Friedrich-Alexander-Universität
Erlangen-Nürnberg

Module description

for the degree programme

Master of Science Advanced Signal Processing & Communications Engineering (Prüfungsordnungsversion: 20212)

Table of contents

Technical Mandatory Electives

1	**Module name** 151664	**Advanced communication networks**	**5 ECTS**
2	Courses / lectures	Übung: Advanced Communication Networks - Tutorial (0 SWS) Vorlesung: Advanced Communication Networks (4 SWS)	- 5 ECTS
3	Lecturers	Walid Ghanem Prof. Dr. Laura Cottatellucci	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	Telecommunications have become ubiquitous in daily life and wireless networks play a fundamental role thanks to their capability to support mobility. In a wireless communication, the concept of link does not exist. Users radiate energy and communicate through the superposition of each others transmissions which creates interference. Compared to wireline networks this scenario is extremely challenging but also offers unpredictable opportunities in the development of new technologies (massive MIMO, cognitive radio, etc.) and exploitation of new features, e.g., opportunistic communications and multiuser diversity. The exponentially increasing request of higher and higher throughput is satisfied densifying users and access points per unit area and allowing more and more interference while adopting advanced techniques and innovative resource allocation to mitigate the detrimental effects of interference. Objective of this course is to introduce the student to advanced techniques for coordinated medium access control and radio resource management in cellular systems. Power allocation, rate adaptation and scheduling will be discussed both in centralized and distributed settings. Some mathematical methods play a fundamental role in resource allocation, namely, classical Perron-Frobenius theory for nonnegative matrices, convex and nonconvex constrained optimization, distributed optimization and game theory. The course introduces the student to such methods and exemplifies their application to various resource allocation problems. Additionally, the course addresses relevant aspects of resource allocation in wireless networks such as fairness and cross-layer design. *Technical Content* • Properties and challenges of the wireless medium. • Basic concepts of communication networks: the layered architecture. • Evolution of wireless cellular network architectures: From Global System for Mobile to Advanced-Long Term Evolution. • Multiple Access Schemes: CSMA variants, TDMA, FDMA, CDMA, OFDMA, SC-FDMA, SDMA. • Uplink-downlink duality. • Opportunistic scheduling and multiuser diversity.

		• Advanced concepts: small cells and heterogeneous networks, relaying and cooperation, network coding, cognitive radio networks. • Basics of resource allocation: power allocation, rate adaptation, and scheduling. • Classical resource allocation techniques: Centralized and distributed power control based on the Perron-Frobenius theorem. • Fundamentals of convex constrained optimization and application to resource allocation. • Resource allocation and fairness. • Fundamentals of nonconvex optimization and relaxation techniques. • Applications of nonconvex optimization to resource allocation. • Fundamentals of distributed optimization and applications to resource allocation. • Fundamental concepts of game theory. • Resource contention via game theoretical methods.
6	**Learning objectives and skills**	The student • Describes and/or recognizes wireless channel models. • Criticizes the limits of a layered architecture in wireless systems. • Defends the use of cross-layer design in wireless network. • Appraises and compares the distribution of functionalities in network entities for different architectures. • Argue on the pros and contras of different multiple access schemes according to various criteria (e.g. spectral efficiency, power efficiency, robustness to interference). • Compares and contrasts micro-diversity and various macro-diversity schemes. • Computes the total rate of SDMA with various receivers. • Relates the multiple access in uplink to broadcasting in downlink and justifies the concept of uplink-downlink duality. • Uses uplink-downlink duality to design a precoder and allocate power. • Contrasts multiple access in uplink and broadcasting in downlink in terms of channel state acquisition both for TDD and FDD transmission. • Uses multiuser diversity for opportunistic scheduling. • Compares multiuser diversity for users having identical and different channel statistics. • Contrasts opportunistic scheduling in terms of channel state acquisition and feedback both for uplink and downlink and for both FDD and TDD transmission schemes. • Appraises the impact of multiple antennas on opportunistic scheduling. • Analyses different settings with interference in small cells and designs countermeasures. • Categorizes relaying schemes in LTE.

		• Analyses performance of relaying schemes. • Argues on possible improvements of relaying schemes via network coding and physical layer network coding. • Uses the Perron-Frobenious theorem to allocate power in a centralized manner. • Judges the feasibility of a power control problems and formulates alternative approaches in case of unfeasibility. • Uses the Perron-Frobenious theorem to design a distributed power control scheme. • Judges the convergences of distributed power control based on the Perron-Frobenius theorem and appraises the robustness of asynchronous power control. • Applies techniques of convex optimization to discriminate convex problems and determine necessary and/or sufficient conditions for global optimality. • Judges the applicability of KKT conditions and duality. • Uses KKT conditions to solve convex optimization problems. • Uses duality to solve convex optimization problems. • Applies convex optimization to resource allocation in wireless communications. • Compares different definitions of fairness and applies them to rate allocation. • Appraises the effect of channel knowledge at the transmitter on different fairness criteria. • Applies KKT conditions for opportunistic user scheduling. • Describes a proportional fair algorithm for opportunistic scheduling. • Applies relaxation to nonconvex quadratic constrained quadratic programming. • Formulates resource allocation problems as constrained optimization programming. • Contrasts various distributed optimization methods. • Applies the concept of best response to determine Nash equilibria. • Argues about existence and uniqueness of Nash equilibria. • Assesses if a given game is a potential game and solves it. • Defends the concept of Pareto optimality in resource allocation. • Contrasts the concepts of pure and mixed strategies in game theory. • Uses coupled constrained concave game to allocate powers in heterogeneous networks.
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.

14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 412023	**Channel coding on graphs**	**5 ECTS**
2	Courses / lectures	Vorlesung: Channel Coding on Graphs (4 SWS) Übung: Channel Coding on Graphs - Tutorial (0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Nikita Shanin	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	*Description* In today's communications world, channel coding underlies the physical layer of all major communication systems. For example: algebraic block coding (Reed-Solomon codes) are used in the CD and DVD standards; trellis coded modulation is used in line modems; low-density parity check codes (LDPC) are used in satellite communications (DVB-S2 standard), LAN (10GBase-T Ethernet) and wireless LAN (Wi-Fi 802.11); turbo codes are implemented in 3G/4G mobile communications (e.g. in UMTS and LTE) and in (deep space) satellite communications. Recently, polar codes have been adopted for the eMBB (Enhanced Mobile Broadband) control channels for the 5G NR (5th Generation New Radio) interface. Objective of this course is to provide an introductory but thorough background on codes over graphs and covers both classical convolutional codes and the modern theory of random-like codes with iterative decoding. Namely, LDPCs (Low Density Parity Check Codes, Turbo Codes, and Polar Codes. Students will acquire the fundamental knowledge to design and analyze performance of channel codes on graphs, as well as implement the corresponding encoders and decoders. *Technical Content* • Role of channel coding in a communication system. • Idealized channel models : the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel. • Some preliminary basic concepts from linear block codes: Parity Check, Hamming distance, weight enumerating functions, performance evaluations, and performance bounds. • Factor graphs and belief propagation. • Binary random-like codes: LDPC codes and message-passing decoding, threshold behaviour of message passing decoding: density evolution analysis. Design of LDPC ensembles. • Polar Codes: Polarization, polar channel coding, performance, encoding and decoding. • Binary convolutional codes : the algebraic structure, the dynamic structure, Viterbi decoding, performance analysis via weight enumerating function, the forward-backward algorithm. • Other random-like codes: the Turbo Codes. Efficient decoding of Turbo Codes via forward-backward algorithm and

		interpretation via factor graphs. Performance analysis and exit charts.
6	**Learning objectives and skills**	The student Uses idealized channel models (the binary symmetric channel (BSC), the binary erasure channel (BEC), the constrained-input Gaussian channel) to compute their capacities Contrasts soft output decoders with disjoint detection and decoding, maximum likelihood and maximum a posteriori decoders Relates the concepts of Parity Check, Hamming distance, weight enumerating functions to the performance analysis of codes on graphs Devises factor graphs of proposed communication systems Assesses and justifies the applicability of belief propagation to given factor graphs Assesses and justifies the applicability of message passing to codebooks defined in terms of Tanner graph or parity check matrix Applies message passing to codebooks defined in terms of Tanner graph or parity check matrix Analyses the performance of LDPC code decoding via density evolution Computes exit charts for LDPC codes for the equations of the density evolution Designs LDPC ensemble for a given channel to maximize the code rate Justifies the design of LDPC codes via design of LDPC ensembles Interprets convolutional codes as linear block codes Compares algebraic and dynamic representations of convolutional codes Computes steps of the Viterbi algorithm Summarizes and justifies the fundamental structure of the Viterbi algorithm Computes steps of the BCJR algorithm Summarizes and justifies the fundamental structure of BCJR algorithm

		Compares Viterbi and BCJR algorithms Justifies low complexity and/or practical implementations of the Viterbi and the BCJR algorithm Attaches a direct graph to a convolutional code and computes its transfer function Assesses the performance of the Viterbi decoder via (bit) weight enumerating function based on the transfer function method Interprets a BCJR algorithm as message passing over a factor graph Combines encoders of convolutional codes to generate parallel concatenated codes with interleaver (turbo codes) of given rate Combines encoders of convolutional codes to generate serial concatenated codes with interleaver (turbo codes) Compares the key features of parallel concatenated codes with interleaver (turbo codes) to serial concatenated codes with interleaver (turbo codes) Designs decoders for turbo codes utilizing coupled BCJR-based decoders for convolutional codes Interprets turbo decoders as factor graphs and justifies their implementation via message passing Assesses the performance of turbo codes using exit charts Formulates the concept of source polarization and relates it to polar channel coding Interprets polar channel coding as factor graphs Designs polar channel codes Argues about capacity achievability of polar channel codes
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Variabel
11	**Grading procedure**	Variabel (100%)

12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 700506	**Commmunications systems design**	**5 ECTS**
2	Courses / lectures	Vorlesung: Communications Systems Design (2 SWS) Praktikum: Praktikum Communications Systems Design (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Georg Fischer Christof Pfannenmüller Christof Pfannenmüller Arslan Ali Arslan Ali Christof Pfannenmüller Christof Pfannenmüller	

4	**Module coordinator**	Arslan Ali Prof. Dr.-Ing. Georg Fischer
5	**Contents**	Learning based on LabVIEW communications and NI USRP: Introduction to USRP including hardware blocks of Tx/Rx chains Getting familiar with LabVIEW communications environment and controlling VIs (Panel, diagram, etc.) and fundamentals of LabVIEW programming: data types, arrays, flow control (for/while loop), clusters, case structures, signal sources, sinks, signal processing tools, filters, time/ frequency domain analysis, etc. Transmission and reception of analog modulation schemes: AM/DSB-SC and FM Implementation of digital modulation schemes: ASK, FSK, BPSK, QPSK, 16-QAM, etc. Digital Tx/Rx: symbol mapping, upsampling/downsampling, pulse shaping (rectangular, Gaussian, RRC), matched filtering, pulse alignment, synchronization, and detection Phase synchronization, FDM and image rejection algorithm Eye diagram analysis: ISI, clock jitter, optimal sampling time, detection threshold Power control for over-the-air transmission in sub-6 GHz ISM bands and analysis on fading and multipath propagation effects Channel estimation, equalization (decision directed, linear LS, adaptive LMS), modelling: coherence bandwidth and propagation delay

		Learning based on MATLAB and USRPs (Communications toolbox and SDR support packages): OFDM Tx/Rx with frequency domain equalization (FDE) and synchronization (training sequence and frame detection) LTE downlink transmission (MIMO) including system information blocks (SIB) and spectrum analysis including estimation/calibration of carrier frequency offset (CFO) Impairments/distortion analysis: ACPR, EVM tool: IQ offset errors, phase noise, PA nonlinearity, etc. Learning based on GNU Radio and RTL-SDR: Introduction to GNU Radio with RF prototyping demonstration Spectrum analyzer implementation: RBW, VBW, sweep time, and phase noise Small Project/assignment for students
6	**Learning objectives and skills**	Students Can bridge the gap between communications theory, analog/digital baseband, and RF design Can develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions Can determine the design parameters and assess the interaction between various analog and digital parts Can create efficient Tx/Rx programs and signal processing algorithms in LabVIEW, MATLAB, and GNU Radio Can implement channel estimation and equalization algorithms in TDD and FDD systems Can demonstrate MIMO and OFDM based systems like LTE and beyond Can quantify and evaluate system performance using EVM and impairments analysis
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester

13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 45 h Independent study: 30 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 96850	**Convex optimization in communications and signal processing**	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Convex Optimization in Communications and Signal Processing (1 SWS) Vorlesung: Convex Optimization in Communications and Signal Processing (3 SWS)	- 5 ECTS
3	Lecturers	Adela Vagollari Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	Prof. Dr. Wolfgang Gerstacker
5	**Contents**	Convex optimization problems are a special class of mathematical problems which arise in a variety of practical applications. In this course we focus on the theory of convex optimization, corresponding algorithms, and applications in communications and signal processing (e.g. statistical estimation, allocation of resources in communications networks, and filter design). Special attention is paid to recognizing and formulating convex optimization problems and their efficient solution. The course is based on the textbook "Convex Optimization" by Boyd and Vandenberghe and includes a tutorial in which many examples and exercises are discussed.
6	**Learning objectives and skills**	Students • characterize convex sets and functions, • recognize, describe and classify convex optimization problems, • determine the solution of convex optimization problems via the dual function and the KKT conditions, • apply numerical algorithms in order to solve convex optimization problems, • apply methods of convex optimization to different problems in communications and signal processing
7	**Prerequisites**	Signals and Systems, Communications
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Boyd, Steven ; Vandenberghe, Lieven: Convex Optimization. Cambridge, UK : Cambridge University Press, 2004

1	**Module name** 93015	**Introduction to modern cryptography**	**7,5 ECTS**
2	Courses / lectures	Vorlesung: Einführung in die moderne Kryptographie (4 SWS) Übung: Einführung in die moderne Kryptographie (Übung) (2 SWS)	5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Dominique Schröder	

4	**Module coordinator**	Carina Harrius Prof. Dr. Dominique Schröder
5	**Contents**	This course gives a comprehensive introduction to modern cryptography. The course also serves as a base for other courses on cryptography that are offered by the chair. The topics covered are the following: • Information theoretic security • Computational security • Private key Encryption • Message Authentication Codes • Hash functions • Public key Encryption • Digital Signatures More advanced topics may be covered if time permits.
6	**Learning objectives and skills**	On successfully passing the course, the student is guaranteed to be knowledgeable on the basic concepts of provable security.
7	**Prerequisites**	No previous knowledge in Cryptography or computer Security is required.
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Variabel
11	**Grading procedure**	Variabel (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 165 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Introduction to Modern Cryptography Jonathan Katz and Yehuda Lindell 2nd Edition (2014) (Chapman & Hall/CRC Cryptography and Network Security Series) ISBN-13: 978-1466570269

1	**Module name** 44410	**Embedded systems**	**5 ECTS**
2	Courses / lectures	Übung: Übung zu Eingebettete Systeme (2 SWS) Vorlesung: Eingebettete Systeme (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Patrick Plagwitz Dominik Walter Khalil Esper PD Dr.Ing. Frank Hannig Prof. Dr.-Ing. Jürgen Teich	

4	**Module coordinator**	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	**Contents**	Schwerpunkt des Moduls ist der Entwurf und die Implementierung eingebetteter Systeme unter Einsatz formaler Methoden und rechnergestützter Entwurfsverfahren. Unter eingebetteten Systemen versteht man Rechensysteme, die auf einen Anwendungsbereich zugeschnitten (z.B. mobile Kommunikationsgeräte, Chipkartensysteme, Industriesteuerungen, Unterhaltungselektronik, Medizintechnik) und in einen technischen Kontext eingebunden sind. Das große Interesse am systematischen Entwurf von heterogenen eingebetteten Systemen ist verursacht durch die steigende Vielfalt und Komplexität von Anwendungen für eingebettete Systeme, die Notwendigkeit, Entwurfs- und Testkosten zu senken sowie durch Fortschritte in Schlüsseltechnologien (Mikroelektronik, formale Methoden). ***Content:*** *The focus of this module is the design and implementation of embedded systems using formal methods and computer-aided design techniques.* *Embedded systems are computing systems tailored for a particular application (e.g., mobile communication devices, smart card systems, industrial control, consumer electronics, medical technology) and integrated into a technical context. The keen interest in the systematic design of heterogeneous embedded systems is driven by the increasing diversity and complexity of embedded system applications, the need to reduce design and test costs, and advances in key technologies (microelectronics, formal methods).*
6	**Learning objectives and skills**	Fachkompetenz - Wissen • Die Studierenden setzen sich mit einem aktuellen Forschungsgebiet auseinander. The students deal with a current field of research. Fachkompetenz - Verstehen

		• Die Studierenden verstehen grundlegende Konzepte des Entwurfs eingebetteter Systeme. The students become familiar with the fundamental concepts of designing of embedded systems. Fachkompetenz - Anwenden • Die Studierenden wenden grundlegende Algorithmen an zur Analyse und Optimierung von Hardware-Architekturen und Echtzeit-Softwaresystemen. The students apply basic algorithms to analyze and optimize hardware architectures and real-time software systems. • Die Studierenden erfassen den Hardware/Software-Entwurf von Systemen mit harten Beschränkungen. The students understand the hardware/software design of hard-constrained systems.
7	**Prerequisites**	Die Auswahl dieses Moduls schließt die Auswahl der Module „Eingebettete Systeme (Vorlesung mit erweiterten Übungen)“ und „Eingebettete Systeme (Vorlesung mit Übungen)“ aus.
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Deutsch oder Englisch
17	**Bibliography**	Empfohlenes Buch zur Begleitung und Vertiefung: • Teich J., Haubelt C.: "Digitale Hardware/Software-Systeme: Synthese und Optimierung", Springer-Verlag, 2007, ISBN: 978-3-540-46822-6 Weitere Informationen: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/eingebettete-systeme/

1	**Module name** 645618	**Human computer interaction**	**5 ECTS**
2	Courses / lectures	Übung: Human Computer Interaction Exercises (1 SWS) Vorlesung: Human Computer Interaction (3 SWS)	1,25 ECTS 3,75 ECTS
3	Lecturers	Madeleine Flaucher Prof. Dr. Björn Eskofier	

4	**Module coordinator**	Prof. Dr. Björn Eskofier Madeleine Flaucher Wolfgang Mehringer Anastasiya Zakreuskaya
5	**Contents**	Das Modul vermittelt Konzepte, Prinzipien, Modelle, Methoden und Techniken für die effektive Entwicklung von benutzerfreundlichen Mensch-Computer-Schnittstellen. Das Thema moderner Benutzungsschnittstellen wird dabei für klassische Computer aber auch für mobile Geräte, eingebettete Systeme, Automobile und intelligente Umgebungen betrachtet. Die folgenden Themen werden im Modul behandelt: • Einführung in die Grundlagen der Mensch-Computer-Interaktion, historische Entwicklung • Entwurfsprinzipien und Modelle für moderne Benutzungsschnittstellen und interaktive Systeme • Informationsverarbeitung des Menschen, Wahrnehmung, Motorik, Eigenschaften und Fähigkeiten des Benutzers • Interaktionskonzepte und -stile, Metaphern, Normen, Regeln und Style Guides • Ein- und Ausgabegeräte, Entwurfsraum für interaktive Systeme • Analyse-, Entwurfs- und Entwicklungsmethoden und -werkzeuge für Benutzungsschnittstellen • Prototypische Realisierung und Implementierung von interaktiven Systemen, Werkzeuge • Architekturen für interaktive Systeme, User Interface Toolkits und Komponenten • Akzeptanz, Evaluationsmethoden und Qualitätssicherung Contents: The module aims to teach basic knowledge of concepts, principles, models, methods and techniques for developing highly user-friendly Human-Computer Interfaces. Beyond traditional computer systems, modern user interfaces are also discussed in the context of automobile and intelligent environments, mobile devices and embedded systems.

		This module addresses the following topics: • Introduction to the basics of Human-Computer Interaction • Design principles and models for modern user interfaces and interactive systems • Information processing of humans, perception, motor skills, properties and skills of the users • Interaction concepts, metaphors, standards, norms and style guides • In- and output devices, design space for interactive systems • Analysis-, design- and development of methodologies and tools for easy-to-use user interfaces • Prototypic implementation of interactive systems • Architectures for interactive systems, User Interface Toolkits and components • Acceptance, evaluation methods and quality assurance
6	**Learning objectives and skills**	• Studierende entwickeln ein Verständnis für Modelle, Methoden und Konzepte der Mensch-Computer-Interaktion. • Sie lernen verschiedene Ansätze für den Entwurf, die Entwicklung und Bewertung von Benutzungsschnittstellen kennen und verstehen deren Vor- und Nachteile. • Die Teilnahme an der Veranstaltung versetzt Studierende in die Lage, einen Entwicklungsprozess in der Mensch-Computer-Interaktion zu verstehen und umzusetzen. • Sie werden weiterhin in die Lage versetzt, dies vor dem Hintergrund der Informationsverarbeitungsfähigkeit, Wahrnehmung und Motorik des Benutzers zu gestalten. • Passende Methoden der Evaluation sowie Akzeptanz- und Qualitätssicherung werden erlernt. Learning Objectives and Competences: • Students develop an understanding of models, methods and concepts in the field of Human-Computer Interaction. • They learn different approaches for designing, developing and evaluating User Interfaces and their advantages and disadvantages. • Joining the course enables students to understand and execute a development process in Human-Computer Interaction. • Students will be able to do a UI evaluation by learning the basics of information processing, perception and motoric skills of the user. • Appropriate evaluation methods, as well as acceptance and quality assurance aspects, will be learned.
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur

11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	in jedem Semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 96310	**Image and video compression**	**5 ECTS**
2	Courses / lectures	Übung: Übung Image and Video Compression (1 SWS)	-
3	Lecturers	Andy Regensky	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	*Multi-Dimensional Sampling* Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling *Entropy and Lossless Coding* Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding *Statistical Dependency* Joint entropy and statistical dependency, run-length coding, fax compression standards *Quantization* Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization *Predictive Coding* Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) *Transform Coding* Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts *Subband Coding* Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding *Visual Perception and Color* Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats *Image Coding Standards*

		JPEG and JPEG2000 *Interframe Coding* Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding *Video Coding Standards* H.261, H.263, MPEG-1, MPEG-2 / H.262, H.264 / MPEG-4 AVC, H.265 / MPEG-H HEVC
6	**Learning objectives and skills**	Die Studierenden • veranschaulichen die mehrdimensionale Abtastung und den Einfluss darauf durch Bewegung im Videosignal • unterscheiden und bewerten verschiedene Verfahren zur verlustfreien Codierung von Bild- und Videodaten • verstehen und analysieren Verbundentropie und statistische Abhängigkeiten in Bild- und Videodaten • berechnen skalare und vektorielle Quantisierer nach unterschiedlichen Optimierungsvorgaben (minimaler mittlerer quadratischer Fehler, entropiecodiert, eingebetteter Quantisierer) • bestimmen und evaluieren optimale ein- und zwei-dimensionale lineare Prädiktoren • wenden Prädiktion und Quantisierung sinnvoll in einem gemeinsamen DPCM-System an • verstehen das Prinzip und die Effekte von Transformations- und Teilbandcodierung für Bilddaten einschließlich optimaler Bitzuteilungen • beschreiben die Grundzüge der menschlichen visuellen Wahrnehmung für Helligkeit und Farbe • analysieren Blockschaltbilder und Wirkungsweisen hybrider Coder und Decoder für Videosignale • kennen die maßgeblichen internationalen Standards aus ITU und MPEG zur Bild- und Videokompression. The students • visualize multi-dimensional sampling and the influence of motion within the video signal • differentiate and evaluate different methods for lossless image and video coding • understand and analyze mutual entropy and statistical dependencies in image and video data • determine scalar and vector quantization for different optimization criteria (minimum mean square error, entropy coding, embedded quantization)

		• determine and evaluate optimal one-dimensional and two-dimensional linear predictor • apply prediction and quantization for a common DPCM system • understand the principle and effects of transform and subband coding for image data including optimal bit allocation • describe the principles of the human visual system for brightness and color • analyze block diagrams and the functioning of hybrid coders and decoders for video signals • know the prevailing international standards of ITU and MPEG for image and video compression.
7	**Prerequisites**	Modul Signale und Systeme II" und das Modul Nachrichtentechnische Systeme"
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	J.-R. Ohm, Multimedia Communications Technology", Berlin: Springer-Verlag, 2004

1	**Module name** 96300	**MIMO communication systems**	**5 ECTS**
2	Courses / lectures	Vorlesung: MIMO Communication Systems (3 SWS) Übung: MIMO Communication Systems - Tutorial (1 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Robert Schober Hedieh Ajam	

4	**Module coordinator**	Prof. Dr.-Ing. Robert Schober
5	**Contents**	Modern communication systems employ multiple antennas at the transmitter and/or receiver creating a multiple-input multiple-output (MIMO) system. This course covers the fundamental mathematical and communication theoretical concepts necessary for the design and analysis of MIMO communication systems. Relevant topics include MIMO Channel Capacity, Receive Diversity, Transmit Diversity, Space-Time Coding, Spatial Multiplexing, MIMO Transceiver Design, Multi-user MIMO, Massive MIMO, Relay-based MIMO, and applications in modern communication systems.
6	**Learning objectives and skills**	The students • learn about different MIMO channel models, • analyze MIMO communication systems with respect to their channel capacity and reliability, • determine MIMO figures of merit such as coding gain, diversity gain, and multiplexing gain, • compare and evaluate different MIMO receiver designs, • characterize the rate region of multiuser systems, • analyze massive MIMO systems, • discuss the advantages and disadvantages of different relay network architectures. Die Studierenden • lernen verschiedene MIMO-Kanalmodelle kennen, • analysieren MIMO-Kommunikationssysteme hinsichtlich der Kanalkapazität und Zuverlässigkeit, • ermitteln MIMO-Kenngrößen wie Codierungsgewinn, Diversitätsgewinn und Multiplexgewinn, • vergleichen und beurteilen verschiedene MIMO-Empfangsstrategien, • charakterisieren die Ratenregion von Mehrteilnehmersystemen, • analysieren Massive-MIMO-Systeme, • diskutieren die Vor- und Nachteile verschiedener Relaisnetzwerkarchitekturen.
7	**Prerequisites**	Basic course in communications
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212

10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 43141	**Mobile communications**	**5 ECTS**
2	Courses / lectures	Übung: Mobile Communications - Tutorial (1 SWS) Vorlesung: Mobile Communications (3 SWS)	- 5 ECTS
3	Lecturers	Dr.-Ing. Ali Bereyhi Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	History of mobile communications, cellular systems, sectorization, spectral efficiency, co-channel interference, adjacent-channel interference, near-far effect, cellular network architecture, antenna types and parameters, free space propagation, reflection, attenuation, diffraction, scattering, classification of channel models, ground reflection model, Okumura-Hata model, shadowing, narrow-band fading, time- variant channels, scattering function, delay-Doppler spectrum, diversity principles, combining methods, diversity gain, multiplexing, duplexing, digital modulation, Gaussian filtered minimum shift keying, basics of channel coding, interleaving, global system for mobile communications, physical versus logical channels, frame structure, call set-up, synchronization, channel estimation, hand-off
6	**Learning objectives and skills**	The students explain the cellular structure of mobile communication systems. They students explain the physical mechanics of radio wave propagation in the cm-band. The students explain the GSM cellular communications standard. The students discuss the pros and cons of several multiple-access and duplexing methods. The students discuss the pros and cons of several modulation and coding formats. The students decide which antenna type is suitable for a given morphological structure of the environment. The students predict the amplitude and dynamic of the antenuation between a mobile transmitter and a fixed receiver. The students utilize diversity methods to improve the link quality. The students determine the coverage probability of a given cellular communication system. The students collaborate on solving exercise problems. The students discuss which system solutions fit to which environments.
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur (90 Minuten)
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester

16	**Teaching and examination language**	Englisch
17	**Bibliography**	Proakis, J.: Digital Communications, McGraw-Hill, 4th ed., 2001. Rappaport, T.: Wireless Communications: Principles & Practice, Prentice Hall, 2nd ed., 2001. Mouly, M., Paulet, M.: The GSM System for Mobile Communications, Cell & SYS, France, 1992. Goldsmith, A.: Wireless Communications, Cambridge Univ. Press, 2005.

1	**Module name** 44362	**Quality of service in communication systems**	**5 ECTS**
2	Courses / lectures	Vorlesung: Quality of Service in Communications (2 SWS) Übung: Quality of Service in Communications (Ex-QoSiC) (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr. Reinhard German Lisa Maile	

4	**Module coordinator**	Prof. Dr. Reinhard German
5	**Contents**	Zunächst wird der Begriff der Dienstgüte (Quality-of-Service, QoS) eingegrenzt und es werden die wichtigsten Ansätze zur Erzielung von Dienstgüte besprochen und in ausgewählten Netztechnologien untersucht. Dann werden unterschiedliche Methoden vorgestellt, mit denen Systeme bezüglich ihrer Dienstgüte bewertet und ausgelegt werden können: • Netzplanung und optimierung, • stochastische Analyse (Markow-Ketten, Warteschlangen), • Netzwerksimulation, • deterministische Analyse mit Network Calculus zur Ermittlung von Dienstgütegarantien • Messung (HW-, SW-, Hybrid-Monitoring, Benchmarks). Alle Methoden werden an Beispielen demonstriert. *Contents:* We introduce the term quality-of-service (QoS), discuss important approaches to achieve certain degrees of QoS, and show how the implementation in computer networks. Then a number of methodologies to assess and design systems with respect to their QoS: • network planning and optimization, • network simulation, • stochastic analysis (Markov chains, non-Markovian models, queuing systems), • deterministic analysis with network calculus to determine QoS guarantees • measurements (hardware, software, and hybrid monitoring, benchmarks). All methods are illustrated by examples.
6	**Learning objectives and skills**	Die Studierenden erwerben • Kenntnisse in Methoden zur Modellierung und Bewertung von quantitativen, nicht-funktionalen Eigenschaften von vernetzten Systemen • Kenntnisse in Mechanismen von vernetzten Systemen zur Erzielung von Dienstgüte *Learning targets and competences:*

		The students get • experience in methods to model and evaluate quantitative, non-functional properties of computer networks and related systems • knowledge of mechanisms of computer networks to achieve quality-of-service
7	**Prerequisites**	Rechnerkommunikation, Kommunikationssysteme, grundlegende Programmierkenntnisse (optimal in R und C++)
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	• Kurose, Ross. Computer Networking: A Top-Down Approach Featuring the Internet. 6th Ed., Addison Wesley, 2013 • W. Stallings. Data and Computer Communications, 10th ed., Pearson Education, 2014 • W. Stallings. Foundations of Modern Networking: SDN, NFV, QoE, IoT, and Cloud, Pearson Education, 2016

1	**Module name** 96316	**Radar, RFID and Wireless Sensor Systems (RWS)**	**5 ECTS**
2	Courses / lectures	Übung: Radar, RFID and Wireless Sensor Systems Exercises (2 SWS) Vorlesung: Radar, RFID and Wireless Sensor Systems (2 SWS)	- 5 ECTS
3	Lecturers	Dr.-Ing. Christian Carlowitz Prof. Dr.-Ing. Martin Vossiek	

4	**Module coordinator**	Prof. Dr.-Ing. Martin Vossiek
5	**Contents**	Radar, RFID and wireless sensor and wireless locating systems are essential for automotive advanced driver-assistance systems (ADAS), autonoumous driving and flying, robotics, industrial automation, logistics and novel human machine interfaces. Further key areas include medical electronics, building technology and cyber-physical systems. The module "Radar, RFID and Wireless Sensors" is an introduction into functional principles, building blocks, hardware and signal processing concepts and applications of modern radar, RFID, wireless sensor and real time locating systems. Covered applications include automotive radar, road and air traffic control systems, as well as robotics, industrial automation and medical technology. RWS is an identical replacement of the former module "Drahtlose Sensoren, Radar- und RFID-Systeme DSR.
6	**Learning objectives and skills**	The students • learn about the setup, function and application of wireless sensors, Radar and RFID-systems • can analyze, discuss and implement basic components and system structures, signal theory, data processing and use cases • can determine the underlying physical limitations and sources of errors • are able to analyze and create system specifications and can compare and rate the usability of wireless esnsors, Radar and RFID-systems • can create and define independently applications and system designs of RWSs
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Sensors for Ranging and Imaging", Graham Brooker, Scitech Publishing Inc., 2009 Radar mit realer und synthetischer Apertur", H. Klausing, W. Holpp, Oldenbourg, 1999 Praxiswissen Radar und Radarsignalverarbeitung" Albrecht K. Ludloff, 2008 "RFID at ultra and super high frequencies: theory and application Dominique Paret, John Wiley & Sons, 2009. RFID-Handbuch: Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC", Klaus Finkenzeller, Carl Hanser Verlag, 6. Auflage 2012.

1	**Module name** 96460	**Speech and audio signal processing**	**5 ECTS**
2	Courses / lectures	Übung: Übung zur Sprach- und Audiosignalverarbeitung (1 SWS) Vorlesung: Sprach- und Audiosignalverarbeitung (3 SWS)	- 5 ECTS
3	Lecturers	Mhd Modar Halimeh Prof. Dr.-Ing. Walter Kellermann	

4	**Module coordinator**	Prof. Dr.-Ing. Walter Kellermann
5	**Contents**	It concentrates on algorithms for speech and audio signal processing with applications in telecommunications and multimedia, especially • physiology and models for human speech production and hearing: source-filter model, filterbank model of the cochlea, masking effects, • representation of speech and audio signals: estimation and representation of short-term and long-term statistics in the time and frequency domain as well as the cepstral domain; typical examples and visualizations • source coding for speech and audio signals: criteria, scalar and vector quantization, linear prediction, prediction of the pitch frequency; waveform coding, parametric coding, hybrid coding, codec standards (ITU, GSM, ISO-MPEG) • basic concepts of automatic speech recognition (ASR): feature extraction, dynamic time warping, Hidden Markov Models (HMMs) • basic concepts of speech synthesis: text-to-speech systems, model-based and data-driven synthesis, PSOLA synthesis system • signal enhancement for acquisition and reproduction: noise reduction, acoustic echo cancellation, dereverberation using single-channel and multichannel algorithms. Es werden Grundlagen und Algorithmen der Verarbeitung von Sprach- und Audiosignalen mit Anwendungen in Telekommunikation und Multimedia behandelt, insbesondere: • Physiologie und Modelle der Spracherzeugung und des Hörens: Quelle-Filter-Modell, Filterbank-Modell der Cochlea; Maskierungseffekte; • Darstellung von Sprach- und Audiosignalen: Schätzung und Darstellung der Kurzzeit- und Langzeitstatistik in Zeit-, Frequenz- und Cepstralbereich; typische Beispiele, Visualisierungen; • Quellencodierung für Sprache und Audiosignale: Kriterien; skalare und vektorielle Codierung; lineare Prädiktion; Pitchprädiktion; Wellenform-/Parameter-/Hybrid-Codierung; Standards (ITU, GSM, ISO-MPEG)

		• Spracherkennung: Merkmalextraktion, Dynamic Time Warping, Hidden Markov Models • Grundprinzipien der Sprachsynthese: Text-to-Speech Systeme, modellbasierte und datenbasierte Synthese, PSOLA-Synthese • Signalverbesserung bei Signalaufnahme und wiedergabe: Geräuschbefreiung, Echokompensation, Enthallung mittels ein- und mehrkanaliger Verfahren;
6	**Learning objectives and skills**	The students • understand basic physiological mechanisms of human speech production and hearing and can apply them for the analysis of speech and audio signals • apply basic methods for the estimation and representation of the short-term and long-term statistics of speech and audio signals and can analyze such signals by means of these methods • understand current methods for source coding of speech and audio signals and can analyze current coding standards • verstehen die Grundbausteine von Spracherkennungssystemen und können deren Funktion mittels Rechnersimulation analysieren • understand the basic principle of text-to-speech systems and can apply fundamental methods for speech synthesis • can apply basic algorithms for speech enhancement and understand their functionality for real-world data. Die Studierenden • verstehen die grundlegenden physiologischen Mechanismen der Spracherzeugung und des Hörens beim Menschen und können diese zur Analyse von Sprach- und Audiosignalen anwenden • wenden die grundlegenden Methoden zur Schätzung und Darstellung der Kurzzeit- und Langzeitstatistik von Sprach- und Audiosignalen an und können diese damit analysieren • verstehen die aktuellen Methoden zur Quellencodierung von Sprache-und Audiosignalen und können aktuelle Codierstandards analysieren • verstehen die Grundbausteine von Spracherkennungssystemen und können deren Funktion mittels Rechnersimulation analysieren • verstehen die Grundprinzipien von Text-to-Speech Systemen und können elementare Algorithmen zur Sprachsynthese anwenden • können elementare Algorithmen zur Signalverbesserung anwenden und für reale Daten analysieren
7	**Prerequisites**	Vorlesung Signale und Systeme I & II
8	**Integration in curriculum**	Semester: 1

9	**Module compatibility**	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich (90 Minuten)
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Gemäß themenbezogenen Angaben in der Lehrveranstaltung

Technical Lab Courses

1	**Module name** 894349	**Audio processing laboratory**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Audio Processing Laboratory (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Jürgen Herre Prof. Dr. Emanuël Habets Prof. Dr.-Ing. Bernd Edler Prof. Dr. Nils Peters Prof. Dr. Meinard Müller	

4	**Module coordinator**	Prof. Dr. Meinard Müller
5	**Contents**	This lab course offers a general introduction to Python and possibly also to other languages (MATLAB, R, ...). In particular, functions, transforms, and algorithms that are important for analyzing and processing audio signals are covered. After a general part, the lab course will allow the participants to delve into a more specific application within audio and acoustic signal processing.
6	**Learning objectives and skills**	The goal of this lab course is to acquire a deeper understanding of audio processing techniques by experimenting with, modifying and extending existing code. Furthermore, programming skills in Python and possibly also in other languages (MATLAB, R, ...) are acquired. The students understand and implement computer programs for specific experiments described in the script accompanying the lab. They test and evaluate their programs by conducting a series of experiments within the field of audio signal processing. They understand the requirements of practical realizations, synthesize a solution for a given problem, and apply advanced disciplinary knowledge and skills in signal processing. The students evaluate and interpret results by applying various visualization techniques and statistical methods. They collaborate with fellows students, discuss their solutions, give feedback to each other, and reflect upon the underlying theory as well as implementation issues.
7	**Prerequisites**	This lab course requires a good understanding of basic principles in signal processing and some basic programming skills. Furthermore, it is beneficial to have some background in one of the more specific topics

		offered by the International Audio Laboratories Erlangen.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Lab Courses Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	in jedem Semester
13	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Deutsch
16	**Bibliography**	no Bibliography information available!

1	**Module name** 97640	**Laboratory course: Mobile communication**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Mobilkommunikation (3 SWS)	2,5 ECTS
3	Lecturers	Adela Vagollari Yifei Wu Prof. Dr. Wolfgang Gerstacker Dr.-Ing. Clemens Stierstorfer	

4	**Module coordinator**	Prof. Dr. Wolfgang Gerstacker

5	**Contents**	Experiments
		•
		  ◦ Characteristics of real mobile radio channels such as distortions and time variability
		  ◦ models for mobile radio channels
		  ◦ effects on the performance of a mobile radio system
		•
		  ◦ Principles of different equalization methods
		  ◦ equalizer design for GSM / EDGE
		  ◦ simulation of trellis-based equalizers and visualization of the results
		•
		  ◦ Principle of OFDM
		  ◦ implementation-relevant aspects such as nonlinearities and peak-to-average-power ratio
		  ◦ synchronization and equalization
		• MIMO Transmission (2 experiments)
		
		Versuche
		•
		  ◦ Eigenschaften realer Mobilfunkkanäle wie Verzerrungen und Zeitvarianz,
		  ◦ Modelle für Mobilfunkkanäle
		  ◦ Auswirkungen auf die Leistungsfähigkeit eines Mobilfunksystems
		•
		  ◦ Prinzipien verschiedener Entzerrverfahren
		  ◦ Entzerrerdesign für GSM/EDGE
		  ◦ Simulation von trellisbasierten Entzerrern und Visualisierung der Ergebnisse
		•
		  ◦ Prinzip von OFDM
		  ◦ implementierungsrelevante Aspekte wie Nichtlinearitäten und Spitzenwertfaktor
		  ◦ Synchronisation und Entzerrung

		• MIMO Übertragung (2 Versuche)
6	**Learning objectives and skills**	The students • describe the characteristics of real mobile radio channels, • explain the principles of OFDM and MIMO transmission systems, • implement equalization and adaptation procedures in Matlab, • perform radio network simulations, • learn to develop program code, • work together in a small team. Die Studierenden • charakterisieren die Eigenschaften realer Mobilfunkkanäle, • erklären die Funktionsweise von OFDM- und MIMO-Übertragungssystemen, • implementieren Entzerrungs- und Adaptionsverfahren in Matlab, • führen Funknetzsimulationen durch, • erlernen Programmcode eingeständig zu entwickeln, • arbeiten zielorientiert in einem kleinen Team zusammen.
7	**Prerequisites**	Vorkenntnisse aus Vorlesungen zu Nachrichtenübertragung (Communications) und Systemtheorie (Signals and Systems); Inhalte des Moduls "Mobile Communications" sind erforderliche Voraussetzung für eine sinnvolle Teilnahme;
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Lab Courses Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	• There are 8 experiments to be completed as well as an introduction to Matlab. These are described in the course materials. • Each experiment is to be prepared in writing at home. The preparation is checked and evaluated (sufficient/not sufficient) at the beginning of each experiment. • The results of each experiment are to be kept on the experimental computers during the execution of the experiment (programming tasks) and are checked at the end of the experiment (sufficient/not sufficient). Measurement results are to be documented in writing. • To pass the course, 8 sufficient experiment preparations and 8 sufficient experiment executions are required.

		• Es sind 8 Versuche sowie eine Einführung in Matlab zu absolvieren. Diese sind in den Kursunterlagen beschrieben. • Jeder Versuch ist zu Hause schriftlich vorzubereiten. Die Vorbereitung wird zu Beginn eines jeden Versuchs überprüft und bewertet (ausreichend/nicht ausreichend). • Die Ergebnisse eines jeden Versuchs sind während der Versuchsdurchführung auf den Versuchsrechnern vorzuhalten (Programmieraufgaben) und werden zum Abschluss des Versuchs überprüft (ausreichend/nicht ausreichend). Messergebnisse sind schriftlich zu dokumentieren. • Zum Bestehen des Praktikums sind 8 ausreichende Versuchsvorbereitungen und 8 ausreichende Versuchsdurchführungen notwendig.
11	**Grading procedure**	
12	**Module frequency**	nur im Sommersemester
13	**Workload in clock hours**	Contact hours: 35 h Independent study: 40 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Deutsch
16	**Bibliography**	Skriptum zum Praktikum Mobilkommunikation

1	**Module name** 194239	**Lab course image and video processing on embedded platforms**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Laborpraktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen (0 SWS)	2,5 ECTS
3	Lecturers	PD Dr.Ing. Jürgen Seiler Viktoria Heimann	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	Betrachtet man Anwendungen der Bild- und Videosignalverarbeitung stellt man fest, dass viele davon auf mobilen Plattformen ablaufen. Die dort verwendeten Systeme haben aber häufig nur eine reduzierte Leistungsfähigkeit und müssen besonders auf den Energieverbrauch achten. Nichtsdestotrotz sind aber auch einfache, mobile Systeme wie Smartphones oder Tablets in der Lage, anspruchsvolle Signalverarbeitungsaufgaben für Bild- und Videosignale durchzuführen. Dies umfasst zum Beispiel die Codierung von Bildern und Videos, aber auch die Erzeugung von Panoramen oder die Berechnung von Bildern mit hohem Dynamikumfang. Das Praktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen" soll die Herausforderung, die mit einer Verarbeitung dieser Signale auf eingebetteten Plattformen einhergehen genauer vermitteln und es wird aufgezeigt, wie man selbst auf Plattformen mit eingeschränkter Leistungsfähigkeit entsprechende Algorithmen umsetzen kann. Hierzu werden in dem Praktikum Raspberry Pis als Plattform verwendet und die Programmierung erfolgt in Python. Die Versuche umfassen den Aufbau und die Inbetriebnahme der eingebetteten Plattform, eine Einführung in Python und in die grundlegenden Prozesse der Bild- und Videosignalverarbeitung. Weitere Versuchsinhalte sind die Anbindung einer Kamera, Bildsignalverarbeitungsprozesse mit der Kamera und die Implementierung verschiedener digitaler Filter. Das Praktikum beinhaltet außerdem verschiedene Anwendungen computergestützten Sehens (Computer Vision). Die Detektion von Merkmalen und Objekten in Bildern und Videos werden einführend behandelt und aktuelle Computer Vision Anwendungen, wie die Erstellung eines Panoramas werden betrachtet. *Content*: Today, many image and video signal processing applications are running on embedded systems. However, the computational power and the energy storage is a limiting demand for embedded systems. Nevertheless, daily mobile devices like smartphone and tablet are able to perform signal processing tasks for image and video signals, for example coding of images and videos, the creation of a panorama or the calculation of images with high dynamic range.

		The image and video signal processing on embedded systems lab course should show the challenges that occur while handling with such mobile devices and the implementation of such algorithm on an embedded system. Therefore, Raspberry Pis as embedded systems and Python as coding language is used in the laboratory. The experiments include the setup of the Raspberry Pi, an introduction to Python and an introduction to image and video signal processing. In addition, a camera will be connected, signal processing will be done with the camera and digital filters are implemented. Moreover, the laboratory includes different computer vision applications like the creation of a panorama.
6	**Learning objectives and skills**	Die Studierenden • verstehen die Herausforderungen von eingebetteten Plattformen • wenden die Programmiersprache Python für Bild- und Videosignalverarbeitunsalgorithmen an • erzeugen funktionsfähige Programme mit der Programmiersprache Python • beurteilen die Funktionsblöcke von Computer Vision-Algorithmen • bewerten die von ihnen erstellten Programme durch subjektive und objektive Vergleiche • reflektieren den Lernprozess während des Praktikums. The students • understand the challenges of the embedded system • make use of the coding language Python for image and video signal processing algorithms • implement functional programs with Python • evaluate the blocks of computer vision algorithms • evaluate the self-implemented programs by subjective and objective comparison • reflect the learning process in the laboratory.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Lab Courses Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	nur im Wintersemester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 15 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Englisch
16	**Bibliography**	Das Skript zum Praktikum Image and video signal processing on embedded platforms" wird in der Einführungsveranstaltung ausgegeben.

		The laboratory script "Image and video signal processing on embedded platforms will be handed out in the first session.

1	**Module name** 92356	**Praktikum Communications Systems Design**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Praktikum Communications Systems Design (2 SWS)	2,5 ECTS
3	Lecturers	Christof Pfannenmüller Christof Pfannenmüller Arslan Ali Arslan Ali Prof. Dr.-Ing. Georg Fischer Christof Pfannenmüller Christof Pfannenmüller	

4	**Module coordinator**	Arslan Ali Prof. Dr.-Ing. Georg Fischer
5	**Contents**	Learning based on LabVIEW communications and NI USRP: Introduction to USRP including hardware blocks of Tx/Rx chains Getting familiar with LabVIEW communications environment and controlling VIs (Panel, diagram, etc.) and fundamentals of LabVIEW programming: data types, arrays, flow control (for/while loop), clusters, case structures, signal sources, sinks, signal processing tools, filters, time/ frequency domain analysis, etc. Transmission and reception of analog modulation schemes: AM/DSB-SC and FM Implementation of digital modulation schemes: ASK, FSK, BPSK, QPSK, 16-QAM, etc. Digital Tx/Rx: symbol mapping, upsampling/downsampling, pulse shaping (rectangular, Gaussian, RRC), matched filtering, pulse alignment, synchronization, and detection Phase synchronization, FDM and image rejection algorithm Eye diagram analysis: ISI, clock jitter, optimal sampling time, detection threshold Power control for over-the-air transmission in sub-6 GHz ISM bands and analysis on fading and multipath propagation effects Channel estimation, equalization (decision directed, linear LS, adaptive LMS), modelling: coherence bandwidth and propagation delay Learning based on MATLAB and USRPs (Communications toolbox and SDR support packages):

		OFDM Tx/Rx with frequency domain equalization (FDE) and synchronization (training sequence and frame detection) LTE downlink transmission (MIMO) including system information blocks (SIB) and spectrum analysis including estimation/calibration of carrier frequency offset (CFO) Impairments/distortion analysis: ACPR, EVM tool: IQ offset errors, phase noise, PA nonlinearity, etc. Learning based on GNU Radio and RTL-SDR: Introduction to GNU Radio with RF prototyping demonstration Spectrum analyzer implementation: RBW, VBW, sweep time, and phase noise Small Project/assignment for students
6	**Learning objectives and skills**	Students Can bridge the gap between communications theory, analog/digital baseband, and RF design Can develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions Can determine the design parameters and assess the interaction between various analog and digital parts Can create efficient Tx/Rx programs and signal processing algorithms in LabVIEW, MATLAB, and GNU Radio Can implement channel estimation and equalization algorithms in TDD and FDD systems Can demonstrate MIMO and OFDM based systems like LTE and beyond Can quantify and evaluate system performance using EVM and impairments analysis
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Lab Courses Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Praktikumsleistung
11	**Grading procedure**	Praktikumsleistung (100%)
12	**Module frequency**	nur im Wintersemester
13	**Workload in clock hours**	Contact hours: 45 h Independent study: 30 h

14	**Module duration**	1 Semester
15	**Teaching and examination language**	Englisch
16	**Bibliography**	no Bibliography information available!

1	**Module name** 878210	**Lab course machine learning in signal processing**	**2,5 ECTS**
2	Courses / lectures	Praktikum: Lab Course Machine Learning in Signal Processing (4 SWS)	2,5 ECTS
3	Lecturers	Kamal Gopikrishnan Nambiar	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	This is an advanced level lab course in machine learning. Imagine a car driving on an autobahn in an automatic mode. Among other things, the car needs to steer itself to keep driving in it's own lane. To accomplish this, the central problem is to detect the road-lane markings. These are the white solid or dashed lines that are drawn on each side of the lane. The standard modern approach to solve this type of problems is to take a large dataset of labeled examples and train a deep neural network model to accomplish the task. This is how car and pedestrian detection algorithms are developed. The difficulty with the road-lane markings is that there is no labeled dataset of them and creating such dataset would cost millions of dollars. In this lab course we will solve this problem using transfer learning and mathematical modeling: • Create cartoon-like artificial images of a road with known locations for the lane markings. • Train deep neural network on these artificial images with heavy data augmentations that mimic real-world images. • Create a dataset of unlabeled real-life videos by downloading and organizing examples from youtube. • Create a machine learning pipeline for working with these videos efficiently. • Apply the neural network that has been trained on artificial data to the real world videos. • Analyze the quality of results produced by the network. • Use mathematical modeling to correct the outputs of the network. • Retrain the network on the dataset composed of the corrected outputs. • Measure and analyze the quality of the results. The software will be written in Python using JupyterLab development framework. Access to modern GPU server will be provided. The best students will have the opportunity to contribute to the creation of state-of-the-art lane detection system for self-driving cars during or after the corse.
6	**Learning objectives and skills**	Students are able to:

		• Independently design machine learning pipelines to solve complex problems in artificial intelligence. • Choose appropriate algorithms for the problem at hand. • Use standard packages for machine learning in Python: numpy, cvxpy, scikit-learn, pywavelets, pytorch. • Debug and calibrate machine learning algorithms. Develop modification to the standard algorithms as appropriate to the problem at hand. • Explain the theoretical aspects of deep learning.
7	**Prerequisites**	Knowledge of Python programming language is required. Basic theoretical knowledge in machine learning is assumed: consider taking the Machine Learning in Signal Processing (MLSIP) course in the same semester.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Lab Courses Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	
11	**Grading procedure**	
12	**Module frequency**	in jedem Semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 15 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Englisch
16	**Bibliography**	no Bibliography information available!

Technical Electives

1	**Module name** 571704	**4G/5G mobile communications systems**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: 4G/5G Mobile Communication Systems (2 SWS)	2,5 ECTS
3	Lecturers	Dr. Stefan Brück	

4	**Module coordinator**	Dr. Stefan Brück Prof. Dr. Wolfgang Gerstacker
5	**Contents**	Mobile communication plays a significant role in our daily life. Over the last three decades the mobile applications have been tremendously enhanced from voice only over mobile broadband to applications for the mobile internet. Currently, the next generation of cellular systems, the so-called 5th Generation (5G) is developed and first commercial 5G networks are expected to be deployed around mid of 2019. 5G will play an outstanding role for the Internet of Things and will redefine a wide range of industries by enabling new use cases. This lecture will provide the technical foundation of 4G (LTE) and 5G mobile communication systems with a focus on the radio access network and the PHY & MAC layer concepts.
6	**Learning objectives and skills**	The students • learn the technical history of mobile communications from 2nd (GSM), 3rd (UMTS), 4th (LTE) to the 5th (5G New Radio) Generation • understand the system and radio access network architecture of modern cellular communications systems and their enhancements towards 5G • compare the physical layer design of LTE and 5G New Radio • discuss how 5G networks are designed to address a wide range of diverse services and devices • analyze enhanced radio resource management concepts for use cases like cellular V2X (Vehicle-to-Everything) and NB-IoT (Narrowband Internet of Things) Die Studierenden • erfahren die technische Geschichte der Mobilkommunikation von der 2. (GSM), 3. (UMTS), 4. (LTE) bis zur 5. Generation (5G New Radio) • verstehen die System- und Funkzugangsnetzarchitektur moderner zellularer Kommunikationssysteme und ihre Verbesserungen bei 5G • vergleichen das Design der physikalischen Übertragungsschicht von LTE und 5G New Radio • diskutieren, wie 5G-Netze für eine breite Palette unterschiedlicher Dienste und Geräte konzipiert sind • analysieren verbesserte Funkressourcenverwaltungskonzepte für Anwendungsfälle wie zellulare V2X (Vehicle-to-Everything)

		Kommunikation und das NB-IoT (Schmalband-Internet der Dinge)
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Lecture Notes 4G/5G Mobile Communication Systems

1	**Module name** 869547	**Advanced networking LEx**	**5 ECTS**
2	Courses / lectures	Vorlesung: Advanced Networking (2 SWS) Übung: Advanced Networking Exercises (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Kai-Steffen Hielscher Dr.-Ing. Peter Bazan	

4	**Module coordinator**	Dr.-Ing. Kai-Steffen Hielscher
5	**Contents**	Für die durch Big Data, Cloud Computing, Internet-of-Things (IoT) und mobile Endgeräte hervorgerufenen Herausforderungen sind neue Architekturen für Rechnernetze entstanden: Software-Defined-Networking (SDN) entkoppelt die Data Plane (Weiterleitung von Paketen, auf handelsüblicher Hardware) und die Control Plane (Steuerung, auf leistungsfähigen Plattformen) und bietet offene Programmierschnittstellen; Network Functions Virtualization (NFV) erweitert Konzepte zur Server- und Netzwerkvirtualisierung, so dass bisher auf proprietärer Hardware ausgeführte Netzwerkfunktionen (wie z.B. Routing) ebenfalls virtualisiert und auf handelsüblicher Hardware ausgeführt werden können. Die Vorlesung stellt hinter diesen Technologien stehende Konzepte und Standards vor und zeigt, wie sie für Rechenzentren, für Cloud- und Fog-Computing und für IoT-Anwendungen eingesetzt werden können. Content: New architectures for computer networks have emerged to meet the challenges posed by Big Data, Cloud Computing, Internet-of-Things (IoT) and mobile devices: Software-Defined-Networking (SDN) decouples the data plane (forwarding of packets, on commercially available hardware) and the control plane (control, on powerful platforms) and offers open programming interfaces; Network Functions Virtualization (NFV) extends concepts for server and network virtualisation, so that network functions (such as routing) previously executed on proprietary hardware can also be virtualised and executed on commercially available hardware. The lecture introduces concepts and standards behind these technologies and shows how they can be used for data centres, for cloud and fog computing and for IoT applications.
6	**Learning objectives and skills**	Fachkompetenz Verstehen Die Studierenden erlangen Verständnis der grundlegenden Konzepte von • Software Defined Networking • Network Function Virtualization

		• Internet of Things • Cloud Computing. Anwenden Die Studierenden wenden die Erkenntisse in Übungsaufgaben an. Erschaffen Die Studierenden erstellen eigene Laborkofigurationen zu • Software Defined Networking • Internet of Things. Competences: Professional competence Understanding Students will gain an understanding of the basic concepts of • Software Defined Networking • Network Function Virtualization • Internet of Things • Cloud Computing. Apply Students apply the knowledge gained in exercises. Create The students create their own laboratory configurations on • Software Defined Networking • Internet of Things.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Portfolio
11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch

17	**Bibliography**	William Stallings: Foundations of Modern Networking - SDN, QoE, IoT, and Cloud; Pearson

1	**Module name** 621649	**Advanced optical communication systems**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	
6	**Learning objectives and skills**	Students - gain detailed Knowledge on concepts and structure of various optical transmission systems. - are able to analyze, to compare and evaluate the quality of optical data signals with respect to different system concepts. - are able to develop and to optimize link designes of optical transmission systems. - are abke to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results.
7	**Prerequisites**	*Prerequisites: * - Fundamentals in signals and systems. Basic knowledge of fiber optics and optoelectronic components recommended.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Portfolio
11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997

		Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001. Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002. Kaminow, I, Li, T., Willner,A.: Optical Fiber Telecommunications VA, Academic Press, 2008. Lecture notes.

1	**Module name** 93172	**AI-enabled Wireless Networks**	**5 ECTS**
2	Courses / lectures	Vorlesung: AI-enabled wireless networks (2 SWS) Übung: Literature review on the application of machine learning in wireless networks (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Mehdi Harounabadi	

4	**Module coordinator**	Dr.-Ing. Mehdi Harounabadi
5	**Contents**	This course introduces machine learning algorithms such as supervised, unsupervised, reinforcement, deep, and federated learning and their application in the next generation wireless and mobile networks. Different ML use cases are explained which solve problems in different layers of the protocol stack from the physical layer to the application layer. The course includes the following topics: 1.Introduction to machine learning algorithms 2.Python programming language and its ML tools 3.AI-enabled wireless and mobile networks 3.1Cellular networks and ML use cases 3.1.1History of 2G to 4G, 5G and 6G vision 3.1.2ML use cases in physical, MAC and higher layers 3.25G-V2X (cellular-V2X) and ML use cases 3.2.1Sidelink communication as the key enabler 3.2.25G-V2X features and use cases 3.2.3ML use cases in 5G-V2X 3.3Intelligent wireless networks 3.3.1Cognitive radio networks 3.3.2ML use case in wireless networks 4.Standardization activities on AI-enabled wireless networks 4.1.13GPP and 5GAA 4.1.2ETSI Zero touch networks

		Exercises: Literature review on the application of machine learning in wireless networks The exercise of this course includes a literature review research project where students work individually on a relevant topic. The steps to accomplish the research project are as follows: A.Select a topic relevant to the application of ML in wireless networks and register it by email B.Search for the relevant papers and make a list of papers C.Study the papers and prepare a summary D.Present the outcomes Each student should present her/his research study in an intermediate and a final presentation. A summary paper should be written following the "survey papers guideline" using IEEE format. The grade of the research project will be considered as a "Bonus point" (up to 20%) for the final grade.
6	**Learning objectives and skills**	The students will be able to gain the following competencies after the successful completion of the course: • Have knowledge on machine learning algorithms, current and the next generation wireless and mobile networks and their use cases • To know how to develop machine learning algorithms in Python • Know the most important problems in wireless and mobile networks which can be solved by machine learning algorithms • Have an insight on the exiting work relevant to the topic of the course • Learn the procedure of a scientific research study and publication of the outcome
7	**Prerequisites**	*Motivation:* Rapid growth in the number of connected wireless nodes such as mobile phones, low power IoT devices, connected vehicles, etc. will expand the scale of the next generation of wireless and mobile networks. Moreover, the foreseen use cases like connected autonomous vehicles, smart homes and cities, ultra-fast and reliable industrial wireless networks, etc. will require ultra-low latency and highly reliable communication. Existing and traditional algorithms are not feasible for the optimization and management of such networks to fulfill the requirements of the emerging use cases due to their high complexity, high dynamicity, and the massive amount of the generated data by connected devices. Recently, artificial intelligence (AI) is planned to be utilized as a new paradigm for the

		design, development and optimization of the next generation wireless and mobile networks. Machine learning (ML) as a subset of AI will be applied to develop intelligent wireless nodes and infrastructures to address the demands of future use cases.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich (30 Minuten)
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Englisch
16	**Bibliography**	Dahlman, Erik, Stefan Parkvall, and Johan Skold. 5G NR: The next generation wireless access technology. Academic Press, 2020. Sun, Yaohua, et al. "Application of machine learning in wireless networks: Key techniques and open issues." IEEE Communications Surveys & Tutorials 21.4 (2019): 3072-3108. Harounabadi, Mehdi, et al. "V2X in 3GPP Standardization: NR Sidelink in Release-16 and Beyond." IEEE Communications Standards Magazine 5.1 (2021): 12-21. Xie, Junfeng, et al. "A survey of machine learning techniques applied to software defined networking (SDN): Research issues and challenges." IEEE Communications Surveys & Tutorials 21.1 (2018): 393-430.

1	**Module name** 965820	**Approximate computing**	**5 ECTS**
2	Courses / lectures	Übung: Exercises to Approximate Computing (0 SWS) Vorlesung: Approximate Computing (2 SWS)	- 5 ECTS
3	Lecturers	Chetana Pradhan Pierre-Louis Sixdenier Prof. Dr.-Ing. Jürgen Teich Prof. Dr. Oliver Keszöcze	

4	**Module coordinator**	Joachim Falk Prof. Dr. Oliver Keszöcze Prof. Dr.-Ing. Jürgen Teich
5	**Contents**	Approximate Computing denotes a quite young research area that exploits the fact and capability of many applications and systems to tolerate imprecision and/or inexactness of computed results. Prominent areas of applications and novel techniques of computing approximate rather than exact results have brought up new implementations either at hardware and/or software levels for important emergent workloads such as searching, mining, image processing, and data retrieval. Although hardware technology is improving at a fast pace, energy and power are becoming more and more important constraints apart from exactly computing results in an acceptable amount of time. The main goals of approximate computing techniques are therefore to exploit the possible trade-off between power/energy consumption, accuracy, performance, and/or cost, e.g., utilized hardware resources. The purpose of the course approximate computing is to instruct students about the main ideas and concepts of approximate computing. This includes analyzing the trade-off between energy consumption, accuracy, run-time and hardware costs, concrete approximating techniques (e.g. approximate hardware synthesis, approximating algorithms) as well as theoretical background (determining the computational error and its complexity).
6	**Learning objectives and skills**	Fachkompetenz - Wissen • The students know the principles and benefits of Approximate Computing and when it is applicable. • The students know multiple error metrics and their semantic meaning. Fachkompetenz - Verstehen • The students understand the difference between the error metrics. • The students understand the principle of function falsification. • The students can apply the presented approximation techniques.

		Fachkompetenz - Anwenden • The students are capable of choosing the appropriate approximation technique based on given requirements.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Weitere Informationen: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/approximate-computing

1	**Module name** 44522	**Audio Processing for the Internet of Things**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Audio Processing for the Internet of Things (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Nils Peters Dr.-Ing. Stefan Turowski	

4	**Module coordinator**	Prof. Dr. Nils Peters
5	**Contents**	The course focuses on audio and speech processing algorithms within the context of the Internet of Things (IoT). • Foundation (history, components, current challenges) • Overview of relevant wireless protocols (bandwidth, range, latency, spectrum) • Audio device synchronization (NTP, PTP, device orchestration, acoustic wireless sensor networks, asynchronous and event-driven audio sampling) • Acoustic Sensing for Voice User Interfaces (keyword spotting, speech recognition, speaker verification, anti-spoofing) • Acoustic Scene Detection (event detection, scene classification, anomaly detection, sound tagging, blind reverb estimation) • Sound Creation (text-to-speech, sound generative networks) • Data-over-sound (sound-beacon, watermarking, acoustic fingerprint) • Privacy in IoT (edge vs. cloud processing, secure signal processing, federated learning, differential privacy, audio encryption)
6	**Learning objectives and skills**	The students will be able to • understand the principles, key components, and current in IoT • know the differences between various wireless transmission protocols and can give recommendations based on the IoT use case • understand the differences of edge- and cloud-based audio signal processing • understand algorithmic strategies to enhance privacy in IoT use cases • understand the algorithmic components in a voice user interface • understand state-of-the art methods for detection and classification of acoustic scenes and events • learn and apply algorithms to transmit data via acoustic signals • quantify the impact of latency in audio networks and apply strategies for acoustic device synchronization
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich (30 Minuten)

11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Recommendations for each topic are given during the lectures

1	**Module name** 96312	**Image, video and multidimensional signal processing**	**5 ECTS**
2	Courses / lectures	Vorlesung: Bild-, Video- und mehrdimensionale Signalverarbeitung (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr.-Ing. Andre Kaup	

4	**Module coordinator**	Prof. Dr.-Ing. Andre Kaup
5	**Contents**	*Punktoperationen* Histogrammausgleich, Gamma-Korrektur *Binäroperationen* Morphologische Filter, Erosion, Dilatation, Opening, Closing *Farbräume* Trichromat, RGB- Farbraum, HSV-Farbraum *Mehrdimensionale Signale und Systeme* Theorie mehrdimensionaler Signale und Systeme, Impulsantwort, lineare Bildfilterung, Leistungsspektrum, Wiener Filter *Interpolation von Bildsignalen* Bilineare Interpolation, Bicubische Interpolation, Spline Interpolation *Merkmalsdetektion in Bildern* Bildmerkmale, Kantendetektion, Hough Transformation, Harris Ecken Detektor, Texturmerkmale, Grauwertematrix *Skalierungsraumdarstellung* LoG, DoG, SIFT, SURF *Bildabgleich* Projektive Abbildungen, Blockabgleich, Optischer Fluss, Merkmalsbasierter Abgleich mittels SIFT und SURF, RANSAC *Bildsegmentierung* Amplituden Schwellenwertermittlung, K-Means Clustering, Bayes Klassifikation, Regionen-basierte Segmentierung, kombinierte Segmentierung und Bewegungsschätzung, zeitliche Segmentierung von Videos

Bildverarbeitung im Transformationsbereich

Unitäre Transformation, Karhunen-Loeve Transformation, separable Transformationen, Haar und Hadamard Transformation, DFT, DCT

Content:

Point operations

Histogram equalization, gamma correction

Binary operations

Morphological filters, erosion, dilation, opening, closing

Color spaces

Trichromacy, red-green-blue color spaces, color representation using hue, saturation and value of intensity

Multidimensional signals and systems

Theory of multidimensional signals and systems, impulse response, linear image filtering, power spectrum, Wiener filtering

Interpolation of image signals

Bi-linear interpolation, bi-cubic interpolation, spline interpolation

Image feature detection

Image features, edge detection, Hough transform, Harris corner detector, texture features, co-occurrence matrix

Scale space representation

Laplacian of Gaussian, difference of Gaussian, scale invariant feature transform, speeded-up robust feature transform

Image matching

Projective transforms, block matching, optical flow, feature-based matching using SIFT and SURF, random sample consensus algorithm

Image segmentation

Amplitude thresholding, k-means clustering, Bayes classification, region-based segmentation, combined segmentation and motion estimation, temporal segmentation of video

		Transform domain image processing Unitary transform, Karhunen-Loeve transform, separable transform, Haar and Hadamard transform, DFT, DCT
6	**Learning objectives and skills**	Die Studierenden • verstehen Punktoperationen an Bilddaten und Gamma-Korrektur • testen die Wirkung von Rangordnungs- und Medianfiltern an Bilddaten • unterscheiden und bewerten verschiedene Farbräume für Bilddaten • erklären das Prinzip der zwei-dimensionalen linearen Filterung für Bildsignale • berechnen und bewerten die zweidimensionale diskrete Fourier-Transformierte eines Bildsignales • bestimmen vergrößerte diskrete Bildsignale mit Methoden der bilinearen und Spline-Interpolation • überprüfen Bilddaten auf ausgewählte Textur-, Kanten- und Bewegungsmerkmale • analysieren Bild- und Videodaten auf Merkmale in unterschiedlichen Scale-Spaces • erläutern und beurteilen Methoden für das Matching von Bilddaten • segmentieren Bilddaten durch Programmierung von einfachen Klassifikations- oder Clustering-Verfahren • verstehen das Prinzip von Transformation auf Bilddaten und können diese an Beispielen anwenden. The students • understand point operations for image data and gamma correction • test the effects of rank order and median filters for image data • evaluate and differentiate between different color spaces for image data • explain the principle of two-dimensional linear filtering for image signals • calculate and evaluate the two-dimensional discrete Fourier transform of an image signal • determine enlarged discrete image signals by bi-linear and spline interpolation • verify image data for selected texture, edge and motion features • analyze image and video data for features in different scale spaces • explain and evaluate methods for the matching of image data

		• segment image data by implementing basic classification and clustering methods • understand the principle of transformations on image data and apply them exemplarily
7	**Prerequisites**	Vorlesung Signale und Systeme I und II
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur (90 Minuten)
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	J.-R. Ohm: |Multimedia Content Analysis|, Springer, 2016 J. W. Woods: |Multidimensional Signal, Image, and Video Processing and Coding|, Academic Press, 2^nd^ edition, 2012

1	**Module name** 816185	**Body area communications**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Body Area Communications (2 SWS)	2,5 ECTS
3	Lecturers	Benedict Scheiner	

4	**Module coordinator**	Prof. Dr.-Ing. Georg Fischer
5	**Contents**	Contents: The Lecture and exercise deals with the following topics: • Introduction to Body Area Communications • Electromagnetic Characteristics of Human Body • Electromagnetic Analysis Methods • Body Area Channel Modeling • Modulation/Demodulation • Body Area Communication Performance • Electromagnetic Compatibility Consideration
6	**Learning objectives and skills**	Learning objectives • Students understand the challenges in designing Body Area Communication (BAC) systems • Students can conduct basic design decisions with BAC systems, like frequency and modulation selection • Students understand electromagnetic wave propagation in bodies • Students understand the frequency dependent loss and propagation behavior of electromagnetic waves • Students can analyze the communication performance of a BAC system • Students can evaluate Electromagnetic Compatibility of a BAC system • Students can assess the field strength inside body and relate it to regulatory limits like SAR (Specific Absorption rate), frequency dependent maximum electrical and magnetic field strength • Students can sketch block diagrams of BAC systems • tudents can derive channel models for BAC
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Deutsch oder Englisch

17	**Bibliography**	no Bibliography information available!

1	**Module name** 44445	**Cognitive Neuroscience for AI Developers**	**5 ECTS**
2	Courses / lectures	Vorlesung: Cognitive Neuroscience for AI Developers (4 SWS)	5 ECTS
3	Lecturers	Dr. Patrick Krauß Prof. Dr. Andreas Kist	

4	**Module coordinator**	
5	**Contents**	Neuroscience has played a key role in the history of artificial intelligence (AI), and has been an inspiration for building human-like AI, i.e. to design AI systems that emulate human intelligence. Neuroscience provides a vast number of methods to decipher the representational and computational principles of biological neural networks, which can in turn be used to understand artificial neural networks and help to solve the so called black box problem. This endeavour is called neuroscience 2.0 or machine behaviour. In addition, transferring design and processing principles from biology to computer science promises novel solutions for contemporary challenges in the field of machine learning. This research direction is called neuroscience-inspired artificial intelligence. The course will cover the most important works which provide the cornerstone knowledge to understand the biological foundations of cognition and AI, and applications in the areas of AI-based modelling of brain function, neuroscience-inspired AI and reverse-engineering of artificial neural networks.
6	**Learning objectives and skills**	The students • Explain the principles of neural information processing in the brain • compare and analyze methods from neuroscience to study neural networks • explain the neuroscientific underpinnings of artificial intelligence • explain principles and concepts of cognitive science • explain principles and concepts of neuroscience • compare and analyze machine learning methods to analyze neural data • explain approaches from deep learning to model brain function • discuss the commonalities of neuroscience and artificial intelligence • implement the presented methods in Python • explain concepts from cognitive neuroscience for the design of artificial intelligence systems
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Variabel
11	**Grading procedure**	Variabel (100%)

12	**Module frequency**	in jedem Semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 60 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Gazzaniga, Michael. Cognitive Neuroscience - The Biology of the Mind. W. W. Norton & Company, 2018. Ward, Jamie. The Student's Guide to Cognitive Neuroscience. Taylor & Francis Ltd., 2019. Bermúdez, José Luis. Cognitive Science: An Introduction to the Science of the Mind. Cambridge University Press, 2014. Friedenberg, Jay D., and Silverman, Gordon W. Cognitive Science: An Introduction to the Study of Mind. SAGE Publications, Inc., 2015. Gerstner, Wulfram, et al. Neuronal dynamics: From single neurons to networks and models of cognition. Cambridge University Press, 2014.

1	**Module name** 48447	**Compressive Sensing**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Compressive Sensing (4 SWS)	5 ECTS
3	Lecturers	Dr.-Ing. Ali Bereyhi	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	This lecture aims to provide a good background on the concept of compressive sensing and its applications in communications and signal processing. *Part I: Compressive Sensing from the Classical Viewpoint* In the first part, the classic problem of compressive sensing is explained. Important algorithms for sparse recovery in cases with noise-free underdetermined measurements are studied. These algorithms are then modified to address sparse recovery from noisy measurements. Once basic concepts and algorithms are studied, we start with typical analyses in compressive sensing. In this respect, the null space property, restricted isometry property (RIP) and the coherence of a matrix are introduced. Based on these definitions, the concept of recovery guarantee for a sparse recovery algorithm is explained. We then study important recovery guarantees and give some examples of detailed analyses. Finally, we give an introduction to compressive sensing via random matrices and present some key results in this respect. *Part II: Compressive Sensing from a Bayesian Viewpoint* In the second part of the course, we show that compressive sensing can be observed as a Bayesian inference problem. This new viewpoint lets us define the optimal recovery algorithm. We further show that well-known recovery algorithms such as LASSO are interpreted as sub-optimal Bayesian estimators. The key benefit of the Bayesian viewpoint is that it enables us to illustrate approximate message passing (AMP) algorithms: We start with the implementation of a sparse recovery algorithm via the sum-product algorithm and then explain how an AMP algorithm is derived from the sum-product algorithm. The detailed list of contents is as follows: • Introduction to Compressive Sensing • Part I: Compressive Sensing from the Classical Viewpoint • Zero-norm minimization • Basis pursuit • Iterative Algorithms • The method of regularized least-squares

		• Regularization options for sparse recovery • Dantzig selector • Null space property • Coherence of a matrix • Restricted isometry property • Some notes on random matrices • Generic form of a performance guarantee • Some examples of performance guarantee • Part II: Compressive Sensing from a Bayesian Viewpoint • Posterior distribution • Likelihood in a noisy setting • Sparse prior • Recovery algorithm with minimum mean squared error • Computational complexity of the optimal recovery algorithm • Mismatched prior of LASSO algorithm • Mismatched prior of zero-norm regularization • Implementing a Bayesian algorithm via message passing • Approximating a message passing algorithm for large problems • A sample approximate message passing algorithm
6	**Learning objectives and skills**	• The students understand the concept of sparse recovery. • The students apply sparse recovery to model problems in several applications, such as communication and signal processing systems and machine learning. • The students apply classic approaches to recover sparse signal samples from underdetermined observations. • The students implement most important recovery algorithms in compressive sensing, namely basis pursuit, orthogonal matching pursuit, Lasso and Dantzig algorithm. • The students understand how to regularize the method of least-squares in order perform sparse recovery with it. • The students understand under which condition sparse recovery is successful. • The students understand important properties of sensing matrices, namely null space property, coherence of a matrix and restricted isometry property. • They apply the mentioned properties of sensing matrices to determine the effectiveness of a given sensing matrix. • The students understand the analysis of the success probability of a sparse recovery algorithm and the necessary and sufficient conditions for different algorithms. • The students derive the components of a typical sparse recovery algorithm in a Bayesian inference framework. • In the shadow of the Bayesian interpretation, the students understand the behaviour of different sparse recovery algorithms. • The students understand the theoretically optimal minimum mean square bound for compressive sensing. • The students apply the sum-product algorithm to implement a typical sparse recovery algorithm.

		• Starting from the sum-product algorithm, the students determine an approximate message passing algorithm via large-system analysis. • The students understand the state-evolution of the approximate message passing algorithm.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich (30 Minuten)
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	For the first part of the course, we mainly follow the discussions from -Foucart, Simon, and Holger Rauhut. A Mathematical Introduction to Compressive Sensing. Birkhäuser, NewYork, NY, 2013. For the second part, we collect discussions mainly from the following references: • Bereyhi, Ali. Statistical Mechanics of Regularized Least Squares. PhD Dissertation, Friedrich-Alexander University of Erlangen (2020). • Rangan, Sundeep, Alyson K. Fletcher, and Vivek K. Goyal. "Asymptotic analysis of MAP estimation via the replica method and applications to compressed sensing. IEEE Transactions on Information Theory 58, no. 3 (2012): 1902-1923. • Kschischang, Frank R., Brendan J. Frey, and H-A. Loeliger. "Factor graphs and the sum-product algorithm. IEEE Transactions on Information Theory 47, no. 2 (2001): 498-519. • Maleki, Arian. Approximate message passing algorithms for compressed sensing. PhD Dissertation, Stanford University (2011).

1	**Module name** 566245	**Cryptocurrencies**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 0
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? Semester (keine Angaben zur Dauer des Moduls hinterlegt)
16	**Teaching and examination language**	Deutsch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 901895	**Deep learning**	**5 ECTS**
2	Courses / lectures	Vorlesung: Deep Learning (2 SWS) Übung: Deep Learning Exercises (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Andreas Maier Leonhard Rist Zijin Yang	

4	**Module coordinator**	Felix Denzinger Prof. Dr.-Ing. Andreas Maier Fabian Wagner
5	**Contents**	Deep Learning (DL) has attracted much interest in a wide range of applications such as image recognition, speech recognition and artificial intelligence, both from academia and industry. This lecture introduces the core elements of neural networks and deep learning, it comprises: • (multilayer) perceptron, backpropagation, fully connected neural networks • loss functions and optimization strategies • convolutional neural networks (CNNs) • activation functions • regularization strategies • common practices for training and evaluating neural networks • visualization of networks and results • common architectures, such as LeNet, Alexnet, VGG, GoogleNet • recurrent neural networks (RNN, TBPTT, LSTM, GRU) • deep reinforcement learning • unsupervised learning (autoencoder, RBM, DBM, VAE) • generative adversarial networks (GANs) • weakly supervised learning • applications of deep learning (segmentation, object detection, speech recognition, ...) The accompanying exercises will provide a deeper understanding of the workings and architecture of neural networks.
6	**Learning objectives and skills**	The students • explain the different neural network components, • compare and analyze methods for optimization and regularization of neural networks, • compare and analyze different CNN architectures, • explain deep learning techniques for unsupervised / semi-supervised and weakly supervised learning, • explain deep reinforcement learning, • explain different deep learning applications, • implement the presented methods in Python,

		• autonomously design deep learning techniques and prototypically implement them, • effectively investigate raw data, intermediate results and results of Deep Learning techniques on a computer, • autonomously supplement the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of deep learning applications.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur (90 Minuten)
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	in jedem Semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	• Ian Goodfellow, Yoshua Bengio, Aaron Courville: Deep Learning. MIT Press, 2016. • Christopher Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • Yann LeCun, Yoshua Bengio, Geoffrey Hinton: Deep learning. Nature 521, 436444 (28 May 2015)

1	**Module name** 44150	**Diagnostic medical image processing**	**5 ECTS**
2	Courses / lectures	Vorlesung: Medical Image Processing for Diagnostic Applications (VHB-Kurs) (4 SWS)	5 ECTS
3	Lecturers	Manuela Meier Arpitha Ravi Celia Martín Vicario Luis Rivera Monroy	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	English version: The contents of the module comprise basics about medical imaging modalities and acquisition hardware. Furthermore, details on acquisition-dependent preprocessing are covered for image intensifiers, flat-panel detectors, and MR. The fundamentals of 3D reconstruction from parallel-beam to cone-beam reconstruction are also covered. In the last chapter, rigid registration for image fusion is explained. Deutsche Version: Die Inhalte des Moduls umfassen Grundlagen der medizinischen Bildverarbeitung und Aufnahmeprinzipien. Darüber hinaus werden Details der Vorverarbeitung für Bildverstärker, Flachpaneldetektoren und MR erklärt. Die Grundlagen der Rekonstruktion von Parallelstrahl bis hin zur Kegelstrahl-Tomographie werden ebenfalls behandelt. Im letzten Kapitel wird starre Registrierung für Bildfusion erläutert.
6	**Learning objectives and skills**	English Version: The participants • understand the challenges in interdisciplinary work between engineers and medical practitioners. • develop understanding of algorithms and math for diagnostic medical image processing. • learn that creative adaptation of known algorithms to new problems is key for their future career. • develop the ability to adapt algorithms to different problems. • are able to explain algorithms and concepts of the module to other engineers. Deutsche Version: Die Teilnehmenden • verstehen die Herausforderungen in der interdisziplinären Arbeit zwischen Ingenieuren und Ärzten. • entwickeln Verständnis für Algorithmen und Mathematik der diagnostischen medizinischen Bildverarbeitung.

		• erfahren, dass kreative Adaption von bekannten Algorithmen auf neue Probleme der Schlüssel für ihre berufliche Zukunft ist. • entwickeln die Fähigkeit Algorithmen auf verschiedene Probleme anzupassen. • sind in der Lage, Algorithmen und Konzepte des Moduls anderen Studierenden der Technischen Fakultät zu erklären.
7	**Prerequisites**	Ingenieurmathematik Engineering Mathematics
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich/mündlich
11	**Grading procedure**	schriftlich/mündlich (100%)
12	**Module frequency**	in jedem Semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 0 h Independent study: 150 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 43400	**Equalisation and adaptive systems for digital communications**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Equalization and Adaptive Systems for Digital Communications (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	Prof. Dr. Wolfgang Gerstacker
5	**Contents**	Bei der digitalen Übertragung spielen Kanalverzerrungen aufgrund ständig steigender Datenraten eine immer grössere Rolle. Bei vielen Anwendungen müssen für eine zuverlässige Übertragung komplexe Entzerrverfahren eingesetzt werden. Dies gilt sowohl für die leitungsgebundene als auch die drahtlose Kommunikation. Z.B. werden in der xDSL-Systemfamilie (Digital Subscriber Lines), die eine schnelle digitale Übertragung über Ortsanschlussleitungen gewährleistet, oft entscheidungsrückgekoppelte Entzerrverfahren oder Vorcodierungsverfahren eingesetzt und beim Mobilfunkstandard GSM und seiner Weiterentwicklung EDGE (Enhanced Data Rates for GSM Evolution) Maximum-Likelihood-Sequenzschätzung bzw. zustandsreduzierte Entzerrung. Eng im Zusammenhang mit der eigentlichen Entzerrung stehen Adaptionsverfahren, mit denen die Parameter des Entzerrers optimal an den Übertragungskanal angepasst werden können. Lernziel: Ziel der Vorlesung ist eine umfassende Darstellung gebräuchlicher Entzerrungs- und Adaptionsverfahren. Den Teilnehmern sollen fundierte Kenntnisse der verschiedenen Verfahren vermittelt werden, die sie zu deren sinnvollem Einsatz in der Praxis befähigen. Content: Channel distortions are playing an increasingly important role in digital transmission due to constantly increasing data rates. In many applications, complex equalization techniques must be used for a reliable transmission. This applies to both wired and wireless communication. For example, decision feedback equalization or precoding techniques are often used in the xDSL (Digital Subscriber Lines) system family, which ensures fast digital transmission over local subscriber loops, and the GSM system and its advanced version EDGE (Enhanced Data Rates for GSM Evolution) employ maximum likelihood sequence estimation and state-reduced equalization. Closely related to the task of equalization are adaptation methods with which

		the parameters of the equalizer can be optimally adjusted to the transmission channel. Objective: The aim of the lecture is a comprehensive presentation of common equalization and adaptation methods. The participants should acquire an in-depth knowledge of the various procedures which enables them to make meaningful design decisions in practice.
6	**Learning objectives and skills**	Die Studierenden • beschreiben verschiedene Verfahren zur Entzerrung frequenzselektiver Übertragungskanäle wie lineare Entzerrung, entscheidungsrückgekoppelte Entzerrung und Maximum-Likelihood-Sequenzschätzung, • setzen die verschiedenen Ansätze in Blockdiagramme um und optimieren deren Komponenten, • vergleichen Entzerrverfahren hinsichtlich ihrer Leistungsfähigkeit, charakterisiert durch die Fehlerrate, und Komplexität, • wählen geeignete Verfahren für verschiedene Anwendungen wie leitungsgebundene und drahtlose Übertragung aus, • entwerfen neuartige Verfahren für gegebene Anforderungen, • formulieren Adaptionsalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal, • ordnen Entzerrverfahren einen geeigneten Adaptionsalgorithmus zu. Learning Objectives and Competences: The students - describe various methods for equalizing frequency-selective transmission channels such as linear equalization, decision feedback equalization and maximum likelihood sequence estimation, - realize various approaches in block diagrams and optimize their components, - compare equalization methods in terms of their performance, characterized by the error rate, and complexity, - select suitable methods for various applications such as wired and wireless transmission, - design novel schemes for given requirements, - formulate adaptation algorithms for automatic adaptation of the receiver of a transmission system to the channel,

		- assign suitable adaptation algorithms to equalization schemes.
7	**Prerequisites**	Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung Nachrichtentechnische Systeme oder Digitale Übertragung sind für die Teilnahme hilfreich.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Gerstacker, W.: Skriptum zur Vorlesung Entzerrung und adaptive Systeme in der digitalen Übertragung. Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992. Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999. Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995. Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996.

1	**Module name** 96270	**Channel coding**	**5 ECTS**
2	Courses / lectures	Vorlesung mit Übung: Kanalcodierung (3 SWS) Vorlesung mit Übung: Channel Coding (4 SWS) Übung: Übungen zur Kanalcodierung (1 SWS)	5 ECTS 5 ECTS -
3	Lecturers	Dr.-Ing. Clemens Stierstorfer	

4	**Module coordinator**	Dr.-Ing. Clemens Stierstorfer
5	**Contents**	1) Introduction and Motivation 2) Fundamentals of Block Coding 3) Introduction to Finite Fields I 4) Linear Block Codes 5) Linear Cyclic Codes 6) Introduction to Finite Fields II 7) BCH and RS Codes 8) Convolutional Codes 9) Codes with Iterative Decoding
6	**Learning objectives and skills**	Das Modul Kanalcodierung umfasst eine Einführung in die Grundlagen der algebraischen, fehlerkorrigierenden Blockcodes sowie einen Einstieg in die Thematik der Faltungscodes. Iterativ decodierte Codeschemata wie Turbo-Codes und LDPC-Codes werden ebenfalls eingeführt. Im Einzelnen sind die Inhalte oben aufgeführt. Die Studierenden definieren die Problematik der Kanalcodierung, grenzen sie von anderen Codierverfahren (z.B. der Quellencodierung) ab und kennzeichnen die unterschiedlichen Ansätze zur Fehlerkorrektur und -erkennung. Sie nennen Beispiele für Einsatzgebiete von Kanalcodierung und geben einen Überblick über die historische Entwicklung des Fachgebiets. Die Studierenden erstellen Übertragungsszenarien für den Einsatz von Kanalcodierung bestehend aus Sender, Übertragungskanal und Empfänger und beachten dabei die Grundannahmen beim Einsatz von Blockcodes bzw. der Modellierung der Kanäle. Sie formulieren mathematische Beschreibungen der Encodierung sowie der optimalen Decodierung bzw. suboptimaler Varianten. Die Studierenden beherrschen die Grundlagen fehlerkorrigierender linearer Blockcodes, beschreiben diese mathematisch korrekt mittels Vektoren und Matrizen über endlichen Körpern und implementieren und bewerten zugehörige Encoder- und Decoderstrukturen insbesondere Syndromdecoder. Dabei modifizieren sie Generatormatrizen, ermitteln Prüfmatrizen und erstellen Syndromtabellen. Sie schätzen die minimale Hammingdistanz von Codes mittels Schranken ab und können den erzielbaren Codegewinn erläutern. Sie kennen und benutzen beispielhaften Codefamilien (z.B. Hamming-Codes, Simplex-Codes, Reed-Muller-Codes).

Die Studierenden erkennen die Vorteile zyklischer linearer Blockcodes und beschreiben diese mit Polynomen über endlichen Körpern. Sie nutzen die Restklassenrechnung bzgl. Polynomen zur Umsetzung systematischer Encoder und zur Realisierung von Syndromdecodern mittels Schieberegisterschaltungen. Sie kennen beispielhafte Codefamilien.

Die Studierenden nutzen Primkörper, Erweiterungskörper, Minimalpolynome und Kreisteilungsklassen sowie die Spektraldarstellung über endlichen Körpern zur Realisierung von BCH- und Reed-Solomon-Codes gemäß der BCH-Schranke. Sie verstehen die Grundlagen der Decodierung von BCH- und Reed-Solomon-Codes. Sie skizzieren und erläutern die Kanalcodierkonzepte von CD und DVD.

Die Studierenden erklären die Unterschiede von Faltungscodes und Blockcodes, skizzieren anhand von tabellierten Generatorpolynomen zugehörige Encoder und erläutern diese. Sie erklären die Funktionsweise des optimalen Decoders (MLSE) und demonstrieren diese beispielhaft.

Die Studierenden verstehen die Grundlagen der iterativen Decodierung, insbesondere wenden sie die Grundlagen des Information Combining zur Kombination von verschiedenen Beobachtungen an. Sie verstehen die Bedeutung von Log-Likelihood-Ratios bei iterativen Decodieruvorgängen und berechnen diese. Sie skizzieren die grundlegenden Encoder- und Decoderstrukturen von Turbo-Codes und die Grundzüge der Codierung mit LDPC-Codes u.a. der Decodierung mittels Belief Propagation.

Die Vorlesung erfolgt wechselweise auf Deutsch oder Englisch (Winter/ Sommer). Die zur Verfügung gestellten Unterlagen sind ausschließlich in Englisch gehalten. Die Studierenden verwenden entweder die englischen Fachtermini sicher oder kennen diese und drücken sich sicher mit den entsprechenden deutschen Fachbegriffen aus.

Die Umsetzung der angegebenen Algorithmen in eine Programmiersprache (C, Matlab usw.) sollten die Studierenden zu diesem Zeitpunkt des Studiums üblicherweise beherrschen. Übungen hierzu bleiben der Eigeninitiative überlassen.

Students define the problems of channel coding, how to distinguish it from other coding methods (such as source coding) and how to describe the various different approaches to error correction and detection. They are able to list example application areas of channel coding and give an overview of the historical development of the field.

		Furthermore, they describe and analyze transmission scenarios for the application of channel coding which consist of transmitter, transmission channel and receiver, taking into account the general assumptions for applying block codes or modeling the channels. They formulate mathematical descriptions of encoding, optimal decoding and sub-optimal methods. Students illustrate the principles of error-correcting linear block codes and describe them mathematically using vectors and matrices over finite fields. They implement and analyze corresponding encoder and decoder structures, in particular syndrome decoders, and modify generator matrices, construct test matrices and create syndrome tables. They estimate the minimum Hamming distance of codes using bounds and are able to explain the coding gain that can be achieved in individual cases. They analyze and use example code families (e.g. Hamming codes, simplex codes, Reed-Muller codes). Students explain the advantages of cyclic linear block codes and how to describe them with polynomials over finite fields. They apply polynomial modular arithmetic to implement systematic encoders and realize syndrome decoders using shift register circuits. They know and use exemplary code families. Students use prime fields, extension fields, minimal polynomials and cyclotomic cosets, and spectral representation over finite fields to implement BCH and Reed-Solomon codes using the BCH bound. They understand the foundations of decoding BCH and Reed-Solomon codes and how to sketch and explain the channel coding concepts of CDs and DVDs. Students are able to describe the differences between convolutional codes and block codes, to sketch the respective encoders based on tabulated generator polynomials and to explain them. They are able to explain how optimal decoders (MLSE) work using examples. Students sketch the foundations of iterative decoding. In particular, they apply methods of information combining to combine different observations. They use and calculate log-likelihood ratios in iterative decoding processes, sketch the basic encoding and decoding structures of turbo codes and the basics of coding using LDPC codes (including decoding using belief propagation). Students either are able to use the English technical terms correctly or know them and are able to express themselves using the respective technical terms in German.
7	**Prerequisites**	Es ist hilfreich, wenn die Studierenden die erlernten Algorithmen in eine Programmiersprache (C, Matlab usw.) umsetzen können.

		It would be very helpful if the participants can implement the specified algorithms into a programming language (C, Matlab, etc.).
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich Hilfsblatt, Taschenrechner: Sie können ein einzelnes A4-Blatt (Vorder- und Rückseite oder andere Blätter mit offensichtlich identischer Gesamtfläche) verwenden, um Ihre eigene, handschriftliche Formelsammlung aufzuschreiben. Sie können einen nicht programmierbaren Taschenrechner verwenden. Cheat Sheet, Calculator: A single A4 sheet (front and back, or any other collection of sheets with an obviously identical total area size) can be used to write down your own handwritten collection of formulas, etc. You may also bring a non-programmable calculator.
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	in jedem Semester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Deutsch oder Englisch
17	**Bibliography**	• J. Huber, R. Fischer, C. Stierstorfer: Folien zur Vorlesung • M. Bossert: Kanalcodierung, Oldenbourg Wissenschaftsverlag, 3. Auflage, 2013 • M. Bossert: Channel Coding for Telecommunications, John Wiley & Sons, 1999 • B. Friedrichs: Kanalcodierung, Springer Verlag, 1996 • S.B. Wicker: Error Control Systems for Digital Communications and Storage, Prentice-Hall, 1995

1	**Module name** 267499	**Linear and non-linear fibre optics**	**5 ECTS**
2	Courses / lectures	Übung: Linear and non-linear fibre optics: Exercise (2 SWS) Vorlesung: Linear and non-linear fibre optics (2 SWS)	- 5 ECTS
3	Lecturers	Lisa-Sophie Härteis Prof. Dr.-Ing. Bernhard Schmauß	

4	**Module coordinator**	Prof. Dr.-Ing. Bernhard Schmauß
5	**Contents**	Optical data transmission systems are the enabler for our modern communication networks. Since the first systems have been installed, the transmission capacity as well as the transmission distance has been increased dramatically. The migration from point-to-point transmission systems to complex optical networks is still in progress. The fast evolution of optical transmission technology is stimulated by innovations in the field of the system key components. The lectures concentrate on the physical effects and properties of key components like semiconductor lasers, optical modulators, optical fibers, optical amplifiers and detector diodes. Especially also the nonlinear effects of the transmission fiber are discussed. The main focus is on the effects and characteristics which are important to achieve a certain system performance. The influence of component parameters on system performance is presented in examples related to installed systems and systems that are actually in development. The exercises partly use a numerical simulation tool to analyze the component influence on system performance.
6	**Learning objectives and skills**	Students • Understand structure and operation of components of optical communication systems • Rate the optical properties of components and evaluate the influence of operational parameters on system performance • Are able to analyze the influence of linear and nonlinear fiber effects on optical signals and system performance • Can make use of system simulation tools to engineer optical links
7	**Prerequisites**	Recommended prior knowledge: • Semiconductor physics • Ray optics • Photonics
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Portfolio
11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.

14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Agrawal, G.P.: Fiber Optic Communication Systems, Willey, New York, 1992 Kaminow, I, Li, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002 Kaminow, I, Li, T., Willner, A.: Optical Fiber Telecommunications VA, Academic Press, 2008

1	**Module name** 668129	**Machine learning in communications**	**5 ECTS**
2	Courses / lectures	Vorlesung: Machine Learning in Communications (4 SWS) Übung: Tutorial for Machine Learning in Communications (0 SWS)	5 ECTS -
3	Lecturers	Prof. Dr. Laura Cottatellucci Nikita Shanin	

4	**Module coordinator**	Prof. Dr. Laura Cottatellucci
5	**Contents**	Recently, in many areas of wireless communications such as wireless sensor networks (WSNs), heterogeneous networks and complex ad hoc networks, distributed graph algorithms and machine learning on graphs are gaining relevance as fundamental tools in network analysis and information processing. This motivates to deliver a general introduction to fundamentals of machine learning such as detection of clusters on graphs. The introduction is followed by the application of machine learning to the design of physical and data layer techniques in wireless communications and in the optimization of mobile networks.
6	**Learning objectives and skills**	The students • know and explain the fundamentals of machine learning with special attention to machine learning over graphs. • apply these principles in the design and optimisation of wireless communications systems and mobile networks.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 428256	**Machine learning for time series**	**5 ECTS**
2	Courses / lectures	Übung: Maschinelles Lernen für Zeitreihen Übung (2 SWS) Vorlesung: Maschinelles Lernen für Zeitreihen (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Richard Dirauf Philipp Schlieper Dr. Dario Zanca Prof. Dr. Björn Eskofier	

4	**Module coordinator**	Prof. Dr. Oliver Amft Prof. Dr. Björn Eskofier Dr. Dario Zanca
5	**Contents**	Aim of the lecture is to teach Machine learning (ML) and Deep Learning (DL) methods for a variety of time series applications. The following topics will be covered: • Fundamentals and an overview of applications of time series analysis. • Fundamentals of ML methods, such as Gaussian processes, State Space models, and Autoregressive models for time series. • Design, implementation and evaluation of ML methods in order to address time series problems. • Advanced DL methods for time-series, such as Convolutional, Recurrent, and Attention-based models. • Working with widely-used toolboxes that can be used for implementation of ML methods, such as Tensorflow or PyTorch.
6	**Learning objectives and skills**	• Students can describe concepts of time series problems and their wide applications in industry, medicine, finance, etc. • Students can explain concepts of ML/DL methods in general and tackling time series problems in particular • Students understand the characteristics of time series data and are capable of developing and implementing ML/DL methods to model, predict and manipulate such data in concrete problems
7	**Prerequisites**	This is a specialisation lecture; successful completion of the lectures "IntroPR" and/or "Pattern Recognition" / "Pattern Analysis" is recommended. Concepts taught in "IntroPR" are assumed here as basic knowledge.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Variabel
11	**Grading procedure**	Variabel (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h

15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	• Pattern recognition and machine learning. Christopher M. Bishop, Springer, 2006 • The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Trevor Hastie, Robert Tibshirani, Jerome Friedman, Springer, 2009 • Machine Learning: A Probabilistic Perspective. Kevin Murphy, MIT press, 2012 • Deep Learning. Ian Goodfellow and Yoshua Bengio and Aaron Courville, MIT Press, 2016

1	**Module name** 454183	**Molecular communications**	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Molecular Communications (0 SWS) Vorlesung: Molecular Communications (4 SWS)	- 5 ECTS
3	Lecturers	Sebastian Lotter Prof. Dr.-Ing. Robert Schober	

4	**Module coordinator**	Prof. Dr.-Ing. Robert Schober
5	**Contents**	Conventional communication systems employ electromagnetic waves for information transmission. This approach is suitable for typical macroscopic applications such as mobile communication. However, newly emerging applications in biology, nanotechnology, and medicine require communication between so-called nano-machines (e.g. nano-robots and nano-sensors) with sizes on the order of nano- and micro-meter. For such device sizes electromagnetic waves cannot be used for efficient information transmission. Instead Molecular Communication, an approach that is also widely used in natural biological systems, has to be applied. In Molecular Communication, transmitter and receiver communicate by exchanging information-carrying molecules. The design of molecular communication systems requires a basic understanding of relevant biological processes and systems as well as their communication-theoretical modelling and analysis. The course is structured as follows: 1) Introduction to Molecular Communication; 2) Biological Nano-Machines; 3) Molecular Communication in Biological Systems; 4) Synthetic Molecular Communication Systems; 5) Mathematical Modelling and Simulation; 6) Communication and Information Theory for Molecular Communication; 7) Design of Molecular Communication Systems; 8) Applications for Molecular Communication Systems.
6	**Learning objectives and skills**	The students learn how to design synthetic molecular communication systems. They develop an understanding of natural communication processes in biological systems and how to harness these natural processes for the construction of man-made molecular communication systems. The students also learn how to analyse, model, and simulate molecular communication systems.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch

17	**Bibliography**	no Bibliography information available!

1	**Module name** 687141	**Multiuser information and communications theory**	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Multiuser Information and Communications Theory (1 SWS) Vorlesung: Multiuser Information and Communications Theory (3 SWS)	- 5 ECTS
3	Lecturers	Saba Asaad Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	Linear vs. nonlinear multiple-access, CDMA as a canoncal framework for any multiple-access schemes, optimum multiuser detection, linear multiuser detection, interference cancellation, rate region, multiuser source coding, time sharing, multiuser channel codes, multiple-access channel (MAC), capacity region, mutual information versus minimum-mean squared error, Gaussian MAC, power region, Gaussian vector MAC, source coding with side information, degraded broadcast channel, Gaussian broadcast-MAC duality, Gaussian vector broadcast channel, dirty-paper coding, physically degraded relay channel, scalar Gaussian relay channel, Gaussian interference channel, cut-set bound, network coding, fading channels, multiuser water filling, block fading, diversity, user diversity, capacity versus outage, near-far gain, dual antenna arrays
6	**Learning objectives and skills**	The students model any multiple access method as a special case of code-division multiple access. The students apply various algorithms for multiuser detection. The students explain various types of multiuser channels and their limits to transport information. The students explain the limits of distributed source coding algorithms. The students apply the cut-set bound. The students explain the method of dirty-paper coding. The students collaborate on solving exercise problems.
7	**Prerequisites**	Recommended: A basic course on information theory (can be taken in parallel)
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	• El Gamal, A., Kim, Y.: Network Information Theory, Cambridge University Press, 2011 • Cover, T., Thomas, J.: Elements of Information Theory, 2nd ed., Wiley, Hoboken, 2006 • Verdú, S.: Multiuser Detection, Cambridge Univ. Press, Cambridge, 1998 • Tse, D., Viswanath, P.: Fundamentals of Wireless Communications, Cambridge University Press, 2005.

1	**Module name** 44120	**Pattern analysis**	**5 ECTS**
2	Courses / lectures	Vorlesung: Pattern Analysis (3 SWS) Übung: Pattern Analysis Programming (1 SWS)	3,75 ECTS 1,25 ECTS
3	Lecturers	PD Dr.Ing. Christian Rieß Dalia Rodriguez Salas	

4	**Module coordinator**	PD Dr.Ing. Christian Rieß
5	**Contents**	This module introduces the design of pattern analysis systems as well as the corresponding fundamental mathematical methods. The topics comprise: • clustering methods: soft and hard clustering • classification and regression trees and forests • parametric and non-parametric density estimation: maximum-likelihood (ML) estimation, maximum-a-posteriori (MAP) estimation, histograms, Parzen estimation, relationship between folded histograms and Parzen estimation, adaptive binning with regression trees • mean shift algorithm: local maximization using gradient ascent for non-parametric probability density functions, application of the mean shift algorithm for clustering, color quantization, object tracking • linear and non-linear manifold learning: curse of dimensionality, various dimensionality reduction methods: principal component analysis (PCA), multidimensional scaling (MDS), isomaps, Laplacian eigenmaps • Gaussian mixture models (GMM) and hidden Markov models (HMM): expectation maximization algorithm, parameter estimation, computation of the optimal sequence of states/ Viterbi algorithm, forward-backward algorithm, scaling • Markov random fields (MRF): definition, probabilities on undirected graphs, clique potentials, Hammersley-Clifford theorem, inference via Gibbs sampling and graph cuts Das Modul führt in das Design von Musteranalysesystemen sowie die zugrundeliegenden mathematischen Methoden ein. Die Vorlesung umfasst im Einzelnen: • Clustering-Methoden: Soft- und Hard-Clustering • Klassifikations- und Regressionsbäume/-wälder • parametrische und nicht-parametrische Dichteschätzung: Verfahren sind ML- und MAP-Schätzung, Histogramme, Parzenschätzung, Zusammenhang gefaltete Histogramme und Parzenschätzung, adaptives Binning mit Regressionsbäumen. • 'Mean Shift'-Algorithmus: lokale Maximierung durch Gradientenaufstieg bei nicht-parametrischen Dichtefunktionen, Anwendungen des 'Mean Shift'-Algorithmus zum Clustering, Farbquantisierung und Objektverfolgung

		• Linear and Non-Linear Manifold Learning: Curse of Dimensionality, Verschiedene Methode zur Dimensionsreduktion: Principal Component Analysis (PCA), Multidimensionsional Scaling (MDS), Isomap, Laplacian Eigenmaps • Gaußsche Mischverteilungsmodelle (GMM) und Hidden-Markov-Modelle (HMM): 'Expectation Maximization'-Algorithmus, Parameterschätzung, Bestimmung der optimalen Zustandsfolge/Viterbi-Algorithmus, Vorwärts-Rückwärts-Algorithmus, Skalierung • Markov-Zufallsfelder: Definition, Wahrscheinlichkeiten auf ungerichteten Graphen, Cliquen-Potenziale, Hammersley-Clifford-Theorem, Inferenz mit Gibbs-Sampling und Graph Cuts
6	**Learning objectives and skills**	The students • explain the discussed methods for classification, prediction, and analysis of patterns, • compare and analyze methods for manifold learning and select a suited method for a given set of features and a given problem, • compare and analyze methods for probability density estimation and select a suited method for a given set of features and a given problem, • apply non-parametric probability density estimation to pattern analysis problems, • apply dimensionality reduction techniques to high-dimensional feature spaces, • explain statistic modeling of feature sets and sequences of features, • explain statistic modeling of statistical dependencies, • implement presented methods in Python, • supplement autonomously the mathematical foundations of the presented methods by self-guided study of the literature, • discuss the social impact of applications of pattern analysis solutions. Die Studierenden • erläutern die behandelten Methoden zur Klassifikation, Vorhersage und Analyse von Mustern, • vergleichen und analysieren Methoden des Manifold Learning und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus, • vergleichen und analysieren Methoden zur Dichteschätzung und wählen für eine vorgegebene Fragestellung eine geeignete Methode aus, • wenden nicht-parametrische Dichteschätzung auf Probleme der Musteranalyse an, • wenden Dimensionsreduktion bei hochdimensionalen Merkmalsräumen an,

		• erläutern statistische Modellierung von Merkmalsmengen und Merkmalsfolgen, • erklären statistische Modellierung abhängiger Größen, • implementieren vorgestellte Verfahren in Python. • ergänzen eigenständig mathematische Grundlagen der präsentierten Methoden durch selbstbestimmtes Studium der Literatur • diskutieren die gesellschaftlichen Auswirkungen von Anwendungen der Musteranalyse
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Variabel (60 Minuten)
11	**Grading procedure**	Variabel (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Begleitende Literatur / Accompanying literature: • C. Bishop: Pattern Recognition and Machine Learning, Springer Verlag, Heidelberg, 2006 • T. Hastie, R. Tibshirani und J. Friedman: The Elements of Statistical Learning, 2nd Edition, Springer Verlag, 2009 • A. Criminisi and J. Shotton: Decision Forests for Computer Vision and Medical Image Analysis, Springer, 2013

1	**Module name** 44130	**Pattern recognition**	**5 ECTS**
2	Courses / lectures	Übung: Pattern Recognition Exercises (1 SWS) Vorlesung: Pattern Recognition (3 SWS)	1,25 ECTS 3,75 ECTS
3	Lecturers	Siming Bayer Paul Stöwer Prof. Dr.-Ing. Andreas Maier	

4	**Module coordinator**	Prof. Dr.-Ing. Andreas Maier
5	**Contents**	Mathematical foundations of machine learning based on the following classification methods: • Bayesian classifier • Logistic Regression • Naive Bayes classifier • Discriminant Analysis • norms and norm dependent linear regression • Rosenblatt's Perceptron • unconstraint and constraint optimization • Support Vector Machines (SVM) • kernel methods • Expectation Maximization (EM) Algorithm and Gaussian Mixture Models (GMMs) • Independent Component Analysis (ICA) • Model Assessment • AdaBoost Mathematische Grundlagen der maschinellen Klassifikation am Beispiel folgender Klassifikatoren: • Bayes-Klassifikator • Logistische Regression • Naiver Bayes-Klassifikator • Diskriminanzanalyse • Normen und normabhängige Regression • Rosenblatts Perzeptron • Optimierung ohne und mit Nebenbedingungen • Support Vector Maschines (SVM) • Kernelmethoden • Expectation Maximization (EM)-Algorithmus und Gaußsche Mischverteilungen (GMMs) • Analyse durch unabhängige Komponenten • Modellbewertung • AdaBoost
6	**Learning objectives and skills**	Die Studierenden • verstehen die Struktur von Systemen zur maschinellen Klassifikation einfacher Muster • erläutern die mathematischen Grundlagen ausgewählter maschineller Klassifikatoren

		• wenden Klassifikatoren zur Lösung konkreter Klassifikationsproblem an • beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren Students • understand the structure of machine learning systems for simple patterns • explain the mathematical foundations of selected machine learning techniques • apply classification techniques in order to solve given classification tasks • evaluate various classifiers with respect to their suitability to solve the given problem • understand solutions of classification problems and implementations of classifiers written in the programming language Python
7	**Prerequisites**	• Well grounded in probability calculus, linear algebra/matrix calculus • The attendance of our bachelor course 'Introduction to Pattern Recognition' is not required but certainly helpful. • Gute Kenntnisse in Wahrscheinlichkeitsrechnung und Linearer Algebra/Matrizenrechnung • Der Besuch der Bachelor-Vorlesung 'Introduction to Pattern Recognition' ist zwar keine Voraussetzung, aber sicherlich von Vorteil.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Deutsch oder Englisch
17	**Bibliography**	• Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001 • Trevor Hastie, Robert Tobshirani, Jerome Friedman: The Elements of Statistical Learning - Data Mining, Inference, and Prediction, 2nd edition, Springer, New York, 2009

		• Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, New York, 2006

1	**Module name** 96316	**Radar, RFID and Wireless Sensor Systems (RWS)**	**5 ECTS**
2	Courses / lectures	Übung: Radar, RFID and Wireless Sensor Systems Exercises (2 SWS) Vorlesung: Radar, RFID and Wireless Sensor Systems (2 SWS)	- 5 ECTS
3	Lecturers	Dr.-Ing. Christian Carlowitz Prof. Dr.-Ing. Martin Vossiek	

4	**Module coordinator**	Prof. Dr.-Ing. Martin Vossiek
5	**Contents**	Radar, RFID and wireless sensor and wireless locating systems are essential for automotive advanced driver-assistance systems (ADAS), autonoumous driving and flying, robotics, industrial automation, logistics and novel human machine interfaces. Further key areas include medical electronics, building technology and cyber-physical systems. The module "Radar, RFID and Wireless Sensors" is an introduction into functional principles, building blocks, hardware and signal processing concepts and applications of modern radar, RFID, wireless sensor and real time locating systems. Covered applications include automotive radar, road and air traffic control systems, as well as robotics, industrial automation and medical technology. RWS is an identical replacement of the former module "Drahtlose Sensoren, Radar- und RFID-Systeme DSR.
6	**Learning objectives and skills**	The students • learn about the setup, function and application of wireless sensors, Radar and RFID-systems • can analyze, discuss and implement basic components and system structures, signal theory, data processing and use cases • can determine the underlying physical limitations and sources of errors • are able to analyze and create system specifications and can compare and rate the usability of wireless esnsors, Radar and RFID-systems • can create and define independently applications and system designs of RWSs
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h

		Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Sensors for Ranging and Imaging", Graham Brooker, Scitech Publishing Inc., 2009 Radar mit realer und synthetischer Apertur", H. Klausing, W. Holpp, Oldenbourg, 1999 Praxiswissen Radar und Radarsignalverarbeitung" Albrecht K. Ludloff, 2008 "RFID at ultra and super high frequencies: theory and application Dominique Paret, John Wiley & Sons, 2009. RFID-Handbuch: Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC", Klaus Finkenzeller, Carl Hanser Verlag, 6. Auflage 2012.

1	**Module name** 451971	**Random matrices in communications and signal processing**	**5 ECTS**
2	Courses / lectures	Vorlesung: Random Matrices in Communications and Signal Processing (2 SWS) Übung: Tutorial for Random Matrices in Communications and Signal Processing (2 SWS)	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	Dual antenna arrays, compressive sensing, Wishart distribution, factor iid model, Kronecker model, convergence of random variables, semi-circle law, quarter circle law, full circle law, Haar distribution, Marchenko-Pastur distribution, Stieltjes transform, Girkos law, unitary invariance, freeness, free convolution, R-transform, free central limit theorem, free Poisson limit theorem, subordination, S-transform, R-diagonal random matrices, R-diagonal free convolution, Haagerup-Larsen law, operator-valued freeness, linearization of noncommutative polynomials, free Fourier transform, self-averaging properties, microscopic vs. macroscopic random variables, quenched random variable, a statistical physics point of view of digital systems, spin glasses, frozen disorder, replica method, replica continuity, replica symmetry, replica symmetry breaking, approximate message passing, classification of np-complete problems
6	**Learning objectives and skills**	The students find the limiting eigenvalue distributions of various types of random matrices. The students explain Stieltjes, R- and S-transforms. The students explain the limits of various types of fading channels. The students design coding and decoding methods for a given type of multiuser channel. The students perform additive and multiplicative free convolution. The students calculate the asymptotic eigenvalues distributions of given random matrix ensembles. The students construct random matrix ensembles with a given eigenvalue distribution. The students linearize matrix polynomials. The students derive the Boltzmann distribution. The students utilize saddle point integration. The students perform replica calculations.

		The students explain the meaning of replica symmetry breaking. The students collaborate on solving exercise problems.
7	**Prerequisites**	Recommended: Good skills in linear algebra, probability theory and complex analysis
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	• Mingo, J., Speicher, R.: Free Probability and Random Matrices, Springer, 2017 • Couillet, R., Debbah, M.: Random Matrix Methods for Wireless Communications, Cambridge Univ. Press, Cambridge, 2011. • Mezard, M., Montanari, A.: Information, Physics, and Computation, Oxford Graduate Texts, 2009.

1	**Module name** 741941	**Reconfigurable computing (lecture with exercises)**	**5 ECTS**
2	Courses / lectures	Vorlesung: Reconfigurable Computing (2 SWS) Übung: Exercises to Reconfigurable Computing (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Jürgen Teich Tobias Hahn Mauro Martin Letras Luna Pierre-Louis Sixdenier	

4	**Module coordinator**	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	**Contents**	**Content:** Reconfigurable (adaptive) computing is a novel yet important research field investigating the capability of hardware to adapt to changing computational requirements such as emerging standards, late design changes, and even to changing processing requirements arising at run-time. Reconfigurable computing thus benefits from a) the programmability of software similar to the Von Neumann computer and b) the speed and efficiency of parallel hardware execution. The purpose of the course reconfigurable computing is to instruct students about the possibilities and rapidly growing interest in adaptive hardware and corresponding design techniques by providing them the necessary knowledge for understanding and designing reconfigurable hardware systems and studying applications benefiting from dynamic hardware reconfiguration. After a general introduction about benefits and application ranges of reconfigurable (adaptive) computing in contrast to general-purpose and application-specific computing, the following topics will be covered: • Reconfigurable computing systems: Introduction of available technology including fine grained look up table (LUT-) based reconfigurable systems such as field programmable gate arrays (FPGA) as well as newest coarse grained architectures and technology. • Design and implementation: Algorithms and steps (design entry, functional simulation, logic synthesis, technology mapping, place and route, bit stream generation) to implement (map) algorithms to FPGAs. The main focus lies on logic synthesis algorithms for FPGAs, in particular LUT technology mapping. • Temporal partitioning: techniques to reconfigure systems over time. Covered are the problems of mapping large circuits which do not fit one single device. Several temporal partitioning techniques are studied and compared. • Temporal placement: Techniques and algorithms to exploit the possibility of partial and dynamic (run-time) hardware

		reconfiguration. Here, OS-like services are needed that optimize the allocation and scheduling of modules at run-time. • On-line communication: Modules dynamically placed at run-time on a given device need to communicate as well as transport data off-chip. State-of-the-art techniques are introduced how modules can communicate data at run-time including bus-oriented as well as network-on-a-chip (NoC) approaches. • Designing reconfigurable applications on Xilinx Virtex FPGAs: In this part, the generation of partial bitstreams for components to be placed at run-time on Xilinx FPGAs is introduced and discussed including newest available tool flows. • Applications: This section presents applications benefiting from dynamic hardware reconfiguration. It covers the use of reconfigurable systems including rapid prototyping, reconfigurable supercomputers, reconfigurable massively parallel computers and studies important application domains such as distributed arithmetic, signal processing, network packet processing, control design, and cryptography.
6	**Learning objectives and skills**	**Learning objectives and competencies:** Domain-specific knowledge • The students know to exploit run-time reconfigurable design methodologies for adaptive applications. Domain-specific comprehension • The students understand the mapping steps and optimization algorithms. • The students classify different types and kinds of reconfigurable hardware technologies available today. • The students clarify pros and cons of reconfigurable computing technology. • The students summarize applications benefiting from reconfigurable computing. • The students describe the design of circuits and systems-on-a-chip (SoC) on FPGAs.
7	**Prerequisites**	Selection of this module prohibits the selection of the modules "Reconfigurable Computing" or "Reconfigurable Computing (Lecture with Extended Exercises)" by the student.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Portfolio
11	**Grading procedure**	Portfolio (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h

15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Further reading material: • The Hamburg VHDL Archive (see Documentation link for free books) http://tams-www.informatik.uni-hamburg.de/research/vlsi/vhdl/index.php • Interactive VHDL Tutorial with 150 examples from ALDEC http://www.aldec.com/downloads/ • Easy FPGA tutorials, projects, and boards http://www.fpga4fun.com • Xilinx WebPack ISE and Modelsim MXE (free FPGA synthesis tool and free VHDL simulator) http://www.xilinx.com/ise/logic_design_prod/webpack.htm • Symphony EDA free VHDL simulator (select FREE Edition license) http://www.symphonyeda.com/products.htm • Icarus open-source Verilog simulator http://www.icarus.com/eda/verilog/ Further information: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/reconfigurable-computing/

1	**Module name** 714289	**Reconfigurable computing (lecture with extended exercises)**	**7,5 ECTS**
2	Courses / lectures	Vorlesung: Reconfigurable Computing (2 SWS) Übung: Extended Exercises to Reconfigurable Computing (2 SWS) Übung: Exercises to Reconfigurable Computing (2 SWS)	2,5 ECTS 2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Jürgen Teich Pierre-Louis Sixdenier Mauro Martin Letras Luna Tobias Hahn	

4	**Module coordinator**	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	**Contents**	**Content:** Reconfigurable (adaptive) computing is a novel yet important research field investigating the capability of hardware to adapt to changing computational requirements such as emerging standards, late design changes, and even to changing processing requirements arising at run-time. Reconfigurable computing thus benefits from a) the programmability of software similar to the Von Neumann computer and b) the speed and efficiency of parallel hardware execution. The purpose of the course reconfigurable computing is to instruct students about the possibilities and rapidly growing interest in adaptive hardware and corresponding design techniques by providing them the necessary knowledge for understanding and designing reconfigurable hardware systems and studying applications benefiting from dynamic hardware reconfiguration. After a general introduction about benefits and application ranges of reconfigurable (adaptive) computing in contrast to general-purpose and application-specific computing, the following topics will be covered: • Reconfigurable computing systems: Introduction of available technology including fine grained look up table (LUT-) based reconfigurable systems such as field programmable gate arrays (FPGA) as well as newest coarse grained architectures and technology. • Design and implementation: Algorithms and steps (design entry, functional simulation, logic synthesis, technology mapping, place and route, bit stream generation) to implement (map) algorithms to FPGAs. The main focus lies on logic synthesis algorithms for FPGAs, in particular LUT technology mapping. • Temporal partitioning: techniques to reconfigure systems over time. Covered are the problems of mapping large circuits

		which do not fit one single device. Several temporal partitioning techniques are studied and compared. • Temporal placement: Techniques and algorithms to exploit the possibility of partial and dynamic (run-time) hardware reconfiguration. Here, OS-like services are needed that optimize the allocation and scheduling of modules at run-time. • On-line communication: Modules dynamically placed at run-time on a given device need to communicate as well as transport data off-chip. State-of-the-art techniques are introduced how modules can communicate data at run-time including bus-oriented as well as network-on-a-chip (NoC) approaches. • Designing reconfigurable applications on Xilinx Virtex FPGAs: In this part, the generation of partial bitstreams for components to be placed at run-time on Xilinx FPGAs is introduced and discussed including newest available tool flows. • Applications: This section presents applications benefiting from dynamic hardware reconfiguration. It covers the use of reconfigurable systems including rapid prototyping, reconfigurable supercomputers, reconfigurable massively parallel computers and studies important application domains such as distributed arithmetic, signal processing, network packet processing, control design, and cryptography.
6	**Learning objectives and skills**	**Learning objectives and competencies:** Domain-specific knowledge • The students know to exploit run-time reconfigurable design methodologies for adaptive applications. Domain-specific comprehension • The students understand the mapping steps, and optimization algorithms. • The students classify different types and kinds of reconfigurable hardware technologies available today. • The students clarify pros and cons of reconfigurable computing technology. • The students summarize applications benefiting from reconfigurable computing. Domain-specific practice • The students apply design tools for implementation of circuits and systems-on-a-chip (SoC) on FPGAs during practical training. Social competency • The students perform group work in small teams during practical training.

7	**Prerequisites**	Selection of this module prohibits the selection of the modules "Reconfigurable Computing" or "Reconfigurable Computing (Lecture with Exercises)" by the student.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 90 h Independent study: 135 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Further reading material: • The Hamburg VHDL Archive (see Documentation link for free books) http://tams-www.informatik.uni-hamburg.de/research/vlsi/vhdl/index.php • Interactive VHDL Tutorial with 150 examples from ALDEC http://www.aldec.com/downloads/ • Easy FPGA tutorials, projects, and boards http://www.fpga4fun.com • Xilinx WebPack ISE and Modelsim MXE (free FPGA synthesis tool and free VHDL simulator) http://www.xilinx.com/ise/logic_design_prod/webpack.htm • Symphony EDA free VHDL simulator (select FREE Edition license) http://www.symphonyeda.com/products.htm • Icarus open-source Verilog simulator http://www.icarus.com/eda/verilog/ Further information: https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/reconfigurable-computing/

1	**Module name** 93185	**Reinforcement Learning**	**5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	Dr.-Ing. Christopher Mutschler
5	**Contents**	The lecture aims at teachin Reinforcement Learning (RL) and will cover the following topics: • Introduction to Reinforcement Learning (Agent-Environment-Interface, Markov Decision Processes) • Dynamic Programming (Bellman Equations, Value Iteration, Policy Iteration) • Model-Free Prediction • Model-Free Control • Value Function Approximation (Linear VFA and DQNs) • Policy-based Reinforcement Learning (Monte-Carlo Policy Gradient, Advantage Estimators, TRPO, PPO) • Model-based RL • Offline RL • Explainable RL • Exploration-Exploitation • Simulation to Reality Transfer • Research frontiers & hot topics, Sim2Real & Real-World Applications
6	**Learning objectives and skills**	The students will learn to • understand the basic principle behind sequestration decision making problems and how to translate them into a formal model • compare and analyze methods different agents to search for policies • implement the presented methods in PyTorch, • discuss the social impact of applications that automate decision making
7	**Prerequisites**	Es handelt sich hier um eine Spezialisierungsvorlesung, eine erfolgreiche Absolvierung der Vorlesungen IntroPR" und/oder Pattern Recognition"/"Pattern Analysis" wird empfohlen. Konzepte, die in IntroPR" vermittelt werden, werden hier als Grundwissen vorausgesetzt.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Variabel
11	**Grading procedure**	Variabel (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester

16	**Teaching and examination language**	Englisch
17	**Bibliography**	• Richard S. Sutton and Andrew G. Barto. 2018. Reinforcement Learning: An Introduction. A Bradford Book, Cambridge, MA, USA. • Bellman, R.E. 1957. Dynamic Programming. Princeton University Press, Princeton, NJ. Republished 2003: Dover, ISBN 0-486-42809-5. • Csaba Szepesvari and Ronald Brachman and Thomas Dietterich. 2010. Algorithms for Reinforcement Learning. Morgan and Claypool Publishers. • Warren B. Powell. 2011. Approximate Dynamic Programming. Wiley. • Maxim Lapan. 2020. Deep Reinforcement Learning Hands-On: Apply modern RL methods to practical problems of chatbots, robotics, discrete optimization, web automation, and more, 2nd Edition. Packt Publishing. • Dimitri P. Bertsekas. 2017. Dynamic Programming and Optimal Control. Athena Scientific. • Miguel Morales. 2020. grokking Deep Reinforcement Learning. Manning. • Laura Graesser and Keng Wah Loon. 2019. Foundations of Deep Reinforcement Learning: Theory and Practice in Python. Addison-Wesley Data & Analytics.

1	**Module name** 44521	**Selected Topics of Deep Learning for Audio, Speech, and Music Processing**	**2,5 ECTS**
2	Courses / lectures	No courses / lectures available for this module!	
3	Lecturers	No lecturers available since there are no courses / lectures for this module!	

4	**Module coordinator**	
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 0
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich (30 Minuten)
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	no Module frequency information available!
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
15	**Module duration**	?? Semester (keine Angaben zur Dauer des Moduls hinterlegt)
16	**Teaching and examination language**	Deutsch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 43960	**Self-Organized Networks**	**5 ECTS**
2	Courses / lectures	Übung: Self-organized networks (Ex) (2 SWS) Vorlesung: Self-organized networks (2 SWS)	- -
3	Lecturers	Dr.-Ing. Mehdi Harounabadi	

4	**Module coordinator**	Dr.-Ing. Mehdi Harounabadi
5	**Contents**	no content description available!
6	**Learning objectives and skills**	no learning objectives and skills description available!
7	**Prerequisites**	Self-organized networks (2,5 ECTS) Self-organization refers to processes in physical and biological systems which form patterns by interactions of internal parts of the system and/or their interactions with the environment without any form of external interventions. The resulting organization of systems in this case is fully decentralized and distributed over their parts. There are numerous examples of self-organizing systems e.g. flock of birds, neural learning, evolutionary computation, swarm of robots, and self-organizing networks. The principles of self-organization are applied in different communication technologies such as wired and wireless networks. Transport Control Protocol (TCP), Carrier Sense Multiple Access (CSMA), Adaptive Modulation and Coding (AMC) are some examples of self-organized protocols. Besides, Self-Organizing Network (SON) has been defined by 3GPP as the standardization organization of cellular networks. SON refers to the functionality of cellular systems (e.g. 4G and 5G) which enables the system to perform self-configuration, self-optimization and self-healing. Artificial intelligence and mostly machine learning algorithms play an important role in the implementation of SON. This course aims to give you an insight to the self-organization systems and specially self-organizing networks and illustrate the importance of AI and ML in their implementation. The content of this course includes: • o Self-organizing features and protocols in communication networks o In wired networks o In wireless networks § IEEE 802.11 § Ad hoc and sensor networks § UAV networks o Self-Organizing Networks (SON) in 4G and 5G § Self-configuration § Self-optimization § Self-healing Methods for implementation of self-organizing systems o Bio-inspired methods o Artificial intelligence The final exam is in a written form where students should answer to questions based on the lectures, slides and their understating and analysis from the content of the course.
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Variabel
11	**Grading procedure**	Variabel (100%)

12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	Literature review on self-organizing networks (2,5 ECTS) The exercise of this course includes a literature review research project where students work individually on a relevant topic. The steps to accomplish the research project are as follows: A. Select a topic relevant to self-organizing networks and register it by email B. Search for the relevant papers and make a list of papers C. Study the papers and prepare a summary D. Present the outcomes

1	**Module name** 250058	**Signal analysis**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Signalanalyse (2 SWS)	-
3	Lecturers	Dr.-Ing. Heinrich Löllmann	

4	**Module coordinator**	Dr.-Ing. Heinrich Löllmann
5	**Contents**	Es werden im Rahmen dieser Vorlesung unterschiedliche Verfahren zur Analyse digitaler Signale, sowie deren Anwendungsmöglichkeiten behandelt. Die folgenden Konzepte werden dabei insbesondere behandelt: • Fourieranalyse von Signalen • Signalanalyse mittels Zeit-Frequenz-Transformationen • Parametrische und nichtparametrische Signalanalyse • Verfahren zur Frequenzschätzung • Räumliche Signalanalyse • Filterbänke und Wavelets. In this course, different approaches for the analysis of digital signals and their applications are treated, which comprises the following topics: • Fourier analysis of signals • Signal analysis by means of time-frequency transformations • Parametric and non-parametric signal analysis • Frequency estimation • Spatial signal analysis • Filter-banks and wavelets.
6	**Learning objectives and skills**	Die Studierenden • beschreiben, welche Methoden der Signalanalyse für unterschiedlichen Arten von Signalen angewendet werden • beschreiben grundlegende Methoden der spektralen Signalanalyse • erläutern wodurch die spektrale und zeitliche Auflösung bei der Spektralanalyse von Signalen begrenzt wird • beschreiben die Konzepte sowie die Vor- und Nachteile der parametrischen und nichtparametrischen Signalanalyse • erklären unterschiedliche Verfahren der Zeit-Frequenz-Analyse • stellen die Analyse von Signalen mittels Filterbänke und Wavelets dar • können Verfahren zur Frequenzschätzung erläutern • formulieren Verfahren zur Analyse räumlicher Signale. The students • describe which methods for signal analysis can be applied for different types of signals • describe fundamental approaches for spectral signal analysis • explain the limiting factors for the time and frequency resolution for the spectral analysis of signals

		• describe concepts as well as the pros and cons of parametric and non-parametric signal analysis • explain different approaches for time-frequency analysis • describe the analysis of signals by means of filter-banks and wavelets • explain methods for frequency estimation • formulate approaches for spatial signal analysis.
7	**Prerequisites**	Fundierte Kenntnisse in digitaler Signalverarbeitung. Requirements Solid knowledge in digital signal processing
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich Mündliche Prüfung mit einer Dauer von 30 min. Oral examination of 30 min duration.
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch
17	**Bibliography**	P. Stoica und R. Moses: "Spectral Analysis of Signals", Pearson Prentice Hall, 2005

1	**Module name** 96880	**Speech enhancement**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Speech Enhancement (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Emanuël Habets	

4	**Module coordinator**	Prof. Dr. Emanuël Habets
5	**Contents**	**Description** We live in a noisy world! In all applications related to speech, from hands-free communication to human-machine interfaces, a speech signal of interest captured by one or more microphones is contaminated by noise and reverberation. The quality and intelligibility of the signal of interest depend highly on the level of noise and reverberation. Therefore, it is highly desirable, and sometimes even indispensable, to "clean up" the captured signals before storage, transmission, or reproduction. This course discusses both model-driven and data-driven methods to estimate the signal of interest and aims to provide a strong foundation for researchers, engineers, and graduate students interested in signal and speech enhancement. **Relation to other courses** This course is the most advanced course offered by the university on this topic and serves as an excellent basis from which to commence research in the area. Various aspects of the course bring students up to date with the very latest developments in the field, as seen in recent international conferences and journals. This course is well complimented by |Selected Topics in Perceptual Audio Coding| (Prof. Herre) and | Auditory Models| (Prof. Edler).
6	**Learning objectives and skills**	• Formulate the speech enhancement problem mathematically. • Derive optimal single- and multi-channel filters to reduce noise and reverberation. • Evaluate and compare the performance of single- and multi-channel filters for speech enhancement. • Understand how reference signals and other prior information can be used in a speech enhancement system. • Understand the limitations and challenges of existing speech enhancement systems. • Understand the importance of binaural cues and the influence of a speech enhancement system on the binaural cues in the context of hearing aids. • Design a microphone array and analyze its performance.

		• Design a speech enhancement system for a given acoustic scenario. • Evaluate subjectively and objectively the performance of a speech enhancement system in terms of speech quality and intelligibility.
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Deutsch oder Englisch
17	**Bibliography**	no Bibliography information available!

1	**Module name** 498723	**Transforms in signal processing**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Transformationen in der Signalverarbeitung (2 SWS)	2,5 ECTS
3	Lecturers	PD Dr.Ing. Jürgen Seiler	

4	**Module coordinator**	PD Dr.Ing. Jürgen Seiler
5	**Contents**	Das Modul "Transformationen in der Signalverarbeitung" behandelt mehrere verschiedene Transformationen, die im Rahmen der Signalverarbeitung Verwendung finden. Dabei werden zuerst die grundlegenden Konzepte von Transformationen diskutiert und die Vorteile die Transformationen mit sich bringen erläutert. Im Anschluss daran werden die grundlegenden Eigenschaften von Integraltransformationen betrachtet und die Laplace- und die Fourier-Transformation im Detail untersucht. Um auch zeitlich veränderliche Signale gut transformieren zu können werden danach die Kurzzeit-Fourier-Transformation und die Gabor-Transformation eingeführt. Im Anschluss daran erfolgt eine Betrachtung der Auswirkung der Abtastung auf transformierte Signale, bevor die z-Transformation als Transformation für diskrete Signale behandelt wird. Abschließend erfolgt die Betrachtung weiterer Transformationen für diskrete Signale wie der Diskreten Fourier-Transformation oder linearer Block-Transformationen. The module "Transforms in Signal Processing" covers several different transforms which are used in the field of signal processing. For this, first the basic concepts of transforms are discussed and the advantages which are offered by the different transforms are presented. Subsequent to this, fundamental properties of integral transforms are considered and the Laplace- and the Fourier-Transform are examined in detail. To be able to transform time-varying signals, the Short-Time Fourier-Transform and the Gabor-Transform are introduced, afterwards. Subsequent to this, the impact of sampling on transformed signals is analyzed before the z-Transform as a transform for discrete signals is covered. Finally, further transforms for discrete signals like the Discrete Fourier-Transform or Linear-Block Transforms are discussed.
6	**Learning objectives and skills**	Die Studierenden können nach Besuch der Vorlesung • Anwendungsmöglichkeiten von Transformationen bestimmen • Integraltransformationen gegenüberstellen und untersuchen • die Existenz von Transformationen hinterfragen • die Eindeutigkeit von Transformationen überprüfen • Sätze und Eigenschaften von Transformationen entwickeln • zu Transformationen zugehörige inverse Transformationen einschätzen • die Zusammenhänge zwischen verschiedenen Transformationen einschätzen • auf Zusammenhänge zwischen Ausgangssignalen und transformierten Signalen folgern • Symmetriebeziehungen von Transformationen ausarbeiten

		• Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten Educational Objectives and Competences: After attending the lecture, students will be able to • determine applications of transforms • contrast and examine integral transforms • question the existence of transforms • evaluate the uniqueness of transforms • develop theorems and properties of transforms • evaluate to transforms corresponding inverse transforms • evaluate the relationships between different transforms • asses the relationship between original signal and transformed signals • devise the symmetry properties of transforms • devise the relationship between continuous and discrete signals
7	**Prerequisites**	None
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	mündlich
11	**Grading procedure**	mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Deutsch
17	**Bibliography**	K. Krüger, Transformationen - Grundlagen und Anwendungen in der Nachrichtentechnik, Vieweg Verlag, Braunschweig B. Girod, R. Rabenstein, A. Stenger, Einführung in die Systemtheorie, B. G. Teubner Verlag, Stuttgart

1	**Module name** 43420	**Transmission and detection for advanced mobile communications**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Transmission and Detection for Advanced Mobile Communications (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Wolfgang Gerstacker	

4	**Module coordinator**	Prof. Dr. Wolfgang Gerstacker
5	**Contents**	The aim of this lecture is that the students acquire a basic knowledge of advanced transmission and detection techniques which are relevant to practical mobile communications systems. In the first part, it is shown how equalization schemes like decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE) can be applied to the GSM/EDGE (Enhanced Data Rates for GSM Evolution) standard. Also, channel estimation for GSM/EDGE is covered. In GSM/EDGE, disturbance by interfering signals of other users is a further major problem. Therefore, interference cancellation algorithms are discussed in detail. The cases of several receive antennas and one receive antenna (single antenna interference cancellation) are distinguished. Several receive antennas can be also utilized for increasing the robustness against fading, applying diversity combination techniques. In the case of the availability of several transmit antennas only, additional space-time coding has to be used for realization of diversity gains. These aspects are also discussed in depth. Furthermore, an introduction to code-division multiple access (CDMA) transmission is given and it is shown how CDMA is applied in the UMTS system. The lecture is concluded by an introduction to digital transmission in the Long Term Evolution (LTE) system.
6	**Learning objectives and skills**	The students • describe basic equalization algorithms such as decision-feedback equalization (DFE) and maximum-likelihood sequence estimation (MLSE), • apply equalization algorithms to the GSM / Enhanced Data Rates for GSM Evolution (EDGE) mobile communication system, • formulate channel estimation methods for mobile communication systems, • characterize the interference problem in GSM / EDGE, - design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively, • characterize the performance of mobile communication networks for different reception schemes, • devise receivers for the realization of diversity gains for multiple receive antennas,

		• design space-time coding schemes for the realization of diversity gains for multiple transmit antennas, • describe transmission schemes which are based on code-division multiple access (CDMA), • apply reception techniques for CDMA to the UMTS system, • characterize the uplink transmission in the Long Term Evolution (LTE) system, • develop receivers for LTE. Die Studierenden • beschreiben grundlegende Entzerrverfahren wie entscheidungsrückgekoppelte Entzerrung (Decision-Feedback Equalization, DFE) und Maximum-Likelihood-Sequenzschätzung (Maximum-Likelihood Sequence Estimation, MLSE), • wenden Entzerrverfahren auf das GSM/EDGE (Enhanced Data Rates for GSM Evolution) Mobilfunksystem an, • formulieren Kanalschätzverfahren für Mobilfunksysteme, • charakterisieren das Interferenzproblem bei GSM/EDGE, • entwerfen Interferenzunterdrückungsverfahren für GSM/EDGE für Empfänger mit einer Antenne (Single Antenna Interference Cancellation) und mehreren Antennen, • bewerten die Leistungsfähigkeit von Mobilfunknetzen bei Einsatz verschiedener Empfangsverfahren, • konzipieren Empfänger zur Realisierung von Diversitätsgewinnnen bei empfangsseitiger Antennendiversität • entwerfen Space-Time-Codierverfahren zur Realisierung von Diversitätsgewinnen bei sendeseitiger Antennendiversität, • beschreiben auf Code-Division Multiple Access (CDMA) basierende Übertragungsverfahren, • wenden Empfangsverfahren für CDMA auf das UMTS-System an, • charakterisieren die Aufwärtsstrecke von Long Term Evolution (LTE), • entwerfen Empfänger für LTE.
7	**Prerequisites**	Systemtheorie, Nachrichtenübertragung
8	**Integration in curriculum**	no Integration in curriculum available!
9	**Module compatibility**	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	schriftlich oder mündlich
11	**Grading procedure**	schriftlich oder mündlich (100%)
12	**Module frequency**	nur im Sommersemester
13	**Resit examinations**	The exams of this moduls can only be resit once.
14	**Workload in clock hours**	Contact hours: 30 h Independent study: 45 h
15	**Module duration**	1 Semester
16	**Teaching and examination language**	Englisch

17	**Bibliography**	Lecture notes

1	**Module name** 48432	**Game theory with Applications to Information Engineering**	**2,5 ECTS**
2	Courses / lectures	Vorlesung: Game Theory with Applications to Information Engineering (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr. Veronika Grimm	

4	**Module coordinator**	
5	**Contents**	The course is an introduction to the fundamentals of game theory and mechanism design. Motivations are drawn from topics in information engineering and networked systems (e.g. incentive-compatible/dynamic resource allocation in networks, distributed control of wireline and wireless communication networks, multi-agent systems, pricing and investment decisions in the Internet). Also social and economic contexts will be covered in order to put the engineering applications into a broader perspective. The course emphasizes theoretical foundations of game theory and develops knowledge on the standard equilibrium notions in different environments.
6	**Learning objectives and skills**	Students acquire a more formal understanding of game theoretical concepts and learn to differentiate between different types of games and their appropriate solution concepts, including Strategic Form Games, Dynamic Games with Complete Information, Static Games with Incomplete Information, and Dynamic Games with Incomplete Information. They learn the applications of these concepts to real-world multi-person decision problems and to give predictions based on the equilibrium concepts studied in the course.
7	**Prerequisites**	Basic knowledge of game theory and its core applications
8	**Integration in curriculum**	Semester: 2
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur (60 Minuten) The exam covers all materials from the lectures and exercise classes.
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	nur im Sommersemester
13	**Workload in clock hours**	Contact hours: ?? h (keine Angaben zum Arbeitsaufwand in Präsenzzeit hinterlegt) Independent study: ?? h (keine Angaben zum Arbeitsaufwand im Eigenstudium hinterlegt)
14	**Module duration**	1 Semester Semester
15	**Teaching and examination language**	Deutsch
16	**Bibliography**	Main: Fudenberg, D. and Tirole, J. (2007), Game Theory, Cambridge, MIT Press. Further:

		Osborne, M. and Rubenstein, A. (1994), A Course in Game Theory, Cambridge, MIT Press.

1	**Module name** 48410	**Information theory and coding**	**5 ECTS**
2	Courses / lectures	Übung: Tutorial for Information Theory and Coding (1 SWS) Vorlesung: Information Theory and Coding (3 SWS)	- 5 ECTS
3	Lecturers	Dr.-Ing. Ali Bereyhi Prof. Dr.-Ing. Ralf Müller	

4	**Module coordinator**	Prof. Dr.-Ing. Ralf Müller
5	**Contents**	1. Introduction: binomial distribution, (7,4)-Hamming code, parity-check matrix, generator matrix 2. Probability, entropy, and inference: entropy, conditional probability, Bayes law, likelihood, Jensens inequality 3. Inference: inverse probability, statistical inference 4. The source coding theorem: information content, typical sequences, Chebychev inequality, law of large numbers 5. Symbol codes: unique decidability, expected codeword length, prefix-free codes, Kraft inequality, Huffman coding 6. Stream codes: arithmetic coding, Lempel-Ziv coding, Burrows-Wheeler transform 7. Dependent random variables: mutual information, data processing lemma 8. Communication over a noisy channel: discrete memory-less channel, channel coding theorem, channel capacity 9. The noisy-channel coding theorem: jointly-typical sequences, proof of the channel coding theorem, proof of converse, symmetric channels 10. Error-correcting codes and real channels: AWGN channel, multivariate Gaussian pdf, capacity of AWGN channel 11. Binary codes: minimum distance, perfect codes, why perfect codes are bad, why distance isnt everything 12. Message passing: distributed counting, path counting, low-cost path, min-sum (=Viterbi) algorithm 13. Exact marginalization in graphs: factor graphs, sum-product algorithm 14. Low-density parity-check codes: density evolution, check node degree, regular vs. irregular codes, girth

15. Lossy source coding: transform coding and JPEG compression

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1. Einleitung: Binomialverteilung, (7,4)-Hamming-Code, Paritätsmatrix, Generatormatrix

2. Wahrscheinlichkeit, Entropie und Inferenz: Entropie, bedingte Wahrscheinlichkeit, Bayessches Gesetz, Likelihood, Jensensche Ungleichung

3. Inferenz: Inverse Wahrscheinlichkeit, statistische Inferenz

4. Das Quellencodierungstheorem: Informationsgehalt, typische Folgen, Tschebyschevsche Ungleichung, Gesetz der großen Zahlen

5. Symbolcodes: eindeutige Dekodierbarkeit, mittlere Codewortlänge, präfixfreie Codes, Kraftsche Ungleichung, Huffmancodierung

6. Stromcodes: arithmetische Codierung, Lempel-Ziv-Codierung, Burrows-Wheeler-Transformation

7. Abhängige Zufallsvariablen: Transinformation, Datenverarbeitungslemma

8. Kommunikation over gestörte Kanäle: diskreter gedächtnisloser Kanal, Kanalcodierungstheorem, Kanalkapazität

9. Das Kanalcodierungstheorem: verbundtypische Folgen, Beweis des Kanalcodierungstheorems, Beweis des Umkehrsatzes, symmetrische Kanaäle

10. Fehlerkorrigierende Codes und reale Kanäle: AWGN-Kanal, mehrdimensionale Gaußsche WDF, Kapazität des AWGN-Kanals

11. Binäre Codes: Minimaldistanz, perfekte Codes, Warum perfekte Codes schlecht sind, Warum Distanz nicht alles ist

12. Nachrichtenaustausch: verteiltes Zählen, Pfadzählen, günstigster Pfad, Minimumsummenalgorithmus

13. Exakte Marginalisierung in Graphen: Faktorgraph, Summenproduktalgorithmus

14. LDPC-Codes: Dichteevolution, Knotenordnung, reguläre und irreguläre Codes, Graphumfang

		15. Verlustbehaftete Quellencodierung: Transformationscodierung und JPEG-Kompression
6	**Learning objectives and skills**	The students apply Bayesian inference to problems in both communications and everyday's life. The students explain the concept of digital communications by means of source compression and forward-error correction coding. For the design of communication systems, they use the concepts of entropy and channel capacity. They calculate these quantities for memoryless sources and channels. The students proof both the source coding and the channel coding theorem. The students compare various methods of source coding with respect to compression rate and complexity. The students apply source compression methods to measure mutual information. The students factorize multivariate functions, represent them by graphs, and marginalize them with respect to various variables. The students explain the design of error-correcting codes and the role of minimum distance. They decode error-correcting codes by means of maximum-likelihood decoding and message passing. The students apply distributed algorithms to problems in both communications and everydays life. The students improve the properties of low-density parity-check codes by widening the girth and/or irregularity in the degree distribution. The students transform source images into the frequency domain to improve lossy compression. -- Die Studierenden wenden Bayessche Inferenz auf Probleme in der Nachrichtentechnik und im Alltagsleben an. Die Studierenden erklären die konzeptuelle Trennung von digitaler Übertragung in Quellen- und Kanalcodierung.

		Kommunikationssysteme entwerfen sie unter Betrachtung von Entropie und Kanalkapazität. Sie berechnen diese Größen für gedächtnislose Quellen und Kanäle. Die Studierenden beweisen sowohl das Quellen- als auch das Kanalcodierungstheorem. Die Studierenden vergleichen verschiedenartige Quellencodierungsverfahren hinsichtlich Komplexität und Kompressionsrate. Die Studierenden verwenden Quellencodierverfahren zur Messung von Transinformation. Die Studierenden faktorisieren Funktionen mehrerer Veränderlicher, stellen diese als Graph dar und marginalisieren sie bezüglich mehrerer Veränderlicher. Die Studierenden erklären den Entwurf von Kanalcodes und den Einfluss der Minimaldistanz. Sie decodieren Kanalcodes gemäß maximaler Likelihood und Nachrichtenaustausch. Die Studierenden wenden verteilte Algorithmen auf Probleme der Nachrichtentechnik und des Alltagslebens an. Die Studierenden verbessern die Eigenschaften von LDPC-Codes durch Erhöhung des Umfangs und/oder durch irreguäre Knotenordnungsverteilungen. Die Studierenden transformieren Bildquellen zur Verbesserung verlustbehafteter Kompression iin den Frequenzbereich.
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur (90 Minuten)
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	in jedem Semester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Englisch
16	**Bibliography**	MacKay, D.: Information Theory, Inference, and Learning Algorithms, Cambridge University Press, Cambridge, 2003.

1	**Module name** 48440	**Machine learning in signal processing**	**5 ECTS**
2	Courses / lectures	Übung: Supplements for Machine Learning in Signal Processing (1 SWS) Vorlesung: Machine Learning in Signal Processing (3 SWS)	- 5 ECTS
3	Lecturers	Kamal Gopikrishnan Nambiar Prof. Dr. Vasileios Belagiannis	

4	**Module coordinator**	PD Dr.Ing. Jürgen Seiler
5	**Contents**	This course is an introduction into machine learning and artificial intelligence. The special emphasis is on applications to modern signal processing problems. The course is focused on design principles of machine learning algorithms. The lectures start with a short introduction, where the nomenclature is defined. After this, probabilistic graphical models are introduced and the use of latent variables is discussed, concluding with a discussion of hidden Markov models and Markov fields. The second part of the course is about deep learning and covers the use of deep neural networks for machine learning tasks. In the last part of the lecture, the use of deep neural networks for speech processing tasks is introduced. The course is based on the materials and video footage from Dr. Roland Maas. He is an outstanding machine learning expert and a former member of the Chair of Multimedia Communications and Signal Processing.
6	**Learning objectives and skills**	After attending the lecture, students will be able to • understand regression and classification problems • apply PDF estimation algorithms • understand Gaussian mixture models and expectation-maximization • apply principal component analysis and independent component analysis • assess different estimation algorithms • explain the application of machine learning to system identification • apply hidden Markov models • understand different artificial neural network architectures • explain deep learning principles • apply artificial neural networks • devise learning strategies for deep neural networks • assess the application of deep neural networks for speech processing tasks.
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212

10	**Method of examination**	schriftlich/mündlich
11	**Grading procedure**	schriftlich/mündlich (100%)
12	**Module frequency**	nur im Wintersemester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Englisch
16	**Bibliography**	Literature: • C. M. Bishop: Pattern Recognition and Machine Learning, http://www.research.microsoft.com/en-us/um/people/cmbishop/PRML • S. Theodoridis and K. Koutroumbas: Pattern Recognition • M. Nielsen: Neural Networks and Deep Learning.

1	**Module name** 48400	**Mathematical optimization in communications and signal processing**	**5 ECTS**
2	Courses / lectures	Vorlesung: Mathematical Optimization for Communications & Signal Processing (2 SWS)	5 ECTS
3	Lecturers	Prof. Dr. Frauke Liers-Bergmann Florian Rösel Martina Kuchlbauer	

4	**Module coordinator**	Prof. Dr. Frauke Liers-Bergmann
5	**Contents**	Content: The focus of this module is on methods for modeling and solving optimization problems as they occur in the field communication and signal processing. Starting from practical applications, different classes of optimization problems are introduced that include linear, mixed-integer linear, continuous non-linear as well as mixed-integer non-linear optimization problems. Advantages and disadvantages of different modeling techniques will be outlined and different reformulations will be presented in order to achieve efficient solution approaches. Students will learn how to present optimization results properly as well as how to interpret and evaluate these results for practical applications in communications and signal processing.
6	**Learning objectives and skills**	The students a)have an overview over mathematical optimization in practice b)apply mathematical optimization modeling and solution techniques c)decide which solution approaches are suitable for which class of models d)know available software and how to use it
7	**Prerequisites**	None
8	**Integration in curriculum**	Semester: 1
9	**Module compatibility**	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	**Method of examination**	Klausur (90 Minuten)
11	**Grading procedure**	Klausur (100%)
12	**Module frequency**	nur im Wintersemester
13	**Workload in clock hours**	Contact hours: 60 h Independent study: 90 h
14	**Module duration**	1 Semester
15	**Teaching and examination language**	Englisch
16	**Bibliography**	no Bibliography information available!