Information and Coding Theory

The **research activities** of the Information and Coding Theory (ICT) group of the University of Kiel are in the general area of signal processing for wireless digital communication and localization. Currently, focus is on the following areas:

- Development of advanced signal processing algorithms suitable for future radio systems like 5G mobile radio and ultra-fast (100+ Gbps) near-range wireless internet access. We develop and analyse key enabling techniques such as massive MIMO and cognitive radio. Among the goals is to increase the data rate, to reduce transmission power and signal bandwidth per data bit, and to support more licensed and unlicensed users.
- Visible Light Communications (VLC). VLC is an emerging technique employing light emitting diode (LED) arrays. The LEDs can simultaneously be used for illumination purposes as well as for data communications. VLC is an alternative to wireless local area networks (WLAN) but can be applied in many other applications, like aircraft cabins, hospitals, factories, optical underwater communication systems, etc. Among the goals are high data rates and reliable transmission at low cost.
- Molecular communications. One promising approach to solve the problem of in-body communication is molecular communication, which uses molecules as the information carrier. Molecular communication is expected to provide an energy efficient solution for in-body information transmission, because the molecules diffuse freely through the medium without spending any extra energy for propagation. Molecular communication is expected to be applicable both for sensing and actuation purposes.
- Underwater techniques. High-speed underwater communications, swarm communication and navigation, as well as localization and exploration are among our research interests in the area of underwater techniques.

The main expertise is in the field of channel coding (turbo codes, low-density parity check codes, decoding with reliability information, space-time codes), applied information theory (particularly multi-user information theory), digital modulation schemes (adaptive modulation and channel coding, superposition modulation, orthogonal frequency-division multiplexing), joint communication and localization, and the development of modern receiver algorithms (equalization, channel estimation, synchronization, interference rejection).

Since 2013, ICT has started activities in the area of underwater robotics. The goal is to design and build a swarm of autonomous underwater vehicles (AUVs), serving as a teaching and research platform. Advanced techniques like cooperative communication and cooperative localization can be implemented and tested on this platform. In 2015, an AUV Alliance has been established by the GEOMAR Helmholtz Centre for Ocean Rearch Kiel, the University of Applied Sciences in Kiel, and the Faculty of Engineering.

Concerning **teaching**, we offer lectures and exercises on channel coding, information theory, wireless communications and advanced wireless communications with a focus on baseband processing. In B.Sc. programs we teach in German language, in M.Sc. programs in English. Lectures on time series analysis (with emphasis on medical applications), radar signal processing, and underwater techniques are offered in the form of teaching assignments. Furthermore, several labs and seminars are provided for our B.Sc. and M.Sc. students.

Results

Ultra High-Speed Wireless Indoor Communication (Niklas Doose). Recent developments in industry and consumer electronic products demand reliable communication at very high data rates. Two famous examples are the fifth mobile radio standard (5G), which demands higher peak data rate, improved coverage, more reliability and a shorter latency, and wireless Internet (wwww). The Deutsche Forschungsgemeinschaft (DFG) has started a research focus program (SPP 1655) that explicitly addresses a data rate of 100 Gbps and beyond, which is currently achievable only in wired and in

optical networks. Within this research focus program, a variety of advanced techniques are examined to develop system components that are able to deliver the required rate.

In our contribution, the following key enabling techniques are studied: The implementation as an ultra-wideband (UWB) system provides high bandwidth that can be utilized with parallel orthogonal frequency-division multiplexing (OFDM) systems. Additionally, the deployment of a so-called massive MIMO scenario promises great beamforming gains and the ability to offer a signal-to-noise ratio that is needed for high-level modulation schemes. However, the required data rate leads to modulation orders that are unfeasible for practical receivers. Therefore, the application of multi-mode antennas is absolutely essential to be able to process multiple streams in hand-held mobile devices. Consequently, the spectral efficiency can be distributed over the streams and the decoding bottleneck is relaxed.

While we concentrate on the baseband signal processing, the project is a cooperation with the Wireless Communications group (CWC) chaired by Prof. Manteuffel, who developed and realized the multi-mode antennas and works on microwave hardware issues of the system concept.

In an initial step, the suitability of multi-mode antennas for application in MIMO systems has been shown with respect to the correlation between antnenna elements and with respect to the channel capacity. As an example, the channel capacity of systems occupying the same physical space can be compared for multi-mode antennas and standard crossed dipole antennas. The ergodic Shannon capacity of a MIMO system using multi-mode antennas outperforms the corresponding MIMO system that uses crossed dipole antennas.

Additional to the performance gains possible with the hardware under investigation, an algorithmic system optimization has been examined. A joint optimization of beamforming and power control has been introduced in order to maximize the system throughput and to minimize the interference on other systems. Besides simple scaling methods of known beamforming solutions, numerical optimization techniques have been considered. In numerical results, a performance gain of 17 bits/s/Hz has been demonstrated for small-scale systems and 4 bit/s/Hz for large-scale systems, respectively, both compared to the corresponding state-of-the-art (down-scaling) scheme.

LED-based Communication with Focus on Indoor and on Underwater Communication (Gilbert J.M. Forkel). With increasing bandwidth requirements for mobile communication, optical free-space communication employing light emitting diodes (so-called visible light communication (VLC)), is developing as a promising candidate for the fifth mobile radio generation (5G). Most importantly the available optical spectrum is extremely wide compared to radio communication. Additionally, low cost and high-power transmitters have become available with the boom of LEDs in lighting applications.

The focus of our research interest is on using optical free-space communication for indoor applications (like office buildings, aircraft cabins, and Industry 4.0), as well as for underwater scenarios. This enables many new applications. For example, robots may interact with each other in hostile environments by means of light. Furthermore, high-speed communication is enabled within a swarm of cooperating autonomous underwater vehicles (AUVs).

Molecular Communication (Martin Damrath). Due to recent progress in nanotechnology, so-called nanomachines becomes more and more realistic. Nanomachines are simple "machines" whose components have sizes of up to a few hundred nanometers. Thus they are limitated to a specific task they can perform, e.g. processing, sensing and actuation. To enable even more complex tasks like targeted drug delivery or health monitoring, an autonomous swarm of nanomachines, a nanonetwork, is envisioned. One of the key technologies regarding this swarm realization is the communication between nanomachines. However, the communication is very challenging with respect to the limitations of nanomachines in energy, size and complexity. Furthermore the biocompatibility should be given, to enable the operation in human body.

One promising approach to solve the communication task is molecular communication, which uses molecules as information carrier. Molecular communication not only guarantees biocompatibility, but also provides an energy efficient way to transmit information, because the molecules diffuse freely through the medium without spending any extra energy for propagation. However the diffusion-based channel is different to the classical radio-based channel and thus provides

different challenges. Our research is concentrated on the question, how we can adopt classical communication methods with the molecular communication approach.

In an initial step, a theoretical model for diffusion-based molecular communication has been proposed which provides a basis for our research. Classical channel coding, equalization and detection methods were applied to that model, as well as novel approaches. Furthermore, a macroscopic molecular communication testbed has been set-up to verify theoretical results by means of a practical implementation.

Resource Allocation in Cognitive Radio (Abdullah Yaqot). Due to increasing demands for new services and applications given the observation that nowadays the radio spectrum is scarcely used, reusing this partially occupied spectrum intelligently and opportunistically becomes a candidate solution: this is where the cognition concept comes in.

Cognitive radio (CR) is an intelligent communication strategy that adapts itself according to the surrounding environment. CR has the ability to reconfigure its transmission parameters such as modulation order, resource allocation, bandwidth, transmission power, etc. through programmable modules based on the software-defined radio principle. However, CR has limitations due to interference, mainly because of the coexisting primary radio on the same spectral and geographical area. Given a dynamic environment, CR has to offer reliable, seamless, and high-quality services in order to fulfil the requirements. Furthermore, CR has to manage the inter-user interference spectrally efficiently to be able to become a reliable technology for upcoming 5G networks. Motivated by the aforementioned, optimal resource allocation strategies can meet the required high data rates by developing spectrally efficient strategies for power and subcarriers as well as cutting-edge precoding designs.

By means of multicarrier and multiantenna structures (like MIMO and OFDM), some benefits can be gained such as beamforming and more degrees of freedom in subcarrier allocation. Moreover, the frequency selectivity can be mitigated. CR network could work with several primary technologies like WiMAX, LTE, GSM, CDMA, etc. if synchronization and channel knowledge issues are addressed accordingly. The main challenge in practical CR networks happens to be the trade-off between spectral and time efficiencies. Towards this goal, promising results have been obtained.

Personnel

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

Scientific Staff:

Dipl.-Ing. R. Adam Joint Navigation and Communication	01.04.2009-31.12.2015	DFG/CAU
Prof. Dr.-Ing. S. Badri-Höher Lecturer	01.10.2014-31.12.2015	FH Kiel
M.Sc. M. Damrath Molecular Communication	01.01.-31.12.2015	CAU
M.Sc. N. Doose Ultrawideband Communication	01.12.2013-31.12.2015	DFG
Dipl.-Ing. G. Forkel Visible Light Communications	01.10.2012-31.12.2015	CAU
Dr. rer. nat. A. Galka Lecturer	01.06.2009-31.12.2015	UKSH

Dr.-Ing. J. Mietzner Lecturer	01.10.2014-31.12.2015	Industry
M.Sc. A. Mourad In-Car Interference Cancellation	26.09.2014-31.12.2015	External PhD Student
Dipl.-Ing. (FH) J. Sticklus Optical Underwater Channel Modelling	15.12.2014-31.12.2015	GEOMAR
M.Sc. L. Wolff Sonar Processing	01.12.2013-31.12.2015	External PhD Student
M.Sc. A. Yaqot Convex Optimization for Cognitive Radio	01.10.2012-31.12.2015	DAAD
Dipl.-Wirtsch.-Ing. V. Zeiger Underwater Navigation	01.01.2010-31.12.2015	External PhD Student
M.Sc. S. Zhang Swarm Navigation	01.09.2014-31.12.2015	External PhD Student

Lectures, Seminars, and Laboratory Course Offers

Winter 2014/2015

Grundlagen der Kanalcodierung, 2 (+ 1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Information Theory and Coding I, 2 (+ 1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Advanced Wireless Communications (DSP), 2 (+ 1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Communications Lab, 4 hrs Practical/Week,
P.A. Hoeher (+ W. Rosenkranz, G. Schmidt, and Research Assistants)

Advanced Topics Lab, 4 hrs Practical/Week,
P.A. Hoeher (+ W. Rosenkranz, G. Schmidt, and Research Assistants)

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

B.Sc. Project, 3 hrs Seminar/Week,
P.A. Hoeher (+ and Research Assistants)

Radar Signal Processing, 2 (+ 1) hrs Lecture (+ Exercises)/Week,
J. Mietzner

Summer 2015

Theoretische Grundlagen der Informationstechnik, 2 (+ 1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Information Theory and Coding II, 2 (+ 1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Wireless Communications (DSP), 2 (+1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Real-time Signal Processing Lab, 4 hrs Practical/Week,
P.A. Hoeher (+ W. Rosenkranz, G. Schmidt, and Research Assistants)

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

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

B.Sc. Project, 3 hrs Seminar/Week,
P.A. Hoeher (+ and Research Assistants)

Winter 2015/2016

Grundlagen der Kanalcodierung, 2 (+1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Information Theory and Coding I, 2 (+1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Advanced Wireless Communications (DSP), 2 (+1) hrs Lecture (+ Exercises)/Week,
P.A. Hoeher (+ and Research Assistants)

Communications Lab, 4 hrs Practical/Week,
P.A. Hoeher (+ W. Rosenkranz, G. Schmidt, and Research Assistants)

Advanced Topics Lab, 4 hrs Practical/Week,
P.A. Hoeher (+ W. Rosenkranz, G. Schmidt, and Research Assistants)

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

B.Sc. Project, 3 hrs Seminar/Week,
P.A. Hoeher (+ and Research Assistants)

Radar Signal Processing, 2 (+1) hrs Lecture (+ Exercises)/Week,
J. Mietzner

Underwater Techniques, 2 (+1) hrs Lecture (+ Exercises)/Week,
S. Badri-Hoeher

Third-Party Funds

DFG, *Ultrawideband Communication based on Massive MIMO and Multimode Antennas for Mobile Terminals*,
01.12.2013-30.11.2016 (1xE13+Material and Travelling Expenses)

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:

- BMW, Munich
- German Aerospace Research Establishment (DLR), Oberpfaffenhofen
- Fraunhofer Institute for Integrated Circuits (FHG-IIS), Erlangen

- GEOMAR Helmholtz Centre for Ocean Research, Kiel
- Huawei Technologies, Shanghai
- subCtech, Kiel
- Tesat Spacecom, Backnang
- Universitätsklinikum Schleswig-Holstein (UKSH), Kiel.

Diploma, Bachelor's and Master's Theses

J.P. Janssen, *Optische Reichweitenerhöhung,* 17.02.2015
H. Flieger, *Amplitudenbasierte Positionierung mittels der Abstrahlcharakteristik von LEDs,* 23.02.2015
V. Gupta, *Radio Resource Management in Cognitive Radio,* 03.03.2015
N. Preinl, *Entwurf eines Datenmodems basierend auf magnetischer Induktion,* 25.05.2015
A. Musralina, *Signal Design and Evaluation for Electromagnetic Exploration of the Seafloor,* 26.05.2015
J. Ditzel, *Anwendung von Kanalcodierung im Bereich der molekularen Kommunikation,* 30.06.2015
F. Steinberg, *Datenübertragung mit weißen LED-Leuchten: Gesamtsystementwurf und Prototypentwicklung,* 21.09.2015
C. Baumann, *Entzerrung im Bereich der molekularen Kommunikation,* 03.11.2015

Dissertations / Postdoctoral Lecture Qualifications

M. Noemm, *Sonar Signal Design and Evaluation with Emphasis on Diver Detection,* 25.02.2015

Publications

Published in 2015

P.A. Hoeher, N. Doose, *A Massive MIMO Terminal Concept based on Small-size Multi-mode Antennas,* Trans. Emerging Telecommunications Technologies, **doi:10.1002/ett.2934**, (2015)

N. Doose, P.A. Hoeher, *Massive MIMO Ultra-Wideband Communications Using Multi-Mode Antennas,* in Proc. International ITG Conference on Systems, Communications and Coding (SCC), Hamburg, (2015)

M. Noemm, *Sonar Signal Design and Evaluation with Emphasis on Diver Detection,* Dissertation, University of Kiel, (2015)

M. Noemm, P.A. Hoeher, *CutFM Sonar Signal Design,* Applied Acoustics, doi:10.1016/j.apacoust.2014.10.011, **90**, 95 - 110 (2015)

G.F. Forkel, P.A. Hoeher, *Amplitude Modulation by Superposition of Independent Light Sources,* Proc. 6th International Conference on Optical Communication Systems, Colmar, France, doi:10.5220/0005542700290035, 29 - 35 (2015)

Further Activities and Events

Till December 2015, publications by Prof. Hoeher have been cited 10.000 times (Source: Google Scholar).