

Module description

for the degree programme

Master of Science Advanced

Signal Processing &

Communications Engineering

(Version of examination regulation: 20212)

for the summer term 2025

Table of contents

Master's thesis (1999).....	4
Mathematical optimization in communications and signal processing (48400).....	5
Information theory and coding (48410).....	6
Statistical Signal Processing (48420).....	9
Machine learning in signal processing (48440).....	12
Selected Topics in ASC (48451).....	14
Deep Learning (48455).....	16
Kick-Off Seminar, Winter and Summer School (48460).....	18
Research Project (Major) (48470).....	20
Technical Mandatory Electives	
Mobile communications (43141).....	23
Quality of service in communication systems (44362).....	25
Embedded systems (44410).....	27
Research Project (Minor) (48480).....	30
Introduction to modern cryptography (93015).....	32
MIMO communication systems (96300).....	33
Image and video compression (96310).....	35
Advanced communication networks (151664).....	38
Channel coding on graphs (412023).....	42
Human computer interaction (645618).....	45
Communcations systems design (700506).....	48
Technical Lab Courses	
Laboratory course: Communications systems design (92356).....	51
Laboratory course: Image and video signal processing on embedded platforms (97525).....	53
Laboratory course: Mobile communication (97640).....	55
Laborpraktikum Multimediakommunikation (97651).....	58
Lab course machine learning in signal processing (878210).....	60
Audio processing laboratory (894349).....	62
Laboratory course: Numerical methods for semiconductor components (92504).....	64
Laborpraktikum Digitale Signalverarbeitung (97520).....	66
Digital communication Lab (93511).....	68
Laboratory architectures for digital signal processing (182405).....	72
Technical Electives	
Equalisation and adaptive systems for digital communications (43400).....	75
Transmission and detection for advanced mobile communications (43420).....	78
Pattern analysis (44120).....	81
Pattern recognition (44130).....	83
Audio processing for the Internet of Things (44522).....	86
Compressive sensing (48447).....	88
Reinforcement learning (93185).....	91
Channel coding (96270).....	93
Image, video and multidimensional signal processing (96312).....	97
Radar, RFID and wireless sensor systems (RWS) (96316).....	99
Introduction to deep learning (43405).....	101
Computer vision (713618).....	103
Advanced topics in deep learning (42800).....	105
Next Generation Mobile Communication Systems: 5G-Advanced and 6G (96065).....	107
Speech enhancement (96880).....	109
Signal analysis (250058).....	111

Linear and non-linear fibre optics (267499).....	113
Machine learning for time series (428256).....	115
Image, video and multidimensional signal processing (447324).....	117
Random matrices in communications and signal processing (451971).....	118
Molecular communications (454183).....	120
Transforms in signal processing (498723).....	122
Advanced optical communication systems (621649).....	124
Machine learning in communications (668129).....	126
Multiuser information and communications theory (687141).....	127
Body area communications (816185).....	129
Advanced networking LEx (869547).....	131
Music Processing (916185).....	133
Approximate computing (965820).....	134
Communications systems design (92355).....	136
Radar signal processing (44400).....	138
Architectures for digital signal processing (96010).....	141
Convex optimization in communications and signal processing (96850).....	143
Microwave technology (92720).....	145
Speech and audio signal processing (96460).....	147
Biomedical signal analysis (23070).....	149
Communication networks (92290).....	153
Seminar on Selected Topics in Machine Learning (92374).....	155
Reconfigurable computing (43190).....	157
Advanced deep learning (93873).....	160

1	Module name 1999	Master's thesis (M.Sc. Advanced Signal Processing & Communications Engineering 20212) Master's thesis	30 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	no Integration in curriculum available!
9	Module compatibility	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Written or oral (6 Monate)
11	Grading procedure	Written or oral (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 (no information for Module duration available)
16	Teaching and examination language	german
17	Bibliography	

1	Module name 48400	Mathematical Optimization in Communications and Signal Processing Mathematical optimization in communications and signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Frauke Liers-Bergmann	
5	Contents	<p>Content:</p> <p>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.</p>	
6	Learning objectives and skills	<p>The students</p> <p>a) have an overview over mathematical optimization in practice</p> <p>b) apply mathematical optimization modeling and solution techniques</p> <p>c) decide which solution approaches are suitable for which class of models</p> <p>d) know available software and how to use it</p>	
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	Written examination (90 minutes)	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in winter semester	
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h	
14	Module duration	1 semester	
15	Teaching and examination language	english	
16	Bibliography		

1	Module name 48410	Information Theory and Coding Information theory and coding	5 ECTS
2	Courses / lectures	Übung: Informationstheorie und Codierung - Übung (1 SWS) Vorlesung: Informationstheorie und Codierung (3 SWS)	- 5 ECTS
3	Lecturers	Prof. Dr.-Ing. Ralf Müller Johanna Fröhlich	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	<p>1. Introduction: binomial distribution, (7,4)-Hamming code, parity-check matrix, generator matrix</p> <p>2. Probability, entropy, and inference: entropy, conditional probability, Bayes law, likelihood, Jensens inequality</p> <p>3. Inference: inverse probability, statistical inference</p> <p>4. The source coding theorem: information content, typical sequences, Chebychev inequality, law of large numbers</p> <p>5. Symbol codes: unique decidability, expected codeword length, prefix-free codes, Kraft inequality, Huffman coding</p> <p>6. Stream codes: arithmetic coding, Lempel-Ziv coding, Burrows-Wheeler transform</p> <p>7. Dependent random variables: mutual information, data processing lemma</p> <p>8. Communication over a noisy channel: discrete memory-less channel, channel coding theorem, channel capacity</p> <p>9. The noisy-channel coding theorem: jointly-typical sequences, proof of the channel coding theorem, proof of converse, symmetric channels</p> <p>10. Error-correcting codes and real channels: AWGN channel, multivariate Gaussian pdf, capacity of AWGN channel</p> <p>11. Binary codes: minimum distance, perfect codes, why perfect codes are bad, why distance isnt everything</p> <p>12. Message passing: distributed counting, path counting, low-cost path, min-sum (=Viterbi) algorithm</p> <p>13. Exact marginalization in graphs: factor graphs, sum-product algorithm</p> <p>14. Low-density parity-check codes: density evolution, check node degree, regular vs. irregular codes, girth</p> <p>15. Lossy source coding: transform coding and JPEG compression</p> <p>--</p> <p>1. Einleitung: Binomialverteilung, (7,4)-Hamming-Code, Paritätsmatrix, Generatormatrix</p> <p>2. Wahrscheinlichkeit, Entropie und Inferenz: Entropie, bedingte Wahrscheinlichkeit, Bayessches Gesetz, Likelihood, Jensensche Ungleichung</p> <p>3. Inferenz: Inverse Wahrscheinlichkeit, statistische Inferenz</p> <p>4. Das Quellencodierungstheorem: Informationsgehalt, typische Folgen, Tschebyschevsche Ungleichung, Gesetz der großen Zahlen</p> <p>5. Symbolcodes: eindeutige Dekodierbarkeit, mittlere Codewortlänge, präfixfreie Codes, Kraftsche Ungleichung, Huffmancodierung</p>

		<p>6. Stromcodes: arithmetische Codierung, Lempel-Ziv-Codierung, Burrows-Wheeler-Transformation</p> <p>7. Abhängige Zufallsvariablen: Transinformation, Datenverarbeitungslemma</p> <p>8. Kommunikation over gestörte Kanäle: diskreter gedächtnisloser Kanal, Kanalcodierungstheorem, Kanalkapazität</p> <p>9. Das Kanalcodierungstheorem: verbundtypische Folgen, Beweis des Kanalcodierungstheorems, Beweis des Umkehrsatzes, symmetrische Kanäle</p> <p>10. Fehlerkorrigierende Codes und reale Kanäle: AWGN-Kanal, mehrdimensionale Gaußsche WDF, Kapazität des AWGN-Kanals</p> <p>11. Binäre Codes: Minimaldistanz, perfekte Codes, Warum perfekte Codes schlecht sind, Warum Distanz nicht alles ist</p> <p>12. Nachrichtenaustausch: verteiltes Zählen, Pfadzählen, günstigster Pfad, Minimumsummenalgorithmus</p> <p>13. Exakte Marginalisierung in Graphen: Faktorgraph, Summenproduktalgorithmus</p> <p>14. LDPC-Codes: Dichteevolution, Knotenordnung, reguläre und irreguläre Codes, Graphumfang</p> <p>15. Verlustbehaftete Quellencodierung: Transformationscodierung und JPEG-Kompression</p>
6	<p>Learning objectives and skills</p>	<p>The students apply Bayesian inference to problems in both communications and everyday's life.</p> <p>The students explain the concept of digital communications by means of source compression and forward-error correction coding.</p> <p>For the design of communication systems, they use the concepts of entropy and channel capacity.</p> <p>They calculate these quantities for memoryless sources and channels.</p> <p>The students proof both the source coding and the channel coding theorem.</p> <p>The students compare various methods of source coding with respect to compression rate and complexity.</p> <p>The students apply source compression methods to measure mutual information.</p> <p>The students factorize multivariate functions, represent them by graphs, and marginalize them with respect to various variables.</p> <p>The students explain the design of error-correcting codes and the role of minimum distance.</p> <p>They decode error-correcting codes by means of maximum-likelihood decoding and message passing.</p> <p>The students apply distributed algorithms to problems in both communications and everyday's life.</p> <p>The students improve the properties of low-density parity-check codes by widening the girth and/or irregularity in the degree distribution.</p> <p>The students transform source images into the frequency domain to improve lossy compression.</p> <p>--</p> <p>Die Studierenden wenden Bayessche Inferenz auf Probleme in der Nachrichtentechnik und im Alltagsleben an.</p>

		<p>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 irreguläre Knotenordnungsverteilungen. Die Studierenden transformieren Bildquellen zur Verbesserung verlustbehafteter Kompression in den Frequenzbereich.</p>
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	<p>Written examination (90 minutes) Die Prüfung besteht aus einem 120-minütigen schriftlichen Test.</p> <hr/> <p>The examination is a 120-minute written test.</p>
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	MacKay, D.: Information Theory, Inference, and Learning Algorithms, Cambridge University Press, Cambridge, 2003.

1	Module name 48420	Statistical Signal Processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Walter Kellermann	
5	Contents	<p>The course concentrates on fundamental methods of statistical signal processing and their applications. The main topics are:</p> <p>*Discrete-time stochastic processes in the time and frequency domain*</p> <p>Random variables (RVs), probability distributions and densities, expectations of random variables, transformation of RVs, vectors of normally distributed RVs, time-discrete random processes: probability distribution and densities, expectation, stationarity, cyclostationarity, ergodicity, correlation functions and correlation matrices, spectral representations, principal component analysis (PCA), Karhunen-Loève transform (KLT).</p> <p>*Estimation theory*</p> <p>estimation criteria, prediction, classical and Bayesian parameter estimation (including MMSE, Maximum Likelihood, and Maximum A Posteriori estimation), Cramer-Rao bound</p> <p>*Linear signal models*</p> <p>Parametric models (cepstral decomposition, Paley-Wiener theorem, spectral flatness), non-parametric models (all-pole, all-zero and pole-zero models, lattice structures, Yule-Walker equations, PARCOR coefficients, cepstral representation)</p> <p>*Signal estimation*</p> <p>Supervised estimation, problem classes, orthogonality principle, MMSE estimation, linear MMSE estimation for normally distributed random processes, optimum FIR filtering, optimum linear filtering for stationary processes, prediction and smoothing, Kalman filters, optimum multichannel filtering (Wiener filter, LCMV, MVDR, GSC)</p> <p>*Adaptive filtering*</p> <p>Gradient methods, LMS, NLMS, APA and RLS algorithms and their convergence behavior</p> <p>*Zeitdiskrete Zufallsprozesse im Zeit- und Frequenzbereich*</p> <p>Zufallsvariablen (ZVn), Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte; Transformation von ZVn; Vektoren normalverteilter ZVn; zeitdiskrete Zufallsprozesse (ZPe): Wahrscheinlichkeitsverteilungen und dichten, Erwartungswerte, Stationarität, Zyklstationarität, Ergodizität, Korrelationsfunktionen und -matrizen, Spektraldarstellungen; Principal Component Analysis, Karhunen-Loeve Transformation;</p> <p>*Schätztheorie*</p> <p>Schätzkriterien; Prädiktion; klassische und Bayessche Parameterschätzung (inkl. MMSE, Maximum Likelihood, Maximum A Posteriori); Cramer-Rao-Schranke</p> <p>*Lineare Signalmodelle*</p>	

		<p>Parametrische Modelle (Cepstrale Zerlegung, Paley-Wiener Theorem, Spektrale Glattheit); Nichtparametrische Modelle: Allpole-/Allzero-/ Pole-zero-(AR/MA/ARMA) Modelle; Lattice-Strukturen, Yule-Walker Gleichungen, PARCOR-Koeffizienten, Cepstraldarstellungen;</p> <p>*Signalschätzung* Überwachte Signalschätzung, Problemklassen; Orthogonalitätsprinzip, MMSE-Schätzung, lineare MMSE-Schätzung für Gaußprozesse; Optimale FIR-Filter; Lineare Optimalfilter für stationäre Prozesse; Prädiktion und Glättung; Kalman-Filter; optimale Multikanalfilterung (Wiener-Filter, LCMV, MVDR, GSC);</p> <p>*Adaptive Filterung* Gradientenverfahren; LMS-, NLMS-, APA- und RLS-Algorithmus und Ihr Konvergenzverhalten.</p>
6	Learning objectives and skills	<p>The students:</p> <ul style="list-style-type: none"> analyze the statistical properties of random variables, random vectors, and stochastic processes by probability density functions and expectations as well as correlation functions and matrices and their frequency-domain representations know the Gaussian distribution and its role to describe the properties of random variables, vectors and processes understand the differences between classical and Bayesian estimation, derive and analyze MMSE and ML estimators for specific estimation problems, especially for signal estimation analyze and evaluate optimum linear MMSE estimators (single- and multichannel Wiener filter and Kalman filter) for direct and inverse supervised estimation problems evaluate adaptive filters for the identification of optimum linear estimators. <p>Die Studierenden</p> <ul style="list-style-type: none"> analysieren die statistischen Eigenschaften von Zufallsvariablen, -vektoren und stochastischen Prozessen mittels Wahrscheinlichkeitsdichten und Erwartungswerten, bzw. Korrelationsfunktionen, Korrelationsmatrizen und deren Frequenzbereichsdarstellungen kennen die spezielle Rolle der Gaußverteilung und ihre Auswirkungen auf die Eigenschaften von Zufallsvariablen, -vektoren und Prozessen verstehen die Unterschiede klassischer und Bayesscher Schätzung, entwerfen und analysieren MMSE- und ML-Schätzer für spezielle Schätzprobleme, insbesondere zur Signalschätzung analysieren und evaluieren lineare MMSE-optimale Schätzer (ein- und vielkanalige Wiener-Filter und Kalman-Filter) für direkte und inverse überwachte Schätzprobleme; evaluieren adaptive Filter zur Identifikation optimaler linearer Signalschätzer
7	Prerequisites	Module Signale und Systeme I und Signale und Systeme II, Digitale Signalverarbeitung oder gleichwertige

8	Integration in curriculum	semester: 1
9	Module compatibility	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	A. Papoulis, S. Pillai: Probability, Random Variables and Stochastic Processes; McGraw-Hill, 2002 (englisch) D. Manolakis, V. Ingle, S. Kogon: Statistical and Adaptive Signal Processing; Artech House, 2005 (englisch)

1	Module name 48440	Machine Learning in Signal Processing Machine learning in signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis	
5	Contents	<p>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.</p> <p>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.</p>	
6	Learning objectives and skills	<p>After attending the lecture, students will be able to</p> <ul style="list-style-type: none"> • 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	Written examination (90 minutes) Schriftliche Prüfung von 90min Dauer	

11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Literature: <ul style="list-style-type: none"> • 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 48451	Selected Topics in ASC	2,5 ECTS
2	Courses / lectures	Vorlesung: Selected Topics in ASC - Modern Satellite Communications (Prof. George Karagiannidis, Summer 2025) (2 SWS)	2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Ralf Müller	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller	
5	Contents	<p>This course covers the fundamentals of Content Distribution, i.e., how to jointly store/cache and deliver information over a cache-enabled network, and the fundamentals of Service Distribution, i.e., how to jointly store, process, and deliver information over a distributed cloud network with integrated storage, computation, and communication resources. The course is highly recommended for students and researchers in the basic science areas of statistics, signal processing, data compression, and data transmission, as well as the applied science fields of communications, networking, and cloud computing.</p> <p>Detailed syllabus</p> <ul style="list-style-type: none"> • PART 1: Content Distribution <ul style="list-style-type: none"> • Network information flow, network coding, multicast • Caching, index coding, content reuse • Fundamental of network compression • Fundamental distributed storage which special focus on dynamic content • PART 2: Service Distribution <ul style="list-style-type: none"> • Cloud network flow, service representation, cloud-network representation • end-to-end service optimization, joint communication-computation-storage • resource allocation • Dynamic cloud network control, stability region, Lyapunov control, <ul style="list-style-type: none"> • o Network slicing, system automation, metaverse experiences 	
6	Learning objectives and skills	<p>This course provides students with the knowledge, tools, and methods to understand:</p> <ul style="list-style-type: none"> • the fundamentals of content distribution, i.e., how to jointly store/cache and deliver information over a cache-enabled network • the fundamentals of service distribution, i.e., how to jointly store, process, and deliver information over a network with storage, computation, and communication resources. <p>The knowledge learned in this course has wide applicability to highly impactful technology sectors,</p>	

		from the design and optimization of communication networks and systems, the design and optimization of content delivery networks, systems, and algorithms, and the design and optimization of future highly distributed cloud-integrated networks supporting next-generation applications.
7	Prerequisites	The students who will take this course should have a working knowledge of Probability Theory and Stochastic Processes along with the underlying requisite Mathematics (like calculus and algebra). They should also have a basic background in Communication Systems. Finally, some acquaintance with notions of optimization will be useful.
8	Integration in curriculum	semester: 2
9	Module compatibility	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 48455	Deep Learning	5 ECTS
2	Courses / lectures	Vorlesung: Deep Learning (2 SWS) Übung: DL E (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Prof. Dr.-Ing. Andreas Maier Zijin Yang Alexander Barnhill	

4	Module coordinator	Prof. Dr.-Ing. Andreas Maier Fabian Wagner
5	Contents	<p>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.</p> <p>This lecture introduces the core elements of neural networks and deep learning, it comprises:</p> <ul style="list-style-type: none"> • (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, ...) <p>The accompanying exercises will provide a deeper understanding of the workings and architecture of neural networks.</p>
6	Learning objectives and skills	<p>The students</p> <ul style="list-style-type: none"> • 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,

		<ul style="list-style-type: none"> • 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	semester: 2
9	Module compatibility	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	<ul style="list-style-type: none"> • 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 48460	Kick-Off Seminar, Winter and Summer School	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. Ralf Müller
5	Contents	<p>Kick-off seminar:</p> <p>The three-day kick-off seminar takes place immediately prior to the lecture period of the first semester. It is intended to enable students to get to know one another and teaching staff to engage in exchange, mentors in particular. The programme consists of courses imparting useful soft skills in the areas of self-management, time management, teamwork, presentation techniques and academic writing. Also included is cultural training in preparation for working in environments with an international character and time periods spent abroad.</p> <p>Winter School:</p> <p>ASC students will participate in a one-week winter school held at the end of the first semester, with lectures that focus on industrial and professional experience. While scientific knowledge is one thing, social ability is also important to one's career. The main focus of the winter school is people and project management.</p> <p>Summer School:</p> <p>ASC students are required to participate in a two-week summer school jointly operated by TUM, Uni Stuttgart and FAU. It takes place after the second semester at the "Ferienakademie" in Sarntal, in which students from the three universities and various disciplines gather to work on timely projects.</p> <p>Students work in small groups on dedicated scientific topics that change from year to year. During the summer school, students will give presentations, submit reports, discuss their results in depth with both fellow students and supervisors, and compile proceedings. Alternatively, students can also design software projects which they will implement in this two-week period. Aside from scientific projects, the summer school is accompanied by many social activities, including hiking and campfire talks with industry leaders. Throughout this two-week summer school, ASC students have practical hands-on experience while having fun with their peers.</p>
6	Learning objectives and skills	The kick-off seminar allows the new students to get in touch with each other and their future professors right before the start of the programme. The winter school offers training on soft-skills, such as project and people management, as well as business development.

		The summer school prepares them for research-based training by working on scientific projects in a team.
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	Seminar achievement
11	Grading procedure	Seminar achievement (pass/fail)
12	Module frequency	no Module frequency information available!
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	?? semester (no information for Module duration available)
15	Teaching and examination language	english
16	Bibliography	

1	Module name 48470	Research Project (Major)	15 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. Ralf Müller
5	Contents	<p>This module is intended to develop the skills needed for independent scientific practice, through in-depth work within a topic such as audio processing, video coding, wireless communications, molecular communication, system design and implementation, machine learning, game theory, information theory, communication networks, or embedded systems. (Note that the topics for the Research Project Major Module must be different from the topic for the Research Project Minor Module.) Students first agree on a topic with their mentor and then define particular project aspects with an advisor from the appropriate field. A project typically includes attending relevant lectures (especially from the elective module catalog), internships, seminars, working with scientific literature ("directed reading"), evaluating algorithms, and designing hardware implementations. Cooperation with international research partners, potentially leading to a stay abroad, is strongly encouraged. Students must complete a final report for this module, aiming towards a conference publication.</p> <p>The Research Project Major Module bridges the gap between theoretical foundations and technical implementations. Students pursue their individual interests by consulting with their mentor and choosing optional mandatory elective modules and technical elective modules, allowing an application-specific immersion. By more advanced lectures and one-on-one directed reading courses, students deepen their knowledge of communications and multimedia technology. This project gives an interdisciplinary character to the ASC study programme. The Research Project Major Module implements innovative learning and teaching practices a key element is continuous contact between students and faculty. In directed reading courses, a small group of students studies and exchanges views on current scientific literature, supported by faculty. Faculty members also introduce students to scientific practice early on through scientific projects. Summer/winter schools and soft skills courses complement the scientific coursework and provide key skills.</p>
6	Learning objectives and skills	<p>Domain-Specific Knowledge:</p> <p>Students have a solid theoretical background in communications and multimedia technology. Students develop a deep understanding of digital techniques for information acquisition, processing, analysis and transmission. In this context, students compare and contrast various methods and techniques by analyzing and evaluating them. Furthermore, students apply theoretical knowledge by implementing and testing concrete applications of social relevance. The elements</p>

		<p>above develop the skills needed to transfer knowledge from theory into practice.</p> <p>Learning and Methodological Skills: The students apply specific signal processing techniques. They are able to communicate their results in a scientifically appropriate manner. They are capable of writing scientific texts independently and in a limited amount of time. Students recognize connections and inter-relations within a topic and are able to associate them with specific problem formulations.</p> <p>Personal Skills: Students are conscious of the strengths they can contribute to a project and the weaknesses that they must address through specific measures. Students expand their understanding of a topic by implementing algorithms and procedures, and testing them within concrete application scenarios. Students discuss their findings and challenges with faculty. Students have a solid command of independent scientific practice.</p> <p>Interpersonal Skills: Students communicate and discuss ideas in an intercultural context, in the style that is prevalent for scientific conferences and workshops. They can present and explain complex ideas in an easily comprehensible manner.</p>
7	Prerequisites	None
8	Integration in curriculum	semester: 3
9	Module compatibility	Pflichtmodul Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Portfolio
11	Grading procedure	Portfolio (100%)
12	Module frequency	Every 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: 375 h
15	Module duration	1 semester
16	Teaching and examination language	english
17	Bibliography	

Technical Mandatory Electives

1	Module name 43141	Mobile Communications Mobile communications	5 ECTS
2	Courses / lectures	Übung: Mobile Communications - Tutorial (1 SWS) Vorlesung: Mobile Communications (3 SWS)	- 5 ECTS
3	Lecturers	Bastian Eisele 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	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	<p>Proakis, J.: Digital Communications, McGraw-Hill, 4th ed., 2001.</p> <p>Rappaport, T.: Wireless Communications: Principles & Practice, Prentice Hall, 2nd ed., 2001.</p> <p>Mouly, M., Paulet, M.: The GSM System for Mobile Communications, Cell & SYS, France, 1992.</p> <p>Goldsmith, A.: Wireless Communications, Cambridge Univ. Press, 2005.</p>

1	Module name 44362	Quality of Service of Communication Systems 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 Anna Arestova	

4	Module coordinator	Prof. Dr. Reinhard German
5	Contents	<p>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:</p> <ul style="list-style-type: none"> • Netzplanung und optimierung, • stochastische Analyse (Markow-Ketten, Warteschlangen), • Netzwerksimulation, • deterministische Analyse mit Network Calculus zur Ermittlung von Dienstgütegarantien • Messung (HW-, SW-, Hybrid-Monitoring, Benchmarks). <p>Alle Methoden werden an Beispielen demonstriert. *Contents:*</p> <p>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:</p> <ul style="list-style-type: none"> • 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). <p>All methods are illustrated by examples.</p>
6	Learning objectives and skills	<p>Die Studierenden erwerben</p> <ul style="list-style-type: none"> • 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 <p>*Learning targets and competences:*</p> <p>The students get</p> <ul style="list-style-type: none"> • experience in methods to model and evaluate quantitative, non-functional properties of computer networks and related systems

		<ul style="list-style-type: none"> • 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	Written or oral (90 minutes)
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	<ul style="list-style-type: none"> • 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 44410	Eingebettete Systeme Embedded systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	Contents	<p>Schwerpunkt des Moduls ist der Entwurf und die Implementierung eingebetteter Systeme unter Einsatz formaler Methoden und rechnergestützter Entwurfsverfahren.</p> <p>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).</p> <p><i>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).</i></p>
6	Learning objectives and skills	<p>Fachkompetenz - Wissen</p> <ul style="list-style-type: none"> Die Studierenden setzen sich mit einem aktuellen Forschungsgebiet auseinander. The students deal with a current field of research. <p>Fachkompetenz - Verstehen</p> <ul style="list-style-type: none"> Die Studierenden verstehen grundlegende Konzepte des Entwurfs eingebetteter Systeme. The students become familiar with the fundamental concepts of designing of embedded systems. <p>Fachkompetenz - Anwenden</p> <ul style="list-style-type: none"> 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.

		<ul style="list-style-type: none"> 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	<p>Die Auswahl dieses Moduls schließt die Auswahl der Module „Eingebettete Systeme (Vorlesung mit erweiterten Übungen)“ und „Eingebettete Systeme (Vorlesung mit Übungen)“ aus. <i>Selecting this module excludes the selection of the modules “Embedded Systems (Lecture with Extended Exercises)” and “Embedded Systems (Lecture with Exercises)”.</i></p> <p>Organisatorisches:</p> <ul style="list-style-type: none"> Die Vorlesung erfolgt in deutscher Sprache. Zusätzlich stehen Folien und Vorlesungsaufzeichnungen in englischer Sprache zur Verfügung. Die Übungen werden sowohl auf Deutsch als auch auf Englisch angeboten. Studierende können die Prüfung wahlweise auf Deutsch oder Englisch ablegen. <p>Organizational:</p> <ul style="list-style-type: none"> The lecture is given in German. Slides and lecture recordings are also provided in English. German as well as English exercises are offered. Students can choose between taking the exam either in German or English.
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	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter 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	german english
17	Bibliography	<p>Empfohlenes Buch zur Begleitung und Vertiefung:</p> <ul style="list-style-type: none"> Teich J., Haubelt C.: "Digitale Hardware/Software-Systeme: Synthese und Optimierung", Springer-Verlag, 2007, ISBN: 978-3-540-46822-6 <p>Weitere Informationen:</p>

	https://www.cs12.tf.fau.de/lehre/lehveranstaltungen/vorlesungen/eingebettete-systeme/
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1	Module name 48480	Research Project (Minor)	10 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. Ralf Müller
5	Contents	<p>This module is intended to develop the skills needed for independent scientific practice, through in-depth work within a topic such as audio processing, video coding, wireless communications, molecular communication, system design and implementation, machine learning, game theory, information theory, communication networks, or embedded systems. (Note that the topics for the Minor Research Project Module must be different from the topic for the Major Research Project Module.) Students first agree on a topic with their mentor and then define particular project aspects with an advisor from the appropriate field. A project typically includes attending relevant lectures (especially from the elective module catalog), internships, seminars, working with scientific literature ("directed reading"), evaluating algorithms, and designing hardware implementations. Cooperation with international research partners, potentially leading to a stay abroad, is strongly encouraged. Students must complete a final report for this module, aiming towards a conference publication.</p> <p>The Minor Research Project Module bridges the gap between theoretical foundations and technical implementations. Students pursue their individual interests by consulting with their mentor and choosing optional mandatory elective modules and technical elective modules, allowing an application-specific immersion. By more advanced lectures and one-on-one directed reading courses, students deepen their knowledge of communications and multimedia technology. This project gives an interdisciplinary character to the ASC study programme. The Minor Research Project Module implements innovative learning and teaching practices a key element is continuous contact between students and faculty. In directed reading courses, a small group of students studies and exchanges views on current scientific literature, supported by faculty. Faculty members also introduce students to scientific practice early on through scientific projects. Summer/winter schools and soft skills courses complement the scientific coursework and provide key skills.</p>
6	Learning objectives and skills	<p>Domain-Specific Knowledge</p> <p>Students have a solid theoretical background in communications and multimedia technology. Students develop a deep understanding of digital techniques for information acquisition, processing, analysis and transmission. In this context, students compare and contrast various methods and techniques by analyzing and evaluating them. Furthermore, students apply theoretical knowledge by implementing and testing concrete applications of social relevance. The elements</p>

		<p>above develop the skills needed to transfer knowledge from theory into practice.</p> <p>Learning and Methodological Skills</p> <p>The students apply specific signal processing techniques. They are able to communicate their results in a scientifically appropriate manner. They are capable of writing scientific texts independently and in a limited amount of time. Students recognize connections and inter-relations within a topic and are able to associate them with specific problem formulations.</p> <p>Personal Skills</p> <p>Students are conscious of the strengths they can contribute to a project and the weaknesses that they must address through specific measures. Students expand their understanding of a topic by implementing algorithms and procedures, and testing them within concrete application scenarios. Students discuss their findings and challenges with faculty. Students have a solid command of independent scientific practice.</p> <p>Interpersonal Skills</p> <p>Students communicate and discuss ideas in an intercultural context, in the style that is prevalent for scientific conferences and workshops. They can present and explain complex ideas in an easily comprehensible manner.</p>
7	Prerequisites	None
8	Integration in curriculum	semester: 3
9	Module compatibility	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Portfolio
11	Grading procedure	Portfolio (100%)
12	Module frequency	Every 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: 250 h
15	Module duration	1 semester
16	Teaching and examination language	english
17	Bibliography	

1	Module name 93015	Einführung in die moderne Kryptographie Introduction to modern cryptography	7,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Carina Harrius Prof. Dr. Dominique Schröder	
5	Contents	<p>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:</p> <ul style="list-style-type: none"> • Information theoretic security • Computational security • Private key Encryption • Message Authentication Codes • Hash functions • Public key Encryption • Digital Signatures <p>More advanced topics may be covered if time permits.</p>	
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	Variable	
11	Grading procedure	Variable (100%)	
12	Module frequency	Only in winter 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: 165 h	
15	Module duration	1 semester	
16	Teaching and examination language	english	
17	Bibliography	<p>Introduction to Modern Cryptography</p> <p>Jonathan Katz and Yehuda Lindell 2nd Edition (2014)</p> <p>(Chapman & Hall/CRC Cryptography and Network Security Series)</p> <p>ISBN-13: 978-1466570269</p>	

1	Module name 96300	MIMO Communication Systems 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	Hedieh Ajam Prof. Dr.-Ing. Robert Schober	

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	<p>The students</p> <ul style="list-style-type: none"> 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. <p>Die Studierenden</p> <ul style="list-style-type: none"> 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	Written or oral (90 minutes)	

		Written exam (Klausur), 90 minutes.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	

1	Module name 96310	Image and Video Compression Image and video compression	5 ECTS
2	Courses / lectures	Vorlesung: Image and Video Compression (IVC) (4 SWS) Übung: Übung zu Image and Video Compression	5 ECTS -
3	Lecturers	Prof. Dr.-Ing. Andre Kaup Anna Meyer	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	<p>Multi-Dimensional Sampling</p> <ul style="list-style-type: none"> Sampling theorem revisited, 2D sampling, spatiotemporal sampling, motion in 3D sampling <p>Entropy and Lossless Coding</p> <ul style="list-style-type: none"> Entropy and information, variable length codes, Huffman coding, unary coding, Golomb coding, arithmetic coding <p>Statistical Dependency</p> <ul style="list-style-type: none"> Joint entropy and statistical dependency, run-length coding, fax compression standards <p>Quantization</p> <ul style="list-style-type: none"> Rate distortion theory, scalar quantization, Lloyd-Max quantization, entropy coded scalar quantization, embedded quantization, adaptive quantization, vector quantization <p>Predictive Coding</p> <ul style="list-style-type: none"> Lossless predictive coding, optimum 2D linear prediction, JPEG-LS lossless compression standard, differential pulse code modulation (DPCM) <p>Transform Coding</p> <ul style="list-style-type: none"> Principle of transform coding, orthonormal transforms, Karhunen-Loève transform, discrete cosine transform, bit allocation, compression artifacts <p>Subband Coding</p> <ul style="list-style-type: none"> Principle of subband coding, perfect reconstruction property, discrete wavelet transform, bit allocation for subband coding <p>Visual Perception and Color</p> <ul style="list-style-type: none"> Anatomy of the human eye, sensitivity of the human eye, color spaces, color sampling formats <p>Image Coding Standards</p> <ul style="list-style-type: none"> JPEG and JPEG2000 <p>Interframe Coding</p> <ul style="list-style-type: none"> Interframe prediction, motion compensated prediction, motion estimation, motion compensated hybrid coding <p>Video Coding Standards</p> <ul style="list-style-type: none"> 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	<p>Die Studierenden</p> <ul style="list-style-type: none"> veranschaulichen die mehrdimensionale Abtastung und den Einfluss darauf durch Bewegung im Videosignal

		<ul style="list-style-type: none"> • 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 Blockschalbilder und Wirkungsweisen hybrider Coder und Decoder für Videosignale • kennen die maßgeblichen internationalen Standards aus ITU und MPEG zur Bild- und Videokompression. <p>The students</p> <ul style="list-style-type: none"> • 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" dringend empfohlen
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	Written or oral (90 minutes)

		Schriftliche Prüfung von 90 min Dauer
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	J.-R. Ohm: Multimedia Communications Technology, Springer-Verlag, 2004

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

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	<p>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.</p> <p>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.</p> <p>*Technical Content*</p> <ul style="list-style-type: none"> • 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.

		<ul style="list-style-type: none"> • 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	<p>The student</p> <ul style="list-style-type: none"> • 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.

		<ul style="list-style-type: none"> • Analyses performance of relaying schemes. • Argues on possible improvements of relaying schemes via network coding and physical layer network coding. • Uses the Perron-Frobenius 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-Frobenius 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	<p>Information Theory and Coding</p> <p>It is advisable that the student is familiar with basic concepts of Mobile Communications</p>
8	Integration in curriculum	semester: 2

9	Module compatibility	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Oral (30 minutes) Oral exam, 30 minutes
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	

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

4	Module coordinator	Prof. Dr. Laura Cottatellucci
5	Contents	<p>*Description*</p> <p>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.</p> <p>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.</p> <p>*Technical Content*</p> <ul style="list-style-type: none"> • 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

		<p>Formulates the concept of source polarization and relates it to polar channel coding</p> <p>Interprets polar channel coding as factor graphs</p> <p>Designs polar channel codes</p> <p>Argues about capacity achievability of polar channel codes</p>
7	Prerequisites	None
8	Integration in curriculum	semester: 2
9	Module compatibility	Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Oral (30 minutes) Oral exam, 30 minutes
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	

1	Module name 645618	Human Computer Interaction 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	Prof. Dr. Björn Eskofier Ann-Kristin Seifer Syrine Slim Madeleine Flaucher	

4	Module coordinator	Prof. Dr. Björn Eskofier Madeleine Flaucher	
5	Contents	<p>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.</p> <p>Die folgenden Themen werden im Modul behandelt:</p> <ul style="list-style-type: none"> • 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 <p>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:</p> <ul style="list-style-type: none"> • Introduction to the basics of Human-Computer Interaction • Design principles and models for modern user interfaces and interactive systems 	

		<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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. <p>Learning Objectives and Competences:</p> <ul style="list-style-type: none"> • 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	Electronic examination Electronic exam (in presence), 90min
11	Grading procedure	Electronic examination (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	

1	Module name 700506	Communications Systems Design Communications systems design	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi Torsten Reißland
5	Contents	<p>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.</p> <p>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</p>
6	Learning objectives and skills	Students

		<p>Can bridge the gap between communications theory, analog/digital baseband, and RF design</p> <p>Can develop quick and flexible prototypes for real-time communications systems and standards using SDR solutions</p> <p>Can determine the design parameters and assess the interaction between various analog and digital parts</p> <p>Can create efficient Tx/Rx programs and signal processing algorithms in LabVIEW, MATLAB, and GNU Radio</p> <p>Can implement channel estimation and equalization algorithms in TDD and FDD systems</p> <p>Can demonstrate MIMO and OFDM based systems like LTE and beyond</p> <p>Can quantify and evaluate system performance using EVM and impairments analysis</p>
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	Oral
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
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	english
17	Bibliography	

Technical Lab Courses

1	Module name 92356	Praktikum Communications Systems Design Laboratory course: Communications systems design	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Communications Systems Design	2,5 ECTS
3	Lecturers	Torsten Reißland	

4	Module coordinator	Arslan Ali Prof. Dr.-Ing. Georg Fischer Prof. Dr.-Ing. Norman Franchi
5	Contents	<p>The lab course is based on the GNU Radio software platform. It includes a general introduction into GNU Radio, Python programming and Software Defined Radios (SDRs), as well as a more thorough introduction into USRPs.</p> <p>The students learn how to set up pure simulations of communication systems in Gnu Radio, how to use it in conjunction with Software Defined Radios and how to develop and test custom modules in Python. Regarding Gnu Radio the usage of different data types, variables, structures (e.g. vectors and streams), hierarchical development and flow control are part of the course.</p> <p>The course is structured into 8 exercises which first cover different modulation schemes like AM, PAM, and OFDM. In the later part of the course topics of practical relevance like synchronization (time, frequency, phase, frame) and equalization are covered. One synchronization scheme for OFDM is to be implemented by the students in Python. Most exercises have the goal to transmit audio data, first in a simulation, then in a loopback with one device and later between several devices. Setups to evaluate metrics like eye diagrams and EVM are introduced in a practical manner.</p> <p>Passing an introduction test is prerequisite for the participation in the lab course.</p>
6	Learning objectives and skills	<p>Students</p> <ul style="list-style-type: none"> 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 GNU Radio Can implement channel estimation and equalization algorithms in TDD and FDD systems Can demonstrate OFDM based systems Can quantify and evaluate system performance using EVM and impairments analysis

7	Prerequisites	Prerequisite for this course is proper knowledge in the fundamentals of digital communications and digital signal processing.
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	Practical achievement At the begin of the lab course, the prerequisites are tested with a short (15 min) written test. Passing this test is required to participate in the experiments. The lab course itself consists of six experiments. At the end of every experiment the students have to present their respective final result. The understanding of the theoretical concepts will be check orally.
11	Grading procedure	Practical achievement (100%)
12	Module frequency	Every semester The lab course takes place as a block course (1 week) in each semester.
13	Workload in clock hours	Contact hours: 40 h Independent study: 35 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

1	Module name 97525	Laborpraktikum Bild- und Videosignalverarbeitung auf eingebetteten Plattformen Laboratory course: Image and video signal processing on embedded platforms	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup
5	Contents	<p>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.</p> <p>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.</p>
6	Learning objectives and skills	<p>Die Studierenden</p> <ul style="list-style-type: none"> • verstehen die Herausforderungen von eingebetteten Plattformen • wenden die Programmiersprache Python für Bild- und Videosignalverarbeitungsalgorithmen an • erzeugen funktionsfähige Programme mit der Programmiersprache Python • beurteilen die Funktionsblöcke von Computer Vision-Algorithmen

		<ul style="list-style-type: none"> • bewerten die von ihnen erstellten Programme durch subjektive und objektive Vergleiche • reflektieren den Lernprozess während des Praktikums.
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	<p>Practical achievement</p> <p>Das Praktikum basiert auf neun Versuchen, die im Praktikums-Skript beschrieben sind. Jeder Versuch muss zu Hause vorbereitet werden und wird vor jedem Versuch überprüft. Die Ergebnisse der vorbereiteten Aufgaben im Praktikum werden am Ende des Versuchs überprüft. Dazu müssen die Teilnehmenden die erarbeiteten Lösungen den Tutoren erläutern. Das Praktikum ist bestanden, wenn alle neun Versuche erfolgreich abgeschlossen wurden.</p>
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 15 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Das Skript zum Praktikum Image and video signal processing on embedded platforms" wird in der Einführungsveranstaltung ausgegeben.

1	Module name 97640	Laborpraktikum Mobilkommunikation Laboratory course: Mobile communication	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Mobilkommunikation / Lab Course Mobile Communications - Group 1 (3 SWS)	2,5 ECTS
		Praktikum: Praktikum Mobilkommunikation / Lab Course Mobile Communications - Group 2 (3 SWS)	2,5 ECTS
3	Lecturers	apl. Prof. Dr. Wolfgang Gerstacker	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker	
5	Contents	<h3>Experiments</h3> <ul style="list-style-type: none"> • <ul style="list-style-type: none"> ◦ 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 • <ul style="list-style-type: none"> ◦ Principles of different equalization methods ◦ equalizer design for GSM / EDGE ◦ simulation of trellis-based equalizers and visualization of the results • <ul style="list-style-type: none"> ◦ Principle of OFDM ◦ implementation-relevant aspects such as nonlinearities and peak-to-average-power ratio ◦ synchronization and equalization • MIMO Transmission (2 experiments) 	
		<hr/> <h3>Versuche</h3> <ul style="list-style-type: none"> • <ul style="list-style-type: none"> ◦ Eigenschaften realer Mobilfunkkanäle wie Verzerrungen und Zeitvarianz, ◦ Modelle für Mobilfunkkanäle ◦ Auswirkungen auf die Leistungsfähigkeit eines Mobilfunksystems • <ul style="list-style-type: none"> ◦ Prinzipien verschiedener Entzerrverfahren ◦ Entzerrerdesign für GSM/EDGE ◦ Simulation von trellisbasierten Entzerrern und Visualisierung der Ergebnisse • <ul style="list-style-type: none"> ◦ Prinzip von OFDM ◦ implementierungsrelevante Aspekte wie Nichtlinearitäten und Spitzenwertfaktor ◦ Synchronisation und Entzerrung • MIMO Übertragung (2 Versuche) 	
6	Learning objectives and skills	<h3>The students</h3> <ul style="list-style-type: none"> • describe the characteristics of real mobile radio channels, 	

		<ul style="list-style-type: none"> • 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. <hr/> <h3>Die Studierenden</h3> <ul style="list-style-type: none"> • charakterisieren die Eigenschaften realer Mobilfunkkanäle, • erklären die Funktionsweise von OFDM- und MIMO-Übertragungssystemen, • implementieren Entzerrungs- und Adaptionverfahren 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	<p>Practical achievement</p> <ul style="list-style-type: none"> • 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. <hr/> <ul style="list-style-type: none"> • 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

		<p>Versuchs überprüft (ausreichend/nicht ausreichend). Messergebnisse sind schriftlich zu dokumentieren.</p> <ul style="list-style-type: none"> • Zum Bestehen des Praktikums sind 8 ausreichende Versuchsvorbereitungen und 8 ausreichende Versuchsdurchführungen notwendig.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 35 h Independent study: 40 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	Skriptum zum Praktikum Mobilkommunikation

1	Module name 97651	Laborpraktikum Image and Video Compression Laborpraktikum Multimediakommunikation	2,5 ECTS
2	Courses / lectures	Praktikum: Lab Course Image and Video Compression (3 SWS)	2,5 ECTS
3	Lecturers	Geetha Ramasubbu Marc Windsheimer	

4	Module coordinator	PD Dr. Christian Herglotz	
5	Contents	<ul style="list-style-type: none"> • Einführung in die Programmierumgebung MATLAB • Realisierung der Verarbeitungsblöcke von Videocodern • Aufbau eines Videocodecs und optionale Erweiterungen • Durchführung eines subjektiven Vergleichs verschiedener Videocodecs • Präsentation und kritische Beurteilung der Ergebnisse 	
6	Learning objectives and skills	<p>Die Studierenden</p> <ul style="list-style-type: none"> • erzeugen ein funktionsfähiges Programmsystem mit der Programmierumgebung MATLAB, • beurteilen die Funktionsblöcke von Video-Codern, • gestalten ihren eigenen Videocodec und entwickeln dazu von ihnen selbst gewählte optionale Erweiterungen, • bewerten die von ihnen realisierten Videocodecs durch einen subjektiven Vergleich, • reflektieren den Lernprozess während des Praktikums. 	
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	<p>Practical achievement</p> <p>Das Praktikum umfasst zehn Sitzungen à vier Stunden plus zwei Sitzungen à zwei Stunden, die sieben Arbeitspakete, einen subjektiven Test und eine Abschlusspräsentation beinhalten. Jedes Arbeitspaket erfordert eine Vorbereitung in schriftlicher Form und wird vor Beginn jeder Sitzung geprüft und bewertet (bestanden/nicht bestanden). Während jeder der zehn obligatorischen Laborsitzungen müssen die Studierenden Programmieraufgaben bearbeiten, die am Ende jeder Sitzung überprüft werden (bestanden/nicht bestanden). Nach diesen zehn Programmiersitzungen muss ein funktionierender Videocodec abgegeben werden. Außerdem müssen die Studierenden an einem subjektiven Test teilnehmen, bei dem die Ergebnisse des Codecs bewertet werden. In der letzten Sitzung muss jeder Videocodec von den Studierenden präsentiert werden. Ein Zertifikat über die erfolgreiche Teilnahme am Labor wird ausgestellt, wenn alle Arbeitspakete ausreichend vorbereitet und umgesetzt wurden, die Ergebnisse aller Arbeitspakete zu einem funktionsfähigen und lauffähigen Videocodec zusammengefasst wurden, der für den subjektiven Test geeignet ist, der subjektive Videotest durchgeführt wurde und der fertige Videocodec bei der Abschlusspräsentation vorgestellt wurde.</p>	

11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	Das Skriptum Praktikum Image and Video Compression wird in der Einführungsveranstaltung ausgegeben.

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	Amir El-Ghoussani Prof. Dr. Vasileios Belagiannis Michele De Vita	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis	
5	Contents	<p>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,</p> <p>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.</p> <p>In this lab course we will solve this problem using transfer learning and mathematical modeling:</p> <ul style="list-style-type: none"> • 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. <p>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 course.</p>	
6	Learning objectives and skills	<p>Students are able to:</p> <ul style="list-style-type: none"> • Independently design machine learning pipelines to solve complex problems in artificial intelligence. • Choose appropriate algorithms for the problem at hand. 	

		<ul style="list-style-type: none"> • 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	Practical achievement Zum Bestehen des Praktikums müssen die Programmieraufgaben der 5 Versuche erfolgreich bearbeitet werden.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in summer semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 15 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	<ol style="list-style-type: none"> 1) Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. 2) Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning. 3) Raschka, S., Liu, Y. H., Mirjalili, V., & Dzulgakov, D. (2022). Machine Learning with PyTorch and Scikit-Learn: Develop machine learning and deep learning models with Python.

1	Module name 894349	Audio Processing Laboratory 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. 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	Practical achievement The lab course consists of four lab units. Each unit is presented for 15 minutes per participant, and is graded with up to three points. In order to pass the lab course, a total of at least 6 points must be achieved, with at least 1 point in each individual unit.	
11	Grading procedure	Practical achievement (pass/fail)	

12	Module frequency	Every semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	

1	Module name 92504	Praktikum: Numerische Methoden der Halbleiterbauelemente Laboratory course: Numerical methods for semiconductor components	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Numerische Methoden der Halbleiterbauelemente (2 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Friedhard Römer	

4	Module coordinator	Dr.-Ing. Friedhard Römer	
5	Contents	<ul style="list-style-type: none"> • Selbständige Implementierung von numerischen Algorithmen sowie Anwendung von kommerziellen Simulationswerkzeugen am Beispiel der Halbleiterbauelemente • Grundlagen der numerischen Simulation von Kontinuumsgleichungen am Beispiel des Halbleitertransports 	
6	Learning objectives and skills	<p>Fachkompetenz Wissen</p> <ul style="list-style-type: none"> • Lösungen partieller Differentialgleichungssysteme unter Verwendung der finiten Volumen sowie der finiten Differenzen • Interpretation und Beurteilung von Simulationsergebnissen anhand von Stromtransport in Halbleitern • Bedienung von kommerziellen Simulationswerkzeugen, inkl. Gemeotrieezeugung, Diskretisierung, Parameter-Datenbanken, sowie Visualisierung von Daten 	
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	Practical achievement es gibt nur bestanden/nicht bestanden für das Praktikum, keine Note.	
11	Grading procedure	Practical achievement (100%) Die Prüfungsleistung besteht aus der numerischen Simulation der Aufgaben auf den Laborrechnern und dem daraus erstellten Praktikumsbericht.	
12	Module frequency	Only in summer semester	
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h	
14	Module duration	1 semester	
15	Teaching and examination language	german	
16	Bibliography	<ul style="list-style-type: none"> • S. Selberherr, Analysis and Simulation of Semiconductor Devices 	

- J. Jin, The Finite Element Method in Electromagnetics
- Vorlesungsskript

1	Module name 97520	Laborpraktikum Digitale Signalverarbeitung	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Walter Kellermann	
5	Contents	<p>In diesem Laborpraktikum wird die Theorie aus der Vorlesung Digitale Signalverarbeitung in der Praxis angewandt, unter Verwendung der Programmierumgebung MATLAB. Die behandelten Themen umfassen Quantisierung, Spektralanalyse, FIR- und IIR-Filterentwurf, Filterbänke, sowie adaptive Filter.</p> <p>Das Praktikum besteht aus 5 Versuchsterminen, an denen die Teilnehmer in Zweiergruppen Programmieraufgaben lösen, und einem 5-tägigen Block, in dem jede Gruppe ein individuelles Projekt aus dem Bereich der Digitalen Signalverarbeitung bearbeitet.</p> <p>Das Praktikum erfordert vorhandene MATLAB-Programmierkenntnisse. Es ist möglich, das Praktikum parallel zur Vorlesung Digitale Signalverarbeitung zu besuchen, allerdings ist es dazu notwendig, die jeweiligen Vorlesungsinhalte vor dem Praktikumstermin zu wiederholen, und an Übung und Tutorium teilzunehmen.</p> <p>*Contents*</p> <p>In this laboratory course the theory from the lecture Digital Signal Processing is applied in practice, using the programming environment MATLAB. The topics include quantization, spectral analysis, FIR and IIR filter design, filter banks and adaptive filters.</p> <p>The course consists of 5 guided experiments in which students work on programming problems in groups of two, and a 5-day block course where each group works on an individual project from the field of digital signal processing.</p> <p>The preparation, as well as the results of the past experiment will be examined by a short test at the beginning of each experiment. For passing the lab course, a minimum number of points from the tests and the project is required.</p> <p>The course requires previous experience in MATLAB programming. It is possible to take the course in parallel to the DSP lecture, however, revision of the relevant lecture contents before each lab lesson, and participation in the DSP exercises and tutorials is required.</p>	
6	Learning objectives and skills	<p>Die Studierenden</p> <ul style="list-style-type: none"> • erzeugen funktionsfähige MATLAB-Programme zu den einzelnen vorgezeichneten Experimenten und wenden damit das in Vorlesung und Übung erworbene Wissen an • analysieren und evaluieren den von ihnen implementierten Algorithmus • verstehen die Anforderungen praktischer Realisierungen von Algorithmen zur Digitalen Signalverarbeitung 	

		<ul style="list-style-type: none"> reflektieren ihren eigenen Lernprozess während des Praktikums.
7	Prerequisites	dringend empfohlen: Vorlesung Signale und Systeme I & II
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical Lab Courses Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	<p>Practical achievement</p> <p>Es müssen 5 Versuche erfolgreich absolviert werden und danach in Zweier-Gruppen ein wissenschaftliches Projekt bearbeitet werden, worüber eine 3 bis 4-seitige Dokumentation angefertigt werden muss. Zu Beginn jedes Versuchs wird der Stand der Vorbereitung, sowie die Versuchsergebnisse des vergangenen Termins in einem schriftlichen Testat geprüft. Für das Bestehen des Praktikums ist eine Mindestpunktzahl aus den Testaten und dem Blockpraktikum nötig</p>
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	<p>The script for this lab course will be handed out at the introductory meeting. Moreover, the following books are recommended</p> <ul style="list-style-type: none"> J.G. Proakis, D.G. Manolakis: Digital Signal Processing. 4th edition. Prentice Hall, Englewood Cliffs, NJ, 2007. A.V. Oppenheim, R.V. Schaffer: Digital Signal Processing. Prentice Hall, Englewood Cliffs, NJ, 1975. K.D. Kammeyer, K. Kroschel: Digitale Signalverarbeitung: Filterung und Spektralanalyse mit MATLAB®-Übungen . 8. Aufl. Teubner, Stuttgart, 2012

1	Module name 93511	Praktikum Digitale Übertragung Digital communication Lab	2,5 ECTS
2	Courses / lectures	Praktikum: Praktikum Digitale Übertragung / Lab Course Digital Communications - Afternoon Group (3 SWS)	2,5 ECTS
		Praktikum: Praktikum Digitale Übertragung / Lab Course Digital Communications - Morning Group (3 SWS)	2,5 ECTS
3	Lecturers	Dr.-Ing. Clemens Stierstorfer	

4	Module coordinator	Prof. Dr.-Ing. Robert Schober	
5	Contents	<ul style="list-style-type: none"> • 1 Digital Transmission of Data 1.1 Introduction, Background, Motivation 1.2 Purpose 1.3 Lab Environment 1.3.1 Transmitter 1.3.2 Receiver 1.4 Lab Exercises 1.4.1 Signal Generation at the Transmitter 1.4.2 (Coherent) Receivers for Pulse Amplitude Modulation 1.4.3 Transmission over the AWGN Channel • 2 Implementation of Transmitter and Receiver in Matlab 2.1 Introduction, Background, Motivation 2.2 Purpose 2.3 Lab Environment 2.3.1 Oversampling factor 2.3.2 Transmitter 2.3.3 Channel 2.3.4 Receiver 2.4 Lab Exercises 2.4.1 Transmitter 2.4.2 Channel 2.4.3 Receiver 2.4.4 BER calculation • 3 Variants of PAM-Transmission Schemes 3.1 Introduction, Background, Motivation 3.2 Purpose 3.3 Lab Environment 3.4 Lab Exercises 3.4.1 Basic Pulse Shape 3.4.2 Offset-QAM 3.4.3 Gaussian Minimum Shift-Keying 3.4.4 "Carrierless Amplitude and Phase Modulation • 4 OFDM 4.1 Introduction, Background, Motivation 4.1.1 Orthogonal Frequency-Division Multiplexing 4.1.2 Bit Loading 4.2 Purpose 4.3 Lab Environment 4.4 Lab Exercises 4.4.1 OFDM Transmitter 4.4.2 OFDM Receiver 4.4.3 Bit Loading • 5 Signal Space Representation 5.1 Introduction, Background, Motivation 5.2 Purpose 5.3 Lab Environment 5.4 Signal Space Representation 5.4.1 Orthogonality 5.4.2 Orthogonalization 5.5 Lab Exercises 5.5.1 Transmission with signal elements 5.5.2 Gram-Schmidt Procedure 5.5.3 Frequency Shift Keying • 6 Signal Processing in MIMO Systems 6.1 Introduction, Background, Motivation 6.2 Lab Environment 6.3 Lab Exercises 6.3.1 System Model 6.3.2 SISO 6.3.3 SIMO 6.3.4 MIMO 	
6	Learning objectives and skills	<p>Die Studierenden vertiefen und erweitern ihre Kenntnisse der digitalen Nachrichtenübertragungsverfahren und der zugehörigen mathematischen Grundlagen anhand von Laborversuchen. Sie analysieren die Eigenschaften digitaler Pulsamplitudenmodulation und Varianten digitaler PAM. Dazu erzeugen sie im Labor mit der zur Verfügung gestellten Ausrüstung Sendesignale, die sie mit Hilfe üblicher Messgeräte (Oszilloskop, Effektivwertmesser) analysieren. Sie bauen Übertragungsstrecken für diese PAM-Verfahren auf und untersuchen die</p>	

Effekte auf Empfängerseite. Sie bestimmen Störabstände, Fehlerraten usw.

Des Weiteren setzen die Studierenden ihre Kenntnisse der PAM-Übertragungsverfahren in selbst erstellte MATLAB-Routinen um, die die Simulation einer kompletten PAM-Übertragung mit Sender, Kanal und Empfänger am Rechner modellieren. In einem weiteren Versuch ergänzen die Studierenden dieses Modell um eine OFDM-Übertragung und analysieren die Funktionsweisen von OFDM-Sendern und -empfängern. Sie untersuchen die Arbeitsweise von Ladealgorithmen bei OFDM-Systemen und implementieren diese in MATLAB.

Die Studierenden verdeutlichen sich das Konzept der Signalraumdarstellung in der digitalen Übertragung und implementieren ein beispielhaftes System in MATLAB. Sie erstellen Routinen zur Gram-Schmidt-Orthogonalisierung und zur FSK-Übertragung in MATLAB.

Die Studierenden analysieren einfache MIMO-Szenarien und implementieren entsprechende Empfängeralgorithmen.

Die Studierenden bereiten die Bearbeitung der Versuche im Labor anhand der ausgegebenen Unterlagen und den Unterlagen zum Modul "Digitale Übertragung selbständig vor. Sie sind in der Lage, die für den jeweiligen Versuch notwendigen theoretischen Kenntnisse vor und während des Versuchs zu erklären und zur Lösung der Laboraufgaben und vorbereitenden Hausaufgaben einzusetzen. Sie dokumentieren die durchgeführten Versuche selbständig in ihren Unterlagen, so dass die Nachvollziehbarkeit der Arbeiten jederzeit gegeben ist. Die Arbeit im Labor organisieren sie in Kleingruppen (2-3 Personen) selbst. Sie erkennen die Notwendigkeit gewissenhafter Vorbereitung der Lerninhalte und disziplinierter Arbeitsweise im Labor.

Die Unterrichtssprache ist wahlweise Deutsch oder Englisch. Unterlagen werden ausschließlich auf Englisch zur Verfügung gestellt, weswegen die Studierenden die englischen Fachtermini kennen und nutzen.

Students deepen and extend their knowledge of digital message transmission methods and the associated mathematical principles by means of laboratory experiments. They analyze the properties of digital pulse amplitude modulation and variants of digital PAM. To this end, they generate transmit signals in the laboratory using the equipment provided and analyze them with the aid of standard measuring instruments (oscilloscope, rms meter). They build transmission links for these PAM methods and investigate the effects on the receiver side. They determine signal-to-noise ratios, error rates, etc.

Furthermore, the students implement their knowledge of the PAM transmission methods in self-created MATLAB routines, which model the simulation of a complete PAM transmission with transmitter, channel and receiver on the computer. In another experiment, students add an OFDM transmission to this model and analyze the operation of OFDM transmitters and receivers. They investigate the operation of loading algorithms in OFDM systems and implement them in MATLAB.

Students clarify the concept of signal space representation in digital transmission and implement an example system in MATLAB.

		<p>They create routines for Gram-Schmidt orthogonalization and FSK transmission in MATLAB. Students analyze simple MIMO scenarios and implement corresponding receiver algorithms.</p> <p>The students independently prepare the experiments in the laboratory using the issued documents and the documents for the module "Digital Transmission". They are able to explain the theoretical knowledge required for the respective experiment before and during the experiment and use it to solve the laboratory tasks and preparatory homework. They independently document the experiments carried out in their records so that the supervisors can trace the work at any time. They organize the work in the laboratory themselves in small groups (2-3 persons). They recognize the necessity of certain preparation of the learning content and disciplined working methods in the laboratory.</p> <p>The language of instruction is either German or English. Documents are provided exclusively in English, which is why the students know and use the English technical terms.</p>
7	Prerequisites	<p>Das Praktikum richtet sich ausschließlich an Studierende, die das Moduls "Digitale Übertragung bereits absolviert haben oder es parallel zum Praktikum belegen. Die Inhalte dieses Moduls sind unabdingbare Grundlage und werden von den Studierenden beherrscht, d.h., sie können die entsprechenden Zusammenhänge erklären, Problemstellungen mathematisch formulieren und benötigte Größen berechnen.</p> <p>Grundlegende Kenntnisse der Software MATLAB sind notwendig (bspw. aus "Software für die Mathematik" oder "Simulationstools").</p> <p>The lab course is aimed exclusively at students who have already completed the "Digital Transmission" module or who are taking it in parallel with the lab course. The contents of this module are an indispensable basis and are mastered by the students, i.e. they can explain the corresponding relationships, formulate problems mathematically and calculate required quantities.</p> <p>Basic mastery of the MATLAB software is necessary</p>
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	<p>Practical achievement</p> <ul style="list-style-type: none"> • There are 5 experiments to complete as well as an online test on Matlab knowledge and basic knowledge of digital communications. The details are described in the course materials. • Each experiment must be prepared in writing at home. The preparation will be checked and evaluated at the beginning of each experiment (sufficient/insufficient). • The results of each experiment must be recorded on the experimental computers during the execution of the experiment (programming tasks) and are checked at the end of the experiment (sufficient/insufficient). The measured results must be documented in writing.

		<ul style="list-style-type: none"> To pass the course, 5 sufficient experiment preparations, 5 sufficient experiment executions and the passed asynchronous online test are required. <hr/> <ul style="list-style-type: none"> Es sind 5 Experimente zu absolvieren sowie vorab ein Online-Test zu Matlab-Kenntnissen und Grundkenntnissen in digitaler Kommunikation. Die Einzelheiten sind in den Kursunterlagen beschrieben. Jedes Experiment muss zu Hause schriftlich vorbereitet werden. Die Vorbereitung wird zu Beginn eines jeden Experiments überprüft und bewertet (ausreichend/nicht ausreichend). Die Ergebnisse jedes Experiments sind während der Durchführung des Experiments auf den Versuchsrechnern festzuhalten (Programmieraufgaben) und werden am Ende des Experiments kontrolliert (ausreichend/nicht ausreichend). Die gemessenen Ergebnisse sind schriftlich zu dokumentieren. Zum Bestehen des Kurses sind 5 ausreichende Versuchsvorbereitungen, 5 ausreichende Versuchsdurchführungen sowie der bestandene asynchrone Online-Test erforderlich.
11	Grading procedure	Practical achievement (pass/fail)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 30 h Independent study: 45 h
14	Module duration	1 semester
15	Teaching and examination language	german english
16	Bibliography	<ul style="list-style-type: none"> Skriptum zum Praktikum Skriptum zur Vorlesung Digitale Übertragung bzw. Digital Communications übliche Standardlehrwerke zur Thematik (Proakis, Haykin usw.)

1	Module name 182405	Praktikum Architekturen der digitalen Signalverarbeitung Laboratory architectures for digital signal processing	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer	
5	Contents	<ul style="list-style-type: none"> • Aufbau einer akustischen FSK Datenverbindung • Einführung in die VHDL Programmierung eines FPGAs • Erzeugung einer PRBS Sequenz • Effiziente Implementierung eines Sinusgenerators mit Hilfe des Cordic Algorithmus • Digitale Filterung • Demodulation/Detektion 	
6	Learning objectives and skills	<p>Die Studierenden erlangen Grundlagenkenntnisse in der Programmierung mit MATLAB und VHDL</p> <p>Die Studierenden sind in der Lage, eine digitales Datenübertragungssystem vom Sender bis zum Empfänger theoretisch zu konzeptionieren, in MATLAB zu simulieren und praktisch in VHDL auf einem FPGA umzusetzen</p> <p>Die Studierenden erhalten die theoretische und praktische Fähigkeit, digitale Signale zu definieren, zu verarbeiten, digitale Filter zu erzeugen und Signale mit diesen zu manipulieren</p> <p>Die Studierenden verstehen die Schnittstelle zwischen der digitalen und analogen Ebene und sind in der Lage, diese Schnittstellen auf einem FPGA Evaluation Board zu verwenden</p>	
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	<p>Practical achievement</p> <p>Praktikumsleistung als Studienleistung (unbenotet):</p> <p>2 Versuche ("Matlab Aufgaben" und "VHDL Aufgaben"). Je Versuch ist ein Protokoll (mit 3-5 Seiten) den erreichten Ergebnissen und dem funktionierenden selbständig erarbeitetem Programmcode abzugeben. Vor jedem Versuch erfolgt eine Überprüfung der ausreichenden Kenntnis der Versuchsbedingungen im Rahmen einer 5 minütigen mündlichen Prüfung</p>	
11	Grading procedure	Practical achievement (pass/fail)	
12	Module frequency	Only in winter semester	
13	Workload in clock hours	Contact hours: 45 h Independent study: 30 h	

14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	

Technical Electives

1	Module name 43400	Entzerrung und adaptive Systeme in der digitalen Übertragung Equalisation and adaptive systems for digital communications	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker	
5	Contents	<p>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.</p> <p>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.</p> <p>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.</p> <p>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.</p>	

6	Learning objectives and skills	<p>Die Studierenden</p> <ul style="list-style-type: none"> • 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 Adaptionalgorithmen zur automatischen Anpassung des Empfängers eines Übertragungssystems an den Kanal, • ordnen Entzerrverfahren einen geeigneten Adaptionalgorithmus zu. <p>Learning Objectives and Competences: The students</p> <ul style="list-style-type: none"> - 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	<p>Vorkenntnisse in Systemtheorie und digitaler Signalverarbeitung, sowie entweder der Vorlesung Nachrichtentechnische Systeme oder Digitale Übertragung sind für die Teilnahme hilfreich.</p>
8	Integration in curriculum	<p>no Integration in curriculum available!</p>
9	Module compatibility	<p>Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212</p>
10	Method of examination	<p>Written or oral The examination is a 30-minute oral exam. The examination language is English.</p>
11	Grading procedure	<p>Written or oral (100%)</p>
12	Module frequency	<p>Only in winter semester</p>

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	english
17	Bibliography	<p>Gerstacker, W.: Skriptum zur Vorlesung Entzerrung und adaptive Systeme in der digitalen Übertragung.</p> <p>Huber, J.: Trelliscodierung, Springer Verlag, Berlin, 1992.</p> <p>Benedetto, S., Biglieri, E.: Principles of Digital Transmission with Wireless Applications, Kluwer Academic Publishers, New York, 1999.</p> <p>Proakis, J. G.: Digital Communications. McGraw-Hill, New York, 3. ed., 1995.</p> <p>Haykin, S.: Adaptive Filter Theory, Prentice Hall, Upper Saddle River, NJ, 3. ed., 1996.</p>

1	Module name 43420	Transmission and Detection for Advanced Mobile Communications 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	apl. Prof. Dr. Wolfgang Gerstacker	

4	Module coordinator	apl. Prof. Dr. Wolfgang Gerstacker	
5	Contents	<p>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.</p>	
6	Learning objectives and skills	<p>The students</p> <ul style="list-style-type: none"> • 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, <p>- design interference suppression schemes for GSM/EDGE for receivers with a single antenna (single antenna interference cancellation) and multiple antennas, respectively,</p> <ul style="list-style-type: none"> • 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, 	

		<ul style="list-style-type: none"> 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. <p>Die Studierenden</p> <ul style="list-style-type: none"> 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 Diversitätsgewinnen bei empfangsseitiger Antennendiversität entwerfen Space-Time-Codiervverfahren 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	Written or oral Oral exam, 30 minutes.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester
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	english

1	Module name 44120	Pattern Analysis Pattern analysis	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Pattern Analysis (4 SWS)	5 ECTS
3	Lecturers	Christian Riess	

4	Module coordinator	Christian Riess
5	Contents	<p>This lecture is the sequel to the lecture "Pattern Recognition". As such, it covers topics from the chapters 8-14 from the book "Pattern Recognition and Machine Learning" by Christopher Bishop.</p> <p>These topics include various aspects of Bayesian modeling, including (but not limited to) probabilistic graphical models, mixture modeling, variational inference, sampling methods, manifold learning, Markov random fields, hidden Markov models, tree-based methods and ensembling.</p>
6	Learning objectives and skills	<p>The students</p> <ul style="list-style-type: none"> • 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
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	<p>Variable (60 minutes)</p> <p>Die Prüfung ist eine schriftliche Klausur mit Multiple Choice mit einer Dauer von 60 Minuten. / The form of examination is a written exam with multiple choice with a duration of 60 minutes.</p>
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	<p>Begleitende Literatur / Accompanying literature:</p> <ul style="list-style-type: none"> • 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 Pattern recognition	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andreas Maier	
5	Contents	<p>Mathematical foundations of machine learning based on the following classification methods:</p> <ul style="list-style-type: none"> • 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 <p>Mathematische Grundlagen der maschinellen Klassifikation am Beispiel folgender Klassifikatoren:</p> <ul style="list-style-type: none"> • 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	<p>Die Studierenden</p> <ul style="list-style-type: none"> • verstehen die Struktur von Systemen zur maschinellen Klassifikation einfacher Muster • erläutern die mathematischen Grundlagen ausgewählter maschineller Klassifikatoren • wenden Klassifikatoren zur Lösung konkreter Klassifikationsproblem an 	

		<ul style="list-style-type: none"> • beurteilen unterschiedliche Klassifikatoren in Bezug auf ihre Eignung • verstehen in der Programmiersprache Python geschriebene Lösungen von Klassifikationsproblemen und Implementierungen von Klassifikatoren <p>Students</p> <ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter 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	german or english english
17	Bibliography	<ul style="list-style-type: none"> • Richard O. Duda, Peter E. Hart, David G. Stock: Pattern Classification, 2nd edition, John Wiley&Sons, New York, 2001 • Trevor Hastie, Robert Tibshirani, 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 44522	Audio Processing for the Internet of Things 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		

4	Module coordinator	Prof. Dr. Nils Peters	
5	Contents	<p>The course focuses on audio and speech processing algorithms within the context of the Internet of Things (IoT).</p> <ul style="list-style-type: none"> • 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	<p>The students will be able to</p> <ul style="list-style-type: none"> • 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	Oral (30 minutes)	

11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
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	english
17	Bibliography	Recommendations for each topic are given during the lectures

1	Module name 48447	Compressive Sensing Compressive sensing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller
5	Contents	<p>This lecture aims to provide a good background on the concept of compressive sensing and its applications in communications and signal processing.</p> <p>*Part I: Compressive Sensing from the Classical Viewpoint*</p> <p>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.</p> <p>Finally, we give an introduction to compressive sensing via random matrices and present some key results in this respect.</p> <p>*Part II: Compressive Sensing from a Bayesian Viewpoint*</p> <p>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.</p> <p>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.</p> <p>The detailed list of contents is as follows:</p> <ul style="list-style-type: none"> • 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

		<ul style="list-style-type: none"> • 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	<p>Learning objectives and skills</p>	<ul style="list-style-type: none"> • 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	Oral (30 minutes)
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	<p>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.</p> <p>For the second part, we collect discussions mainly from the following references:</p> <ul style="list-style-type: none"> • 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 93185	Reinforcement Learning Reinforcement learning	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Reinforcement Learning (4 SWS)	-
3	Lecturers	Dr.-Ing. Christopher Mutschler	

4	Module coordinator	Dr.-Ing. Christopher Mutschler	
5	Contents	<p>The lecture aims at teaching Reinforcement Learning (RL) and will cover the following topics:</p> <ul style="list-style-type: none"> • 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	<p>The students will learn to</p> <ul style="list-style-type: none"> • understand the basic principle behind sequential 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	<p>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.</p>	
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	<p>Variable (90 minutes)</p> <ul style="list-style-type: none"> • The examination will include a written exam of 90 minutes at the end of the semester • The exam will cover the content of the lecture as well as that of the exercises (the exam will hence contain a mixture of theoretical questions and practical coding tasks) <p>Please note that the exam will only take place in summer terms.</p>	

11	Grading procedure	Variable (100%) Written Exam (100 %)
12	Module frequency	Only in summer semester The lecture and exam will only be able during summer terms.
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	english
17	Bibliography	<ul style="list-style-type: none"> • 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 96270	Kanalcodierung Channel coding	5 ECTS
2	Courses / lectures	Vorlesung mit Übung: Channel Coding (4 SWS)	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	<p>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.</p> <p>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.</p> <p>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.</p> <p>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).</p> <p>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.</p>	

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).

		<p>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.</p> <p>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.</p> <p>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.</p> <p>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).</p> <p>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.</p>
7	Prerequisites	<p>Es ist hilfreich, wenn die Studierenden die erlernten Algorithmen in eine Programmiersprache (C, Matlab usw.) umsetzen können.</p> <p>It would be very helpful if the participants can implement the specified algorithms into a programming language (C, Matlab, etc.).</p>
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	<p>Written or oral (90 minutes)</p> <p>Die Prüfung ist eine 90-minütige schriftliche Klausur.</p> <p>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.</p> <hr/> <p>The examination is a 90-minute written test.</p> <p>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.</p>

11	Grading procedure	Written or oral (100%)
12	Module frequency	Every 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	german or english
17	Bibliography	<ul style="list-style-type: none"> • 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 96312	Bild-, Video- und mehrdimensionale Signalverarbeitung Image, video and multidimensional signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup	
5	Contents	<ul style="list-style-type: none"> • <ul style="list-style-type: none"> ◦ Histogrammausgleich, Gamma-Korrektur • <ul style="list-style-type: none"> ◦ Morphologische Filter, Erosion, Dilatation, Opening, Closing • <ul style="list-style-type: none"> ◦ Trichromat, RGB- Farbraum, HSV-Farbraum • <ul style="list-style-type: none"> ◦ Theorie mehrdimensionaler Signale und Systeme, Impulsantwort, lineare Bildfilterung, Leistungsspektrum, Wiener Filter • <ul style="list-style-type: none"> ◦ Bilineare Interpolation, Bicubische Interpolation, Spline Interpolation • <ul style="list-style-type: none"> ◦ Bildmerkmale, Kantendetektion, Hough Transformation, Harris Ecken Detektor, Texturmerkmale, Grauwertematrix • <ul style="list-style-type: none"> ◦ LoG, DoG, SIFT, SURF • <ul style="list-style-type: none"> ◦ Projektive Abbildungen, Blockabgleich, Optischer Fluss, Merkmalsbasierter Abgleich mittels SIFT und SURF, RANSAC • <ul style="list-style-type: none"> ◦ Amplituden Schwellenwertermittlung, K-Means Clustering, Bayes Klassifikation, Regionen-basierte Segmentierung, kombinierte Segmentierung und Bewegungsschätzung, zeitliche Segmentierung von Videos • <ul style="list-style-type: none"> ◦ Unitäre Transformation, Karhunen-Loeve Transformation, separable Transformationen, Haar und Hadamard Transformation, DFT, DCT 	
6	Learning objectives and skills	Die Studierenden <ul style="list-style-type: none"> • verstehen Punktoperationen an Bilddaten und Gamma-Korrektur • testen die Wirkung von Rangordnungs- und Medianfiltern an Bilddaten • unterscheiden und bewerten verschiedene Farbräume für Bilddaten 	

		<ul style="list-style-type: none"> • 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.
7	Prerequisites	Vorlesung Signale und Systeme I und II empfohlen
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	Written examination (90 minutes) Schriftliche Prüfung von 90 min Dauer
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter 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	english
17	Bibliography	<ul style="list-style-type: none"> • J.-R. Ohm: [Multimedia Content Analysis], Springer, 2016 • J. W. Woods: [Multidimensional Signal, Image, and Video Processing and Coding], Academic Press, second edition, 2012

1	Module name 96316	Radar, RFID and Wireless Sensor Systems (RWS) 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	<p>Radar, RFID and wireless sensor and wireless locating systems are essential for automotive advanced driver-assistance systems (ADAS), autonomous driving and flying, robotics, industrial automation, logistics and novel human machine interfaces. Further key areas include medical electronics, building technology and cyber-physical systems.</p> <p>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.</p> <p>RWS is an identical replacement of the former module "Drahtlose Sensoren, Radar- und RFID-Systeme DSR."</p>	
6	Learning objectives and skills	<p>The students</p> <ul style="list-style-type: none"> • 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 sensors, 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	<p>Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212</p> <p>Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212</p>	
10	Method of examination	Written (90 minutes)	
11	Grading procedure	Written (100%)	
12	Module frequency	Only in summer 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	english
17	Bibliography	<p>Sensors for Ranging and Imaging", Graham Brooker, Scitech Publishing Inc., 2009</p> <p>Radar mit realer und synthetischer Apertur", H. Klausing, W. Holpp, Oldenbourg, 1999</p> <p>Praxiswissen Radar und Radarsignalverarbeitung" Albrecht K. Ludloff, 2008</p> <p>"RFID at ultra and super high frequencies: theory and application Dominique Paret, John Wiley & Sons, 2009.</p> <p>RFID-Handbuch: Grundlagen und praktische Anwendungen von Transpondern, kontaktlosen Chipkarten und NFC", Klaus Finkenzeller, Carl Hanser Verlag, 6. Auflage 2012.</p>

1	Module name 43405	Introduction to Deep Learning Introduction to deep learning	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis	
5	Contents	<p>The students will learn the basics in <i>deep learning</i>, including classical neural network models and recent architectures. The students will acquire knowledge on processing different types of data with deep neural networks. In the exercises, the students will implement some of the standard models for classification or regression tasks and acquire knowledge on machine learning applications.</p> <p>The lecture topics include:</p> <ul style="list-style-type: none"> • Learning from data, machine learning and deep learning • Machine learning principles • Artificial neural networks • Convolutional neural networks • Back-propagation • Network optimization • Initialisation, regularisation • Deep network architectures • Generative models • Auto-encoders • Sequential models • Deep learning applications 	
6	Learning objectives and skills	<p>The students will learn:</p> <ul style="list-style-type: none"> • Machine learning theory • Artificial neural networks • Deep neural networks • Modern architectures • Model and parameter learning 	
7	Prerequisites	Basic knowledge of higher mathematics and programming	
8	Integration in curriculum	semester: 2	
9	Module compatibility	<p>Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 2012</p> <p>Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 2012</p>	
10	Method of examination	<p>Written examination (90 minutes)</p> <p>Schriftliche Prüfung von 90min Dauer</p>	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in winter 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	english	
17	Bibliography		<ul style="list-style-type: none"> • Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Rojas, R. (2013). Neural networks: a systematic introduction. • Friedman, J., Hastie, T., & Tibshirani, R. (2001). The elements of statistical learning.

1	Module name 713618	Computer vision	5 ECTS
2	Courses / lectures	Übung: Computer Vision Exercise (2 SWS) Vorlesung: Computer Vision (2 SWS)	2,5 ECTS 2,5 ECTS
3	Lecturers	Dr.-Ing. Vanessa Klein Muhammad Sohail Prof. Dr. Tim Weyrich Prof. Dr. Bernhard Egger	

4	Module coordinator	Prof. Dr. Tim Weyrich
5	Contents	This lecture discusses important algorithms from the field of computer vision. The emphasis lies on 3-D vision algorithms, covering the geometric foundations of computer vision, and central algorithms such as stereo vision, structure from motion, optical flow, and 3-D multiview reconstruction. Participants of this advanced course are expected to bring experience from prior lectures either from the field of pattern recognition or from the field of computer graphics.
6	Learning objectives and skills	<p>Die Vorlesung stellt eine Auswahl von Methoden aus dem Gebiet der Computer Vision vor, die in dem Feld eine zentrale Stellung einnehmen. In den Übungen implementieren und evaluieren die Studierenden selbständig diese Methoden. Die Studierenden arbeiten die ganze Zeit über an populären Computer Vision-Methoden wie zum Beispiel Stereosehen, optischer Fluss und 3D-Rekonstruktion aus mehreren Ansichten. Für diese Probleme</p> <ul style="list-style-type: none"> • beschreiben die Studierenden perspektivische Projektion, Rotationen und verwandte geometrische Grundlagen, • erklären die Studierenden die behandelten Methoden, • diskutieren die Studierenden Vor- und Nachteile verschiedener Modalitäten zur Erfassung von 3D-Informationen, • implementieren die Studierenden einzeln und gemeinschaftlich in Kleingruppen Code, • entdecken die Studierenden optimale Vorgehensweisen in der Datenaufnahme, • erkunden und bewerten die Studierenden unterschiedliche Möglichkeiten für die Evaluation, • diskutieren und präsentieren die Gruppenarbeiter in Gruppen die Vor- und Nachteile ihrer Implementierungen, • diskutieren und reflektieren die Studierenden gesellschaftliche Auswirkungen von Anwendungen des 3D-Rechnersehens. <p>The lecture introduces computer vision algorithms that are central to the field. In the exercises, participants autonomously implement and evaluate these algorithms. The participants work throughout the time on popular computer vision algorithms, like for example stereo vision, optical flow, and 3-D multiview reconstruction. For these problems, the participants</p> <ul style="list-style-type: none"> • describe perspective projection, rotations, and related geometric foundations, • explain the presented methods,

		<ul style="list-style-type: none"> • discuss the advantages and disadvantages of different modalities for acquiring 3-D information, • implement individually and in small groups code, • discover best practices in data acquisition, • explore and rank different choices for evaluation, • discuss and present in groups the advantages and disadvantages of their implementations, • discuss and reflect the social impact of applications of computer vision algorithms.
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	Variable (90 minutes) Dieses Modul wird mit einer Klausur (90 Minuten) geprüft. The form of examination is a written exam of 90 minutes.
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	Richard Szeliski: "Computer Vision: Algorithms and Applications", Springer 2011.

1	Module name 42800	Advanced Topics in Deep Learning Advanced topics in deep learning	5 ECTS
2	Courses / lectures	Vorlesung: Advanced Topics in Deep Learning (4 SWS) Übung: Supplements for Advanced Topics in Deep Learning	5 ECTS -
3	Lecturers	Prof. Dr. Vasileios Belagiannis Amir El-Ghoussani	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	<p>The students will learn advanced deep learning topics, including recent network architectures, generative models, self-supervision, interpretability and explainability. In the exercises, the students will implement advanced models and techniques for classification or regression tasks.</p> <p>The lecture topics include:</p> <ul style="list-style-type: none"> • Geometric deep learning • Attention and transformers • Unsupervised and self-supervised learning • Generative models • Interpretability • Explainability • Efficient Inference • Uncertainty estimation • Transfer learning and domain adaptation • Few-shot learning <p><i>Die Studierenden lernen erweiterte Themen des Deep Learning kennen, darunter aktuelle Netzwerkarchitekturen, generative Modelle, Selbst-Überwachung, Interpretierbarkeit und Erklärbarkeit. In den Übungen werden die Studierenden fortgeschrittene Modelle und Techniken für Klassifizierungs- oder Regressionsaufgaben implementieren.</i></p> <p><i>Zu den Vorlesungsthemen gehören:</i></p> <ul style="list-style-type: none"> • Geometric deep learning • Attention and transformers • Unsupervised and self-supervised learning • Generative models • Interpretability • Explainability • Efficient Inference • Uncertainty estimation • Transfer learning and domain adaptation • Few-shot learning

6	Learning objectives and skills	<p>The students will learn:</p> <ul style="list-style-type: none"> • State-of-the-art topics in Deep Learning • Recent Neural network architectures • Generative modelling • Lifelong learning approaches • Robustness and reliability in Deep Learning. <p><i>Die Studierenden lernen:</i></p> <ul style="list-style-type: none"> • Neueste Themen im Bereich Deep Learning • Neueste Architekturen neuronaler Netze • Generative Modellierung • Lifelong learning • Robustheit und Zuverlässigkeit beim Deep Learning.
7	Prerequisites	<p>Basic knowledge of machine learning, deep learning, and programming.</p> <p><i>Grundkenntnisse in Machine Learning, Deep Learning und Programmierung</i></p>
8	Integration in curriculum	semester: 1
9	Module compatibility	<p>Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212</p> <p>Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212</p>
10	Method of examination	<p>Written examination (90 minutes)</p> <p>Written exam of 90 min duration</p> <p><i>Schriftliche Prüfung von 90 min Dauer</i></p>
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in summer semester
13	Resit examinations	The exams of this moduls can only be resit once.
14	Workload in clock hours	<p>Contact hours: 60 h</p> <p>Independent study: 90 h</p>
15	Module duration	1 semester
16	Teaching and examination language	english
17	Bibliography	<ul style="list-style-type: none"> • Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). Deep learning. • Deisenroth, M. P., Faisal, A. A., & Ong, C. S. (2020). Mathematics for machine learning. Cambridge University Press. • Molnar, C. (2020). Interpretable machine learning. Lulu. com.

1	Module name 96065	Next Generation Mobile Communication Systems: 5G-Advanced and 6G	2,5 ECTS
2	Courses / lectures	Vorlesung: Next Generation Mobile Communication Systems: 5G-Advanced and 6G (2 SWS)	2,5 ECTS
3	Lecturers	apl. Prof. Dr. Wolfgang Gerstacker Dr. Stefan Brück	

4	Module coordinator	Dr. Stefan Brück apl. Prof. Dr. Wolfgang Gerstacker	
5	Contents	<p>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.</p>	
6	Learning objectives and skills	<p>The students</p> <ul style="list-style-type: none"> • 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) <p>Die Studierenden</p> <ul style="list-style-type: none"> • 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 Funkzugangnetzarchitektur moderner zellulärer 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	Oral The examination is a 30-minute oral exam. The examination language is English.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
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	
17	Bibliography	Lecture Notes 4G/5G Mobile Communication Systems

1	Module name 96880	Speech Enhancement Speech enhancement	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Emanuël Habets	
5	Contents	<p>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.</p> <p>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.</p> <p>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).</p>	
6	Learning objectives and skills	<ul style="list-style-type: none"> • 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. 	

		<ul style="list-style-type: none"> 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	Written or oral
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in winter semester
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	german or english
17	Bibliography	

1	Module name 250058	Signal Analysis Signal analysis	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Heinrich Löllmann	
5	Contents	<p>Es werden im Rahmen dieser Vorlesung unterschiedliche Verfahren zur Analyse digitaler Signale, sowie deren Anwendungsmöglichkeiten behandelt. Die folgenden Konzepte werden dabei insbesondere behandelt:</p> <ul style="list-style-type: none"> • Fourieranalyse von Signalen • Signalanalyse mittels Zeit-Frequenz-Transformationen • Parametrische und nichtparametrische Signalanalyse • Verfahren zur Frequenzschätzung • Räumliche Signalanalyse • Filterbänke und Wavelets. <p>In this course, different approaches for the analysis of digital signals and their applications are treated, which comprises the following topics:</p> <ul style="list-style-type: none"> • 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	<p>Die Studierenden</p> <ul style="list-style-type: none"> • 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. <p>The students</p> <ul style="list-style-type: none"> • 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 	

		<ul style="list-style-type: none"> • 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	Oral Mündliche Prüfung mit einer Dauer von 30 min. Oral examination of 30 min duration.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
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	english
17	Bibliography	P. Stoica und R. Moses: "Spectral Analysis of Signals", Pearson Prentice Hall, 2005

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	Andreas Rittler Prof. Dr.-Ing. Bernhard Schmauß	

4	Module coordinator	Prof. Dr.-Ing. Bernhard Schmauß	
5	Contents	<p>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.</p>	
6	Learning objectives and skills	<p>Students</p> <ul style="list-style-type: none"> • 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	<p>Recommended prior knowledge:</p> <ul style="list-style-type: none"> • 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	Oral (30 minutes)	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in summer 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	english
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 428256	Maschinelles Lernen für Zeitreihen Machine learning for time series	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Björn Eskofier Dr. Dario Zanca	
5	Contents	<p>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:</p> <ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 " <i>IntroPR</i> " and/or " <i>Pattern Recognition</i> " / " <i>Pattern Analysis</i> " is recommended. Concepts taught in " <i>IntroPR</i> " 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 electronic exam (remote), 90 min.	
10	Method of examination	Written examination (90 minutes)	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in winter 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	english
17	Bibliography	<ul style="list-style-type: none"> • 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 447324	Image, Video, and Multidimensional Signal Processing Image, video and multidimensional signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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	no Integration in curriculum available!
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Oral
11	Grading procedure	Oral (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 (no information for Module duration available)
16	Teaching and examination language	german
17	Bibliography	

1	Module name 451971	Random Matrices in Communications and Signal Processing Random matrices in communications and signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

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	Oral

		The examination is a 30-minute oral exam.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter 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	english
17	Bibliography	<ul style="list-style-type: none"> • 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 454183	Molecular Communications Molecular communications	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Robert Schober	
5	Contents	<p>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.</p>	
6	Learning objectives and skills	<p>The students are able to design synthetic molecular communication systems. They can explain natural communication processes in biological systems and how to harness these natural processes for the construction of man-made molecular communication systems. The students can also analyse, model, and simulate molecular communication systems.</p>	
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	<p>Oral The examination is a 30-minute oral exam. The examination language is English.</p>	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in winter 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	english
17	Bibliography	

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

4	Module coordinator	Jürgen Seiler
5	Contents	<p>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.</p>
6	Learning objectives and skills	<p>Die Studierenden können nach Besuch der Vorlesung</p> <ul style="list-style-type: none"> • 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

		<ul style="list-style-type: none"> Zusammenhänge zwischen kontinuierlichen und diskreten Signalen ausarbeiten <p>Educational Objectives and Competences: After attending the lecture, students will be able to</p> <ul style="list-style-type: none"> 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	Oral Mündliche Prüfung von 30 min Dauer.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in summer semester
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	english
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 621649	Advanced Optical Communication Systems Advanced optical communication systems	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Bernhard Schmauß	
5	Contents	<p>Multiplex Techniques: electrical / optical time division multiplexing, wavelength division multiplexing</p> <ul style="list-style-type: none"> • Dispersion Management: dispersion and bitrate, dispersion compensation, dispersion in WDM systems • Noise and Power Management: power budget, OSNR management, OSNR calculation • Management of Nonlinearities: self & cross phase modulation (SPM / XPM), four wave mixing (FWM), Raman scattering, solitons • Spectral Efficiency: definition, increase of spectral efficiency • Modulation Formats: intensity modulation, multilevel transmission, CS-RZ, SSB Transmission, DPSK, DQPSK, Coherent Transmission • Optical Regeneration: 2R-Regeneration by nonlinearities, distributed regeneration, 3R-Regeneration 	
6	Learning objectives and skills	<p>Students</p> <ul style="list-style-type: none"> • 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 designs of optical transmission systems. • are able to systematically improve the performance of optical links taking into account state of the art and leading edge scientific results. 	
7	Prerequisites	<p>Recommended Prerequisites:</p> <ul style="list-style-type: none"> • 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	Oral (30 minutes) Examination: oral exam (30 Minutes)	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in winter semester	
13	Resit examinations	The exams of this module 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	english
17	Bibliography	<p>Agrawal, G.P.: Fiber-Optic Communication Systems, John Wiley & Sons, 1997</p> <p>Agrawal, G.P.: Nonlinear Fiber Optics, John Wiley & Sons, 3. Auflage, 2001.</p> <p>Kaminow, I, Koch, T.: Optical Fiber Telecommunications IVA, Academic Press, 2002.</p> <p>Kaminow, I, Li, T., Willner,A.: Optical Fiber Telecommunications VA, Academic Press, 2008.</p> <p>Lecture notes.</p>

1	Module name 668129	Machine Learning in Communications Machine learning in communications	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Laura Cottatellucci	
5	Contents	<p>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.</p> <p>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.</p>	
6	Learning objectives and skills	<p>The students</p> <ul style="list-style-type: none"> • 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	<p>Oral</p> <p>The examination is a 30-minute oral exam. The examination language is English.</p>	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in winter semester	
13	Resit examinations	The exams of this moduls can only be resit once.	
14	Workload in clock hours	<p>Contact hours: 60 h</p> <p>Independent study: 90 h</p>	
15	Module duration	1 semester	
16	Teaching and examination language	english	
17	Bibliography		

1	Module name 687141	Multuser Information and Communications Theory Multuser information and communications theory	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Ralf Müller	
5	Contents	Linear vs. nonlinear multiple-access, CDMA as a canonical 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	<p>The students model any multiple access method as a special case of code-division multiple access.</p> <p>The students apply various algorithms for multiuser detection.</p> <p>The students explain various types of multiuser channels and their limits to transport information.</p> <p>The students explain the limits of distributed source coding algorithms.</p> <p>The students apply the cut-set bound.</p> <p>The students explain the method of dirty-paper coding.</p> <p>The students collaborate on solving exercise problems.</p>	
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	Oral The examination is a 30-minute oral exam.	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in winter 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	english	

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 816185	Body Area Communications Body area communications	2,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer	
5	Contents	<p>Contents:</p> <p>The Lecture and exercise deals with the following topics:</p> <ul style="list-style-type: none"> • 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	<p>Learning objectives</p> <ul style="list-style-type: none"> • 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 • Students 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	Oral (30 minutes)	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in winter semester	
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	english
17	Bibliography	

1	Module name 869547	Advanced Networking LEx Advanced networking LEx	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Kai-Steffen Hielscher	
5	Contents	<p>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.</p> <p>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.</p>	
6	Learning objectives and skills	<p>Fachkompetenz Verstehen Die Studierenden erlangen Verständnis der grundlegenden Konzepte von</p> <ul style="list-style-type: none"> • Software Defined Networking • Network Function Virtualization • Internet of Things • Cloud Computing. <p>Anwenden Die Studierenden wenden die Erkenntnisse in Übungsaufgaben an. Erschaffen</p>	

		<p>Die Studierenden erstellen eigene Laborkonfigurationen zu</p> <ul style="list-style-type: none"> • Software Defined Networking • Internet of Things. <p>Competences:</p> <p>Professional competence</p> <p>Understanding</p> <p>Students will gain an understanding of the basic concepts of</p> <ul style="list-style-type: none"> • Software Defined Networking • Network Function Virtualization • Internet of Things • Cloud Computing. <p>Apply</p> <p>Students apply the knowledge gained in exercises.</p> <p>Create</p> <p>The students create their own laboratory configurations on</p> <ul style="list-style-type: none"> • 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	<p>Portfolio</p> <p>Prüfungsleistung, mehrteilige Prüfung, Dauer (in Minuten): 30, benotet Anteil an der Berechnung der Modulnote: 100.0 % weitere Erläuterungen:</p> <p>Die Modulprüfung besteht aus:</p> <ul style="list-style-type: none"> • Bearbeitung (zwei)wöchentlicher Aufgabenblätter in Gruppenarbeit. Für diese unbenotete Studienleistung sind alle Aufgabenblätter korrekt zu lösen und abzugeben. • mündliche Prüfung (Dauer: 30 Minuten)
11	Grading procedure	Portfolio (100%)
12	Module frequency	Only in winter 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	english
17	Bibliography	William Stallings: Foundations of Modern Networking - SDN, QoE, IoT, and Cloud; Pearson

1	Module name 916185	Music Processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Meinard Müller Dr.-Ing. Maximilian Schäfer	
5	Contents	<ul style="list-style-type: none"> • a short history of electrical and electronic music • processing of audio signals by parametric filters and effects • different methods for digital sound synthesis • sound reproduction in real and in virtual environments • feature design principles for music-specific aspects like harmony, rhythm, timbre, and melody • practical and musical relevance of feature representations in the context of current music analysis and retrieval tasks • development of music-specific signal processing techniques 	
6	Learning objectives and skills	<p>The students</p> <ul style="list-style-type: none"> • specify the requirements for audio realtime processing, • apply their knowledge about discrete-time signals and systems to processing and synthesis of musical sounds, • design their own software realizations for sound synthesis • understand the properties of various representations of music • apply basic algorithms for analysis and comparison of music • discuss the importance and relevance of parameters for the analysis of music • predict the suitability of different methods for the analysis of certain musical signals 	
7	Prerequisites	Recommended are knowledge in signals and systems, a solid mathematical background and some personal interest in music	
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	Oral	
11	Grading procedure	Oral (100%)	
12	Module frequency	Only in winter 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	english	
17	Bibliography		

1	Module name 965820	Approximate Computing Approximate computing	5 ECTS
2	Courses / lectures	Übung: Exercises to Approximate Computing (2 SWS) Vorlesung: Approximate Computing (2 SWS)	- 5 ECTS
3	Lecturers	Pierre-Louis Sixdenier Khalil Esper Jose Juan Hernandez Morales Prof. Dr.-Ing. Jürgen Teich	

4	Module coordinator	Joachim Falk Prof. Dr.-Ing. Jürgen Teich
5	Contents	<p>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.</p> <p>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.</p> <p>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).</p>
6	Learning objectives and skills	<p>Fachkompetenz - Wissen</p> <ul style="list-style-type: none"> 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. <p>Fachkompetenz - Verstehen</p> <ul style="list-style-type: none"> 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. <p>Fachkompetenz - Anwenden</p> <ul style="list-style-type: none"> 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	Variable Oral exam in case of less than 20 participants (duration 30 mins). Otherwise, written exam (duration 90 mins).
11	Grading procedure	Variable (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	<p>Weitere Informationen:</p> <p>https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/approximate-computing</p>

1	Module name 92355	Communications systems design	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	Prof. Dr.-Ing. Georg Fischer
5	Contents	<ul style="list-style-type: none"> • Introduction • Analogue-Digital Balance • Software Defined Radio • ADC/DAC Converter Performance Metrics and their evolution over time • Signal Distortion mechanisms and metrics (IP3, EVM, ACPR, Spectral mask, wideband noise, reverse intermod) • Impairment modelling • System Complexity Analysis for Mixed Signal Systems • Transceiver architectures, design and analysis • Chained Noise figures and IP3 figures • Dynamic Range in RX and TX, Automatic Gain Control in RX and power control in TX • Synchronous versus asynchronous Architectures (RF DAC, PLM) • Challenges by Duplex operation, FDD, TDD, same frequency, TX-RX <p>isolation, transmitter leakage cancelation</p> <ul style="list-style-type: none"> • Simulation techniques (HB, Transient, Circuit Envelope) • Power Amplifier Systems, Amplifier architectures, Vector quantised PA, Class-S, DSM, PWM • Amplifier linearization, digital predistortion • MIMO Architectures • Implementation of Active Antenna Arrays, calibration • Spectrum Engineering • Physical Layer definition in light of implementation challenges <p>The exercise will be conducted based on PC and USRP Software Defined Radios. National Instruments Labview Comsuite Toolbox will be used for designing and studying Communication Systems.</p>
6	Learning objectives and skills	<p>Students</p> <ul style="list-style-type: none"> • can compare key performance indicators of alternative transceiver architectures • can construct the line up with TX and RX • can formulate requirements for transceivers • can gauge isolation between TX and RX • can choose a power amplifier class based on requirements • can rate physical layer properties • can assess complexity in analogue and digital domain

		<ul style="list-style-type: none"> • can plan a simulation strategy for analysing transceivers - can categorise transceiver architectures for single or multiple antennas • Can develop a predistortion system for power amplifiers
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 Technical Lab Courses Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Oral The form of examination is an oral exam of 30 minutes.
11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter semester
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	english
17	Bibliography	<p>Ralf Rudersdorfer, Radio Receiver Technology: Principles, Architectures and Applications, Wiley, 2014</p> <p>Frank Ellinger, Radio Frequency Integrated Circuits and Technologies, Springer, 2008</p> <p>Abbas Mohammadi und Fadhel M. Ghannouchi, RF Transceiver Design for MIMO Wireless Communications, Springer, 2012</p>

1	Module name 44400	Radar Signal Processing Radar signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Gerhard Krieger
5	Contents	<p>Radar is a key technology for a growing number of sensing tasks that range from the detection, location and tracking of moving objects to high-resolution imaging of surfaces, sub-surfaces and 3-D volumes. While the traditional radar applications focused on aerospace security, weather services and traffic surveillance, radar is now becoming a central contactless sensor technology for the automotive sector, medical diagnostics, gesture control, civil engineering, as well as large scale environmental and climate change monitoring, to name only a few. Associated with the new applications is an increasing demand for advanced signal processing techniques to extract the relevant information from the microwave echoes acquired by single- and multi-aperture radar systems in complex environments. This lecture will give an overview of a variety of one-, two-, and three-dimensional radar signal and image processing algorithms and their application for different sensing tasks. The theoretical derivations are complemented by computer examples and simulations that form an integral part of both the lecture and the exercises.</p> <p>The lecture covers the following topics:</p> <ul style="list-style-type: none"> • Introduction (radar principles & applications, signal & noise models, interference, Doppler shift) • Basics of Signal Processing with Python (Jupyter Notebooks) • Data Acquisition (I/Q demodulation, complex signal representation, sampling, quantization) • Range Processing (radar waveforms, pulse compression, ambiguity function, sidelobe reduction) • Doppler Processing (MTI, clutter suppression, range-Doppler ambiguities, spectral estimation) • Detection Theory (target models, Neyman-Pearson criterion, CFAR detector, CRBs) • Multi-Channel Processing (spatial filtering, interference suppression, adaptive beamforming) • Synthetic Aperture Radar (basics of coherent imaging, SAR data model, time-domain processing) • SAR Focusing Algorithms (range-Doppler, chirp scaling, motion compensation, autofocus) • SAR Image Analysis (image statistics, speckle filtering, segmentation, classification) • Radar Polarimetry (wave representations, scattering models, polarimetric decomposition) • Interferometry (interferometric processing chain, statistical performance models, applications)

		<ul style="list-style-type: none"> • Tomography (principles of 3-D imaging, tomographic processing, remote sensing applications) • Space-Time Adaptive Processing (GMTI, optimum processor, pre- & post-Doppler STAP) • Advanced Topics (bi- & multistatic radar, MIMO radar, compressive sensing)
6	Learning objectives and skills	<p>Fachkompetenz</p> <p>Verstehen</p> <ul style="list-style-type: none"> • understand the basic principles and applications of radar systems • understand the statistical properties of SAR images and their combinations • understand current developments associated with bi- and multistatic SAR, MIMO radar, etc. <p>Anwenden</p> <ul style="list-style-type: none"> • implement signal processing algorithms for radar detection and parameter estimation • use performance metrics for the evaluation of radar systems and signal processing algorithms • focus coherent radar raw data into high-resolution SAR images • apply space-time adaptive processing techniques for ground moving target indication <p>Analysieren</p> <ul style="list-style-type: none"> • select and apply spectral processing techniques for clutter and interference suppression • simulate the performance of radar systems in complex environments <p>Erschaffen</p> <ul style="list-style-type: none"> • combine multiple complex-valued SAR images into higher-level information products
7	Prerequisites	<p>Keine formalen Voraussetzungen, aber grundlegende Kenntnisse erforderlich in</p> <ul style="list-style-type: none"> • Signal- und Systemtheorie, • Wahrscheinlichkeitstheorie • Lineare Algebra. <p>Von Vorteil wären zudem Vorkenntnisse auf einem Teil der folgenden Gebiete:</p> <ul style="list-style-type: none"> • statistische Signalverarbeitung • Hochfrequenztechnik • Radarsysteme • Nachrichtentechnische Systeme.
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Oral Prüfungsform: mündlich (30 Minuten)

11	Grading procedure	Oral (100%)
12	Module frequency	Only in winter 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	english
17	Bibliography	<ul style="list-style-type: none"> • The handouts distributed at the beginning of each lecture cover the entire material and are fully sufficient for exam preparation. • <ul style="list-style-type: none"> ◦ M. Richards, Fundamentals of Radar Signal Processing, McGraw-Hill, 2nd ed., 2014 ◦ I. Cumming, F. Wong, Digital Processing of Synthetic Aperture Radar Data, Artech House, 2004 ◦ J. Curlander, R. Donough, Synthetic Aperture Radar Systems & Signal Processing, Wiley, 1991 ◦ F. Ulaby, D. Long, Microwave Radar and Radiometric Remote Sensing, Michigan Press, 2014 ◦ C. Oliver, S. Quegan, Understanding Synthetic Aperture Images, Scitech, 2004 ◦ H. Van Trees, Optimum Array Processing, Wiley Interscience, 2002 ◦ J. Guerci, Space-Time Adaptive Processing for Radar, Artech House, 2nd ed., 2015 ◦ R. Hanssen, Radar Interferometry, Kluwer Academic Publishers, 2001 ◦ J. Li, P. Stoica, MIMO Radar Signal Processing, Wiley, 2008

1	Module name 96010	Architekturen der digitalen Signalverarbeitung Architectures for digital signal processing	5 ECTS
2	Courses / lectures	Übung: Übungen zu Architekturen der Digitalen Signalverarbeitung (2 SWS) Vorlesung: Architekturen der Digitalen Signalverarbeitung (2 SWS)	- 5 ECTS
3	Lecturers	Sebastian Peters Timo Maiwald	

4	Module coordinator	Prof. Dr.-Ing. Georg Fischer
5	Contents	<p>Inhalt:</p> <ul style="list-style-type: none"> • Basis-Algorithmen der Signalverarbeitung (FFT, Fensterung, Digitale FIR- und IIR-Filter) • Nichtideale Effekte bei Digitalfiltern (Quantisierung der Filterkoeffizienten, Quantisierte Arithmetik) • CORDIC-Architekturen • Architekturen für Multiratenysteme (Abtastratenumsetzer) • Architekturen digitaler Signalgeneratoren • Maßnahmen zur Leistungssteigerung (Pipelining) • Architekturen digitaler Signalprozessoren • Anwendungen <p>Content:</p> <ul style="list-style-type: none"> • Basic algorithms of signal processing (FFT, windowing, digital FIR and IIR-filters) • Non-idealities of digital filters (quantization of filter coefficients, fixed-point arithmetic) • CORDIC-architectures • Architectures of systems with multiple sampling rates (conversion between different sampling rates) • Digital signal generation • Measures of performance improvement (pipelining) • Architecture of digital signal processors • Applications
6	Learning objectives and skills	<p>Die Studierenden erlangen Grundlagenkenntnisse der Signaltheorie und können zeit- und wertkontinuierliche sowie zeit- und wertdiskrete Signale im Zeit- und Frequenzbereich definieren und erklären Die Studierenden sind in der Lage, ein klassisches Echtzeitsystem zur digitalen Signalverarbeitung konzeptionieren und die Einzelkomponenten nach den Anforderungen zu dimensionieren Die Studierenden erlangen einen Überblick über Vor- und Nachteile analoger sowie digitaler Signalverarbeitung Die Studierenden verstehen die Theorie der Fourier-Transformation und sind in der Lage, die Vorteile der Fast-Fourier-Transformation in der digitalen Signalverarbeitung zu verstehen und anzuwenden Die Studierenden können digitale Filter dimensionieren und beurteilen</p> <p>===Englisch=== Students</p>

		<ul style="list-style-type: none"> • can obtain fundamentals of signal theory and can define as well time-continuous and value-continuous as time-discrete and value-discrete signals in time and frequency domain • can construct a realtime digital signal processing system and dimension its components according requirements • can review pros and cons of analogue versus digital signal processing • can apply fourier transformation and illustrate the advantages of fast fourier transformation in the context of digital signal processing • can dimension digital filters and evaluate their performance
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	Electronic examination (60 minutes) Klausur (E-Exam 60 Min.)
11	Grading procedure	Electronic examination (100%)
12	Module frequency	Only in summer 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	english
17	Bibliography	

1	Module name 96850	Convex Optimization in Communications and Signal Processing Convex optimization in communications and signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	apl. 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	<p>Students</p> <ul style="list-style-type: none"> • 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 Electives Master of Science Advanced Signal Processing & Communications Engineering 20212 Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212	
10	Method of examination	Written or oral (90 minutes) Die Prüfung ist eine 90-minütige schriftliche Klausur. Prüfungssprache ist Englisch. <hr/> The examination is a 90-minute written test. The examination language is English.	
11	Grading procedure	Written or oral (100%)	
12	Module frequency	Only in winter 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	english
17	Bibliography	Boyd, Steven ; Vandenberghe, Lieven: Convex Optimization. Cambridge, UK : Cambridge University Press, 2004

1	Module name 92720	Hochfrequenztechnik Microwave technology	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Martin Vossiek	
5	Contents	<p>Nach einer Einführung in die Frequenzbereiche und Arbeitsmethoden der Hochfrequenztechnik werden die Darstellung und Beurteilung linearer n-Tore im Wellen-Konzept systematisch hergeleitet und Schaltungsanalysen in der Streumatrix-Darstellung durchgeführt. Bauelemente wie Dämpfungsglieder, Phasenschieber, Richtungsleitungen, Anpassungstransformatoren, Resonatoren und Mehrkreisfilter sowie Richtkoppler und andere Verzweigungs-n-Tore erfahren dabei eine besondere Behandlung, insbesondere in Duplex- und Brückenschaltungen. Rauschen in Hochfrequenzschaltungen wirkt vor allem in Empfängerstufen störend und ist zu minimieren. Antennen und Funkfelder mit ihren spezifischen Begriffen, einschließlich der Antennen- Gruppen bilden einen mehrstündigen Abschnitt. Abschließend werden Hochfrequenzanlagen, vor allem Sender- und Empfängerkonzepte in den verschiedenen Anwendungen wie Rundfunk, Richtfunk, Satellitenfunk, Radar und Radiometrie vorgestellt und analysiert.</p>	
6	Learning objectives and skills	<p>Die Studierenden</p> <ul style="list-style-type: none"> erwerben fundierte Kenntnisse über die typischen passiven HF-Bauelemente sowie den Umgang mit Streuparametern und die Analyse von HF-Schaltungen. lernen Antennenkonzepte und elementare Berechnungsmethoden für Antennen, Funkfelder, Rauschen und HF-Systeme kennen. sind in der Lage, die Kenngrößen und die hochfrequenten Eigenschaften von HF-Bauelementen und Baugruppen sowie Antennen und einfachen HF-Systemen zu berechnen und zu bewerten. 	
7	Prerequisites	<p>Empfohlene Voraussetzungen:</p> <ul style="list-style-type: none"> Passive Bauelemente und deren HF-Verhalten Elektromagnetische Felder I 	
8	Integration in curriculum	semester: 1	
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212	
10	Method of examination	Written examination (90 minutes) Prüfungsform: schriftlich (90 Minuten)	
11	Grading procedure	Written examination (100%)	
12	Module frequency	Only in winter 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	german
17	Bibliography	Zinke, O.,Brunswig, H.: Lehrbuch der Hochfrequenztechnik, Band 1, 6. Auflage. Springer-Verlag: Berlin (2000). Voges, E.: Hochfrequenztechnik. Hüthig Verlag (2004)

1	Module name 96460	Speech and Audio Signal Processing Speech and audio signal processing	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Walter Kellermann	
5	Contents	<p>Es werden Grundlagen und Algorithmen der Verarbeitung von Sprach- und Audiosignalen mit Anwendungen in Telekommunikation und Multimedia behandelt, insbesondere:</p> <ul style="list-style-type: none"> • 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, Enthaltung mittels ein- und mehrkanaliger Verfahren; 	
6	Learning objectives and skills	<p>Die Studierenden</p> <ul style="list-style-type: none"> • 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 	

		<ul style="list-style-type: none"> • können elementare Algorithmen zur Signalverbesserung anwenden und für reale Daten analysieren
7	Prerequisites	Vorlesung Signale und Systeme I & II empfohlen
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212 Technical Mandatory Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Written or oral (90 minutes) Klausur mit einer Dauer von 90 min. Es sind keine Hilfsmittel zugelassen.
11	Grading procedure	Written or oral (100%)
12	Module frequency	Only in summer semester Die Prüfung wird noch angeboten aber nicht die Vorlesung, die letztmalig im Sommer-Semester 2022 stattgefunden hat.
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	english
17	Bibliography	

1	Module name 23070	Biomedizinische Signalanalyse Biomedical signal analysis	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr. Björn Eskofier Daniel Krauß	
5	Contents	<p>Inhalt</p> <p>Im Rahmen der Vorlesung werden (a) die Grundlagen der Generation von wichtigen Biosignalen im menschlichen Körper, (b) die Messung von Biosignalen und (c) Methoden zur Analyse von Biosignalen erläutert und dargestellt.</p> <p>Behandelte Biosignale sind unter anderem Aktionspotential (AP), Elektrokardiogramm (EKG), Elektromyogramm (EMG), Elektroenzephalogramm (EEG), oder Mechanomyogramm (MMG). Bei der Messung liegt der Fokus beispielsweise auf der Messtechnik oder der korrekten Sensor- bzw. Elektrodenanbringung. Im größten Teil der Vorlesung, Analyse von Biosignalen, werden Konzepte zur Filterung für die Artefaktreduktion, der Wavelet Analyse, der Ereigniserkennung und der Wellenformanalyse behandelt. Zum Schluss wird einen Einblick in überwachte Verfahren der Mustererkennung gegeben.</p> <p>Für weitere Informationen, besuchen Sie bitte unseren zugehörigen StudOn Kurs.</p> <p>Content</p> <p>The lecture content explains and outlines (a) basics for the generation of important biosignals of the human body, (b) measurement of biosignals, and (c) methods for biosignals analysis.</p> <p>Considered biosignals are among others action potential (AP), electrocardiogram (ECG), electromyogram (EMG), electroencephalogram (EEG), or mechanomyogram (MMG). The focus during the measurement part is for example the measurement technology or the correct sensor and electrode placement. The main part of the lecture is the analysis part. In this part, concepts like filtering for artifact reduction, wavelet analysis, event detection or waveform analysis are covered. In the end, an insight into pattern recognition methods is obtained.</p> <p>For more information, please visit our associated StudOn course</p>	
6	Learning objectives and skills	<p>Die Studierenden können nach erfolgreichem Abschluss des Kurses</p> <p>Fachkompetenz</p> <p>Wissen</p> <ul style="list-style-type: none"> die Entstehung, Messung und Charakteristika der wichtigsten Biosignale des menschlichen Körpers wiedergeben <p>Verstehen</p>	

- die wesentlichen Ursachen von Artefakten in Biosignalen erklären
- Zusammenhänge zwischen der Entstehung der Biosignale des menschlichen Körper und dem gemessenen Signal erklären
- Messmethoden der wichtigsten Biosignale erklären
- Filteroperationen zur Eliminierung von Artefakten erläutern
- bekannte Algorithmen der Verarbeitung bestimmter Biosignal erklären (z.B. Pan Tompkins für EKG)
- typische Komponenten und ihre Bedeutung in einer generischen Signalanalyse Kette erläutern
- die Struktur und Funktionsweise von Systemen zur maschinellen Klassifikation einfacher Muster darstellen

Anwenden

- Signalcharakteristiken im Zeit- und Frequenzbereich bestimmen
- Algorithmen der Biosignalverarbeitung anwenden und in Python implementieren
- Filteroperationen zur Eliminierung von Artefakten anwenden und in Python implementieren
- Methoden selbstständig auf interdisziplinäre Fragestellungen der Medizin und der Ingenieurwissenschaften anwenden
- das Ergebnis von typischen Filteroperationen abschätzen

Analysieren

- Filtercharakteristika von Schaltkreisen ableiten
- Algorithmen der Biosignalverarbeitung vergleichen
- Klassifikationsprobleme in Python lösen
- Typische Artefakte in Biosignalen erkennen und Lösungsstrategien vorschlagen

Evaluieren (Beurteilen)

- Biosignale mit medizinischen Normalwerten vergleichen und im medizinischen Kontext evaluieren
- Klassifikationsergebnisse beurteilen
- die Bedeutung der Biosignalverarbeitung für die Medizintechnik diskutieren
- Probleme in Gruppen kooperativ und verantwortlich lösen und in der Übungsgruppe bzw. im Forum diskutieren

After completion of the course, students are able to

Knowledge

- reproduce the generation, measurement, and characteristics of important biosignals of the human body

Understanding

- explain the causes of artifacts in biosignals
- explain relations between the generation of biosignals and the measured signal
- explain methods for the measurement of important biosignals
- explain filter operations for the reduction of artifacts

		<ul style="list-style-type: none"> • explain algorithms for the analysis of important biosignals (e.g. Pan Tompkins for EKG) • explain typical components and their importance in the signal analysis chain • explain the structure and functioning of systems for machine learning and pattern recognition <p>Application</p> <ul style="list-style-type: none"> • determine signal characteristics in the time and frequency domain • apply and implement algorithms for signal analysis in Python • implement filter operations for the reduction of artifacts in Python • estimate the result of filter operations • apply methods to interdisciplinary problems in medicine and medical engineering <p>Analyze</p> <ul style="list-style-type: none"> • derive filter characteristics from electric circuits • compare signal analysis algorithms • solve classification problems in Python • recognize typical artifacts in biosignals and propose solutions for their reduction <p>Evaluation</p> <ul style="list-style-type: none"> • compare biosignals with medical norm values and evaluate them in a medical context • evaluate classification results • discuss the importance of biomedical signal analysis for medical engineering • solve and discuss problems in groups cooperatively in the group exercises and the online forum
7	Prerequisites	<p>Prerequisites</p> <p>The Biosig lectures and exercises do not have formal requirements. However, we expect you to have some knowledge about the following topics:</p> <ul style="list-style-type: none"> • Basics of Physiology and Anatomy (High-school level) • <ul style="list-style-type: none"> ◦ Basic elements of electronic circuits (resistor, capacitor, inductor) and related equations • Basic math: Integration, Differentiation, Limits • <ul style="list-style-type: none"> ◦ Fourier Transform (qualitative understanding) ◦ Basic filter types ◦ z-plane (qualitative understanding) <p>Furthermore, some knowledge in the following topics will be beneficial to easily understand the content of the lecture:</p> <ul style="list-style-type: none"> • Advanced filter concepts • z-plane math / z-transform / pole-zero plots

		<ul style="list-style-type: none"> • Frequency domain math / detailed understanding of Fourier transform and its properties • Laplace transform • Basics of Python (for the exercises) <p>If you want to refresh your knowledge on all the aforementioned topics, we recommend the following lectures and online resources: Note that some of them go beyond the requirements of this lecture for many topics!</p> <ul style="list-style-type: none"> • Signals and Systems I • Grundlagen der Anatomie und Physiologie für Medizintechniker • Video Series: Introduction to discrete Control (and further videos from this channel, as general introduction to filter and z-plane math) • A visual introduction to Fourier Transform • Udacity Python Course Course materials from the Stanford "Introduction to Scientific Python"
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Electronic examination Electronic Exam (in presence), 90min.
11	Grading procedure	Electronic examination (100%)
12	Module frequency	Only in winter 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	english
17	Bibliography	<ul style="list-style-type: none"> • R.M. Rangayyan, Biomedical Signal Analysis: A case-study approach. 1st ed., 2002, New York, NY: John Wiley & Sons. • E.N. Bruce, Biomedical Signal Processing and Signal Modeling. 1st ed., 2001, New York, NY: John Wiley & Sons.

1	Module name 92290	Kommunikationsnetze Communication networks	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Prof. Dr.-Ing. Andre Kaup	
5	Contents	<p>*Hierarchische Strukturen von Netzfunktionen* OSI-Schichtenmodell, Kommunikation im OSI-Modell, Datenstrukturen, Vermittlungseinrichtungen</p> <p>* Datenübertragung von Punkt zu Punkt* Signalverarbeitung in der physikalischen Schicht, synchrones und asynchrones Multiplex, Verbindungsarten</p> <p>*Zuverlässige Datenübertragung* Fehlervorwärtskorrektur, Single-Parity-Check-Code, Stop-and-Wait-ARQ, Go-back-N-ARQ, Selective-Repeat-ARQ</p> <p>*Vielfachzugriffsprotokoll* Polling, Token Bus und Token Ring, ALOHA, slotted ALOHA, Carrier-Sensing-Verfahren</p> <p>*Routing* Kommunikationsnetze als Graphen, Fluten, vollständiger Baum und Hamilton-Schleife, Dijkstra-Algorithmus, Bellman-Ford-Algorithmus, statisches Routing mit Alternativen</p> <p>*Warteraumtheorie* Modell und Definitionen, Little's Theorem, Exponentialwarteräume, Exponentialwarteräume mit mehreren Bedienstationen, Halbexponentialwarteräume</p> <p>*Systembeispiel Internet-Protokoll* Internet Protokoll (IP), Transmission Control Protocol (TCP), User Datagram Protocol (UDP)</p> <p>*Multimedianeetze* Klassifikation von multimedialen Anwendungen, Codierung von Multimediadaten, Audio- und Video-Streaming, Protokolle für interaktive Echtzeit-Anwendungen (RTP, RTCP), Dienstklassen und Dienstgütegarantien</p>	
6	Learning objectives and skills	<p>Die Studierenden</p> <ul style="list-style-type: none"> • verstehen den hierarchischen Aufbau von digitalen Kommunikationsnetzen • unterscheiden grundlegende Algorithmen für zuverlässige Datenübertragung mit Rückkanal und beurteilen deren Leistungsfähigkeit • analysieren Protokolle für Vielfachzugriff in digitalen Kommunikationsnetzen und berechnen deren Durchsatz • unterscheiden Routingverfahren und berechnen optimale Vermittlungswege für beispielhafte Kommunikationsnetze 	

		<ul style="list-style-type: none"> • abstrahieren und strukturieren Warteräume in Kommunikationsnetzen und berechnen maßgebliche Kenngrößen wie Aufenthaltsdauer und Belegung • verstehen grundlegende Mechanismen für die verlustlose und verlustbehaftete Codierung von Mediendaten • kennen die maßgeblichen Standards des Internets für Sicherung, Vermittlung und Transport von digitalen Daten
7	Prerequisites	Kenntnisse über Grundbegriffe der Stochastik
8	Integration in curriculum	semester: 1
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Written examination (90 minutes)
11	Grading procedure	Written examination (100%)
12	Module frequency	Only in winter 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	german
17	Bibliography	M. Bossert, M. Breitbach, "Digitale Netze", Stuttgart: Teubner-Verlag, 1999

1	Module name 92374	Seminar on Selected Topics in Machine Learning	2,5 ECTS
2	Courses / lectures	Seminar: Seminar on Selected Topics in Machine Learning The participants must be present at all in-person events. <i>Die Teilnehmenden müssen an allen Präsenzterminen anwesend sein.</i>	2,5 ECTS
3	Lecturers	Amir El-Ghoussani Marc Hölle Prof. Dr. Vasileios Belagiannis Michele De Vita	

4	Module coordinator	Prof. Dr. Vasileios Belagiannis
5	Contents	<p>The students will study, understand, and present scientific publications from the literature on machine learning and deep learning. At the end of the seminar, the student will be able to summarise and present a publication.</p> <p>The seminar covers a wide range of research topics in the field of machine learning and deep learning, including generative and foundation models, different types of learning and applications machine learning.</p> <p><i>Die Studierenden werden wissenschaftliche Veröffentlichungen aus der Literatur über maschinelles Lernen und Deep Learning analysieren, verstehen und präsentieren. Am Ende des Seminars sind die Studierenden in der Lage, eine Publikation zusammenzufassen und vorzustellen.</i></p> <p><i>Das Seminar deckt ein breites Spektrum an Forschungsthemen auf dem Gebiet des maschinellen Lernens und des Deep Learning ab, einschließlich generativer und Foundation-Modelle, verschiedene Arten des Lernens und Anwendungen des maschinellen Lernens.</i></p>
6	Learning objectives and skills	<p>The students will learn to:</p> <ul style="list-style-type: none"> • Conduct literature reviews. • Present and analyse a scientific topic. • Write a report on a specific problem. • Discuss and communicate research findings. <p><i>Die Studierenden lernen</i></p> <ul style="list-style-type: none"> • Literaturrecherchen durchzuführen. • ein wissenschaftliches Thema zu präsentieren und zu analysieren. • einen Bericht über ein spezifisches Problem zu schreiben. • Forschungsergebnisse zu diskutieren und zu kommunizieren.
7	Prerequisites	Basic knowledge in Machine Learning and Deep Learning beneficial

		<i>Grundlegende Kenntnisse in Machine Learning und Deep Learning von Vorteil</i>
8	Integration in curriculum	semester: 3
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212
10	Method of examination	Seminar achievement The assigned topic must be successfully presented at the end of the seminar. <i>Das zugewiesene Thema muss am Ende des Seminars präsentiert werden sowie in einem schriftlichen Bericht dargestellt werden.</i>
11	Grading procedure	Seminar achievement (100%) The given presentation and the submitted report are included in the grade. <i>Der gehaltene Vortrag und eingereichte Bericht gehen in die Notenbildung ein.</i>
12	Module frequency	Only in summer semester
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	english
17	Bibliography	Literature research is one of the learning objectives of the seminar. In the event that more in-depth literature is required, this will be made available during the seminar. <i>Die Literaturrecherche ist eines der Lernziele des Seminars. Für den Fall, dass tiefer gehende Literatur benötigt wird, wird diese im Rahmen des Seminars zur Verfügung gestellt.</i>

1	Module name 43190	Reconfigurable Computing with extended exercises Reconfigurable computing	7,5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Joachim Falk	
5	Contents	<p>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:</p> <ul style="list-style-type: none"> • 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 	

		<p>including bus-oriented as well as network-on-a-chip (NoC) approaches.</p> <ul style="list-style-type: none"> • 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	<p>Learning objectives and competencies:</p> <p>Domain-specific knowledge</p> <ul style="list-style-type: none"> • The students know to exploit run-time reconfigurable design methodologies for adaptive applications. <p>Domain-specific comprehension</p> <ul style="list-style-type: none"> • 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. <p>Domain-specific practice</p> <ul style="list-style-type: none"> • The students apply design tools for implementation of circuits and systems-on-a-chip (SoC) on FPGAs during practical training. <p>Social competency</p> <ul style="list-style-type: none"> • 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", "Reconfigurable Computing (Lecture with Exercises)", 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	Variable Oral exam in case of less than 20 participants (duration 30 mins). Otherwise, written exam (duration 90 mins). In both cases, successful completion of all tasks of the extended exercises is mandatory at the workstations in our lab at the chair.
11	Grading procedure	Variable (100%) The exam determines the final grade of the module.

12	Module frequency	Only in winter 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: 135 h
15	Module duration	1 semester
16	Teaching and examination language	german english
17	Bibliography	<p>Further reading material:</p> <ul style="list-style-type: none"> • 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/ <p>Further information:</p> <p>https://www.cs12.tf.fau.de/lehre/lehrveranstaltungen/vorlesungen/reconfigurable-computing/</p>

1	Module name 93873	Advanced Deep Learning Advanced deep learning	5 ECTS
2	Courses / lectures	No teaching units are offered for the module in the current semester. For further information on teaching units please contact the module managers.	
3	Lecturers	-	

4	Module coordinator	Dr.-Ing. Vincent Christlein	
5	Contents	<p>Deep Learning-based algorithms showed great performance in many fields of image processing and pattern recognition and compete with technologies such as compressive sensing and iterative optimization. The basis for the success of these algorithms is the availability of large amounts of data (big data) for training and of high computing power (typically GPUs or TPUs).</p> <p>In this course we will explore advanced deep learning methods. In particular, we will aim to develop a deeper understanding of topics beyond SGD optimization, CNNs and simple RNN networks, for example: attention in neural networks, self- and unsupervised learning, representation learning, multi-task and multi-modal learning, as well as diffusion and energy-based models. The selection of topics will be continuously adapted to reflect current research interests at high-impact conferences like CVPR, ICCV/ECCV, NeurIPS, ICLR and ICML. The goal of this is course is to develop both a sound theoretical understanding of these approaches and identify areas of application for these advanced techniques. This will be complemented by programming exercises to facilitate an in-depth understanding. Where suitable, we will further discuss ethical and societal implications of the discussed machine learning methods.</p>	
6	Learning objectives and skills	<p>By the end of this course, students will be able to:</p> <ul style="list-style-type: none"> • understand advanced techniques in deep learning • identify a suitable approach as well as its benefits and shortcomings • discuss the technical requirements of different approaches • read and discuss recent papers in the discipline 	
7	Prerequisites	<p>We strongly recommend students to have acquired a thorough understanding of fundamental Machine Learning and Deep Learning techniques, e.g., from the lecture + exercises "Deep Learning".</p> <p>Furthermore, programming experience in Python and Pytorch will be necessary to complete the exercises.</p>	
8	Integration in curriculum	semester: 1	
9	Module compatibility	Technical Electives Master of Science Advanced Signal Processing & Communications Engineering 20212	
10	Method of examination	Tutorial achievement Written examination (60 minutes)	
11	Grading procedure	Tutorial achievement (pass/fail)	

		Written examination (100%)
12	Module frequency	Only in winter semester
13	Workload in clock hours	Contact hours: 60 h Independent study: 90 h
14	Module duration	1 semester
15	Teaching and examination language	english
16	Bibliography	