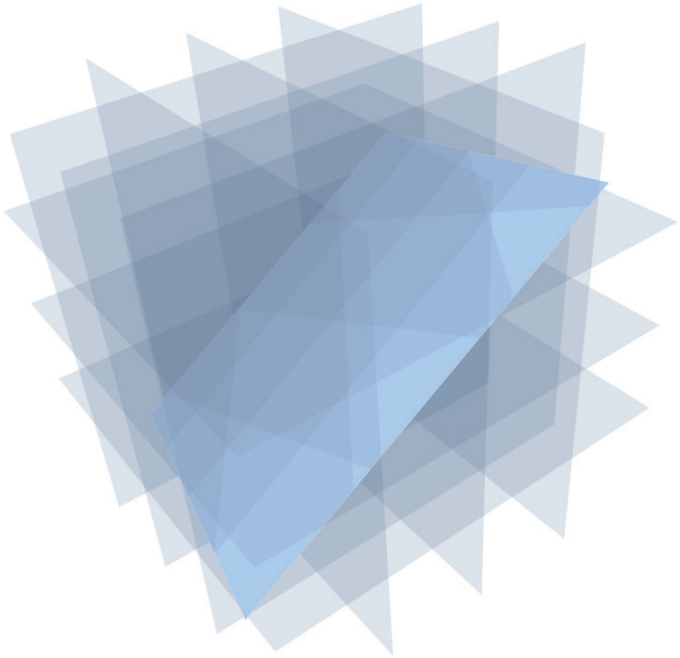
Tätigkeitsbericht 1.10.2016 - 30.9.2018

Lehr- und Forschungseinheit für Nachrichtentechnik
Institute for Communications Engineering

Lehrstuhl für Nachrichtentechnik
Chair of Communications Engineering

Professur für Leitungsgebundene Übertragungstechnik
Associate Professorship of Line Transmission Technology

Professur für Coding for Communications and Data Storage
Assistant Professorship of Coding for Communications and Data Storage



Technische Universität München

The cover design is by *Patrick Schulte* and the following text by *Lars Palzer*.

The figure illustrates the geometry of *Quantized Compressive Sensing*. Compressive Sensing is a recent mathematical theory that addresses the efficient acquisition and compression of natural signals. In many cases, these signals exhibit a certain lower dimensional structure. For example, images can often be represented by only a few Wavelet coefficients. More details on the back cover (inside).

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Wir danken Herrn *Leo Hausleiter* für die engagierte und angenehme Zusammenarbeit während der Herstellung dieses Heftes.

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Vorwort

Liebe Mitarbeiter und Freunde unserer Forschergruppen
LNT, LÜT und COD,

seit dem letzten Tätigkeitsbericht von Ende 2016 hat sich vieles und gleichzeitig auch wenig geändert. Das Jahresende ist ein guter Zeitpunkt, um über die jüngste Vergangenheit und die damit verbundenen Veränderungen nachzudenken.

Sie werden zunächst feststellen, dass sich das Berichtsformat geändert hat; die Broschüre ist schlanker geworden und enthält weniger Details. Der Hauptgrund ist der allgemeine Wunsch, den Aufwand für die Erstellung unseres Berichts zu reduzieren. Außerdem berücksichtigen wir, dass die Professuren

– LNT (Lehrstuhl für Nachrichtentechnik, Gerhard Kramer - siehe Kapitel 2),
– LÜT (Professur für Leitungsgebundene Übertragungstechnik, Norbert Hanik - siehe Kapitel 3) und
– COD (Professur für *Coding for Communications and Data Storage*, Antonia Wachter-Zeh - siehe Kapitel 4)

von unserer Fakultät verwaltungstechnisch in einer gemeinsamen Lehr- und Forschungseinheit zusammengefasst werden. Ich möchte hinzufügen, dass die Professur NAV (Lehrstuhl für Kommunikation und Navigation, Christoph Günther - siehe Kapitel 5) durch administrative Aufgaben und gemeinsame gesellschaftliche Veranstaltungen mit unserer Lehr- und Forschungseinheit verbunden ist und wie in der Vergangenheit auch in diesem Bericht wieder zu Wort kommt.

Beginnen muss ich dieses Vorwort mit einer traurigen Nachricht: Professor Hans Marko, Leiter des Lehrstuhls für Nachrichtentechnik über 31 Jahre von 1962 bis 1993, ist am 12. September 2017 im Alter von 92 Jahren verstorben. Auf der nächsten Seite folgt eine Würdigung seiner großen Verdienste für den LNT, die im Januar 2018 in der Broschüre TUMcampus erschienen ist. Viele seiner ehemaligen Kollegen und mehrere seiner 75 Doktoranden nahmen an der Beerdigung am 18.09.2017 in Gräfelfing teil, um sich an seine herausragenden Rollen als Forscher, Lehrer und Mentor zu erinnern.

In den beiden letzten Jahren gab es wieder mehrere personelle Veränderungen:

– Viele der Postdocs, die am LNT über längere Zeit forschten, haben uns 2017 verlassen. Sie gingen zu Universitäten in China und den USA oder arbeiten nun bei Unternehmen in Europa. Drei neue Dr.-Ing. haben ihre Dissertationen abgeschlossen und gute Jobs in München gefunden. Zwei neue Postdocs und acht neue Doktoranden kamen hinzu.
– Eine zweite wichtige Änderung im März 2018 war, dass Ingo Viering - seit 2004 CEO des LNT-Startups Nomor Research - Honorarprofessor der Fakultät für Elektrotechnik und Informationstechnik der TUM wurde. Ingo unterrichtet seit vielen Jahren einen Kurs für drahtlose Kommunikation im Masterstudiengang.
– Eine weitere wichtige Änderung Ende 2017 bestand darin, dass Georg Böcherer seine Habilitation abschloss und zu Huawei nach Paris ging. Sein Ausscheiden führte im Januar 2018 zur Einstellung von Christian Deppe von der Universität Bielefeld. Als neuer Akademischer Rat hat Christian neben der Lehre und Forschung viele administrative Aufgaben, und ich freue mich sehr, dass er unserer Gruppe beigetreten ist. Derzeit arbeitet Christian an der Theorie der Quanteninformation und leitet ein BMBF-Projekt zum Thema „Quantenrepeater“.
– Schließlich ist noch zu erwähnen, dass Rita Henn-Schlune Ende des Jahres in den Ruhestand treten wird. Wir danken ihr für ihre langjährige Arbeit am LNT und wünschen ihr für die nächste Phase ihres Lebens viel Glück!

Was aus den vielen und hochrangigen Preisen abgelesen werden kann, war unsere Lehr- und Forschungseinheit im Berichtszeitraum 2016-2018 sehr erfolgreich, siehe Kapitel 7. Zum Beispiel haben wir im März 2018 erfahren, dass Antonia Wachter-Zeh den Heinz Maier-Leibnitz-Preis der DFG 2018 gewonnen hat. Bald darauf erhielt sie einen *ERC Starting Grant*.

Auch in den letzten beiden Jahren haben wir etliche Veranstaltungen und Workshops (siehe Kapitel 6) organisiert,

1 Foreword Vorwort

– darunter 2016 den *Munich Workshop on Information Theory of Optical Fiber* (MIO-2016),
– den *Munich Workshop on Coding and Applications* (MWCA-2017) ,
– und schließlich den *Munich Workshop on Coding and Cryptography* (MWCC-2018).

Persönlich war ich besonders mit der Organisation des *IEEE International Symposium on Information Theory* (ISIT-2017) in Aachen und des *IEEE Information Theory Workshop* (ITW-2017) in Kaohsiung, Taiwan, beschäftigt.

Noch ein kurzer Ausblick auf die kommenden Jahre 2019 und 2020: Wir arbeiten weiter auf dem Gebiet der Informations- und Kommunikationstheorie, vielleicht mit etwas mehr Sicherheitsthemen und der Quantenkommunikation als neuem Thema. Bald werden viele unserer derzeitigen Doktoranden ihren Abschluss machen.

Abschließend danke ich allen Mitgliedern unserer Lehr- und Forschungseinheit für ihre Unterstützung und die geleistete Arbeit sowie für ihr Engagement für LNT, LÜT und COD.

München, im November 2018

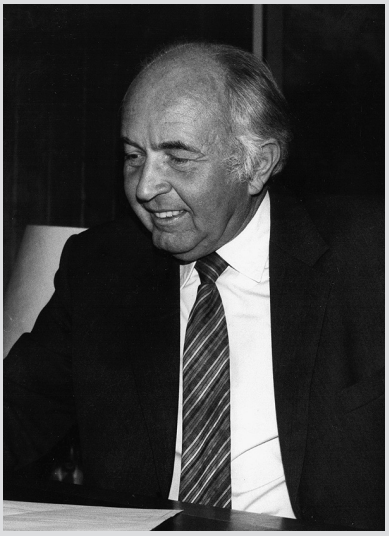
Gerhard Kramer

Hans Marko

Am 12. September 2017 verstarb Prof. Hans Marko, emeritierter Ordinarius für Nachrichtentechnik der TUM, im Alter von 92 Jahren.

Hans Marko, 1925 in Kronstadt/ Siebenbürgen geboren, studierte Nachrichtentechnik an der TH Stuttgart und promovierte 1953 bei Richard Feldtkeller. Anschließend arbeitete er bei der Standard Elektrik Lorenz AG und entwickelte eines der ersten Pulscodemodulations-Systeme Deutschlands. Nebenher hielt er Vorlesungen an den Hochschulen Stuttgart und Karlsruhe und verfasste seine Habilitationsschrift. 1962 wurde er mit erst 37 Jahren zum Leiter des neu geschaffenen Instituts für Nachrichtentechnik an die damalige TH München berufen.

Die von ihm und seinem Institut bearbeiteten Wissenschaftsgebiete umfassten unter anderem die Anwendung der Systemtheorie in technischen, biologischen und kybernetischen Systemen, deren mehrdimensionale Erweiterung auf Bildverarbeitung und Mustererkennung, die Weiterentwicklung der Shannonschen Informationstheorie zur bidirektional–orientierten Kommunikationstheorie sowie theoretische Untersuchungen und praktische Realisierungen hochratiger digitaler Übertragungssysteme über Kabel und Glasfaser.



Hans Marko war Autor und Herausgeber von zahlreichen Büchern und mehr als hundert Veröffentlichungen und Patenten. Viele hochrangige Ehrungen sind ihm zuteil geworden: »Fellow« des IEEE und Preisträger der Nachrichtentechnischen Gesellschaft, 1983 Karl–Küpfmüller–Preis der Informationstechnischen Gesellschaft im VDE, 1985 Ehrendoktorwürde der TH Darmstadt, 1994 Verdienstkreuz der Bundesrepublik Deutschland.

Wir nehmen Abschied von einem brillanten und bei seinen Schülern und Kollegen hochangesehenen Professor »der alten Schule«, der bis zu seiner Emeritierung 31 Jahre in Lehre und Forschung erfolgreich wirkte. Er betreute neun Habilitationen und 75 Promotionen. Auch nach seiner Emeritierung blieb Hans Marko seinem Lehrstuhl stets verbunden. Wir erinnern uns in Dankbarkeit und werden sein Vermächtnis stets in Ehren halten.

Gerhard Kramer, Norbert Hanik, Günter Söder

(erschienen in TUMcampus 1|18)

Dear Associates and Friends of LNT, LÜT, and COD,

1 Foreword Vorwort

Both much and little has changed since the last report, and the end of the year is always a good time to reflect on activities of the recent past. You might notice that the report format has changed, we are slowly moving towards a leaner booklet with less detail. The main reason is a general wish to reduce the effort needed to create such a report. Another change is that we now call ourselves a research and teaching unit, or a "Lehr- und Forschungseinheit" in German, which includes

- LNT (Chair of Communications Engineering, Gerhard Kramer - see Chapter 2)
- LÜT (Professorship of Line Transmission Technology, Norbert Hanik - see Chapter 3) and
- COD (Professorship of Coding for Communications and Data Storage, Antonia Wachter-Zeh - see Chapter 4).

I will add that the Professorship NAV (Chair of Communications and Navigation) led by Christoph Günther is associated with our research and teaching unit through administrative duties and social events.

I will continue with sad news: our former head Professor Hans Marko passed away at the age of 92 on September 12, 2017. The German text is on a nearby page, and I believe that some details will interest our English readers. Hans Marko was Chair at TUM for 31 years from 1962 until 1993, during which time he played a major role in the development of cybernetics and digital communications in Germany. His recognitions include IEEE Fellow, the first Karl Küpfmüller Prize of the Information Technology Society (ITG) of the Association of Electrical Engineering, Electronics and Information Technology (VDE) in 1993, an honorary doctorate from the Technical University of Darmstadt in 1985, and the Cross of Merit of the Federal Republic of Germany in 1994. He supervised nine habilitations and 75 doctorates. Several of his former colleagues and students attended his funeral in Gräfelfing to remember his oustanding roles as researcher, teacher, and mentor.

As every two years, there were several personnel changes at the research and teaching unit.

- For several years, we had many postdocs at LNT, but most left in 2017. They joined universities in China and the United States, or started working for companies in Europe. Three new Dr.-Ing. completed their dissertations and found good jobs in Munich. Two new postdocs and eight new doctoral candidates joined us.
- An important change in March 2018 was that Ingo Viering became an "Honorarprofessor" of the TUM Department of Electrical and Computer Engineering. Ingo has been teaching a Master-level course on wireless communications for many years, and he is CEO of the LNT startup Nomor Research since 2004.
- Another important change in late 2017 was that Georg Böcherer completed his Habilitation and joined Huawei in Paris. His departure led to hiring Christian Deppe from the University of Bielefeld in January 2018. As our new "Akademischer Rat", Christian has many administrative responsibilities in addition to teaching and research, and I am very pleased that he joined the group. He currently works on quantum information theory, and he leads a BMBF project on quantum repeaters.
- Finally, Rita Henn-Schlune will be retiring at the end of 2018. We thank her for her many years of service to the LNT, and we wish her much happiness in the next phase of her life!

The past two years have been unusually successful if one counts the number of unit members winning major prizes, see Chapter 7. For example, in March 2018 we heard that Antonia Wachter-Zeh won the 2018 Heinz Maier-Leibnitz Prize of the DFG, and soon thereafter she secured an ERC Starting Grant. Before that, she had won a TUM Institute for Advanced Study Hans Fischer Fellowship through which she hosted Prof. Camilla Hollanti from Aalto University, Finland, for several months.

Next, Georg Böcherer was awarded the Johann-Philipp-Reis Award of the VDE/ITG in 2017. Tobias Fehenberger won a 2018 ITG-Dissertation Award. Our former postdoc Mansoor Yousefi received the 2018 IEEE Information Theory Society Paper Award together with TUM Ambassador and TUM Hans Fischer Senior Fellow Frank Kschischang. The doc-

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toral researchers also received a variety of awards, you can read more about them in the report. Finally, Prof. Mari Kobayashi from Centrale Supélec was awarded a Humboldt Fellowship for Experienced Researchers, and she has been visiting LNT since the fall of 2017.

The last two years were again busy with events and workshops (see Chapter 6), including the

- 2016 Munich Workshop on Information Theory of Optical Fiber (MIO 2016),
- 2017 Munich Workshop on Coding and Applications (MWCA 2017), and the
- 2018 Munich Workshop on Coding and Cryptography (MWCC 2018).

Personally, I was especially busy with organizing the 2017 IEEE International Symposium on Information Theory (ISIT) in Aachen, and the 2017 IEEE Information Theory Workshop (ITW) in Kaohsiung, Taiwan.

As an outlook for 2019-2020, soon many additional doctoral students will graduate. We will continue to work on information theory and communications, with perhaps some more emphasis on security topics and, as a new topic, quantum communications.

Finally, as always, I would like to thank all members of our research and teaching unit for their support and hard work, and for their and your dedication to our research groups.

München, November 2018

Gerhard Kramer

Lehrstuhl für Nachrichtentechnik (LNT)
Chair of Communications Engineering

Gerhard Kramer et al.

2
LNT

The beginning of the *Chair of Communications Engineering* was in 1962, when the *Institut für Elektrische Nachrichtentechnik und Messtechnik* at the *Technische Hochschule München* (THM) was split into two independent units. Heads of the LNT were H. Marko (1962-1993), J. Hagenauer (1993-2006), R. Kötter (2007-2009) and G. Kramer (since 2010).

2.1 People

Scientific Staff

Kramer, Gerhard, Prof. Dr. sc. techn.	Professor and Chair
Hagenauer, Joachim, Prof. (i.R.) Dr.-Ing. Dr.-Ing. E.h.	Emeritus Professor
Hauske, Gert, Prof. (i.R.) Dr.-Ing.	Emeritus Professor
Deppe, Christian, Dr. Math. (since 01.01.2018)	Senior Researcher
Ferrara, Roberto, Dr. (since 01.08.2018)	Senior Researcher
Sidorenko, Vladimir, Dr.	Senior Researcher
Ahmadian, Amir, M.Sc.	Doctoral Researcher
Amjad, Rana Ali, M.Sc.	Doctoral Researcher
Coşkun, Mustafa Cemil, M.Sc. (since 01.03.2017)	Doctoral Researcher
Donev, Delcho, M.Sc. (since 01.02.2017)	Doctoral Researcher
García Gómez, Javier, M.Sc. (since 01.11.2016)	Doctoral Researcher
Günlü, Onur, M.Sc.	Doctoral Researcher
Jerkovits, Thomas, M.Sc. (since 01.11.2017)	Doctoral Researcher
Nedelcu, Andrei, M.Sc.	Doctoral Researcher
Palzer, Lars, M.Sc.	Doctoral Researcher
Pikus, Marcin, M.Sc.	Doctoral Researcher
Prinz, Tobias, M.Sc.	Doctoral Researcher
Schulte, Patrick, M.Sc.	Doctoral Researcher
Staudacher, Markus, M.Sc.	Doctoral Researcher
Steiner, Fabian, M.Sc.	Doctoral Researcher
Yuan, Peihong, M.Sc.	Doctoral Researcher

Left the chair during the reporting period

Bartz, Hannes, Dr.-Ing. (until 31.03.2017)	Doctoral Researcher
Böcherer, Georg, Dr.-Ing. habil. (until 30.11.2017)	Postdoc & Habilitation
Dierks, Stefan, Dr.-Ing. (until 30.09.2017)	Doctoral Researcher
Geiger, Bernhard, Dr. techn. (until 31.07.2017)	Postdoc
Wu, Yongpeng, Dr. (until 31.05.2017)	Postdoc
Wu, Youlong, Dr. (until 31.05.2016)	Postdoc

Our new colleagues at LNT

Mustafa Cemil Coşkun, M.Sc.,was born in Kayseri, Turkey, in 1991. He received the B.S. degree in Electrical and Electronics Engineering from Boğaziçi University, Turkey, and the M.Sc. degree in Communications Engineering from the Technical University of Munich (TUM) in 2014 and 2017, respectively. He is a member of the Institute for Communications Engineering (LNT) at TUM as a research assistant under the supervision of Prof. Kramer since 2017. His research interests are in the field of coding theory, with emphasis on short blocklengths and list decoders. Mustafa likes travelling and meeting people.

Dr. Christian Deppe was born in Herford, Germany in 1971. He received the Dipl.-Math. degree in 1996, and the Dr.-Math. degree in 1998, both from the Universität Bielefeld. His Ph.D. thesis was under the supervision of Prof. Ahlswede.

Christian was a research and teaching assistant with the Fakultät für Mathematik from 1998 to 2010. From 2011 to 2013 he was project leader of the BMBF project "Sicherheit und Robustheit des Quanten-Repeaters".

In 2014 he was supported by a DFG project at the Institute of Theoretical Information Technology, TUM. In 2015 he had a temporary professorship at the Fakultät für Mathematik und Informatik, Friedrich-Schiller Universität Jena.

Since January 2018 he is the administration manager at our Institute. His research interests are Quantum Information Theory and Combinatorial Coding Theory. In his leisure time Christian likes to play Badminton and Doppelkopf.

Dr. **Roberto Ferrara** was born in Venice, Italy, in 1987. Roberto graduated as a Bachelor student in Physics at the University of Padova and as a Master Student in Physics at the Niels Bohr Institute (NBI), University of Copenhagen. His Master's thesis studied new properties of private states in an effort to answer open questions when using quantum repeaters for quantum key distribution. Roberto graduated with a Ph.D. in the field of Quantum Information Theory at the Department of Mathematical Sciences, University of Copenhagen, under the supervision of Matthias Christandl. The dissertation is entitled „An Information-Theoretic Framework for Quantum Repeaters" and investigated the theoretical description of Quantum Repeater networks with a focus on Key and Entanglement Distribution, where part of the research interests included general entanglement measures.

In August 2018, Roberto joined the LNT as a Research Assistant of Prof. Kramer and Dr. Deppe. During the next three years he will study the identification capacities of quantum channels in various noise and attack models. In his free time, Roberto plays rugby with München RFC.

Delcho Donev, M.Sc., was born in Shtip, Macedonia, in 1991. He received his B.Sc. degree in Electrical Engineering and Information Technologies - Telecommunications from Ss. Cyril and Methodius University in Skopje in 2014 and his M.Sc. degree in Communications Engineering from TUM in 2016. His Master's thesis at LNT was on Polar-Coded Pulse Position Modulation for the Poisson Channel.

In February 2017, he joined LNT as a research assistant of Prof. Kramer. His research is supported by Munich Aerospace. His research interests are in the fields of information theory and efficient waveforms for short block length communications.

In his leisure time Delcho plays chess and guitar.

Javier García Gómez, M.Sc., was born in Valladolid, Spain, in 1992. He received the B.Eng. degree in Telecommunications Engineering at Universidad Politécnica de Madrid (UPM) in 2014, and the M.Sc. degree in Communications Engineering from the Technical University of Munich (TUM) in 2016. His

Master's thesis under the supervision of M.Sc. J. Munir and Prof. J. A. Nossek was on Linear and Non-Linear Estimation Methods for Single-Carrier and Multi-Carrier Coarsely Quantized MIMO Systems.

In November 2016, he joined LNT as a research assistant of Prof. Kramer. His research interests are information theory of nonlinear optical fibers and the Nonlinear Fourier Transform.

From July to September 2018, he was a summer intern at Nokia Bell Labs in Crawford Hill, NJ, USA, where he worked on the design of efficient multi-dimensional constellations for optical communications.

In his free time, Javier likes to hike, swim, learn languages and have wild and deep discussions about the meaning of life.

Thomas Jerkovits, M.Sc., was born in Kempten, Germany, in 1989. He received the B.Sc. degree in Electrical Engineering from Ulm University and the M.Sc. degree in Electrical Engineering from the Technical University of Munich (TUM) in 2013 and 2015, respectively. His Bachelor's thesis under the supervision of Dr. Alexander Zeh was on bounds on the minimum distance of cyclic codes, and his Master's thesis under the supervision of Dr. Gianluigi Liva and Dr. Balazs Matuz was on turbo code design using time-variant convolutional codes as constituent codes.

After his graduation at TUM in 2015, he joined the Satellite and Navigation department at the Institute for Communication and Navigation at the German aerospace center (DLR) as a research assistant. He continues to work on iterative and modern coding schemes for satellite applications, including turbo codes, LDPC codes, spatially coupled codes and polar codes. At the end of 2017 he joined the newly created post-quantum cryptography research group within the same department at DLR.

In 2017, he additionally joined LNT as a Doctoral Researcher and teaching assistant of Prof. Gerhard Kramer. His research interests are in the field of coding theory, with emphasis on code-based cryptography and their corresponding cryptanalysis.

In his free time, Thomas likes to hike, travel, listen to music and he enjoys to prepare some delightful meals.

Balázs Matuz was born in Budapest, Hungary, in 1982. He received his diploma in Electrical Engineering and Information Technology in 2007 from the Technische Universität München (TUM) and his Ph.D. degree (with distinction) in 2013 from the Technische Universität Hamburg-Harburg (TUHH). Since 2007 he has been a member of the scientific staff at the German Aerospace Center (DLR) in Oberpfaffenhofen, Germany. From 2014 till 2017 he was a co-lecturer at TUM for 'Channel Codes for Iterative Decoding'. Since 2018 he has been a co-lecturer for 'Coded Modulation'. His major interests are related to novel forward error correcting and modulation schemes for satellite and space communication systems. In his free time he enjoys renovating his home.

Fabian Steiner, M.Sc., was born in Prien am Chiemsee in December 1988. He holds a B.Sc. (2011) and M.Sc. (2014) in Electrical Engineering from the Technical University of Munich (TUM). Additionally, he completed his B.Sc. in Management and Technology also from TUM in 2012. During his studies, he spent several months in the US doing research at the Stevens Institute for Technology, Hoboken, NJ, and at Stanford University, Stanford, CA. After graduating with his Master's thesis on „LDPC code design for bit-metric decoding" under the supervision of Dr. Böcherer and Dr. Liva, he joined the professorship of Prof. Utschick to conduct research on coarsely quantized massive MIMO systems, before returning to LNT in September 2016 to fully indulge his passion for designing capacity achieving error correction codes and modulation schemes. He is teaching assistant for „Channel Codes for Iterative Decoding" and „Machine Learning for Communications".

Fabian likes hiking in the Alps, mountain-biking and traveling around the world by any means of transport (by boat on the Cuyabeno river in Ecuador, motor bike in Cambodia and busses in Myanmar).

Lecturers and Guest Scientists

Bartz, Hannes, Dr.-Ing. (since 01.04.2018)	DLR, Oberpfaffenhofen
Kobayashi, Mari, Prof. Dr.	CentraleSupélec, France
Kubin, Gernot, Prof. Dr. techn.	TU Graz, Austria
Liva, Gianluigi, Dr.	DLR, Oberpfaffenhofen
Matuz, Balàzs, Dr.-Ing. (since 01.04.2018)	DLR, Oberpfaffenhofen
Söder, Günter, Apl. Prof. (i.R.) Dr.-Ing. habil.	LNT (retired)
Viering, Ingo, Hon. Prof. Dr.-Ing.	Nomor Research

Non-Scientific Staff

Dorn, Doris	Verwaltungsangestellte
Henn-Schlune, Rita	Sekretärin
Herian, Erika	Offiziantin
Roßmann, Nicole	Verwaltungsangestellte
Schetterer, Robert	Systemadministrator

Left the chair during the reporting period

Kontny, Martin (until 31.07.2017)	Elektroniklabor

Research and Student Work

Susmit Bhattacharjee, Abhijit Danappa, Muhammed Efe, Timothèe Felicio, Muhammad Firas Hammosh, Nikolai Kadrileev, Rayyan Khan, Arda Can Özensoy, Ayush Patel, Aritra Ray, Bilal Uzun, Lukas Wolf, Rui Zhu

2.2 Research

Overview Gerhard Kramer →

p. 10 Shaping for Coded Modulation

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p. 13 MIMO and Massive MIMO

p. 14 Compressed Sensing, Machine Learning, and Security

p. 15 Optical Communications

This chapter reviews LNT's research activities from October 2016 until September 2018. During this time, four postdocs left and two doctoral researchers graduated. We also hired new researchers: Christian Deppe, Roberto Ferrara, and four doctoral candidates joined the chair.

The four postdocs Georg Böcherer, Bernhard Geiger, Yongpeng Wu, and Youlong Wu all left in 2017. Georg completed his Habilitation and immediately joined Huawei in Paris. Bernhard returned to Graz to complete his Schrödinger Fellowship. Yongpeng was with us only briefly on a Humboldt Fellowship, and he quickly joined Shanghai Jiao Tong University as a Research Professor. Shortly before that, Youlong had joined ShanghaiTech University as an Assistant Professor. Additionally, Shirin Saeedi Bidokhti completed her SNSF Fellowship at Stanford in 2017 and joined the University of Pennsylvania as a research assistant professor. We wish them much success in their academic and industrial careers, and we hope to see them in Munich again soon.

The two doctoral candidates who completed their theses were Hannes Bartz and Stefan Dierks. The following describes their work briefly; you will find detail on page 20 and 21.

First, *Hannes Bartz* had his Dr. Ing. exam in April 2017. Hannes worked on the topic of *Algebraic Decoding of Subspace and Rank-Metric Codes*. The idea of these codes is to transmit information in the choice of a subspace or matrix rather than in the choice of a vector. Subspace codes have been applied to authentication, secrecy, distributed storage, and matrix recovery, for example. *Prof. Danilo Silva* of the *Federal University of Santa Catarina* served as the 2nd examiner.

Stefan Dierks had his Dr. Ing. exam in February 2018. His thesis title was *Multiple Antenna Precoding: Indoor Communications and EIRP*, where the acronym is for "equivalent isotropically radiated power". The thesis topic is massive MIMO, and its contributions are divided into two main parts. The first part analyzes the performance of precoding and cooperation schemes in an indoor office environment. The second part develops a new upper bound on EIRP that is simpler to compute than existing methods. *Prof. Emil Björnson* from *Linköping University* served as the 2nd examiner, and Prof. Mari Kobayashi from *CentraleSupélec* was the 3rd examiner.

We welcomed Christian Deppe from the University of Bielefeld in January 2018. His main research areas are quantum information theory and combinatorial coding theory. He won a BMBF project on quantum repeaters in 2018, and this let us hire Roberto Ferrara from the Niels Bohr Institute at the University of Copenhagen. Roberto will be working on identification capacities of quantum channels.

We welcomed four new doctoral candidates since the last report: *Mustafa Cemil Coşkun*, *Delcho Donev*, and *Javier García* completed the TUM MSCE program in 2016 and joined LNT. *Thomas Jerkovits* completed his Master's degree and joined DLR in 2016, where he is mainly supervised by Dr. Gianluigi Liva. The other members of LNT mostly continued the work described in the last report. Their topics can briefly be summarized as follows.

- *Amir Mehdi Ahmadian* (p. 13): precoding and interpolation algorithms for massive MIMO channels and coordinated multipoint.
- *Rana Ali Amjad* (p. 14): theory and algorithms for Markov aggregation, co-clustering, and machine learning.
- *Mustafa Cemil Coşkun* (p. 12): low-complexity message-passing decoders, low-latency coding and channel estimation.
- *Delcho Donev* (p. 12): coded modulation for Poisson channels, waveforms for low-latency communications.
- *Javier García* (p. 15): nonlinear Fourier transform, capacity, and signal processing for optical fiber channels.
- *Onur Günlü* (p. 14): privacy, security, and codes for physical unclonable functions (PUFs).
- *Thomas Jerkovits* (p. 12): tailbiting convolutional codes, post-quantum cryptgraphy.
- *Andrei Nedelcu* (p. 13): low-precision precoding for massive MIMO downlinks, matching circuits for MIMO.
- *Lars Palzer* (p. 14): distributed compressed sensing and vector quantization for sparse sources.

- *Marcin Pikus* (p. 10): shaping algorithms for higher order modulation.
- *Tobias Prinz* (p. 11): higher order modulation and decoding algorithms for polar codes and their generalizations.
- *Patrick Schulte* (p. 10): design of codes and probability distribution matching algorithms.
- *Markus Staudacher* (p. 13): capacity and waveforms for joint communications and sensing.
- *Fabian Steiner* (p. 11): decoder optimization for binary and non-binary LDPC codes.
- *Peihong Yuan* (p. 11): algorithms for polar codes and list decoding.

As usual, the doctoral researchers had substantial teaching duties in addition to their research, and they helped to organize many events. For example, since the last report the LNT organized eight workshops in addition to co-organizing ISIT 2017 in Aachen and ITW 2017 in Kaohsiung, Taiwan. Of course, these tasks slow down research, and perhaps the added time helps to develop better results. Certainly the postdocs and doctoral candidates have had good success in gathering important recognitions, including a VDE-ITG Johann-Philipp-Reis Award in 2017 and an IEEE Information Theory Society Paper Award in 2018.

2
LNT

Shaping for Coded Modulation

Georg Böcherer, Marcin Pikus, Patrick Schulte, Gerhard Kramer

The shaping gap is the difference between the channel capacity and the information rate for uniform signaling. Approaches to overcome the shaping gap can be divided coarsely into two groups, namely:

- Probabilistic shaping
- Geometric shaping.

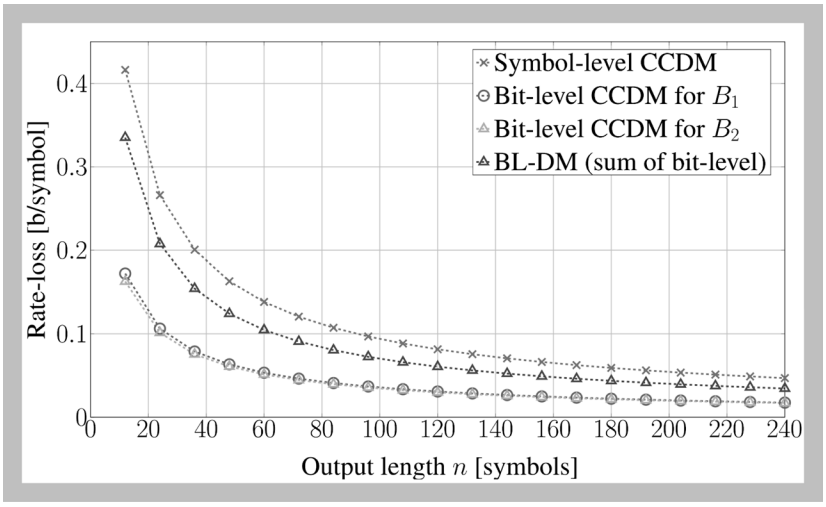
Geometric shaping places constellation points unevenly to form a desired distribution at the channel output.

Probabilistic shaping tries to adapt the statistics of evenly spaced constellation points, i.e., ASK or QAM constellations. In 2014 a new coded modulation scheme was proposed that modifies existing schemes by adding a new module called a distribution matcher. This module transforms a uniformly distributed input sequence of bits into a sequence of symbols with a desired empirical distribution. Thus, it preselects a subset of codewords from a code. Information about the distribution helps the decoder to recover the original message.

Our group is interested in understanding how to build efficient encoders and decoders for this coded modulation scheme. At the same time, we have developed various block-to-block distribution matchers such as the constant composition distribution matcher (CCDM). CCDM is based on arithmetic coding and puts out sequences with the same empirical distribution. Although this restriction seems to limit the distribution matcher, the maximum achievable rate is reached asymptotically.

Distribution matchers have been applied and adapted to several practical problems. For example, optical channels permit long blocks but the computational complexity must be minimized and is ideally split among units that work in parallel. We proposed two classes of algorithms: bit-level probabilistically shaped coded modulation and product distribution matching. Both techniques use a binary distribution matcher to reduce complexity.

Wireless communication systems, on the other hand, use intermediate block lengths. In this regime CCDM suffers excessive rate-loss due to its restricted output. We proposed several algorithms that outperform CCDM and have reasonable complexity. Multi-composition distribution matching (MCDM) uses arithmetic coding and combines all sequences of any empirical distribution. Shell mapping distribution matching (SMDM) implicitly orders sequences according to a symbol-wise defined weight function, e.g., the energy of constellation points, and uses only those with low weight. For future work we plan to investigate other algorithms with very low computational complexity, and hope to obtain solutions that can be implemented efficiently in hardware.



Comparison of various distribution matcher algorithms

Literature:

[1] Böcherer, G.; Steiner, F.; Schulte, P.: Bandwidth-efficient and Rate-matched Low-density Parity-check Coded Modulation. IEEE Trans. Commun. Vol. 63, no. 12, pp. 4651-4665, Dec. 2015

LDPC & Polar Codes

Tobias Prinz, Fabian Steiner, Peihong Yuan, Gerhard Kramer

In December 2017, 3GPP, the standardization body for the upcoming 5G standard, chose low-density parity-check (LDPC) and polar codes as the preferred forward error correction solution. While LDPC codes will be used for the enhanced mobile broadband (eMBB) profile, polar codes are considered for reliably transmitting data for the control channels.

Our group closely follows the standardization and adopted these codes for comparisons and state-of-the-art references in our publications. In our research on LDPC and polar codes, we are interested in their information theoretic foundations, and their practical aspects. We contribute to several industry projects and collaborations. Our research is currently focused on the following directions.

LDPC Codes

We design optimized LDPC codes for probabilistic amplitude shaping (PAS), a coded modulation technique invented at LNT (by G. Böcherer, P. Schulte and F. Steiner) that allows to overcome the shaping gap and operate close to the Shannon limit with unprecedented rate flexibility.

We design non-binary LDPC codes for short blocklengths and show how to use them in a flexible way with higher order modulation. Even if their decoding is computationally more demanding, they may play an important role for ultra-reliable low-latency communication (URLLC) which aims for low frame error rates (below 10^{-6}) and low latencies.

We analyze and improve the belief-propagation decoding algorithm with a coarse quantization of the messages between variable and check nodes for high throughput communication systems (e.g., optical communications). These finite alphabet message passing decoders have an efficient internal data flow.

Polar Codes

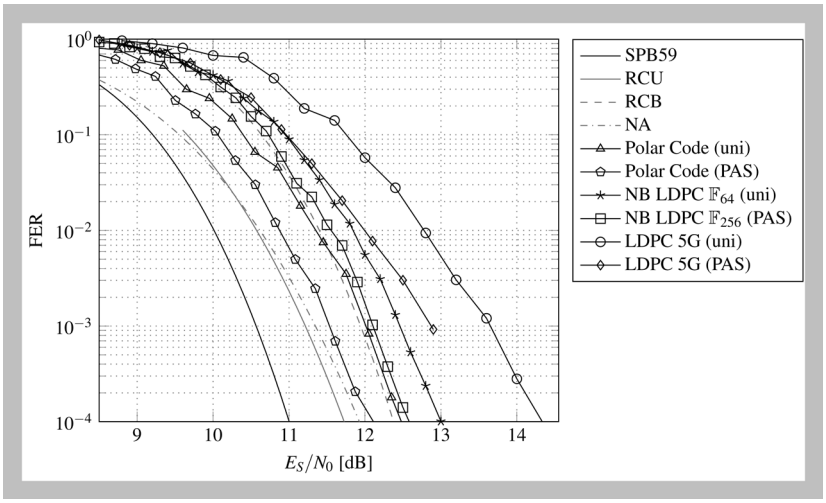
We design polar codes for higher order modulation. To show competitive performance, polar codes must be decoded with a successive cancellation list decoder and an outer CRC code. However, the parameter choices for the list size and the CRC code parameters are not straightforward. We developed good heuristics to select those.

We investigate non-binary polar codes, explain their construction principles and compare them to binary counterparts.

Polar codes can be considered in a broader context, with other polarization matrices than Arıkan's original 2x2 kernel. For example, BMERA codes have a better error exponent and an improved distance spectrum so that a CRC can be shorter.

In all aspects, we use and further extend information theoretic tools, such as finite length achievability and converse bounds, and compare to the best known rates.

We use a state-of-the-art simulation cluster with more than 200 Xeon CPUs and several GPUs to meet the challenging demands of extensive simulation campaigns and to verify our theoretical findings experimentally. We use high performance computing libraries (Intel MKL, OpenMP, OpenMPI and Nvidia's Cuda framework). Simulations are also run on the LRZ supercomputing cluster.



Comparison of state-of-the-art coding schemes for higher-order modulation, a target operating spectral efficiency of 3.0 bpcu and 64-QAM

2
LNT

Coded Modulation for Satellite Links

Mustafa Cemil Coşkun, Delcho Donev, Thomas Jerkovits, Gerhard Kramer

This project encompasses two main research topics. The first topic is the design of optimal waveforms for short block length transmissions with time and bandwidth constraints, and upper and lower bounds on the finite block length capacity. We use Prolate Spheroidal Wave Functions (PSWFs) to design the waveforms, and we introduce time and bandwidth constraints to guarantee low interference on other transmissions. The PSWFs are optimal in the sense that they are the waveforms that have most of their energy inside a given time interval and bandwidth. We modify Shannon's sphere packing bound (SPB) to include these time and bandwidth constraints. This work led us to explore the problem of the intersection of spherical hypercaps on an n-dimensional hypersphere. We compared the bounds for different waveforms.

We also tackled the problem of interference when consecutive transmissions occur, and we explore the capacity loss incurred. We then explore the effect of feedback and the optimal time placement of the feedback information from an information theoretic viewpoint.

The second topic is the tailored design of channel codes for short to medium information blocks, which means from a few tens up to a few thousands of bits. The interest in the topic has been rising recently, mainly due to the development of the 5G mobile communication system and other emerging applications such as machine-type communications (MTC). These kinds of applications often have stringent requirements on reliability and latency, which is referred to as ultra-reliable and low-latency communications (URLLC). The design of good short error correcting codes is crucial for such applications.

Unfortunately, most classic code constructions and tools focus on long block lengths, and they tend to fail in the short block length regime. On the other hand, at short block lengths coding schemes and decoding algorithms become viable that would otherwise require too high complexity, e.g., tail-biting convolutional codes with large memories under wrap-around Viterbi algorithm (WAVA) decoding, polar codes with successive cancelation list decoding (SCL) concatenated with an outer error detecting code, and algebraic codes such as BCH codes with ordered-statistics decoding (OSD). In addition to these, non-binary LDPC codes are a strong competitor if higher complexity is permitted.

Although short codes have been investigated for the AWGN channel by many groups, the tools for designing error-correcting codes are still not completely understood for important classes of models such as fading channels. One part of the project focuses on understanding theoretical benchmarks for these scenarios, as well as designing practical codes together with efficient decoding algorithms to approach the limits.

An important example is how to efficiently communicate over block-fading channels, which is relevant for OFDM-based schemes in LTE or 5G. When the blocks are long, one can afford to use many pilots to estimate the channel. However, the estimation cost is expensive for short blocks, making it difficult to reach the limits of non-coherent communication. For such scenarios, the number of pilots to achieve the best performance for given requirements depends strongly on the algorithms adopted. Recently, we have been investigating the benefits of list decoders, e.g., OSD and SCL decoding, which can reduce the number of pilots. Together with efficient signaling, this may enable current systems to perform close to the limits of non-coherent communications. One of our targets is to generalize efficient list decoding algorithms to different code classes.

Another interesting question is whether one should use a low rate code with a higher order modulation or vice versa. The choice of signaling depends on the power regime in which the system operates, e.g., flash signaling is efficient at low powers for block-fading channels.

Literature:

Östman, J.; Durisi, G.; Ström, E. G.; Coşkun, M. C.; Liva, G.: Short Packets over Block-Memoryless Fading Channels: Pilot-Assisted or Noncoherent Transmission? *In*: IEEE Trans. Comm., Jan. 2018

MIMO and Massive MIMO

Amir Ahmadian, Andrei Nedelcu, Markus Staudacher, Gerhard Kramer

Massive multiple-input multiple-output (massive MIMO) uses large antenna arrays at base stations to serve many users that each have a small number of antennas. The gains of massive MIMO include improved power and spectral efficiencies, and simplified signal processing. The gains are often stated for a large number N of base station antennas and a large number K of user equipments (UEs) when the ratio N/K is held constant.

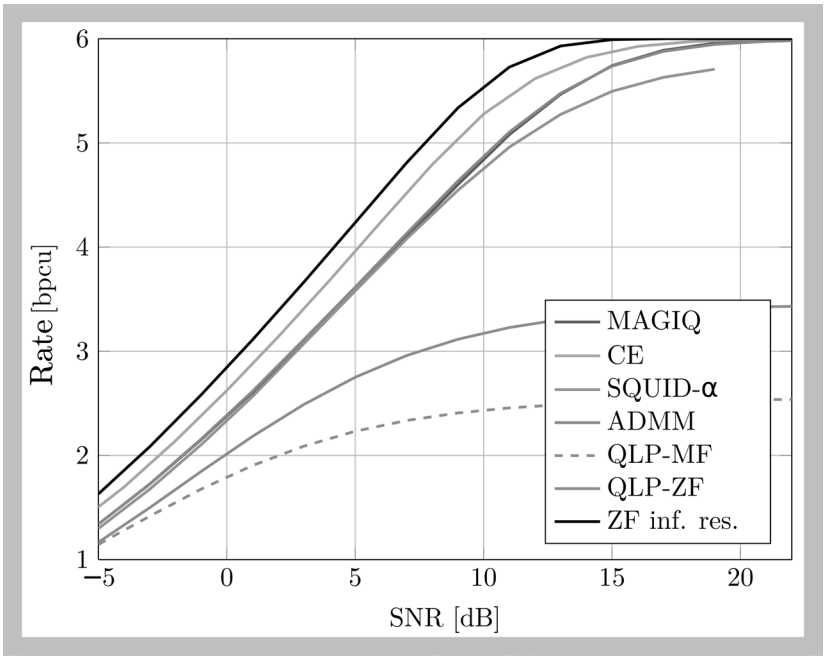
Practical implementation of massive MIMO is challenging. For example, consider a base station deployment where every antenna has a radio frequency (RF) chain. It seems impractical to use high-resolution analog-to-digital and digital-to-analog converters (ADCs/DACs), along with linear but low-efficiency power amplifiers.

Two solutions are as follows. First, hybrid-beamforming uses analog beamformers in the RF chain of each antenna, and the digital baseband processing is shared among different RF chains. Second, low-resolution ADCs/DACs simplify transceivers, e.g., one bit quantizers use simple comparators and they might permit using non-linear power amplifiers. We focus on the second approach, since the DAC and ADC are major power sinks at baseband, and also mixed-signal components whose integration and design are difficult.

Applying a MMSE precoding design criterion, we observe that the optimization problem is not convex, unlike the optimization of classic linear MMSE precoders. The objective function turns out to be biconvex in the transmit signal and the precoding factor, meaning that for a fixed transmit signal the function is convex in the precoding factor, and vice-versa. Next, the constraint set is a bounded discrete Cartesian product set, which gives a combinatorial problem.

The case of one bit quantization DACs can be reformulated as a quadratic binary minimization problem, which is known to belong to the class of NP-hard problems. We thus consider approximation algorithms. Existing algorithms such as ADMM and SQUID take a convex relaxation approach based on the good behavior of the cost function (convex, continuous, Lipschitz), which guarantees that the approximated solution is near the optimum.

We take another approach that is based on coordinate minimization. While the minimization over all coordinates of the transmit signal is expensive, the minimization of each coordinate individually requires only few function evaluations. We call this algorithm MAGIQ (Multi Antenna Greedy Iterative Quantized) MIMO. The figure shows a lower bound on the mutual information obtained by several nonlinear and quantized linear precoders and showcases the superiority of nonlinear techniques.



Rates for 64-QAM with N=128 and K=16

Compressed Sensing, Machine Learning, and Security

Ali Rana Amjad, Onur Günlü, Lars Palzer, Gerhard Kramer

Compressed Sensing is a relatively young mathematical theory that improves the efficiency of signal acquisition systems. This has led to many advances in applications such as medical or satellite imaging. Such acquisition devices employ quantization to store signals digitally. In our work, we are studying both the fundamental performance limits and the performance achieved by specific measurement systems and algorithms.

Recently, we investigated tradeoffs in distributed compressed sensing systems with one-bit quantization. In our model, several signals that share a common structure are measured independently by different devices but reconstructed together. This model applies to, e.g., wireless sensor networks where low-complexity sensor nodes measure correlated signals that are transmitted to central processing units. By considering one-bit quantizers, we let the acquisition systems consist of cheap hardware. We proved that by exploiting the common structure of the signals, the number of measurements in each sensor can be significantly reduced, permitting an even lower hardware complexity at each node.

In addition to the problem of reducing the number and complexity of measurements at each sensor node, we are interested in the security and privacy of sensors and other physical devices.

We consider a physical unclonable function (PUF) that is a challenge-response mapping embodied by a physical device. Its responses should be easy to evaluate, but it should be difficult to determine its response to a random challenge, even if an attacker has a list of other challenge-response pairs. PUFs are used for on-demand secret key generation. This secret key can be used for device authentication and identification, similar to biometric secrecy systems for user authentication and identification.

We approach the problem of developing methods for PUFs in three steps:

(1) we consider practical PUF types and statistically model their responses;
(2) we design transform-coding algorithms to eliminate correlations and to improve the signal-to-noise (SNR);
(3) we develop code constructions for the transform-domain outputs that are information-theoretically tractable.

These steps allow us to build complete secrecy systems that use PUFs to generate secret keys on demand with close to optimal trade-offs among the secret-key, privacy-leakage, and storage rates. As in many other practical designs, information-theoretic optimality comes at the cost of hardware complexity, e.g., a large hardware area for PUFs. We also develop suboptimal but low-complexity algorithms that perform well in practice.

Finally, we study the application of tools from information theory and coding theory to problems in machine learning and data science.

For unsupervised learning, we study two different problems. The first problem deals with Markov aggregation and co-clustering. We proposed a new information theoretic cost function and optimization heuristic for Markov aggregation and studied the application of this framework to the co-clustering problem. We showed that the most effective existing information theoretic co-clustering methods are special cases of our framework. Hence our co-clustering also provides a deeper understanding about the relationships among the previously proposed methods. It also allows us to fairly compare among these methods and study their strengths and weaknesses in a unified manner. The second problem deals with clustering using pairwise similarities. We extended a recently proposed clustering algorithm "Affinity Propagation" and we address its shortcomings, such as lack of global structure discovery, while keeping the attractive features, such as no need for initialization.

In the supervised learning domain we are studying the application of information theoretic measures to design and analyze deep neural networks. For design we studied the information bottleneck principle for training deep neural networks. For analysis, we look at the use of different information measures to rank the importance of individual neurons in an already trained neural network.

Optical Communications

Javier García Gómez and Gerhard Kramer

Fiber optic cables form the backbone of our global communication networks. A useful description of waveform propagation in optical fiber is given by the non-linear Schrödinger equation (NLSE). However, its form does not provide easy insight into information theoretically relevant quantities such as capacity. Meanwhile, the use of standard linear techniques for information transmission over optical fiber has reached a capacity peak. To address the ever increasing demands for data rate, it is necessary to design transmission schemes that take into account the nonlinearity of the fiber.

One of the consequences of the channel nonlinearity is the broadening of the frequency spectrum of the transmitted signals during propagation, which causes interference between channels. Therefore, we consider a modified channel model (*brick-walls filters*) that includes a bandwidth constraint along the fiber [1]. This is a limiting case of a system which has regularly spaced band-pass filters, when the distance between filters goes to 0. We showed that this model preserves the energy of the propagating signal, and we found conditions that ensure interference-free propagation. This makes the model worth considering for communications systems. Several challenges remain, such as the information theoretic analysis of this model and the evaluation of the effect of non-zero filter spacing.

Another tool that has been proposed to overcome the capacity peak is the nonlinear Fourier transform (NFT), which transforms the NLSE into a linear, multiplicative channel. In addition to providing eigenfunctions of the NLSE channel (solitons, see graph), the NFT enables the use of multiplexing techniques such as nonlinear frequency division multiplexing (NFDM) that provide interference-free channels.

However, NFT communication still has too low spectral efficiency to compete with standard wavelength division multiplexing systems. To address this issue, we have developed an extended transmission scheme that uses additional degrees of freedom of the NFT for communication [2].

Another shortcoming of the NFT is that it cannot model the optical noise. We have worked with Bell Labs Stuttgart to investigate solitonic signals and derive a method to predict the statistics of their parameters in the presence of additive time-domain noise [3].

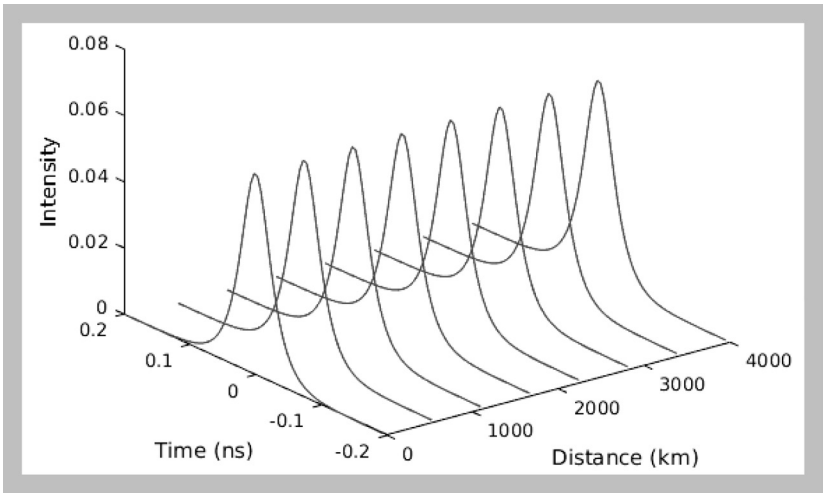
We plan to continue working on the brick-walls filters and the NFT, focusing on improving the achievable rate and finding bounds on the capacity.

Literature:

[1] García, J.; Ghozlan, H.; Kramer, G.: Energy Conservation in Optical Fibers with Distributed Brick-Walls Filters. In: *J. Lightw. Technol.* 36 (9), May 2018, 1626-1633

[2] García, J.: Communication Using Eigenvalues of Higher Multiplicity of the Nonlinear Fourier Transform. In: *ArXiv e-prints*, Feb. 2018

[3] García, J.; Aref, V.: Statistics of the Eigenvalues of a Noisy Multi-Soliton Pulse. In: *ArXiv e-prints*, Aug. 2018



Solitons: The eigenfunctions of the optical channel

This chapter lists the twelve externally-funded research projects of the Chair of Communications Engineering (LNT) in the reporting period 10/2016-09/2018:

- two projects → (A), (B) from the Helmholtz Association (HGF Alliance) with respect to coding;
- four projects → (C) – (F) from the Deutsche Forschungsgemeinschaft (DFG) on physical-layer security, compressed sensing, optical fiber capacity, and cooperative communications.
- one project → (G) from the German Federal Ministry of Education and Research (BMBF) on quantum communications;
- two projects → (H), (I) with the Huawei European Research Center on low latency coded modulation;
- three projects → (J) – (L) with Nokia Bell Labs on massive MIMO precoding.

Five of these projects started before 01.10.2016 and eight projects continue beyond the end of the reporting period (30.09.2018).

The project (E) is a joint project of LNT and LÜT (Prof. Hanik) and (F) is a joint project of LNT and COD (Prof. Wachter-Zeh).

2.3 Projects

(A) Network Coding

Project Team: Fabian Steiner, Patrick Schulte, Dr. Böcherer and Prof. Kramer
Funding Period: 01.01.2012-31.12.2016
Reporting Period: 01.10.2016-31.12.2016
Funding Agency: Helmholtz-Gemeinschaft (HGF-Allianz)
DLR@Uni – Munich Aerospace
Project Partners: Dr. Munari, Dr. Liva, Dr. Berioli,
Institute for Communications and Navigation, German Aerospace Agency (DLR)

(B) Efficient Coding and Modulation for Satellite Links with Severe Delay Constraints

Project Team: Delcho Donev, Mustafa Cemil Coşkun and Prof. Kramer
Funding Period: 01.01.2017-31.12.2019
Reporting Period: 01.01.2017-30.09.2018
Funding Agency: Helmholtz-Gemeinschaft (HGF-Allianz)
DLR@Uni – Munich Aerospace
Project Partners: Dr. Liva, Dr. Matuz,
Institute for Communications and Navigation, German Aerospace Agency (DLR)

(C) Information Theory and Recovery Algorithms for Quantized and Distributed Compressed Sensing

Project Team: Lars Palzer and Prof. Kramer
Funding Period: 01.01.2016-31.12.2018
Reporting Period: 01.10.2016-30.09.2018
Funding Agency: Deutsche Forschungsgemeinschaft (DFG)
Project Partners: Prof. Fornasier and Johannes Maly,
Chair of Applied Numerical Analysis, Faculty of Mathematics, TUM

(D) A Holistic Approach to Key Generation Using Physical Unclonable Functions

Project Team: Onur Günlü and Prof. Kramer
Funding Period: 01.04.2016-31.03.2019
Reporting Period: 01.10.2016-30.09.2018
Funding Agency: Deutsche Forschungsgemeinschaft (DFG)
Project Partners: Prof. Sigl, Chair of Security in Information Technology, TUM

(E) Optical Fiber Communication using the Nonlinear Fourier Transform

Project Team: Javier García Gómez and Prof. Kramer
Funding Period: 01.01.2017-31.10.2019
Reporting Period: 01.01.2017-30.09.2018

Funding Agency: Deutsche Forschungsgemeinschaft (DFG)
Project Partners: Prof. Hanik and Benedikt Leible, Associate Professorship of Line Transmission Technology (LÜT)

(F) Fundamentals of Cooperation in Modern Communication Networks

Project Team: Prof. Kramer and Prof. Wachter-Zeh (COD)
Funding Period: 01.01.2018-31.12.2022
Reporting Period: 01.01.2018-30.09.2018
Funding Agency: Deutsche Forschungsgemeinschaft (DFG)
Project Partners: Prof. Permuter and Prof. Schwartz, Ben Gurion University of the Negev, Israel

(G) Quanteninformationstheorie und Kommunikationstheorie für Quantenrepeater jenseits des Shannon Ansatzes

Project Team: Dr. Deppe and Prof. Kramer
Funding Period: 01.08.2018-31.07.2021
Reporting Period: 01.08.2018-30.09.2018
Funding Agency: Bundesministerium für Bildung und Forschung (BMBF) Verbundprojekt: Quanten-Link-Erweiterung
Project Partners: The network includes 34 partners from universities and 10 partners from industry

(H) Low Latency Coded Modulation

Project Team: Peihong Yuan, Marcin Pikus, Dr. Böcherer and Prof. Kramer
Funding Period: 01.01.2016-31.12.2016
Reporting Period: 01.10.2016-30.12.2016
Funding Agency: Huawei European Research Center
Project Partners: Dr. Xu, Dr. İşcan, Dr. Böhnke, Huawei ERC

(I) Low Latency Coded Modulation II

Project Team: Peihong Yuan, Marcin Pikus, Tobias Prinz and Prof. Kramer
Funding Period: 01.08.2018-31.07.2019
Reporting Period: 01.08.2018-30.09.2018
Funding Agency: Huawei European Research Center
Project Partners: Dr. Xu, Dr. İşcan, Dr. Böhnke, Huawei ERC

(J) Analysis of Low Effort Massive MIMO Precoder Design and Indoor-Outdoor Cooperation

Project Team: Stefan Dierks, Markus Staudacher, Amir Ahmadian, and Prof. Kramer
Funding Period: 01.01.2016-31.12.2016
Reporting Period: 01.10.2016-31.12.2016
Funding Agency: Nokia Bell Labs
Project Partners: Dr. Wegmann, W. Zirwas, Dr. Panzner, Dr. Ganesan, Nokia Bell Labs

(K) Low Cost Booster Arrays for Massive MIMO Precoding

Project Team: Markus Staudacher, Andrei Nedelcu, Amir Ahmadian, Fabian Steiner and Prof. Kramer
Funding Period: 01.01.2017-31.12.2017
Reporting Period: 01.01.2017-31.12.2017
Funding Agency: Nokia Bell Labs
Project Partners: Dr. Wegmann, W. Zirwas, Dr. Panzner and Dr. Ganesan, Nokia Bell Labs

(L) Low Cost Booster Arrays for Massive MIMO Precoding II

Project Team: Andrei Nedelcu, Fabian Steiner, Amir Ahmadian and Prof. Kramer
Funding Period: 01.03.2018-31.08.2018
Reporting Period: 01.03.2018-31.08.2018
Funding Agency: Nokia Bell Labs
Project Partners: Dr. Wegmann, W. Zirwas, Dr. Panzner and Dr. Ganesan, Nokia Bell Labs

2.4 Habilitation and Dissertations

In 2017 Dr.-Ing. Georg Böcherer completed his habilitation at our faculty. It was the eleventh habilitation in the LNT's history (s. p. 19).

In 2017/2018, Hannes Bartz and Stefan Dierks completed their Dr. Ing. dissertations (see pp. 20 - 21).

The current count of all completed Dr. Ing. dissertations at LNT, LÜT, and their predecessor institutes going back to 1906 is 223. Gerhard Kramer has been the first referee in twelve doctoral theses and one Ph.D. thesis since starting at TUM in 2010.

Finally, Prof. Kramer thanks his colleagues Prof. Frans Willems (Eindhoven University) and Prof. Stephan ten Brink (University of Stuttgart) for serving as habilitation mentors, and Prof. Emil Björnson (Linköping University), Prof. Mari Kobayashi (CentraleSupélec) and Prof. Danilo Silva (Federal University of Santa Catarina, Brazil) for serving as co-examiners.

2.4.1 Habilitation

11.10.2017 Dr.-Ing. habil. **Georg Böcherer**
Habilitation: **Principles of Coded Modulation**
Lecture: Information-Theoretic Benchmarks for Coded Modulation
Area: Communications

2.4.2 Dissertations

05.04.2017 Dr.-Ing. **Hannes Bartz**
Thema: **Algebraic Decoding of Subspace and Rank-Metric Codes**
Vorsitzender: Prof. Dr.-Ing. Wolfgang Kellerer
1. Berichter: Prof. Dr. sc. techn. Gerhard Kramer
2. Berichter: Prof. Danilo Silva, Ph.D. (Federal University of Santana Catarina / Brazil)

20.02.2018 Dr.-Ing. **Stefan Dierks**
Thema: **Multiple Antenna Precoding: Indoor Communications and EIRP**
Vorsitzender: Prof. Dr.-Ing. Eckehard Steinbach
1. Berichter: Prof. Dr. sc. techn. Gerhard Kramer
2. Berichter: Prof. Emil Björnson (Linköping University, Sweden)
3. Berichter: Prof. Mari Kobayashi (CentraleSupélec, France)

Principles of Coded Modulation

Habilitation Dr.-Ing. habil. Georg Böcherer

Applied Information Theory

Shannon's famous formula states that the channel capacity in the presence of Gaussian noise is

$$C = 1/2 \cdot \log(1 + \mathrm{SNR})$$

where SNR is the signal-to-noise ratio. Looking into a textbook on information theory, we find that the communication system required to achieve capacity is usually impractical, as it requires infinite latency, a complex forward error correction (FEC) decoder, and unbounded peak-to-average power ratio (PAPR).

A practical system designer must account for stringent latency requirements, he/she is restricted to simple decoders, and prefers the PAPR to be as low as possible.

These are several reasons why many practitioners make only limited use of information theory in communication system analysis and design: they often resort to conventional metrics such as error vector magnitude (EMV) or bit error rate (BER). On the other hand, with the advent of soft decision FEC, e.g., in optical transponders, uncoded BER may not be an appropriate performance metric.

The main motivation of my research and teaching activities towards my habilitation was to better understand how information theory tools can be used in practical system design, e.g. in fiber-optic, mobile, and satellite communication.

Coded Modulation

A fundamental communications challenge is to approach Shannon's capacity in the bandwidth-limited regime, which requires to transmit more than one bit per second per real dimension. This requires *Coded Modulation*, i.e., the suitable combination of higher-order modulation and FEC.

I started to work on this topic in 2012, when I had the luck to serve as the teaching assistant of Dr. Gottfried Ungerböck, the father of Coded Modulation and the 2018 Shannon Award recipient.

In the following years, I developed the lecture „Coded Modulation" for graduate students at the Technical University of Munich (TUM) and my habilitation thesis „Principles of Coded Modulation". A central theme was the development of tools for the design and analysis of systems that integrate probabilistic amplitude shaping (PAS) and FEC. Particular attention has been paid to the fact that the achievable rates are based on receiver designs that can be implemented in practice

After my first year in industry, I can confirm that, in fact, information theory can reflect most of the practical system constraints and gives the right insights for optimal system design, with one important exception: the power consumption of decoding algorithms.

Back to the Future

Complexity and power consumption are becoming the fundamental limitation, and in particular for fiber-optic communications. The reason is the race between computing power (Moore's law) and throughput. When the throughput grows faster than the computing power, a faster internet requires simpler algorithms.

The study of the perfomance vs. power consumption trade-off of FEC decoders is a highly relevant topic and interesting for future research collaborations between academia and industry.

Dr.-Ing. habil. **Georg Böcherer** was born in Freiburg im Breisgau, Germany. He obtained his M.Sc. degree

in Electrical Engineering and Information Technology from the ETH Zürich, Switzerland, in 2007, and his Ph.D. degree from the RWTH Aachen, Germany, in 2012. From 2012 to 2017, he worked as a researcher and lecturer with the Chair of Communications Engineering (LNT) at the Technical University of Munich (TUM), where he received his Dr.-Ing. habil. degree in 2017 and became Privatdozent in 2018.

Together with two Ph.D. students of the TUM, he won the third prize at the 2015 Bell Labs Prize and he received the 2017 Johann-Philipp-Reis Award.

Since December 2017, Dr. Böcherer works as senior research scientist at the Paris Research Center of Huawei Technologies France.

2
LNT

Algebraic Decoding of Subspace and Rank-Metric Codes

Dissertation Dr.-Ing. Hannes Bartz

Millions of data packets are transmitted through communication networks like the Internet every day. Communication networks consist of nodes that are connected by wired or wireless communication channels which are subject to environmental disturbances, e.g., thermal noise, jamming or interference. These physical effects introduce errors in the received data packets which may render the received packets useless.

In 2001, random network coding (RNC) was proposed as a method to achieve the capacity of multicast networks. The main idea of RNC is to mix data packets at intermediate nodes instead of routing them through the network. This coding scheme requires new strategies for error correction since all packets that are mixed with an erroneous packet result in erroneous packets, i.e., errors propagate through the network.

- To combat the effect of error propagation, Kötter and Kschischang proposed subspace codes for error control in RNC. Subspace codes can be constructed using rank-metric codes, e.g. Gabidulin codes.
- Gabidulin codes are the rank-metric equivalent of Reed-Solomon codes and are used, e.g., as space-time codes and for designing quantum resistant cryptosystems.

In this thesis, multivariate interpolation- and syndrome-based decoding schemes for subspace and rank-metric codes are presented and analyzed. The proposed interpolation-based decoding schemes allow to efficiently correct errors beyond the unique decoding region in the corresponding metric (subspace- and rank metric). The decoding schemes can either be used as a list decoder, i.e., a decoder that returns a list of codewords that are close to the received word in the corresponding metric, or as a probabilistic unique decoder that returns a unique codeword with high probability. Upper bounds on the average list size and the decoding failure probability of the presented decoding schemes are derived.

Properties of minimal Gröbner bases for linearized polynomial modules are used to improve the decoding performance, to reduce the average list size, and to reduce the computational complexity. It is shown how the linearized Kötter-Interpolation can be used to construct the required minimal Gröbner bases efficiently.

Improved interpolation- and syndrome-based decoding schemes for interleaved subspace codes are presented that achieve the best known decoding region. An interpolation-based decoding scheme for folded subspace codes is proposed and analyzed. The presented subspace decoding schemes are compared with existing decoding algorithms with respect to different parameters and simulations.

An interpolation-based decoding scheme for folded Gabidulin codes, a variant of rank-metric codes that improves upon existing schemes for high code rates, is presented. The results are used to reduce the average list size of an existing decoding scheme that has an improved decoding performance for low-rate folded Gabidulin codes.

This thesis was published in 2017 by Dr. Hut Verlag in the series "Informationstechnik", ISBN 978-3-8439-3174-8.

Dr.-Ing. Hannes Bartz received his Dipl.-Ing. and Dr.-Ing. degree from the Technical University of Munich

(TUM) in 2010 and 2017, respectively. From 2011-2017, he was a research assistant of Prof. Kramer at the TUM Chair of Communication Engineering (LNT). From 2011-2015 he was the Program Manager of the international Master program "Master of Science in Communications Engineering" (MSCE) at the Technical University of Munich.

In July 2017 he joined the Information Transmission group of the Satellite Networks department of the German Aerospace Center (DLR) where he works on code-based quantum-resistant cryptosystems. Since 2018, he is giving the lecture Coded Modulation at the Technical University of Munich.

In 2012 Hannes Bartz received the Prof. Dr. Ralf Kötter memorial award for his diploma thesis entitled "Implementation of an Error-Correcting Network Code based on a Reed-Solomon Code".

Multiple Antenna Precoding: Indoor Communications & EIRP

Dissertation Dr.-Ing. Stefan Dierks

The mobile data volume continues to increase, and this growth will open possibilities for new applications in mobile networks. One goal of new mobile communication standards, for example, 5th generation mobile networks (5G), is to increase the throughput per unit area or volume by a factor of 1000. The goal can be achieved by:

- densifying base station (BS) deployments and increasing the number of served user equipments (UEs);
- increasing bandwidth, for example, by using millimeter waves;
- increasing spectral efficiency (SE) through multiple antenna communications, i.e., multiple-input multiple-output (MIMO).

The thesis concentrates on the third method using an idea called massive MIMO. MIMO allows one BS to transmit several streams to one or more UEs using spatial degrees-of-freedom. Massive MIMO refers to a "vast" over-provisioning of BS antennas as compared to the number of served single antenna UEs. Massive MIMO claims several advantages over conventional MIMO:

- capacity increases by a factor of 10 or more;
- improved energy efficiency;
- inexpensive, low-power components suffice;
- simplified multiple-access layer;
- reduced latency;
- robustness to jamming and interference.

The thesis consists of two parts. The first part analyzes massive MIMO deployments in an indoor scenario. The second part analyzes equivalent isotropically radiated power (EIRP) of MIMO arrays.

Most mobile traffic is generated by indoor users. The performance of different BS deployments with different levels of cooperation in the downlink of a 3GPP indoor office scenario is analyzed in the first part of the thesis. Interference is often the main limitation in mobile networks. Interference aware signal processing schemes are developed that differ in the level of cooperation between BSs. The transmission schemes and the BS deployments are compared using the following approach: The number of served, single-antenna UEs is fixed and the ratio of total number of BS antennas to the number of served UEs is swept from one to ten. The ratio of BS antennas to served UEs that achieves the massive MIMO benefits and provides a good tradeoff between antenna costs and SE is determined this way. The performance of a single BS is compared to the performance of distributed BSs inside and outside the building, and with different levels of cooperation. As expected, placing a single massive MIMO BS at the center of a building causes UEs to experience large path loss and high wall penetration loss. The results help guide design choices for future mobile communication systems.

In the second part of the dissertation, the EIRP of MIMO arrays is discussed. MIMO arrays, and especially Massive MIMO arrays, concentrate their transmit power in certain spatial directions. The EIRP, i.e., the peak power density, is constrained by regulations which serve to protect other devices and humans. However, the EIRP constraint is rarely included in MIMO performance analyses. For most MIMO arrays one cannot measure or calculate the exact EIRP, but must rely on EIRP bounds. An EIRP lower bound is analyzed in the indoor scenario decribed above. In order to show that EIRP regulations are not violated one must use EIRP upper bounds. An example MIMO array called the uniform linear array (ULA) was considered in detail. Existing upper bounds that apply to single stream transmissions are reviewed, and new upper bounds that also apply to multiple stream transmissions and have less complexity for certain scenarios are proposed.

Dr.-Ing. Stefan Dierks received the B.Sc. and the Diplom-Ingenieur degree in Electrical Engineering from the Technical University of Munich in 2009 and 2011, respectively. From 2011-2017 he worked at LNT under the supervision of Prof. Kramer to obtain his doctoral degree. Since February 2018 he is with Rohde & Schwarz GmbH & Co. KG in Munich in the Center of Competence for Signal Processing.

Prof. Gerhard Kramer participated in seven doctoral examinations as a second reviewer:

- Institut National des Sciences Appliquées de Lyon (INSA de Lyon), France
- Aalborg University, Denmark
- Chinese University of Hong Kong, China
- École polytechnique fédérale de Lausanne (EPFL), Switzerland
- Imperial College London, UK
- TU Wien, Austria
- Universität Ulm, Germany

2.4.3 External Thesis Evaluations

10.10.2016 Dr.-Ing. **Michael Cyran**
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
Thesis Title: **Channel Coding and Precoding for Linear Network Coding**
1. Berichter: Prof. Dr.-Ing. Robert Fischer (Universität Ulm, Germany)
2. Berichter: Prof. Dr.-Ing. habil. Dr. h.c. Johannes Huber (FAU Erlangen-Nürnberg, Germany)
3. Berichter: Prof. Dr. sc. techn. Gerhard Kramer

19.10.2016 **Marco Mondelli**, Ph.D.
École polytechnique fédérale de Lausanne (EPFL), Switzerland
Thesis Title: **From Polar to Reed-Muller Codes: Unified Scaling, Non-standard Channels, and a Proven Conjecture**
Supervisor: Prof. Rüdiger Urbanke, Ph.D. (EPFL, Switzerland)
Rapporteur: Prof. Dr. sc. techn. Gerhard Kramer, and others

14.12.2016 **Ling Liu**, Ph.D.
Imperial College London, UK
Thesis Title: **Polar Codes and Polar Lattices for Efficient Communication and Source Quantization**
Supervisor: Prof. Dr. Ling Cong (Imperial College London, UK)
Examiner: Prof. Dr. sc. techn. Gerhard Kramer

31.08.2017 **Kasper Fløe Trillingsgaard**, Ph.D.
Aalborg University, Denmark
Thesis Title: **Feedback and Short Block Length Coding**
Supervisor: Prof. Petar Popovski, Ph.D. (Aalborg University, Denmark)
Examiners: Prof. Dr. sc. techn. Gerhard Kramer, and others

15.11.2017 **Georg Pichler**, Ph.D.
Technische Universität Wien, Austria
Thesis Title: **Information Bottleneck Method**
1. Berichter: Prof. Dr. Gerald Matz (TU Wien, Austria)
2. Berichter: Prof. Dr. sc. techn. Gerhard Kramer, and others

12.12.2017 **Victor Quintero**, Ph.D.
Institut National des Sciences Appliquées de Lyon (INSA de Lyon), France
Thesis Title: **Interference Channel and Feedback**
Supervisor: Prof. Dr. Jean Marie Gorce (INSA de Lyon, France)
Examiners: Prof. Dr. sc. techn. Gerhard Kramer, and others

25.05.2018 **Tao Guo**, Ph.D.
Chinese University of Hong Kong, China
Thesis Title: **The Explicit Coding Rate Region of Symmetrical Multilevel Diversity Coding**
Supervisor: Prof. Dr. Raymond Yeung (Chinese University of Hong Kong, China)
Examiners: Prof. Dr. sc. techn. Gerhard Kramer, and others

2.5 Teaching

2.5.1 Modules for Bachelor students (BSEI)

Nachrichtentechnik 1 / Digital Communications 1
Mandatory module for BSEI 4, 3V+2Ü, 5 ECTS, Language: GER
Summer Term 2017: G. Kramer with P. Schulte
Summer Term 2018: G. Kramer with P. Schulte

Nachrichtentechnik 2 / Digital Communications 2
Elective module for BSEI 5, 2V+2Ü, 5 ECTS, Language: GER
Winter Term 2016/2017: G. Kramer with S. Dierks, T. Prinz
Winter Term 2017/2018: G. Kramer with S. Dierks, T. Prinz

Basic Laboratory Course on Telecommunications
Elective module for BSEI 5/6, 4P, 5 ECTS, Language: GER/EN
Winter Term 2016/2017: G. Kramer with A. Nedelcu, M. Stinner
Summer Term 2017: G. Kramer with A. Nedelcu, S. Dierks
Winter Term 2017/2018: G. Kramer with A. Nedelcu, P. Schulte
Summer Term 2018: G. Kramer with A. Nedelcu, T. Prinz

Mobile Communications
Elective module for BSEI 6, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2017: G. Kramer with M. Staudacher, S. Dierks
Summer Term 2018: G. Kramer with M. Staudacher, T. Prinz

2.5.2 Modules for Master students (MSEI, MSCE)

Information Theory
Elective module for MSEI 1/MSCE 1, 3V+2Ü, 5 ECTS, Language: EN
Winter Term 2016/2017: G. Kramer with L. Palzer, P. Yuan
Winter Term 2017/2018: G. Kramer with L. Palzer, F. Steiner

Communications Laboratory
Elective module for MSCE 1, 4P, 6 ECTS, Language: EN
Winter Term 2016/2017: G. Kramer with O. Günlü, M. Staudacher
Winter Term 2017/2018: G. Kramer with O. Günlü, M. Staudacher

On following pages you will find a list of courses offered by Professor Kramer (LNT) and his staff for students of the TUM Department of Electrical and Computer Engineering (ECE or EI) during the report period 2016 – 2018. Chapter 2.5.1 and Chapter 2.5.2 describe the courses for

- Bachelor students (BSEI),
- Master students (MSEI, MSCE).

The abbreviations in the list are
V: Vorlesung (Lecture),
Ü: Übung (Tutorial),
P: Praktikum (Laboratory),
S: Seminar.

It should also be noted that:

- Since the Winter Term 2017/2018 there is a new lecture: Machine Learning for Communications. The course covers neural networks, probabilistic models, and graphical models to solve communications problems. Students learn about Bayesian inference and learning algorithms for sources, channels, and codes.

- Dr. Ingo Viering, lecturer for *System Aspects in Communications* since 2008, was appointed Honorary Professor in the spring of 2018. Congratulations!

Multi-user Information Theory
Elective module for MSEI 2/MSCE 2, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2017: G. Kramer with G. Böcherer, R.A. Amjad
Summer Term 2018: G. Kramer with C. Deppe, R.A. Amjad

Wireless Communications Laboratory
Elective module for MSEI 2, 4P, 5 ECTS, Language: EN
Summer Term 2017: G. Kramer with O. Günlü, A. Nedelcu
Summer Term 2018: G. Kramer with O. Günlü, P. Schulte

Coded Modulation
Elective module for MSEI 2/MSCE 2, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2017: G. Böcherer
Summer Term 2018: H. Bartz, B. Matuz with T. Jerkovits, F. Steiner

Channel Codes for Iterative Decoding
Elective module for MSEI 2/MSCE 2, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2017: G. Liva with B. Matuz, F. Steiner
Summer Term 2018: G. Liva with B. Matuz, F. Steiner

Advanced Topics in Communications Engineering
Elective module for MSEI 2/MSCE 2, 2V+1Ü, 5 ECTS, Language: EN
Summer Term 2017: A. Aminzadeh with O. Günlü, S. Dierks
Summer Term 2018: G. Kubin with J. García Gómez, T. Prinz

Advanced Topics in Signal Processing
Elective module for MSEI 2/MSCE 2, 2V+1Ü, 5 ECTS, Language: EN
Summer Term 2017: G. Kubin with J. García Gómez, P. Schulte

Hauptseminar Digitale Kommunikationssysteme
Elective module for MSEI 2/MSEI 3, 3S, 5 ECTS, Language: GER
Winter Term 2016/2017: G. Kramer, N. Hanik with T. Kernetzky (both LÜT)
Summer Term 2017: G. Kramer, N. Hanik (LÜT) with T. Prinz
Winter Term 2017/2018: G. Kramer, N. Hanik with T. Kernetzky (both LÜT)
Summer Term 2018: G. Kramer, N. Hanik with T. Kernetzky (both LÜT)

Seminar on Topics in Communications Engineering
Elective module for MSEI 2/MSCE 2, 3S, 5 ECTS, Language: EN
Winter Term 2016/2017: G. Kramer, N. Hanik (LÜT) with R.A. Amjad
Winter Term 2017/2018: G. Kramer, N. Hanik (LÜT) with R.A. Amjad

System Aspects in Communications
Elective module for MSEI 3/MSCE 3, 2V+2Ü, 5 ECTS, Language: EN
Winter Term 2016/2017: I. Viering with A. Nedelcu
Winter Term 2017/2018: I. Viering with A. Nedelcu

Machine Learning for Communications NEW
Elective module for MSEI 3/MSCE 3, 2V + 2Ü, 5 ECTS, Language: EN
Winter Term 2017/2018: G. Kramer, G. Böcherer with F. Steiner

2.5.3 External courses

Optical Fiber Models and their Capacity
2017 North American School of Information Theory, Georgia Tech, Atlanta, GA
09.06.2017: Gerhard Kramer

Advanced Information Theory
Technical University of Denmark, Lyngby, Denmark
10.08. – 23.08.2017: Gerhard Kramer

GIAN Course on Network Information Theory
Indian Institute of Technology Kanpur, India,
20.03. – 24.03.2018: Gerhard Kramer

Digitale Nachrichtentechnik
Chinesisch-Deutsches Hochschulkolleg (CDHK), Shanghai, China
24.04.- 28.04.2017: Stefan Dierks

Machine Learning for Communications
Chinesisch-Deutsches Hochschulkolleg (CDHK), Shanghai, China
26.03.–30.03.2018: Fabian Steiner

Prof. Kramer and his assistants held the courses listed here at other universities outside of Munich. The annual courses at the CDHK in Shanghai, the Summer Academy in the Sarntal, and at TUMAsia in Singapore have been a tradition for many years.

Participants at the Summer Academy 2018

Compressed Sensing
Summer Academy (Ferienakademie), Course 9, Sarntal, South Tyrol, Italy
17.09.–29.09.2017 Gerhard Kramer and Ralf Müller (FAU Erlangen), with Lars Palzer and Ali Bereyhi (FAU Erlangen), and guests, Antonia Tulino (Nokia Bell Labs) and Giuseppe Caire (TU Berlin)

Redundancy and Irrelevance in Source and Channel Coding
Summer Academy (Ferienakademie), Course 9, Sarntal, South Tyrol, Italy
23.09. – 05.10.2018 Gerhard Kramer, André Kaup and Bernd Edler (both with FAU Erlangen), with Mustafa Kemil Coşkun and Ning Guo (FAU Erlangen)

Digital Communications
TUMAsia, Singapore
13.02. - 24.02.2017 Gerhard Kramer with Patrick Schulte
08.02 - 23.02.2018 Gerhard Kramer with Lars Palzer

2.6 Students Theses

2.6.1 Master's Theses

During the period 10/2016-09/2018 Prof. Kramer and assistants of the *Chair of Communications Engineering* (LNT) supervised a number of theses and projects:
- 29 Master's theses
- 22 MSEI and MSCE research internships (p. 28)
- 28 Bachelor's theses (p. 30)
- 36 Bachelor's internships (p. 32)

The *Master's Thesis* (MT) in the regular Master program of our Faculty (MSEI) is rated with 30 ECTS, which corresponds to full-time work over 24 weeks. It thus contributes to the overall rating of one quarter. The time between registration and submission may not exceed 52 weeks. Normally, however, the work should be completed within six months. The MSCE study program is comparable to MSEI, but the Master's Thesis time is strictly limited to six months.

04.10.2016 **Manuela Meier -** Supervisor: H. Bartz, Dr. Sidorenko
Syndrome Decoding of Interleaved Subspace Codes

06.10.2016 **Houda Bannour -** Supervisor: A. Nedelcu, S. Kerger Rohde & Schwarz (in the following: R & S)
Design of a FEC Scheme for High Data Rate-Anti Jam Speech Waveform Inteligibility Optimization

22.11.2016 **Delcho Donev -** Supervisor: Dr. Böcherer, Dr. Liva (DLR)
Coded Pulse Position Modulation for the Poisson Channel

01.12.2016 **Marcel Grec -** Supervisor: P. Schulte, F. Lázaro-Blasco (DLR)
Fountain Codes under Inactivation Decoding

01.12.2016 **Berkay Köprü -** Supervisor: P. Schulte, Dr. İşcan, Dr. Böhnke (both Huawei)
Coding Schemes for Multiple Access Communications

10.01.2017 **Clemens Blöchl** - Supervisor: R. A. Amjad, Dr. Geiger
Aggregation of (Hidden) Markov Models - Theory and Applications

10.01.2017 **Lukas Holzbaur** - Supervisor: H. Bartz
Decoding Schemes for Staircase Codes

25.01.2017 **Dinesh Manohar Gandhinathan** - Supervisor: Dr. Böcherer, P. de Kerret, Prof.Gesbert (both Eurecom)
Jointly Consistent Estimation for Decentralized Network Cooperation

01.02.2017 **Uday Yatnalli** - Supervisor: Dr. Böcherer, Prof. Gesbert, Dr. Chen (Eurecom)
Learning Radio Maps for UAV-aided Wireless Networks: A Segmented Regression Approach?

02.02.2017 **Mustafa Cemil Coşkun** - Supervisor: Dr. Liva, DLR
Successive Cancellation Decoding of Product Codes

25.04.2017 **Julian Leyh** - Supervisor: O. Günlü, H. Klenner (R & S)
Transmitter Impairment Measurement in the Digital Terrestrial Multimedia Broadcast Standard

25.04.2017 **Xiaotong Liu** - Supervisor: A. Nedelcu
Degrees of Freedom in Impedance Matching for MIMO Receivers

04.07.2017 **Zafzouf Ghassen** - Supervisor: M. Staudacher, Dr. Bialkowski (University of Queensland)
Investigation into Signal Waveforms for 5G & Information-theoretic Analysis of MIMO OFDM Systems

13.09.2017 **Qionghui Cao** - Supervisor: P. Yuan
FPGA Implementation of Partial-Parallel LDPC Decoder

13.09.2017 **Wenfei Li** - Supervisor: P. Yuan
Bit-Interleaved Coded Modulation and Multilevel Coding for Polar Codes

13.09.2017 **Longxi Xu** - Supervisor: P. Yuan
FPGA Implementation of Polar Encoder and Simplified Successive Cancellation Decoder

27.10.2017 **Kei Kavoos Afghahi** - Supervisor: M. Staudacher, N. Petreska (Fraunhofer ESK)
Methoden zur Adaptiven Kanalallokation in einem Multi-Zellen System

30.11.2017 **Kairen Liu** - Supervisor: R. A. Amjad, Dr. Geiger
Information-theoretic Analysis of Neural Networks

08.01.2018 **Tobias Popetz** - Supervisor: T. Prinz, B. Sterzbach (R & S)
Reproduction of Observed Mobile Device Communication Sequences in a Simulation Setup

22.01.2018 **Achraf Kamoun** - Supervisor: F. Steiner
Advanced Multi-Stream QAM Detection

12.02.2018 **Rayyan Khan** - Supervisor: R. A. Amjad, Prof. Kleinsteuber (TUM-LDV)
Designing Clustering Algorithms based on Message-passing Approximation Techniques

26.02.2018 **Ralf Peteranderl** - Supervisor: A. Nedelcu
MIMO Receiver Matching Strategies for Compact Antenna Arrays considering Parasitic Scatterers

19.04.2018 **Diego Lentner** - Supervisor: Dr. Böcherer, F. Steiner
Dirty Paper Coding for Higher-Order Modulation and Finite Constellation Interference

26.06.2018 **Alexandru Git** - Supervisor: F. Steiner, Dr. Matuz (DLR)
Low-Density Parity-Check Code Design for Probabilistic Amplitude Shaping with On-Off Keying Modulation

26.07.2018 **Hussein Hammoud** - Supervisor: L. Palzer
Optimal Signaling over Linear Gaussian Channels under Peak Power Constraints

09.08.2018 **Harald Joachim Bayerlein** - Supervisor: R. A. Amjad, P. de Kerret, Prof. Gesbert (both Eurecom)
Trajectory Optimization for Autonomous Flying Base Station via Reinforcement Learning

03.09.2018 **Joachim Neu -** Supervisor: Dr. Liva, DLR
Quantized Polar Code Decoders: Analysis and Design

18.09.2018 **Olivia Ngwabou** - Betreuer: P. Schulte
An Improved Soft-Decision List Decoding of Short-Length LDPC Codes based On Multi-Tree Search Decoding

18.09.2018 **Thomas Wiegart** - Betreuer: F. Steiner, T. Prinz, P. Yuan
Polar Code Design for Parallel Channels

2.6.2 MSEI and MSCE Research Internships

The *MSEI and MSCE Research Internship* (German: Forschungspraxis, FP) spans a total of 9 weeks (full time) and is rated with 12 ECTS, but is not included in the final grade. The FP is mandatory and should give insight into current research topics.

20.12.2016 **Joachim Neu** - Supervisor: F. Steiner
Evaluation of Spatially Coupled LDPC Codes

21.12.2016 **Edward Wall** - Supervisor: Dr. Geiger
Finite-Precision Gaussian Mixture Models

10.01.2017 **Muhammad Umer Anwaar -** Supervisor: R. A. Amjad, Dr. Geiger
Coding Techniques for Natural Language Processing

10.01.2017 **Niklas Jünger -** Supervisor: S. Dierks
Energy-Efficiency of Massive MIMO and Network MIMO in a Local Area Scenario

25.04.2017 **Liu Xiaotong -** Supervisor: A. Nedelcu
Simulator in Matlab for MIMO Multiport Communications

18.07.2017 **Tobias Popetz -** Supervisor: T. Prinz &
Fa. Rohde & Schwarz
Analysis of Mobile Device Communication Sequences Observed in Public Networks for Reproduction in a Simulated Network

18.07.2017 **Muhammad Firas Hammosh** - Supervisor: Dr. Geiger
Is Online PCA Information-Preserving?

01.11.2017 **Emna Ben Yacoub -** Supervisor: Dr. Geiger, R. A. Amjad
M-Type Approximation of Hidden Markov Models

02.11.2017 **Basak Ülker -** Supervisor: J. García Gómez
Characterization of the Effect of Filtering on a Fiber Optic System Using OptiWave

02.11.2017 **Yining Tian** - Supervisor: P. Schulte & Fa. NXP
Chinese C-ITS Dedicated Short Range Communication (DSRC) Standard Baseband Simulation

14.11.2017 **Hiba Arnout -** Supervisor: T. Prinz
Implementation of a Compressed Sensing Method using a Deterministic Hadamard Construction

14.12.2017 **Nurettin Turan -** Supervisor: F. Steiner
Hard-Decision Decoding with BCH codes

14.12.2017 **Thomas Wiegart** - Supervisor: F. Steiner
Non-Binary LDPC Codes for Probabilistic Shaping

15.03.2018 **Li Ruifei** - Supervisor: Prof. Kramer & DLR
Multiple-Step Search for Good Protographs

23.03.2018 **Wafa Labidi** - Supervisor: P. Schulte
Exploiting Non-linear Outer Code Properties in the LDPC Decoder

19.04.2018 **Yitao Jin** - Supervisor: O. Günlü, T. Kernetzky
Hardware Optimization for Physical Unclonable Functions

19.04.2018 **Mohamed Mezghani -** Supervisor: O. Günlü, M. Skorski (IST Austria)
Privacy Leakage Minimization for Key Agreement

24.05.2018 **Diego Vargas Romero** - Supervisor: Dr. Bartz (DLR)
Implementation of a Gabidulin Code Encoder and Decoder over C#

06.06.2018 **Run Yang -** Supervisor: J. García Gómez
Numerical Measurement of Mutual Information

06.06.2018 **Thomas Gabler** - Supervisor: J. García Gómez
Detection of Variable-width Soliton Pulses

26.06.2018 **Rami Ezzine** - Supervisor: L. Palzer
Two-Terminal Quantized Compressive Sensing with Approximate Message Passing Reconstruction

18.09.2018 **Ramiz Hasan Siddiqui -** Supervisor: R. A. Amjad
Implementation of Radio Transmitter and Receiver with USRP for Broadband Maritime Communication

2.6.3 Bachelor's Theses

The *Bachelor's Thesis* (BT) is part of the six-semester Bachelor program (BSEI). It is rated with 12 ETCS and should be completed in 9 weeks à 40 hours per week (360 hours). The total duration is 18 weeks of at least 20 hours per week.

25.04.2017 **Alyssa Akremi -** Supervisor: A. Ahmadian
Reduced Complex Precoding for CoMP Massive MIMO Sparse Channels

25.04.2017 **Anas Azouni -** Supervisor: T. Prinz
Error Detecting Outer Codes for Polar Codes

28.04.2017 **Mohamed Selmane -** Supervisor: P. Schulte
Schedule Analysis for LDPC Codes

26.05.2017 **Mohamed Ben Chikha** - Supervisor: L. Palzer
Lossy Source Coding Performance of Low-Complexity Compressive Sensing

26.05.2017 **Kai Tan Kian** - Supervisor: P. Schulte
Performance Analysis of HARQ Transmission Schemes

01.06.2017 **Eng Huat Loo** - Supervisor: A. Nedelcu
Receive Antenna Selection - A Circuit Theoretic Approach

20.06.2017 **Wael Touzri** - Supervisor: J. García Gómez
Energy Conservation in Periodically Filtered Fiber Optic Channels

04.07.2017 **Sirine Ammar** - Supervisor: R. A. Amjad, Dr. Geiger
Community Detection in Dramatic Plays

18.07.2017 **Houssem Amami** – Supervisor: J. García Gómez
Inter-Channel Interference in Optical Narrow-Band Multi-Channel Systems with Distributed Filters

18.07.2017 **Mohamed Nabil Babai** - Supervisor: R. A. Amjad, Dr. Geiger
Determining the Number of Clusters in a Data Set for k-Means

18.07.2017 **Fares Charfi** - Supervisor: O. Günlü, T. Kernetzky
Transform Implementation for Secret-key Storage with Physical Identifiers

18.07.2017 **Mohamed Ibn Haj Hmida** - Supervisor: O. Günlü, Dr. Geiger
Mapping Optimization for Key Generation from Correlated Physical Outputs

18.07.2017 **Nurettin Turan** - Supervisor: F. Steiner
Implementation of a General-purpose LDPC Encoder

10.10.2017 **Michael Müller** - Supervisor: F. Steiner & Fa. SES/MX1
Entwicklung und Implementierung eines Algorithmus für die bandbreitenoptimierte Übertragung von „Start-Over"-Inhalten via Satellit

13.10.2017 **Khalil Messaoudi** - Supervisor: L. Palzer
State Evolution Analysis of Quantized Compressive Sensing

03.11.2017 **Timothee Felicio** - Supervisor: T. Prinz
Implementation of Lower Bounds for the Error Probability of Gaussian Channels for Finite Blocklengths

13.11.2017 **Katharina Rieke** - Supervisor: F. Steiner
Near Maximum Likelihood Decoding with OSD for Short Blocklengths

28.11.2017 **Oussama Ben Cheikh Larbi** - Supervisor: A. Nedelcu
The Impact of Frequency-selective Matching on the Capacity of Compact MIMO systems

01.12.2017 **Wiem Boukhzar** - Supervisor: L. Palzer
Performance Analysis of Quantized Compressive Sensing

22.01.2018 **Kevin Li** - Supervisor: M. Pikus
Communication over Unknown Channels

26.02.2018 **Matyas Mehn -** Supervisor: P. Schulte, P. Yuan
Implementierung eines Shell-Mappers in VHDL

05.03.2018 **Yao Yang Low -** Supervisor: P. Schulte
Shell Mapper Distribution

21.03.2018 **Felix Kruse -** Supervisor: T. Prinz, F. Steiner, P. Yuan
Performance Comparison of Polar and BMERA Codes under Successive Cancellation List (SCL) Decoding

23.04.2018 **Zhonglin Li** - Supervisor: P. Yuan
Most Reliable Basis Decoding for Short Block Codes

23.04.2018 **Samuel Karl Armin Schedler** - Supervisor: P. Schulte, P. Yuan
Implementierung eines Baum Encoders und Decoders in VHDL

15.05.2018 **Shena Koh** - Supervisor: P. Schulte, F. Steiner
Time Resource Analysis for Multicore Communications Chain Simulations

27.06.2018 **Khalil Chouchen** - Supervisor: J. García Gómez
Implementation of the Kramers-Kronig Coherent Receiver

26.07.2018 **Patrick Willner -** Supervisor: F. Steiner
Finding Short Cycles in LDPC Codes

2.6.4 Bachelor's Internships

The *Bachelor's Internship* (German: Ingenieurpraxis, IP) is mandatory for the Bachelor program BSEI. The duration and the rating of the IP is the same (360 hours, 12 ECTS) as for the BT.

31.10.2016 **Hasan Yagiz Özkan** - Supervisor: Prof. Kramer & Fa. Bases Teknoloji Arge Sanay, Istanbul
Image Tracking Algorithm Development

22.11.2016 **Mohamed Nabil Babai** - Supervisor: Dr. Stinner
Migration of Media Content for the LNTwww

22.11.2016 **Clarissa Hamann** - Supervisor: Prof. Kramer & Dedan Kimathi University, Kenia
Zu Grundlagen der Elektrotechnik I

22.11.2016 **Laila Niazy** - Supervisor: Prof. Kramer & Dedan Kimathi University, Kenia
Zu Grundlagen der Elektrotechnik II

20.12.2016 **Thomas Wengerter** - Supervisor: Prof. Kramer & Fa. Rohde & Schwarz
Entwicklung Peiltechnik

02.02.2017 **Safwen Dridi** - Supervisor: T. Kernetzky (LÜT), Prof. Söder
Portieren von Quizaufgaben und Mediendateien des LNTwww

25.04.2017 **Alexander Matthies** - Supervisor: Prof. Kramer & Fa. Rohde & Schwarz
Inbetriebnahme und Test eines DSP-Boards

08.09.2017 **Yiming Yan -** Supervisor: J. García Gómez
Mutual Information between Filtered Narrow-band Channels in a Fiber Optic Link

18.10.2017 **David Jobst** - Supervisor: T. Kernetzky (LÜT), Prof. Söder
Porting Interactive Flash Programs to HTML5

04.12.2017 **Felix Kruse** - Supervisor: T. Prinz
Implementation of a Successive Cancellation List Decoder

20.12.2017 **Omar Ben Charfeddine** - Supervisor: P. Schulte
Shell Mapping Implementation for Big Integers

26.02.2018 **Patrick Willner** - Supervisor: P. Schulte
Shell Mapping for Variable Block Length Sizes

26.02.2018 **Barbara Lenz** - Supervisor: Prof. Kramer, Dr. Stiller (MBDA GmbH)
Post-Processing von RCS-Messungen mit MATLAB

19.04.2018 **Johannes Kunz** - Supervisor: Prof. Kramer & Fa. Müller-BBM, Planegg
GUI-Design und Programmierung eines XML-Config Editors

23.04.2018 **Rudolf Mayer** - Supervisor: Prof. Kramer & Deutsche Telekom GmbH München
Einführung und Inbetriebnahme des WDM-Systems Cisco Next Generation (NG)-ROADM

26.07.2018 **Tijani Aziz Feki** - Supervisor: O. Günlü
Optimized Transform Coding for Physical Unclonable Functions

26.07.2018 **Ines Boussarsar** - Supervisor: P. Schulte
Transmission by Audio Experiment - Pulses and OFDM

26.07.2018 **Lobna Boussarsar** - Supervisor: P. Schulte
Transmission by Audio Experiment - Compression and GUI

26.07.2018 **Yosri Ben Haj Ali** - Supervisor: P. Schulte
Channel Model Simulator

26.07.2018 **Abidi Helmi** - Supervisor: Prof. Kramer & Fa. Attocube Systems
Display Programming and Public Cryptography

26.07.2018 **Constantin Runge** - Supervisor: Prof. Kramer & Fa. Rohde & Schwarz
Integration von Wellenformen

Here you will find a compilation of Prof. Gerhard Kramer's and Prof. Joachim Hagenauer's activities in committees at TUM and external scientific associations.

2.7 Assignments and Service

Gerhard Kramer

TUM Assignments
- Co-Director, Master of Science in Communications Engineering (MSCE) Program, ECE Dept. (since 2010)
- Member, TUM Institute for Advanced Study Advisory Council (2011-2017)
- Member and chair of several W3-Professor search committees (since 2011)
- Member, TUM Appointment and Tenure Board (since 2012)
- Member, TUM Awards Committee (since 2014)
- Chair, Committee for Equal Opportunity, ECE Dept. (2014-18)
- Gender Equality Officer, ECE Dept. (since 2015)
- Member, Bachelor Study Examination Board, ECE Dept. (since 2016)
- Mentor, TUM Faculty Tenure Track Professorship (since 2016)
- Deputy Director, TUM International Graduate School of Science and Engineering (IGSSE) (since 2016)

Professional Service
- Fellow of the IEEE (since 2010)
- Member, ITG-Fachausschuss 5.1: Informations und Systemtheorie (since 2011)
- Advisor, IEEE Schools of Inf. Theory in Europe, North America, East Asia, and Latin America (since 2011)
- Editor, Foundations and Trends in Communications and Information Theory (since 2012)
- Member, Board of Curators of the Eduard Rhein Foundation (since 2013)
- Member, IEEE Richard W. Hamming Medal Committee (2014-2017)
- Member, IEEE Information Theory Society Committees: School (2014-2017), Nomination and Appointments (2017-2019), Society Finances (2018)
- Member, Technical Program Committees of IEEE and other Conferences: ISIT (2018), ISTC (2018), IZS (2018), IWCIT (2017, 2018), LAWCI (2018), ITG SCC (2017), WCNC (2017, 2018), WSA (2017, 2018), CNS (2017, 2018), ISWCS (2018), ICC-CT (2018), ICC-MASSAP (2017, 2018), ICC-SDN (2017), WF-5G (2018), WiOpt (2018), BalkanCom (2018), BlackSeaCom (2017, 2018)
- Member, Bayerische Akademie der Wissenschaften (BAdW, since 2015)
- Member, BAdW Forum Technologie (since 2016)
- Mentor and Selection Committee Member, Max Weber Programm des Freistaats Bayern (since 2016)
- Member, BAdW Auswahlkomitee des Jungen Kollegs (since 2017)
- Vertrauensdozent, Bayerische EliteAkademie (seit 2017)
- General Co-Chair, IEEE Int. Symp. Information Theory (ISIT 2017)
- General Co-Chair, IEEE Information Theory Workshop (ITW 2017)
- Chair, Panel evaluating the Department of Electrical Engineering, Chalmers University, Sweden (2018)

Joachim Hagenauer

TUM Assignments

- Vorstand des Internationalen Begegnungszentrums (IBZ) der Münchner Universitäten (until 2018)
- Mitglied im Scientific Board der TUM „Research Opportunity Week“ (since 2012)
- Mitglied im Auswahlausschuss „Scherer Gastprofessoren“ der TUM (since 2013)

Professional Service

- Fellow der Information Theory (IT) Society des IEEE (since 1993)
- Mitglied der Deutschen Akademie der Technikwissenschaften: acatech (since 2002)
- Mitglied der Bayerischen Akademie der Wissenschaften (BAdW, since 2003)
- Mitglied des BAdW-Forums „Technologie“ (since 2005)
- Mitglied im VDE Slaby Kreis (since 2007)

2.8 Publications

2.8.1 Book Chapters & Dissertations

The publications of the Chair of Communications Engineering (LNT) are listed below:

- 3 Book Chapters and Dissertations,
- 33 Journal Publications,
- 42 Conference Publications,
- 20 Posters,
- 69 Talks.

Bartz, H. Algebraic Decoding of Subspace and Rank-Metric Codes. *In:* Dr. Hut Verlag, in the series “Informationstechnik”, Dissertation TUM, ISBN 978-3-8439-3174-8, 2017

Bossert, M.; Sidorenko, V.; Wachter-Zeh, A.: Coding Techniques for Transmitting Packets Through Complex Communication Networks. *In:* Communications in Interference Limited Networks. Springer International Publishing, 2016

Hou, J.; Kramer, G.; Bloch, M.: Effective Secrecy: Reliability, Confusion and Stealth. *In*: Boche, H.: Khisti, A.; Poor, H. V. ; Schaefer, R. F. (Ed.): Information Theoretic Security and Privacy of Information Systems. Cambridge University Press, June 2017

2.8.2 Journal Articles

Aydinian, H.; Cicalese, F.; Deppe, C.; Lebedev, V.: A Combinatorial Model of Two-Sided Search. *In*: Int. J. Foundations of Computer Science **29** (04), 481-504, Apr. 2018

Bartz, H.; Sidorenko, V.: Algebraic Decoding of Folded Gabidulin Codes. Designs, Codes and Cryptography **82** (1), 449-467, Jan. 2017

Bartz, H.; Sidorenko, V.: On Syndrome Decoding of Punctured Reed-Solomon and Gabidulin Codes. *In*: Electronic Notes in Discrete Mathematics (ENDM) **57**, 33 – 38, March 2017

Bartz H.; Sidorenko V.: Improved Syndrome Decoding of Lifted L-Interleaved Gabidulin Codes. *In*: Designs, Codes and Cryptography, https://doi.org/10.1007/s10623-018-0563-5, Sept. 2018

Blöchl, C.; Amjad, R.A.; Geiger, B.C.: Co-Clustering via Information-theoretic Markov Aggregation. *In*: IEEE Trans. Knowledge Data Engineering, June 2018

Boche, H.; Cai, M.; Deppe, C.; Nötzel, J.: Classical-quantum Arbitrarily Varying Wiretap Channel: Secret Message Transmission under Jamming Attacks. *In*: J. Mathematical Physics **58** (10), 102203, Oct. 2017

Boche, H.; Deppe, C.: Secure Identification for Wiretap Channels; Robustness, Super-Additivity and Continuity. *In*: IEEE Trans. Inf. Forensics Security **13** (7), 1641-1655, July 2018

Boche, H.; Deppe, C.: Secure Identification under Passive Eavesdroppers and Active Jamming Attacks. *In*: IEEE IEEE Trans. Inf. Forensics Security **14**, 472-485, July 2018

Dierks, S.; Kramer, G.; Panzner, B.; Zirwas, W.: Analysis of Massive MIMO and Base Station Cooperation in an Indoor Scenario. *In*: IEEE Trans. Wireless Commun. **17** (1), Jan. 2018

Fehenberger, T.; Alvarado, A.; Böcherer, G.; Hanik, N.: On Probabilistic Shaping of Quadrature Amplitude Modulation for the Nonlinear Fiber Channel. *In*: IEEE/OSA Lightwave Techn. **34** (21), 5064-5074, Nov. 2016

Garcia, J.; Ghozlan, H.; Kramer, G.: Energy Conservation in Optical Fibers with Distributed Brick-Walls Filters. *In*: IEEE/OSA Lightwave Techn. **36** (9), 1626-1633, May 2018

Geiger, B. C., Kubin, G.: Information-theoretic Analysis of Memoryless Deterministic Systems. *In*: Entropy **18** (11), Nov. 2016

Ghozlan, H.; Kramer, G.: Models and Information Rates for Wiener Phase Noise Channels. *In*: IEEE Trans. Inf. Theory **63** (4), 2376-2393, Apr. 2017

Ghozlan, H.; Kramer, G.: Models and Information Rates for Multiuser Optical Fiber Channels with Nonlinearity and Dispersion. *In*: IEEE Trans. Inf. Theory **63** (10), Oct. 2017, 6440-6456

Günlü, O.; İşcan, O.; Sidorenko, V.; Kramer, G.: Code Constructions for Physical Unclonable Functions and Biometric Secrecy Systems. *In*: IEEE Trans. Inf. Forensics Security **13** (8), Aug. 2018

Günlü, O.; Kernetzky, T.; İşcan, O.; Sidorenko, V.; Kramer, G.; Schaefer, R. F.: Secure and Reliable Key Agreement with Physical Unclonable Functions. *In*: Entropy, Special Issue on Information Theoretic Security **20** (5), Article 340, May 2018

Günlü, O.; Kittichokechai, K.; Schaefer, R. F.; Caire, G.: Controllable Identifier Measurements for Private Authentication with Secret Keys. *In*: IEEE Trans. Inf. Forensics Security **13** (08), Aug. 2018

Goldfeld, Z.; Kramer, G.; Permuter, H. H.; Cuff, P.: Strong Secrecy for Cooperative Broadcast Channels. *In*: IEEE Trans. Inf. Theory **63** (1), Jan. 2017

Goldfeld, Z.; Kramer, G.; Permuter, H. H.: Broadcast Channels with Privacy Leakage Constraints. *In*: IEEE Trans. Inf. Theory **63** (8), 5138-5161, Aug. 2017

Idler, W.; Buchali, F.; Schmalen, L.; Lach, E.; Braun, R.-P.; Böcherer, G.; Schulte, P.; Steiner, F.: Field Trial of a 1 Tb/s Super-Channel Network using Probabilistically Shaped Constellations. *In*: IEEE/OSA Lightwave Technol. **35** (8), 1399-1406, Apr. 2017

Kramer, G.: Autocorrelation Function for Dispersion-free Fiber Channels with Distributed Amplification. *In*: IEEE Trans. Inf. Theory **64** (7), July 2018

Leinonen, M.; Codreanu, M.; Juntti, M.; Kramer, G.: Rate-distortion Performance of Lossy Compressed Sensing of Sparse Sources. *In*: IEEE Trans. Commun. **66** (5), May 2018

Napp, D., Pinto, R., Sidorenko, V.: Concatenation of Convolutional Codes and Rank Metric Codes for Multi-shot Network Coding. *In*: Designs, Codes and Cryptography **86**, 303-318, Feb. 2018

Östman, J.; Durisi, G.; Ström, E. G.; Coşkun, M. C.; Liva, G.: Short Packets over Block-Memoryless Fading Channels: Pilot-Assisted or Noncoherent Transmission? *In*: IEEE Trans. Comm., Jan. 2018

Pikus, M.; Xu, W.: Bit-Level Probabilistically Shaped Coded Modulation. *In*: IEEE Commun. Lett. **21** (9), 1929-1932, Sept. 2017

Puchinger, S.; Rosenkilde, J.; Li, W; Sidorenko, V.: Row Reduction Applied to Decoding of Rank-metric and Subspace Codes. *In*: Designs, Codes and Cryptography **82** (1), 389-409, Jan. 2017

Renner, J; Fehenberger, T.; Yankov, P.; Da Ros, F.; Forchhammer, S.; Böcherer, G; Hanik, N.: Experimental Comparison of Probabilistic Shaping Methods

for Unrepeated Fiber Transmission. *In*: IEEE/OSA Lightwave Technol. **35** (22), Sept. 2017

Saeedi Bidokhti, S.; Kramer, G.: Capacity Bounds for Diamond Networks with an Orthogonal Broadcast Channel. *In*: IEEE Trans. Inf. Theory **62** (12), Dec. 2016

Saeedi Bidokhti, S.; Kramer, G.; Shamai (Shitz), S.: Capacity Bounds on the Downlink of Symmetric, Multi-relay, Single receiver C-RAN Networks. *In*: Entropy 19 (11), article 610, Nov. 2017

Sheikh, A.; Graell i Amat, A.; Liva, G.; Steiner, F.: Probabilistically-shaped Coded Modulation with Hard Decision Decoding for Coherent Optical Systems. *In*: IEEE/OSA Lightwave Technol., Jan. 2018

Thangaraj, A.; Kramer, G.; Böcherer, G.: Capacity Bounds for Discrete-time, Amplitude-constrained, Additive White Gaussian Noise Channels. *In*: IEEE Trans. Inf. Theory **63** (7), 4172-4182, July 2017

Yankov, M. P.; Da Ros, F.; da Silva, E. P.; Fehenberger, T.; Barletta, L.; Zibar, D.; Oxenlowe, L.; K.; Galili, M.l; Forchhammer, S.: Nonlinear Phase Noise Compensation in Experimental WDM Systems with 256QAM. *In*: IEEE/OSA Lightwave Technol. **35** (8), 1438-1443, Aug. 2017

Wigger, M.; Timo, R; Shamai, S.: Conferencing in Wyner's Asymmetric Interference Network: Effect of number of rounds. *In*: IEEE Trans. Inf. Theory **63** (2), Feb. 2017

2.8.3 Conference Publications

Ahmadian, A. M.; Siva Ganesan, R.; Zirwas, W.: Performance Evaluation of Linear Beamforming Receiver for Large CoMP Sparse Massive MIMO Channel Matrices. *In*: Proc. IEEE 85th Vehicular Technol. Conf. (VTC Spring), Sydney, Australia, June 2017

Bartz, H., Meier, M., Sidorenko, V.: Improved Syndrome Decoding of Interleaved Subspace Codes. *In*: Proc. JWCC-2017

Baur, S.; Deppe, C.; Boche, H.: Secure Storage for Identification. *In*: Proc. SPAWC-2018

Boche, H.; Deppe, C.: Secure Identification Under Jamming Attacks. *In*: Proc. SPAWC-2018

Boche, H.; Deppe, C.; Notzel, J.; Winter, A.: Fully Quantum Arbitrarily Varying Channels: Random Coding Capacity and Capacity Dichotomy. *In*: Proc. ISIT-2018

Boche, H.; Deppe, C.; Winter, A.: Secure and Robust Identification via Classical-Quantum Channels. *In*: Proc. ISIT-2018

Böcherer, G.; Prinz, T.; Yuan, P.; Steiner, F.: Efficient Polar Code Construction for Higher-Order Modulation. *In*: Proc. IEEE Wireless Commun. Networking Conf. (WCNC), San Francisco, CA, USA, March 2017

Böcherer, G.; Steiner, F.; Schulte, P.: Fast Probabilistic Shaping Implementationfor Long-Haul Fiber-Optic Communication Systems. *In*: Proc. 44th European Conf. Optical Commun., Gothenburg, Sweden, Sept. 2017

Coşkun, M. C.; Liva, G.; Amat, A. G.; Lentmaier, M.: Successive Cancellation Decoding of Single Parity-Check Product Codes. *In*: Proc. ISIT-2017

Deppe, C.; Lebedev, V.: Q-ary Error-Correcting Codes with Feedback. *In*: Proc. ACCT-2018

Deppe, C.; Lebedev, V.: Optimal Algorithms for Q-ary Error-Correcting Feedback Codes with Limited Magnitude. *In*: Proc. ACCT-2018

Dierks, S.; Jünger, N.: Energy Efficiency of Massive MIMO and Network MIMO in an Indoor Scenario. *In*: Proc. WSA-2017

Donev, D.; Böcherer, G.: Polar-Coded Pulse Position Modulation for the Poisson Channel. *In*: Proc. 9th Advanced Satellite Multimedia Systems Conf., Berlin, Germany, Sept. 2018

Fehenberger, T.; Alvarado, A.; Böcherer, G.; Hanik, N.: On the Impact of Probabilistic Shaping on SNR and Information Rates in Multi-Span WDM Systems. *In*: Proc. OFC-2017

Geiger, B. C.; Amjad, R. A.: Mutual Information-Based Clustering: Hard or Soft? *In*: Proc. SCC-2017

Geiger, B. C.; Koch, T.: On the Information Dimension Rate of Stochastic Processes. *In*: Proc. ISIT-2017, 888-592

Geiger, B. C.; Wu, Yuchen: Higher-Order Kullback-Leibler Aggregation of Markov Chains. *In*: Proc. SCC-2017, 1-6

Gohari, A.; Günlü, O.; Kramer, G.: On achieving a positive rate in the source model key agreement problem. *In*: Proc. ISIT-2018

Günlü, O.; Belkacem, A.; Geiger, B.: Secret-key Binding to Physical Identifiers with Reliability Guarantees. *In*: Proc. IEEE Int. Conf. Commun., Paris, France, May 2017

Legend to Chapter 2.8.3

ACCT-2018:
16th International Workshop on Algebraic and Combinatorial Coding Theory, Svetlogorsk, Russia, Sept. 2018

ECOC-2018:
44th European Conference on Optical Communication, Rome, Italy, Sept. 2018

ISIT-2017:
IEEE International Symposium on Information Theory, Aachen, Germany, June 2017

ISIT-2018:
IEEE International Symposium on Information Theory, Vail, Colorado, USA, June 2018

JWCC-2017:
18th Joint Workshop on Communications and Coding, Planneralm, Austria, March 2017

OFC-2017:
Optical Fiber Communication Conference, Los Angeles, CA, USA, March 2017

OFC-2018:
Optical Fiber Communication Conference, San Diego, CA/USA, March 2018

Legend to Chapter 2.8.3 (cont.)

SCC-2017:
11th International ITG Conference on Systems, Communications and Coding, Hamburg, Germany, Feb. 2017

SPAWC-2018:
IEEE 19th International Workshop on Signal Processing Advances in Wireless Communications, Kalamata, Greece, June 2018

SPCC-2017:
Signal Processing in Photonic Communications, New Orlens, LA, USA, July 2017

WSA-2018:
22nd International ITG Workshop on Smart Antennas, Bochum, Germany, March 2018

Günlü, O., İşcan, O., Sidorenko, V., Kramer, G.: Reliable Secret-key Binding for Physical Unclonable Functions with Transform Coding. *In*: Proc. IEEE Global Conf. Signal Inf. Process., Washington D.C., USA, Dec. 2016

Günlü, O.; Kramer, G.: Secret Key Agreement with Physical and Biometric Identifiers. *In*: Proc. Angewandte Informationstheorie (AIT) Workshop, Berlin, Germany, May 2018

Kittichokechai, K.; Günlü, O.; Schaefer, R.; Caire, G.: Private Authentication with Controllable Measurement. *In*: Proc. 50th Annual Asilomar Conf. Signals, Systems, and Computers, Pacific Grove, CA, USA, Nov. 2016

Kobayashi, M.; Caire, G.; Kramer, G.: Joint State Sensing and Communication with Receiver State Information. *In*: Proc. ISIT-2018

Kramer, G.: Information Theory for Dispersion-free Fiber Channels with Distributed Amplification. *In*: Proc. *2017 CLEO Pacific Rim Conf.,* Singapore, Aug. 2017

Kusters, L.; Günlü, O.; Willems, F.M.J.: Zero Secrecy Leakage for Multiple Enrollments of Physical Unclonable Functions. *In*: Proc. Symp. Information Theory and Signal Processing in the Benelux, University of Twente, The Netherlands, May 2018

Maly, J.; Palzer, L.: Distributed Compressed Sensing with One-Bit Measurements and Hard Thresholding. *In*: Proc. 89th Annual Meeting of the Int. Ass. Appl. Mathematics and Mechanics, Munich, March 2018

Nedelcu, A.; Barletta, L.: Waveform Design for Wiener Phase Noise Channels and Multi-Sample Receivers. *In*: Proc. 21st Int. ITG Workshop Smart Antennas, TU Berlin, March 2017

Nedelcu, A.; Steiner, F.; Kramer, G.; Staudacher, M.; Baracca, P.; Zirwas, W.; Ganesan, R. S.; Wesemann, S.: Quantized Precoding for MIMO Downlink Channels with MAGIQ. *In*: Proc. WSA-2018

Prinz, T.; Yuan, P.; Böcherer, G.; Steiner, F.; İşcan, O.; Böhnke, R.; Xu, W.: Polar Coded Probabilistic Amplitude Shaping for Short Packets. *In*: Proc. IEEE Int. Workshop Signal Processing Advances in Wireless Commun., Hokkaido, Japan, July 2017

Saeedi Bidokhti, S.; Kramer, G.; Shamai (Shitz), S.: Capacity Bounds on the Downlink of Symmetric, Multi-relay, Single Receiver C-RAN Networks. *In*: Proc. ISIT-2017

Schulte, P.; Geiger, B. C.: Divergence Scaling of Fixed-Length, Binary-Output, One-to-one Distribution Matching. *In*: Proc. ISIT-2017, 3085-3089

Schulte, P.; Steiner, F.: Probabilistic Amplitude Shaping and Distribution Matching. *In*: Proc. 4th International Professor's Day on ICT Algorithm Design, Cape Town, South Africa, Nov. 2017

Schulte, P.; Steiner, F.; Böcherer, G.: Four Dimensional Probabilistic Shaping for Fiber-Optic Communication. *In*: Proc. SPCC-2017:

Sidorenko, V.:, Bartz, H.: On Interleaved Subspace Codes Correcting Packet Insertions in Networks with Random Linear Coding. *In*: Proc. ICTAD-2017

Sidorenko, V., Bartz, H., Wachter-Zeh, A.: Interleaved Subspace Codes in Fountain Mode. *In*: Proc. ISIT-2017

Sidorenko, V.; Li, W.; Zhou, Z.: On the Skew Transform and the Skew Complexity of Sequences. *In*: Proc. ACCT-2018

Staudacher, M.; Kramer, G.; Zirwas, W.; Panzner, B.; Ganesan, R.S.: Optimized Combination of Conventional and Constrained Massive MIMO Arrays. *In*: Proc. WSA-2017

Steiner, F.; Böcherer, G.: Comparison of Geometric and Probabilistic Shaping with Application to ATSC 3.0. *In*: Proc. SCC-2017

Steiner, F.; Da Silva, F.; Yankov M.; Böcherer, G.; Schulte, P.; Forchhammer, S.; Kramer, G.: Experimental Verification of Rate Flexibility and Probabilistic Shaping by 4D Signaling. *In*: Proc. OFC-2018

Steiner, F; Liva, G; Böcherer, G.: Ultra-Sparse Non-Binary LDPC Codes for Probabilistic Amplitude Shaping. *In*: Proc. IEEE GLOBECOM, Singapore, Dec. 2017

Steiner, F.; Schulte, P.; Böcherer, G.: Blind Decoding-Metric Estimation for Probabilistic Shaping via Expectation Maximization. *In*: Proc. ECOC-2018

Sula, E.; Gastpar, M.; Kramer, G.: Sum-rate Capacity for the Gaussian Multiple Access Channel with Feedback. *In*: Proc. ISIT-2018

2.8.4 Posters

Amjad, R.A.; Geiger, B.: Mutual Information Based Clustering: Hard or Soft? *In*: JWCC-2017

Coşkun, M. C.; Liva, G.: Successive Cancellation List Decoding of Single Parity-Check Product Codes. *In*: JWCC-2017 and ESIT-2017

Coşkun, M. C.; Liva, G.; Amat, A. G.; Lentmaier, M.: Successive Cancellation Decoding of Single Parity-Check Product Codes: Analysis and Improved

Legend to Chapter 2.8.4

ESIT-2017:
IEEE European School of Information Theory, Madrid, Spain, May 2017

Legend to Chapter 2.8.4 (cont.)

ESIT-2018:
IEEE European School of Information Theory, University Residential Centre of Bertinoro, Italy, May 2018

ISIT-2018:
IEEE International Symposium on Information Theory, Vail, Colorado, USA, June 2018

JWCC-2017:
18th Joint Workshop on Communications and Coding, Planneralm, Austria, March 2017

Matheon-2017:
3rd International Matheon Conference on Compressed Sensing and its Applications, TUM-LTI, Dec. 2017

MSC-2018:
Munich Doctoral Seminar on Communications, TUM-LNT, July 2018

TUM/COM-2018:
2018 TUM-COM Workshop on Ultra-Reliable Low-Latency Communications and Applications for 5G, Schneefernerhaus, Zugspitze, June 2018

Decoding Algorithms. *In*: Latin American Week on Coding and Information, Campinas, Brazil, July 2018

Coşkun, M. C.; Östman, J.; Durisi, G.; Ström E. G.; Liva, G.: Pilot-Assisted Short Packet Transmission over Memoryless Block-Fading Channels. *In*: ESIT-2018

Dierks, S.; Jünger, N.: On the Energy Efficiency of Massive MIMO and Network MIMO in an Indoor Scenario. *In*: JWCC-2017

Donev, D.: The Prolate Spheroidal Wave Functions in Finite Block Length Communications. *In*: ESIT-2018 and TUM-COM-2018

Donev, D.; Kramer, G.: Surface and Intersection Area of Spherical Caps on a n-dimensional Hypersphere. *In*: MSC-2018

Garcia, J.; Aref, V.: Statistics of the Eigenvalues of a Noisy Multi-Soliton Pulse. *In:* 44th European Conference on Optical Communication, Rome, Italy, Sept. 2018

Garcia, J.; Kramer, G.: Energy Coupling in Optical WDM Systems with Frequency-Dependent Attenuation Profile. *In*: JWCC-2017

Geiger, B. C.; Wu, Y.: Higher-Order Kullback-Leibler Aggregation of Markov Chains. *In*: JWCC-2017

Günlü, O.; Geiger, B.: The Optimal Transform for Key Storage with Biometric and Physical Identifiers. *In*: JWCC-2017

Günlü, O.; İşcan, O.; Sidorenko, V.; Kramer, G.: Secret-key Binding with Transform Coding for PUFs. *In*: Munich Workshop on Physical Unclonable Functions, TUM-LNT, Nov. 2017

Günlü, O.; İşcan, O.; Sidorenko, V.; Kramer, G.: Wyner-Ziv Polar Code Construction for Key Agreement with PUFs. *In*: 1st TUM-Eurecom Workshop on Communications and Security, TUM-LNT, Dec. 2017

Günlü, O.; İşcan, O; Sidorenko, V.; Kramer, G.: Nested Polar Code Construction for Key Agreement with Physical Unclonable Functions. *In:* ISIT-2018

Günlü, O.; Sidorenko, V.: Lightweight Code-based Quantizer and Transform Design for Security and Privacy. *In*: Munich Workshop on Coding and Applications, TUM-LNT, July 2017

Günlü, O.; Sidorenko, V.; Kramer, G.: Optimal Key Agreement with PUFs Under Varying Environmental Conditions. *In*: Munich Workshop on Coding and Cryptography, TUM-LNT, Apr. 2018

Maly, J.; Palzer, L.: Distributed Compressed Sensing with One-Bit Measurements. *In*: Matheon-2017 and TUM/Eurecom-2017

Östman, J.; Durisi, G.; Ström E. G.; Coşkun, M. C.; Liva, G.: Pilot-Assisted Short Packet Transmission over Memoryless Block-Fading Channels. *In*: TUM-COM-2018

Palzer, L.: Compressed Sensing with Scalar Quantization. *In*: JWCC-2017

Prinz, T.: Performance of Polar and BMERA Codes under Successive Cancellation List Decoding. *In*: MSC-2018

2.8.5 Talks

Bartz, H.; Sidorenko, V.: Power Decoding of Punctured Subspace Codes. Institute of Information Transmission Problems (IITP), Moscow, Russia, Oct. 2016

Böcherer, G.: Probabilistic Shaping: A Technique to Boost Fiber-Optic Transmission. TUM Institute for Advanced Study: Wednesday Coffee Talk, Dec. 2016

Böcherer, G.; Steiner, F.: New Modulation and Coding Paradigms for 5G and Beyond. *In*: ISWCS-2017

Amjad, R. A., Geiger, B. C., Blöchl, C.: Information Theoretic Cost Functions for Markov Aggregation and Clustering. Seminar at Eurecom, France, Oct. 2017

Böcherer, G.: Probabilistic Shaping in Fiber-Optic Communication Systems. ITG Workshop 5.3.1, TUM-LNT, Feb. 2017

Böcherer, G.: Probabilistic Shaping: An Information-Theoretic Foundation. In: JWCC-2017

Coşkun, M. C.; Liva, G.: Successive Cancellation List Decoding of Single Parity-Check Product Codes. In: ESIT-2017

Dierks, S.: Massive MIMO in a Local Area Scenario. SIST Seminar - ShanghaiTech University, Shanghai, China, Apr. 2017

Donev, D.: Prolate Spheroidal Wave Functions. *In*: JWCC-2017

Garcia, J.: Achievable Rates of Nonlinear Fourier Transform-based Optical Communication Systems. Christian-Albrechts-Universität zu Kiel, Sept. 2017

Legend to Chapter 2.8.5

ESIT-2018:
IEEE European School of Information Theory, University Residential Centre of Bertinoro, Italy, May 2018

ICSEE-2016
IEEE ICSEE Special Session on Optical Communication, Eilat, Israel, Nov. 2016

ITSDL-2016:
IEEE Information Theory Society Distinguished Lecture, Imperial University, University of York & University of Cambridge, UK, Dec. 2016

ICTAD-2017:
4th International Professor's Day on ICT Algorithm Design, Cape Town, South Africa, Nov. 2017

ISWCS-2017:
14th International Symposium on Wireless Communication Systems, Bologna, Italy, Aug. 2017

JWCC-2017:
18th Joint Workshop on Communications and Coding, Planneralm, Austria, March 2017

Legend to Chapter 2.8.5 (cont.)

LAWCI-2018:
Latin American Week on Coding and Information, Campinas, Brazil, July 2018

MPUF-2017:
Munich Workshop on Physical Unclonable Functions, TUM-LNT, Nov. 2017

MSC-2018:
Munich Doctoral Seminar on Communications, TUM-LNT, July 2018

OFC-2017:
Optical Fiber Communication Conference, Los Angelas, CA, USA, March 2017

OFC-2018:
Optical Fiber Communication Conference, San Diego, CA/USA, March 2018

TUM/COM-2018:
2018 TUM-COM Workshop on Ultra-Reliable Low-Latency Communications and Applications for 5G, Schneefernerhaus, Zugspitze, June 2018

Garcia, J.: Optical Communication Using the Nonlinear Fourier Transform. Electrical Engineering Department, Princeton University, Aug. 2018

Garcia, J.: Optical Communication Using the Nonlinear Fourier Transform. University of Warsaw, Poland, Sept. 2018

Garcia, J.; Ghozlan, H.; Kramer, G.: Energy Conservation in Optical Fibers with Distributed Brick-walls Filters. Rank Prize Funds symposium: Challenges to Meeting Demand Capacity on Long-Haul Optical Fibre Links, Grasmere, UK, June 2018

Geiger, B. C.; Amjad, R. A.: Generalized Kullback-Leibler Aggregation of Markov Chains. Workshop on Information and Communication Theory in Control Systems, TUM-RCS, May 2017

Geiger, B. C; Amjad, R. A.: Community Detection in Shakespeare's Plays. TUM-LNT, Dec. 2017

Gohari, A.; Günlü, O.; Kramer, G.: On a Measure of Private Common Information. TUM-LNT, Aug. 2017

Gohari, A.; Günlü, O.; Kramer, G.: Secret Key Generation From Correlated Sources. Seminar on Quantum Information Theory, Mathematical Physics Institute, TUM, Aug. 2017

Gohari, A.; Günlü, O.; Kramer, G.: On a Measure of Private Common Information. Sharif University Seminar, Iran, Oct. 2017

Gohari, A.; Günlü, O.; Kramer, G.: Positive Rate in the Multiple Round Key Agreement Problem. *In*: MSC-2018

Günlü, O.; Geiger, B.; Kramer, G.: Privacy and Secrecy with Physical Identifiers: Physical Unclonable Functions. Huawei Technologies France, Paris, France, May 2017

Günlü, O.; Geiger, B; Kramer, G.: Key Agreement with Physical Unclonable Functions. *In*: TUM/Eurecom2-2018

Günlü, O.; Geiger, B; Kramer, G.: Key Agreement with Physical Identifiers. Information and Communication Theory (ICT) Lab Seminar, TU Eindhoven, The Netherlands, March 2018

Günlü, O.; İşcan, O.; Sidorenko, V.; Kramer, G.: Optimal Code Construction for Secret-key Generation from PUFs. *In*: MPUF-2017

Günlü, O.; Kramer, G.: Research Directions: Physical and Biometric Identifiers for Key Agreement. Signal Processing Systems (SPS) Group Meeting, TU Eindhoven, Feb. 2018

Günlü, O.; Kramer, G.: Reliable Key Agreement with Biometric and Physical Identifiers under Varying Environmental Conditions. PUF Seminar, The Netherlands, March 2018

Günlü, O.; Schaefer, R. F.: Key Agreement through Broadcast Channel Measurements. Information Theory and Applications Workshop, San Diego, CA, USA, Feb. 2018

Kramer, G.: Models and Capacity Bounds for Optical Fiber Channels. *In*: ITSDL-2016

Kramer, G.: Energy and Entropy Conservation for Optical Fiber Channels. *In*: ICSEE-2016

Kramer, G.: JH Codes und Kunst. Verabschiedungs-Kolloquium für Prof. Johannes Huber, FAU Erlangen, March 2017

Kramer, G.: Advances in Coded Modulation for Optical Communications. In: OFC-2017

Kramer, G.: Communicating over Gaussian Interference Networks with Strong Feedback Links. Workshop on Inf. and Communication Theory in Control Systems, TUM-RCS, May 2017

Kramer, G.: Communicating over Gaussian Interference Networks with Strong Feedback Links. KTH-TUM Information Theory Workshop, Stockholm, Sweden, May 2017

Kramer, G.: Probabilistic Amplitude Shaping: An Architecture for Coded Modulation. Iran Workshop Commun. Inf. Theory, Tehran, Iran, May 2017

Kramer, G.: My Experience with Grant Proposals. TUM Tenure Track Academy Retreat, Raitenhaslach, Germany, June 2017

Kramer, G.: Spectral Broadening and Receiver Power for Dispersion-Free Fiber Channels. Balkan Conf. Commun. Networking, Tirana, Albania, June 2017

Kramer, G.: Information Theory for Certain Fiber Channel Models with Distributed Amplification. Annual Network Meeting and Workshop III, FP7 ITN Project ICONE, Birmingham, UK, June 2017

Kramer, G.: Information Theory and Applications to Optical Fiber. Munich Humboldt Club, June 2017

Kramer, G.: Optical Fiber Models and their Capacity. North American School Inf. Theory, Atlanta, GA, USA, June 2017

Legend to Chapter 2.8.5 (cont.)

TUM/Eurecom-2017:
1st TUM-Eurecom Workshop on Communications and Security, TUM-LNT, Dec. 2017

TUM/Eurecom2-2018:
2nd TUM-EURECOM Workshop on Communications and Machine Learning, TUM-LNT, July 2018

TUM/Eurecom3-2018:
3st TUM-Eurecom Workshop on Communications and Security, TUM-LNT, July 2018

Kramer, G.: Visions in Information Theory: Towards 2030, New Mathematical Tools for ICT. Huawei Paris Research Center Vision Forum, Paris, France, July 2017

Kramer, G.: Communication Theory for a Model of Dispersion-free Fiber Channels with Distributed Amplification. SPOC Workshop, Kragerup Gods, Denmark, Aug. 2017

Kramer, G.: Experiences with my Alexander von Humboldt Professorship. Special ECOC Symposium, Sept. 2017

Kramer, G.: Capacity of Cloud-RAN Downlink Channels. Technical University of Vienna, Austria, Nov. 2017

Kramer, G.: Coding for Cloud-RAN Downlink Channels. INRIA CITI Lab Workshop, Lyon, France, Dec. 2017

Kramer, G.: Coding and Capacity for Cloud-RAN Downlink Channels. Ollendoff Minerva Center Lecture, Technion, Haifa, Israel, Feb. 2018

Kramer, G.: Information Theory for Simplified Optical Fiber Models. ITG-Workshop 5.3.1, Helmut-Schmidt-Universität Hamburg, Feb. 2018

Kramer, G.: Information Theory for Cloud-RAN Downlink Channels. Faculty of Engineering Seminar, Bar Ilan University, Israel, March 2018

Kramer, G.: Information Theory and Strategies for Cloud-RAN Downlink Channels. Iran Workshop on Communication and Information Theory, Sharif University, Tehran, Iran, Apr. 2018

Kramer, G.: Information Theory for a Few Models inspired by Optical Fiber Communication. Eindhoven Workshop on Optical Communications, TU Eindhoven, The Netherlands, Apr. 2018

Kramer, G.: Information Theoretic Models with Block Fading and Fast Feedback. *In*: TUM/COM-2018

Kramer, G.: Digital Communications Education at TUM (Part 1) and Information Theory for an Example of Secret Key Agreement by Public Discussion (Part 2). Fotonik Seminar, DTU, Lyngby, Denmark, Aug. 2018

Kramer, G.: Review of Communication Theory of Selected Secrecy Systems. DTU Fotonik Seminar, DTU, Lyngby, Denmark, Aug. 2018

Kramer, G.: Energy Conservation in Optical Fibers with Distributed Brickwalls Filters. SPOC Workshop, Sophiendal, Denmark, Aug. 2018

Kramer, G.: Information Theory for Selected Optical Fiber Models. Shanghai Tech Workshop on Information, Learning, and Decision (SWILD), Shanghai, China, June 2018

Kramer, G.: How to Shape and Code Symbols for High-Rate Communications. ECE Department Symposium, Ben Gurion University, Israel, and Ollendoff Minerva Center Lecture, Technion, Haifa, Israel, May 2018

Kramer, G.; Saeedi Bidokhti, S.: Capacity of Cloud-RAN Downlink Channels. *In*: ICSEE-2016

Maly, J.; Palzer, L.: Distributed Compressed Sensing with One-Bit Measurements and Hard Thresholding. *In*: TUM/Eurecom3-2018

Nedelcu, A.: Precoding for the Quantized Massive MIMO Downlink. *In*: TUM/Eurecom-2017

Östman, J.; Durisi, G.; Ström E. G.; Coşkun, M. C.; Liva, G.: Pilot-Assisted Short Packet Transmission over Memoryless Block-Fading Channels. TUM/COM-2018

Prinz, T.: Polar Coded Probabilistic Amplitude Shaping. *In*: ICTAD-2017

Prinz, T.: Performance of Polar and BMERA Codes under Successive Cancellation List Decoding. *In*: MSC-2018

Prinz, T.; Steiner, F.; Yuan, P.: Pretty Good Codes for Short Packets. ITG Fachgruppe „Angewandte Informationstheorie", Bremen, Oct. 2017

Schulte P.: Shell Mapping Distribution Matching. *In*: MSC-2018

Sidorenko V.: Generalized Minimum Distance Decoding for Correcting Array Errors. Moscow Institute for Physics and Technology, Oct. 2017

Sidorenko V.: On Skew Complexity of Sequences with Applications to Algebraic Decoding. School of Mathematics, Southwest Jiaotong University, Chengdu, China, May 2018

Sidorenko V.: Skew Complexity of Sequences and Algebraic Decoding. College of Sciences, University of Petroleum, Qingdao, China, June 2018

Sidorenko V.; Bartz H.: On Syndrome Decoding of Interleaved Gabidulin and Subspace Codes. School of Mathematics and Information, China West Normal University, Sichuan Nanchong, China, May 2018

Sidorenko V.; Bartz H.: On Error-Control for Linear Network Coding. Institute for Information Transmission Problems of Russian Academy of Sciences, Moscow, Russia, July 2018

Sidorenko, V., Bartz, H., Wachter-Zeh, A.: Interleaved Subspace Codes in Fountain Mode. Moscow Institute for Physics and Technology, Russia, Feb. 2017

Sidorenko V., Bartz H., Wachter-Zeh A.: On Syndrome Decoding of Interleaved Gabidulin and Subspace Codes. Institute of Mathematics of University of Zurich, Switzerland, Sept. 2017

Steiner, F.: High Rate Coded Modulation for Coherent DCI with 4D Signaling. Huawei Workshop on Data Center Connectivity, Munich, June 2018

Steiner, F.; Prinz, T.; Yuan, P.: Overview of Forward Error Correction Schemes for Short Blocklengths. Workshop on Information and Communication Theory in Control Systems, TUM-RCS, May 2017

3 LÜT

Professur für Leitungsgebundene Übertragungstechnik (LÜT)
Associate Professorship of Line Transmission Technology

Greeting Message from Norbert Hanik

Dear reader of the present activity report,

on the following pages I would like to give a brief overview of changes and highlights of our research group. During the last two years two research projects have been successfully completed.

Dr.-Ing. **Jingkan Chen** received a Ph.D. degree in 2016 (with high distinction) with his thesis entitled *Orthogonal Frequency-Division Multiplexing in Fiber-Optic Communication Systems* **on** the use of OFDM in Optical Communication Systems, particulary in Optical Access Networks. After a two-years employment at Coriant GmbH Munich, subsequent to his Ph.D., he now remigrated to his hometown Shanghai, where he continues working in the field of transmission technology.

Dr.-Ing. **Tobias Fehenberger** finished his work on Coded Modulation with his thesis about *Analysis and Optimization of Coded Modulation for Nonlinear Fiber-Optic Communication Systems*. In addition to his thesis (likewise rated "with high distinction") Dr. Fehenberger received numerous prestigious awards for his scientific results and for outstanding performance in teaching. In this respect the ITG-Dissertation Award 2018 of the German *Informationstechnische Gesellschaft* (Society of Information Technology) is particularly noteworthy, granted to him at the Berlin-Brandenburg Academy of Science in November 2018.

Currently our research group is working on four different topics in the field of optical communications.

Ginni Khanna is engaged in the BMBF project SENDATE, evaluating and optimizing methods for digital pre-distortion of optical signals to compensate linear and nonlinear degradations. In the final work package (the project will end in May 2019) concepts for encryption of optical signals at the physical layer shall be evaluated.

Since January 2017 **Benedikt Leible** is working on a DFG project evaluating the potential of Nonlinear Frequency Division Multiplexing. In this project, methods shall be developed and optimized to generate optical signals with the *Nonlinear Fourier Transform*, which are optimally adapted to the nonlinearity of silica fibers.

Amita Shresta, an external Ph.D. candidate engaged at the DLR Oberpfaffenhofen, is designing adaptive modulation schemes for optical free-space communication between a geostationary satellite and the ground station.

Last, but not least, **Tasnad Kernetzky** changed his research topic. He is now engaged in the framework of a DFG research cluster which is targeting on the design of an *Ultra Broadband Photonic Signal Processor*. Currently he is working on optimum wavelength- and mode-selection for ultra-broadband, multi-modal, optical phase-conjugation.

The mindful reader certainly noticed that our research group, in addition to its head, is composed of only four active Ph.D. students. Apart from the fact that small groups can be effective and successful (see the distinctions and awards mentioned above), this is also because two additional research positions of our group are currently vacant. If the reader is aware of excellent graduates, willing and capable to do high-end research in the field of optical communications, I would be grateful, if you put us in touch.

For enthusiasts of statistical data acquisition who like to be fully advised of

- our numerous publications,
- organized or planned conferences and workshops,
- supervised Master and Bachelor's Theses,
- supervised projects of industry and research internships of our students, or
- generally of the extensive research and teaching activities of the Professorship of Wireline Communications.

I refer to the exhaustless data-pool of the website of our teaching- and research-unit for communications under https://www. lnt.ei.tum.de/en/home/.

With best regards,

Norbert Hanik

4 COD

Professur für Coding for Communications and Data Storage (COD)
Assistant Professorship of Coding for Communications and Data Storage

Antonia Wachter-Zeh et al.

On 01.10.2016 Antonia Wachter-Zeh was appointed Tenure Track Assistant Professor by the *TUM Department of Electrical and Computer Engineering*. This date also marks the beginning of the *Professorship of Coding for Communications and Data Storage*, which forms an administrative unit together with LNT and LÜT (Lehr- und Forschungseinheit).

4.1 People

Scientific Staff

Wachter-Zeh, Antonia, Prof. Dr.-Ing.	Tenure Track Assistant Professor
Hollanti, Camilla, Prof. (since 01.08.2017)	TUM-IAS Hans Fischer Fellow

Camilla will spend ten months with COD over a three-year period. In the reporting period she was in Munch during 11/2017 -05/2018 and in August 2018.

Puchinger, Sven, Dr.-Ing.	Senior Researcher
Holzbaur, Lukas, M.Sc. (since 01.03.2017)	Doctoral Researcher
Lenz, Andreas, M.Sc. (since 01.11.2016)	Doctoral Researcher
Renner, Julian, M.Sc. (since 01.11.2017)	Doctoral Researcher

Left the chair during the reporting period

Freij-Hollanti, Ragnar, Dr. (01.11.2017- 01.08.2018)	Senior Researcher

Research and Student Work

Sarmad Ansari, Anubhab Banjeree, Emna Ben Yacoub, Amir Biran, Amine Gouiaa, Lukas Holzbaur, Niklas Jünger, Sayantini Majumdar, Hedongliang Liu, Vo Son Ha Nguyen, Aditya Pradeep, Johannes Rosenberger, Venkatesh Satagopan, Yogesh Shankar, Marvin Xhemrishi

Our new colleagues at COD

Prof. **Antonia Wachter-Zeh** is a Rudolf Mößbauer Tenure Track Assistant Professor at the Technical University of Munich (TUM) since October 2016. At the same time, she heads the group "Coding for Communications and Data Storage" and is a Fellow at the TUM Institute for Advanced Study (TUM IAS).

From October 2009 to October 2013, Antonia was a doctoral researcher and teaching assistant under the co-supervision of Martin Bossert at the Institute of Communications Engineering, Ulm University, Germany, and Pierre Loidreau at the Institut de Recherche Mathématique de Rennes (IRMAR), Université de Rennes 1, Rennes, France. The topic of her dissertation was "Decoding of Block and Convolutional Codes in Rank Metric". From November 2013 to August 2016, she was a Postdoctoral Researcher at the Computer Science Department of the Technion, Israel Institute of Technology, in the group of Tuvi Etzion, Ronny Roth, and Eitan Yaakobi.

Antonia's main research interests are coding theory, efficient algorithms, security (in particular code-based cryptography and physical unclonable functions), and applying error-correcting codes to communications and storage in general, in particular to network coding, non-volatile memories, distributed data storage, and DNA storage.

Antonia is a recipient of the DFG Emmy Noether research program (since 2016), the DFG Heinz Maier-Leibnitz-Preis in 2018, and an ERC Starting Grant in 2018. She is the (co-)organizer of a Dagstuhl seminar on Algebraic Coding Theory, the Munich Workshop on Coding and Applications 2017 (MWCA 2017), and the Munich Workshop on Coding and Cryptography 2018 (MWCC 2018).

Since September 2018 Antonia is Member of the Master Examination Board of our faculty, and since 2016 she has been member of the Technical Program Committees of the

- 11th International Workshop on Coding and Cryptography (WCC 2019), Saint-Jacut-de-la Mer, France,
- 9th Annual Non-Volatile Memories Workshop 2018 (NVMW 2018), UCSD, California, US,
- 8th Annual Non-Volatile Memories Workshop 2017 (NVMW 2017), UCSD, California, US,
- Conference on Information Technology and Systems 2015, Sochi, Russia.

Prof. **Camilla Hollanti** received the M.Sc. and Ph.D. degrees from the University of Turku, Finland, in 2003 and 2009, respectively, both in pure mathematics. Her research interests lie within applications of algebraic number theory to wireless communications and physical layer security, as well as in combinatorial and coding theoretic methods related to distributed storage systems and private information retrieval.

For 2004-2011 Camilla was with the University of Turku. Since 2011, she has been with the Department of Mathematics and Systems Analysis at Aalto University, Finland, where she currently works as Full Professor and leads a research group in Algebra, Number Theory, and Applications. During 2017-2020, Camilla is also affiliated with the TUM Institute for Advanced Study, where she holds a 3-year Hans Fischer Fellowship, funded by the German Excellence Initiative and the EU 7th Framework Programme.

Camilla is an editor of the AIMS Journal on Advances in Mathematics of Communications. She is a coauthor of 80 scientific peer-reviewed publications and a recipient of several grants, including five Academy of Finland grants in 2010-2018. In 2014, she received the World Cultural Council Special Recognition Award for young researchers. In 2017, the Finnish Academy of Science and Letters awarded her the Väisälä Prize in Mathematics.

Dr. **Ragnar Freij-Hollanti** received his M.Sc. from the University of Gothenburg in 2007, and his Ph.D. in Mathematics from Chalmers University of Technology in 2012. During 2012-2017, he was a postdoctoral researcher in mathematics and communications theory at Aalto University, and during 2017-2018, he was a senior researcher at the Institute for Communications Engi-

neering at the Technical University of Munich. Since 2018, he is again at Aalto University as a university teacher. His research interests are in algebraic and geometric combinatorics, and their applications to coding and communications theory.

Lukas Holzbaur, M.Sc., was born in Stuttgart, Germany, in 1992. He received the B.Sc. and M.Sc degree

in Electrical Engineering at the Technical University of Munich (TUM) in 2014 and 2017, respectively. His Master's thesis under the supervision of Dr. Hannes Bartz and Prof. Antonia Wachter-Zeh was on Improved Decoding of Staircase Codes.

In March 2017, he joined COD as a Research Assistant of Prof. Antonia Wachter-Zeh. His research interests are in the field of coding theory, with emphasis on algebraic coding and coding for distributed data storage. In his leisure time Lukas plays Basketball and Tennis.

Andreas Lenz, M.Sc., was born in Dachau, Germany, in 1991. He received his B.Sc and M.Sc degrees in

Electrical Engineering and Information Technology at TUM in 2013 and 2016, respectively, both with high distinction.

During his studies he worked on analog filter optimization for sub-Nyquist channel estimation. As part of his Master studies, he was an exchange student at the University of Alberta, Canada. From 2014 until 2016 he worked on mobile network analysis systems at Rohde & Schwarz. For his Master's thesis, he visited Prof. Swindlehurst from the University of California, Irvine. In 2016, he joined the TUM COD group headed by Prof. Wachter-Zeh, where he is involved in research on error correcting codes for insertion and deletion errors. Since 2016, Andreas is teaching assistant of the lecture "Channel Coding".

In his leisure time, Andreas competes in ballroom dancing and enjoys playing the guitar.

Dr.-Ing. Sven Puchinger was born in Karlsruhe, Germany, in 1990. He received a B.Sc. in Electrical

Engineering (2009-2012) and a B.Sc. in Mathematics (2013-2016) from Ulm University, Germany, and was an exchange student at the University of Toronto, Canada, for two semesters in 2012-2013. From 2014 to 2018, Sven was a research assistant and PhD student at the Institute of Communications Engineering, Ulm University, Germany, where he was advised by Prof. Dr.-Ing. Martin Bossert. He joined the Coding for Communications and Data Storage (COD) group at LNT as a postdoctoral researcher in May 2018. His research interests are construction and decoding of algebraic codes in Hamming and rank metric, related computer algebra methods,

and applications of coding theory in networks and cryptography. Sven is married and has a child. His private interests are sports and photography.

Julian Renner, M.Sc., was born in Eggenfelden, Germany in 1991. He received the B.Sc. and M.Sc. de-

grees (with high distinction) in electrical engineering from TUM in 2014 and 2016, respectively. For his Master's thesis, he worked on a joint research project of the TUM Institute for Communications Engineering and the Coding and Visual Communication Group, Department of Photonics Engineering, Technical University of Denmark (DTU); the topic was *Multidimensional Probabilistic Shaping for the Nonlinear Fiber Channel*.

Since November 2017, he is pursuing the Dr.-Ing. degree at the COD group of the Technical University of Munich. His research interests are in the fields of cryptography and coding theory. In his leisure time, Julian enjoys several kinds of sports.

4.2 Research

Overview Antonia Wachter-Zeh

The COD group recently celebrated its second birthday. Despite being such a young group, we have some interesting things to report!

Our main research focus is coding theory with applications to storage, security, and privacy. The two workshops that we organized (MWCA2017 and MWCC2018) each attracted about 80 international participants, and we received very encouraging feedback from the community.

Prof. **Camilla Hollanti** from Aalto University in Finland received a *Hans Fischer Fellowship* from the TUM Institute for Advanced Study in 2017. She spent her sabbatical from November 2017 to May 2018 in the COD group and will come to Munich for a few shorter visits in the future. We collaborated on several topics in private information retrieval, and developed a new lecture together called „Security in Communications and Data Storage".

The COD group hosted several international guest professors, for example Tuvi Etzion (Technion), Eitan Yaakobi (Technion), Sergey Bezzateev (St. Petersburg State University), and Bernhard Häupler (Carnegie Mellon University).

In 2018, I was awarded the *DFG Heinz Maier-Leibnitz Award,* which is said to be the most important German award for young scientists. This award was presented at a very nice ceremony in Berlin in May 2018.

Further, I recently won an *ERC Starting Grant* which will begin in spring 2019 and deal with DNA storage and cryptography. Andreas Lenz received a *Fulbright Fellowship* that he will use to visit Prof. Paul Siegel at UCSD in the coming spring.

Currently, the COD group consists of one postdoctoral researcher, four Dr.-Ing. students, and me.

Andreas Lenz joined the COD group as its first doctoral candidate in December 2016. He is working on coding for DNA storage. This includes research on fundamental theoretical problems such as correcting insertions and deletions (sometimes including classical substitution errors) as well as investigating the DNA storage „channel" and designing codes for this channel. His work will be funded by the ERC Starting Grant.

Lukas Holzbaur started as a doctoral candidate in March 2017 after finishing his Master thesis on staircase codes, which he did under the co-supervision of Dr.-Ing. Hannes Bartz. Lukas is now working on the DFG Emmy Noether project, in particular on coding for distributed data storage. This includes so-called locally repairable codes and their (list) decoding. Recently, he started to work on problems in privacy. This fall he is visiting Camilla at Aalto University.

Since November 2017, **Julian Renner** is working on code-based cryptography (soon within the ERC Starting Grant). The goal is to design post-quantum secure cryptosystems based on classical coding theory. Currently, he is applying rank-metric codes to code-based cryptography. In collaboration with the TUM-SEC research group, we are implementing some of these systems in hardware.

Dr. **Ragnar Freij-Hollanti** was a postdoc from November 2017 to August 2018. He contributed to the new „Security" lecture and worked on coding for distributed data storage and private information retrieval.

Dr.-Ing. **Sven Puchinger** joined the TUM-COD group in May 2018 as a postdoctoral researcher. His research interests are coding theory, computer algebra, and applications, in particular physical unclonable functions and code-based cryptography. He is currently working within the German-Israeli DIP project where we collaborate with Prof. Moshe Schwartz on network coding problems.

Shortly after the reporting period, **Haider al Kim** joined COD. He is funded by a DAAD scholarship. In December 2018 **Georg Maringer** and in March 2019 **Lia** *(Hedongliang)* **Liu** will start as doctoral candidates.

On the following pages we describe three research projects in detail:
- Coding for DNA Storage,
- Distributed Storage and Private Information Retrieval,
- Post Quantum Cryptography.

Finally, you will find a list of supervised student theses (Chapter 4.5) and publications (Chapter 4.6).

Coding for DNA Storage

Andreas Lenz, Antonia Wachter-Zeh, and Eitan Yaakobi

Reliable and high capacity archival storage is necessary inevitable in a modern society as is storing of biometric data. This becomes evident not only by the necessity of archived data for prosecuting criminals, but also is an essential aspect of ethics concerning the preservation of historic events for future generations. DNA based storage is a novel technology, where digital information is stored in synthetic DNA molecules. The recent advance in DNA sequencing methods and decrease in sequencing costs have paved the way for storage methods based on DNA. The natural stability of DNA molecules (the genetic information from fossils is maintained over tens of thousands of years) motivate their use for long-term archival storage. Furthermore, because the information is stored on molecular levels, such storage systems have extremely high data densities. Recent experiments report densities of 2 PB/gram, which corresponds to the capacity of a thousand conventional hard disk drives in one gram of DNA.

However, DNA storage is prone to errors, and therefore one must protect the embodied data with error-correcting schemes that can recover the stored data even in the presence of errors. There are three main types of errors that must be dealt with in DNA based storage. Since the data is spread over many short DNA sequences, some DNA strands might be lost during the reading process. Then, during the data replication process, errors that result from mutations can corrupt the data. Error correcting schemes for such errors, i.e., duplications, have been investigated in [1] and [2]. Further, current high-speed sequencing methods can be erroneous, and single symbols of the sequenced strands can be mistaken or inserted, respectively deleted from the sequence.

The Figure illustrates a typical DNA-based storage system. Binary user data is encoded to DNA strands and protected by an error-correcting code. These strands are synthesized and stored. To access the data, the strands are sequenced and eventual errors (illustrated by underlined symbols) are corrected.

This project deals with the design of error-correcting schemes that can cope with these kinds of errors. One focus lies on the design of efficient codes that require a small amount of redundancy, but still provide sufficient reliability [3]. Further, the optimality of these schemes is investigated by finding the capacities of such DNA based storage systems. Error-correcting schemes for insertion and deletion errors, which are the main type of errors in DNA based storage systems, form an essential part of this project.

Literature:

[1] Lenz, A., Wachter-Zeh, A., Yaakobi, E.: Duplication-Correcting Codes. Designs, Codes, and Cryptography, June 2018

[2] Lenz, A., Juenger, N., Wachter-Zeh, A., Yaakobi, E.: Bounds and Constructions for Multi-Symbol Duplication Error-Correcting Codes. Proc. ACCT 2018

[3] Lenz, A., Siegel, P., Wachter-Zeh, A., Yaakobi, E.: Coding over Sets for DNA Storage. Proc. ISIT 2018

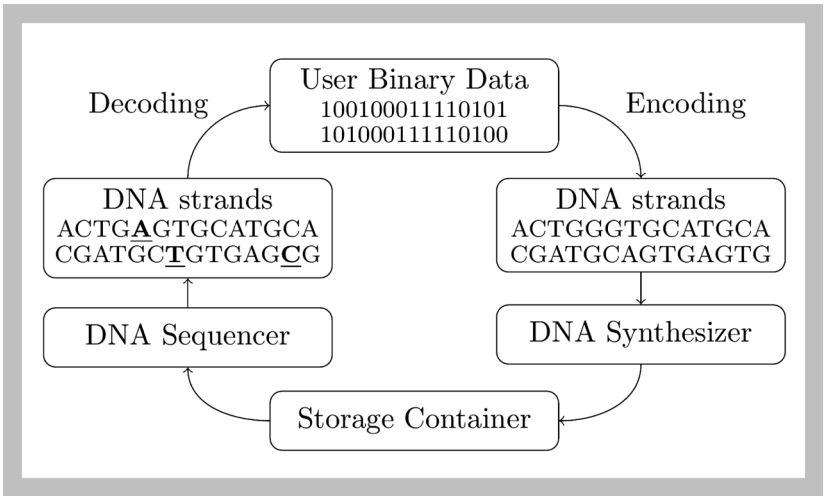


Illustration of a DNA based storage system

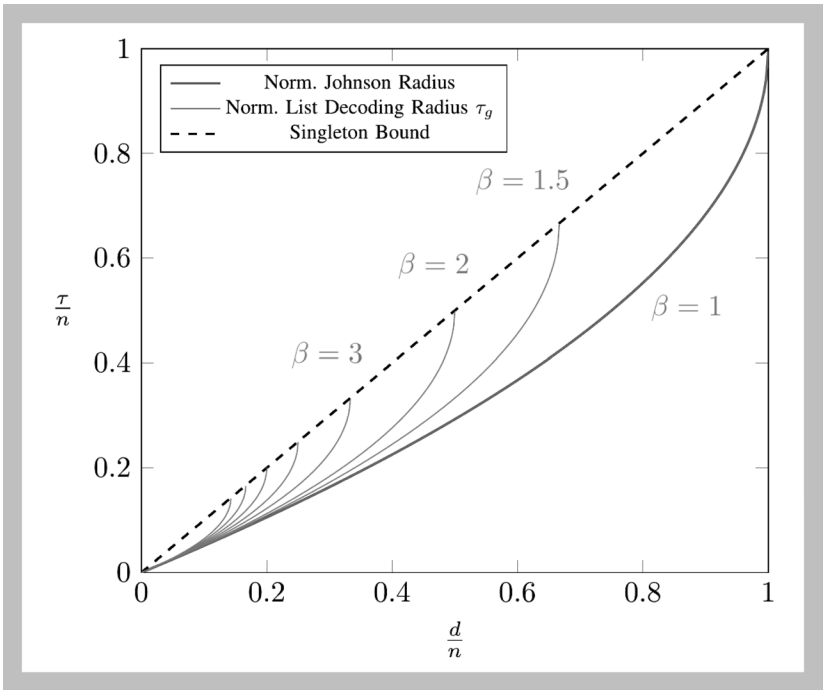
Distributed Storage and Private Information Retrieval

Lukas Holzbaur and Antonia Wachter-Zeh

With the increase in popularity of cloud storage, the scale of distributed data storage has increased massively in past years. This makes coding solutions that decrease the storage overhead and improve the availability worth the additional implementation effort. The coding solutions should cope with failures of data servers and offer recovery that is efficient when considering the topology of the server network. One approach that has gained attention in the past years is *locally recoverable codes.* In the likely case of few servers failing, these codes allow recovery from only a subset of other servers, e.g., from servers that are physically close or well connected. This decreases the total required network traffic and decreases the downtime of servers compared to solutions based on classic block codes. In a recent work we developed an improved decoder for such codes that corrects more errors by a list decoding based approach [1]; a comparison with the best previously known decoding radius is given in the figure.

Data storage media like flash memories (used in USB flash drives or solid state drives) suffer from manufacturing imperfections, wear-out, and fluctuating read/write errors. These give rise to special error models, e.g., crisscross errors, which require specifically designed coding solutions. We introduced a new construction that achieves locality with respect to crisscross errors [2].

Data retrieval from a data base shared by many users is a common occurrence in online services (e.g., Netflix, YouTube). Privacy protection regulations, such as the new EU data protection laws, pose new challenges for providers of such services. Private Information Retrieval (PIR) offers coding solutions that hide the identity of the file a user desires, while minimizing the communication overhead. Most existing approaches focus retrieving entire files without delay constraints, which is not well suited for, e.g., video streaming. To address this issue we introduced a scheme that allows to retrieve large files (e.g., movies) in a streaming manner [3]. This decreases the decoding delay while keeping the storage and communication overhead low.



Normalized List Decoding Radius

Literature:

[1] Holzbaur, L.; Wachter-Zeh, A.: List Decoding of Locally Repairable Codes. *In:* Proc. IEEE Int. Symp. Inf. Theory (ISIT), June 2018

[2] Liu, H.; Holzbaur, L; Wachter-Zeh, A.: Locality in Crisscross Error Correction. *In:* Int. Workshop on Algebraic and Combinatorial Coding Theory, Sept. 2018

[3] Holzbaur, L.; Freij-Hollanti, R. Wachter-Zeh, A.; Hollanti, C.: Private Streaming with Convolutional Codes. *In:* IEEE Inf. Theory Workshop (ITW), Nov. 2018

Post Quantum Cryptography

Julian Renner and Antonia Wachter-Zeh

Nowadays, we often use encryption schemes without realizing that they are being used. Every mobile phone call, WhatsApp message and e-mail, and also each use of our debit card, credit cards, car keys and many other applications are protected by these methods. Secure encryption has become important to protect our privacy, and to protect ourselves against criminals.

The security of these methods are based on Cryptography, which applies mathematical properties of number theory and abstract algebra. The goal is to find mathematical problems that allow us to encrypt messages efficiently, while at the same time decryption should be practically feasible only if one knows the secret key. However, for unauthorized parties who do not have the secret key, it should be computationally infeasible to retrieve the message from the encrypted text, called the ciphertext. The field of cryptography can be divided into two main categories: symmetric and asymmetric cryptography. In the symmetric case, both the person who is encrypting and the person who is decrypting know the secret key. In the asymmetric case, only the person who is decrypting knows the secret key, cf. the blockdiagram in the figure. Asymmetric cryptography algorithms are usually based either on the difficulty of computing the discrete logarithm, or on the difficulty of decomposing a large number into its prime factors.

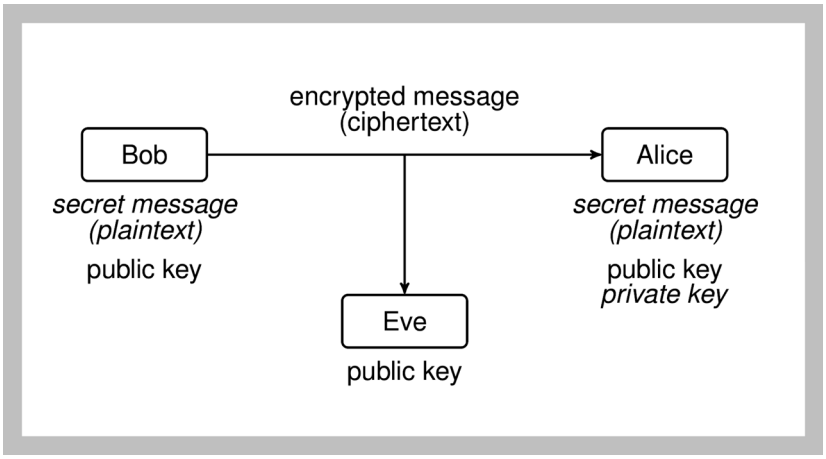
At the moment, quantum computers are receiving attention. Not only research institutes and universities such as TUM, but also profit-orientated companies like Google and IBM are working intensively on developing quantum computers. One reason is that these computers can perform certain computations much more efficiently than classical computers. For example, quantum computers can compute discrete algorithms and prime factor decompositions in a very short time, and are thus a security risk for our private data.

The threat of quantum computers motivated the *National Institute of Standards and Technology* (NIST) to initiate a process to solicit, evaluate, and standardize one or more quantum-resistant public-key cryptographic algorithms. One promising class of candidates is cryptosystems based on error correcting codes. Besides codes that perform well in the Hamming metric, codes that can correct errors with a large rank weight are interesting for cryptography. The systems introduced in [1] and [2] belong to the latter. We are working to better understand the security of these algorithms, and to develop improved algorithms.

Literature:

[1] Wachter-Zeh, A.; Puchinger, S.; Renner, J.: Repairing the Faure-Loidreau Public-Key Cryptosystem. *In:* Proc. IEEE Int. Symp. Inf. Theory (ISIT), June 2018

[2] Puchinger, S.; Renner, J.; Wachter-Zeh, A.: Twisted Gabidulin Codes in the GPT Cryptosystem. *In:* 16th Int. Workshop on Algebraic and Combinatorial Coding Theory (ACCT), Sept. 2018



Blockdiagram of Asymmetric Cryptography

4.3 Projects

This chapter lists the four externally-funded research projects of the Professorship of Coding for Communications and Data Storage (COD) in the reporting period 10/2016-09/2018:
– three projects → (A), (C), (D) from the Deutsche Forschungsgemeinschaft (DFG)
– one project → (B) from the TUM Institute for Advanced Study.
The project (C) is a joint project of LNT and COD.

The ERC Starting Grant "inCREASE: Coding for Security and DNA Storage" will start soon (European Commission, Horizon 2020, 5 years duration).

(A) Error-Correcting Coding Strategies for Data Storage and Networks

Project Team: Prof. Antonia Wachter-Zeh, Dr. Ragnar Freij-Hollanti, Lukas Holzbaur, and Julian Renner
Funding Period: 01.10.2016 – 30.09.2021
Reporting Period: 01.10.2016 – 30.09.2018
Funding Agency: Deutsche Forschungsgemeinschaft (DFG)
DFG Emmy Noether Research Program

(B) Privacy and Locality in Distributed Data Storage Systems

Project Team: Prof. Camilla Hollanti, Prof. Antonia Wachter-Zeh, and Lukas Holzbaur
Funding Period: 01.04.2017 – 31.03.2020
Reporting Period: 01.04.2017 – 30.09.2018
Funding Agency: Technical University of Munich, Institute for Advanced Study (TUM-IAS)

(C) Fundamentals of Cooperation in Modern Communication Networks

Project Team: Prof. Antonia Wachter-Zeh, Prof. Gerhard Kramer (LNT), and Sven Puchinger
Funding Period: 01.01.2018-31.12.2022
Reporting Period: 01.01.2018-30.09.2018
Funding Agency: Deutsche Forschungsgemeinschaft (DFG)
Project Partners: Prof. Permuter and Prof. Schwartz, Ben Gurion University of the Negev, Israel

(D) Munich Workshop on Coding and Applications 2017 (MWCA 2017)

Project Team: Prof. Wachter-Zeh and Vladimir Sidorenko
Funding Period: 2017
Reporting Period: 2017
Funding Agency: Deutsche Forschungsgemeinschaft (DFG), Workshop Funding
Project Partners: TUM Chair of Communications Engineering (LNT)

4.4 Teaching

All courses offered by Prof. Antonia Wachter-Zeh and her staff are graduate-level (MSEI, MSCE). The abbreviations in the list are
V: Vorlesung (Lecture),
Ü: Übung (Tutorial),
P: Praktikum (Laboratory),

Channel Coding
Elective module for MSEI 1/MSCE 1, 3V+2P, 5 ECTS, Language: EN
Winter Term 2016/2017: A. Wachter-Zeh with A. Lenz, H. Bartz (LNT)
Winter Term 2017/2018: A. Wachter-Zeh with A. Lenz

Coding Theory for Storage and Networks
Elective module for MSEI 2/MSCE 2, 2V+2P, 5 ECTS, Language: EN

Summer Term 2017: A. Wachter-Zeh with A. Lenz, L. Holzbaur
Summer Term 2018: A. Wachter-Zeh with J. Renner

Security in Communications and Storage
Elective module for MSEI 3/MSCE 3, 3V, 5 ECTS, Language: EN
Winter Term 2017/2018: A. Wachter-Zeh, C. Hollanti with R. Freij-Hollanti, L. Holzbaur

4.5 Students Theses

During the period 10/2016-09/2018 Prof. Antonia Wachter-Zeh and her assistants of the Assistant Professorship of Coding for Communications and Data Storage (COD) supervised a number of theses and projects:
- three Master's theses
- six MSEI and MSCE research internships
- two Bachelor's theses
- one Bachelor's internship

Master's Theses

10.01.2017 **Lukas Holzbaur** - Supervisor: Prof. Wachter-Zeh, H. Bartz (LNT)
Decoding Schemes for Staircase Codes

15.03.2018 **Niklas Jünger** - Supervisor: A. Lenz
Tandem Duplication Correcting Codes for DNA-based Storage

18.07.2018 **Molka Elleuch** - Supervisor: Prof. Wachter-Zeh, L. Heidt, Dr. Zeh (both Infineon Technologies)
Key Size Reduction of Code-based Cryptography

MSEI and MSCE Research Internships

12.07.2017 **Sayantini Majumdar** - Supervisor: A. Lenz
Sequence Reconstruction for Insertion and Deletion Errors

12.07.2017 **Anubhab Banerjee** - Supervisor: Prof. Wachter-Zeh
Analysis of Some Code-Based Cryptosystems

08.01.2018 **Venkatesh Satagopan** - Supervisor: Prof. Wachter-Zeh
Error Correction for Partially Stuck Memory Cells

09.03.2018 **Amir Biran** - Supervisor: A. Lenz
Statistical Analysis of Errors in DNA Based Storage Systems

23.04.2018 **Hedongliang Liu** - Supervisor: L. Holzbaur
Locality in Crisscross Decoding

15.05.2018 **David Ginthör** - Supervisor: J. Renner
Distributed Source Coding (DSC) in Wireless Sensor Networks

Bachelor's Theses

19.03.2018 **Johannes Rosenberger** - Supervisor: A. Lenz
Decoding Methods for DNA Storage Based on Reed-Solomon Codes

25.09.2018 **María del Mar Morejón de Girón Albelda** - Supervisor: L. Holzbaur
Locality in Product Codes

Bachelor's Internship

23.04.2018 **Amine Gouiaa** - Supervisor: L. Holzbaur, Fa. NTT
Data Chatbots

4.6 Publications

The publications of the Professorship of Coding for Communications and Data Storage (COD) are listed below:
- one Book Chapter,
- ten Journal Publications,
- nineteen Conference Publications,
- seven Posters,
- ten Talks.

4.6.1 Book Chapter

Bossert, M.; Sidorenko, V.; Wachter-Zeh, A.: Coding Techniques for Transmitting Packets Through Complex Communication Networks. In: Communications in Interference Limited Networks. Springer International Publishing, 2016

4.6.2 Journal Articles

Bartz, H.; Wachter-Zeh, A.: Efficient Decoding of Interleaved Subspace and Gabidulin Codes beyond their Unique Decoding Radius Using Gröbner Bases. *In*: Advances in Mathematics of Communications 12 (4), 773-804, Apr. 2018

Dochtermann, A.; Freij-Hollanti, R.: Warmth and Connectivity of the Edge Space of Graphs. *In*: Advances in Applied Mathematics **96** (5), 176-194, May 2018

Etzion, T.; Wachter-Zeh, A.: Vector Network Coding Based on Subspace Codes Outperforms Scalar Linear Network Coding. IEEE Trans. Inf. Theory 64 (4), 2460 - 2473, Apr. 2018

Lenz, A.; Stein, M.; Swindlehurst, A. L.: Joint Transmit and Receive Filter Optimization for Sub-Nyquist Delay-Doppler Estimation. *In*: IEEE Trans. Signal Processing **66** (10), p. 2542 - 2556, Feb. 2018

Lenz, A.; Wachter-Zeh, A.; Yaakobi, E.: Duplication-Correcting Codes. *In*: Designs, Codes, and Cryptography, Special Issue: Coding and Cryptography, p. 1-22, Aug. 2018

Renner, J; Fehenberger, T.; Yankov, P.; Da Ros, F.; Forchhammer, S.; Böcherer, G; Hanik, N.: Experimental Comparison of Probabilistic Shaping Methods for Unrepeated Fiber Transmission. *In*: IEEE/OSA Lightwave Technol. **35** (22), Sept. 2017

Puchinger, S.; Wachter-Zeh, A.: Fast Operations on Linearized Polynomials and their Applications in Coding Theory. *In*: J. Symbolic Computation 89 (8), 194-215, Aug. 2017

Schoeny, C.; Wachter-Zeh, A.; Gabrys, R.; Yaakobi, E.: Codes Correcting a Burst of Deletions or Insertions. IEEE Trans. Inf. Theory **63** (4), Apr. 2017

Wachter-Zeh, A.: List Decoding of Crisscross Errors. IEEE Trans. Inf. Theory **63** (1), Jan. 2017

Wachter-Zeh, A.: List Decoding of Insertions and Deletions. (accepted for) IEEE Trans. Inf.. Theory **64** (9), 6297-6304, Sept. 2018

4.6.3 Conference Publications

Beelen, P.; Bossert, M.; Puchinger, S.; Rosenkilde, J.: Structural Properties of Twisted Reed-Solomon Codes with Applications to Cryptography. *In*: Proc. ISIT-2018

Grezet, M.; Freij-Hollanti, R.; Westerbäck, T.; Olmez, O.; Hollanti C.: Bounds on Binary Locally Repairable Codes Tolerating Multiple Erasures. *In*: Proc. Zurich Seminar on Information and Communication, Zuirich, Switzerland, Feb. 2018

Holzbaur, L.; Bartz, H., Wachter-Zeh, A.: Improved Decoding of Staircase Codes. In: Proc. Munich Workshop on Information Theory of Optical Fiber (MIO 2016), TUM-LNT, Dec. 2018

Holzbaur, L.; Bartz, H.; Wachter-Zeh, A.: Improved Decoding and Error Floor Analysis of Staircase Codes. *In*: Proc. 10th Int. Workshop Coding and Cryptography, St. Petersburg, Russia, Sept. 2017

Holzbaur, L.; Freij-Hollanti, R.; Wachter-Zeh, A.; Hollanti, C.: Private Streaming with Convolutional Codes. *In*: Proc. IEEE Information Theory Workshop (ITW), Guangzhou, China, Nov. 2018

Holzbaur, L.; Wachter-Zeh, A.: List Decoding of Locally Repairable Codes. *In*: Proc. ISIT-2018

Immler, V.; Hiller, M.; Liu, Q.; Lenz, A.; Wachter-Zeh, A.: Variable-Length Bit Mapping and Error-Correcting Codes for Higher-Order Alphabet PUFs. *In*: Proc. Seventh International Conference on Security, Privacy, and Applied Cryptography Engineering. Goa, India, Dec. 2017

Lembo, S.; Deng, J.; Freij-Hollanti, R.; Tirkkonen, O.; Chen, T.: Hierarchical Network Abstraction for HetNet Coordination. *In*: Proc. IEEE Int. Symp. Personal, Indoor and Mobile Radio Communications, Montreal, Canada, Oct. 2017

Lenz, A.; Jünger, N., Wachter-Zeh, A.: Bounds and Constructions for Multi-Symbol Duplication Error Correcting Codes. *In*: Proc. ACCT-2018

Legend to Chapter 4.6.3

ACCT-2018:
16th International Workshop on Algebraic and Combinatorial Coding Theory, Svetlogorsk, Russia, Sept. 2018

ISIT-2017:
IEEE International Symposium on Information Theory, Aachen, Germany, June 2017

ISIT-2018:
IEEE International Symposium on Information Theory, Vail, Colorado, USA, June 2018

MWCC-2018:
Munich Workshop on Coding and Cryptography, TUM-LNT, Apr. 2018

PIMRC-2017:
IEEE Int. Symp. Personal, Indoor and Mobile Radio Communications, Montreal, Canada, Oct. 2017

SPACE-2017:
Seventh International Conference on Security, Privacy, and Applied Cryptography Engineering. Goa, India, Dec. 2017

Lenz, A.; Siegel, P.; Wachter-Zeh, A.; Yaakobi, E.: Constructions and Bounds for Reliable Data Storage in Unordered DNA Sequences. *In*: Proc. 2018 TUM-COM Workshop on Ultra-Reliable Low-Latency Communications and Applications for 5G, Schneefernerhaus, Zugspitze, June 2018

Lenz, A.; Siegel, P.; Wachter-Zeh, A.; Yaakobi, E.: Coding over Sets for DNA Storage. *In*: Proc. ISIT-2018 and Proc. MWCC-2018

Lenz, A.; Stein, M.; Swindlehurst, A. L.: Analog Transmit Signal Optimization for Undersampled Delay-Doppler Estimation. *In*: Proc. 25th European Signal Processing Conf. (EUSIPCO), Kos, Greek, Aug 2017

Lenz, A.; Wachter-Zeh, A.; Yaakobi, E.: Bounds on Codes Correcting Tandem and Palindromic Duplications. *In*: Proc. 10th Int. Workshop Coding and Cryptography, St. Petersburg, Russia, Sept. 2017

Liu, L.; Holzbaur, L.; Wachter-Zeh, A.: Locality in Crisscross Error Correction. *In*: Proc. ACCT-2018

Puchinger, S.; Renner, J.; Wachter-Zeh, A.: Twisted Gabidulin Codes in the GPT Cryptosystem. *In*: Proc. ACCT-2018

Puchinger, S.; Müelich, S.; Wachter-Zeh, A.; Bossert, M.: Timing Attack Resilient Decoding Algorithms for Physical Unclonable Functions. *In*: Proc. 11th International ITG Conference on Systems, Communications and Coding, Hamburg, Germany, Feb. 2017

Sidorenko, V.; Bartz, H.; Wachter-Zeh, A.: Interleaved Subspace Codes in Fountain Mode. *In*: Proc. ISIT-2017

Tajeddine, R.; Gnilke, O.; Karpuk, D.; Freij-Hollanti, R.; Hollanti, C.: Robust Private Information Retrieval from Coded Systems with Byzantine and Colluding Servers. *In*: Proc. ISIT-2018

Wachter-Zeh, A.: Limits to List Decoding of Insertions and Deletions. *In*: Proc. ISIT-2017

Wachter-Zeh, A.; Puchinger, S.; Renner, J.: Repairing the Faure-Loidreau Public-Key Cryptosystem. *In*: Proc. ISIT-2018

Westerbäck, T.; Grezet, M.; Freij-Hollanti, R.; Hollanti, C.: On the Polymatroidal Structure of Quasi-Uniform Codes with Applications to Heterogeneous Distributed Storage. *In*: Proc. 23rd Int. Symp. Mathematical Theory of Networks and Systems, Hongkong, China, July 2018

4.6.4 Posters

Holzbaur, L.; Bartz, H.; Wachter-Zeh, A: Improved Decoding of Staircase Codes. 18th Joint Workshop on Communications and Coding, Planneralm, Austria, March 2017

Holzbaur, L.; Lenz, A.; Wachter-Zeh, A.: Coding for Reliable Data Storage. TUM Institute for Advanced Study General Assembly, June 2018

Holzbaur, L.; Wachter-Zeh, A.: List Decoding of Locally Repairable Codes. Munich Workshop on Coding and Cryptography (MWCC-2018), TUM-LNT, Apr. 2018

Immler, V.; Hiller, M.; Liu, Q.; Lenz, A.; Wachter-Zeh, A.: Variable-Length Bit Mapping and Error-Correcting Codes for Higher-Order Alphabet PUFs. TUM-Eurecom Workshop on Communications and Security, TUM-LNT, Dec. 2017

Lenz, A.; Wachter-Zeh, A.: Maximum Cardinalities for Tandem and Palindromic Duplication Correcting Codes. 18th Joint Workshop on Communications and Coding, Planneralm, Austria, March 2017

Lenz, A.; Wachter-Zeh, A.; Yaakobi, E.: On Codes Correcting Adjacent Symbol Duplications. Munich Workshop on Coding and Applications (MWCA-2017), TUM-LNT, July 2017

Lenz, A.; Wachter-Zeh, A.; Yaakobi, E.: Codes for Tandem and Palindromic Duplications Errors. IEEE International Symposium on Information Theory, Aachen, Germany, June 2017

4.6.5 Talks

Bartz, H.; Sidorenko, V.: Power Decoding of Punctured Subspace Codes. Institute of Information Transmission Problems (IITP), Moscow, Russia, Oct. 2016

Sidorenko, V., Bartz, H., Wachter-Zeh, A.: Interleaved Subspace Codes in Fountain Mode. Moscow Institute for Physics and Technology, Russia, Feb. 2017

Holzbaur, L., Bartz, H., Wachter-Zeh, A.: Improved Decoding and Error Floor Analysis of Staircase Codes. 4th International Professor's Day on ICT Algorithm Design (ICTAD-2017), Nov. 2017

Stein, M.; Lenz, A.; Swindlehurst, A. L.: On the Channel Parameter Tracking Error for Sub-Nyquist Satellite-Based Synchronization. IEEE Int. Workshop Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), Dec. 2017

Wachter-Zeh, A.: Insertion/Deletion/Correction for Variable-Length PUF Responses. Munich Workshop on Physical Unclonable Functions (MPUF), Nov. 2017

Wachter-Zeh, A.: Coding Theory: “Old” Concepts for “New” Applications. TUM IAS Talk, March 2017

Wachter-Zeh, A.: Coding Theory for Storage and Networks. Talk at DLR, March 2017

Wachter-Zeh, A.: Challenges of Post-Quantum Cryptography. TUM Institute for Advanced Study General Assembly, June 2018

Wachter-Zeh, A.: On a Rank-Metric Code-Based Cryptosystem with Small Key Size. Munich Workshop on Coding and Cryptography, TUM-LNT, Apr. 2018

Wachter-Zeh, A.: Rank-Metric Codes, Subspace Codes & Network Coding. Winter School on Applied Algebra and Coding Theory, University of Würzburg, Germany, Jan. 2018

5 NAV

Lehrstuhl für Kommunikation und Navigation (NAV)
Chair for Communications and Navigation

Christoph Günther et al.

The *Chair for Communications and Navigation* (NAV) started in December 2004 when Christoph Günther was appointed professor by the *TUM Department of Electrical and Computer Engineering*. The NAV chair is supported in administration by LNT. But there is no common research and teaching unit between NAV and LNT/LÜT/COD.

5.1 People

Scientific Staff

Günther, Christoph, Prof. Dr. sc. nat.	Professor and Chair
Henkel, Patrick, Dr.-Ing.	Senior Researcher
Lee, Young-Hee, M.Sc.	Doctoral Researcher
Lülf, Martin, M.Sc.	Doctoral Researcher

Left the chair during the reporting period

Brack, Andreas, M.Sc. (until 30.07.2018)	Doctoral Researcher
Giorgi, Gabriele, Dr. (until 31.08.2017)	Senior Researcher
Zhu, Chen, M.Sc. (until 31.03.2018)	Doctoral Researcher

Lecturers

Dammann, Armin, Dr.-Ing.	DLR, Oberpfaffenhofen
Giorgi, Gabriele, Dr.	DLR, Oberpfaffenhofen
Meurer, Michael, Dr.-Ing. habil.	DLR, Oberpfaffenhofen
Scalise, Sandro, Dr.-Ing.	DLR, Oberpfaffenhofen

Research and Student Work

Montiel Barrazo, Gaith Allah Chebil, Alejandro Guillermo, Xueyang Kang, Ayush Singla

5.2 Teaching

Most of the courses offered by Prof. Christoph Günther and his staff are graduate-level (MSEI, MSCE) in the TUM Department of Electrical and Computer Engineering (ECE).

The *Satellite Communications Lab* is an offer for Bachelor students (BSEI).

The abbreviations in the list are
V: Vorlesung (Lecture),
Ü: Übung (Tutorial),
P: Praktikum (Laboratory)

Satellite Communications Laboratory
Elective module for BSEI 5 6, 4P, 5 ECTS, Language: EN
WT 2016/2017 & ST 2017 & 2018: C. Günther with M. Lülf

Satellite Navigation
Elective module for MSEI 1/MSCE 1, 2V+2Ü, 5 ECTS, Language: EN
Winter Term 2016/2017 & 2017/2018: C. Günther with M. Lülf

Differential Navigation
Elective module for MSEI 2/MSCE 2, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2017 & 2018: C. Günther with P. Henkel

Satellite Navigation Laboratory
Elective module for MSEI 2/MSCE 2, 4P, 5 ECTS, Language: EN
Summer Term 2017 & 2018: C. Günther with M. Lülf

Inertial Navigation
Elective module for MSEI 2/MSCE 2, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2017 & 2018: P. Henkel

Satellite Communications
Elective module for MSEI 2/MSCE 2, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2017 & 2018: S. Scalise & T. de Cola (DLR)

Robot and Swarm Navigation
Elective module for MSEI 2/MSCE 2, 2V+2Ü, 5 ECTS, Language: EN
Summer Term 2018: A. Dammann

Precise Point Positioning with GPS and Galileo
Elective module for MSEI 3/MSCE 3, 2V+2Ü, 5 ECTS, Language: EN
Winter Term 2016/2017 & 2017/2018: P. Henkel

Hauptseminar Navigation
Elective module for MSEI 3/MSCE 3, 5S, 5 ECTS, Language: EN
Winter Term 2016/2017 & 2017/2018: P. Henkel

Visual Navigation
Elective module for MSEI 3/MSCE 3, 2V+2Ü, 5 ECTS, Language: EN
Winter Term 2016/2017 & 2017/2018: G. Giorgi

Differential Navigation
Elective module for MSEI 3/MSCE 3, 2V+2Ü, 5 ECTS, Language: EN
Winter Term 2016/2017 & 2017/2018: M. Meurer

5.3 Dissertation and Student Theses

Dissertation

18.10.2017 Dr.-Ing. **Zhibo Wen**
Thema: **Bias Estimation for Precise Point Positioning**
Vorsitzende: Prof. Dr. Antonia Wachter-Zeh
1. Berichter: Prof. Dr. sc. nat. Christoph Günther
2. Berichter: Dr. techn. Bernhard Hofmann-Wellenhof, TU Graz, Austria

Master's Theses

21.10.2016 **Michael Georg Löb** - Supervisor: Dr. Henkel
Tightly Coupled Full 3D Attitude Determination for Real Time Kinematic Positioning

03.11.2016 **Shrivathsan Narayanan** - Supervisor: Prof. Günther
Modelling Tropospheric Delays for Ground-Air Radio Navigation System for High Integrity Application

25.11.2016 **Chiraz Nafouki** - Supervisor: Dr. Giorgi
Visual SLAM with Ranging Aid

09.02.2017 **Robert Pöhlmann** - Supervisor: Dr. Henkel
Combining Multipath Assisted Positioning for Terrestrial Signals with GNSS and Inertial Sensors

20.02.2017 **Dimitrios Vasileios Psychas** - Supervisor: Dr. Henkel, Prof. Hugentobler, Lehrstuhl für Astronomische und Physikalische Geodäsie, TUM
Estimation of GNSS Satellite Phase Biases using a Global Network of Reference Stations

30.09.2017 **Alexander Blum** - Supervisor: Dr. Henkel
Road Marking-based Visual Positioning using Aerial Imagery

08.12.2017 **Christian Trainotti** - Supervisor: Prof. Günther
Control of the Reverse Driving of a Truck with Trailers using Differential Braking

01.02.2018 **Sebastian Johannes Buckel** - Supervisor: Dr. Henkel
Anbindung und Nutzung einer zentralen Lokalisierungsplattform in der Automobilproduktion

08.02.2018 **Julia Angela Kolbinger** - Supervisor: A. Brack
Entwicklung, Analyse und Vergleich eines Unscented Kalman Filters mit Standardverfahren in der Navigation

In 2017 our former colleague Zhibo Wen completed his dissertation at our faculty.

During the period 10/2016-09/2018 Prof. Christoph Günther and his assistants of the Chair of Communications and Navigation supervised fifteen Master's theses and four Bachelor's theses.

In addition, they supervised some MSEI and MSCE research internships and Bachelor's internships, which are not listed here individually.

16.03.2018 **Daniel Schleipfer** - Supervisor: Dr. Henkel
Development of an RTK Simulator

23.03.2018 **Michael Severin Heinrich** - Supervisor: Dr. Henkel
Development of a Multi-Sensor RTK Module for Autonomous Systems

16.04.2018 **Ran Tang** - Supervisor: Prof. Günther
A Regression Forest-based Camera Relocalization Method for RGB-D SLAM

05.07.2018 **Ludwig Paul Färber** - Supervisor: Dr. Henkel
Integration of Visual Odometry into Multi-Sensor Fusion for Precise Positioning

30.07.2018 **Jacques Burghard Georges Isoard** - Supervisor: Dr. Henkel
Realization of Heterogeneous Clock Ensembles with Kaman Filter

03.09.2018 **Michael Schagginger** - Supervisor: Dr. Henkel
Development of an Enhanced Multi-Sensor RTK Simulator

Bachelor's Theses

30.10.2017 **Alexander Albert Mathis** - Supervisor: Dr. Henkel
Estimation of Satellite Parameters with Triple-Frequency Measurements

30.07.2018 **Jakob Giez** - Supervisor: Dr. Henkel
Integration of Galileo into the RTK Positioning and Snow Parameter Estimation

23.08.2018 **Valaenthin Tratter** - Supervisor: Dr. Henkel
Integration of Multi-GNSS NEO M8T Module and Wi-Fi into Multi-Sensor Module

13.09.2018 **Marcus Buttge** - Supervisor: M. Lülf
Development of an Antenna Pattern Measurement Procedure for Satellite Communications

5.4 Assignments of Christoph Günther

- Member, ITG-Fachausschuss 5.1: Informations- und Systemtheorie
- Member, Board of Curators of the Eduard Rhein Foundation
- Mitglied des Programmausschusses Kommunikation und Navigation des DLR-Raumfahrtmanagements
- Member, Technical Program Committees of Conferences: ISIT (2018), DGLRK (Chairman 2017), POSNAV (2018)

5.5 Research and Projects

Overview Christoph Günther

Our economy significantly depends on navigation and new applications are constantly emerging as performance improves. At our institute we aim at contributing to this in different ways. This includes enhancing the accuracy of satellite navigation using carrier phase measurements and providing navigation in situations in which satellite signals are not available.

Furthermore, the unintentional launch of Galileo E14 and E18 into an elliptical orbit provided an opportunity to verify the predicted relativistic frequency shift. The isolation of this shift from all other influences, including orbit perturbations, clock imperfections, atmospheric delays, solar pressure, and station movements is a difficult task described by *Martin Lülf*. The initial evaluation suggests that the signals generated by the H-Masers on the satellites lead to an agreement with Einstein's relativity theory, which outperforms the results obtained so far.

The first Galileo satellites were launched in 2011 and have thus passed half their life-time. DLR is developing a proposal for a successor system, called Kepler, to which we are contributing. Key properties are the support of global instantaneous Precise Point Positioning (PPP) and the support of global integrity. Kepler relies on a constellation of satellites similar to Galileo and a constellation of Low Earth Orbiting (LEO) satellites, which are used to perform measurements free of atmospheric influences. Optical inter-satellite links are used for ultra-precise time and frequency transfer, ranging and intra-system communications and lead to an unprecedented performance. The latter is achieved essentially without terrestrial infrastructure.

The highest accuracy in satellite navigation is achieved using carrier phase measurements. This requires that the ambiguities due to the periodicity of the carrier phase are resolved. Limiting the probability of wrongly estimating ambiguities, however, significantly reduces the availability of solutions. *Andreas Brack* completed his work on a mathematical framework for estimating subsets of ambiguities to best match the desired performance. The latter is both analyzed in simulations and using real data.

The correct resolution of carrier phase ambiguities strongly depends on any form of measurement biases. As a consequence, many current systems use differential measurements with respect to some nearby reference stations. The alternative approach is to use PPP. In this case, individual error components are modelled, and the determination of precise orbits, clock offsets and signal biases are essential. Today, PPP augmentation data is matched to a particular combination of measurement data. *Patrick Henkel* for the first time developed a solution for undifferenced and uncombined measurements, which allows adapting any combination of measurements in a manner that best suits the application.

Satellite navigation is not always available. This might be due to the location, to natural disturbances, and also to jamming and spoofing. The latter are a big concern in aeronautics. In the *Luftfahrt Forschungsprojekt* MICONAV, we developed and tested a system based on terrestrial radio ranging, as well as inertial and barometric measurements.

Valles Marineris is a major crater on Mars and the name of a project funded by DLR-Raumfahrtmanagement. The mission is to explore this deep trench by swarms of rovers and crawlers. Camera vision is the essential means for navigation in this context. The dead reckoning character of vision systems causes the solution to drift. Additionally, monocular cameras systems do not allow for an estimation of scale. *Chen Zhu* explored the possibility to improve the vision based solution by using a radio link to a single fixed station (e.g. the lander) or between rovers. This led him to estimate the global scale as well as trajectories without drift accumulation. Although stereo vision solves the scale problem, it accumulates drifts as well. *Young-Hee Lee* used a similar idea to improve the performance of stereo vision in the absence of loop closure.

This overview also takes into account the work of Andreas Brack, Gabriele Giorgi and Chen Zhu, who left the NAV chair in 2018. The theses of Andreas and Chen are currently under evaluation.

Estimation of satellite position, clock and bias corrections

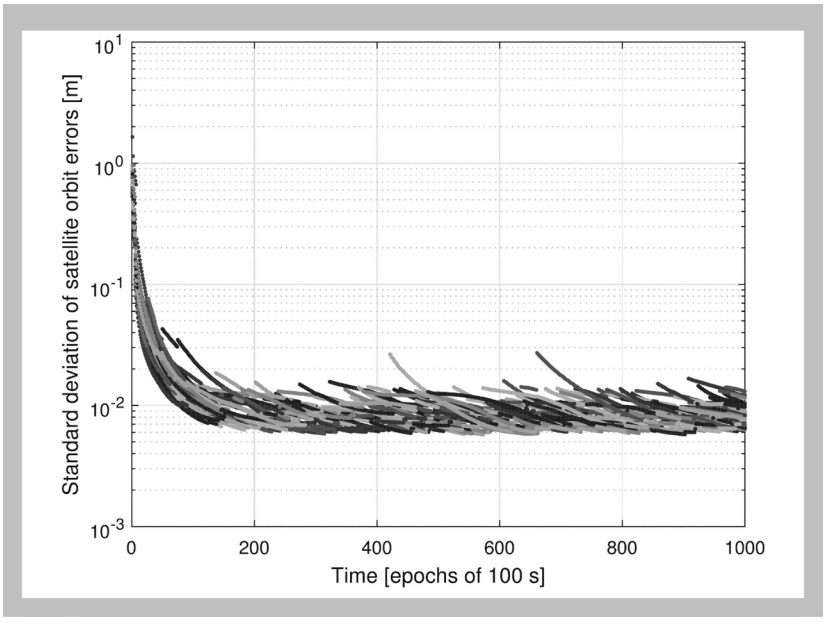
Patrick Henkel and Christoph Günther

Precise Point Positioning (PPP) denotes the absolute positioning of a Global Navigation Satellite System (GNSS) receiver without the direct use of raw measurements from a reference station. It is of great interest to numerous applications that can not rely on cellular communications due its gaps. A high absolute positioning accuracy requires that the PPP user corrects himself the measurements for numerous error sources including ionospheric and tropospheric delays, orbital errors, receiver and satellite clock offsets and phase/ code biases, carrier phase integer ambiguities, Earth and ocean tides, antenna phase center offsets and variations. These errors are determined in different manners: The position, clock offset, carrier phase ambiguities and atmospheric delays of the user are estimated by the user, e.g. by using a Kalman filter. Earth and ocean tides can be accurately modeled using rough estimates of the user position and of the moon. Antenna phase center variations are determined by calibration. The satellite position, clock offset and phase bias corrections are determined by a global network of GNSS reference stations. The focus of our work is on the latter step.

We process undifferenced and uncombined measurements from an arbitrary number of frequencies such that the user can correct its measurements for the satellite position, clock and bias errors and apply any linear combination to its measurements.

We cluster the global network of GNSS receivers to exploit the common satellite visibility and integer property of ambiguities within each cluster. We choose a common reference receiver and reference satellite within each cluster and relate the unknown state parameters of all other receivers and satellites within each cluster to the state parameters of the common reference receiver and reference satellite. Thereby, the integer ambiguities of any non-reference receiver/ satellite are expressed in terms of the integer ambiguities of the reference receiver/ satellite and so-called double difference integer ambiguities. A Kalman filter is used to estimate all state parameters including the mapped clock offsets, ionospheric and tropospheric delays, satellite position, clock and bias corrections and carrier phase integer ambiguities. In a second step, we combine the satellite position, clock and bias corrections from all clusters.

The simulation results showed that satellite position, clock and bias corrections can be determined with a precision of better than two centimeters for all satellites at any time, and that the integer ambiguity fixing enables a much faster convergence of these satellite corrections than without fixing.



Precision of multi-cluster satellite position corrections: After initial convergence, the precision varies between 5 mm and 2 cm for all satellites at any time.

Literature:
[1] Henkel, P; Psychas, D; Günther, C; Hugentobler, U: Estimation of Satellite Position, Clock and Phase Bias Corrections, Journal of Geodesy, 1199 – 1217, May 2018.

Stereo Vision-based Simultaneous Localization and Mapping with Ranging Aid

Young-Hee Lee, Gabriele Giorgi and Chen Zhu

Stereo visual odometry is a viable tool for exploring unknown and GNSS-denied environments. Unlike monocular vision, it is possible to determine camera poses and build a map database without scale ambiguity. However, incremental errors are unavoidable since stereo visual odometry is a dead-reckoning process in which the current state is propagated from previous states.

The loop closing technique, in which a rover re-visits a portion of the environment already stored in the map, is generally applied to mitigate accumulating estimation errors in visual odometry and achieve global consistency. However, it is challenging to accurately detect and correct loops without introducing significant computational complexity to the system. Furthermore, revisiting previously mapped places introduces a constraint when planning an exploration path.

We propose a different approach to resolve the drift problem: fusion of keyframe- and feature-based stereo visual odometry and ranging measurements. Rover's poses are incrementally recovered by tracking the feature observations in the current frame from a local map. In parallel, the local map is refined on another processing thread, while formulating a global map database with ranging constraints between the keyframes and a static base station. At the end of the sequence, we define the least squares problem with a cost function given by the summation of re-projection and distance squared errors over all the constraints in the global graph. Ranging constraints are absolute distance measurements, independent from the past states, enabling compensating cumulative biases and more accurately estimating the rover's poses.

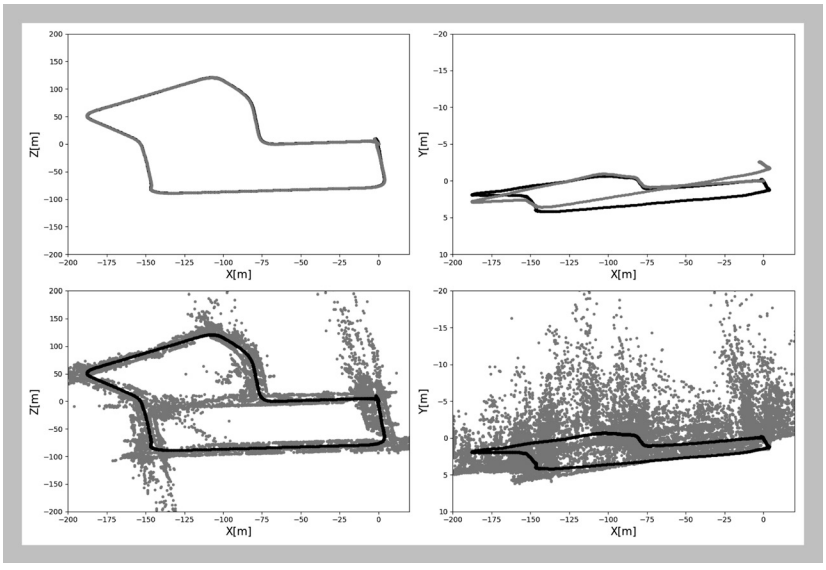
We evaluated [1,2] the proposed algorithm on a public stereo vision dataset, with synthetically generated distance measurements. The evaluation results show drift mitigation capabilities comparable to those of stereo vision-only SLAM with closing loops. .

The figure visualizes the improvement obtained in terms of drift reduction when applying the developed algorithm on a real dataset: without any need for loop closures, our method provides a navigation solution in GNSS-denied environments outperforming standard visual odometry techniques.

Literature:

[1] Lee, Y.H.; Zhu, C.; Giorgi, G.; Günther, C.: Stereo vision-based simultaneous localization and mapping with ranging aid. *In*: Proc. Position, Location and Navigation Symposium (PLANS), IEEE/ION, 404-409, Apr. 2018

[2] Zhu, C.; Giorgi, G.; Günther, C.: 2D Relative Pose and Scale Estimation with Monocular Cameras and Ranging. *In*: Navigation 65 (1), 25-33, Jan. 2018



Ground truth trajectory (black); Trajectories and map points estimated with stereo visual odometry without closing a loop (blue) and the proposed algorithm (green)

Testing General Relativity Using Galileo Satellites

Martin Lülf, Gabriele Giorgi and Christoph Günther

The theory of general relativity predicts that a clock at a higher altitude appears to tick faster than a reference clock placed at a lower altitude. This effect is called gravitational redshift.

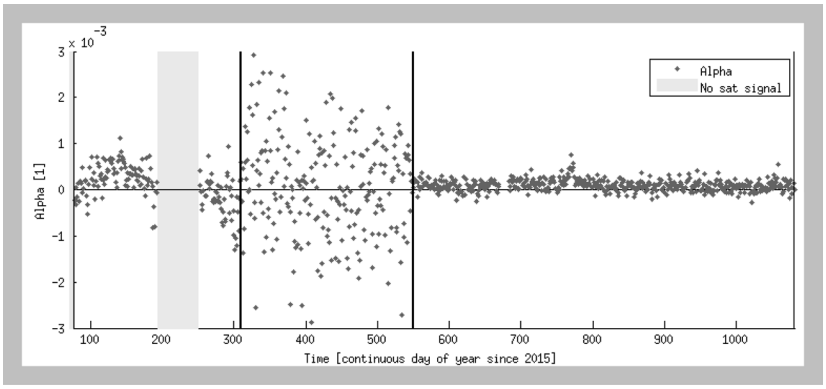
So far, the most accurate measurement of this effect was performed in 1976 by the Gravity Probe A (GP-A) experiment [1], with an accuracy of 140 ppm. The experiment sent a rocket with a very stable hydrogen maser on a ballistic trajectory. Three different signals were exchanged between the ground station and the rocket to compensate for first-order Doppler shift and atmospheric delays and obtain the relative time dilation between the clocks on the rocket and on ground. The experiment lasted one hour and 55 minutes.

Due to a malfunction of the Soyuz launch vehicle during deployment of two Galileo satellites (denoted with E18 and E14) these satellites were injected into eccentric orbits rather than into their nominal, almost circular ones. They thus experience a varying gravitational potential. These satellites carry passive hydrogen masers, similar to those used in the GP-A experiment. Although the altitude difference is substantially smaller for the Galileo satellites, these repeat the same trajectory every ~13 hours, gifting us with two GP-A-like experiments per day.

The navigation signals transmitted by the satellites enable determining their orbits with cm-level accuracy and to estimate the clock offsets with sub-nanosecond accuracy. These signals are continuously observed and stored by a global network of ground stations since the end of 2014. Together, the satellites have already provided over 2000 days of data and are expected to be transmitting for several additional years, thus allowing us to improve the accuracy of the measured gravitational redshift effect over time.

While the GP-A experiment was specifically tailored to extract the signature of the gravitational redshift, the primary purpose of the Galileo navigation signals is to localize users on earth. As a consequence, a number of impairments and disturbances are not eliminated by design and must be estimated [2]. These include the satellite orbits, earth tides, atmospheric delays, carrier phase ambiguities and hardware-dependent biases. In order to assess the accuracy of the estimated satellite clock, an accurate and unbiased stochastical model needs to be formulated, which requires careful analysis and over bounding of observations and estimation errors.

In a joint effort with the center of applied space technology and microgravity (ZARM) and the European space agency (ESA), we have already increased the accuracy of the estimation of GP-A by a factor of four [3] and are working on further improvements.



Alpha estimates for Galileo 6 (E 14 / GSAT-0202)

Literature:

[1] Vessot, R.F.C.; Levine, M.W.: A Test of the Equivalence Principle using a Space-borne Clock. *In*: General Relativity and Gravitation, 10, pp. 181–204, 1979

[2] Giorgi, G. et al.: Testing General Relativity using Galileo Satellite Signals. *In: Proc.* EUSIPCO, Aug. 2016

[3] Herrmann, S. et al.: Test of the Gravitational Redshift with Galileo Satellites in an eccentric orbit. *In:* Physical Review Letters, 2018, to be published

Estimate Scale of Vision and Relative Pose of Two Rovers

Chen Zhu, Gabriele Giorgi, Young-Hee Lee and Christoph Günther

Autonomous robotic platforms are utilized in the exploration of extreme environments, e.g., extraterrestrial exploration or catastrophe rescues. In order to increase the system robustness against hazards in the missions, e.g., strike during landing, and to improve the exploration efficiency, a robotic swarm including multiple autonomous units can be applied. Autonomous navigation of the swarm elements often relies on several sensors such as cameras. Due to constraints on size, weight, accommodation and costs in swarm elements, monocular cameras are used instead of stereo rigs in most cases. VSLAM techniques using monocular cameras have been developed in recent years to estimate the trajectory of vehicles and to simultaneously reconstruct the map of the environment. However, due to the sensor nature of monocular cameras, all the monocular VSLAM algorithms can only estimate the trajectory and map points location with a global scale factor ambiguity.

We propose to combine monocular VSLAM algorithms, e.g. [1], with the measurement of ranges between two swarm elements for determining the trajectories and their global scale. Specifically, the trajectory of each rover can be estimated with a scale ambiguity from the variation of the images using a monocular camera. Since the distance between the two vehicles is a function of the vehicle position, the global scale of the trajectories, as well as the initial relative pose between the two rovers can be estimated by applying the ranging information. The relative pose and the global scale of the rover trajectories are estimated by a least-square optimization. The details of the method are described in [2].

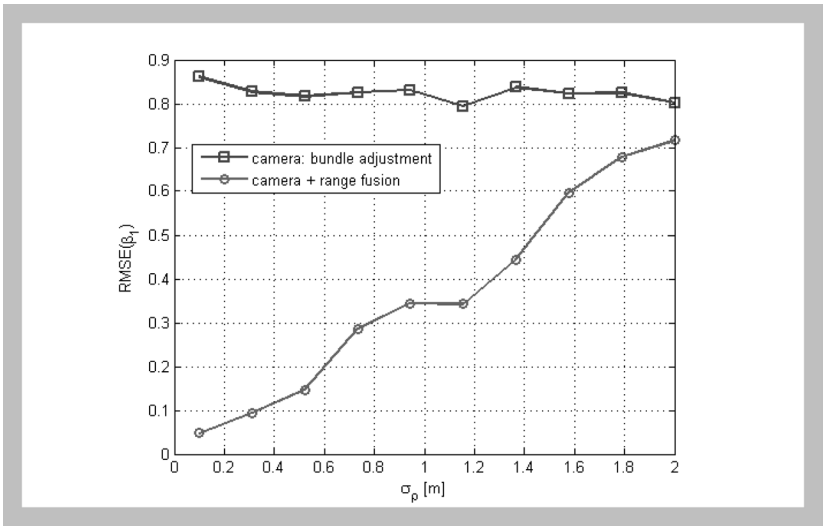
Moreover, by applying the visual and the ranging measurements in a tightly-coupled way, the accuracy of the trajectory estimation can be improved compared with the vison-only approach. The pose estimation in visual SLAM is purely based on dead reckoning concept, if the rovers do not revisit mapped places and detect loop closures. Consequently, the estimation error accumulates as the rover moves, and the obtained trajectory will drift away from the true one over time. By fusing the visual measurements with ranging measurements that are independently obtained, the drift can be mitigated since the ranging error does not accumulate over time. In publication [3], the improvement by fusing the vision with ranging measurements is demonstrated and analyzed both theoretically and by simulation.

Literature:

[1] Mur-Artal, R.; Montiel, J. M. M.; Tardos, J. D.: Orb-slam: A Versatile and Accurate Monocular SLAM System. *In*: IEEE Trans. Robotics (**31**) 5, 1147–1163, Oct. 2015.

[2] Zhu, C.; Giorgi, G.; Günther, C.: 2D Relative Pose and Scale Estimation with Monocular Cameras and Ranging. J. Inst Navig **65**, 25–33; doi: 10.1002/navi.223, March 2018

[3] Zhu, C.; Giorgi, G.; Lee, Y.; Günther, C.: Enhancing Accuracy in Visual SLAM by Tightly Coupling Sparse Ranging Measurements between two Rovers. *In*: 2018 IEEE/ION Position, Location and Navigation Symp. (PLANS), Monterey, CA, 440-446, Apr. 2018



Position error of rover 1 in reference frame

5.6 Publications

5.6.1 Book Chapters

Giorgi, G.: Attitude Determination. In: Springer Handbook of Global Navigation Satellite Systems (Chapter 27). Edited by P.J.G. Teunissen and O. Montenbruck, Springer Handbooks, 2017. DOI: 10.1007/978-3-319-42928-1, ISBN: 978-3-319-42926-7

5.6.2 Journal Articles

The publications of the Chair of Communications and Navigations (NAV) are listed below:
- one Book Chapter,,
- eight Journal Publications,
- eleven Conference Publications.

Brack, A.: Optimal Estimation of a Subset of Integers with Application to GNSS. *In*: Artificial Satellites **51** (4), 123-134, Dec. 2016

Brack, A.: Reliable GPS+BDS RTK Positioning with Partial Ambiguity Resolution. *In*: GPS Solutions **21** (3), 1083-1092, July 2017

Gomez, H.; Giorgi, G.; Eissfeller, B.: Pose Estimation and Tracking of Non-cooperative Rocket bodies using Time-of-Flight Cameras. In: Acta Astronautica Volume **39** (10), 165 – 175, Oct. 2017. DOI: j.actaastro.2017.07.002

Henkel, P.: Calibration of Magnetometers with GNSS Receivers and Magnetometer-aided GNSS Ambiguity Fixing. *In*: IEEE Sensors **17** (6), 1-13, June 2017

Henkel, P.; Banjara, B.: Precise Positioning in Alpine Areas with Troposphere and Multipath Estimation. *In*: IEEE Sensors **20** (18), 8397-8409, Aug. 2018

Henkel, P.; Koch, F.; Appel, F.; Bach, H.; Prasch, M,; Schmid, L.; Schweizer, J.; Mauser, W.: Snow Water Equivalent of Dry Snow derived from GNSS Carrier Phases. *In*: IEEE Trans. Geoscience and Remote Sensing **56** (6), 3561-3572, June 2018

Henkel, P.; Psychas, D.; Günther, C.; Hugentobler, U.: Estimation of Satellite Position, Clock and Phase Bias Corrections. *In*: J. Geodesy **92** (10), 1199-1217, May 2018

Zhu, C.; Giorgi, G.; Günther, C.: 2D Relative Pose and Scale Estimation with Monocular Cameras and Ranging. *In*: NAVIGATION **65** (1), 25-33, March 2018

5.6.3 Conference Publications

Brack, A.: Long Baseline GPS+BDS RTK Positioning with Partial Ambiguity Resolution. *In*: Proc. ION ITM 2017, Monterey, CA, USA, Febr. 2017

Günther, C.: Kepler - Satellite Navigation System without Clocks and Ground Infrastructure. *In*: Proc. ION GNSS+, Miami, FL, USA, Sept. 2018

Heinrich, M.; Sperl, A.; Mittmann, U.; Henkel, P.: Reliable Multi-GNSS Real-Time Kinematic Positioning. *In*: Proc. 60th IEEE ELMAR Symp., Zadar, Croatia, Sept. 2018

Henkel, P.; Blum, A.; Günther, C.: Precise RTK Positioning with GNSS, INS, Barometer and Vision, Proceedings of the 30th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2017), Portland, Oregon, USA, September 2017

Henkel, P.; Günther, C.: Cascaded Real-Time Kinematic Positioning with Multi-Frequency Linear Combinations. *In*: Proc. 60th IEEE ELMAR Symp., Zadar, Croatia, Sept. 2018

Henkel, P.; Psychas, D.; Günther, C.: Satellite Phase Bias Estimation with Global Networks and High-Dimensional Integer Ambiguity Fixing, Proceedings of the 30th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2017), Portland, Oregon, USA, September 2017

Henkel, P.; Sperl, A.; Mittmann, U.; Bensch, R.; Färber, P.; Günther, C.: Precise Positioning of Robots with Fusion of GNSS, INS, Odometry, Barometer, Local Positioning System and Visual Localization. *In*: Proc. ION GNSS+, Miami, FL, USA, Sept. 2018

Krause, J.; Henkel, P.: Integration of Barometric Height into RTK Positioning for Fast Ambiguity Refixing. *In*: Proc. 60th IEEE ELMAR Symp., Zadar, Croatia, Sept. 2018

Lamm, M.; Koch, F.; Appel, F.; Henkel, P.: Estimation of Snow Parameters with GPS and Galileo. *In*: Proc. 60th IEEE ELMAR Symp., Zadar, Croatia, Sept. 2018

Lee, Y. H.; Zhu, C.; Giorgi, G.; Günther, C.: Stereo Vision-based Simultaneous Localization and Mapping with Ranging Aid, Position, Location and Navigation Symposium (PLANS), Monterey, CA, USA, 2018

Zhu, C.; Giorgi, G.; Günther, C.: Planar Pose Estimation using a Camera and Single-Station Ranging Measurements, Proceedings of the 30th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2017), Portland, Oregon, USA, September 2017

6 International Relations

6.1 Organized Workshops

(A) Workshop on Information Theory of Optical Fiber (MIO 2016)

When & where: 06.12.2016 – 07.12.2016, TUM-LNT

Organization:	T. Fehenberger (TUM-LÜT), J. García, G. Kramer (TUM-LNT), R. Essiambre (TUM-IAS)
Supported by:	Alexander von Humboldt Foundation, DFG
Topics:	Capacity of Fiber Channels and Networks, Nonlinear Fourier Transform, Multi-mode Optical Communication, Coded modulation and Transceiver design
12 Talks:	P. Andrekson (Chalmers), V. Aref, R. Dar, N. Fontaine (Nokia Bell Labs USA), A. Ellis (Aston), M. Kuschnerov (Huawei), R. Luís (NICT Japan), A. Mecozzi (L'Aquila), M. Shtaif (Tel Aviv), R. Slavik (ORC), M. Sorokina & S. K. Turitsyn (Aston), D. Zibar (DTU),
14 Posters:	Y. Chen (Coriant), S. Civelli (Sant'Anna), S. Dris (VPI Photonics), F. Frey (Ulm), L. Galdino, D. Semrau (UCL), J.W. Goossens (Huawei), L. Holzbaur (TUM-COD),

In the reporting period 10/2016 - 09/2018, ten workshops were organized by LNT, LÜT and COD. In addition, Gerhard Kramer was particularly busy with organizing ISIT 2017 (*IEEE International Symposium on Information Theory*) in Aachen and ITW 2017 (*IEEE Information Theory Workshop*) in Taiwan.

Group photo of MIO 2016 participants with Christmas concert musicians

6 International Relations

The workshops took place mainly in our rooms at TUM. Two workshops (JWCC and TUM-COM) were at Planneralm in Austria and in the Schneefernerhaus on the Zugspitze near Garmisch-Partenkirchen.

K. Keykhosravi (Chalmers), A. Span (Stuttgart), M. Song (Telecom ParisTech), I. Tavakkolnia (Edinburgh), M. Yankov (DTU), M. I. Yousefi (ParisTech)
Social Event: Dinner at Löwenbräukeller

(B) ITG-Workshop 5.3.1: Modellierung und Simulation photonischer Komponenten und Systeme

When & where: 16.02.2017 – 17.02.2017, TUM-LNT
Organization: N. Hanik (TUM-LÜT)
Supported by: Alexander von Humboldt Foundation
16 Talks: H. Baytekin (ADVA), G. Böcherer (TUM-LNT), C. Castro & W. Rosenkranz (Kiel), S. Dris, H. Louchet & A. Richter (VPI Photonics), T. Fehenberger & N. Hanik (TUM-LÜT), F. Frey, J. K. Fischer & R. Fischer (HHI Berlin + Ulm), A. Geisler & C. Schäffer (Uni Hamburg), D. Hillerkuss et al. (Huawei Austria), G. Khanna, N. Hanik & B. Spinnler (Coriant), M. Köppel, M. Deckelmann & B. Schmauss (FAU), S. Li, J. Koch, D. Clausen & S. Pachnicke (Kiel), F. Schmidt (TU Berlin), A. Shrestha & D. Giggenbach (DLR), S. Werzinger, S. Gussner & B. Schmauss (FAU), Z. Wu & B. Lankl (Uni Bw)

(C) 18th Joint Workshop on Communications and Coding (JWCC 2017)

When & where: 13.03.2017 – 15.03.2017, Planneralm, Austria
Participants: Doctoral students and professors from LNT, LÜT, COD (TUM), University of Stuttgart and Graz University of Technology

Group photo of JWCC 2017 participants in the snow at Planneralm

Organization: T. Prinz, F. Steiner (TUM-LNT)
Supported by: Alexander von Humboldt Foundation
6 Talks: G. Böcherer, D. Donev (TUM-LNT), S. Cammerer (Stuttgart), W. Roth, C. Knoll, M. Steinberger (Graz)
22 Posters: R.A. Amjad, H. Bartz, M. Coşkun, S. Dierks, J. Garcia, B. Geiger, O. Günlü, T. Jerkovits, L. Palzer, M. Pikus (TUM-LNT), T. Fehenberger, T. Kernetzky, B. Leible (TUM-LÜT), L. Holzbaur, A. Lenz (TUM-COD), A. Elkelesh (Stuttgart), M. Köberl, A. Lässer, A. Luppi, M. Rotulo (Graz), C. Schnelling (RWTH Aachen), F. Guilloud (Telecom Bretagne)
Social Event: Skiing and Tobagganing

(D) 2017 IEEE International Symposium on Information Theory (ISIT 2017)

When & where: 25.06.2017 – 30.06.2017, Aachen, Germany
Participants: 864 registered including 318 students
Organization: Rudolf Mathar (RWTH Aachen), Gerhard Kramer (TUM-LNT)

(E) 2017 Munich Workshop on Coding and Applications (MWCA 2017)

When & where: 03.07.2017, TUM-LNT
Organization: A. Wachter-Zeh (TUM-COD), V. Sidorenko (TUM-LNT)
Supported by: DFG, TUM Institute for Advanced Study, Alexander von Humboldt Foundation
Topics: Coding Theory, Coding for Storage, Coding for Memories, Network Coding
8 Talks: T. Etzion, E. Yaakobi (Technion, Israel), I. Tamo (Tel Aviv University), A. Barg (University of Maryland), I. Dumer (University of California Riverside), O. Milenkovic (University of Illinois), G. Kabatiansky (IITP Moscow, Russia), J. Rosenthal (Unversity of Zurich)
20 Posters: F. M. de Assis (UFCG, Brazil), R. Bitar (Illinois), E. Egorova (Moscow), C. Franck & U. Sorger (Luxembourg), S. Kruglik & A. Frolov (Skolkovo & IITP RAS), R. Gabrys (UIUC), A. Heidarzadeh (Texas University), S. K. Hanna (Illinois), J. Lavauzelle (INRIA Saclay), W. H. Mow (Hong Kong), N. Raviv (Ben-Gurion University), D. Napp, R. Pinto & P. Vettori (Aveiro, Portugal), M. Ebada, A. Elkelesh, S. Cammerer & S. ten Brink (Stuttgart), J. Lieb (Würzburg), A. Sheikh, A. Graell i Amat & G. Liva (DLR), S. Müelich & M. Schelling, S. Puchinger (Ulm), T. Jerkovits (DLR), O. Günlü (TUM-LNT), A. Lenz (TUM-COD),
Social Event: Beergarden “Chinesischer Turm”

(F) 2017 IEEE Information Theory Workshop (ITW 2017)

When & where: 06.10.2017 – 10.10.2017, Kaohsiung, Taiwan

Participants: 176 registered including 57 students
Organization: Po-Ning Chen (NCTU, Taiwan), Chih-Peng Li (NSYSU, Taiwan), Gerhard Kramer (TUM-LNT)

(G) 2017 Munich Workshop on Physical Unclonable Functions (MPUF 2017)

When & where: 29.10.2017, TUM-LNT
Organisation: O. Günlü, G. Kramer (TUM-LNT), T. Kernetzky (TUM-LÜT), M. Pehl, G. Sigl (TUM-SEC)
Supported by: Alexander von Humboldt Foundation, DFG
Topics: Information-theoretic Security and Privacy, Low-complexity Error-correcting Code Design, Hardware Optimization, Modeling and Evaluation of PUF Outputs, Side-channel Attacks on PUFs
8 Talks: C. Frisch, M. Pehl, L. Tebelmann, F. Wilde (TUM-SEC), R. Hesselbarth, M. Hiller (Fraunhofer-AISEC), A. Wachter-Zeh (TUM-COD), O. Günlü (TUM-LNT)
Social Event: Café Altschwabing with "Glühwein"

(H) 1st TUM-Eurecom Workshop on Communications and Security

When & where: 14.12.2017 – 15.12.2017, TUM-LNT
Organization: R. A. Amjad (TUM-LNT), Paul de Kerret (Eurecom, France), Michael Joham (TUM-MSV)
Supported by: German-French Academy for the Industry of the Future, Alexander von Humboldt Foundation
Topics: Communication Theory, Security, Information Theory, Machine Learning
11 Talks: G. Kramer (TUM-LNT) & D. Gesbert (Eurecom), I. Atzeni, A. Francillion, P. de Kerret (Eurecom), S. Diggavi, C. Fragouli (UCLA), H. Bartz (DLR), M. Joham, D. Neumann (TUM-MSV), M. Kobayashi, A. Nedelcu (TUM-LNT)

Group photo of MWCA 2018 participants

11 Posters: H. Bayerlein, T. Hayes, S. Poeplau (Eurecom), R. Freij-Hollanti, O. Gnilke & C. Hollanti (Aalto & TUM-COD), C. Jonischkeit, J. Kirsch, M. Newinger, T. Wiese (TUM-MSV), A. Lenz (TUM-COD), O. Günlü, L. Palzer (TUM-LNT)
Social Event: Dinner at Löwenbräukeller

(I) 2018 Munich Workshop on Coding and Cryptography (MWCC 2018)

When & where: 10.04.2018 - 11.04.2018, TUM-LNT
Organization: A. Wachter-Zeh et al., R. Freij-Hollanti, C. Hollanti (TUM-COD), V. Sidorenko (TUM-LNT)
Supported by: DFG, TUM Institute for Advanced Study, Alexander von Humboldt Foundation
Topics: Coding theory, Cryptography, Private Information Retrieval
14 Talks: D. Augot (INRIA, France), Tuvi Etzion, Eitan Yaakobi (Technion, Israel), R. Freij-Hollanti (Aolto), S. Blackburn (London), J. Rosenthal (Zurich), A. Wachter-Zeh (TUM-COD), A. Graell i Amat, K. Mitrokotsa (Chalmers), Ø. Ytrehus (Bergen), S. El Rouayheb (Rutgers), D. Karpuk (Colombia), A. Barbero (Valladolid), C. Dimitrakakis (Chalmers)
26 Posters: S. Bezzateev (St. Petersburg), S. Cammerer (Stuttgart), J. J. Climent, X. Soler-Escrivà &V Requena (Alacant), R. d'Oliveira (Rutgers), E. Egorova, M. Samokhina & O. Trushina (Russia), V. Estrada (Copenhagen), C. Franck (Luxembourg), O. Günlü (TUM-LNT), L. Holzbaur, A. Lenz (TUM-COD), A. Horlemann (St. Gallen), A. Klockmann (Potsdam), I. Kubjas, Y. Yakimenka (Tartu, Estonia), P. Kumar (Copenhagen), S. Kumar (Bergen), S. Kurz (Bayreuth), J. Lieb (Würzburg), U. Martínez-Peñas (Toronto), M. Mitev (Essex, UK), S. Müelich, J. Pfeiffer

Organizers and poster session of MWCC 2018

(Ulm), A. Neri (Zurich), S. Rani (India), P. Vettori (Aveiro, Portugal)
Social Event: Dinner at Wirtshaus Maxvorstadt

(J) 2018 Symposium: Information Transmission with Photons
When & where: 20.04.2018, Bayerische Akademie der Wissenschaften (BAdW), München
Organization: Bayerische Akademie der Wissenschaften, FAU Erlangen, TU München, C. Deigele (BAdW), J. Huber, M. Bechtold (FAU), G. Kramer (TUM-LNT)
Supported by: Free State of Bavaria
Participants: 120 senior pupils from 50 Bavarian schools and the „Talent im Land Bayern“ program
7 Talks: P. Winzer (Bell Labs Nokia), C. Günther (DLR & TUM-NAV), C. Müller-Hirschkorn (MPI Erlangen), D. Frey (LMU München), B. Inan (EPA), G. Khanna, T. Fehenberger (TUM-LÜT)

(K) 2018 TUM-COM Workshop on URLLC and Applications for 5G
When & where: 04.06.2018 - 06.06.2018, Schneefernerhaus, Zugspitze
Organization: TUM Center of Competence Communications & TUM-LNT H. Gürsu, M. Vilgelm (LKN), M. Coşkun (TUM-LNT)
Topics: Ultra-Reliable Low-Latency Communications (URLLC)
5 Talks: G. Durisi (Chalmers, Sweden), J. Gross (KTH Royal Institute, Sweden), W. Kellerer (TUM-LKN), G. Kramer (TUM-LNT), P. Popovski (Aalborg University, Denmark)
20 Posters: Doctoral researchers of TUM-COM: F. Clazzer, M. Grec (DLR), S. Baur, C. Arendt (TUM-LTI), M. Iwanow (MSV / Huawei), B. Güleçyüz (LMT), A. Lenz (TUM-COD), H. Gürsu, M. Vilgelm, M. Klügel, S. Zoppi, A. Papa, O. Ayan, H. Vijayaraghavan, S. Ayvaşık (LKN), M. Coşkun, D. Donev, T. Jerkovits, W. Labidi, A. Git (TUM-LNT)

(L) 3rd TUM-Eurecom Workshop on Secure Communications
When & where: 12.07.2018, TUM-LNT
Organization: R.A. Amjad, G. Kramer (TUM-LNT)
Supported by: German-French Academy for the Industry of the Future
Participants: Researchers from Eurecom and the TUM chairs LNT, MSV and SEC
Topics: Physical Unclonable Functions, Neural Networks for Interference Channels, Machine Learning for Security Analytics
5 Talks: Paul de Kerret, S. Poeplau (Eurecom), B. Kolosnjaji, M. Reza Norouzian (TUM-SEC), O. Günlü (TUM-LNT)

(M) 2018 Munich Doctoral Seminar on Communications (MSC)
When & where: 19.07.2018 – 20.07.2018, TUM-LNT
Organization: P. Schulte, G. Kramer (TUM-LNT)

Topics:	Information Theory, Coding and Communications
11 Talks:	H. Vinck (Univ. Duisburg-Essen), F. Willems (TU Eindhoven), T. Fehenberger, T. Kernetzky (TUM-LÜT), A. Wachter-Zeh, L. Holzbaur, S. Puchinger (COD), A. R. Amjad, O. Günlü, M. Kobayashi, M. Pikus (LNT)
15 Posters:	S. Baur (LKN), M. Cai (TUM-LTI), G. Khanna, B. Leible (TUM-LÜT), J. Renner (COD), D. Donev, W. Labidi, H. Liu, L. Palzer, T. Prinz, P. Schulte, M. Staudacher, F. Steiner, T. Wiegart, P. Yuan (LNT)
Social Event:	Fachschaft Barbeque

6.2 Research Visits

We here list all research stays of our professors and graduate students with a duration of at least two days. Some visits also went on for several months.

The universities and companies visited are in Austria, Denmark, Sweden, France, Israel, the Netherlands and the United States.

We thank all hosts for their hospitality. The visits often lead to new friendships and give an appreciation of different cultures and work environments.

Gerhard Kramer
- 21.05. – 22.05.2017:
  Royal Institute of Technology (KTH), Stockholm, Sweden
  Prof. Mikael Skoglund
- 08.08. – 31.08.2017 & 30.07. – 31.08.2018:
  Technical University of Denmark (DTU), Lyngby, Denmark,
  Otto Mønsted Guest Professor,
  Prof. Søren Forchhammer
- 02.03. – 06.03.2018 & 13.05. – 14.05.2018:
  Ben Gurion University of the Negev (BGU), Beersheba, Israel,
  Prof. Haim Permuter
- 27.02. – 02.03.2018 & 12.05. – 13.05.2018:
  Israel Institute of Technology (Technion), Haifa, Israel,
  Prof. Shlomo Shamai

Rana Ali Amjad
- 03.10. – 09.10.2017:
  Eurecom, Sophia Antipolis, France
  Prof. David Gesbert & Dr. Paul Kerret
- 09.05. – 18.05.2018:
  Graz University of Technology, Austria
  Prof. Gernot Kubin & Dr. Bernhard Geiger

Mustafa Cemil Coşkun
- 11.12. – 15.12.2017:
  Chalmers University of Technology, Gothenburg, Sweden
  Prof. Giuseppe Durisi & Prof. Alexandre Graell i Amat

Tobias Fehenberger
- 28.09 – 10.12.2017:
  Mitsubishi Electric Research Labs, Cambridge, MA, USA
  Dr. David Millar

Javier García Gómez
- 25.06. – 07.09.2018:
  Bell Labs Crawford Hill, Holmdel, NJ, USA
  Dr. René-Jean Essiambre

Onur Günlü
- 02.02. - 31.03.2018:
  Information and Communication Theory Lab, TU Eindhoven, The Netherlands: Prof. Frans M. J. Willems

Andreas Lenz
- 17.07. - 13.09.2017:
  University of California, San Diego (UCSD), CA, USA
  Prof. Paul Siegel, Center for Memory and Recording Research
- 21.11. - 12.12.2018:
  Israel Institute of Technology (Technion), Haifa, Israel
  Prof. Eitan Yaakobi, Computer Science Department

Fabian Steiner
- 17.08. - 14.09.2017:
  Technical University of Denmark (DTU), Lyngby, Denmark,
  Prof. Søren Forchhammer, Dr. Metodi Yankov & Dr. Francesco da Ros
- 02.09. – 02.11.2018:
  University of California, Los Angeles (UCLA), CA, USA,
  Prof. Rick Wesel & Prof. Dariush Divsalar

Peihong Yuan
- 04.03.2018 - 10.03.2018:
  Ben Gurion University of the Negev (BGU), Beersheba, Israel,
  Prof. Haim Permuter

6.3 Guest Talks

In the reporting period 10/2016 - 09/2018, thirty-seven scientists visited us and gave a lecture. They came from Germany, Austria, Belgium, France, Finland, Russia, Sweden, Switzerland, Spain, Brazil, China, India, Japan, Israel, Iran, and the United States.

The list also includes eight talks in the Satellite Navigation Colloquium organized by the NAV chair.

26.10.2016 Prof. **Wolfgang Ertmer**, Leibnitz Universität Hannover: Quantum Systems in µ-g and on Earth - New Horizons for Quantum Sensors (NAV-Colloquium)

26.10.2016 Dr. **John Burke**, US Air Force Research Laboratory: A Compact, High Performance all Optical Atomic Clock based on Telecom Lasers (NAV-Colloquium)

21.11.2016 **Prof. Pierre Loidreau**, University of Rennes, France: Skew Polynomials, Gabidulin Codes, Coding and Cryptography

23.11.2016 Prof. **Toshimichi Otsubo**, Hitotsubashi University, Japan: Satellite Laser Ranging Station Network Simulations and Prospects for the Future (NAV-Colloquium)

12.01.2017 Prof. **Frederic Guilloud**, Telecom Bretagne, Brest, France:
Continuous Phase Modulation: A "New" Waveform for 5G Massive Machine-Type Communications

25.01.2017 Prof. **Wolfgang Kaiser**, Technische Universität München:
Als Wissenschaftler bei den Bell Labs in Murray Hill vor 60 Jahren

07.03.2017 **Sven Müelich**, M.Sc., Ulm University, Germany:
Error Correction Schemes for Physical Unclonable Functions

22.03.2017 Dr. **Gwezheneg Robert**, French Department of Defense, France: Gabidulin Codes for Space-Time Coding

05.04.2017 Dr. **Elsa Dupraz**, IMT-Atlantique, Brest, France:
Source Coding and Big Data: Massive Random Access and Learning over Compressed Data

06.04.2017 Dr. **Danilo Silva**, Federal University of Santa Catarina (UFSC), Brazil:
On Integer-forcing Precoding for the Gaussian MIMO Broadcast Channel

10.05.2017 Prof. **Sanjoy Mitter**, Massachusetts Institute of Technology (MIT), Cambridge, MA, USA:
Information Flow in Stochastic Control

04.07.2017 Dr. **Yury Polyanskiy**, Massachusetts Institute of Technology (MIT), Cambridge, MA, USA:
Fundamental Limits and Schemes for Random-access in Wireless Channels

12.07.2017 Prof. **Kristine Larson**, University of Colorado Boulder, CO, USA: Environmental Sensing with Reflected GPS Signals (NAV-Colloquium)

13.07.2017 Prof. **Junping Chen**, Shanghai Astronomical Observatory, China: Analysis of Inner-consistency of BDS Broadcast Ephemeris Parameters and their Performance Improvement (NAV-Colloquium)

19.07.2017 Dr. **Yuval Kochman**, Hebrew University of Jerusalem, Israel:
Distributed Hypothesis Testing via Equivalence to Channel Coding

24.07.2017 **Jan Kodet**, Prof. **Ulrich Schreiber**, TUM and Geodetic Observatory Wettzell, Germany: Co-location of the Space Geodesy Instruments on the Observation Level (NAV-Colloquium)

07.08.2017 Prof. **Amin Aminzadeh**, Sharif University of Technology, Tehran, Iran:
On a Measure of Private Common Information

6 International Relations

25.08.2017 Prof. **Ayfer Özgür**, Stanford University, CA, USA:
The Capacity of the Relay Channel

22.09.2017 **Khac-Hoang Ngo**, M.Sc., CentraleSupélec, Gif-sur-Yvette, France: An Achievable DoF Region for the Two-user Non-coherent MIMO Broadcast Channel with Statistical CSI

04.10.2017 Dr. **Christian Deppe**, Bielefeld University, Germany:
Search Games with Lies and Data Transmission Models with Errors

19.10.2017 Dr.-Ing. **Gholamreza Alirezaei**, RWTH Aachen University, Germany: Optimal One-Bit Quantizers - Is the Optimum Quantization Threshold Symmetric or Asymmetric?

24.10.2017 Prof. **Mari Kobayashi**, CentraleSupélec, Gif-sur-Yvette, France: Coded Caching over Wireless: Challenges and some Solutions

25.10.2017 Dipl.-Ing. **Georg Pichler**, TU Wien, Austria:
Clustering by Mutual Information

15.11.2017 Prof. **Camilla Hollanti**, Aalto University, Helsinki, Finland:
Private Information Retrieval from Coded Storage

22.11.2017 Dr. **Ragnar Freij-Hollanti**, Aalto University, Helsinki, Finland:
Coding for Data Storage via Matroid Theory

05.12.2017 **Marco Mondelli**, Ph.D., Stanford University, CA, USA:
Fundamental Limits of Weak Recovery with Applications to Phase Retrieval

05.12.2017 Prof. **Felix Ulmer**, University of Rennes 1, France:
Skew Reed Muller Codes

13.12.2017 Dr. **Christian Häger**, Chalmers University of Technology, Gothenburg, Sweden: Coding and Deep Learning for High-Speed Fiber-Optic Communication Systems

18.12.2017 Prof. **Eitan Yaakobi**, Technion, Haifa, Israel:
Nearly Optimal Constructions of PIR and Batch Codes

19.12.2017 Dr. **Oliver Gnilke**, Aalto University, Helsinki, Finland:
Private Information Retrieval with non-MDS Codes and Small Field Sizes

09.01.2018 **Julia Lieb**, Ph.D., University of Würzburg:
Construction of MDP Convolutional Codes

17.01.2018 **Marco Falcone**, European Space Agency, Paris, France:
Galileo System Status and Future Plans (NAV-Colloquium)

30.01.2018 Prof. **Tuvi Etzion**, Technion, Israel:
Applications and Distance Measures of Subspace Codes

19.02.2018 Prof. **Emil Björnson**, Linköping University, Sweden:
Cracking the Pilot Contamination Nut

26.02.2018 Prof. **Vladimir Lebedev**, IITP, Moscow, Russia:
Algorithms for Q-ary Error-correcting Codes with Feedback

27.02.2018 **Julien Lavauzelle**, M. Sc., INRIA Saclay, France:
Construction of Computationally Efficient PIR Protocols

06.03.2018 Prof. **Andreas Winter**, Universitat Autònoma de Barcelona, Spain: Locking vs Private Capacity of Quantum Channels

09.03.2018 Prof. **Pratap Misra**, Tufts University, Boston, MA, USA:
The value of a "perfect" GNSS clock (NAV-Colloquium)

19.04.2018 Dr. **Gottfried Ungerböck**, Switzerland
Guidance from Information Theory - An Engineering Perspective

26.04.2018 Prof. **Paolo Vettori**, University of Aveiro, Portugal:
MRD Rank Metric Convolutional Codes

16.05.2018 Dr. **Thomas Westerbäck**, Aalto University, Helsinki, Finland:
Polymatroid Theory applied to Coding Theory

18.05.2018 Prof. **Navin Kashyap**, Indian Institute of Science, Bombay, India: Probabilistic Forwarding over Networks: To Code or not to Code?

04.06.2018 **Elena Andreeva**, Ph.D., KU Leuven, Belgium:
Authenticated Encryption, State of the Art and Directions

06.07.2018 Prof. **Giuseppe Durisi**, Chalmer University of Technology, Gothenburg, Sweden:
Design of Short-packet Transmission Systems through Finite-blocklength Information Theory

06.07.2018 Prof. **Alexandre Graell i Amat**, Chalmer University of Technology, Gothenburg, Sweden:
A (very) Brief Introduction to Spatially Coupled Codes

7 Honors and Awards

(1) Thomson Reuters Highly Cited Researcher in Computer Science, 2014-2016

Gerhard Kramer was honored by Thomson Reuters for the years 2014-2016 as one of the most influential researchers in *Computer Science*. Influence is determined by citation analysis to identify those who have published work with the most impact over the past decade. Highly cited articles rank in the top 1% by citations for their field and year of publication.

(2) IEEE Information Theory Society Distinguished Lecturer 2015-2016

The IEEE Information Theory Society established the Distinguished Lecturer Program to promote interest in information theory by supporting chapters who wish to invite prominent information theory researchers to give talks at their events. Distinguished Lecturers are selected by the Membership and Chapters (MC) Committee in consultation with the Board of Governors. Gerhard was elected for the period 2015-2016.

Gerhard Kramer

Chair of Communications Engineering (LNT) since October 2010; Alexander von Humboldt Professor

(1) DFG Emmy Noether Program (2016)

The *Emmy Noether Program* gives exceptionally qualified early career researchers the chance to qualify for the post of professor at a university by leading an independent junior research group for a period of six years.

(2) TUM Institute for Advanced Study (TUM-IAS) Rudolf Mößbauer Tenure Track Assistant Professor

Within the TUM Faculty Tenure Track system, TUM-IAS created a special fellowship offering merit-based academic career options from the appointment as Assistant Professor through a permanent position as Associate Professor and on to Full Professor. *Rudolf Mößbauer Tenure Track Professorships* are intended for outstanding, high-potential early-career scientists who

Antonia Wachter-Zeh

Assistant Professorship of Coding for Communications and Data Storage (COD) since October 2016; Inaugural lecture on January 30, 2017

7 Honors and Awards

Antonia with D. Dzwonnek (DFG, left) and State Secretary C. Quennet-Thielen (BMBF)

have already achieved a major scientific breakthrough and who have the ambition of developing a new field of endeavor when joining TUM.

(3) 2018 Heinz Maier-Leibnitz Prize of the DFG

On May 29, 2018, the German Research Foundation (DFG) has awarded the *2018 Heinz Maier-Leibnitz Prize* to Antonia Wachter-Zeh and nine other young researchers. The prize is considered the most important award for early-career researchers in Germany. It is named after the nuclear physicist Heinz Maier-Leibnitz, the former president of the German Research Foundation and one of TUM's most prominent scientists.

(4) 2018 ERC Starting Grant

The European Research Council (ERC) has awarded a *Starting Grant* to Antonia Wachter-Zeh. Her project *inCREASE* (Coding for Security and DNA Storage) deals with protecting data from unauthorized access and errors. ERC Starting Grants are aimed at scientists with 2-7 years of experience since the completion of their doctoral studies, and who have a scientific track record showing great promise and an excellent research proposal.

Georg Böcherer

Senior Researcher at LNT from April 2012 until November 2017; Habilitation at the TUM-ECE Department in November 2017

(1) 2017 Johann-Philipp-Reis Award of the ITG/VDE

On November 22, 2017, Georg Böcherer was awarded with the highly recognized *Johann-Philipp-Reis-Preis* of the Information Technology Society (ITG) of the German Association of Electrical Engineering, Electronics, and Information Technology e.V. (VDE). The award is given to engineers up to the age of 40 who have published an outstanding, innovative work in the field of communications that is expected to have an impact on the economy.

Georg's work being recognized is *Bandwidth Efficient and Rate-Matched Low-Density Parity-Check Coded Modulation* published in the IEEE Transactions on Communications in December 2015. This paper introduces a new layered architecture for coded modulation. The paper further develops information theory that proves that the architecture achieves Shannon capacity with unprecedented flexibility.

Johann Philipp Reis was born in 1834 in Gelnhausen and died in 1874 in Friedrichsdorf. He constructed the first device for sound transmission, the telephone. On October 26, 1861, he introduced the device for the first time in Frankfurt am Main, Germany.

The Johann-Philipp-Reis Award has been given biannually since 1986 by the VDE, the cities of Friedrichsdorf in the Taunus and Gelnhausen, and the Deutsche Telekom.

(1) 2018 Bell Labs Fellow

The Bell Labs Fellows Award recognizes and honors Nokia employees who have made outstanding, sustained research and development contributions to the company. It is the highest honor bestowed on members of the technical community. René-Jean Essiambre was named a Bell Labs Fellow in 2018.

René-Jean Essiambre

Physicist at Nokia Bell Labs in Murray Hill; TUM Ambassador and TUM Rudolf Diesel Industry Fellow

(2) 2018 Nobel Prize in Physics Lecture (presenting for Arthur Ashkin)

At the *Nobel Prize Ceremony* on December 10, 2018, in Stockholm, Sweden, René-Jean Essiambre will give the lecture on physics in representation of Arthur Ashkin, the physics Nobel Laureate 2018.

(1) 2017 Graduate Student Fellowship Award (IEEE Photonics Society)

Tobias Fehenberger has been awarded a Graduate Student Fellowship Award by the IEEE Photonics Society for his *very impressive accomplishments and academic record*. Tobias received his award during the Awards Banquet of the IEEE Photonics Conference in Florida, USA, in October 2017.

The Graduate Student Fellowship Program provides fellowships to outstanding IEEE Photonics Society student members based on their research excellence and contributions to IEEE publications and conferences. Just ten Fellowships are awarded each year to the most exceptional students from all over the world.

Tobias Fehenberger

Doctoral/Senior Researcher with the Professorship of Line Transmission Technology (LÜT) from February 2012 until August 2018

(2) 2018 Friedrich-von-Klinggräff Medal

Mit der Friedrich-von-Klinggräff-Medaille, benannt nach nach dem Gründer des Kösener Senioren-Convents-Verbandes, werden junge Corpsstudenten und Alte Herren ausgezeichnet, die sowohl im Studium als auch im Corps überdurchschnittlich engagiert und erfolgreich waren – also z.B. ein Doppelstudium oder Studium und Promotion in kurzer Zeit mit hervorragenden Noten beendet

7 Honors and Awards

Tobias and Prof. Hans D. Schotten, Managing Director of the ITG. (Photo: Hannibal / VDE

haben und gleichzeitig eine überdurchschnittliche Corpsaktivität vorweisen können. Seit seiner Gründung im Jahre 1986 hat der Stifterverein Alter Corpsstudenten e.V. 168 Corpsstudenten mit der Friedrich-von-Klinggräff-Medaille ausgezeichnet.

(3) 2018 ITG-Dissertation Award

Our alumnus Tobias Fehenberger received the 2018 dissertation award of the Information Technology Society (ITG) of the German Association of Electrical Engineering, Electronics, and Information Technology e.V. (VDE) for his thesis *Analysis and Optimization of Coded Modulation for Nonlinear Fiber-Optic Communication Systems*. The supervisor was Prof. Norbert Hanik.

Each year, three theses from the field of communications engineering are awarded the prize. The award ceremony took place at the Berlin-Brandenburg Academy of Sciences and Humanities on November 5, 2018.

Mari Kobayashi

Professor at Centrale Supélec, France; Guest Scientist at LNT since 2017

(1) Humboldt Fellowship for Experienced Researchers in 2017

Mari Kobayashi received a Humboldt Fellowship for Experienced Researchers from the Alexander von Humboldt Foundation. This prestigious fellowship is granted to approximately 500 applicants annually across all fields of research and at all German universities. The fellowship provides funding for Mari's sabbatical stay at TUM and LNT.

7 Honors and Awards

(1) 2018 IEEE Information Theory Society Paper Award

Frank Kschischang and Mansoor Yousefi won the 2018 IEEE Information Theory Society (ITSoc) Paper Award for their three-part paper on *Information Transmission using the nonlinear Fourier Transform* (NFT), published in the IEEE Transactions on Information Theory in July 2014. The ITSoc Paper Award is given annually for an outstanding publication in the fields of interest to the Information Theory Society appearing anywhere during the preceding four calendar years.

(2) 2018 Fellow of the Canadian Academy of Engineering

Frank was named a Fellow of the Canadian Academy of Engineering on June 18, 2018. The ceremony took place in Calgary.

(3) 2018 IEEE Information Theory Society Padovani Lecturer

In January 2018 Frank was named a IEEE Information Theory Society Padovani Lecturer. The award, sponsored by a generous gift of Roberto Padovani and administered by the IEEE Foundation, defrays travel and accommodation expenses to a lecturer selected to speak at the North American Summer School of Information Theory.

Frank Kschischang

Distinguished Professor at the University of Toronto, Canada; TUM Ambassador and TUM Hans Fischer Senior Fellow

(1) Fulbright Scholarship for Doctoral Candidates

Andreas Lenz received a Fulbright Scholarship for Doctoral Candidates in 2018. The scholarship supports and funds research stays with a duration between four and six months at an American University. With this scholarship, Andreas will visit the University of California, San Diego, in spring 2019 for a research project in collaboration with Prof. Paul Siegel, who is Chair of the Center for Memory and Recording Research.

Andreas Lenz

Doctoral Researcher with the COD group since 2016; Topic: Coding for DNS Storage

(1) 2018 Professor Dr. Ralf Kötter Memorial Award

Tobias Prinz is the recipient of the *2018 Professor Dr. Ralf Kötter Memorial Award* for his outstanding Master's thesis entitled "Polar Codes for Higher-Order Modulation and Probabilistic Amplitude Shaping". The results of the Master's thesis have been presented at several IEEE conferences, including the 2017 IEEE Workshop on Signal Processing Advances in Wireless Communications in Sapporo, Japan.

The prize was initiated in 2009 and is endowed by Ruth and Hubert Kötter, the parents of Ralf Kötter, head of the LNT from 2007-2009. The award ceremony took place on April 14, 2018 in the City Hall of Kronberg/Taunus. The laudatio for Tobias was given by Prof. Gerhard Kramer.

Tobias Prinz

Doctoral Researcher with the LNT since July 2016; Topic: Higher order modulation and decoding algorithms for polar codes

7 Honors and Awards

Award Ceremony in the City Hall of Kronberg/Taunus. From the left: Jörg, Hubert, and Ruth Kötter, Tobias Prinz, Klaus Temmen (Mayor of Kronberg), and Gerhard Kramer

Thomas Stockhammer

Doctoral Researcher with the LNT (1996-2004); CEO and Co-founder of Nomor Research; Director Technical Standards at Qualcomm (2014-)

(1) The 3GPP Excellence Award 2018

Thomas Stockhammer received the 3GPP Excellence Award in 2018 for his outstanding contributions and leadership in delivering Rel-14 Enhanced Television (enTV) Services via 3GPP eMBMS. He has provided technical input, support for progress, and at the same time ensured that the 3GPP status and progress are understood by the broadcasters. *3GPP's enTV specifications provide the basis for broadcast delivery in 5G.* The award was conferred at SA4#97 by the 3GPP SA4 leadership team in Fukuoka, Japan.

Ingo Viering

Lecturer with the LNT since 2006; Co-founder and CEO of the LNT start-up Nomor Research

(1) "Honorarprofessor" of the TUM Department of Electrical and Computer Engineering.

Ingo Viering became an *Honorarprofessor* of the TUM Department of Electrical and Computer Engineering in 2018. Ingo has been teaching the Master-level course *System Aspects in Communications* for many years.

His activies are an excellent example of the added value that industry lectures bring to a technical university: education on an important industry topic, internships and theses topics for students, employment opportunities, and contact to a company at the forefront of standardization activities.

7 Honors and Awards

Award Ceremony in Berlin:From the left: Dr. Gerd Kraft and Dr. Franziska Zeitler (both DLR Raumfahrtmanagement), Fabian Steiner, Patrick Schulte and Thomas Jarzombek MdB (Koordinator der Bundesregierung für Luft- und Raumfahrt)

(1) TUM's Shapecomm wins Space Industry Competition

Shapecomm CEO Fabian Steiner won the *INNOspace Masters ideas competition* for innovative proposals for satellite and space applications. Together with his Shapecomm partners *Patrick Schulte* and *Georg Böcherer*, he developed and implemented a novel technology for bandwidth efficient communication called *Probabilistic Amplitude Shaping* that overcomes the limitations of current satcom modems. Applications include satellite broadcasting services for TV and radio, inflight entertainment, and broadband internet access to remote areas. The technology could possibly culminate in DVB-S3.

On June 5, 2018, in Berlin, Fabian Steiner of LNT and Shapecomm was selected as the overall winner of the INNOspace Masters competition. The shapecomm UG was founded in January 2017 by G. Böcherer, P. Schulte and F. Steiner of the LNT to offer consulting, development and research in the field of telecommunications.

Fabian Steiner

Doctoral Researcher with the LNT since August 2016; CEO of the LNT start-up Shapecomm

(1) 2018 IEEE Information Theory Society Paper Award

Mansoor Yousefi and Frank Kschischang won the 2018 IEEE Information Theory Society (ITSoc) Paper Award for their three-part paper on *Information Transmission using the nonlinear Fourier Transform* (NFT), published in the IEEE Transactions on Information Theory in July 2014. The ITSoc Paper Award is given annually for an outstanding publication in the fields of interest to Information Theory Society appearing anywhere during the preceding four calendar years.

Mansoor Yousefi

Assistant Professor at the Telecom ParisTech; Postdoc with the LNT from October 2012 to February 2016

(2) 2018 ERC Starting Grant

The European Research Council (ERC) awarded a Starting Grant to Mansoor Yousefi. His project *COMNET* (Communication using the nonlinear Fourier transform) deals with increasing data rates on fiber-optic channels.

ERC Starting Grants are aimed at scientists with 2-7 years of experience since the completion of their doctoral studies, and who have a scientific track record showing great promise and an excellent research proposal.

8 Other
Sonstiges

Günter Söder et al.

8.1 Abschlussbericht zum LNTwww

Ich berichte in dieser Reihe nochmals (und letztmalig) über unser E-Learning-Projekt LNTwww: ***L**erntutorial für die **N**achrichten**T**echnik im **w**orld **w**ide **w**eb*. 2001 haben Klaus Eichin und ich mit LNTwww begonnen und 2018 wurde es (bis auf wenige Kleinigkeiten) erfolgreich fertiggestellt.

LNTwww ist eine virtuelle Lehrveranstaltung im Umfang von 36 Semesterwochenstunden mit 23 SWS Vorlesung (eher theoretisch orientiert) und 13 SWS Übungen (Anwendung des Gelernten). Bereitgestellt werden ferner viele im Rahmen unseres LNTwww-Projekts erstellten multimedialen (meist interaktiven) Elemente.

Unter **https://www.LNTwww.de** gelangen Sie zur Startseite. Dort finden Sie neben einer Bedienungsanleitung („Über LNTwww“) und aktuellen Hinweisen folgende Links:

- **Büchersammlung**: Hier kommen Sie zu neun Fachbüchern, die das Lehrgebiet der Informations- und Telekommunikationstechnik und der dazugehörigen Grundlagenfächer in didaktisch aufbereiteter Form präsentieren.
- **Aufgaben**: Bereitgestellt werden zu den 40 Theoriekapiteln mehr als 600 Aufgaben mit ausführlichen Musterlösungen.
- **Lernvideos**: Aufrufbar sind mehr als 30 Lernvideos im mp4– und ogv–Format, teilweise zwei- oder dreiteilig. Diese laufen in der neuen Version auf (fast) allen Browsern und auf Smartphones.
- **Interaktive Applets**: Angeboten werden zehn neu erstellte Applets basierend auf HTML5, zudem noch 50 unserer früheren Module im SWF-Format.

Hauptarbeit der beiden letzten Jahre war die Überführung der Vorgängerversion 2 in die jetzige Wiki-Version, was leider nicht automatisiert zu bewerkstelligen war, und die Neuprogrammierung der Applets in HTML 5.

Ich bedanke mich bei den beteiligten Studierenden für ihr Engagement, bei MoliTUM für die finanzielle Förderung, insbesondere aber bei meinem Kollegen Tasnád Kernetzky (LÜT), der für alle auftretenden Probleme immer wieder eine Lösung fand. Mein Dank geht zudem an alle bei LNTwww irgendwie Beteiligten, die unter „Autoren“ genannt sind.

Aufgabe der nächsten Monate wird sein, noch möglichst viele Applets für Smartphones zugänglich zu machen (Umwandlung von SWF in HTML5).

8 Other
Sonstiges

8.2 Neuerungen in der Infrastruktur

Wie in den Jahren zuvor sind unter dieser Rubrik als erstes wieder viele Baumaßnahmen zu nennen. Die Vorderfront unseres Gebäudes N4 hat eine neue Fassade bekommen (siehe linkes Foto) und das Treppenhaus wurde renoviert (Fußboden, Wände, Geländer). Die mit viel Lärm und Dreck (L&D) verbundenen Arbeiten sind nun beendet. Alles ist sehr schön geworden, vielleicht etwas steril.

Auch bezüglich unserer Räume gab es viele Veränderungen (wieder L&D). Die frühere E-Werkstatt haben wir an den Lehrstuhl von Prof. Boche (LTI) abgegeben und den EIKon-Raum mussten wir aus Platzgründen schließen. Die Rechnerräume für Studierende und Gäste wurden in das frühere Mobilfunklabor verlegt. Diese wurden auch neu möbliert und mit leistungsfähigen Xeon-Workstations ausgestattet. Wir bedanken uns bei MoliTUM für die finanzielle Unterstützung.

Die so frei gewordenen Räume im dritten Flur wurden in fünf Büros umgewidmet, u.a. für Antonia Wachter-Zeh (COD) und ihre Mitarbeiter. Neue Besprechungs- bzw. Seminarräume mit separatem Eingang wurden durch Verkleinerung von „großem Praktikum“ und Bibliothek gewonnen. Diese und auch unser großer Seminarraum N2408 wurden mit lichtstarken Beamern ausgestattet.

Unser Lehrstuhlgebäude N4

Neu eingerichteter Besprechungsraum

Alle von LNT / LÜT / COD / NAV bedanken sich bei Robert Schetterer, der durch sein Organisationstalent die Beeinträchtigung unserer Arbeiten in Grenzen gehalten hat und aus Brandschutzgründen zig Kubikmeter Papier der Ära „60 Jahre LNT in N4“ entsorgt hat. Martin Kontny hat ihn bis Juli 2017 tatkräftig unterstützt.

Robert ist eigentlich Systemadministrator für alle Forschungsgruppen. Auch in diesem seinem Kerngeschäft zeigt er großen Einsatz und liefert hervorragende, manchmal unkonventionelle Arbeit ab. Auch den anderen Sysadmins T. Prinz (LNT), M. Lülf (NAV), T. Fehenberger und T. Kernetzky (beide LÜT) gilt unser Dank.

8.3 Persönliches

Abschließend berichten wir über persönliche Ereignisse von derzeitigen und ehemaligen Mitgliedern von LNT, LÜT und COD – natürlich nur positive.

Erika Herian und Gerhard Kramer

Runde Geburtstage

85. Geburtstag:
Gottfried Binkert, Akademischer Direktor am LNT 1963–1994.

60. Geburtstag:
Erika Herian, Offiziantin am LNT seit 1985.

50. Geburtstag:
Dr.-Ing. **Rupert Herzog**, Doktorand am LNT 1994 – 2000, jetzt DPA,
Dr.-Ing. **Thomas Hindelang**, Doktorand am LNT 1994 – 2000, jetzt EPA.

Wir gratulieren allen Jubilaren und wünschen für die Zukunft alles Gute.

Hanna und Lars Palzer

Hochzeiten

Aug. 2018: Herzlichen Glückwunsch an **Hanna Becker** & **Lars Palzer!**

Geburten

Jan. 2017: **Lea** – ihr Vater Markus Staudacher ist seit 2014 als Doktorand von Gerhard Kramer am LNT.

Aug. 2017: **Jonathan** – sein Vater Stefan Dierks war von 2011-2017 Mitarbeiter des LNT und hat seine Dissertation 2018 abgeschlossen.

Febr. 2018: **Emma** – ihr Vater Sven Puchinger ist erst seit Mai bei COD; bei ihrer Geburt und seiner Promotion war er noch in Ulm.

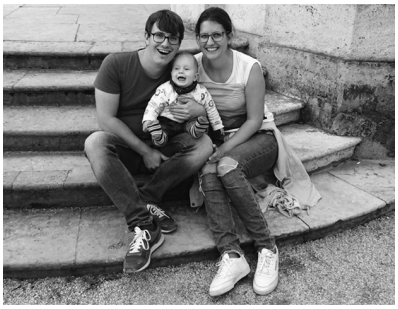
Febr. 2018: **Johannes** – sein Vater Tobias Prinz ist seit 2016 Doktorand von Gerhard Kramer am LNT.

Febr. 2018: **Paul Alexander** und **Karl Johannes** – ihr Vater Tobias Fehenberger war 2011-2018 bei LÜT; Promotion 2017 bei Norbert Hanik.

Sept. 2018: **Aurelian** – seine Mutter Antonia Wachter-Zeh ist seit 2016 bei COD; seine Schwester Amira geht bereits in den Kindergarten.

Aurelian und Amira

8 Other / Sonstiges



Johannes mit seinen Eltern Anna und Tobias

Paul Alexander (li) und Karl Johannes

Jonathan mit Stefan und Bruder Jannik (3)

Lea mit Markus

Emma mit Sven

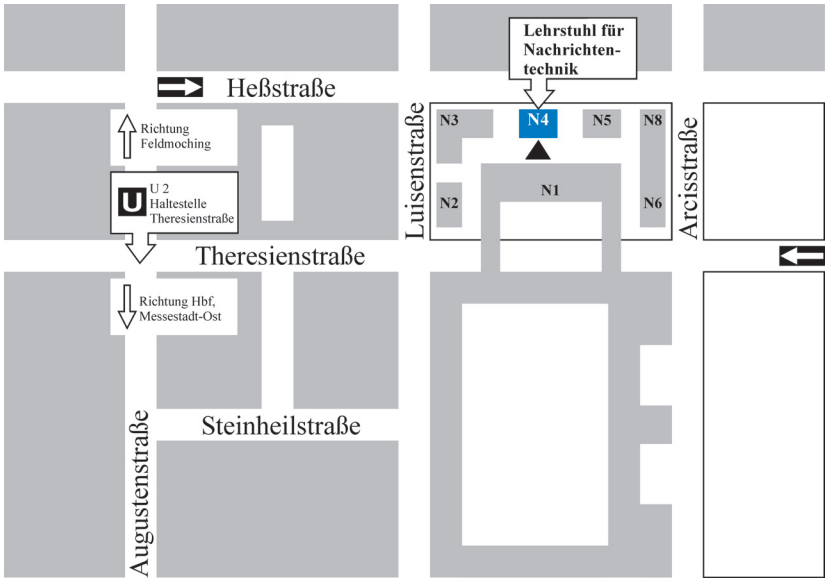
Die Lehr- und Forschungseinheit für Nachrichtentechnik beglückwünscht alle Eltern und wünscht den Neugeborenen trotz der derzeit etwas verrückten Welt eine glückliche Kindheit und Jugendzeit, verständnisvolle Eltern und ein erfülltes Leben.

The cover design is by *Patrick Schulte* and the following text by *Lars Palzer*.

The figure illustrates the geometry of *Quantized Compressive Sensing*. Compressive Sensing is a recent mathematical theory that addresses the efficient acquisition and compression of natural signals. In many cases, these signals exhibit a certain lower dimensional structure. For example, images can often be represented by only a few Wavelet coefficients. Mathematically, we can model such signals as living on some lower-dimensional manifold that is embedded into a higher dimensional space. The key insight of this theory is that such signals can be reconstructed from a small number of linear measurements. Linear measurements are created through superpositions of different components of the signal and can be represented by a matrix multiplication. Thus, these linear measurements simply rotate and scale the signal manifold. If one takes enough measurements (this can be drastically fewer than the ambient signal dimension such as the number of pixels in an image), the structure of the signal can be preserved by the measurements and the signal can be reconstructed via numerically efficient algorithms.

As a simple example, we might have a four-dimensional space where all signals of interest live on a two-dimensional hyperplane. Through a measurement matrix, this hyperplane is rotated and mapped into a three-dimensional measurement space, which is depicted in our figure. Here, we additionally employ scalar quantization in order to store the measurements on a digital system. The quantization cells are illustrated by the many parallel hyperplanes that cut the space into small boxes.

Together with the Chair for Applied and Numerical Analysis (Prof. Fornasier) at TUM, we are investigating fundamental limits and efficient algorithms for quantized and distributed Compressive Sensing in the framework of the DFG Priority Programme *Compressed Sensing in Information Processing* (CoSIP).



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