Program

Wednesday, March 14

Wednesday, March 14, 13:00 - 14:00
K01: Keynote I
Recent Advances in Cache-aided Wireless Networks
Speaker: Dr. Aylin Yener, Professor

Wednesday, March 14, 14:00 - 18:30
D01: Demo Session (invited)

Wednesday, March 14, 14:25 - 16:05
S01: C-RAN
Chair: Suzan Bayhan

14:25 *Scheduling Strategies for Hierarchical Beamforming in Cloud RAN*
Boriana Boiadjieva, Hussein Al-Shatri and Anja Klein

14:50 *Improving TCP Fairness over Latency Controlled 5G mmWave Communication Links*
Marcus Pieska, Andreas J. Kassler, Henrik Lundqvist and Tao Cai
In order to increase the capacity of 5G networks, using mmWave band communication links both for access and backhaul are an interesting alter- native due to the large spectrum portion available at those frequency bands. However, mmWave bands exhibit special propagation characteristics which require the usage of highly directional and beam-steerable antennas in order to cope with significantly higher pathloss. Using such links in urban scenarios may lead to frequent blocking events due to moving pedestrians or cars, which may result in the links dynamically changing their characteristics from Line-of-Sight (LOS) to Non Line-of-Sight (NLOS) or outage (OUT). Due to the sudden significant variation in available capacity when changing the link states, TCP connections may experience sudden spikes in end-to-end latency and severe bufferbloat. Although bufferbloat solutions such as CoDel can be deployed to control the delay, they significantly impact both capacity and fairness between different TCP flows sharing the same mmWave link. In this paper, we study this fairness issue when running multiple TCP connections over fluctuating mmWave links and deploying AQM schemes to control the latency. We study the effect of length and severity of the NLOS episode upon fairness and latency.

15:15 *Enabling Flexibility of Traffic Split Function in LTE-WiFi Aggregation Networks through SDN*
Suzan Bayhan and Anatolij Zubow
One option to expand LTE downlink capacity is LTE-WiFi aggregation (LWA) which uses the carrier WiFi APs to deliver traffic tunneled from the LTE eNBs. LWA requires careful splitting of the traffic between LTE and WiFi resources to ensure good load balance among the colocated eNBs and APs. Currently, the eNB decides on how to split the traffic. However, due to its local knowledge, the split may not be optimal. Instead, we take benefits of Software-Defined Networking (SDN) by decoupling the control and data forwarding plane, where a centralized entity, namely traffic split function controller (TSFC), can allocate resources more efficiently using its broader knowledge. We propose that a dumb datapath element (the TSF) splits flows/packets between ports, i.e., eNB and AP(s), as defined by a remote control process, i.e. the TSFC. However, it is not clear where the TSFC should be located in the network hierarchy, e.g., at each eNB or deep in the core network or even in the cloud, due to several opposing forces. Centralization at the higher layers brings more global knowledge at the expense of increased delay and control messages. Our paper models and analyzes how the location of the TSFC affects the LWA performance.

15:40 *WizHaul: An Automated Solution for vRAN Deployments Optimization*
Josep Xavier Salvat, Andres Garcia-Saavedra, Xi Li and Xavier Costa-Perez
Future 5G deployments will support a flexible split of Base Station (BS) functions, i.e., it will be possible to decide which atomic operations will be co-located on the edge and which ones will be processed on a Central Unit (CU). Thus, network owners will be able to decide how much centralization they would like to retain in different deployments. However, deciding which BS components should be offloaded to a CU becomes a challenge because routing and BS function placement choices are coupled. We present WizHaul, a software framework enabling the implementation of a centralized functional split decision-making engine for future 5G networks. The purpose of WizHaul is twofold. First, it may be used in a network planning phase to settle the optimal amount of centralization. Second, it may also be used to support network automation/adaptation scenarios where network failures or congestion in the cloud may draw the current configuration infeasible.

Wednesday, March 14, 16:30 - 18:10
S02: Caching
Chair: Daniela Tuninetti

16:30 *On Combination Networks with Cache-aided Relays and Users*
Kai Wan, Daniela Tuninetti, Pablo Piantanida and Mingyue Ji
This invited paper extends the recent work by the Authors on centralized combination networks with end-user caches to more general (for example, less symmetric network topologies) settings.

16:50 *Mobility-Aware Coded Storage and Delivery*
Mehmet Emre Ozfatura and Deniz Gündüz
Content caching at small-cell base stations (SBSs) is a promising method to mitigate the excessive backhaul load and delay, particularly for on-demand video streaming applications. A cache-enabled heterogeneous cellular network architecture is considered in this paper, where mobile users connect to multiple SBSs during a video downloading session, and the SBSs request files, or fragments of files, from the macro-cell base station (MBS) according to the user requests they receive. A novel coded storage and delivery scheme is introduced to reduce the load on the backhaul link from the MBS to the SBSs. The achievable backhaul delivery rate as well as the number of sub-files required to achieve this rate are studied for the proposed coded delivery scheme, and it is shown that the proposed scheme provides significant reduction in the number of sub-files required, making it more viable for practical applications.

17:10 *Coded Caching in a Cell-Free SIMO Network*
Mozghan Bayat, Ratheesh K. Mungara and Giuseppe Caire
The coded caching scheme proposed by Maddah- Ali and Niesen considers the delivery of items (files) in a given content library to users through the so-called single bottleneck link network. While the single bottleneck link network is a deterministic error-free model, where the multicast rate to all users is fixed irrespectively of the number of users, in order to apply this paradigm to a wireless network, it is important to make sure that the common rate at which the multicast message is transmitted remains large as the number of users increase. This paper focuses on a variant of the Maddah-Ali and Niesen scheme successively proposed for the so-called combination network, where the multicast message is further encoded by an MDS code and the MDS-coded blocks are simultaneously transmitted from different nodes, referred to in the wireless context of this paper as Remote Radio Heads (RRHs). In the proposed system, each user is equipped with an antenna array and can select to decode a certain number of RRH transmissions, while either zero-force some others, or simply treat the others (the weak ones) as noise. The system is "cell-free" in the sense that each user can independently and individually (in a usercentric manner) decide which RRHs to decode, without any explicit association of users to RRHs. We study the performance of the proposed system when users and RRHs are distributed according to 2-dimensional homogeneous Poisson Point Process ad the propagation is affected by Rayleigh fading and distance dependent pathloss. We use stochastic geometry to derive the average rate of a typical user and the ergodic rate CDF, where ergodicity is with respect to the small-scale Rayleigh fading and the randomness of the rates is due to the large-scale pathloss, which is random due to the random geometry. Our analysis allows to optimize the system with respect to the MDS coding rate. Also, form our analysis it follows that the proposed system is fully scalable, in the sense that it can support an arbitrarily large number of users, while maintaining a non-vanishing peruser rate.

Thursday, March 15

Thursday, March 15, 09:00 - 10:00
K02: Keynote II
Analog to Digital Compression in Antenna Arrays
Speaker: Dr. Yonina C. Eldar, Professor

Thursday, March 15, 10:30 - 12:10
S03: Massive MIMO for mobile broadband communications and new 5G services
Chair: Elisabeth de Carvalho

10:30 *Low-complexity channel estimation in correlated massive MIMO channels*
Samer Bazzi and Wen Xu
In this paper, we propose low-complexity channel estimation schemes in spatially correlated massive MIMO channels. Minimum-mean-square-error (MMSE) estimators at the user(s) and optimized downlink (DL) training sequences that exploit channel correlations are standard used techniques. To keep the training overheads acceptable, only the case with less observations (training sequences) than the length of the channel vector is considered. Though the standard least squares (LS) estimator is not defined in this case, we show in the single-user case that with optimized training sequences, the MMSE estimator is alternatively given by a simpler expression

that is reminiscent of the LS estimator at high signal-to-noise-ratio (SNR). In the multiuser case, LS-like estimators simplify the channel estimation sum MSE function and allow obtaining training solutions in closed-form, thereby avoiding existing iterative procedures. The simplified formulation further allows deriving a novel result on the minimum training duration that drives the channel estimation sum MSE to zero as the SNR goes to infinity in multiuser scenarios with spatially correlated channels. The obtained training duration depends on two crucial factors: the ranks of the spatial covariance matrices, and the overlap between their range spaces. The proposed solution results in comparable estimation and sum rate performance to existing solutions in the medium and high SNR regime while substantially reducing the computational complexity at both sides of the link.

10:50 *Joint User Activity and Non-Coherent Data Detection in mMTC-Enabled Massive MIMO Using Machine Learning Algorithms*

Kamil Senel and Erik G. Larsson

Machine-type communication (MTC) services are expected to be an integral part of future cellular systems. A key challenge of MTC is the detection of the set of active devices among a large number of devices. The sparse characteristics of MTC makes the compressed sensing (CS) approaches a promising solution to the device detection problem and CS-based techniques are shown to outperform conventional device detection approaches. However, utilizing CS-based approaches for device detection along with channel estimation and using the acquired estimates for coherent data transmission may not be the optimal approach especially for the cases where the goal is to convey a few bits of data. In this work, we propose a non-coherent transmission technique for the MTC uplink and compare its performance with coherent transmission. Furthermore, we demonstrate that it is possible to obtain more accurate channel state information by combining the conventional estimators with CS-based techniques.

11:10 *Hierarchical Sparse Channel Estimation for Massive MIMO*

Mahdi Barzegar Khalilsarai, Gerhard Wunder, Saeid Haghighatshoar, Giuseppe Caire, Gitta Kutyniok, Ingo Roth and Axel Flinth

Massive MIMO, i.e. deploying large number of antennas at the base station, is a key technology for 5G [1]. Although its benefits are by now well understood and documented, the critical bottleneck for massive MIMO deployment is still the acquisition of channel state information (CSI), with designs attempting to balance the conflicting requirements of training overhead and co-pilot contamination reduction, in addition to the standard requirement of computational efficiency. This problem is even more important in massive machine type communications (MTC) where accurate CSI with low-training overhead is of critical importance. Towards addressing these issues, one major line of works applies compressed sensing (CS) techniques in order to account for and exploit the sparsity properties of the wireless channel. The typical approach comes in two stages: first the spatial covariance matrix is estimated while, second, the dedicated (wideband) user channels are estimated within the estimated spatial subspaces. This approach has been mostly applied to the narrowband signaling case, exploiting the channel sparsity in the, so called, angle domain (see [2] for an overview). Extensions of CS techniques to the wideband (OFDM) massive MIMO channel have been recently considered in [3], [4], [5]. One intuitive motivation for such an approach is that there is more "space" in this larger structure so that pilot contamination induced by co-pilots in other cells is effectively combated. Initial work has been provided in [3], arguing that with large enough resolution in angular and time domain controlled by the number of antennas and subcarriers, the channels become approximately orthogonal so that pilot contamination diminishes. Notably, the subspace estimates are obtained through pilot coordination over multiple slots, but not primarily through sparse channel estimation. Moreover, the claimed orthogonality is not rigorous and crucially depends on the parameter setting, let alone that bandwidth (i.e. subcarriers) is not a free design parameter. In [4], a computationally efficient CS-based CSI acquisition approach is proposed, utilizing observations from only a limited number of subcarriers and antennas. Moreover, a fine resolution of angle and time domain together with a sparse subspace tracking algorithm is proposed. The resulting algorithm shows good performance and is exploited for pilot decontamination purposes. A similar setting is also considered in [5], where a minimum mean squared error (MMSE) channel estimator is proposed, however, requiring prior knowledge of the channel second order statistics. Generally, a two stage approach may require excessive observations in time in order to obtain an accurate estimate of the received signal covariance matrix, which is critical, e.g., in massive MTC setting. Another major problem is that the proposed CS algorithms lack rigorous performance analysis in terms of estimation error and, equally important, number of utilized subcarriers in order to achieve it. This is mainly due to the specific Kronecker-like measurement structure of the equivalent CS problem, where, as we will show, the classical CS assumptions fail to hold entailing convergence issues and leakage effects. However, targeting for low complexity algorithms as well as small training overhead say in future MTC applications, it is imperative to understand such structures and to derive a tailored algorithmic framework. Contributions: We propose an efficient "one stage" uplink massive MIMO wideband (OFDM) channel estimation taking into account only the sparsity of the wideband channel into account without any additional prior knowledge. In particular, we identify that the channel estimation problem can be posed as the identification of a vector that is hierarchically sparse, i.e., it is not only sparse but its support possesses certain structural properties. This property together with the Kronecker-like measurement is taken into account for the design of an efficient CS-inspired algorithm tailored for this particular setup. In addition, by extending the standard CS analysis methodology to hierarchical sparse vectors, we provide a rigorous analysis of the algorithm performance in terms of estimation error as well as number of pilot subcarriers required to achieve it. We believe, that this is the first paper that draws a rigorous connection between the hierarchical framework and Kronecker measurements. Preliminary simulations show that exploitation of the hierarchical sparsity property leads to improved estimation performance compared to standard CS algorithms that ignore this property. Even worse, standard algorithms may completely fail in some specific parameter settings. Obviously, this might have some profound impact on system parameters such as pilot signal design, user capacity per cell etc.

11:30 *On the Application of Cylindrical Arrays for Massive MIMO in Cellular Systems*

Martin Kurras, Miao Yan, Lars Thiele, Niels Hadaschik, Marcus Grossmann, Markus Landmann and Varatharaajan Sutharshun

In this paper, the potential application of Uniform Circular Arrays (UCAs) instead of sectorized Uniform Planar Arrays (UPAs) in cellular deployments is studied. This includes fundamental observations on the aperture size observed by users. Furthermore, coverage trade-offs are investigated in terms of rate showing that with uniform user distributions the UCAs provides higher minimum rates while sacrificing peak rate compared to sectorized UPAs. Additional, the impact from sectorization, multiuser, and inter-sector interference is evaluated by numerical analysis. Finally, in order to enable the use of UCAs in standardization so called Array-Response-Matched (ARM) codebooks are proposed that can be constructed similar to the Discrete Fourier Transform (DFT) based codebooks currently used for UPAs. The construction and numerical evaluation of the ARM codebooks is also included in the paper.

11:50 *Massive MIMO for Ultra-reliable Communications with Constellations for Dual Coherent-noncoherent Detection*

Alexandru-Sabin Bana, Marko Angjelichinoski, Elisabeth de Carvalho and Petar Popovski

The stringent requirements of ultra-reliable low-latency communications (URLLC) require rethinking of the physical layer transmission techniques. Massive antenna arrays are seen as an enabler of the emerging 5th generation systems, due to increases in spectral efficiency and degrees of freedom for transmissions, which can greatly improve reliability under demanding latency requirements. Massive array coherent processing relies on accurate channel state information (CSI) in order to achieve high reliability. In this paper, we investigate the impact of imperfect CSI in a single-input multiple-output (SIMO) system on the coherent receiver. An amplitude-phase keying (APK) symbol constellation is proposed, where half of the symbols are transmitted with a lower power, and half with a higher power, such that there exist two energy levels. The symbols are demodulated using a dual non-coherent and coherent detection strategy, in order to improve symbol reliability. Simulation results show that for inaccurate CSI, the proposed scheme enhances receiver performance.

Thursday, March 15, 12:10 - 14:20
P01: 5G Wireless
Chairs: Marco Di Renzo, Eduard Jorswieck

A Study of Delay Drifts on Massive MIMO Wideband Channel Models

Carlos F Lopez and Chengxiang Wang

In this paper, we study the effects of the variations of the propagation delay over large-scale antenna-arrays used in massive multiple-input multiple-output (MIMO) wideband communication systems on the statistical properties of the channel. Due to its simplicity and popularity, the Elliptical geometry-based stochastic channel model (GBSM) is employed to demonstrate new non-stationary properties of the channel in the frequency and spatial domains caused by the drift of delays. In addition, we show that the time of travel of multi-path components (MPCs) over large-scale arrays may result in overlooked frequency and spatial decorrelation effects. These are theoretically demonstrated by deriving the space-time-frequency correlation functions (STFCFs) of both narrowband and wideband Elliptical models. Closed-form expressions of the array-variant frequency correlation function (FCF), power delay profile (PDP), mean delay, and delay spread of single- and multi-confocal Elliptical models are derived when the angles of arrival (AOAs) are von Mises distributed. In such conditions, we find that the large dimensions of the antenna array may limit the narrowband characteristic of the single-ellipse model and alter the wideband characteristics (PDP and FCF) of the multi-confocal Elliptical channel model. Although we present and analyze numerical and simulation results for a particular GBSM, similar conclusions can be extended to other GBSMs.

Power Control for D2D Underlay in Multi-cell Massive MIMO Networks

Amin Ghazanfari, Emil Björnson and Erik G. Larsson

This paper propose a new power control and pilot allocation scheme for device-to-device (D2D) communication underlaying a multi-cell massive MIMO system. In this scheme, the cellular users in each cell get orthogonal pilots which are reused with reuse factor across cells, while the D2D pairs share another set of orthogonal pilots. We derive a closed-form capacity lower bound for the cellular users with different receive processing schemes. In addition, we derive a capacity lower bound for the D2D receivers and a closed-form approximation of it. Then we provide a power control algorithm in which we maximize the minimum spectral efficiency of the users in the network. Finally, we provide a numerical evaluation where we compare of our proposed power control algorithm with the maximum transmit power case and the case of conventional multi-cell massive MIMO without D2D communication. Based on the provided results, we conclude that our proposed scheme increases the sum spectral efficiency of multi-cell massive MIMO networks.

Distributed Power Control in Downlink Cellular Massive MIMO Systems

Trinh Van Chien, Emil Björnson, Erik G. Larsson and Tuan Anh Le

This paper compares centralized and distributed methods to solve the power minimization problem with quality-of-service (QoS) constraints in the downlink (DL) of Massive multiple-input multiple-output (MIMO) systems. In particular, we study the computational complexity, number of parameters that need to be exchanged between base stations (BSs), and the convergence of iterative implementations. Although a distributed implementation based on dual decomposition (which only requires local statistical channel knowledge at each BS) typically converges to the global optimum after a few iterations, many parameters need to be exchanged to reach convergence.

A Novel Beamforming Scheme for Mobile-to-Mobile Millimeter Wave Communications

Yi Tan, Chengxiang Wang, Zhu Qiuming, Zhi Zhang, Zhonghua Wang, Jie Huang and Rui Feng

Due to using beamforming technology in millimeter wave (mmWave) communication, the movement of transmitter (Tx) and receiver (Rx) will cause the mis-alignment of Tx and Rx beams. In order to deal with this problem, a novel physical layer beamforming scheme is proposed in this paper, namely, double Gaussian beams (DGBs) scheme, which treats the static and moving Tx/Rx scenarios in the same manner. We model the DGBs channels by three Markov states, and the connection ratio of Markov state is used as the metric to study the performance of DGBs scheme from the channel point of view. We show that the DGBs channels have very similar light-of-sight (LOS) state connection ratio compared with that of the measured mmWave channels based on similar set up of the Tx and Rx beams.

Robust Energy-Efficient Power Control and Beam-forming in Network Flooding

Abdelrahman Abdelkader and Eduard Jorswieck

In a device-to-device wireless multi-hop communication scenario with resource-constrained devices, energy efficiency of communication plays a huge role. Based on the recently proposed Glossy network flooding protocol, we tackle the problem of robust multicast beamforming with imperfect CSI, and analyze its performance. The effect of number of CSI feedback bits B from receiving nodes to transmitting nodes on energy efficiency is investigated. Numerical simulations show that there exists an optimal number of feedback bits that maximizes energy efficiency. The programming problem for finding optimal B is formulated for a maximum allowed outage of 5% and the effect that has on energy efficiency is studied. Results show that higher outage requirements result in larger values of optimal number of feedback bits B for maximum energy efficiency.

Millimeter Wave Dual-Band Multi-Beam Waveguide Lens-Based Antenna

Vedaprabhu Basavarajappa, Alberto Pellón, Ana Rosa Ruiz, Beatriz Bedia Exposito, Lorena Cabria and Jose Basterrechea

A multi-beam antenna with a dual band operation in the 28 GHz and 31 GHz millimeter wave band is presented. The antenna has a gain of around 15 dBi in each of the three ports. The spatial footprint of the antenna is 166 mm x 123 mm x 34 mm.

Receive Antenna Selection and Hybrid Precoding for Receive Spatial Modulation in Massive MIMO Systems

Ahmed Raafat, Adrian Agustin and Josep Vidal

Recently, a receive spatial modulation (RSM) for massive multiple-input-multiple-output operating in millimeter wave (mmWave) was introduced with the purpose of simplifying user terminal circuit by employing only one radio-frequency chain and attaining high spectral efficiency by exploiting the receive spatial dimension. However, when RSM is applied in a mmWave channel, it demands a challenging receive antenna selection (RAS) procedure. On the other hand, the power consumption at the transmitter side is high when a full digital (FD) precoder is envisioned. We consider the joint problem of RAS and precoder designs based low complexity hybrid architecture. For the sake of simplicity, we divide this problem into two subproblems. First, we design the RAS assuming FD precoder, and then, we design the hybrid precoder. We propose two novel and efficient RAS methods. First, we formulate the RAS as non-convex optimization problem. Then, we convert it into a convex optimization problem by introducing novel lower bounds and relaxing non-convex constraints. Second, we provide a near optimal iterative algorithms where we (add/remove) one (good/poor) antenna per iteration. We propose novel zero forcing hybrid precoder based convex optimization that maximizes the received power. We prove that the proposed precoder is optimal when the channel is highly spatially sparse. We evaluate the performance between proposed designs and the best known methods in terms of average mutual information and energy efficiency showing significant improvements.

Modeling Spatially-Correlated Cellular Networks by Using Inhomogeneous Poisson Point Processes

Shanshan Wang, Marco Di Renzo and Xiaojun Xi

In this paper, we introduce a new methodology for modeling and analyzing downlink cellular networks, where the Base Stations (BSs) constitute a motion-invariant Point Process (PP) that exhibits some degree of interactions among the points, i.e., spatial inhibition (repulsion) or spatial aggregation (clustering). The proposed approach is based on the theory of Inhomogeneous Poisson PPs (I-PPPs) and is referred to as Inhomogeneous Double Thinning (IDT) approach. The proposed approach consists of approximating the original motion-invariant PP with an equivalent PP that is made of the superposition of two conditionally independent I-PPPs. The inhomogeneities are mathematically modeled through two distance-dependent thinning functions and a tractable expression of the coverage probability is obtained and validated by simulations.

Utility-based Downlink Pilot Assignment in Cell-Free Massive MIMO

Giovanni Interdonato, Pål Frenger and Erik G. Larsson

We propose a strategy for orthogonal downlink pilot assignment in cell-free massive MIMO (multiple-input multiple-output) that exploits knowledge of the channel state information, the channel hardening degree at each user, and the mobility conditions for the users. These elements, properly combined together, are used to define an user pilot utility metric, which measures the user's real need of a downlink pilot for efficient data decoding. The proposed strategy consists in assigning orthogonal downlink pilots only to the users having a pilot utility metric exceeding a predetermined threshold. Instead, users that are not assigned with an orthogonal downlink pilot decode the data by using the statistical channel state information. The utility-based approach guarantees higher downlink net sum throughput, better support both for high-speed users and shorter coherent intervals than prior art approaches.

Measurement Based Assessment of Spatial and Temporal Correlation of Base Station Load

Panagiotis Matzoros, Eduard Jorswieck and George Agapiou

For the revolution way from the current networks to the 5G era and beyond a set of stringent requirements and key performances should be meet. These define the need for more efficient procedures of designing and upgrading the Radio Access Network. In this paper we assess large scale measurements from an existing LTE network of a dense urban area (city) by focusing on the user load. In particular, we examine the spatial correlation of two clusters with different location characteristics by using a mathematical measure based on majorization. Finally we consider the temporal auto- and cross-correlation of the base stations in different locations. The assessment explains certain user and mobility

Closed-Form Capacity Bounds for Downlink and Uplink Decoupling

Alexis I. Aravanis, Antonio Pascual-Iserte and Olga Muñoz-Medina

Downlink (DL) and uplink (UL) decoupling (DUDe) is a new architectural paradigm where DL and UL are not constrained to be associated to the same base station (BS). Thus, a user having access to multiple BSs within a dense cellular network can receive the DL traffic from one BS and send its UL traffic through another. Building upon this architectural paradigm, the present paper provides tight analytical bounds in closed form for the UL ergodic capacity that depend solely on the density of the infrastructure. The devised bounds account for the backbone network congestion and the synchronization of the acknowledgments of the decoupled channels. The proposed bounds are compared against extensive numerical simulations demonstrating the tractability and accuracy of the expressions.

Massive MIMO Channel Performance Analysis Considering Separation of Simultaneous Users

Mohammed Zahid Aslam, Yoann Corre, Emil Björnson and Yves Lostanlen

One of the key aspects of massive MIMO (mMIMO) is its ability to spatially differentiate between multiple simultaneous users. The spatial separability improves as the number of base station (BS) antenna elements is increased. In real BS deployments, the number of BS array elements will be fixed, and expected to provide the required service to a certain number of simultaneous users in the existing propagation environment. The mMIMO performance is investigated in this paper, in an urban macro-cell scenario, using three kinds of channel models with different complexity levels: the independent and identically distributed Rayleigh fading model, a geometry-based stochastic model, and a physical ray-based software. Two performance indicators are analyzed: the favorable propagation metric and the multi-user eigenvalue distribution. Two frequencies (2 GHz and 28 GHz) and two antenna array shapes (linear and circular) are considered and compared.

Transceiver Design for GFDM with Index Modulation in Multi-user Networks

Merve Yuzgeccioglu and Eduard Jorswieck

Index modulation (IM) techniques can be applied to different media in order to achieve spectral- and energy-efficient communication as well as indices of subcarriers of a generalized frequency division multiplexing (GFDM) data block. In this work, error performance of a GFDM-IM multi-user system is studied and shown that better error performance than classical GFDM can be achieved by employing IM to GFDM.

NOCA versus IDMA using UFMC for 5G Multiple Access

Mohammadhossein Attar, Yejian Chen, Sher Ali Cheema, Thorsten Wild and Martin Haardt

Non-orthogonal multiple access (NOMA) schemes are gaining a lot of attentions for fifth generation (5G) cellular networks. As compared to the conventional orthogonal multiple access technologies, NOMA techniques can accommodate much more users via non-orthogonal resource allocation. Existing dominant NOMA schemes can be divided into two main categories: power-domain multiplexing and code-domain multiplexing. In this work, we evaluate the performance of two code-domain multiplexing techniques: interleave-division multiple access (IDMA) and non-orthogonal coded access (NOCA). We propose different detection schemes for these access schemes. Specifically, we integrate these techniques with one of the 5G air interface proposals, i.e., universal filtered multicarrier (UFMC). We compare the performance of these multiple access schemes with cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) based IDMA and NOCA techniques. Our results indicate that a large number of users can be accommodated with these techniques. Moreover, using UFMC or CP-OFDM in conjunction with these code-domain multiplexing techniques provides a similar performance in a synchronous environment.

A Statistical Approach for RF Exposure Compliance Boundary Assessment in Massive MIMO Systems

Paolo Baracca, Andreas Weber, Thorsten Wild and Christophe Grangeat

Massive multiple-input multiple-output (MIMO) is a fundamental enabler to provide high data throughput in next generation cellular networks. By equipping the base stations (BSs) with tens or hundreds of antenna elements, narrow and high gain beams can be used to spatially multiplex several user equipment (UE) devices. While increasing the achievable performance, focusing the transmit power into specific UE directions also poses new issues when performing the radio frequency (RF) exposure assessment. In fact, the spatial distribution of the actual BS transmit power strongly depends on the deployment scenario and on the position of the UEs. Traditional methods for assessing the RF exposure compliance boundaries around BS sites are generally based on maximum transmit power and static beams. In massive MIMO systems, these approaches tend to be very conservative, in particular when time averaging is properly considered. In this work, we propose to leverage the three dimensional spatial channel model standardized by the Third Generation Partnership Project in order to assess reasonably foreseeable compliance boundaries of massive MIMO BSs. The analysis is performed by considering BSs fully loaded and different configurations of active UEs per cell. Numerical results show that the statistical approach developed in this paper allows reducing to nearly half the compliance distance when compared to the traditional method.

Stepwise Transmit Antenna Selection in Downlink Massive Multiuser MIMO

Ali Bereyhi, Saba Asaad and Ralf R. Müller

Due to the large power consumption in RF-circuitry of massive MIMO systems, practically relevant performance measures such as energy efficiency or bandwidth efficiency are neither necessarily monotonous functions of the total transmit power nor the number of active antennas. Optimal antenna selection is however computationally infeasible in these systems. In this paper, we propose an iterative algorithm to optimize the transmit power and the subset of selected antennas subject to non-monotonous performance measures in massive multiuser MIMO settings. Numerical results are given for energy efficiency and demonstrate that for several settings the optimal number of selected antennas reported by the proposed algorithm is significantly smaller than the total number of transmit antennas. This fact indicates that antenna selection in several massive MIMO scenarios not only reduces the hardware complexity and RF-costs, but also enhances the energy efficiency of the system.

Leakage Based Beam Shaping for Cooperative Communication in MANETs

Tim Rüegg, Raphael T. L. Rolny and Armin Wittneben

Using the concepts of phased arrays, cooperative communication in military MANTEs has the potential to strongly increase the transmission range while reducing the probability of being detected by hostile units. However, due to the random placement of the nodes and their potentially large separation, the standard pattern synthesis tools can not be applied or require large computational complexity. In this context, we propose leakage based beam shaping, a low complexity pattern synthesis approach which minimizes the leakage power in undesired directions while maintaining coherent addition in the desired direction. By carefully evaluating its performance under various perspectives, we are going to investigate its potential and practical feasibility in military MANETs.

Influence of Channel Parameters on Noncoherent Massive MIMO Systems

Stephan Bucher, George Yammine, Robert F.H. Fischer and Christian Waldschmidt

In multi-user massive MIMO uplink systems, noncoherent detection schemes offer an appealing alternative to classical coherent detection algorithms. Sorted decision-feedback differential detection (DFDD) in combination with noncoherent decision-feedback equalization (nDFE) over the users have been demonstrated to achieve comparable results to the coherent case. Up to now, the assessment of noncoherent detection has been performed on the basis of an idealized channel model. In this paper, the influence of channel parameters on the performance of noncoherent massive MIMO systems is analyzed via an extensive simulation study. Thereby, a realistic channel model, in particular the COST 2100 channel model, forms the basis for the evaluation. It is shown that performance is highly dependent on the actual channel settings as well as on the power control of the transmitter. A further outcome is that the idealized channel model in previous studies ignores correlation effects and exhibits other power distributions among the receiving antennas. As a consequence, further optimization steps for noncoherent detection are required.

BEM-Based Channel Estimation for 5G Multicarrier Systems

João Dias, Rodrigo C. de Lamare and Yuriy Zakharov

In this paper, we investigate channel estimation techniques for 5G multicarrier systems. Due to the characteristics of the 5G application scenarios, channel estimation techniques have been tested in Orthogonal Frequency Division Multiplexing (OFDM) and Generalized Frequency Division Multiplexing (GFDM) systems. The orthogonality between subcarriers in OFDM systems permits inserting and extracting pilots without interference. However, due to pulse shaping, subcarriers in GFDM are no longer orthogonal and interfere with each other. Due to such interference, the channel estimation for GFDM is not trivial. A robust and low-complexity channel estimator can be obtained by combining a minimum mean-square error (MMSE) regularization and the basis expansion model (BEM) approach. In this work, we develop a BEM-type channel estimator along with a strategy to obtain the covariance matrix of the BEM coefficients. Simulations show that the BEM-type channel estimation shows performance close to that of the linear MMSE (LMMSE), even though there is no need to know the channel power delay profile, and its complexity is low.

Explicit CSI Feedback Design for 5G New Radio phase II

Rana Ahmed, Eugene Visotsky and Thorsten Wild

Massive multiple input multiple output (MIMO) systems are expected to boost the data throughput and reliability in future 5G systems. In order to enable advanced radio concepts in New Radio (NR) phase II, such as multiple transmit receive point (multi-TRP) transmission, accurate channel state information (CSI) knowledge at gNB side is essential. This paper provides a practical explicit CSI feedback scheme, which exploits time domain channel sparsity. A heuristic greedy algorithm is used to discover the channel support and feed it back to the gNB. Simulation results comparing the proposed approach against recently standardized NR phase I Type II CSI feedback, show an improved performance for the proposed design.

Area Rate Evaluation based on Spatial Clustering of massive MIMO Channel Measurements

Maximilian Arnold, Johannes Pfeiffer and Stephan ten Brink

Channel models for massive MIMO are typically based on matrices with complex Gaussian entries, extended by the Kronecker and Weichselberger model. One reason for observing a gap between modeled and actual channel behavior is the absence of spatial consistency in many such models, that is, spatial correlations over an area in the x, y-dimensions are not accounted for, making it difficult to study, e.g., area-throughput measures. In this paper, we propose an algorithm that can distinguish between regions of non-line-of-sight (NLoS) and line-of-sight (LoS) via a rank-metric criterion combined with a spiral search. With a k-means clustering algorithm a throughput per region (i.e., cluster) can be calculated, leading to what we refer to as "area-throughput". For evaluating the proposed orthogonality clustering scheme we use a simple filtered MIMO channel model which is spatially consistent, with known degrees of freedom. Moreover, we employ actual (spatially consistent) area channel measurements based on spatial sampling using a spider antenna and show that the proposed algorithm can be used to estimate the degrees of freedom, and, subsequently, the number of users that maximizes the throughput per square meter.

Subcarrier-Interlaced FDD for Faster-than-TDD Channel Tracking in Massive MIMO Systems

Maximilian Arnold, Xiaojie Wang and Stephan ten Brink

Canonical Massive MIMO uses time division duplex (TDD) to exploit channel reciprocity within the coherence time, avoiding feedback of channel state information (CSI), as is required for precoding at the base station. We extend the idea of exploiting reciprocity to the coherence bandwidth, allocating subcarriers of a multicarrier (OFDM)-based system in an interlaced fashion to up- and downlink, respectively, referred to as (OFDM-)subcarrier interlaced FDD (IFDD). Exploiting this "two-dimensional" channel reciprocity within both time and frequency coherence does not require any CSI feedback and, even more so, offers faster-than-TDD channel tracking. To address imperfections of actual hardware, we conducted measurements, verifying the practical viability of IFDD. As it turns out, the scheme incurs similar transmit/receive isolation issues (self-interference) as well-known from the full-duplex (FDup) literature. As will be shown, such hardware challenges like self-interference or frequency offsets are not critical for massive MIMO operation, but can be neglected as the number of antennas grows large. Finally, we quantify how IFDD allows to track the channel variations much faster than TDD over a wide range of commonly used pilot symbol rates.

Sub Tiling - a flexible CSI Reference Signal Concept for 5G New Radio Systems

Wolfgang Zirwas, Rakash SivaSiva Ganesan and Berthold Panzner

Mobile cellular radio systems have to support a multitude of user end devices with varying channel characteristics, ranging from static sensors over nomadic users up to high speed UEs on roads or highways. The channel characteristics of these devices vary accordingly from highly frequency selective in non line of sight scenarios to highly time variant on motor highways. Covering all these use cases simultaneously by a single CSI reference signal pattern, conventionally, leads to a high overhead for reference signals as it requires a dense grid of pilot signals, fulfilling the sampling theorem in time and frequency. In 5G new radio (NR) standardization adaptive CSI RS patterns per frequency subband are being proposed and discussed. Here, we suggest as alternative solution a so called sub tiling concept, which provides inherent flexibility for an either dense in time or in frequency channel estimation. That way simultaneously nomadic users with frequency selective NLOS channels can be supported from the same CSI RS pattern as fast moving UEs with relatively flat radio channels.

A Greedy Approach for Multiuser mmWave Hybrid Precoding with Subarray Architectures

Marcin Iwanow, Samer Bazzi and Wolfgang Utschick

We consider a multiuser mmWave downlink with hybrid digital-analog transceivers, where the analog stage is realized with a network of phase shifters. Moreover, we concentrate on a case particularly relevant from the practical perspective. Namely, we constrain the analog stages such that disjoint antenna subarrays are processed separately in the analog domain. In this abstract, we provide initial results which extend the promising results from [1] to a multiuser scenario. Like in the referenced work, we separate the design of the digital and analog processing, and concentrate on the latter.

Thursday, March 15, 14:20 - 15:20
K03: Keynote III

Title: Low Latency by Space and Time Redundancy
Speaker: Dr. Emina Soljanin, Professor

Thursday, March 15, 15:20 - 16:40
S04: Recent Advances in MIMO Systems
Chair: Ralf R. Müller

15:20 *Hybrid Analogue Digital Outphasing Beamforming Architecture with Amplitude and Phase Control*

Bernhard Gäde, Mohammad Ali Sedaghat and Ralf R. Müller

A partially connected hybrid analogue-digital beamformer architecture with adjustable amplitude and phase weights in both the digital and the analogue part is presented. Amplitude control in the analogue beamformer is enabled by a lossless passive outphasing network. The architecture is designed to be implementation-friendly as the only required RF components are low-resolution phase shifters, power dividers, and hybrid couplers. If phase shifters of arbitrary resolution are assumed, any beamforming weights can be generated, whereas finite resolution phase shifters naturally lead to quantisation in amplitude and phase. In that case, in order to find the optimum phase shifter states for approximating a given beamforming vector, a full search over all possible states is necessary. To avoid the associated computational costs, a suboptimal but faster and less memory consuming algorithm is presented. Furthermore, an antenna arrangement for sub-connected hybrid beamforming utilising low-redundancy sub-arrays is proposed. For sub-array based processing, the performance in the presence of a sparse channel can be improved compared against conventional antenna arrangements.

15:40 *Precoding Design for Massive MIMO Systems with Sub-connected Architecture and Per-antenna Power Constraints*

Phuong Le Cao, Tobias J. Oechtering and Mikael Skoglund

This paper designs precoding matrices for massive MIMO systems with a sub-connected architecture, RF power constraints and per-antenna power constraints. The system is configured such that each RF chain serves a group of antennas. It is shown that the optimal precoder is designed based on a generalized water-filling and joint sum and per-antenna optimal power allocation solution while the optimal analog precoder is designed based on the per-antenna power allocation only. We study the most interesting case where the power constraint on the RF chain is smaller than the sum of the corresponding per-antenna power constraints. Therefore, the optimal power is allocated based on two properties: Each RF chain uses full power and if the optimal power allocation of the unconstraint problem violates a per-antenna power constraint then it is optimal to allocate the maximal power for that antenna.

16:00 *Precoding for MIMO Uplink Transmission Over EM-Lens-Based Correlated Channels*

George Yammine, Sebastian Stern and Robert F.H. Fischer

In multiple-input/multiple-output (MIMO) systems, advanced equalization or precoding schemes are not only known for providing interference mitigation, but they also have been proven to exploit the MIMO channel's diversity. However, in the case of massive MIMO, the computational complexity of such schemes make them unfeasible. To solve this problem for the uplink scenario, an electromagnetic (EM) lens may be employed at the receiver. It effectively focuses the received power onto a smaller number of antennas. Hence, the application of techniques known from classical (non-massive) MIMO systems is enabled in MIMO systems with a large number of antennas. However, building such EM-lens-enabled systems comes with a drawback. Due to physical limitations, it may be impossible to space the antenna elements in a way to provide spatially decoupled channels at the receiver, which results in a performance loss. In this paper, this issue is addressed by first extending the EM-lens-enabled system to include multiple antennas at the transmitter. Following this, different equalization strategies for this scenario are assessed. The performance of the proposed strategies is evaluated by means of numerical simulations. To this end, different levels of spatial channel correlations are considered for both uncoded and coded transmission.

16:20 *Low-complexity and Statistically Robust Beamformer Design for Massive MIMO Systems*

Mahdi Nouri Boroujerdi, Saeid Haghighatshoar and Giuseppe Caire

Massive MIMO is a variant of multiuser MIMO in which the number of antennas at the base station (BS) M is very large and typically much larger than the number of served users (data streams) K. Recent research has illustrated the system-level advantages of such a system and in particular the beneficial effect of increasing the number of antennas M. These benefits, however, come at the cost of dramatic increase in hardware and computational complexity. This is partly due to the fact that the BS needs to compute suitable beamforming vectors in order to coherently transmit/receive data to/from each user, where the resulting complexity grows proportionally to the number of antennas M and the number of served users K. Recently, different algorithms based on tools from random matrix theory in the asymptotic regime of $M,K \to \infty$ with $\frac{K}{M} \to \rho \in (0,1)$ have been proposed to reduce the complexity. The underlying assumption in all these techniques, however, is that the exact statistics (covariance matrix) of the channel vectors of the users is a priori known. This is far from being realistic, especially that in the high-dim regime of $M\to \infty$, estimation of the underlying covariance matrices is well known to be a very challenging problem. In this paper, we propose a novel technique for designing beamforming vectors in a massive MIMO system. Our method is based on the randomized Kaczmarz algorithm and does not require knowledge of the statistics of the users' channel vectors. We analyze the performance of our proposed algorithm theoretically and compare its performance with that of other competitive techniques based on random matrix theory and approximate message passing via numerical simulations. Our results indicate that our proposed technique has a comparable performance while being highly robust to variations in the channel statistics.

Thursday, March 15, 17:10 - 18:50
S05: Multi-antenna systems for Next Generation SatCom
Chair: Ana Pérez-Neira

17:10 *Two-level Precoding for High Throughput Satellites with non-Cooperative Gateways*
Tomas Ramirez, Carlos Mosquera and Roberto López-Valcarce

17:30 *Rate Splitting for MIMO Multibeam Satellite Systems*
Miguel Ángel Vázquez, Màrius Caus and Ana Pérez-Neira
This paper deals with the problem of precoding in multibeam satellite system with rate splitting (RS). In contrast to the single-stream (SS) case where a unique frame is transmitted towards each beam, in RS we consider the simultaneous transmission of a single common frame to all beams jointly with each beam intended frame transmission. In this context, every user terminal (UT) firstly decodes the public frame which contains data from all UTs at all beams and; posteriorly, its intended frame (private frame) which contains information from the UTs located at the same beam. With this, each UT receives information from both the public and the private frame, leading to a system sum-rate increase in some cases. This performance increase is evaluated by computing an upper-bound of the attainable rates. Moreover, a low-complexity precoding alternative is proposed considering a decoupled design of the precoding of the private frames and public message. This technique is evaluated considering a real multibeam satellite system. A substantial gain with respect to the current benchmark technique is identified.

17:50 *Non-Linear Precoding based Hybrid Space-Ground Beamforming for Multi-Beam Satellite Systems*
Nuan Song, Tao Yang and Martin Haardt
Multi-beam mobile satellite systems have a great potential in providing broadband mobile services over a large area to achieve a high system throughput. On ground beamforming techniques are quite promising but require a large feeder link bandwidth to deliver all the feeds' signals. There are two potential solutions to solve this problem. 1) Hybrid space-ground beamforming is able to reduce the feeder link bandwidth and save spectral resources, which exhibits a good trade-off between the performance and the space/ground complexity. 2) The ground based beamforming using multiple distributed gateways divides the whole spectrum of the feeder link into several sub-sets, relaxing the bandwidth and processing requirements at each gateway. In this paper, we propose a distributed non-linear precoding based hybrid space-ground beamforming technique, where on-board beamforming aims at suppressing interference among gateways and on-ground beamforming is implemented distributively at each gateway. The proposed technique takes advantages of both the hybrid scheme and the distributed multiple gateway architecture, and does not require any cooperation or any exchange of channel state information among gateways. We show the benefits of the proposed technique over the fully on ground beamforming schemes as well as its linear counterparts.

18:10 *Optimal Deployment of Base Stations in Cognitive Satellite-Terrestrial Networks*
Satyanarayana Vuppala, Mathini Sellathurai and Symeon Chatzinotas
We investigate the performance of a downlink multibeam cognitive satellite terrestrial network (CSTN) in which a secondary network (mobile terrestrial system) shares resources with a primary satellite network given that the interference temperature constraint is satisfied. Utilising tools from stochastic geometry, we derive the closed-form optimal density of base stations subject to interference temperature and outage probability constraints set by satellite system. In addition, the gains of directional beamforming are analysed when the terrestrial system employs multiple-input-multiple-output (MIMO) transceivers or by the use of millimeter wave links between terrestrial BSs and users.

18:30 *MIMO Feeder Links for High Throughput Satellites*
Thomas Delamotte, Robert T. Schwarz, Kai-Uwe Storek and Andreas Knopp
Feeder links have become one of the main bottlenecks in the design of high throughput satellite systems. To support more than 1 Tbit/s of sum data rate, several tens of spatially separated feeder beams in the Q/V-band must be deployed. Meanwhile, their angular separation is limited by geographical constraints, and interbeam interference becomes a performance limiting factor. Moreover, strong rain fades affect the links' availability. In this work, a MIMO-based smart gateway architecture is introduced to address these challenges. This solution allows to halve the number of required feeder beams and also improves the robustness against rain fades. The potential of the approach is demonstrated in terms of system outage probability for a realistic scenario with 25 active and 2 redundant MIMO feeder beams distributed in Europe.

Friday, March 16

Friday, March 16, 09:00 - 10:00
K04: Keynote IV
Advances in Robust Statistics for Signal Processing
Speaker: Dr. Abdelhak M. Zoubir

Friday, March 16, 10:30 - 12:10
S06: Resource Allocation and Optimisation
Chair: Wolfgang Utschick

10:30 *Throughput and Energy-Efficient Network Slicing*

Bho Matthiesen, Osman Aydin and Eduard Jorswieck

Network slicing allows 5G network operators to provide service to multiple tenants with diverging service requirements. This paper considers network slicing aware optimal resource allocation in terms of throughput and energy efficiency. We define a heterogeneous Quality of Service (QoS) framework for a sliced radio access network network with per-slice zero-forcing beamforming and jointly optimize power and bandwidth allocation across slices and users. The Pareto boundary of this multi-objective optimization problem is obtained by two different algorithms based on the utility profile and scalarization approaches combined with generalized fractional programming. Numerical results show the merits of jointly allocating bandwidth and transmission power and how throughput and global energy efficiency are influenced by slice specific QoS requirements.

10:50 *MSE Analysis of the Projected Gradient Algorithm on Unions of Subspaces*

Thomas Wiese, Kamel Shibli and Wolfgang Utschick

We present a mean-squared-error (MSE) analysis of the projected gradient algorithm when applied to linear inverse problems with constraint sets that are unions of subspaces. This algorithm has been recently presented as a generalization of the iterative hard thresholding algorithm. The main difficulty with the MSE analysis is to calculate the expected value of the supremum of a continuous random process. We present a simple approach to calculate the expected supremum, which builds upon the concept of Lipschitz random processes.

11:10 *Linear Transceiver Design for Multi-Carrier Full-Duplex MIMO Decode and Forward Relaying*

Vimal Radhakrishnan, Omid Taghizadeh and Rudolf Mathar

In this paper, we discuss the linear precoding and decoding design problem for a multi-carrier (MC) full-duplex (FD) decode-and-forward (DF) relaying system. We consider the effects of hardware distortions, which contribute to residual self-interference and also inter-carrier leakage. The impact of the imperfect channel estimation is also taken into account. The problem of linear precoding and decoding design is then studied with the goal of maximizing the system sum rate, leading into a non-convex optimization problem. In addition to the traditional per-carrier DF relaying, the case with a joint subcarrier DF is also studied, taking advantage from a group-wise decoding and encoding. An alternating quadratic convex program (AQCP) is then proposed in each case, with a monotonic improvement at each iteration, leading to a guaranteed convergence. Numerical simulations show a significant gain in terms of the end-to-end system sum rate, in particular when the hardware distortions increase and inter-carrier leakage becomes a dominant factor.

11:30 *Joint Antenna Selection and Phase-only Beamforming using Mixed-Integer Nonlinear Programming*

Tobias Fischer, Ganapati Hegde, Frederic Matter, Marius Pesavento, Marc Pfetsch and Andreas M Tillmann

In this paper, we consider the problem of joint antenna selection and analog beamformer design in downlink single-group multicast networks. Our objective is to reduce the hardware costs by minimizing the number of required phase shifters at the transmitter while fulfilling given distortion limits at the receivers. We formulate the problem as an L-zero minimization problem and devise a novel branch-and-cut based algorithm to solve the resulting mixed-integer nonlinear program to optimality. We also propose a suboptimal heuristic algorithm to solve the above problem approximately with a low computational complexity. Computational results illustrate that the solutions produced by the proposed heuristic algorithm are optimal in most cases. The results also indicate that the performance of the optimal methods can be significantly improved by initializing with the result of the suboptimal method.

11:50 *Multi-Step Knowledge-Aided Iterative Conjugate Gradient for Direction Finding*

Silvio Bernardes, Pinto and Rodrigo C. de Lamare

In this work, we propose a Krylov subspace-based algorithm for direction-of-arrival (DOA) estimation, referred to as multi-step knowledge-aided iterative conjugate gradient (CG) method (Multi-Step KAI-CG), which achieves more accurate estimates than those of prior work. Differently from existing knowledge-aided methods, which make use of available known DOAs to improve the estimation of the covariance matrix of the input data, the proposed Multi-Step KAI-CG exploits knowledge of the structure of the covariance matrix and its perturbation terms and the gradual incorporation of prior knowledge, which is obtained on line. Simulation results illustrate the improvement achieved by the proposed method and the influence of iterations on its performance.

Friday, March 16, 12:10 - 14:20
P02: Signal Processing for Wireless
Chair: Martin Haardt

Proper Time-Sharing as a Baseline for Studying Improper Signaling in Interference Channels

Christoph Hellings and Wolfgang Utschick

So-called improper complex signals have been shown to be beneficial in the Gaussian interference channel under the assumptions that all input signals are Gaussian and that interference is treated as noise. In order to show the benefits of improper signals, it is necessary to know the best possible strategy with proper signals as a baseline for comparison. Two such baselines have been considered in the existing literature: globally optimal proper signaling strategies without time-sharing as well as with time-sharing in the sense of averaging the per-user rates over several operation points. In this paper, we discuss a third baseline solution: if we interpret time-sharing in a more general way and average not only the rates, but also the transmit powers over several operation points, we can obtain an enlarged proper signaling rate region. In a numerical example, we demonstrate that the comparison between proper signaling and recently proposed improper signaling solutions can lead to quite different conclusions depending on which proper signaling baseline is considered.

Quantized Precoding for Multi-Antenna Downlink Channels with MAGIQ

Andrei Nedelcu, Fabian Steiner, Gerhard Kramer, Markus Staudacher, Paolo Baracca, Wolfgang Zirwas, Rakash SivaSiva Ganesan and Stefan Wesemann

A multi-antenna, greedy, iterative, and quantized (MAGIQ) precoding algorithm is proposed for downlink channels. MAGIQ allows a straightforward integration with orthog- onal frequency-division multiplexing (OFDM). MAGIQ is com- pared to three existing algorithms in terms of information rates and complexity: quantized linear precoding (QLP), SQUID, and an ADMM-based algorithm. The information rate is measured by using a lower bound for finite modulation sets, and the complexity is measured by the number of multiplications and comparisons. MAGIQ and ADMM achieve similar information rates with similar complexity for Rayleigh flat-fading channels and one-bit quantization per real dimension, and they outperform QLP and SQUID for higher order modulation.

A Robust Time-Domain Beam Alignment Scheme for Multi-User Wideband mmWave Systems

Xiaoshen Song, Saeid Haghighatshoar and Giuseppe Caire

Millimeter wave (mmWave) communication with large array gains is a key ingredient of next generation (5G) wireless networks. Effective communication in mmWaves usually depends on the knowledge of the channel. We refer to the problem of finding a narrow beam pair at the transmitter and at the receiver, yielding high Signal to Noise Ratio (SNR) as Beam Alignment (BA). Prior BA schemes typically considered deterministic channels, where the instantaneous channel coefficients are assumed to stay constant for a long time. In this paper, in contrast, we propose a time-domain BA scheme for wideband mmWave systems, where the channel is characterized by multi-path components, different delays, Angle-of-Arrivals/Angle-of-Departures (AoAs/AoDs), and Doppler shifts. In our proposed scheme, the Base Station (BS) probes the channel in the downlink by some sequences with good autocorrelation property (e.g., Pseudo-Noise (PN) sequences), letting each user estimate its best AoA-AoD that connects the user to the BS with two-sided high beamforming gain. We leverage the sparse nature of mmWaves in the AoA-AoD-time domain, and formulate the BA problem as a Compressed Sensing (CS) of a non-negative sparse vector. We use the recently developed Non-Negative Least Squares (NNLS) technique to efficiently find the strongest path connecting the BS and each user. Simulation results show that the proposed scheme outperforms its counterpart in terms of the training overhead and robustness to fast channel variations.

Multi-Frequency Kalman Filtering for Joint Ionospheric Delay and Multipath Mitigation

Andreas Iliopoulos, Friederike Fohlmeister, Christoph Enneking, Thomas Jost and Felix Antreich

Global navigation satellite systems (GNSS) are used in a wide range of applications, such as aeronautics or maritime navigation. Under nominal conditions, the GNSS based position offers a high reliability and accuracy. However, the principles used for GNSS based navigation suffer a decreased accuracy under the presence of multipath and an unknown ionospheric delay. In the case of multipath reception, the estimated delay is biased by the superposition of the line-of-sight (LOS) and the multipath signal. Conventional channel equalization techniques for code division multiple access (CDMA) based communication systems cannot easily be applied in the GNSS context. In contrast to other systems the satellite signal power is significantly less than the noise power. Additionally, the spreading code are significantly longer that other CDMA communication systems. Finally, GNSS processing suffers greatly from multipath with a delay less than the chip duration, whereas other CDMA communications systems focus largely on intersymbol interference. To mitigate the ionospheric delay, single frequency GNSS receiver generally employ a coarse model of the total electron content (TEC) [2], [3], which is transmitted in the satellite broadcast message. Dual frequency GNSS receivers, i.e. receivers which can track and process GNSS signals on two frequencies, can mitigate the ionospheric delay in post processing. They exploit the fact that the channel through the ionosphere is dispersive, i.e. the signal delay is frequency dependent [4]. Therefore, the ionospheric delay can be mitigated by appropriately combining delay measurements from two frequencies. However, this post processing ionospheric delay mitigation cannot be conducted under the presence of multipath signals. Therefore, we propose a joint ionospheric delay and multipath mitigation algorithm for multifrequency GNSS receivers. The algorithm, presented in this paper, combines the Kalman Filter based multipath mitigation method from [1] and the signal combination method for ionospheric delay mitigation [4]. By combining the measurements from two or more frequencies directly in the tracking loop, the ionospheric delay mitigation benefits from a reduced delay measurement noise even under pure LOS reception. In the case of no ionospheric delay, i.e. a no TEC in the ionosphere,the multipath mitigation algorithm benefits from using multiple frequencies.

A Generalized Hard Thresholding Pursuit on Infinite Unions of Subspaces

Michael Koller, Thomas Wiese and Wolfgang Utschick

Hard thresholding pursuit (HTP) has been introduced to the field of compressive sensing as an algorithm to solve underdetermined linear systems of equations where the solution is assumed to be a sparse vector. This sparsity constraint of the solution can be expressed in terms of a finite union of particular subspaces. The present paper shows how HTP can be generalized to linear inverse problems with solutions in an arbitrary (infinite) union of subspaces. We incorporate the idea of inexact projections. This allows for more flexibility in calculating a crucial step of the generalized HTP, which is beneficial in practical considerations. In the final version, we will show how the HTP algorithm can be used in conjunction with Root MUSIC for channel estimation in millimeter wave communication systems.

Tensor-Based Near-Field Localization in Bistatic MIMO Radar Systems

Ivan Podkurkov, Liana Hamidullina, Evgenii Traikov, Martin Haardt and Adel Nadeev

Several new algorithms have been proposed recently for near-field target localization and parameter estimation in Bistatic MIMO Radar systems. The new approaches include the usage of the exact spherical wavefront model, which avoids a systematic error introduced by the Fresnel approximation that is commonly made on impinging wavefronts in order to simplify the estimation problem. In this paper, we propose a new Tensor based Near-Field Localization (TeNFiL) algorithm that utilizes the Canonical Polyadic (CP) decomposition of the received data in order to obtain high-resolution estimates of the parameters of the dominant targets that are automatically paired. Those parameters include the distances to the transmit and the receive reference antennas, the directions of departure (DoDs) and the directions of arrival (DoAs). The algorithm is based on the Semi-algebraic framework for approximate CP decompositions via Simultaneous Matrix Diagonalizations (SECSI). It is used to compute an approximate low rank CP decomposition of the noise corrupted measurements in a robust and efficient way. The simulations show that TeNFiL outperforms recent state of the art algorithms, especially if the targets are closely spaced.

Statistical Properties and Variations of LOS MIMO Channels at Millimeter Wave Frequencies

Tim Hälsig, Darko Cvetkovski, Eckhard Grass and Berthold Lankl

In this paper we provide measurement results for different millimeter wave LOS MIMO setups in static scenarios. We show short, on the symbol level, and longer, for several thousands of symbols, channel properties and discuss their source and impact. While, as expected, the variations are not significant on the symbol level, they need to be accounted for when longer time frames are considered.

Virtual Clustering: A Communication Cost Reduction Strategy for Distributed Consensus-Based Estimation in Cooperative Networks

Shengdi Wang, Guang Xu, Henning Paul and Armin Dekorsy

In this paper, we consider the problem of distributed consensus-based estimation in cooperative networks, e.g., wireless sensor networks (WSNs). To solve this problem and achieve an accurate consensus-based estimate solution, many iterative distributed algorithms require the information exchange among nodes at each iteration suffering from huge communication overhead. In our previous work, a new strategy of virtual clustering was discussed with the purpose of reducing communication overhead for distributed consensus-based estimation. By classifying the data using virtual clusters, data with reduced size will be transmitted during the distributed processing. Here, we further propose two methods to reduce the size of transmitted data for arbitrary network topologies. One method is based on finding the shortest path in a network and the other relies on linear independence of constraint qualification (LICQ). The study shows that both methods can successfully reduce communication overhead. Moreover, the second method outperforms the first one and provides the optimal communication cost for the distributed consensus-based estimation.

Enhancing Localization Performance of TDoA Systems Using Raytracing Multipath Fingerprint

Marcelo Nogueira de Sousa, Reiner S. Thomä and Eduardo Correa

Time Difference of Arrival (TDoA) is a technique used to feed a multilateration scheme to extract the position of an electromagnetic emitters. In practical urban environment, the performance of TDoA sensors are affected by multipath wave components, where different rays are sum up at each sensor increasing the error position. There are some statistical methods to mitigate Non-Line-of-Sight (NLoS) effects, they use signal processing tools to improve the accuracy, but such techniques could not work when almost all the sensors only get the NLoS ray components. The Ray Tracing (RT) simulation tools can give an estimation about the description of multipath propagation that affects localization algorithms. The technique proposed uses time reversibility of the Channel Impulse Response and a Ray Tracing propagation tool to build an geographic time difference fingerprint that is used to enhance the performance. The main idea behind such approach is to add the scenario information and features in the signal processing, what can be applied in real localization problems where a TDoA system is deployed in hash Multipath. A measurement campaign was done to validate the technique and showed an enhancement in the localization precision.

The Diversity Multiplexing Tradeoff for Interference Networks

Aydin Sezgin

The diversity-multiplexing tradeoff (DMT) for interference networks, such as the interference channel, the X channel, the Z interference channel and the Z channel, is analyzed. In particular, we investigate the impact of rate-splitting and channel knowledge at the transmitters. We also use the DMT of the Z channel and the Z interference channel to distill insights into the “loud neighbor” problem for femto-cell networks.

Randomized Multiple Candidate Iterative Hard Thresholding Algorithm for Direction of Arrival Estimation

Yuneisy Esthela Garcia, Martin Haardt and Rodrigo C. de Lamare

The sparse recovery problem by l0 minimization which is of central importance in compressed sensing (CS)-based algorithms for direction of arrival (DoA) estimation has attracted considerable interest recently. This paper proposes a greedy algorithm called randomized multiple candidate iterative hard thresholding (RMC-IHT) which generates a set of potential candidates using the iterative hard thresholding algorithm and selects the best candidate based on the a priori knowledge of the distribution of the signal and noise matrices. We also consider the case of correlated sources. Simulation results illustrate the improvement achieved by RMC-IHT.

Distributed estimation and Power Allocation for Passive Radar Sensor Networks with Imperfect CSI

Vimal Radhakrishnan, Omid Taghizadeh and Rudolf Mathar

In this paper we address the design of a distributed passive radar sensor network system, including the power allocation among sensors, as well as linear signal fusion, considering the channel state information (CSI) estimation error. Analytical solutions are obtained for each case, achieving an optimum performance. In particular, it is assumed that both sensing and communication wireless channels are estimated erroneously, however, with a known error covariance. The performance of the proposed methods is numerically evaluated over different levels of thermal noise and CSI error, where a superior performance is observed compared to the available designs which assume the availability of perfect CSI.

Sensitivity based event-triggered TDMA-MAC protocol for a distributed optimal control problem

Shaban Guma and Naim Bajcinca

We present the design of a sensitivity based event-triggered TDMA protocol in conjunction with a distributed optimization algorithm utilizing dual subgradient method. The event-triggered scheme is based on the impact of the information exchange into the underlying Lagrange function. The proposed algorithm is applied to distributed feedforward control of vehicle dynamics.

Contribution to Drone Detection by Exploiting Parameter Estimation for a Prototype mm-Wave Radar System

Stephan Häfner, Matthias Röding, Gerd Sommerkorn, Robert Müller, Reiner S. Thomä, Giovanni Del Galdo and Jan Goerlich

An estimator to infer parameters from radar measurements is presented, applicable for further detection and localisation of unmanned aircraft systems. The problem of parameter estimation is presented as an inverse problem, necessitating a model of the radar data. Based on the specified data model a maximum-likelihood based objective function for parameter estimation is derived. The objective function is minimised by a framework similar to the RIMAX framework, including joint parameter and model order estimation. A SIMO radar system is presented and employed to test and demonstrate the estimators capability in simulations as well as test measurements.

Combining Matrix Design for 2D DoA Estimation with Compressive Antenna Arrays

Sankalp Pawar, Anastasia Lavrenko, Florian Roemer, Mohamed Ibrahim, Giovanni Del Galdo and Reiner S. Thomä

In compressive arrays, a (large) number of antenna outputs is linearly combined to a lower number of receiver channels with the aim to reduce hardware complexity without significantly compromising the estimation performance. In this paper, we develop a method for the combining matrix design for 2D DoA estimation with compressive arrays. We base our design on the antenna's spatial correlation function (SCF) in an attempt to produce an effective compressive array with estimation capabilities close to those of the original array before the combining. Due to the need to consider the SCF both in azimuth and elevation, the size of the resulting optimization problem becomes prohibitive.To reduce the optimization complexity, we propose an iterative design approach that allows a trade-off between complexity and the performance.

Adaptive RLS Channel Estimation and SIC for Large-Scale Antenna Systems with 1-Bit ADCs

Zhichao Shao, Lukas T N Landau and Rodrigo C. de Lamare

We propose a novel low-resolution-aware recursive least squares channel estimation algorithm for uplink multiuser multiple-input multiple-output systems. In order to reduce the energy consumption, 1-bit ADCs are used on each receive antenna. The loss of performance gains can be recovered by the large-scale antennas at receiver. The proposed adaptive channel estimator can mitigate the distortions due to the coarse quantization. Moreover, we propose a low-resolution-aware minimum mean square error based successive interference canceler to successively mitigate the multiuser interference. Simulation results have shown good performance of the system in terms of mean square error and bit error rate.

A Novel Joint Precoding and Association Optimization Framework for C-RANs with Restricted Fronthauls

Alireza Zamani, Omid Taghizadeh and Anke Schmeink

Joint optimization of associations and precoders in wireless communication networks has become a crucial problem,due to the growing density of network infrastructure and users.Furthermore, network operators continue to show interest in improved energy efficiency and less power consumption. Due to the non-convex structure of the joint optimization problem, current methods and solvers struggle to offer satisfactory solutions. In the present paper, we provide a novel approach for joint optimization of the precoders and associations in a cooperative network with limited fronthaul capacity links. The proposed method provides an approximation of the original problem in the form of a mixed integer quadratic program (MIQP), solved via off the shelf numerical solvers. The second contribution of our work is a distributed hybrid association strategy, which serves as an alternative to the centralized MIQP approximation method. The performance of both methods is evaluated, suggesting that the proposed MIQP approximation framework can be used as a benchmark for other heuristic methods,due to its better performance and higher complexity. Meanwhile,the hybrid association strategy is deemed suitable for a distributed implementation in less computationally advanced networks.

NLOS Identification for Indoor Localization using Random Forest Algorithm

Mohammed Ramadan, Vladica Sark, Jesús Gutiérrez and Eckhard Grass

Non-line-of-sight (NLOS) identification is a major challenge to indoor ranging and localization systems. Recently, many researchers have investigated this problem and a variety of NLOS identification approaches have been proposed. In this paper, we exploit features extracted from the channel impulse response (CIR) and implement the random forest (RF) machine learning algorithm to tackle the NLOS identification problem. We evaluate the RF algorithm against the popular least squares-support vector machine (LS-SVM) and other state-of-the-art classification algorithms in terms of identification performance and computational complexity. Our evaluation results show that the proposed algorithm outperforms other classification algorithms and achieves NLOS and LOS identification accuracy of 97.3 % and 95 % respectively. Furthermore, it has smaller computational complexity than the LS-SVM, making it best suitable for real-time implementation.

Improving Robustness for Anisotropic Sparse Recovery using Matrix Extensions

Carsten Herrmann, Yun Lu, Christian Scheunert and Peter Jung

Recovery guarantees in compressed sensing (CS) often require upper bounds on the noise level. The robustness with respect to additive errors of unknown power depends on quotient bounds of the measurement matrix. For isotropic random matrices like iid. Gaussian matrices these bounds are known to behave well. In this work we focus instead on explicitly given anisotropic sensing matrices which are more relevant for real world applications. We propose straightforward quotient-modifications of CS decoders using matrix extensions to improve robustness. We reformulate this as a recovery problem under partial off-support knowledge and discuss the implications. Finally, we present numerical results for measurement matrices taken from a particular radar application where our idea of matrix extensions shows substantial performance improvements.

Friday, March 16, 14:20 - 15:20
K05: Keynote V
Collimated Light Propagation: The Next Frontier in Underwater Wireless Communications
Speaker: Dr. Mohamed-Slim Alouini

Friday, March 16, 15:20 - 17:00
S07: UAV-aided communications
Chair: David Gesbert

15:20 *On the Impact of Radio Channel over REM-Aware UAV-Aided Mobile Networks*

Silvia Mignardi, Chiara Buratti and Roberto Verdone

This paper studies the use of Unmanned Aerial Vehicles (UAVs) as support to today's cellular networks. UAVs operate like Small Cells moving according to traffic and service needs; coverage and capacity become adaptive to time-spatial variations of the user demand. The Unmanned Aerial Base Station (UABS) is requested to fly over areas in which users requesting service are not covered by the nearest Terrestrial Base Station (TBS) in real-time. In our scenario users ask for a video streaming service, having stringent requirements in downlink throughput but a latency of tens of seconds. We are considering a UAV trajectory design that accounts for the actual position of unsatisfied users grouped in clusters. The trajectory is computed by a central controller as a function of the distance of the UABS from the next cluster, user density, energy consumed by drone and spatial fairness. In this paper we analyze the impact of having at disposal precise Radio Environment Map (REM) information and different antenna systems mounted on the drone. Since these techniques impact the link between the UABS and ground users, network throughput and coverage range are affected in different ways for each solution. Simulation results will show for each case the performance achieved by the system.

15:40 *Simultaneous User Association and Placement in Multi-UAV Enabled Wireless Networks*

Omid Esrafilian and David Gesbert

In this paper, we are proposing a map-based approach for the optimal placement of multiple UAV-based flying wireless relays in a cellular network. The tackled problem is two-fold, involving a joint UAV-user association problem and 3D placement problem. While related problems were addressed before, the novelty of our approach lies in the fact it builds on a combination of probabilistic and deterministic LoS classifiers which exploits the availability of a 3D city map. While the original problem is very challenging in its dimension, we give a low-complexity approach to the placement problem by approximating the optimum UAV positions with a suitably weighted combination of user positions. Our simulations suggest a performance close to that obtained with high complexity exhaustive search for placement.

16:00 *Exploiting Antenna Arrays for Position Tracking of Unmanned Aerial Vehicles*

Andrea M Tonello and Venkata Pathuri Bhuvana

This paper firstly identifies and discuses the main challenges in exploiting antenna arrays to track the position unmanned aerial vehicles (UAVs). Then, a specific radio localization method based on the multiple differential phase-of-arrival (D-PoA) and time-of-arrival (TOA) measures at a 3-axial uniform linear array (3A-ULA) is presented to estimate the positron of an UAV with respect to a reference point. The D-PoA and TOA measures are coupled with a dynamic motion model of the UAV to enable the usage of non-linear Bayesian estimation methods such as the particle filter (PF) and the cuabture Kalman filter (CKF) to improve the positioning accuracy. Furthermore, a comparison in terms of accuracy and complexity of the PF and the CKF for the considered application is presented. To assess the estimation accuracy of these methods, a confined area random aerial trajectory emulator algorithm is used to generate actual paths of the flying UAVs.

16:20 *On the Potential of 5G mmWave Pencil Beam Antennas for UAV Communications: An Experimental Evaluation*

Karsten Heimann, Janis Tiemann, Stefan Böcker and Christian Wietfeld

Beamforming and pencil beam antennas are expected to become a major component of 5G mmWave networks. While spatial separation and high gains are anticipated benefits, the suitability of those new antenna types in highly dynamic scenarios, such as the use on Unmanned Aerial Vehicles (UAVs), requires appropriate real-time steering capabilities and needs to be proven in practice. In this paper we present results of lab experiments leveraging a wireless robotics testbed implementing a mmWave link at 28 GHz between a fixed base station equipped with a pencil beam antenna and an UAV. The setup allows the investigation of the beam tracking performance in terms of signal strength, quality and throughput for different antenna tapers, tracking algorithms and mobility patterns. This – to the best of our knowledge – first experiment applying mmWave communications at 28 GHz for air-to-ground communications confirms the potential and feasibility of pencil beam antennas for UAV communications. In case the antennas are aligned within a given error margin, a stable air-to-ground connection was observed during the flight experiments.

Friday, March 16, 17:30 - 18:30
S08: Multiple Antenna Systems and Applications
Chair: Aydin Sezgin

17:30 *Adaptive Massive MIMO for fast moving connected vehicles: it will work with Predictor Antennas!*

Dinh-Thuy Phan-Huy, Stefan Wesemann, Joachim Björsell and Mikael Sternad

Predicting the channel between a massive multiple input multiple output antenna and a car is a challenge, due to the short-term fading. It becomes essentially impossible by conventional extrapolation from past estimates if the car has moved by half a wavelength or more in space at the time when the channel estimate will be needed. This problem would prevent us from using the best fifth generation adaptive antenna downlink precoding schemes for very fast moving connected vehicles. A potential solution is to add another vehicle antenna, a "predictor antenna", which senses the channel in advance. In this paper, based on drive tests and channel measurements from a 64-element antenna to a car, we for the first time show that this concept works for massive MIMO downlinks. Thanks to the use of a predictor antenna, the complex OFDM downlink channels can be predicted with an accuracy that enables maximum ratio transmit beamforming with close to ideal beamforming gain for non-line-of-sight channels. Zero forcing transmission to two users results in a signal-to-interference ratio of 20 dB to 30 dB when predicting non-line-of-sight channels up to three wavelengths ahead in space. These first experiment shows that the predictor antenna concept is a potential solution to make fifth generation adaptive antennas work for very fast moving connected vehicles.

17:50 *On the Impact of the Mutual Impedance of an Antenna Array on Power and Achievable Rate*

Tobias Laas, Josef A. Nossek, Samer Bazzi and Wen Xu

In this paper, we consider antennas arrays with small mutual resistance, and assess the impact of neglecting both the small mutual resistance and the mutual reactance, on the radiated power and on the achievable rates. This extends our earlier results on antenna arrays with zero mutual resistance, which show that when those antenna arrays are excited by practical radio frequency amplifiers modeled as linear sources, the radiated power depends on the mutual reactance and that there is a gap between capacity and the achievable rate when neglecting the mutual reactance. In this investigation, we consider a Uniform Linear Array (ULA) consisting of $\lambda/2$-dipoles spaced by $\lambda/2$, and compare it to a ULA consisting of hypothetical isotropic radiators spaced by $\lambda/2$. Numerical results are given for the ergodic rates in an independent and identically distributed channel in the up- and downlink, with a base station transmitting to a single antenna mobile. Furthermore, the investigation is extended to a more realistic channel model based on QuaDRiGa.

18:10 *Semi-Blind Channel Estimation in Massive MIMO by Mutual Information Rate as Contrast Function*

Ebrahim Amiri, Ralf R. Müller and Wolfgang Gerstacker

A massive multiple-input multiple-output system is considered. In order to improve channel estimation, we propose a semi-blind data-aided method based on complex independent component analysis (ICA) and using the mutual information rate as the contrast function. We do not require the powers of the interfering users to differ

from the powers of the users of interest. The noise is first suppressed by subspace projection, then the uplink data symbols including the signal of interest and the interfering signals are extracted by ICA. Finally, the detected data symbols are used as pseudo-pilots to estimate the channel matrix of the users in the cell of interest. Simulation results confirm that the proposed method outperforms previous blind channel estimation methods.