIMO Resource Allocation for Uplink DFT-precoded OFDMA*, 10.09.2010

Publications

Published in 2010

T. Wo, M. Noemm, D. Hao, P.A. Hoeher, *Iterative Processing for Superposition Mapping*, Journal of Electrical and Computer Engineering, **vol. 2010, Article ID 706464**, (2010)
T. Wo, P.A. Hoeher, *Low-Complexity Gaussian Detector for MIMO Systems*, Journal of Electrical and Computer Engineering, **vol. 2010, Article ID 609509**, (2010)
C. Schlegel, P.A. Hoeher, O. Axelsson, L. Perez, *Iterative Signal Processing in Communications*, Journal of Electrical and Computer Engineering, **vol. 2010, Article ID 862392**, (2010)
M. Noemm, T. Wo, P.A. Hoeher, *Multilayer APP detection for IDM*, Electronics Letters, **46**, 96 - 97 (2010)
Ch. Knievel, Z. Zhi, P.A. Hoeher, G. Auer, *2D Graph-based Soft Channel Estimation for MIMO-OFDM*, IEEE International Conference on Communications, Capetown, South Africa, (2010)

Z. Shi, T. Wo, P. Hoeher, *Graph-based Soft Iterative Receiver for Higher-order Modulation,* IEEE International Conference on Communication and Technology, Nanjing, China, (2010)
D. Hao, P.A. Hoeher, *Superposition Modulation with Reliability-Based Hybrid Detection,* Proc. International Symposium on Turbo Codes and Iterative Information Processing, Brest, Frankreich, (2010)
Z. Shi, T. Wo, P.A. Hoeher, *Superposition Mapping with Adaptive Bit Loading for BICM-OFDM Systems,* Proc. International Symposium on Turbo Codes and Iterative Information Processing, Brest, Frankreich, (2010)
T. Wo, P.A. Hoeher, *A Universal Coding Approach for Superposition Mapping,* Proc. International Symposium on Turbo Codes and Iterative Information Processing, Brest, Frankreich, (2010)
T. Wo, P.A. Hoeher, *Superposition Mapping with Application in Bit-interleaved Coded Modulation,* Proc. 8th International ITG Conference on Source and Channel Coding, Siegen, (2010)
K. Schmeink, R. Block, Ch. Knievel, P.A. Hoeher, *Joint Channel and Parameter Estimation for Joint Communication and Navigation using Particle Swarm Optimization,* Proc. Workshop on Positioning, Navigation and Communication (WPNC), Dresden, (2010)

Presentations

Ch. Knievel, *2D Graph-based Soft Channel Estimation for MIMO-OFDM,* International Conference on Communication 2010, Cape Town, South Africa, 23.-27.05.2010
Ch. Knievel, *Graph-based Multi-dimensional Channel Estimation for LTE-A,* 5th IEEE Workshop on Advanced Information Processing for Wireless Communication Systems, Copenhagen, Denmark, 14.-15.10.2010
M. Noemm, *Superposition mapping with application in bit-interleaved coded modulation,* 5th IEEE Workshop on Advanced Information Processing for Wireless Communication Systems, Copenhagen, Denmark, 14.-15.10.2010
M. Noemm, *Interleave-Division Multiplexing (IDM),* Huawei Technologies, Shanghai, China, 17.10.2010
K. Schmeink, *Joint Channel and Parameter Estimation for Combined Communication and Navigation using Particle Swarm Optimization,* Int. Workshop on Positioning, Navigation and Communication, Dresden, Germany, 11.03.2010
K. Schmeink, *Particle Swarm Optimization for Channel Parameter Estimation in the Framework of Joint Communication and Positioning,* ITG-Fachgruppe Angewandte Informationstheorie, Rostock/Warnemünde, Germany, 07.10.2010
Z. Shi, Ch. Knievel, *Pilot Design for Multi-User MIMO-OFDM Operating in a Cellular Environment,* DoCoMo Euro Labs, Munich, Germany, 01.10.2010
P.A. Hoeher, *Superpositionsmodulation: Die bessere Alternative?,* University of Erlangen-Nuremberg, Erlangen, Germany, 11.10.2010

Further Activities and Events

Prof. Dr. Peter Adam Hoeher is a director of the Institute of Electrical and Information Engineering, member of the Convention of the Faculty of Engineering, head of the examination board on Digital Communications, member of the examination board on Electrical Enineering, head of the advisory board of the Institute of Electrical and Information Engineering, and the Bafög representative of the Institute. He is a member of the Excellence Cluster ''The Future Ocean''. He is an IEEE Senior member, vice-chair of the German chapter of the IEEE Communications Society, member of the VDE/ITG Fachausschuss 5.1, and co-founder and managing director of a start-up in telecommunications. He is heading an appointments committee on Control Theory.

Dipl.-Ing. Christopher Knievel is member of the examination board on Electrical & Information Engineering and on Industrial Engineering.

M.Sc. Meelis Noemm is a member of the examination board on Digital Communications.

Dipl-Ing. Kathrin Schmeink is a member of the Convention of the Faculty of Engineering, a member of the study board on doctorate regulations, and a member of the appointments committee on Biocompatible Nano Materials.