Information and Coding Theory

The research activities of the Information and Coding Theory Lab (ICT) of the University of Kiel are in the area of wireless digital communications. The main expertise is in the area of channel coding (Turbo codes, LDPC codes, decoding with reliability information, space-time codes), applied information theory, digital modulation schemes (adaptive modulation and channel coding, IDM, OFDM, DS-CDMA, IDMA), joint communication and navigation, and development of modern receiver algorithms (equalisation, channel estimation, synchronisation, interference rejection). Among the applications are cellular radio systems (GSM and UMTS enhancements, WLAN, LTE, LTE-Advanced), underwater acoustic communications, satellite radio, and terrestrial broadcasting systems.

The Information and Coding Theory Lab is member of the Wireless World Research Forums (WWRF), the Australian Communications Research Network (ACoRN) and the Excellence Cluster “The Future Ocean”.

Concerning teaching, we offer lectures and exercises in channel coding, information theory, and wireless communications I and II, partly in English language within the international master program on “Digital Communications”. A lecture on system identification is offered in form of a teaching assignment. Furthermore, seminars and labs are provided.

Results

Joint Communication and Navigation

Joint communication and navigation is getting a hot research topic. The interest to combine these two disciplines increases more and more because there are many synergy effects that can be exploited. For example there are advantages for resource planning, handover, or beamforming in mobile communications systems. Another important application is the automated localisation of emergency calls in order to improve the rescue services. But as promising the applications of joint communication and navigation are, as challenging it is to combine these techniques in one system with a unique signal design. This is exactly the problem ICT tries to solve.

The system concept proposed by ICT is based on Multi-Layer Interleave-Division Multiple Access (ML-IDMA), which is a very flexible multiple access scheme: With a simple transmission scheme the data rates can easily be adapted to changing channel conditions as encountered in mobile radio channels. As the requirements concerning signal design and signal processing are quite different for communication and navigation, a wide variety of topics was covered during this work: On one side, pulse shaping, channel coding, frame synchronisation and channel estimation were investigated for the proposed system model. On the other side, different positioning techniques and algorithms as well as suitable methods to extract the parameters needed for positioning from the transmitted signal were studied. Furthermore, channel modelling was an important issue that was examined. First promising results were achieved by Monte Carlo simulations.

Bandwidth and Power Efficiency of Interleave-Division Multiplexing

The demand for high-rate mobile communication is currently experiencing an explosive growth. Since the frequency spectrum is becoming a more and more expensive resource, future mobile systems are demanded to have high bandwidth efficiency. Besides, as mobile systems are mostly battery-driven, power efficiency is a critical concern as well. Interleave-division multiplexing (IDM), invented at ICT, is a new modulation technique which uses superposition to perform signal mapping. A big advantage of this scheme is that the quadrature components of the transmit signal are nearly Gaussian distributed, which is a desirable feature from an information theoretical point of view.

A thorough investigation is done on the power and bandwidth efficiency of IDM, and a deep insight into its performance limit is obtained. It is previously known that the bandwidth efficiency of IDM with equal power allocation and uniform phase allocation is limited by about 3 bits/s/Hz in two signal dimensions. During this work, we find that this is in fact a common misunderstanding. This 3 bits/s/Hz limit indeed comes from the receiver algorithm based on the Gaussian approximation instead of IDM itself. Given an optimal soft-output detector, IDM with equal power allocation and uniform
phase allocation can achieve a very high bandwidth efficiency. A limit is still not seen at 12 bits/s/Hz in a single-antenna scenario. On the other hand, theoretical as well as numerical analyses reveal the fact that unequal power allocation in conjunction with uniform phase allocation always degrades with respect to power efficiency. Combining the above results, the conclusion is that, for IDM with uniform phase allocation, there is not so much reason to apply unequal power allocation.

Multi-Carrier Interleave Division Multiplexing

Multi-carrier transmission, particularly orthogonal frequency division multiplexing (OFDM), is very popular today due to its ability of eliminating intersymbol interference with an affordable complexity. It is previously known that the supportable bandwidth efficiency of single-carrier IDM considerably drops if the channel is severely delay spread. Hence, it makes sense to investigate hybrid IDM-OFDM transmission schemes.

In this work, two types of hybrid IDM-OFDM transmission schemes are developed. The first one is direct concatenation of IDM and OFDM, which effectively solves the problem of intersymbol interference. Besides, the large spreading factor of IDM helps in retrieving the frequency diversity of the fading channel. The second one is a novel integration of IDM, OFDM, and adaptive modulation. Due to a more efficient utilisation of the bandwidth resource, this approach outperforms the first scheme in the sense of higher power efficiency. It is also found that, for adaptive modulation, IDM provides higher power efficiency and better granularity, compared to the conventional PSK/QAM schemes.

Graph-Based Soft Estimation of Fast Fading Channels

Often, a wireless device can be moving at a high velocity, e.g., in a high-speed train. In that case, the physical link between the transmitter and receiver will be rapidly time-varying, which presents a fundamental challenge for reliable channel estimation and data detection. Factor graphs and soft channel estimation are recently recognised as two powerful tools for the task of channel estimation.

In this work, an element-wise soft channel estimator based on a factor graph is developed. With a novel probabilistic model of the fading process of wireless channels, this estimator is able to track the time variation of fast fading channels in a very efficient manner. Since no matrix inversion is necessary, this estimator has very low computational complexity. Suitable training insertion schemes are also investigated. It is found that, the training superimposed burst structure enabled by using IDM is the best choice for tracking ultra fast fading channels.

Frame Synchronisation for IDM Systems

A promising transmission technique called Interleave-Division Multiplexing (IDM) recently became popular. IDM is a joint modulation/channel coding scheme. Characterised by layer-specific interleaving on chip level, IDM provides a high power and bandwidth efficiency.

Frame synchronisation is an important issue for IDM systems. The beginning of the frames should be determined before data detection and decoding in the receiver. Frame synchronisation can be accomplished by inserting pilot symbols in the frame. The pilot symbols can be time-division multiplexed (TDM) with the data symbols or superimposed with them. In IDM systems, the frame synchronisation efficiently can be performed by using a superimposed pilot layer. A correlation-based method is proposed both for frame synchronisation and channel estimation. Different pilot placements were investigated and compared. It is observed that good performance can be achieved by using the superimposed frame synchronisation method.

Unequal Error Protection for IDM Systems

In multimedia communications, text, audio signals, and video signals are multiplexed and jointly transmitted through communication networks. The transmitted information bits usually have different error sensitivity which requires different protection levels. In this case, unequal error protection (UEP) provides a more efficient solution than equal error protection.
IDM is well suitable to support unequal error protection. The layered structure of IDM makes it convenient for employing different UEP techniques. We investigated several UEP schemes based on different power allocation, different spreading factors, and different coding rates. The relationship between the mutual information within the IDM detector and the bit error rate is exploited, and the extrinsic information transfer (EXIT) chart is used for the analysis of the performance of these UEP schemes. Exhaustive Monte-Carlo simulations were avoided by using the EXIT chart assisted techniques.

**Mobile Underwater Acoustic Communications**

The need of underwater data transmissions exists in many application areas. Examples include communication to submarines, sensor data transmission, or communication to autonomous underwater vehicles (AUV). Underwater networks are a growing field of interest for cooperating sensors.

Because electromagnetic waves are affected by strong absorption in water, acoustic waves are often used for communications. But the underwater acoustic channel is very demanding compared to terrestrial or satellite radio channels. This is due to severe channel impairments corrupting communication signals. The transmission suffers from a slower and time-varying propagation speed of about 1500 m/s, which introduces large latencies. It also makes the signals more vulnerable to Doppler effects because the Doppler effect is determined by the relation of transmitter or receiver speed to the propagation speed of the carrier wave. The Doppler effect resulting from moving transmitters and/or receivers causes a certain frequency shift. But the transmitted signal is also subject to a random Doppler spread due to drifting transducers and moving reflective boundaries, i.e., the ocean surface. Moreover, the underwater acoustic channel shows a severe delay spread up to hundreds of milliseconds caused by many reflection paths and slow propagation, especially in shallow water environments.

In summary, the impairments to overcome are the multipath propagation, the delay spread, the Doppler spread, and the long latencies in a time-varying channel. Moreover, the usable bandwidths in the region of some kilohertz are comparably small.

Commercially available systems usually implement incoherent M-FSK modulation for robust communications, but with low bandwidth efficiency and small data rates. For higher data rates, coherent modulation formats are necessary to better utilise the limited bandwidth. Techniques well known from wireless terrestrial communications like multicarrier transmission or MIMO approaches are subject of research for adoption to underwater applications at ICT. The results are supposed to be evaluated also in practice in the Kiel harbour and during sea trials.

**Staff**

Head of the group: Prof. Dr.-Ing. P. A. Höher; Secretary: A. Kruse (50%), S. Schuchardt (50%)

Technical Staff: Dipl.-Ing. T. Rabsch (50%)

Scientific Staff:

  Cross-Layer Design, Interleave-Division Multiple Access
  Interleave-Division Multiplexing
  Joint Navigation and Communication
- Dipl.-Ing. C. Schröder 01.10.-31.12.2008 FWG  
  Kohärente UWK-Algorithmen für die UT 3000
  Graph-based Channel Estimation
Lectures, Seminars and Laboratories

Winter 2007/2008

Kanalcodierung, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
P.A. Höher (+ und Mitarbeiter)

Mobilmobilfunkkommunikation II, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
P.A. Höher (+ und Mitarbeiter)

Information Theory and Coding I, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
P.A. Höher (+ und Mitarbeiter)

Wireless Communications, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
P.A. Höher (+ und Mitarbeiter)

System Identification, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
W. Gerstacker

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

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

Informationstechnik und Codierung, 1 Std. Seminar/Woche,
P.A. Höher

Summer 2008

Informationstheorie, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
P.A. Höher (+ und Mitarbeiter)

Mobilmobilfunkkommunikation I, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
P.A. Höher (+ und Mitarbeiter)

Information Theory and Coding I, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
P.A. Höher (+ und Mitarbeiter)

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

Informationstechnik und Codierung, 1 Std. Seminar/Woche,
P.A. Höher

Winter 2008/2009

System Identification, 2 (+1) Std. Vorlesung (+ Übungen)/Woche,
I. Nissen

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

Advanced Topics Lab, 4 Std. Praktikum/Woche,
P.A. Höher (+ U. Heute, W. Rosenkranz, und Mitarbeiter)
Third-Party Funds

DFG, Multi-Layer Interleave-Division Multiple Access (HO 2226/9-1), 01.01.2007-31.12.2008 (123645 EUR)
DFG, Multi-Antenna Multi-Layer Interleave-Division Multiple Access (HO 2226/10-1), 01.07.2007-30.06.2010 (185468 EUR)
DFG, Gemeinsame Navigation und Kommunikation basierend auf Interleave-Division Multiple Access, 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, Kohärente UWK-Algorithmen für die UT 3000, 01.07.2008-30.06.2011 (270835 EUR)
Industry, Pilot Design for Multi-User MIMO OFDM Operating in Cellular Networks, 01.10.2008 (160000 EUR)

Other Cooperation, and Technology Transfer

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

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

Diploma, Bachelor and Master Theses

E. Ciplakoglu, Untersuchung und Minderung von Mehrwegeausbreitungseffekten für ein IDMA-basiertes Kommunikations- und Navigationssystem, 01.01.2008
R. Ramadane, Development of an Acoustic Underwater Modem, 01.01.2008
J. Qian, PAPR Reduction for Multi-Layer IDMA Systems, 01.03.2008
Ch. Schröder, MIMO Kanalmodellierung für DSL Nebensprechunterdrückung,, 01.03.2008
M. Gregory, Optimisation of Synchronisation Techniques of an Optical Free Space Transmission System taking into account Channel Coding Methods, 01.05.2008
N. Schrammar, User Selection in Multi-User-MIMO Systems, 01.06.2008
E. Mustafin, Frame Synchronisation for Multi-Layer Interleave-Division Multiple Access, 01.11.2008
Y. Wu, Unequal Error Protection for Interleave-Division Multiplexing Techniques, 01.11.2008
M. Noemm, On the Power Efficiency of Interleave-Division Multiplexing, 01.11.2008
R. Zhou, Multi-Antenna Interleave-Division Multiplexing for Ultra-Fast Fading Channels, 01.11.2008
Z. Shi, Multi-Antenna Multi-Carrier Interleave-Division Multiplexing, 01.11.2008
R. Kreimeyer, Entwicklung eines akustischen Mehrträger-Unterwassermodems, 01.12.2008
Publications

Published in 2008


Other Activities and Events

Prof. Dr.-Ing. Peter Adam Hoeher has been the Managing Director of the Institute of Electrical and Information Engineering from May 2006 till September 2008. He is proponent and member of the Excellence Cluster “The Future Ocean” of the University of Kiel. In 2008, he has been the vice chair of the German Chapter of the IEEE Communications Society (ComSoc), member of the VDE/ITG expert committee 5.1, member of the VDE/ITG professional groups “Algorithms for Signal Processing” and “Applied Information Theory”. In the winter term 2008/09 he enjoyed a sabbatical, which he partly spent at the City University of Hong Kong.

Dipl.-Ing. Kathrin Schmeink has been a tutor for pupils during the project “Power Girls” in July 2008. Since July 2008, she is a member of the Convent of the Faculty of Engineering.