FIFTIETH
ASILOMAR CONFERENCE ON
SIGNALS, SYSTEMS & COMPUTERS

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Welcome from the General Chairman

Prof. Phil Schniter
The Ohio State University, USA

Welcome the 50th Asilomar Conference on Signals, Systems, and Computers! I am honored to serve as the general chair for this special "50th anniversary" edition of the Conference. I first attended in 1997 and have returned almost every year since then. What keeps me coming back are the high-quality technical program, the relaxed and friendly atmosphere, and the natural beauty of Asilomar State Park.

This year, we come together to celebrate the remarkable impact that Asilomar has made, over the last 50 years, on the fields of signal processing, communications, circuits, and control. As we know, these fields are key to many of the core technologies that we use in our day-to-day lives.

For 50 years now, Asilomar has brought together top researchers from academia, industry, and government laboratories to advance the frontier of knowledge. As our lives become ever more enriched by technology, the importance of Asilomar will only grow in the years to come.

I am very excited by this year's technical program, which was brilliantly crafted by the Technical Program Chair, Gerald Matz, and his team: Jeff Andrews, Andreas Burg, Romain Couillet, Joakim Jaldén, Marco Lops, Antonia Papandreou-Suppapola, Marios Pattichis, Alejandro Ribeiro, and Wei Yu.

This year's program consists of 392 accepted papers, of which 208 where invited. Among these papers, 81 were submitted to the student paper contest, from which a list of 7 finalists were selected. On Sunday afternoon before the Welcome Reception, these finalists will present their work before a panel of judges organized by Scott Acton. We encourage everyone to attend this special session. The top 3 finishers will be announced before Tuesday's plenary lecture.

This year we are honored to have two plenary talks. The first plenary will be given on Sunday evening by Dr. John Treichler of Raytheon, Inc. John, who has been attending Asilomar since 1978, is famous for many contributions to signal processing and communications. I am very much looking forward to his lecture on "Fifty years of the Asilomar conference and its role in the flowering of DSP technology."

The second plenary will be given on Tuesday morning by Prof. Thomas Strohmer of the University of California at Davis. Thomas is an eminent researcher on the mathematics of signal processing, where he has made many lasting contributions. I am very excited about his lecture, entitled "You can have it all: Rapid, robust, and reliable solution of bilinear problems in signal processing."

I am thrilled and honored to serve as the General Chair of the 50th Asilomar Conference. I hope that you all enjoy the conference this year and discover everything that it has to offer.

Phil Schniter, Columbus, OH, June 2016.

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Track H: Speech Image and Video Processing
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Vice Track Chair
Wei Yu
University of Toronto, Canada

2016 Asilomar Conference Session Schedule

sunday Afternoon, November 6, 2016

3:00–7:00 PM	Registration — Merrill Hall
3:00–5:15 PM	Student Paper Contest — Heather Hall
5:30–6:30 PM	50th Anniversary Address, John Treichler —Nautilus Hall
6:30–9:00 PM	Welcoming Reception — Merrill Hall

Monday Morning, November 7, 2016

7:30–9:00 AM	Breakfast – Crocker Dining Hall
8:00 AM–6:00 PM	Registration
9:45–10:15 AM	Coffee Social

8:15–11:55 AM MORNING SESSIONS

MA1	Towards 5G (Invited)
MA2a	Spectrum Sharing Between Communication and Radar Systems (Invited)
MA2b	Hybrid Analog/Digital Precoding (Invited)
MA3a	Topology of Networks (Invited)
MA3b	Smart Grid (Invited)
MA4a	High Dimensional Inference, Random Matrices, and Applications (Invited)
MA4b	Information Theory and Statistical Learning (Invited)
MA5a	Sequential Signal Processing (Invited)
MA5b	Multisensor Systems and Statistical Inference (Invited)
MA6	Signals and Systems in Visual Cultural Heritage (Invited)
MA7a	Computer Arithmetic I
MA7b	Neural Signal Processing
MA8a1	Efficient Hardware Implementation (Poster)
MA8a2	Error Correction and Network Coding (Poster)
MA8a3	Massive MIMO (Poster)
MA8a4	Neural Imaging (Poster)
MA8b1	Design Methodologies for Signal Processing Systems (Poster)
MA8b2	Sparse Methods and Compressive Sensing (Poster)
MA8b3	Speech and Image Analysis (Poster)

12:00–1:00 PM Lunch – Crocker Dining Hall

Monday Afternoon, November 7, 2016

1:30–5:10 PM AFTERNOON SESSIONS

MP1a	Algorithm and Hardware Aspects for 5G Wireless Systems (Invited)
MP1b	Wireless Networks (Invited)
MP2a	Interference Limited Next Generation Satellite Communications (SatnexIV) (Invited)
MP2b	Signal Processing for Low-Resolution Sampling (Invited)
MP3a	Communication and Coding for Distributed Computing (Invited)
MP3b	Distributed Optimization (Invited)
MP4a	Sparse Sampling for Data Analytics (Invited)
MP4b	High-dimensional Inference (Invited)
MP5a	Recent Advances in Nonstationary Signal Processing (Invited)
MP5b	Recent Advances in Covariance Matrix Estimation for Array Processing (Invited)
MP6a	Emerging Models and Methods in Image and Video Processing (Invited)
MP6b	Speech Signal Processing and Health Applications (Invited)
MP7a	Advances in Neuronal Modeling (Invited)
MP7b	Advances in Neural Array Processing (Invited)
MP8a1	Beamforming and Array-based Estimation I (Poster)
MP8a2	Communication Networks (Poster)
MP8a3	Estimation and Learning Theory for Communications (Poster)
MP8a4	Model Selection, Source Separation and Classification (Poster)
MP8b1	Beamforming and Array-based Estimation II (Poster)
MP8b2	Communication Theory (Poster)
MP8b3	Implementations of DSP Kernels (Poster)

2016 Asilomar Conference Session Schedule
(continued)

Monday Evening, November 7, 2016

6:30–9:30 PM 50th Anniversary Conference Banquet at the Monterey Bay Aquarium. Buses leave Asilomar grounds at 5:40 pm and 6:00 pm. See registration materials for details and fees.

Tuesday Morning, November 8, 2016

7:30–9:00 AM Breakfast — Crocker Dining Hall
8:00 AM–5:00 PM Registration
8:15–9:45 AM TA1a — Conference Welcome and Plenary Session — Chapel

10:15–11:55 AM MORNING SESSIONS
TA1b Biological Communications (Invited)
TA2b Recent Advances in Massive MIMO (Invited)
TA3b Distributed Signal Processing
TA4b Sketching and Optimizing for Big Data (Invited)
TA5b Hardware Aspects for Compressive Sensing and Analog-to-Information Conversion (Invited)
TA6b Phase Retrieval for Imaging: Theory and Methods (Invited)
TA7b Biological Neural Systems (Invited)
TA8b1 Array Processing and Wireless Communications (Poster)
TA8b2 Communication System Theory (Poster)
TA8b3 MIMO and Multistatic Radars (Poster)

12:00–1:00 PM Lunch – Crocker Dining Hall

Tuesday Afternoon, November 8, 2016

1:30–5:35 PM AFTERNOON SESSIONS
TP1a Millimeter Wave Cellular Systems (Invited)
TP1b 5G Cellular Theory
TP2a Implementation of Decoders for Polar Codes (Invited)
TP2b Beamforming and Linear Processing
TP3a Multiagent Systems and Game Theory (Invited)
TP3b Graph Signal Processing (Invited)
TP4a Bilinear Inverse Problems (Invited)
TP4b Five Puzzles and Euclid's Bag of Tricks (Invited)
TP5a Detection over Very Large Datasets (Invited)
TP5b Source Localization and Sparse Array Design
TP6a Big Data Analytics for Image and Video Processing (Invited)
TP6b Optimization and Adaptive Methods
TP7a Signal Processing for Dynamic Functional Brain Network Analysis (Invited)
TP7b Implementation of Full-Duplex Radio Transceivers (Invited)
TP8a1 Network Data Analysis (Poster)
TP8a2 Relaying and Full Duplex Communications (Poster)
TP8a3 Subspaces, Covariances and Tensors (Poster)
TP8b1 Computer Arithmetic II (Poster)
TP8b2 Image and Video Sensor Processing and Communications (Poster)
TP8b3 Processing of Physiological Signals (Poster)

Tuesday Evening Open Evening — Enjoy the Monterey Peninsula

2016 Asilomar Conference Session Schedule
(continued)

Wednesday Morning, November 9, 2016

7:30–9:00 AM	Breakfast — Crocker Dining Hall
8:00 AM–12:00 PM	Registration — Copyright forms must be turned in before the registration closes at 12:00 noon.

8:15 AM–11:30 PM MORNING SESSIONS

WA1a	Approximate Computing and Fault Tolerance (Invited)
WA1b	Communication System Development
WA2a	Physical Layer Security (Invited)
WA2b	Massive MIMO in the Field
WA3a	Cognitive Networking (Invited)
WA3b	Signal Processing with Lattices (Invited)
WA4a	Decentralized Optimization and Learning (Invited)
WA4b	Modelling and Inference with Graphs
WA5	Tensor Signal Processing (Invited)
WA6a	Emerging Sensing Technologies for Assisted Living (Invited)
WA6b	Image and Video Quality Assessment
WA7	Cognitive Radar (Invited)

12:00–1:00 PM Lunch — This meal is not included in the registration.

Student Paper Contest

Heather - Sunday, November 6, 2016, 3:00–5:15 PM

Track A *"On the Impact of Blockage on the Throughput of Multi-tier Millimeter-Wave Networks"*

Shuqiao Jia, David Ramirez, Rice University, United States; Lei Huang, Yi Wang, Huawei Technologies Co. Ltd., China; Behnaam Aazhang, Rice University, United States

"Fundamental Limits of Secure Device-to-Device Coded Caching"

Ahmed A. Zewail, Aylin Yener, Pennsylvania State University, United States

Track B *"Robust Precoding Design for Massive MISO Downlink"*

Mostafa Medra, Timothy Davidson, McMaster University, Canada

Track C *"A Distributed Range-based Algorithm for Localization in Mobile Networks"*

Sam Safavi, Usman Khan, Tufts University, United States

Track D *"Parallel Asynchronous Lock-free Algorithms for Nonconvex Big-Data Optimization"*

Loris Cannelli, Gesualdo Scutari, Purdue University, United States; Francisco Facchinei, University of Rome, La Sapienza, Italy; Vyacheslav Kungurtsev, Czech Technical University in Prague, Czech Republic

Track E *"Two-Dimensional Sparse Arrays with Hole-Free Coarray and Reduced Mutual Coupling"*

Chun-Lin Liu, Palghat Vaidyanathan, California Institute of Technology, United States

Track G *"Memristor Based Adder Circuit Design"*

Nagaraja Revanna, Earl Swartzlander, University of Texas at Austin, United States

Coffee breaks will be at 9:55 AM and 3:10 PM. (except Tuesday morning when refreshments will be served outside Chapel from 9:45–10:15 AM)

Sunday, November 6, 2016

PLENARY SESSION 5:30–6:30 PM

50th Anniversary Asilomar Distinguished Lecture

Fifty years of the Asilomar conference, and its role in the flowering of DSP technology

John Treichler
Raytheon Applied Signal Technology, USA

Abstract
When this conference was first held at Asilomar in 1967, computers were rare beasts, control systems were mostly analog, digital signa ls processing was mostly theory, and Silicon Valley hadn't even been named yet [That happened in 1971]. This talk chronicles the incredible evolution of those technologies over the past 50 years and highlights many of the points where the research and practice brought together at this annual conference proved highly influential in the progress of the tightly related fields of communications, control, estimation, coding, and signal processing algorithm design. Little did the founders of this conference understand the impact that it, and the technology it helped develop, would have on the world.

Biography
John Treichler received his BA and MEE degrees from Rice University, Houston, TX in 1970 and his PhDEE from Stanford in 1977. He served as a line officer aboard destroyers in the US Navy from 1970 to 1974. In 1977 he joined ARGO Systems in Sunnyvale, CA and then helped found Applied Signal Technology, Inc. in 1984 after serving for a year as an Associate Professor of Electrical Engineering at Cornell University. Applied Signal Technology, now a mission area within the Space and Airborne Systems (SAS) business unit of Raytheon, Inc, designs and builds advanced signal processing equipment used by the United States government and its allies for foreign intelligence collection. For three years he was the president of the Raytheon Applied Signal Technology business unit and continues as the unit's Chief Technical Officer. He was elected a Fellow in the Institute of Electrical and Electronics Engineers (IEEE) in 1991. He was awarded the IEEE Signal Processing Society's Technical Achievement Award in 2000 and its first Industrial Leader Award in 2016. He recently completed a three-year tour as the IEEE Signal Processing Society's Vice President for Membership and Awards and is on the board of directors of the IEEE Foundation. In 2016 he was elected a member of the National Academy of Engineering.

Tuesday, November 8, 2016

CONFERENCE OPENING AND PLENARY SESSION 8:15 – 9:45 AM

1. Welcome from the General Chair:

Prof. Philip Schniter

The Ohio State University, USA

2. Session TA1a Distinguished Lecture for the 2016 Asilomar Conference

You can have it all: Rapid, robust, and reliable solution of bilinear problems in signal processing

Thomas Strohmer
University of California, Davis, USA

Abstract

I will first decribe how I once failed to catch a murderer (dubbed the "graveyard murderer" by the media), because I failed in solving a blind deconvolution problem. Here, blind deconvolution refers to the following problem: Assume we are given a function y which arises as the convolution of two unknown functions g and h. When and how is it possible to recover g and h from the knowledge of y? Blind deconvolution pervades many areas of science and technology, including astronomy, medical imaging, optics, and communications engineering. Blind deconvolution is obviously ill-posed and even under additional assumptions this is a very difficult non-convex problem full of undesirable local minima. I will present the first numerically efficient blind deconvolution algorithm that comes with rigorous convergence guarantees. We will also consider more general bilinear problems, such as the case where we are given a mixture of blind deconvolution problems. Here we need to correctly blindly deconvolve and separate (demix) multiple functions at the same time from just a single measured function. I will describe a powerful convex framework for the solution of this problem and discuss its importance for the future Internet-of-Things.

Biography

Thomas Strohmer is Professor of Mathematics at the University of California, Davis. His research interests are in applied harmonic analysis, numerical analysis, signal- and image processing, high-dimensional data analysis, and mathematics of information. He got his M.S. and Ph.D. in Mathematics in 1991 and 1994 respectively from the University of Vienna, Austria. He spent one year as Erwin-Schroedinger fellow at the Department of Statistics at Stanford University in 1997 before joining the University of California, Davis in 1998. His recent awards include the 2013 IEEE Signal Processing Society Best Paper Award and the 2014 SIAM Outstanding Paper Prize. Dr. Strohmer is on the editorial board of several journals. He also serves as consultant to industry in the areas of telecommunications, bioengineering, and signal- and image processing.

Program of the
2016 Asilomar Conference on
Signals, Systems, and Computers

Technical Program Chairman
Prof. Gerald Matz
Vienna University of Technology

Track A – Communications Systems

Session: MA1 – Towards 5G

Co-Chairs: ***Angel Lozano,*** *UPF, Barcelona* ***and Maxime Guillaud,*** *Huawei Research, Paris*

MA1-1 **8:15 AM**

A Novel Alternative to Cloud-RAN for Throughput Densification: Coded Pilots and Fast User-Packet Scheduling at Remote Radio Heads

Ozgun Y. Bursalioglu, Chenwei Wang, Haralabos Papadopoulos, DOCOMO Innovations Inc, United States; Giuseppe Caire, Technische Universität Berlin, Germany

Antenna densification is expected to play a key role in achieving the large gains in area spectral efficiency (ASE) envisioned for 5G and beyond wireless networks. In this work we consider practical options for operating systems with large antenna-array remote radio heads (RRH), which, in contrast to C-RAN architectures, do not require joint processing across the RRH deployment. In particular, the designs we present and optimize leverage coded user-pilot assignments and "on the fly" user-packet scheduling at each remote head. As our analysis suggests, such designs can yield large ASE gains without requiring centralized processing across the RRH system.

MA1-2 **8:40 AM**

Integer-Forcing Analog-To-Digital Conversion for Massive MIMO Systems

Luis G. Ordóñez, Iñaki Estella, Maxime Guillaud, Huawei Technologies, France

Massive MIMO systems are considered to be one of the key technologies in 5G wireless communication systems. The large number of received signals to be processed in massive MIMO systems renders conventional high-precision analog-to-digital conversion (ADC) not feasible in terms of cost- and power-efficiency, since ADC power consumption scales exponentially with the number of quantization bits. We consider a low-resolution ADC architecture inspired by the principles of integer-forcing source coding, which jointly reconstructs the received quantized signals in the digital domain. This architecture effectively exploits the correlation among the received signals in order to increase the achievable uplink transmission rates.

MA1-3 **9:05 AM**

Analytical Handle for ZF Reception in Distributed Massive MIMO

Rajitha Senanayake, University of Melbourne, Australia; Angel Lozano, Universitat Pompeu Fabra, Spain; Peter Smith, Victoria University of Wellington, New Zealand; Jamie Evans, University of Melbourne, Australia

This paper considers distributed massive MIMO networks where a large number of antennas, either collocated or geographically scattered over a region, communicate with mobile users. This communication is impaired by interference from similar transmissions in adjacent regions and by noise. Focusing on zero-forcing (ZF) reception, we derive simple expressions that very accurately approximate the instantaneous signal-to-interference-plus-noise ratio (SINR) and the ergodic spectral efficiency of an arbitrary user. These expressions enable short-cutting any assessment of the network-level performance, either analytical or simulation-based.

MA1-4 **9:30 AM**

The Impact of Beamforming and Coordination on Spectrum Pooling in MmWave Cellular Networks

Hossein Shokri, KTH Royal Institute of Technology, Sweden; Federico Boccardi, Ofcom, United Kingdom; Elza Erkip, New York University, United States; Carlo Fischione, KTH Royal Institute of Technology, Sweden; Gabor Fodor, Ericsson, Sweden; Marios Kountouris, Huawei Technologies Co. Ltd., France; Petar Popovski, Aalborg University, Denmark; Michele Zorzi, University of Padova, Italy

In this paper we study the possibility of spectrum sharing between multiple mmWave cellular networks, also referred as spectrum pooling. In particular we assess the impact of beamforming and intra and inter-operator coordination on the network performance, measured in terms of user rate. Our initial results show that from a technical perspective spectrum pooling could lead to a more efficient use of the spectrum than a traditional exclusive spectrum allocation.

BREAK **9:55 AM**

MA1-5 **10:15 AM**

Limited Feedback Based Double-Sided Full-Dimension MIMO for Mobile Backhauling

Stefan Schwarz, Markus Rupp, Technische Universität Wien, Austria

We consider wireless backhauling in mobile networks, employing large-scale full-dimension MIMO antenna arrays on both sides of the link. Our focus is on design strategies for transmit and receive antenna combiners, assuming FDD transmission and limited feedback operation. We investigate the performance of two competing philosophies: 1) An algebraic approach in which antenna combiners are calculated from explicit channel state information; 2) A geometric approach that utilizes implicit geometric information, such as, signal arrival/departure angles, to determine antenna combiners. We propose a geometric precoding approach that provides robustness with respect to user movement and investigate merits of both schemes.

MA1-6 **10:40 AM**

Downlink Massive MIMO Capacity Bound with Blind Gain Estimation at the Terminal

Hien Quoc Ngo, Erik G. Larsson, Linkoping University, Sweden

This paper considers the downlink of a Massive multiple-input multiple-output (MIMO) system with maximum-ratio and zero-forcing processing. Blind gain estimation, where no downlink pilots are transmitted but instead each terminal estimates its instantaneous effective channel gain directly from the received data, is considered. A tight capacity lower bound is derived. The resulting rate performance is evaluated in representative scenarios and compared with the two cases of no gain estimation, and estimation from downlink pilots.

MA1-7 **11:05 AM**

Overloaded MU-MISO Transmission with Imperfect CSIT

Enrico Piovano, Hamdi Joudeh, Bruno Clerckx, Imperial College London, United Kingdom

A required feature for the next generation of communication systems will be the capability to serve simultaneously a number of users with different CSIT qualities and receiver capabilities greater than M transmitting antennas. In this paper, we introduce a novel transmission scheme where common messages are superimposed on top of precoded private messages. The developed strategy allows to serve all users in a non-orthogonal manner and the analysis shows an enhanced performance compared to existing schemes.

MA1-8 **11:30 AM**

Enforcing Coordination in Network MIMO with Unequal CSIT

Paul de Kerret, Antonio Bazco, David Gesbert, EURECOM, France

We consider a distributed CSI setting in which multiple Transmitters (TXs) are endowed with CSI of hetereogeneous quality levels due to imperfect feedback and backhaul links, and seek to cooperate through joint precoding. Each local precoder is designed at each TX on the basis of the locally available channel estimate. We develop a new robust transmission scheme improving significantly the DoF. For that purpose, novel transmission paradigms are introduced, such as the use of a novel specific quantizer, and the estimation and forwarding, up to local CSI quality level, of the reconstructed interference terms on the TX side.

Track B – MIMO Communications and Signal Processing

Session: MA2a – Spectrum Sharing Between Communication and Radar Systems

Chair: ***Athina Petropulu,*** *Rutgers University*

MA2a-1 **8:15 AM**

Bargaining over Fair Performing Dual Radar and Communication Task

Andrey Garnaev, Wade Trappe, Rutgers University, WINLAB, United States; Athina Petropulu, Rutgers University, United States

The problem of fairness for a dual communication and radar system employing multicarrier waveforms is investigated. To gain insight into the problem, we present a model for performance fairness for both tasks based on the alpha-fairness criteria is presented. We first solve for the fairness criteria for each fixed α. Then, over the continuum of optimal alpha-fair protocols we find the optimal protocol as the Nash bargaining solution. For such a protocol, an increase in gains for one objective is achieved at an expense to the other objective. Numerical modeling is provided to illustrate the efficiency of the optimal protocol.

MA2a-2 **8:40 AM**

Spectrum Sharing Between MIMO-MC Radars and Communication Systems

Bo Li, Athina Petropulu, Rutgers University, United States

Recently, the co-existence of radar and communication systems has attracted considerable interest. In this paper, we consider the MIMO radars with matrix completion (MIMO-MC), sharing spectrum with a MIMO communication system in the presence of interfering clutter. MIMO-MC radars greatly reduce the sample size without degrading the performance. We show the feasibility of transmit precoding for MIMO-MC radars with guaranteed recovery accuracy of the full data matrix. Transmit precoders at both systems are jointly designed with the radar sub-sampling scheme to maximize radar SINR while the communication system meeting certain rate and power constraints. Efficient optimization algorithms are also provided.

MA2a-3 **9:05 AM**

Spectrum Sharing with Radars: Impact of Radars on Wi-Fi

Hossein-Ali Safavi-Naeini, Sumit Roy, University of Washington, United States

Spectrum sharing between radar and communication systems has the potential to enable access to hundreds of MHz of new spectrum leading to increased wireless network capacity. Prior to deploying wireless systems in the same band as radars, we must examine the impact of radar interference on system throughput. In this paper, we study the impact of radar interference on Wi-Fi links through signal level simulations. We examine the role of various front-end components in the WLAN receiver, the consequences of interference during various stages of signal reception (e.g. synchronization and channel estimation), as well as mitigation mechanisms including modified decoding.

MA2a-4 **9:30 AM**

Spectrum Maps for Cognition and Co-Existence of Communication and Radar Systems

Maarit Melvasalo, Visa Koivunen, Jarmo Lunden, Aalto University, Finland

Cognitive radios and radars require situation awareness of the time-space-frequency varying spectrum. Its state may be presented as spectrum maps that are used to share spectral resources among radar and communication systems and manage interference and jamming. Distributed RF measurements in distinct locations are needed in creating such maps and describe the state of the spectrum between the sensor locations and how it evolves. This facilitates waveform agility, interference management and co-existence. Advanced methods stemming from spatial statistics and machine learning are developed for creating spectrum maps for co-existence. The performance of the methods is studied in simulation.

Track B – MIMO Communications and Signal Processing

Session: MA2b – Hybrid Analog/Digital Precoding

Co-Chairs: ***Mats Bengtsson,*** *KTH Royal Institute of Technology****; Hadi Ghauch,*** *KTH Royal Institute of Technology* ***and Taejoon Kim,*** *City University of Hong Kong*

MA2b-1 **10:15 AM**

Alternating Minimization for Hybrid Precoding in Multiuser OFDM mmWave Systems

Xianghao Yu, Jun Zhang, Hong Kong University of Science and Technology, Hong Kong SAR of China; Khaled B. Letaief, Hong Kong University of Science and Technology, Hong Kong and Hamad bin Khalifa University, Qatar

Hybrid precoding is a cost-effective approach to support directional transmissions for millimeter wave (mmWave) communications. While existing works on hybrid precoding mainly focus on single-user single-carrier transmission, in practice multicarrier transmission is needed to combat the much increased bandwidth and multiuser MIMO can provide additional spatial multiplexing gain. In this paper, effective hybrid precoding algorithms based on alternating minimization (AltMin) will be proposed for multiuser OFDM mmWave systems, which will alternatively optimize the digital and analog precoders. Special attention will be paid on low-complexity algorithms for practical implementation. Simulation results will show the performance gains of the proposed algorithms.

MA2b-2 **10:40 AM**

Subspace Estimation and Hybrid Precoding for Wideband Millimeter-Wave MIMO System

Wai Ming Chan, Taejoon Kim, City University of Hong Kong, Hong Kong SAR of China; Hadi Ghauch, Mats Bengtsson, KTH Royal Institute of Technology, Sweden

There has been growing interest in millimeter-wave multiple-input multiple-output systems, which would likely employ hybrid analog-digital architectures with massively large-sized array antennas in wideband (e.g., 1~3 GHz). Primary challenges here are efficiently estimating the large dimensional frequency-selective channels and customizing the hybrid analog-digital precoders.

The goal of this paper is hence to address the latter challenges. We propose techniques by exploiting the reciprocity of the sparse channel to iteratively estimate the digital subspace of each subcarrier and the common analog subspace of all subcarriers. We investigate narrow-band and wideband hybrid precoder design techniques and show numerically the enhanced throughput performance.

MA2b-3 **11:05 AM**

Multiuser Hybrid Precoding for Frequency Selective Millimeter Wave Systems

Nuria Gonzalez-Prelcic, University of Vigo, Spain; Robert W. Heath, University of Texas at Austin, United States

Many designs for hybrid precoders operating at mmWave have been proposed in the recent literature for the single-user case. Most of these designs work only with a narrowband frequency flat channel model. In this paper, we propose a design of the hybrid precoders in a multiuser scenario, considering a frequency selective clustered channel model. The precoders and combiners are designed without explicit estimation of the channel, assuming that only second order statistics of the signal received at the antenna array are available. Compressive estimation of these statistics is also proposed, since only the received signal after combining can be measured.

MA2b-4 **11:30 AM**

Hybrid Precoding for Millimeter Wave Systems with a Constraint on User Electromagnetic Radiation Exposure

David Love, Miguel Castellanos, Purdue University, United States; Bertrand Hochwald, University of Notre Dame, United States

The rapid growth of wireless technology worldwide has prompted interest in the underutilized millimeter band from 30 to 300 GHz. Regulation agencies set limits on the amount of electromagnetic radiation absorbed by users, measuring dosimetric quantities such as specific absorption rate (SAR) to assess compliance. The increased rate of energy deposition in human tissue at high frequencies remains a growing concern as wireless cellular networks begin to incorporate millimeter wave technologies. In this paper, we present a baseband model for SAR- aware wireless communication and a strategy for optimal hybrid precoding in millimeter wave systems with SAR constraints.

Track C – Networks

Session: MA3a – Topology of Networks

Co-Chairs: ***Harish Chintakunta,*** *Florida Polytechtic University* ***and Hamid Krim,*** *North Carolina State University*

MA3a-1 **8:15 AM**

Influence of Topology in Information Flow in Social Networks

Harish Chintakunta, Athanasios Gentimis, Florida Polytechnic University, United States

This paper studies the relationship between the topological structure of a social network, and the information flow within it. In our recent work, we showed that a particular core-periphery decomposition using topological collapses has (a) structural properties desired in the decomposition, and (b) communal properties in the peripheral components. In this paper, we investigate the role of the core in the information flow. Specifically, we study time-evolving collaborative networks and quantify the influence of the core nodes in forming new connections.

MA3a-2 **8:40 AM**

Persistent Homology Lower Bounds on Distances in the Space of Networks

Weiyu Huang, Alejandro Ribeiro, University of Pennsylvania, United States

High order networks are hypergraphs collecting relationships between elements of tuples, not necessarily pairs. Valid metric distances between high order networks have been defined but they are difficult to compute given large networks. The goal here is to find tractable approximations of these network distances. The paper does so by mapping high order networks to filtrations of simplicial complexes and showing that the distance between networks can be lower bounded by the difference between homological features. As for applications, the persistent homology methods succeed in discriminating engineering and mathematics communities, and in differentiating engineering communities with different research interests.

MA3a-3 **9:05 AM**

Node Dominance: Discovering Hypernym-Hyponym Relations for Building Taxonomies

Hui Guan, North Carolina State University, United States; Harish Chintakunta, Florida Polytechnic University, United States; Hamid Krim, North Carolina State University, United States

Automated building of taxonomies aims at constructing hierarchies of concepts that express broader-narrower semantic (i.e., hypernym-hyponym) relations. A major challenge for the task is to automatically discover such relations. In this paper, we propose a novel, unsupervised method for building the semantic hierarchy based on a node dominance criterion, which naturally results in a directed acyclic graph representation of taxonomy structure. We build a concept graph by identifying the links between concepts based on distributional semantics, and then apply the node dominance criterion on the graph to detect hypernym-hyponym relations.

MA3a-4 **9:30 AM**

Persistent Homology of Directed Networks

Samir Chowdhury, Facundo Memoli, The Ohio State University, United States

While persistent homology has been successfully used to provide topological summaries of point cloud data, the question of computing persistent homology of graphs or networks remains unclear. In particular, the existing literature does not provide a treatment of persistent homology for directed networks that is sensitive to asymmetry. We study a method for constructing simplicial complexes from weighted, directed networks that captures directionality information, and we are able to prove that the persistent homology of such complexes is stable with respect to a certain notion of network distance. We illustrate our construction on a database of simulated hippocampal networks.

Track C – Networks

Session: MA3b – Smart Grid

Chair: ***Hao Zhu,*** *University of Illinois at Urbana Champaign*

MA3b-1 **10:15 AM**

A Learning Based Method for Real Time Prediction of Cascading Failures

Yue Zhao, Stony Brook University, United States; Jianshu Chen, Microsoft Research, United States

Real time prediction of impending cascading failures in a dynamically evolving power grid is studied. As the cascade look-ahead window increases, the number of future cascade scenarios grows exponentially. A novel learning based method is developed to compute the marginal failure probability of each line due to cascades at times deep into the future. The proposed method enjoys the unique advantage that a labeled data set can be generated in an arbitrarily large amount at very low cost. Numerical results demonstrate that the off-line trained predictive model provides very fast, online and accurate prediction of cascading failures.

MA3b-2 **10:40 AM**

On the Solution of the Three-Phase Load Flow in Distribution Networks

Mohammadhafez Bazrafshan, Nikolaos Gatsis, University of Texas at San Antonio, Iran

For a three-phase distribution network with constant-PQ wye and delta loads, a solution to the load flow problem can be obtained by the Z-Bus iterative method. In this work, we derive explicit conditions on loads and the network admittance matrix such that the Z-Bus iterations are a contraction mapping, proving the existence of a unique fixed-point and guaranteeing that the updates will achieve the unique solution. The region of contraction is estimated and validated for IEEE test feeders.

MA3b-3 **11:05 AM**

A Compressive Sensing Framework for the Analysis of Solar Photo-Voltaic Power

Raksha Ramakrishna, Anna Scaglione, Bita Analui, Arizona State University, United States

We propose a new stochastic model for Solar PV outputs that explicitly captures the effect of the clouds coverage as a shot noise process that modulates the deterministic solar irradiation pattern. We rely on compressive sensing methods to estimate the parameters of this model, thereby fitting the available data. Unlike methods that provide exclusively a forecast, one can leverage the rich information coming from this parametric model for stochastic optimization and decision making. To illustrate our technique we analyze a Solar PV dataset and confirm that this stochastic model effectively captures the variability of solar power production.

MA3b-4 **11:30 AM**

Power Network Topology Control for Mitigating the Effects of Geomagnetically Induced Currents

Cecilia Klauber, Hao Zhu, University of Illinois, United States

Solar storms can induce quasi-dc geomagnetically induced current (GIC) flows in power grids, resulting in transformer damage, system stability and reliability issues. The present paper considers the problem of designing operational GIC mitigation strategies by switching transmission lines. This topology control approach could relieve the grid from temporarily high level of GIC flows, without significantly affecting its secure operations. We will cast the problem as a mixed-integer linear program, and develop computationally tractable solutions using linear sensitivity analysis to select candidate switching lines while maintaining system connectivity. The effectiveness has been demonstrated using a 20-bus GIC test case.

Track D – Signal Processing and Adaptive Systems

Session: MA4a – High Dimensional Inference, Random Matrices, and Applications

Chair: ***Matthew McKay,*** *Hong Kong University of Science and Technology*

MA4a-1 **8:15 AM**

Free Component Analysis

Hao Wu, Raj Rao Nadakuditi, University of Michigan, United States

We describe algorithms for separating 'free' components from a mixture of several components. We discuss fundamental limits, applications and insights relative to independent component analysis. We highlight the role of free entropy and discuss high dimensional models for which free component analysis (FCA) better separates components than independent component analysis (FCA).

MA4a-2 **8:40 AM**

Random Matrix Improved Subspace Clustering

Romain Couillet, CentraleSupelec, France; Abla Kammoun, King Abdullah University of Science and Technology, France

This article introduces a spectral method for statistical subspace clustering. The method is built upon standard kernel spectral clustering techniques, however carefully tuned by theoretical understanding arising from random matrix findings. We show in particular that our method provides high clustering performance while standard kernel choices provably fail. An application to user grouping based on vector channel observations in the context of massive MIMO wireless communication networks is provided.

MA4a-3 **9:05 AM**

Inference of Principal Components of Noisy Correlation Matrices with Prior Information: from Statistical Physics to Applications to Proteins

Remi Monasson, CNRS & Ecole Normale Supérieure, France

We consider the problem of inferring the principal component of a population correlation matrix from one empirical realization (sample correlation matrix) with the help of prior information about the component entries. The problem is recast in statistical physics terms, and the phase diagram of the so-called spiked covariance model is computed for a variety of priors, e.g. favoring large entries. We show that prior information allows one to infer correctly the principal component, even if the naive estimator (top component of the sample correlation matrix) is ineffective. Applications to protein structural predictions based on amino-acid correlations will be presented.

MA4a-4 **9:30 AM**

A Tailored Sparse PCA Method for Finding Vaccine Targets Against Hepatitis C

Ahmed Abdul Quadeer, David Morales-Jimenez, Matthew McKay, Hong Kong University of Science and Technology, Hong Kong SAR of China

In this paper, we present an approach to identify, with high statistical significance, parts of the Hepatitis C virus (HCV) genome that may be most susceptible to immune pressure and thus may help in the design of an efficacious vaccine against this highly mutable virus. The proposed approach is based on a statistical study of the publicly-available HCV sequences, using a tailored sparse PCA method. The obtained results are validated using available clinical and structural data.

Session: MA4b – Information Theory and Statistical Learning

Chair: ***Pablo Piantanida,*** *CentraleSupélec*

MA4b-1 10:15 AM

Information-Theoretic Analysis of Stability and Bias of Learning Algorithms

Maxim Raginsky, University of Illinois at Urbana-Champaign, United States

Machine learning algorithms are stochastic transformations that map training data to hypotheses. Following Bousquet and Elisseeff, we say that such an algorithm is stable if its output does not depend too much on any individual training example. Since stability is closely connected to generalization, it is of theoretical and practical interest to obtain sharp quantitative estimates on the generalization bias of machine learning algorithms in terms of their stability properties. We propose several information-theoretic measures of algorithmic stability and use them to upper-bound the generalization bias of learning algorithms.

MA4b-2 10:40 AM

Estimation from Pairwise Comparisons: Statistical and Computational Aspects

Nihar Shah, University of California, Berkeley, United States; Sivaraman Balakrishnan, Carnegie Mellon University, United States; Martin Wainwright, University of California, Berkeley, United States

Data in the form of noisy pairwise comparisons arises in many domains such as sports, crowdsourcing and operations research. Some fundamental inferential questions include estimating a total or partial order of the items or estimating the set of underlying pairwise-comparison probabilities. Prior works on these topics generally rely on very restrictive "parametric" models that often provide poor fits to the data. Instead, we consider much more flexible models for pairwise comparison data that have been found to be quite robust in practice. We establish tight statistical (information-theoretic) guarantees under these models and also address the various associated computational challenges.

MA4b-3 11:05 AM

Beyond Maximum Likelihood: Boosting the Chow-Liu Algorithm for Large Alphabets

Jiantao Jiao, Yanjun Han, Tsachy Weissman, Stanford University, United States

We propose a modification of the classical Chow-Liu algorithm on learning tree graphical models. We show that in high dimensional distributions, i.e.,the regime where the alphabet size of each node is comparable to the number of observations, the Chow–Liu algorithm is highly sub-optimal, and propose a new algorithm. The key ingredient in our new algorithm is to replace the empirical mutual information in the Chow-Liu algorithm with an essentially minimax estimator proposed recently by Jiao, Venkat, Han, and Weissman. We demonstrate the improved performance of this approach in two problems: learning tree graphical models and Bayesian network classification.

MA4b-4 11:30 AM

Adaptive Sequential Learning

Craig Wilson, Google, Inc., United States; Venugopal Veeravalli, University of Illinois at Urbana-Champaign, United States

A framework is introduced for solving a sequence of optimization problems that arise in learning a sequence of slowly changing tasks, using optimization algorithms such as stochastic gradient descent (SGD). A method based on estimates of the change in the minimizers and properties of the optimization algorithm is introduced for adaptively selecting the number of samples needed from the distributions underlying each problem in order to ensure that the excess risk does not exceed a target level. Experiments with synthetic and real data are used to confirm that our approach performs well.

Track E – Array Signal Processing

Session: MA5a – Sequential Signal Processing

Co-Chairs: ***Venugopal Veeravalli,*** *University of Illinois at Urbana Champaign* ***and George Moustakides,*** *University of Patras*

MA5a-1 **8:15 AM**

On Parallel Sequential Change Detection Controlling False Discovery Rate

Jie Chen, Wenyi Zhang, H. Vincent Poor, University of Science and Technology of China, China

In this work, a parallel sequential change detection model is investigated. In the model, a plurality of independent parallel data streams, each of which has a change-point with a certain prior probability distribution, are sequentially observed. A sequential procedure is developed to inspect these parallel data streams and to decide, for each of them, whether a change has occurred. The sequential procedure is shown to guarantee the false discovery rate. The average detection delay over the parallel data streams is also quantified in asymptotic regimes. Numerical experiments using real datasets are conducted to illustrate the proposed sequential procedure.

MA5a-2 **8:40 AM**

Distributed Quickest Detection with Optional Observations at the Fusion Center

Bo Jiang, Lifeng Lai, Worcester Polytechnic Institute, United States

In this paper, we consider the problem of distributed quickest detection with optional observations at the fusion center. In this setup, after receiving binary decisions from sensors, the fusion center can either raise the alarm immediately or can opt to take a few observations of its own before raising the alarm. We characterize optimal decision rules at the fusion center along with optimal rules at the sensors.

MA5a-3 **9:05 AM**

How to Quickly Detect a Change While Sleeping (almost) All the Time

Venkat Chandar, D.E. Shaw, United States; Aslan Tchamkerten, Télécom Paristech, France

Change-point detection procedures usually operate under full sampling; all observations are available until when the change is declared. Is this necessary? This paper addresses this question and characterizes the minimum sampling rate needed in order to detect a transient change of known duration duration as efficiently as under full sampling.

MA5a-4 **9:30 AM**

Dynamic Change-Point Detection using Correlation Networks

Shanshan Cao, Yao Xie, Georgia Institute of Technology, United States; Yuxin Chen, Stanford University, United States

Assume N sensors each acquiring a sequence of observations over time. At some unknown time k, a small subset of sensors may become defective. Assume when there is no change, the distribution of the observations may have an arbitrary time-varying characteristic due to data dynamic, for instance, variations of power usage in power networks. Moreover, the good sensors are positively correlated with each other, while the defective sensors are irregularly correlated with each other and with the good sensors. Based on this, we develop a new non-parametric procedure based on a correlation network consisting of pairwise correlation of sensors.

Track E – Array Signal Processing

Session: MA5b – Multisensor Systems and Statistical Inference

Chair: ***Visa Koivunen,*** *Aalto University*

MA5b-1 **10:15 AM**

How to Capture a Stopping Time: the Independent Case

George Moustakides, University of Patras, Greece

A stopping time τ is controlled by a process $\{X_t\}$ and we are interested in the immediate detection of its onset using a sequential scheme. The sequential detector is an alternative stopping time T which is based on observations $\{\xi_t\}$ that are obtained sequentially. We cast the detection problem as a constrained optimal stopping problem and provide the optimum detector for the case where the pair process $\{(X_t,\xi_t)\}$ is i.i.d.~and τ corresponds to the first entry time of X_t into some fixed and known set $\cA$.

MA5b-2 **10:40 AM**

Wideband Capon Beamforming with Pre-Steering

Richard Kozick, Bucknell University, United States; Christian Coviello, University of Oxford, United Kingdom

Passive beamforming produces an estimate of the energy emanating from a near-field source location by "steering" the wideband sensor signals with time delays, summing the steered signals, and computing the energy. An image of the spatial energy distribution is obtained by repeating the process over a grid of source locations. Capon beamforming provides adaptive interference reduction through real-valued beamforming weights that are determined from the spatial covariance matrix of pre-steered wideband signals. We analyze the interference rejection of this Capon beamformer with pre-steered wideband signals and show its effectiveness in a medical ultrasound application with in vivo measured data.

MA5b-3 **11:05 AM**

Sparsity-Promoting Bootstrap Method for Large-Scale Data

Visa Koivunen, Emad Mozafari, Aalto University, Finland

There is a need for scalable statistical inference methods for analyzing Big Data that produce quantitative information on their performance. Bootstrap is widely used for inference. We propose a scalable bootstrap method method that operates with smaller number of data points on multiple distinct subsets of data. It stems from the BLB method and is compatible with distributed storage and processing. Iterative reweighted l1 method is used for bootstrap replicas to find a sparse solution in the face of high-dimensional signal model. The performance of the proposed method in finding confidence intervals and parameter estimates is studied.

MA5b-4 **11:30 AM**

New Contributions to Estimation Theory with Applications in Wave Energy, IEEE 1588, Cybersecurity, MIMO Radar and the Internet of Things

Qian He, University of Electronic Science and Technology, China; Jiangfan Zhang, Anand Guruswamy, Basel Alnajjab, Rick S. Blum, Lehigh University, United States

The visionary researchers that established the beautiful and powerful foundations of Estimation Theory seemed to leave little unanswered. Nonetheless, with a focus on new emerging applications, this paper will present some new fundamental and important theory that builds on the impressive previously established foundations while introducing some important but lesser known applications (in the signal processing community) and demonstrating these applications can benefit greatly from signal processing attention. A surprising result on the maximum dimension of a parameter vector that can be accurately estimated with a quantized system will be given, along with some new useful bounds and approximations.

Track H – Speech, Image and Video Processing

Session: MA6 – Signals and Systems in Visual Cultural Heritage

Co-Chairs: ***Andy Klein,*** *Western Washington University* ***and Rick Johnson,*** *Cornell University*

MA6-1 **8:15 AM**

Automated Classification of Pen Strokes in Van Gogh's Drawings

Rosaleena Mohanty, University of Wisconsin-Madison, United States; William Sethares, University of Wisconsin-Madison and Rijksmuseum, United States; Teio Meedendorp, Louis van Tilborgh, Van Gogh Museum, Netherlands

Vincent Van Gogh used a large number of different kinds of strokes, hatchings, and dots to convey his unique vision in pen and ink. This paper presents a first attempt to automatically catalog the various kinds of pen strokes used throughout Vincent's career. The output of the process may be pictured in two ways: one which segments the sketch into regions dominated by a single style of stroke, and one which identifies and separates every occurrence of every stroke throughout the drawing.

MA6-2 **8:40 AM**

Non-Negative Dictionary Learning for Paper Watermark Similarity

David Picard, Thomas Henn, ETIS ENSEA/Université de Cergy-Pontoise/CNRS, France; Georg Dietz, papierstruktur.de, France

In this paper, we investigate the retrieval of paper watermark by visual similarity. We propose to perform the visual similarity by encoding small regions of the watermark using a non-negative dictionary optimized on a large collection of watermarks. The local codes are then aggregated into a single vector representing the whole watermark. Experiments are carried out on a test of tracings (manual binarization of watermarks).

MA6-3 **9:05 AM**

Automated Chain Line Marking and Pattern Matching in Radiographs of Rembrandt's Prints

Xuelie Xi, Cornell University, United States; Devin Conathan, University of Wisconsin, United States; Amanda House, Cornell University, United States; William Sethares, University of Wisconsin-Madison and Rijksmuseum, United States; C. Richard Johnson, Jr., Cornell University, United States

This paper presents improved algorithms for the semi-automatic extraction of chain line patterns from x-radiograph images of Rembrandt's prints. The performance of the new system is evaluated on a dataset of low-energy x-radiographs of several hundred Rembrandt prints containing watermarks and countermarks. For images with 8 or more chain lines, the new chain line pattern matching procedure alone can reduce the full image set to 1/6 of its original size for further comparison and moldmate hunting.

MA6-4 **9:30 AM**

Deep Learning Classification of Photographic Paper Based on Clustering by Domain Experts

Andrea Frost, Western Washington University, United States; Sally Wood, Santa Clara University, United States; Paul Messier, Yale University, United States; David Palzer, Andrew G. Klein, Western Washington University, United States

Prior work on texture analysis of historic, photographic papers has focused primarily on measures of texture similarity, and automated grouping or clustering of these paper textures in a way that is meaningful to art conservators remains an open problem. In this work a deep learning approach to automated classification is presented, with clusters derived from a human sorting experiment conducted by 19 art conservators and paper experts and subsequently extended through crowd-sourcing. The proposed approach uses deep residual convolutional neural networks, and results are presented on the performance in automatically classifying images when compared to human experts.

BREAK **9:55 AM**

MA6-5 **10:15 AM**

Applying Measures of Texture Similarity to Wove Paper

Patrice Abry, CNRS / ENS Lyon, France; Andrew G. Klein, Western Washington University, United States; Paul Messier, Yale University, United States; Margaret H. Ellis, Morgan Library & Museum, United States; William A. Sethares, University of Wisconsin, United States; David Picard, ENSEA, France; Yuanhao Zhai, David L. Neuhoff, University of Michigan, United States; Stephane Roux, ENS Lyon, France; Stephane Jaffard, Université Paris-Est - Créteil Val-de-Marne, France; Herwig Wendt, CNRS / University of Toulouse, France; C. Richard Johnson, Jr., Cornell University, United States

Wove paper, made on a mold that incorporates wires in a tightly woven screen pattern, is a popular type of paper for writing and printing. To aid the study and classification of art historical works on wove paper, this work describes the application of five image-processing approaches to texture similarity developed independently by five teams. Using books of historical wove papers, a data set of raking light photomicrographs images was assembled, and the teams' results on the ability of the five image processing strategies in detecting outliers and affinities among similarity groupings built into the dataset are reported.

MA6-6 **10:40 AM**

Multispectral Imaging at the Interface of Cultural Heritage Research and Undergraduate Education

Erich Uffelman, Mallory Stephenson, Washington and Lee University, United States; John Delaney, Kathryn Dooley, National Gallery of Art (Washington, DC), United States

The National Gallery of Art (NGA) has pioneered multispectral imaging systems that are powerful tools for the analysis of art works and that can be constructed for under $20,000. Obtaining a dozen or more different images of a painting in different wavelength regions from 400-1000 nm enables an image cube to be constructed which can then be interrogated with remote sensing software such as ENVI. Washington and Lee University (W&L) has been working with NGA to integrate this equipment into undergraduate research involving cultural heritage objects at numerous museums.

MA6-7 **11:05 AM**

Spatial-Spectral Representation for X-Ray Fluorescence Image Super-Resolution

Qiqin Dai, Northwestern University, United States; Emeline Pouyet, Northwestern University / Art Institute of Chicago Center for Scientific Studies in the Arts, United States; Oliver Cossairt, Marc Walton, Aggelos Katsaggelos, Northwestern University, United States

In this project, we propose a super resolution (SR) approach to obtain high resolution (HR) XRF images, with the aid of a conventional HR RGB image. Our proposed XRF image SR algorithm can also be applied to spectral images obtained by any other raster scanning methods, such as Scanning Electron Microscope (SEM), Energy Dispersive Spectroscopy (EDS) and Wavelength Dispersive Spectroscopy (WDS).

MA6-8 **11:30 AM**

Automatic Registration and Mosaicking of Color, Infrared, and X-Radiograph Images of Old Master Paintings Along with Automated Thread Counting

Damon Conover, John Delaney, National Gallery of Art; George Washington University, United States; Murray Loew, George Washington University, United States

A novel image mosaicking and registration algorithm has been developed to 'fuse' 2-D technical multi-modal images of old master paintings to a reference image (typically, a color image) collected at high spatial resolution. The algorithm is robust: it can accommodate large differences in content between the various imaging modalities (reflective infrared (IRR), x-ray radiographs and chemical-image cubes; hyperspectral reflectance and x-ray fluorescence (XRF)). The algorithm has been expanded to provide image products such as elemental maps from the XRF data, and thread-counting weave maps, including phase and magnitude.

Track G – Architecture and Implementation

Session: MA7a – Computer Arithmetic I

Chair: ***Earl Swartzlander,*** *University of Texas at Austin*

MA7a-1 **8:15 AM**

A Theoretical Analysis of Square versus Rectangular Component Multipliers in Recursive Multiplication

Behrooz Parhami, University of California, Santa Barbara, United States

Previous discussions of recursive multiplication focus on how/why the scheme works and how a multiplier of a desired size is built from given component multipliers or multiply-add modules. The form factors (square versus rectangular) for the component multipliers and the one to be synthesized, and how they affect the performance and cost of the resulting multiplier, have not been contemplated. We remedy this shortcoming by dealing with the general problem of synthesizing a possibly nonsquare k-by-l multiplier from b-by-c component multipliers or multiply-add modules, demonstrating that in many cases, the use of rectangular components leads to speed and cost benefits.

MA7a-2 **8:40 AM**

Memristor Based Adder Circuit Design

Nagaraja Revanna, Earl Swartzlander, University of Texas at Austin, United States

Memristors are non-volatile memory elements. In applications like mem-computing, where memory acts both as a site for storing data and logic computations, memristors provide a promising future. In this paper, the design of adders implemented with memristors is discussed. Memristor based designs for standard fixed point adder architectures (ripple carry adder, carry look-ahead adder and parallel prefix adders) are presented. The area and latency are compared. Surprisingly, the Radix-2 CLA has a latency very similar to the parallel prefix adders. The Kogge-Stone adder has the best delay and area among the parallel prefix adders

MA7a-3 **9:05 AM**

Synthesis of Correlated Bit Streams for Stochastic Computing

Megha Parhi, Yin Liu, Marc D. Riedel, Keshab K. Parhi, University of Minnesota, United States

This paper present an approach to synthesize correlated stochastic bit streams with specified correlation coefficients. In general for N correlated bit streams, 2^N -N-1 correlation coefficients can be specified. Using N LFSRs, N uncorrelated stochastic bit streams are first generated. The N correlated bit streams are then generated one at a time using conditional marginal probabilities. The method is illustrated for generating two and three correlated bit streams. The area and power overheads for two correlated bit streams are 9.09% and 2.12%, respectively, and for three correlated bit streams are 21.03% and 4.80%, respectively.

Session: MA7b – Neural Signal Processing

Chair: ***P.P. Vaidyanathan,*** *California Institute of Technology*

MA7b-1 10:15 AM

Efficiency of Estimators in Fluorescence Microscopy

Amir Tahmasbi, Texas A&M University, United States; E. Sally Ward, Texas A&M Health Science Center, United States; Raimund Ober, Texas A&M University, United States

A fundamental question in fluorescence microscopy concerns the lowest possible variance with which a parameter can be estimated. The Cramer-Rao Lower Bound (CRLB) is widely used to assess the performance limits of imaging systems. However, it is known that under certain experimental conditions, namely at low photon counts, the CRLB is not attainable by any unbiased estimator. The use of the CRLB in such situations may lead to overly optimistic estimates of the performance limits of the system. We address this concern by an investigation of conditions under which the CRLB is attainable by an unbiased estimator in fluorescence microscopy.

MA7b-2 10:40 AM

Detection of Protein Repeats using the Ramanujan Filter Bank

Srikanth V. Tenneti, Vaidyanathan P.P., California Institute of Technology, United States

Protein repeats are tandemly repeating segments within an amino acid sequence. They induce several important structural and binding properties on the protein. So far, the most successful detection schemes for such repeats have used computationally expensive techniques such as dynamic programming algorithms, HMMs, and so on. Classical DSP tools such as STFT, unfortunately, perform poorly in the presence of mutations. In this work, a novel technique is proposed based on the recently developed Ramanujan Filter Bank. Fast, accurate, and involving only simple integer computations, its performance is demonstrated on several well-known repeat families.

MA7b-3 11:05 AM

On Inferring Functional Connectivity with Directed Information in Neuronal Networks

Zhiting Cai, Rice University, United States; Curtis Neveu, John Byrne, University of Texas Health Science Center at Houston, United States; Behnaam Aazhang, Rice University, United States

In order to understand modifications in a neural network due to learning, it is paramount to develop an effective tool that is capable of mapping the circuit connectivity and its changes from large-scale recordings of neuronal activity patterns. In this paper, context tree maximizing (CTM) is used to estimate directed information (DI) to measure causal influences among neural spike trains. The method reliably identifies the circuit structures of realistic Hodgkin-Huxley simulated networks. It also produces a promising mapping of a small brain network.

MA7b-4 11:30 AM

Seizure Prediction using Long-Term Fragmented Intracranial Canine and Human EEG Recordings

Zisheng Zhang, Keshab Parhi, University of Minnesota, United States

This paper presents a novel patient-specific algorithm for prediction of seizures. Spectral power features and cross-correlation coefficients are extracted as two feature sets. Selected features are then input to three different classifiers which include AdaBoost, radial basis function kernel support vector machine (RBF-SVM) and artificial neural network (ANN). The algorithm is tested on the American Epilepsy Society Seizure Prediction Challenge database. It is shown the spectral features achieve a mean AUC of 0.7538, 0.7739, and 0.7948 for AdaBoost, SVM, and ANN, respectively. The correlation coefficients achieve a mean AUC of 0.6640, 0.7403, and 0.7875 for AdaBoost, SVM, and ANN, respectively.

Session: MA8a1 – Efficient Hardware Implementation 8:15 AM–9:55 AM

Chair: ***Harald Enzinger,*** *Graz University of Technology*

MA8a1-1
Cost-Performance Tradeoffs in Unreliable Computation Architectures

Mehmet Donmez, Maxim Raginsky, Andrew Singer, Lav Varshney, University of Illinois at Urbana Champaign, United States

We investigate the problem of unreliable computation under cost and fidelity constraints. We introduce a framework, where instead of the actual computation, we observe its noisy version while incurring an associated cost. We consider several cost models formalizing the relation between fidelity of an unreliable computation and its cost. We analyze redundancy-based strategies and demonstrate limits of performance in terms of our framework. We demonstrate that in-memory computing and in-sensor computing lead to different cost-fidelity formulations, and fusing several less costly and unreliable computation, instead of a single costly and more reliable one, yield better cost-performance tradeoff under certain scenarios.

MA8a1-2
Baseband Volterra Filters with Even-Order Terms: Theoretical Foundation and Practical Implications

Harald Enzinger, Karl Freiberger, Gernot Kubin, Graz University of Technology, Austria; Christian Vogel, FH Joanneum - University of Applied Sciences, Austria

We review the derivation of the baseband Volterra series using compact vector notation. After that, we present a new derivation showing that by assuming modified basis functionals in the passband model, one obtains a baseband model which also includes even-order terms. Using our generalized set of basis functionals we demonstrate that the condition number of the regression matrix is decreased, which leads to improved performance of adaptive Volterra filters.

MA8a1-3
Fast Time-Domain Volterra Filtering

Harald Enzinger, Karl Freiberger, Gernot Kubin, Graz University of Technology, Austria; Christian Vogel, FH Joanneum - University of Applied Sciences, Austria

We present two algorithms for fast time-domain Volterra filtering. The first algorithm generalizes Horner's method for polynomial evaluation and computes output samples using the minimum number of operations. The second algorithm is aimed at identification and computes the Volterra series input products using the minimum number of operations. Compared to frequency-domain algorithms, which introduce computational overhead for transformations, the presented time-domain algorithms are faster for short to medium memory lengths.

MA8a1-4
Hardware Implementation of a Series of Transform Matrices Based on Discrete Hirschman Transform

Peng Xi, Victor Debrunner, Florida State University, United States

Abstract--- In this work, we present a fast computational structure for discrete Hirschman Transform (FHT) on the FPGAs. Compared to the traditional FFT, the FHT has better performance in spectral estimation, FIR convolution and especially in Compressive Sensing. In this paper, we introduce the implementation of DHT by using circular shifting of short terms of FFT. This algorithm generates DHT matrices of dimension N based on integer multiplications of N=KL. Our algorithm is implemented on Cyclone II DE2 board. Our simulation result shows that the FHT is superior to FFT in computational speed, space requirement and rounding error performance.

Session: MA8a2 – Error Correction and Network Coding 8:15 AM–9:55 AM

Chair: ***Jeff Andrews,*** *UT Austin*

MA8a2-1

On the Catastrophic Puncturing Patterns for Finite-Length Polar Codes

Song-Nam Hong, Ajou University, ; Dennis Hui, Ivana Maric, Ericsson Research, United States

We identify that for a given information set, there exist the so-called catastrophic puncturing patterns which will surely lead to a block error. We present an efficient recursive method to characterize all catastrophic puncturing patterns and their weight distributions. Based on this, we show why a randomly punctured polar code can suffer from an error floor and further estimate at which value the error floor occurs. To overcome this, we propose a simple greedy algorithm to construct a non-catastrohpic puncturing pattern. Leveraging this algorithm, we construct a rate-compatible polar code which shows better performance than Turbo code.

MA8a2-2

On Error Correction for Asynchronous Communication

Chen Yi, Joerg Kliewer, New Jersey Institute of Technology, United States

We propose a forward error correction scheme for asynchronous sensor communication where the dominant errors consist of pulse deletions and insertions, and where encoding is required to take place in an instantaneous fashion. The presented scheme consists of a combination of a systematic convolutional code, an embedded marker code, and power efficient frequency-shift keying modulation at the sensor node. Decoding is first obtained via a maximum a-posteriori (MAP) decoder for the marker code which achieves synchronization for the insertion and deletion channel, followed by MAP decoding for the convolutional code.

MA8a2-3

Linear Superposition Coding for the Asymmetric Gaussian MAC with Quantized Feedback

Stefan Farthofer, Gerald Matz, Vienna University of Technology, Austria

We propose a linear transceiver scheme for the asymmetric two-user multiple access channel with additive Gaussian noise and quantized feedback. The quantized feedback link is modeled as an information bottleneck subject to a rate constraint. We introduce a superposition scheme that splits the transmit power between an Ozarow-like linear-feedback code and a conventional code that ignores the feedback. We study the achievable sum rate as a function of the feedback quantization rate and we show that sum rate maximization leads to a difference of convex functions problem that we solve via the convex-concave procedure.

MA8a2-4

Physical-Layer Network Coded QAM with Trellis Shaping for the Two-Way Relay Channel

Daniela Donati, Mark Flanagan, University College Dublin, Ireland

Physical-layer network coding (PNC) allows to improve the throughput on the TWRC. Constellation shaping allows to minimize the average transmitted energy. In this paper, we show how low-complexity trellis shaping can be used to provide constellation shaping both at the user nodes and the relay node. The proposed technique works specifically for sign bit shaping and M-ary QAM. Simulation results show that the proposed scheme provides a significantly increased performance in terms of the achievable BER, with 5.3dB shaping gain available at a BER of 10−3 in the case of 256-QAM signaling.

MA8a2-5

Construction of Minimal Sets for Capacity- Approaching Variable-Length Constrained Sequence Codes

Congzhe Cao, Ivan Fair, University of Alberta, Canada

A novel approach to design capacity-approaching variable-length constrained sequence codes has recently been developed. A critical step in this design process is the construction of minimal sets based on a finite state machine description of the encoders. In this paper we propose three generalized criteria to select the state that will result in construction of the minimal set with the best achievable code rate. Both complete and incomplete minimal sets are considered when developing criteria to select the appropriate state. We construct constrained sequence codes to demonstrate the effectiveness of the proposed construction criteria.

Session: MA8a3 – Massive MIMO 8:15 AM–9:55 AM

Chair: ***Timothy Davidson,*** *McMaster University*

MA8a3-1
Massive MIMO via Cooperative Users

Sha Hu, Fredrik Rusek, Ove Edfors, Lund University, Sweden

We consider a case where K closely located users communicate with a base station in the uplink. Each user has a certain number of time-frequency slots at its disposal. At a small cost, the users can communicate with each other and share their data. Thus, they can cooperate in the uplink in order to save transmit power. In this paper, we formulate a game theoretic model for this, and study what savings are possible, and to what extent users are willing to take part in the cooperation.

MA8a3-2
Robust Precoding Design for Massive MISO Downlink

Mostafa Medra, Timothy Davidson, McMaster University, Canada

A low-complexity version of the offset maximization technique for robust precoding is developed for massive MISO downlink systems. Offset maximization precoding provides substantial robustness under different channel uncertainty models, and can be modified to handle per- antenna power constraints. We also provide an improved power loading technique for any set of beamforming directions. This technique provides a low-complexity method for controlling the power required to achieve a specified outage probability at a given target SINR, and it results in significant power savings. The technique also identifies users that should be rescheduled if the system is unable to provide acceptable performance.

MA8a3-3
Analysis and Evaluation of a Practical Downlink Multiuser MIMO Scheduler over LTE Advanced Massive MIMO Systems

Rob Arnott, NEC Telecom Modus, United States; Kengo Oketani, NEC Corporation, United States; Narayan Prasad, Sampath Rangarajan, NEC Laboratories America, United States; Patricia Wells, NEC Telecom Modus, United States

In this paper, we propose and comprehensively analyze a practical downlink MU-MIMO scheduling algorithm over LTE Advanced massive MIMO cellular networks. The scheduling problem is first posed as an optimization problem to maximize the weighted sum rate subject to certain mandatory practical constraints. We propose an efficient approximation algorithm that enforces the key constraints and prove that it yields a meaningful approximation guarantee. The obtained scheduling decision is then further processed to obtain one that is fully compliant to the LTE-A standard. Comprehensive system level evaluation is conducted by emulating an LTE-A massive MIMO network and potential gains are demonstrated.

MA8a3-4
Grassmannian Training for Massive MIMO Cellular Networks

Yonghee Han, Jungwoo Lee, Seoul National University, Republic of Korea

Performance of massive MIMO systems is limited by pilot contamination caused by correlated pilot. Pilot reuse, allowing distant users to use the same pilot, has been recently investigated to mitigate the pilot contamination with a reasonable training overhead. However, existing pilot reuse schemes impose orthogonality constraint on the different pilot sequences, resulting in the inflexibility in optimizing the training period. In this paper, we investigate the use of arbitrary length-pilot in the pilot reuse framework. We also show that training sequence design based on Grassmannian subspace packing provides an optimal spectral efficiency for regular hexagonal cellular networks adopting pilot reuse.

MA8a3-5
Power Allocation for Downlink Path-Based Precoding in Multiuser FDD Massive MIMO Systems Without CSI Feedback

Chin-Wei Hsu, Ming-Fu Tang, Borching Su, National Taiwan University, Taiwan

In this paper, downlink path-based precoding in multiuser FDD massive MIMO is studied to minimize the maximum symbol error rate (SER) among users. While the acquisition of channel state information at the transmitter (CSI-T) for FDD massive MIMO was usually considered impractical due to huge transmission overhead, a recent work utilizes FDD reciprocity between uplink and downlink channels and designs beamformers to serve multiple users without CSI feedback. Extending the work, we propose a power allocation method for the beamformer design that minimizes the Chernoff bound of the SER. Simulation results show that the proposed scheme improves the SER performance.

MA8a3-6
Performance of Cell-Free Massive MIMO Systems with MMSE and PCP Receivers
Elina Nayebi, University of California, San Diego, United States; Alexei Ashikhmin, Thomas L. Marzetta, Bell Laboratories, United States; Bhaskar D. Rao, University of California, San Diego, United States

Cell-Free Massive MIMO comprises a large number of distributed antennas serving much smaller number of users. There is no partitioning into cells and each user is served by all antennas. We investigate uplink transmission with MMSE and PCP (Pilot Contamination Postcoding) receivers. We derive SINR expressions for PCP and MMSE receivers and an asymptotic approximation for SINR of MMSE receiver as a function of large scale fading coefficients only. The obtained approximation is accurate even for a small number of antennas. MMSE and PCP receivers demonstrate five-fold and two-fold gains respectively over matched filter receiver in terms of 5%-outage rate.

MA8a3-7
A Path Selection Algorithm for Sparse Massive MIMO Channels
Maliheh Soleimani, Mahmood Mazrouei-Sebdani, Witold A. Krzymien, University of Alberta, Canada; Jordan Melzer, TELUS Communications, Canada

mm-Wave communications and massive MIMO are two promising technologies to increase the capacity and coverage of future cellular networks. Channel sparsity, where there exist only few propagation paths enabling signal transmission to and reception from mobile users, is a key property of mm-Wave channels. In this paper, we consider the downlink transmission over a sparse massive MIMO channel and propose a novel path selection algorithm to maximize sum rate. We introduce a bipartite graph, which connects angle of departure (AoD) to users in the beam-space domain. The simulation results demonstrate that the proposed algorithm outperforms the conventional user selection algorithms.

Track F – Biomedical Signal and Image Processing
Session: MA8a4 – Neural Imaging 8:15 AM–9:55 AM
Chair: ***Konstantinos Slavakis,*** *University of Buffalo*

MA8a4-1
Detection of Diabetic Peripheral Neuropathy using Spatial-Temporal Analysis in Infrared Videos
Peter Soliz, Carla Agurto, Ana Edwards, Zyden Jarry, VisionQuest Biomedical LLC, United States; Janet Simon, Foot & Ankle Associates of New Mexico, United States; Mark Burge, University of New Mexico Health Sciences Center, United States

Limitations of previous studies based on thermography to detect diabetic peripheral neuropathy (DPN) are addressed in the combined analysis spatial and temporal features. In our approach we extract information of temperature patterns before applying a cold stimulus to the plantar foot. Additionally, we extract temporal features using the parameters of the thermoregulation response and principal component analysis from the recovery stage after cooling. The features are processed by a linear support vector machine (SVM) classifier achieving AUCs of 0.99 and 0.83 for the detection of DPN in females and males respectively.

MA8a4-2
Clustering Brain-Network-Connectivity States using Kernel Partial Correlations
Konstantinos Slavakis, Shiva Salsabilian, David Wack, Sarah Muldoon, Henry Baidoo-Williams, University at Buffalo, United States; Jean Vettel, US Army Research Laboratory, United States; Matt Cieslak, Scott Grafton, University of California, Santa Barbara, United States

In response to the demand on data-analytic tools for brain networks, this paper introduces a framework for clustering (brain)-network-connectivity states. Partial correlations (PCs) and kernel functions are used to monitor dynamics and non-linear intra-connections within a network. Taking advantage of the PCs inherent geometry, clustering of the collected data, and thus identification of the connectivity states, is performed on the manifold of positive-definite matrices. The superior performance of the advocated learning technique over state-of-the-art clustering methods is demonstrated via numerical tests on synthetic and real brain-network data.

MA8a4-3
Automated Selection of Uniform Regions for CT Image Quality Detection
Maitham Naeemi, University of Washington - Bothell, United States; Adam Alessio, University of Washington, United States; Sohini Roychowdhury, University of Washington - Bothell, United States

For CT images, there is presently a need to optimize contrast enhancement to ensure As Low As Reasonably Achievable (ALARA) dosage with diagnostic image quality (IQ). In the proposed method, two windowed CT image subset regions are analyzed together to identify the extent of variation in the corresponding Fourier-domain spectrum. The spectral difference between these windows is used to isolate spatial regions-of-interest with low and high variation, respectively. The number of pixels within these regions is correlated with image acquisition parameters that serve as IQ metrics. Phantom (R^2 = 0.9308) and patient (R^2 = 0.8617) CT images were analyzed, respectively.

MA8a4-4
Big Data Spark Solution for Functional Magnetic Resonance Imaging
Saman Sarraf, Rotman Research Institute at Baycrest, University of Toronto, United States; Mehdi Ostadhashem, Rogers, United States

Healthcare is one of the industries willing to use big data platforms. Medical imaging -pillar in diagnostic healthcare- deals with high volume of data collection and processing. We developed and successfully tested a new pipeline for functional magnetic resonance imaging - fMRI using Big Data Spark / PySpark platform on a single node which allows us to read and load imaging data, convert them to Resilient Distributed Datasets in order perform in-memory data processing. The final results revealed our Spark (PySpark) based solution improved four times the performance and processing time on a single compared to the previous works.

Track G – Architecture and Implementation
Session: MA8b1 – Design Methodologies for Signal Processing Systems 10:15 AM–11:55 AM
Chair: ***Endri Bezati,*** *EPFL*

MA8b1-1
A New Open-Source SIMDVector libm Fully Implemented with High-Level Scalar C
Christoph Lauter, Sorbonne Universités, UPMC Univ Paris 6, UMR 7606, LIP6, France

Systems support mathematical functions like exp, sin, cos through mathematical libraries (libm). With increasingly parallel hardware, scalar libm functions do not suffice; implementations that work on vectors in an element-by-element (SIMD) fashion are required. Only few Open-Source implementations of vector libms exist. They are mostly written in assembly, which hinders portability and maintenance. We present an Open-Source vector libm implemented with high-level scalar C that a modern compiler can translate to SIMD code. The error of all functions does not exceed 5ulp, while performance is up to six-fold higher than with scalar libms.

MA8b1-2
Fast Digital Design Space Exploration with High-Level Synthesis: A Case Study with Approximate Conjugate Gradient Pursuit
Benjamin Knoop, Karthik Vinod, Sebastian Schmale, Dagmar Peters-Drolshagen, Steffen Paul, University of Bremen, Germany

The rapid architecture design paradigm of high-level synthesis (HLS) facilitates extensive design space exploration without much effort. Modern HLS compilers, like Xilinx Vivado HLS, support the evaluation of different architectures by so-called directives. We propose to extend the exploration capabilities through a data type-agnostic programming methodology and shell scripts to automate certain repetitious tasks. Additionally, we report on the first implementation of the Approximate Conjugate Gradient Pursuit algorithm, which is exemplarily used to demonstrate the augmented design space exploration capabilities.

MA8b1-3
High-Level System Synthesis and optimization of Dataflow Programs for MPSoCs
Endri Bezati, Simone Casale Brunet, Marco Mattavelli, École polytechnique fédérale de Lausanne, Switzerland; Jorn Janneck, Lund University, Sweden

The growing complexity of digital signal processing applications make a compelling case the use of high-level design and synthesis methodologies for the implementation on reconfigurable and embedded devices. Past research has shown that raising the level of abstraction of design stages does not necessarily gives penalties in terms of performance or resources. Dataflow programs provide behavioral descriptions capable of expressing both sequential and parallel algorithms and enable natural design abstractions, modularity, and portability. In this paper, a tool implementing dataflow programs onto embedded heterogeneous platforms by means of high-level synthesis, software synthesis and interface synthesis is presented for MPSoCs platfroms.

MA8b1-4
Analyzing Streaming Application Performance on Processor Arrays
James Glenn-Anderson, Supercomputer Systems, Inc., Sweden; Jorn Janneck, Lund University, Sweden

The inherent scalability and architectural regularity of processor array platforms favors application areas with high degrees of parallelism, including signal processing and stream computing. The on-chip network connecting the processor cores represents a shared communication resource and the data streams between the cores in an array will interfere with each other, affecting overall performance in ways that are difficult to anticipate and analyze. This paper proposes an analytical framework based on network calculus and trace analysis that allows designers to derive lower-bounds for application performance taking into account platform topology and processor performance, and is applicable to highly data-dependent applications.

MA8b1-5
Trace-Based Manycore Partitioning of Stream-Processing Applications
Jorn Janneck, Lund University, Sweden; Michalska Malgorzata, Simone Casale-Brunet, Endri Bezati, Marco Mattavelli, École polytechnique fédérale de Lausanne, Switzerland

Application performance on these processor array platforms is highly sensitive to how functionality is physically placed on the device, as this choice crucially determines communication latencies and congestion patterns of the on-chip intercore communication. The problem of identifying the best, or just a good enough, partitioning and placement does not, in general, admit to an analytic solution, and its combinatorial nature makes solving it by pure experimentation impractical. This paper presents an approach that maps stream programs onto processor arrays using trace analysis as a technique for evaluating candidate solutions and for suggesting alternatives.

Track D – Signal Processing and Adaptive Systems
Session: MA8b2 – Sparse Methods and Compressive Sensing 10:15 AM–11:55 AM
Chair: ***Todd Moon,*** *Utah State University*

MA8b2-1
Time-Recursive Multi-Pitch Estimation using Group Sparse Recursive Least Squares
Filip Elvander, Johan Sward, Andreas Jakobsson, Lund University, Sweden

In this work, we propose a time-recursive multi-pitch estimation algorithm, using a sparse reconstruction framework, assuming only a few pitches from a large set of candidates to be active at each time instant. The proposed algorithm utilizes a sparse recursive least squares formulation augmented by an adaptive penalty term specifically designed to enforce a pitch structure on the solution. When evaluated on a set of ten music pieces, the proposed method is shown to outperform state-of-the-art multi-pitch estimators in either accuracy or computational speed.

MA8b2-2
Quantized Low-Rank Matrix Recovery with Erroneous Measurements: Application to Data Privacy in Power Grids
Meng Wang, Rensselaer Polytechnic Institute, United States

We consider recovering a low-rank matrix from quantized and partially erroneous measurements. We recover the matrix by solving the maximum likelihood estimation under the constraint that the matrix is the sum of a low-rank matrix and a sparse matrix. An upper bound of the elative recovery error of our method is provided, and it diminishes as the dimension increases. A

projected gradient method is proposed to solve the non-convex problem approximately. We propose a novel application of this problem in preserving data privacy in power systems. Experiments on real synchrophasor data in Power Systems demonstrate the effectiveness of our method.

MA8b2-3
Bayesian Method for Image Recovery from Block Compressive Sensing
Uditha Wijewardhana, Marian Codreanu, Matti Latva-aho, University of Oulu, Finland

We consider the problem of recovering an image using block compressed sensing (BCS). Traditional BCS algorithms recovers each image block independently and utilizes post-processing methods for removing the blocking artifacts. In contrast, we propose an image recovery method free of post-processing, where we utilize a lapped transform (LT) for the sparse representation of the image in order to reduce the blocking artifacts. Specifically, we derive an iterative image reconstruction method, where a small number of adjacent measurement blocks are jointly processed for recovering an image block. For this purpose, we propose a novel sparse Bayesian learning (SBL) algorithm.

MA8b2-4
Stable Compressive Low Rank Toeplitz Covariance Estimation Without Regularization
Heng Qiao, Piya Pal, University of Maryland, United States

This paper considers the problem of reconstructing a $N\times N$ low rank positive semidefinite Toeplitz matrix from a noisy compressed sketch of size $O(\sqrt{r})\times O(\sqrt{r})$ where $r\ll N$ is the rank of the matrix. A novel algorithm is proposed which only exploits a positive semidefinite (PSD) constraint to denoise the compressed sketch using a simple least squares approach. A major advantage of our algorithm is that it does not require any regularization parameter. The PSD constraint, along with Vandermonde representation of PSD Toeplitz matrices are proved to be sufficient for stable reconstruction in presence of bounded noise.

MA8b2-5
Sparse Bayesian Learning Boosted by Partial Erroneous Support Knowledge
Mohammad Shekaramiz, Todd K. Moon, Jacob H. Gunther, Utah State University, United States

Recovery of clustered sparse signals when having partial erroneous prior knowledge on the signal supports is considered. We provide a sparse Bayesian learning (SBL) model to incorporate such prior knowledge and simultaneously learn the clustering pattern. Specifically, we add one more layer to support-aided SBL algorithm (SA-SBL) by putting a prior on the shape parameters of Gamma distributions, those modeled for the precision of solution. We impose the shape parameters to depend on the estimated measure of clumpiness of the supports. The proposed algorithm is able to modify its erroneous prior knowledge on the supports and learn the clustering pattern.

MA8b2-6
Hyperparameter-Free Sparse Linear Regression of Grouped Variables
Ted Kronvall, Stefan Ingi Adalbjörnsson, Santhosh Nadig, Andreas Jakobsson, Lund University, Sweden

In this paper, we introduce a novel framework for semi-parametric estimation of an unknown number of signals, each parametrized by a group of components. Via a reformulation of the covariance fitting criteria, we formulate a convex optimization problem over a grid of candidate representations, promoting solutions with only a few active groups. Utilizing the covariance fitting allows for a hyperparameter-free estimation procedure, highly robust against coherency between candidates, while still allowing for a computationally efficient implementation. Numerical simulations illustrate how the proposed method offers a performance similar to the group-Lasso for incoherent dictionaries, and superior performance for coherent dictionaries.

MA8b2-7
One-Bit Compressive Sampling with Time-Varying Thresholds: Maximum Likelihood and the Cramer-Rao Bound
Christopher Gianelli, Luzhou Xu, Jian Li, University of Florida, United States; Petre Stoica, Uppsala University, Sweden

This paper considers estimating the parameters of a noisy signal quantized to one-bit via a time-varying thresholding operation. An expression for the Fisher information matrix is derived for a signal parameterized by a vector when the noise is i.i.d. Gaussian with known or unknown variance. The case of single sinusoidal parameter estimation is considered, and the Cramer-Rao bounds for amplitude, frequency, and phase estimators are computed for a variety of parameter values. A maximum likelihood estimator for the sinusoidal signal parameters is proposed, and its performance is compared with the CRB as a function of the number of observations.

Session: MA8b3 – Speech and Image Analysis 10:15 AM–11:55 AM

Chair: ***Marios Pattichis,*** *University of New Mexico*

MA8b3-1
A Joint EMD and Teager-Kaiser Energy Approach Towards Normal and Nasal Speech Analysis

Chris De La Cruz, Balu Santhanam, University of New Mexico, United States

Velopharyngeal inadequacy produced in cleft lip and palate (CLP) situations manifests as hypernasality in underlying speech. Common methods for the analysis of these utterances are one-third octave band analysis and LPC analysis. In this paper, we propose a hybrid approach where the CEEMDAN-2014 algorithm is used to decompose both normal and nasal utterances into underlying intrinsic mode functions and then Teager-Kaiser energy operator-based energy metrics of the IMFs are computed. The proposed energy metrics are shown to produce clear delineation between nasal and normal resonances taken from utterances containing various levels of hypernasality in the American CLP Craniofacial database [10].

MA8b3-2
Iris Recognition using Cross-Spectral Comparison

Jennifer Webb, Delores Etter, Vianka Barboza, Elena Sharp Sharp, Southern Methodist University, United States

This research used a multi-year data collection project that collected iris images from a large number of subjects at LED illumination at different wavelengths ranging from 405 nanometers to 1550 nanometers. This dataset contains largely high quality images, and all images with any quality issues are marked. For this project, we used only good quality images along with government-provided segmentation and template algorithms to examine how images taken with different illumination compare with each other.

MA8b3-3
Efficient Facial Recognition using Vector Quantization of 2D DWT Features

Ahmed Aldhahab, Taif Al Obaidi, Wasfy B. Mikhael, University of Central Florida, United States

A new approach for facial recognition employing Two Dimensional Discrete Wavelet Transform (2D DWT) and Vector Quantization (VQ) is proposed. In the feature extraction step, 2D DWT is applied to the processed facial images for dimensionality reduction and feature extraction. The resultant DWT features are further compacted using VQ. The proposed algorithm is evaluated using four databases, namely, ORL, YALE, FERET, and FEI. Then, the results are analyzed using K-fold Cross Validation (CV). The results show that the proposed approach improves the recognition rates and the storage requirements compared with existing methods.

MA8b3-4
An Efficient DCT template-based Object Detection Method using Phase Correlation

Markus Hörhan, Horst Eidenberger, Vienna University of Technology, Austria

In this work, we propose an efficient algorithm, which utilizes the combination of discrete cosine transform (DCT) and phase correlation (PC) for fast object detection. To test the algorithm's classification performance and computational complexity we conducted several experiments. Furthermore, we compared our experimental results to a state-of-the-art object detection method. The proposed method requires less number of coefficients than fast Fourier transformation (FFT)-based techniques to compute PC. The computational complexity and memory requirements are significantly reduced using this method. According to our results, the proposed algorithm outperforms the baseline method with respect to training time and classification accuracy.

MA8b3-5
Transfer of Multimodal Emotion Features in Deep Belief Networks

Hiranmayi Ranganathan, Shayok Chakraborty, Panchanathan Sethuraman, Arizona State University, United States

In this paper, we investigate the effect of transfer of emotion-rich features between source and target networks on classification accuracy and training time in a multimodal setting for vision based emotion recognition. First, we propose emosource -a 6-layer Deep Belief Network (DBN), trained on popular emotion corpora for emotion classification. Second, we propose two 6-layer DBNs - emotarget and emotargetft and study the transfer of emotion features between source and target networks in a layer-by-layer fashion. To the best of our knowledge, this is the first research effort to study the transfer of emotion features layer-by-layer in a multimodal setting.

MA8b3-6

Direct Classification from Compressively Sensed Images via Deep Boltzmann Machine

Henry Braun, Pavan Turaga, Cihan Tepedelenlioglu, Andreas Spanias, Arizona State University, United States

We examine a potential technique of performing a classification task based on compressively sensed (CS) data, skipping a computationally expensive reconstruction step. A deep Boltzmann machine is trained on a compressive representation of MNIST handwritten digit data, using a random orthoprojector sensing matrix. The network is first pre-trained on uncompressed data in order to learn the structure of the dataset. The outer network layers are then optimized using backpropagation. We find this approach achieves a 1.21% test data error rate at a sensing rate of 0.4, compared to a 0.99% error rate for noncompressive data.

Track G – Architecture and Implementation

Session: MP1a – Algorithm and Hardware Aspects for 5G Wireless Systems

Chair: ***Christoph Studer,*** *Cornell University*

MP1a-1 **1:30 PM**

Many-Antenna MU-MIMO Channel Measurements

Clayton Shepard, Abeer Javed, Ryan Guerra, Jian Ding, Lin Zhong, Rice University, United States

We conducted the most comprehensive many-antenna MU-MIMO channel measurement campaign ever reported. Our measurement system supports full mobility with very high time-frequency resolution. We report channel traces in the UHF, 2.4 GHz, and 5 GHz bands, in diverse environments, with up to 104 base station antennas serving 8 users. Our results show that channels exhibit large capacity fluctuations on the order of milliseconds, even with just pedestrian mobility. However in stationary environments, MU-MIMO channels are long-term stable regardless of frequency, and are minimally affected by environmental mobility. These traces and measurement system are made available online.

MP1a-2 **1:55 PM**

Decentralized Data Detection for Massive MU-MIMO on a GPU Cluster

Kaipeng Li, Rice University, United States; Rishi Sharan, Cornell University, United States; Yujun Chen, Joseph Cavallaro, Rice University, United States; Christoph Studer, Cornell University, United States

Centralized baseband processing in massive MU-MIMO systems poses significant practical implementation challenges caused by the excessive data rates and computational complexity generated by the acquired RF signals. We present a novel distributed approach using the alternating direction method of multipliers (ADMM) that enables decentralized data detection at high throughput on parallel hardware. We present a corresponding implementation on a GPU cluster, which demonstrates that decentralization enables scalable baseband processing to hundreds or thousands of antennas at high throughput, while achieving near-optimal error-rate performance.

MP1a-3 **2:20 PM**

An Energy Efficiency Perspective on Massive MIMO Quantization

Muris Sarajlic, Liang Liu, Ove Edfors, Lund University, Sweden

The large number of transcievers (TRX) in a typical massive MIMO base station makes the energy consumption of each TRX important. By intentionally reducing precision of the hardware energy can be saved, but system performance suffer. Massive MIMO will, however, suffer less than traditional systems due to the, so called, averaging effect where impairments tend to average out across the many TRXs. We perform a detailed analysis of how the chosen number of quantization levels impacts both system performance and energy consumption of the TRX sub-system, making possible a balanced trade-off between the two.

MP1a-4 **2:45 PM**

Limited Feedback in Multi-User MIMO System with Low Resolution ADCs

Jianhua Mo, Robert Heath, University of Texas at Austin, United States

We develop limited feedback methods in a system where a multiple-antenna base station sends signals to many multiple-antenna mobile receivers with low-resolution ADCs. If channel state information is not available with high resolution at the transmitter and the precoding is not well designed, the inter-user interference is a big decoding challenge for receivers with low-resolution quantization. In this paper, we present a limited feedback method for multi-user MIMO systems with low resolution ADCs. We evaluate the power and rate loss incurred by limited feedback in both conventional and novel precoding methods.

Track A – Communications Systems

Session: MP1b – Wireless Networks

Chair: ***Andrea Goldsmith,*** *Stanford University*

MP1b-1 **3:30 PM**

From Niche to Renaissance: Why 5G will be the last G

Mischa Dohler, Kings College London, United Kingdom; Ali Hossaini, Cinema Arts Network, United Kingdom; Prokar Dasgupta, NHS, United Kingdom; Peter Marshall, Ericsson, United Kingdom; Toktam Mahmoodi, Maria Lema, Kings College London, United Kingdom

We are the last global eco-system still advancing its entire technology family in generations, from 1G to the transformational 5G era. The typical 10-year innovation cycles between generations, the “G”s, worked well in the past but are not adequate for the future. This paper proposes a few radical changes to the “G” design approach: a more atomized and stronger co-design within 5G to enable a massive shift from selling the cost of connectivity to co-creating value in ubiquitous connectivity. The insights are underpinned by design experiences with several industry verticals. We hope 5G to be the last “G” of cellular.

MP1b-2 **3:55 PM**

CEAL: Research Challenges in Fog Networking

Mung Chiang, Princeton University, United States

Fog architecture distributes computation, communication, control and storage closer to end users along the cloud-to-things continuum, promising the potential benefits in cognition, efficiency, agility and latency, and possibly enabling applications in 5G, IoT and big data. This talk overviews the opportunities and challenges in this research area and discusses the emergent industry momentum in fog.

MP1b-3 **4:20 PM**

The Beam Alignment Problem in mmWave Wireless Networks

Saeid Haghighatshoar, Giuseppe Caire, Technische Universität Berlin, Germany

Millimeter wave channels exhibit strong gains along a few preferential directions which must be ``learned'' by applying low-dimensional projections at both sides. This allows the beams at the base station and user device equipment to eventually align on the directions where the energy coupling is maximum. We cast this problem in the general framework of ``interactive sampling/collaborative learning'', and propose efficient protocols in order to achieve such beam alignment. We compare the performance of such protocols (including baseline schemes proposed in the literature) in terms of the time needed to achieve a certain target energy capture and interference rejection level.

MP1b-4 **4:45 PM**

Staying Alive - Network Coding for Data Persistence in Volatile Networks

Vitaly Abdrashitov, Muriel Medard, Massachusetts Institute of Technology, United States

We propose a random linear network coded (RLNC) distributed storage system for the efficient repair of failed nodes. This system can operate with highly changing network connectivity, and is persistent in the sense that it allows the user data decoding even after many cycles of node failures and repairs. Data for node repairs is drawn from a small node groups, but no specific node in the group is essential for the repair. We also estimate the performance of the proposed scheme in terms of the probability of successful data decoding from a random subset of l nodes.

Track B – MIMO Communications and Signal Processing

Session: MP2a – Interference Limited Next Generation Satellite Communications (SatnexIV)

Chair: ***Ana Perez-Neira,*** *Universitat Politecnica de Catalunya - Centre Tecnologic de Telecomunicacions de Catalunya*

MP2a-1 1:30 PM

User Selection for Multibeam Satellite Systems: A Stochastic Geometry Perspective.

Mathini Sellathurai, Heriot Watt University, United Kingdom; Satyanarayana Vuppala, Tharm Ratnarajah, University of Edinburgh, United Kingdom

In this paper, we analyze the performance of multibeam satellite communication network consisting multiple randomly distributed users. We use stochastic geometry tools to analyze the performance of this network and consider Poisson point process (PPP) to model the distribution of the users. We analyze the performance of two selection schemes: random and best user selection. The later describes choosing the user with the minimum signal to noise interference value in the network, while the former, selects any user at random. The outage probability and capacity are understood analytically and simualtions.

MP2a-2 1:55 PM

Efficient Satellite Systems Based on Interference Management and Exploitation

Alessandro Ugolini, University of Parma, Italy; Amina Piemontese, Chalmers University of Technology, Sweden; Alessandro Vanelli-Coralli, University of Bologna, Italy; Giulio Colavolpe, University of Parma, Italy

The design of satellite communication systems has been traditionally based on orthogonal signaling. Interference has thus been considered as an undesired effect to be avoided or reduced as much as possible. Recently, this approach has been reviewed both for broadcast and unicast applications. In fact, system and link designs are now based on a different paradigm: interference management and exploitation by design, where interference is considered an asset to be managed, both at the transmitter and the receiver. We will describe some examples of application of this new paradigm and the advantages it can bring in next generation satellite systems.

MP2a-3 2:20 PM

Noma and Interference Limited Satellite Communications

Ana Perez-Neira, Universitat Politecnica de Catalunya, Spain; Marius Caus, Miguel Angel Vazquez, Centre Tecnologic de Telecomunicacions de Catalunya, Spain

NOMA is gaining momentum for 5G communications. In the satellite segment, non-orthogonal multiplexing and resource allocation is also becoming a reality thanks to the advances in decentralized multi-user detection. This enables high throughput satellites that are interference limited rather than noise limited. After an overview of different interference limited satcom scenarios, the paper presents not only a scheduler, but also precoding strategies, which are designed jointly with the decentralized multi-user detector.

MP2a-4 2:45 PM

Optimized Link Adaptation for DVB-S2x Precoded Waveforms Based on SNIR Estimation

Stefano Andrenacci, Danilo Spano, University of Luxembourg, Luxembourg; Dimitrios Christopoulos, Newtec, Belgium; Symeon Chatzinotas, University of Luxembourg, Luxembourg; Jens Krause, SES, Luxembourg; Björn Ottersten, University of Luxembourg, Luxembourg

The present work deals with optimized strategies to address the issue of link adaptation (Adaptive Coding and Modulation - ACM) in a multi-user multi-beam satellite system employing precoding at the gateway side. Accordingly, the focus is on the forward link of a multi-beam satellite system when an aggressive frequency reuse is applied and the Super-Framing structure for DVB-S2X air interface (format specification 2 and 3) enables the use of precoding techniques. A MODCOD allocation based on SNIR estimations at each user terminal through the so-called P2 pre-coded pilots is described and results in terms of throughput are provided.

Session: MP2b – Signal Processing for Low-Resolution Sampling

Chair: ***Robert Heath,*** *University of Texas at Austin*

MP2b-1 3:30 PM

Spatial Coding Based on Minimum BER in 1-Bit Massive MIMO Systems

Hela Jedda, Technische Universität München, Germany; Amine Mezghani, University of California, Irvine, United States; Jawad Munir, Fabian Steiner, Josef A. Nossek, Technische Universität München, Germany

We consider a downlink 1-bit quantized massive MIMO system, where 1-bit digital-to-analog (DACs) and analog-to-digital converters (ADCs) are used at the transmitter and the receiver for economical and computational efficiency. The resulting system model can be depicted as a discrete memoryless channel with input and output vectors belonging to respective QPSK power sets. In the context of massive MIMO systems the input cardinality of the channel is very high. In this work we introduce a method to reduce the input set based on the mimimum bit-error-ratio (BER) criterion combined with a nonlinear precoding technique to improve the BER behavior.

MP2b-2 3:55 PM

Analysis of One-Bit Quantized ZF Precoding for Downlink Multiuser Massive MIMO

Amodh Kant Saxena, University of California, Irvine, United States; Inbar Fijalkow, ETIS / ENSEA - University Cergy-Pontoise - CNRS, France; Amine Mezghani, Lee Swindlehurst, University of California, Irvine, France

One-bit quantized precoding is proposed to simplify the RF front-end with a massive number of antennas. We analyze the asymptotic performance of the one-bit quantized Zero Forcing precoder for a downlink multiuser massive MIMO system. Using the Bussgang decomposition and some random matrix theory tools, we provide a closed-form expression of the symbol error rate and show that the loss due one-bit quantization is less than 2dB.

MP2b-3 4:20 PM

Quantized Channel Estimation and Data Detection in Massive MU-MIMO-OFDM Systems

Christoph Studer, Cornell University, Sweden; Giuseppe Durisi, Chalmers University, Sweden

Coarse quantization at the base station of a massive multi-user (MU) MIMO system promises significant power and cost savings. We investigate the effect of coarse quantization for wideband communication over frequency-selective channels using orthogonal frequency-division multiplexing (OFDM). We present a host of new channel estimation and data detection algorithms for quantized systems. Our algorithms show that massive MU-MIMO-OFDM enables one to achieve near-optimal error-rate performance with coarse quantization at no additional costs in terms of baseband processing complexity.

MP2b-4 4:45 PM

Channel Estimation in Mixed Hybrid-Low Resolution MIMO Architectures for Millimeter Wave Communication

Nuria Gonzalez-Prelcic, Universidade de Vigo, Spain; Cristian Rusu, University of Vigo, Spain; R Heath, University of Texas at Austin, United States

Mixed hybrid low resolution MIMO architectures reduce both the number of ADCs and their resolution to reduce power consumption. In such a system, the received signal suffers from two compression stages. One is due to the analog processing stage and the reduced number of RF chains, while the other is a result of signal quantization due the ADC converters, which further complicates the estimation of the MIMO channel. We propose a compressive channel estimator that exploits the sparse structure of the mmWave channel to compensate for the loss of information inherent to the proposed architecture.

Track A – Communications Systems

Session: MP3a – Communication and Coding for Distributed Computing

Chair: ***Salman Avestimehr,*** *University of Southern California*

MP3a-1 **1:30 PM**

Coded Distributed Computing: Fundamental Limits and Practical Challenges

Songze Li, Qian Yu, University of Southern California, United States; Mohammad-Ali Maddah-Ali, Bell Labs, Alcatel-Lucent, United States; Salman Avestimehr, University of Southern California, United States

We propose a framework for reducing the communication load of distributed computing via coding. In particular, we consider a general distributed computing framework, motivated by commonly used structures like MapReduce, where the overall computation is decomposed into two stages: "Map" and "Reduce". We propose a coded scheme, named "Coded Distributed Computing" (CDC), to demonstrate that increasing the computation load of the Map phase by a factor of r can create novel coding opportunities in the data shuffling phase that reduce the communication load by the same factor. We will then discuss the applications of this result to wireless distributed computing.

MP3a-2 **1:55 PM**

Trade-Offs Between Asynchrony, Concurrency and Storage Cost in Consistent Distributed Storage Systems.

Viveck Cadambe, Pennsylvania State University, United States

We review salient trade-offs in consistent distributed storage systems. The trade-offs are revealed through a fundamental connection between parameters of the recently proposed multi-version coding problem, and physical parameters of storage systems such as the number of parallel data reads and writes, and the degree of asynchrony in the network. We also describe methods that exploit correlated data updates to reduce storage costs.

MP3a-3 **2:20 PM**

Codes Can Speed Up Large-Scale Distributed Computing

Kangwook Lee, Maximilian Lam, Ramtin Pedarsani, Dimitris Papailiopoulos, Kannan Ramchandran, University of California, Berkeley, United States

Modern large-scale computing platforms face several types of randomness, uncertainty and system noise. These include stragglers, system failures, maintenance outages, and communication bottlenecks. In this paper, we will introduce two techniques that can speed up large-scale distributed computation, and guarantee high throughput of the processing system in the presence of unpredictability.

MP3a-4 **2:45 PM**

Avoiding Coordination in Parallel Machine Learning

Dimitris Papailiopoulos, University of California, Berkeley, United States

A common approach to scaling up machine learning is through coordination-free parallel algorithms, where individual processors run independently without much communication. Analyzing the performance of these algorithms can be challenging, as they often introduce race conditions and synchronization problems. We will introduce a general methodology for analyzing asynchronous parallel algorithms. The key idea is to model the effects of core asynchrony as noise in the algorithmic input. This allows us to understand the performance of several popular asynchronous machine learning approaches, and to determine when asynchrony effects might overwhelm them.

Track C – Networks

Session: MP3b – Distributed Optimization

Chair: ***Qing Ling,*** *University of Science and Technology China*

MP3b-1 **3:30 PM**

Distributed Proximal Gradient Methods for Constrained Consensus Optimization

Necdet Serhat Aybat, Erfan Yazdandoost, Pennsylvania State University, United States

We consider cooperative multi-agent consensus optimization problems over an undirected network of agents, where only those agents connected by an edge can directly communicate. The objective is to minimize the sum of agent-specific composite convex functions over agent-specific private conic constraint sets; hence, the optimal consensus decision should lie in the intersection of

these private conic sets. We provide convergence rates in suboptimality, infeasibility and consensus violation; examine the effect of underlying network topology on the convergence rates of the proposed decentralized algorithms; and discuss how to extend these methods to time-varying topology.

MP3b-2 **3:55 PM**

ESOM: Exact Second-Order Method for Consensus Optimization

Aryan Mokhtari, University of Pennsylvania, United States; Wei Shi, University of Illinois at Urbana-Champaign, United States; Qing Ling, University of Science and Technology of China, China

This paper considers decentralized consensus optimization problems where different summands of a global objective function are available at nodes of a network. The method of multipliers is well studied for centralized optimization; however, it is not applicable to decentralized optimization problems since the augmented Lagrangian is not decomposable. We propose ESOM as a decentralized primal-dual method that quadratically approximates the augmented Lagrangian in a way that the primal update is separable over nodes of the network. We show that the sequence of variables generated by ESOM converges linearly to the optimal argument, and verify this result via numerical experiments.

MP3b-3 **4:20 PM**

Distributed Nonconvex Multiagent Optimization over Time-Varying Networks

Ying Sun, Hong Kong University of Science and Technology, Hong Kong SAR of China; Gesualdo Scutari, Purdue University, United States; Daniel Palomar, Hong Kong University of Science and Technology, United States

We study nonconvex distributed optimization in multiagent networks with time-varying (nonsymmetric) connectivity. We introduce the first algorithmic framework for the distributed minimization of the sum of a smooth (possibly nonconvex and nonseparable) function - the agents' sum-utility - plus a convex (possibly nonsmooth and nonseparable) regularizer. The proposed method hinges on successive convex approximation techniques while leveraging push-sum-like broadcasting as a mechanism to distribute the computation among the agents.Convergence to stationary solutions is established. Numerical results show that our new algorithm outperforms current schemes on both convex and nonconvex problems.

MP3b-4 **4:45 PM**

Space-Time Scheduling for Green Data Center Networks

Tianyi Chen, University of Minnesota, United States; Antonio Marques, Rey Juan Carlos University, Spain; Georgios Giannakis, University of Minnesota, United States

With the rapid increase of data demands and global warming concerns, future data centers must be both energy efficient and sustainable. The present contribution puts forward a systematic approach to designing energy-aware traffic-efficient load balancing schemes for data-center networks that are not only optimal, but also computationally efficient and amenable to distributed implementation. Under a stochastic optimization framework, the approach relies on decomposition techniques to develop a two-timescale algorithm that optimizes jointly workload and power balancing schemes across the network. Both delay-tolerant and interactive workloads are accommodated, and novel smart-grid features are incorporated along with renewables and energy storage units.

Track D – Signal Processing and Adaptive Systems

Session: MP4a – Sparse Sampling for Data Analytics

Chair: ***Geert Leus,*** *Delft University of Technology*

MP4a-1 **1:30 PM**

Solving Inverse Source Problems for Linear PDEs using Sparse Sensor Measurements

John Murray-Bruce, Pier Luigi Dragotti, Imperial College London, United Kingdom

Numerous physical phenomena across many applications can be described by partial differential equations (PDEs). In all these applications, sensors collect sparse samples of the resulting phenomena with the aim of detecting its cause/source by analyzing the data collected. Herein we present a novel framework for solving this inverse source problem for linear PDEs by drawing from some recent results in modern sampling theory. Finally we then investigate the validity of our approach using numerical simulations.

MP4a-2 **1:55 PM**

Rethinking Sketching as Sampling: Linear Transforms of Graph Signals

Fernando Gama, University of Pennsylvania, United States; Antonio García Marques, King Juan Carlos University, Spain; Gonzalo Mateos, University of Rochester, United States; Alejandro Ribeiro, University of Pennsylvania, United States

Sampling of bandlimited graph signals is useful for dimensionality reduction and online processing of streaming network data. Most existing sampling methods are focused on reconstruction of the original signal. Oftentimes these signals serve as inputs to computationally-intensive linear transformations. Hence, the interest becomes to approximate the linear operator output efficiently. We propose a novel sampling scheme that leverages the input's bandlimitidness as well as the transformation we wish to approximate. We formulate a joint optimization of sample selection and a sketch of the target linear transformation, so it can be affordably applied to a sampled input and approximate the output.

MP4a-3 **2:20 PM**

Distributed Adaptive Learning of Signals Defined over Graphs

Paolo Di Lorenzo, Paolo Banelli, University of Perugia, Italy; Sergio Barbarossa, Stefania Sardellitti, Sapienza University of Rome, Italy

The aim of this paper is to propose distributed strategies for adaptive learning of signals defined over graphs. The proposed method enables distributed reconstruction and tracking from a limited number of noisy observations taken from a (possibly time-varying) subset of sampled vertices. A detailed mean square analysis is carried out, illustrating the role played by the sampling strategy on the performance of the proposed method. Finally, some useful strategies for the distributed selection of the sampling set are provided. Numerical results validate the theoretical findings, and illustrate the performance of the proposed method for distributed learning of graph signals.

MP4a-4 **2:45 PM**

Subsampling for Graph Signal Detection

Sundeep Prabhakar Chepuri, Geert Leus, Delft University of Technology, Netherlands

Detection theory for graph signals will be powerful for a range of applications within cyber security, traffic management, and network/data science applications in general. For example, it is powerful for detecting malicious activity (or high communication rates, unusual traffic flows between a subset of nodes), which has a different attribute as compared to the expected typical activity. The usual and unusual activities can be respectively regarded as the "noise-only" and "signal-plus-noise" cases. In the final paper, we will address the issue of optimally selecting a subset of nodes, i.e., optimally subsample graph signals, yet accurately distinguish between the two hypotheses.

Track D – Signal Processing and Adaptive Systems

Session: MP4b – High-dimensional Inference

Chair: ***Galen Reeves,*** *Duke University*

MP4b-1 **3:30 PM**

Dynamics of Stochasticl Gradient Method for Online Estimation

Chuang Wang, Yue Lu, Harvard University, United States

We present an exact analysis of the dynamics of several online stochastic gradient methods for high-dimensional estimation problems. In the large systems limit, we show that the dynamics of these algorithms converge to trajectories governed by a set of deterministic, coupled ODEs. This analysis establishes the theoretical performance guarantee of these efficient incremental methods for solving both convex and nonconvex estimation problems in high dimensions.

MP4b-2 **3:55 PM**

Fast and Robust Learning for Mixture of Sparse Linear Models Using Codes

Dong Yin, Ramtin Pedarsani, University of California, Berkeley, United States; Yudong Chen, Cornell University, United States; Kannan Ramchandran, University of California, Berkeley, United States

In this talk, we propose a fast and robust learning algorithm for the mixtures of sparse linear regressions. The design of queries and the learning algorithm use novel approaches based on sparse graph codes. The algorithm can provably achieve order optimal sample and computational complexities in the noiseless case. We also show that the algorithm is stable in the presence of noise.

MP4b-3 **4:20 PM**

A Conditional Central Limit Theorem for Random Projections

Galen Reeves, Duke University, United States

This paper addresses the question of when the conditional distribution of a randomly weighted sum of (non-independent) random variables is approximately Gaussian. This problem arrises in the analysis of high-dimensional data, where is it common to work with lower dimension summaries based on random linear projections. Our results provide bounds on the Kullback-Leibler divergence between between the (random) conditional distributions of these projections and a Gaussian approximation.

MP4b-4 **4:45 PM**

Tensor Decompositions and Sparse Log-Linear Models

James Johndrow, Stanford University, United States; Anirban Bhattacharya, Texas A&M University, United States; David Dunson, Duke University, United States

Contingency table analysis routinely relies on log-linear models, with latent structure analysis providing a common alternative. Latent structure models lead to a low rank tensor factorization of the probability mass function for multivariate categorical data, while log-linear models achieve dimensionality reduction through sparsity. Little is known about the relationship between these notions of dimensionality reduction in the two paradigms. We derive results relating the support of a log-linear model to the nonnegative rank of the associated probability tensor. Motivated by these findings, we propose a new collapsed Tucker class of tensor decompositions, which bridge existing PARAFAC and Tucker decompositions.

Track E – Array Signal Processing

Session: MP5a – Recent Advances in Nonstationary Signal Processing

Chair: ***Antonio Napolitano,*** *Universitá di Napoli*

MP5a-1 **1:30 PM**

Algorithms for Analysis of Signals with Time-Warped Cyclostationarity

Antonio Napolitano, University of Napoli, Italy; William Gardner, University of California, Davis, United States

Two approaches to the analysis of signals with imperfect wide-sense cyclostationarity or polycyclostationarity are presented. The first approach consists of directly estimating the time-warping function (or its inverse) in a manner that transforms the data with imperfect cyclicity into an empirically cyclostationary (CS) or poly-CS signal. The second approach consists of modeling the signal as a time-warped poly-CS stochastic process, thereby providing a wide-sense probabilistic characterization—a time-varying autocorrelation function—which is used to specify an estimator that is intended to remove the impact of time-warping. From this estimate, an estimate of the autocorrelation function of the time-warped process is also obtained.

MP5a-2 **1:55 PM**

The Sound of Silence: Recovering Signals from Time-Frequency Zeros

Patrick Flandrin, CNRS & ENS de Lyon, France

Disentangling multicomponent nonstationary signals into coherent AM-FM modes is usually achieved by identifying « loud » time-frequency trajectories where energy is locally maximum. We will present here an alternative perspective that is based on « silent » points, namely spectrogram zeros. The rationale and the implementation of the approach will be discussed, as well as an application to the characterization of actual gravitational wave chirps embedded in noise.

MP5a-3 **2:20 PM**

Nonstationary Signal Design for Coexisting Radar and Communications Systems

John Kota, Antonia Papandreou-Suppappola, Arizona State University, United States; Garry Jacyna, MITRE Corporation, United States

One possible approach to address spectrum congestion is to develop techniques for sharing available bandwidth between different systems. In this paper, we consider the problem of co-existence between radar and communications systems by designing a common signaling scheme to jointly optimize the performance of both systems. In particular, we derive constraints on the parameters of linear frequency-modulated signals to minimize the interference between the two systems as well as the interference between multiple communications users. We propose a multi-objective optimization for a pulse-Doppler radar system and a multi-user communications system, and analyze the trade-offs in performance under various system constraints.

MP5a-4 **2:45 PM**

Benefits of Noncircular Statistics for Nonstationary Signals

Scott Wisdom, Les Atlas, James Pitton, Greg Okopal, University of Washington, United States

For the nonstationary signals we model and analyze, we show how complementary statistics (as opposed to conventional Hermitian or circular phase-insensitive statistics) can provide useful information about a source. For example, the IEEE AASP Challenge on Detection and Classification of Acoustic Scenes and Events provides a baseline system which uses non-negative matrix factorization which, with a small modification in cost function, becomes tractable as a conventional circular Gaussian model. We contrast this circular model with a noncircular Gaussian model and show its theoretical potential for detection and classification and, on this data set, some potential performance advantages.

Track E – Array Signal Processing

Session: MP5b – Recent Advances in Covariance Matrix Estimation for Array Processing

Chair: ***Frederic Pascal,*** *Supelec*

MP5b-1 **3:30 PM**

Bounds for Estimating the Parameters of Low-Rank Compound-Gaussian Clutter and White Gaussian Noise

Olivier Besson, ISAE-Supaéro, France

We consider the problem of estimating the parameters of a mixture of low-rank compound-Gaussian clutter and white Gaussian noise. Using a minimal and unconstrained parametrization of the clutter covariance matrix, we derive lower bounds for estimation of its parameters. First, assuming the textures are deterministic, the Cram\'{e}r-Rao bound is derived, which enables one to assess the impact of the time-varying textures on the estimation performance. Then, considering the textures as random, hybrid bounds are considered. Furthermore, a lower bound for estimating the projector on the clutter subspace is presented. Numerical simulations enable to evaluate the impact of random, time-varying textures.

MP5b-2 **3:55 PM**

Robust Rank Constrained Kronecker Covariance Matrix Estimation

Arnaud Breloy, LEME, France; Ying Sun, Hong Kong University of Science and Technology, Hong Kong SAR of China; Guillaume Ginolhac, LISTIC, France; Daniel Palomar, Hong Kong University of Science and Technology, Hong Kong SAR of China

In this paper we consider the problem of structured covariance matrix robust estimation. Based on the Majorization-Minimization framework, we derive algorithms to compute robust estimators that satisfy a Kronecker product plus identity structure, which often arises in the context of radar processing (e.g. STAP or MIMO). Additionally, the proposed algorithms allow to enforce the rank of the matrices involved in the Kronecker product decomposition.

MP5b-3 **4:20 PM**

Quaternion Structured Non-Paranormal Distributions

Yonatan Woodbridge, Hebrew University of Jerusalem, Israel; Gal Elidan, Hebrew University of Jerusalem and Google Inc., Israel; Ami Wiesel, Hebrew University of Jerusalem, Israel

This paper presents a new class of multivariate distributions over quaternions. The class allows us to specify flexible non-Gaussian marginals with some correlation between variables, while assuming certain symmetry properties, namely properness. That is, we provide a framework for a rich set of multivariate distributions of proper quaternion random variables, of which the Gaussian is a special case. We consider the problem of non-parametric marginal estimation. Using real data, we compare our class to simpler models assuming Gaussianity or independence. By that, we demonstrate the advantage of our approach that exploits both marginal flexibility and existence of correlation.

MP5b-4 **4:45 PM**

New Properties for the Tyler's Covariance Matrix Estimator

Gordana Draskovic, Frederic Pascal, CentraleSupelec, France

Robust approaches received strong attention in signal and array processing communities. One of the reasons is the flexibility of such methods that can deal with many statistical models and provide several estimation outputs, robust to outliers. An important focus has been done on covariance matrices estimation that play a key role in detection and classification problems. They have

been widely studied and their statistical properties have been derived in different asymptotic regimes. Some insights, at finite distance, are of utmost interest since it allows predicting exact. This work presents the analysis of the Tyler's estimator in comparison to Wishart matrix.

Track H – Speech, Image and Video Processing

Session: MP6a – Emerging Models and Methods in Image and Video Processing

Chair: ***Balasubramaniam Santhanam,*** *University of New Mexico*

MP6a-1 1:30 PM

Sampled Efficient Full-Reference Image Quality Assessment Models

Christos Bampis, Todd Goodall, Alan Bovik, University of Texas at Austin, United States

Existing image quality assessment models compute a full image feature map followed by a pooling step, thereby producing a single quality score. We study alternate quality score spatial sampling strategies that can be used to efficiently compute a quality score. A random sampling scheme is developed for single scale full reference image quality assessment models. Then, a highly efficient grid sampling scheme is proposed, which replaces the ubiquitous convolution operations with local block-based operations. Experiments on four different databases show that this block-based sampling strategy can yield results similar to methods that use a complete image feature map.

MP6a-2 1:55 PM

Feature Extraction and Image Recognition from Superpixels on an Automata Architecture

Tiffany Ly, Rituparna Sarkar, Scott Acton, Kevin Skadron, University of Virginia, United States

An automata processor can execute pattern matching in parallel which brings potential to accelerate image recognition. We introduce a process to encode superpixel features within an automata framework. The objective is to represent subimage features as strings to be processed in the automata that are resilient to rotation, translation and scaling. First, superpixels are extracted via level set-based segmentation and a histogram of oriented gradients is calculated for each. The histograms are converted into strings and processed into regular expressions compatible with an automata processor. Results show robust recognition performance and dramatic improvement over general purpose or graphics processor efficiency.

MP6a-3 2:20 PM

Distributed Video Analysis for the Advancing Out of School Learning in Mathematics and Engineering Project

Cody Eilar, Venkatesh Jatla, Marios Pattichis, Carlos LopezLeiva, Sylvia Celedon-Pattichis, University of New Mexico, United States

We develop a distributed processing system for analyzing classroom videos to assess student learning while participating in the advancing out of school learning in mathematics and engineering (AOLME) project. We demonstrate our system in detecting writing and typing activities based on the Video Distributed Analysis (VIDA) system. VIDA uses a master node to optimally distribute video segments to specific devices (e.g., CPU, GPU) within each heterogeneous processing node. The results are then collected by the master node. We demonstrate the scalability and speedup of VIDA for analyzing videos with large image formats over different numbers of processing nodes.

MP6a-4 2:45 PM

Fingerprint Feature Extraction and Classification using Multirate Frequency Transformations and Wideband AM-FM Energy Demodulation

Wenjing Liu, Balu Santhanam, University of New Mexico, United States

In prior work, an AM-FM signal model coupled with dominant component analysis have been used for fingerprint extraction for eventual fingerprint recognition. In earlier work by the authors, multirate frequency transformations were employed to transform wideband signals into narrowband signals to effect wideband AM-FM demodulation of both 1D and 2D signals. In this paper, we apply the 2D, wideband AM--FM energy-based demodulation approach towards AM--FM feature extraction and recognition. Simulation results are used to demonstrate the efficacy of the proposed approach.

Session: MP6b – Speech Signal Processing and Health Applications

Chair: ***Visar Berisha,*** *Arizona State University*

MP6b-1 3:30 PM

Models for Objective Evaluation of Dysarthric Speech from Data Annotated by Multiple Listeners

Ming Tu, Yishan Jiao, Visar Berisha, Julie Liss, Arizona State University, United States

In subjective evaluation of dysarthric speech, the inter-rater agreement between clinicians can be low. Disagreement among clinicians comes from biases resulting from differences in their perceptual abilities, clinical experiences, etc. Traditionally, averaging across multiple annotators has been used to reduce this variability. In this paper, we propose a new method to solve this problem. We discard the assumption that the bias of one annotator is independent of the speaker and model the relationship between bias and difficulty of the annotation in a regression setting. We evaluate the model on a series of experiments on a dysarthric speech database.

MP6b-2 3:55 PM

Speech and Language Processing for Mental Health Research and Care

Daniel Bone, James Gibson, Theodora Chaspari, Dogan Can, Shrikanth Narayanan, University of Southern California, United States

Speech signal processing is being increasingly explored in health domains given both its centrality as a behavioral cue and the promise of robust, automated analysis of data at scale. In this talk, we discuss two health applications we have undertaken: addiction counseling and autism spectrum disorder. Methods range from deep supervised learning to knowledge-based signal processing of highly subjective constructs of psychological states and traits. A unique aspect of the research has been to model both health care provider and patient behaviors jointly in clinical encounters, wherein any individual behavior cannot be considered in isolation given the inherent mutual influence.

MP6b-3 4:20 PM

Characterization of the Relationship Between Semantic and Structural Language Features in Psychiatric Diagnosis

Natália Bezerra Mota, Federal University of Rio Grande do Norte, Brazil; Facundo Carrillo, Diego Fernandez Slezak, Universidad de Buenos Aires, Argentina; Mauro Copelli, Federal University of Pernambuco, Brazil; Sidarta Ribeiro, Federal University of Rio Grande do Norte, Brazil

Psychiatry describes speech symptoms that are indicative of disorganized thought, but measuring them is not easy. With the progress of natural language processing, it is possible to quantify specific psychiatric symptoms. Graph representations of word trajectories and semantic incoherence have independently been shown to predict Schizophrenia diagnosis. Both analyses assess thought organization through speech, but the relationship between them is unknown. We aim to characterize the relationship between structural and semantic analyses of free reports from patients with and without psychotic symptoms (N=40 psychotic patients and 20 controls). The results show that graph connectivity is inversely correlated with semantic incoherence.

MP6b-4 4:45 PM

Detecting Mild Cognitive Impairment (MCI) from Unstructured Spontaneous Speech

Meysam Asgari, Jeffrey Kaye, Hiroko Dodge, Oregon Health and Science University, United States

We performed linguistic analysis of unstructured spontaneous spoken words, derived from interview session, in order to classify 14 participants with MCI from 27 with intact cognition. From the transcription of interviewees' recordings, we grouped spoken words into 68 word categories using Linguistic Inquiry and Word Count (LIWC), a handcrafted table of words. Number of words grouped in each category of LIWC constructed a vector of 68 dimension representing linguistic features of each subject. We employed a support vector machine (SVM) classifier and a 5-fold cross validation scheme showed 82% classification accuracy well above the chance, 60%.

Session: MP7a – Advances in Neuronal Modeling

Chair: ***Behtash Babadi,*** *University of Maryland*

MP7a-1 1:30 PM

Tracking Epileptic Seizure Activity via Information Theoretic Graphs

Andrea Goldsmith, Jeremy Kim, Yonathan Morin, Stanford University, United States

This work studies estimation of directed information from finite-length time-series. Two approaches are considered: directly estimating the continuous functional via an improvement of the Kraskov-Stögbauer-Grassberger (KSG) estimator; and quantizing the continuous time-series and then estimating the discrete functional. It is shown that the KSG estimator is consistent, while the discrete estimator is consistent when the quantization bins are infinitely small. Simulations based on synthetic data indicate that the KSG estimator is more accurate, but with higher computational complexity. Finally, the two estimators are used to infer the causal influence between electrocorticography time-series recorded from human subjects during epileptic seizures.

MP7a-2 1:55 PM

A Neural Model of High-Acuity Vision in the Presence of Fixational Eye Movements

Alexander Anderson, Kavitha Ratnam, Austin Roorda, Bruno Olshausen, University of California, Berkeley, United States

Recent research suggests that involuntary eye movements during visual fixation enhance our ability to detect high spatial frequencies. But a crucial question remains: what is the biological mechanism that the brain uses to recover the image landing on our retina in the presence of fixational eye movements and imprecise neurons? We propose a computational model based on a Bayesian ideal observer that attempts to estimate the spatial pattern on the retina. From this emerges a neural model containing two populations of cells which we hypothesize to exist in primary visual cortex.

MP7a-3 2:20 PM

Towards Automating Sleep Scoring from Polysomnography Data

Kristin M. Gunnarsdottir, Sridevi V. Sarma, Johns Hopkins University, United States; Rachel M.E. Salas, Charlene E. Gamaldo, Johns Hopkins Medicine, United States

Sleeping disorders are a common problem, adversely affecting overall health. An important tool used to diagnose sleeping disorders is overnight polysomnography, which records various non-invasive physiological signals, including EEG. The data is scored in a laborious subjective process by specialists who assign a sleep stage to every 30 second epoch. This process is heavily dependent upon human factors resulting in poor inter-scorer reliability. Here, we develop a preliminary automatic scoring method using spectral features computed from a single EEG channel. We report an overall scoring accuracy of 81.90% for 5 subjects, showing promise in computational assistance to sleep scoring.

MP7a-4 2:45 PM

Probing the Functional Circuitry Underlying Auditory Attention via Dynamic Granger Causality Analysis

Alireza Sheikhattar, Sina Miran, Jonathan Fritz, Shihab Shamma, Behtash Babadi, University of Maryland, United States

We consider the problem of inferring functional dynamics among multiple cortical areas involved in auditory processing using simultaneous multi-unit recordings. Assuming sparse time-varying point process models for the underlying neurons, we perform adaptive system identification using sparse point process filters. We develop a filtering algorithm for estimating the Granger causality with high temporal resolution and recursively computed confidence intervals. We apply the proposed algorithm to multi-unit recordings from the ferret's primary auditory and prefrontal cortices under behavioral auditory tasks. Our analyses reveal the temporal details of the functional interaction between these cortical areas under attentive behavior at unprecedented spatiotemporal resolutions.

Session: MP7b – Advances in Neural Array Processing

Chair: ***Jun (Jason) Zhang,*** *University of Denver*

MP7b-1 **3:30 PM**

Analysis of Signals Recorded from Human Cerebral Cortex using Micro-Scale Electrode Arrays During Articulate Movements and Epileptiform Activity

Kevin O'Neill, Denise Oswalt, Arizona State University, United States; Kari Ashmont, David Adelson, Phoenix Children's Hospital, United States; Bradley Greger, Arizona State University, United States

Data was collected from epicortical micro-electrode arrays implanted in patients undergoing clinical monitoring for medically refractory epilepsy. Grids consisted of either 40um or 75um diameter electrodes with 1mm inter-electrode spacing. A patient implanted with arrays over primary language cortices enacted a repetitive spoken word task. Cortical activity during the task was used to decode each word and probe cortical network dynamics involved in simple language production. In other subjects, electrode arrays collected epileptiform data which were analyzed to determine onset of ictal activity.

MP7b-2 **3:55 PM**

Decoding Human Intent using a Wearable System and Multi-Modal Sensor Data

Md Muztoba, Cemil Geyik, Umit Y. Ogras, Daniel W. Bliss, Arizona State University, United States

Despite the phenomenal advances in the computational power and functionality of electronic systems, human-machine interaction has been largely limited to simple control panels, keyboard and mouse. Consequently, these systems either rely critically on close human guidance or operate almost independently. A life-changing experience can be achieved by transforming machines from passive tools to agents that can understand the human physiology and know what their user wants. Towards this end, this paper presents first a wearable system that can sense, process and transmit multi-modal physiological signals. Then, it introduces a novel methodology for processing multi-modal data to reliably decode human intent.

MP7b-3 **4:20 PM**

Suppression of Neurostimulation Artifacts and Adaptive Clustering of Parkinson's Patients Behavioral Tasks using EEG

Alexander Maurer, Arizona State University, United States; Sara Hanrahan, Joshua Nedrud, Adam Hebb, Colorado Neurological Institute, United States; Antonia Papandreou-Suppappola, Arizona State University, United States

Deep brain stimulation (DBS) implantation surgery is used to suppress the severe symptoms of patients with Parkinson's disease (PD). Electroencephalogram (EEG) measurements collected during DBS aid in monitoring the patients' behavioral tasks. We consider various methods to suppress DBS artifacts that can impede task processing and classification. These methods concentrate on specific frequency bands that DBS has been shown to affect. The DBS artifact suppressed EEG are then used in an adaptive learning clustering method to discriminate between PD behavioral tasks.

MP7b-4 **4:45 PM**

Causality Analysisin Parkinson's Disease Patients during Behavior Tasks

Abdulaziz Almalaq, Jun Zhang, University of Denver, United States; Sara Hanrahan, Adam Hebb, Joshua Nedrud, Colorado Neurological Institute, United States

The purpose of this paper is to investigate the interactions and causality of different parts of brain using EEG signals recorded during verbal fluency tasks. The behavior tasks include phonemic fluency, semantic fluency, category semantic fluency and reading fluency. Advanced signal processing techniques are used in order to determine the activated frequency bands in the Granger causality for verbal fluency tasks. The graph learning technique for channel strength is used to characterize the complex graph of Granger causality. The study reveals significant difference between PD subjects and healthy controls in terms of brain connectivity.

Session: MP8a1 – Beamforming and Array-based Estimation I 1:30 PM–3:10 PM

Chair: ***Rick Blum,*** *Lehigh University*

MP8a1-1
Multipath Mitigation Techniques for Nonlinear Adaptive Beamforming

Peter Vouras, Naval Research Laboratory, United States

Nonlinear adaptive processing using sparse arrays has received a fair amount of attention in the radar community recently. However, the practical difficulties of nonlinear adaptive beamforming have been neglected. This paper will describe the deleterious impact of multipath on the adapted output of a nested array and show that nulling performance is severely degraded. Insight into the multipath problem for nonlinear adaptive beamforming will be obtained by analyzing an optimal beamformer which suppresses multipath residue at the adapted output and by analyzing the effectiveness of spatial smoothing using the physical array elements.

MP8a1-2
Array Self Calibration using Multiple Data Sets

Benjamin Friedlander, University of California, Santa Cruz, United States

Super-resolution direction finding requires precise knowledge of the array manifold which is difficult to achieve and maintain in practice. A potential solution for this problem is self-calibration - using signals of opportunity to jointly estimate directions and calibration parameters. Existing techniques operate on data collected during a single time interval and require the number of active signals to be sufficiently large. This requirement can seldom be satisfied in practice. Here we extend self-calibration to operate across multiple time intervals containing different signals. This method works even if the number of signals per interval is very small.

MP8a1-3
Convex-Optimization based Geometric Beamforming for FD-MIMO Arrays

Stefan Schwarz, Technische Universität Wien, Austria; Tal Philosof, General Motors, Israel; Markus Rupp, Technische Universität Wien, Austria

With the persistent densification of cellular networks, especially in urban environments, three-dimensional beamforming utilizing full dimension MIMO antenna arrays becomes of interest for mobile communications, since it allows to mitigate the inter-cell interference. In this paper, we consider beamformer optimization with the goal of maximizing the signal power within a certain angular area of interest, while controlling the interference leakage caused outside this area. We relax this nonconvex optimization problem to a closely related convex problem and numerically evaluate the performance of this feasible solution.

MP8a1-4
Reduced-Complexity Direction-of-Arrival Estimation for Large-Aperture Antenna Arrays Employing Spatial Ambiguities

Chung-Cheng Ho, Scott C. Douglas, Southern Methodist University, United States

In spatially-aliased antenna arrays for direction-finding, ambiguities are typically resolved using additional hardware, i.e. sub-arrays. In this paper, we describe a simple and efficient technique for direction-of-arrival estimation on large-aperture arrays whose inter-element spacings cause ambiguities in the angles-of-arrival. Our method employs a limited-range angular MUSIC search from which the ambiguous directions are identified due to the array's structure. A limited set of time-domain correlations are then generated from the array element signals for each identified angle to produce a test statistic whose maximum identifies the true angle of arrival. Numerical evaluations show the viability of the method.

MP8a1-5
Constraint Pursuit Estimator for Covariance-Based Array Processing

Yassine Zniyed, L2S lab., France; Remy Boyer, University of Paris-Sud - L2S lab., France; Mohammed Nabil El Korso, University of Paris X - LEME, France; Sylvie Marcos, CNRS - L2S lab., France

A plethora of contributions have been addressed the problem of non-negative sparse (NNS) vector estimation for real-valued measurements. But, it is of great interest to estimate a NNS vector while the measurements are complex-valued. Interestingly, this problem has not been investigated. Ignoring this structure leads to a degraded estimation accuracy of the non-zero parameters

of interest even for a perfect estimation of the support set and even in the high Signal to Noise Ratio regime. In this work, a new scheme, called Constraint-OMP is proposed. To illustrate our contributions, covariance-based array processing in the spatial Compressed Sensing context is addressed.

MP8a1-6
On Spatial Security Outage Probability Derivation of Exposure Region Based Beamforming with Randomly Located Eavesdroppers

Yuanrui Zhang, Youngwook Ko, Roger Woods, Queen's University Belfast, United Kingdom; Alan Marshall, University of Liverpool, United Kingdom; Joe Cavallaro, Kaipeng Li, Rice University, United States

This paper presents the close-form expression of the spatial security outage probability, which is a novel performance metric that measures the security level of the legitimate transmission from the spatial aspect in the presence of Poisson Point Process distributed eavesdroppers. Beamforming is used to create the exposure region where any randomly located eavesdropper causes secrecy outage, based on which the general expression of the spatial security outage probability is derived. Based on the general expression, the close-form expression is obtained for the circular array, which reveals the impact of the array parameters on the security performance.

MP8a1-7
A User Cooperative Beamforming Approach to PAPR Reduction in MIMO-OFDM Uplink

Antti Arvola, Antti Tölli, University of Oulu, Finland; David Gesbert, EURECOM, France

We consider a scheme for PAPR reduction based on user cooperation in a single-cell multi-user MIMO-OFDM uplink system. The idea is to utilize collaborative beamforming and unused space-frequency resources to transmit dummy symbols on orthogonal streams to reduce per-antenna peak powers. The reduced PAPR enables the users to allocate more power to data transmission, resulting in a higher system sum-rate for a fixed peak transmit power. We formulate a convex PAPR minimization problem that reduces the PAPR of a given time domain transmit signal by exploiting subcarriers with no previous bit allocations.

Track C – Networks
Session: MP8a2 – Communication Networks 1:30 PM–3:10 PM

Chair: ***Chester Sungchung Park,*** *Konkuk University*

MP8a2-1
Partial Interference Cancellation in Ultra-Dense Cellular Networks: Performance Analysis and Optimization

Italo Atzeni, Marios Kountouris, Huawei Technologies, France

The employment of partial zero-forcing (PZF) receiver at the base stations represents an efficient, low-complexity technique for uplink interference management in cellular networks. In this summary, we present our preliminary analysis of the performance of ultra-dense networks (UDNs) with PZF receivers. More specifically, we provide both integral expressions and tight closed-form approximations for the probability of successful transmission. Future research will explore optimizing the number of cancelled interferers and finding the optimal tradeoff between array gain and interference cancellation. We believe that our results and further advances would provide valuable insights into the behavior of interference cancellation in UDNs.

MP8a2-2
Leader Selection in Cooperative Network Based on MDL Subspace Algorithm for Cognitive Radio

Sander Ulp, Tõnu Trump, Tallinn University of Technology, Estonia

This paper presents a simple and robust algorithm for determining a leader node in a cooperative network based on MDL (Minimum Description Length) subspace algorithm. The algorithm aims to improve the performance of the cooperating network in a spectrum sensing problem for cognitive radio. The outline of the communication and selection process is described and the SNR (signal to noise radio) estimation algorithm is given. Simulation results show that the algorithm outperforms the non-cooperating network and a cooperating diffusion network with uniform combination weights.

MP8a2-3
Optimal De-Anonymization in Random Graphs with Community Structure
Efe Onaran, Siddharth Garg, Elza Erkip, New York University, United States

Anonymized social network graphs published for academic or advertisement purposes are subject to de-anonymization attacks by leveraging side information in the form of a second, public social network graph correlated with the anonymized graph where the two are from the same underlying graph of true social relationships. In this paper, we (i) characterize the maximum a posteriori (MAP) estimates of user identities for the anonymized graph and (ii) provide sufficient conditions for successful de-anonymization for underlying graphs with community structure. Our results generalize prior work that assumed Erdos-Renyi graphs, in addition to proving the optimality of the attack strategy adopted.

MP8a2-4
Joint Optimization of Communication Scheduling and Online Power Allocation in Remote Estimation
Xiaobin Gao, Emrah Akyol, Tamer Basar, University of Illinois, Urbana-Champaign, United States

This paper studies a specific sequential decision making problem: joint optimization of power and communication decisions of a remote estimation problem over an additive noise channel. Under some technical assumptions, we obtain team optimal decision policies including threshold-based communication scheduling policies together with piecewise affine encoding and decoding policies. We demonstrate the effectiveness of our joint optimization approach via numerical computations.

MP8a2-5
Layered Caching for Heterogeneous Storage
Avik Sengupta, Virginia Tech, United States; Ravi Tandon, University of Arizona, United States; T. Charles Clancy, Virginia Tech, United States

In modern wireless networks, caching alleviates severe capacity crunch at times of high network load. In this work, we present a novel caching scheme for the case when users have heterogeneous cache sizes. The proposed scheme uses two new ingredients - cache layering and set partitioning. The main challenge in designing caching schemes in presence of heterogeneity is that varying levels of storage presents a variety of storage/multicasting opportunities. Our framework is a principled approach to utilize such opportunities, where each layer delivers a fraction of requested data to a specific set of users and layers operate independently of each other.

MP8a2-6
Energy-Efficient Random Sleep Protocol based on Distributed Coding for Sensor-to-Vehicle Communications
Yuki Goto, Shun Ogata, Koji Ishibashi, University of Electro-Communications, Japan

In this paper, we propose a random sleep protocol based on distributed coding (RSDC) to realize energy efficient sensor-to-vehicle communications. In the proposed protocol, every sensors independently decide to either sleep or transmit with a given sleep probability. The sleep of sensors can be considered as erasures; packets are erased with the sleep probability. We, hence, introduce Luby-transform (LT) codes to efficiently decode erased packets. Also, we compare our proposed protocol with the conventional protocol, and numerical results show that our proposed scheme achieves even higher energy efficiency than the conventional one.

MP8a2-7
Long-Term Power Allocation for Multi-Channel Device-to-Device Communication Based on Limited Feedback Information
Ruhallah AliHemmati, Ben Liang, University of Toronto, Canada; Min Dong, University of Ontario Institute of Technology, Canada; Gary Boudreau, S. Hossein Seyedmehdi, Ericsson Canada, Canada

In this work, we present stochastic optimization solutions to allocate the D2D transmission power over multiple resource blocks (RBs), to maximize the D2D rate, under a sum-power constraint and long-term individual power constraints over each RB at the D2D transmitter which gives probabilistic guarantees on the interference to regular cellular users. We solve the formulated stochastic optimization problem optimally in the Lagrange dual domain with stochastic subgradient updating. We propose a distributed algorithm where each interference-victim cellular user calculates the subgradient and reports it with only limited feedback.

MP8a2-8
Decentralized Coded Caching with Distinct Cache Capacities
Mohammad Mohammadi Amiri, Qianqian Yang, Deniz Gunduz, Imperial College London, United Kingdom

Decentralized coded caching is studied for a server holding N files, each of size F bits, serving K users, each equipped with a cache of distinct capacity. It is assumed that the users' caches are filled in advance during the off-peak hours without the knowledge of the number of users, their identities, or the particular demands. User demands are revealed during the peak hours, and are served simultaneously through an error-free shared link. A decentralized coded caching scheme is proposed, and it is shown to improve upon the state-of-the-art in terms of the delivery rate over the shared link.

Track A – Communications Systems
Session: MP8a3 – Estimation and Learning Theory for Communications 1:30 PM–3:10 PM
Chair: ***Mario Huemer,*** *Johannes Kepler Universität Linz*

MP8a3-1
On the Log-Likelihood Ratio Evaluation of CWCU Linear and Widely Linear MMSE Data Estimators
Oliver Lang, Mario Huemer, Johannes Kepler University, Austria; Christian Hofbauer, Linz Center of Mechatronics GmbH, Austria

For soft decoding, log-likelihood ratios (LLRs) are calculated from estimated data symbols. Data symbols from proper constellation diagrams such as QPSK are often estimated using the linear minimum mean square error (LMMSE) estimator. We prove that the recently introduced component-wise conditionally unbiased (CWCU) LMMSE estimator results in the very same LLRs as the LMMSE estimator for typical model assumptions. For improper constellation diagrams such as 8-QAM, we show that the widely linear versions of the LMMSE and the CWCU LMMSE estimator also yield identical LLRs. In that case, the CWCU estimator allows to reduce the complexity of the LLR determination.

MP8a3-2
Improved SNR-based Estimation of the Attainable Net-Data-Rates in Vectoring VDSL2
Driton Statovci, Martin Wolkerstorfer, Sanda Drakulic, Technische Universität Wien, Austria

Network operators use the reported attainable net-data- rate (AttNDR) of vectored Very-high-speed Digital Subscriber Line 2 (VDSL2) system to qualify an upgrade of customer to higher service rates. Unfortunately, the reported AttNDR is only calculated based on reported signal-to-noise ratio (SNR) values on used tones. We show that the use of reported AttNDR may lead to pessimistic qualification and instead propose a novel, easily calculable metric for line qualification. Its superior performance is confirmed based on data from field and laboratory environments, which show an improvement of up to 75% in AttNDR.

MP8a3-3
Effects of Channel Environment on Timing Advance for Mobile Device Positioning in Long-Term Evolution Networks
Allison Hunt, Alex DeGabriele, John Roth, Justin A. Blanco, T. Owens Walker III, Jeremy Martin, United States Naval Academy, United States

This paper explores the feasibility of using the timing advance parameter in the LTE protocol to assist in mobile user positioning. The timing advance (TA) corresponds to the time it takes a signal to travel from the user to the base station. It is issued by the base station to the user to ensure the uplink signal from the user arrives at the base station at the correct time to avoid intersymbol interference. This paper specifically presents the effect of both line-of-sight and non-line-of-sight environments on the TA-distance relationship to assess the feasibility of a novel TA-based positioning system.

MP8a3-4
Benchmarking of Learning Architectures for Digital Predistortion
Thomas Magesacher, Lund University, Sweden; Peter Singerl, Infineon Technologies AG, Austria

Digital pre-distortion (DPD) is a key element of any medium- to high-power wireless communication transmitter. Indirect and direct learning architectures are the two main parameter-identification approaches for DPD systems. Their advantages and drawbacks have been much debated, unfortunately mostly focusing on singular aspects and based on simulation results.

We present a comprehensive benchmark by both reviewing available theoretical results and fairly comparing linearization performance based on measurement results of a high-power Doherty amplifier using a real-time FPGA-based DPD platform with 312MHz instantaneous bandwidth.

MP8a3-5
Supervised Machine Learning for Signals Having RRC Shaped Pulses
Mohammad Bari, George Washington University, United States; Hussain Taher, University of Engineering & Technology Peshawar, Pakistan; Syed Saad Sherazi, University of Engineering & Technology Bannu, Pakistan; Milos Doroslovacki, George Washington University, United States

Simple and robust features are used to distinguish continuous-phase FSK from QAM-PSK signals. Signals having root raised cosine shaped pulses are simulated to be in extreme noisy conditions having joint impurities of Doppler effect, noise power offset, block and correlated fast fading, lack of symbol and sampling synchronization, carrier offset, and additive white Gaussian noise. The features are based on sample mean and sample variance of the imaginary part of the product of two consecutive complex signal values. Supervised machine learning techniques such as SVM, neural networks, logistic regression, kNN and boosted decision trees are employed for recognition purposes.

MP8a3-6
Nonstationary Jammers Suppression Based on Parametric Sparse Reconstruction
Ben Wang, Harbin Engineering University, China; Yimin Zhang, Temple University, United States; Wei Wang, Harbin Engineering University, China

We propose a nonstationary jammer signal suppression technique based on parametric sparse reconstruction algorithm, where sparsely sampled data are considered. By assuming nonstationary jammers that are characterized by polynomial phase signatures, a data-dependent parametric dictionary matrix is designed. In order to obtain an accurate instantaneous frequency estimation at a low computational complexity, we exploit an iterative multi-round sparse reconstruction scheme in which the dictionary matrix is updated with a finer grid size, thus leading to dictionary entries closer to the true jammer signatures. Simulation results are provided to verify the effectiveness of the proposed technique.

MP8a3-7
Radio Transformer Networks: Attention Models for Learning to Synchronize in Wireless Systems
Timothy J O'Shea, Latha Pemula, Dhruv Batra, T. Charles Clancy, Virginia Tech, United States

We introduce learned attention models into the radio machine learning domain for modulation recognition by leveraging spatial transformer networks and introducing new radio domain appropriate transformations. This attention model allows the network to learn a localization network capable of synchronizing and normalizing a radio signal blindly without knowledge of the signal's structure based on optimization for classification accuracy. Using this architecture we outperform prior results in accuracy vs signal to noise ratio against an identical system and dataset without attention, however we believe such attention models have implications far beyond the task of modulation recognition in the radio domain.

Track D – Signal Processing and Adaptive Systems
Session: MP8a4 – Model Selection, Source Separation and Classification 1:30 PM–3:10 PM
Chair: ***Peter Schreier,*** *Universität Paderborn*

MP8a4-1
Cross-Validation Techniques for Determining the Number of Correlated Components Between Two Data Sets When the Number of Samples Is Very Small
Christian Lameiro, Peter J. Schreier, Universität Paderborn, Germany

We consider the estimation of the number of components that are correlated between two sets of high-dimensional data. In many applications the number of available samples is very small and conventional techniques do not accurately determine the model order. Recent approaches are based on a combined PCA-CCA (principal component analysis and canonical correlation analysis, respectively) setup, for which they jointly determine the required model order for the PCA and CCA steps through information-theoretic criteria and sequence of hypothesis tests. As an alternative, we propose a cross-validation approach to directly determine the number of correlated components for small sample support.

MP8a4-2
Model Selection for High-Dimensional Data
Arash Owrang, Magnus Jansson, KTH Royal Institute of Technology, Sweden

In the presented study, we investigate the task of model selection for high-dimensional data. To accomplish this, we propose an extension to the Bayesian information criterion. Our information criterion is asymptotically consistent either as the number of measurements grows to infinity or as the standard deviation of the noise decreases to zero. The numerical results provided support our claim. Additionally, we highlight the link between model selection for high-dimensional data and the choice of hyper-parameter in ℓ_1-constraint estimators, specifically the LASSO.

MP8a4-3
Bootstrap-Based Detection of the Number of Signals Correlated Across Multiple Data Sets
Tanuj Hasija, Universität Paderborn, Germany; Yang Song, Nanyang Technological University, Singapore; Peter Schreier, Universität Paderborn, Germany; David Ramírez, University Carlos III of Madrid, Spain

In this work, a hypothesis-testing scheme using the bootstrap is presented for determining the number of signals common or correlated across multiple data sets. Handling multiple data sets is challenging due to the different possible correlation structures. For two data sets, the signals are either correlated or independent between the data sets. For multiple data sets, however, there are numerous combinations how the signals can be correlated. Prior studies dealing with multiple data sets all assume a particular correlation structure. In this paper, we present a technique based on the bootstrap that works for arbitrary correlation structure.

MP8a4-4
Demixing Sparse Signals from Nonlinear Observations
Mohammadreza Soltani, Chinmay Hegde, Iowa State University, United States

Signal demixing is of special importance in several applications ranging from astronomy to computer vision. The goal in demixing is to recover a set of signals from their linear superposition. In this paper, we study the more challenging scenario where only a limited number of nonlinear measurements of the signal superposition are available. Our contribution is a simple, fast algorithm that recovers the component signals from the nonlinear measurements. We support our algorithm with a rigorous theoretical analysis, and provide upper bounds on the estimation error plus the sample complexity of demixing the components with a range of simulation results.

MP8a4-5
Dictionary Driven Vehicle Classification
Jeff Druce, Stefano Gonella, Jarvis Haupt, University of Minnesota, United States

This work introduces a method for the classification of vehicles through the analysis of their vibrational response. Our classification strategy hinges on the learning of representative dictionaries equipped with the ability to parsimoniously describe the bulk structure of the data for their respective class. A test signal can then be projected onto the space spanned by each dictionary, thus allowing a nearest subspace methodology to perform the classification. The vehicle's vibrational response is efficiently encoded via its power spectral density function (PSD). The space of PSDs forms a conical manifold with a naturally embedded notion of distance.

MP8a4-6
Obfuscating Poisson & Gaussian Data Using a Rotation in the Complex Plane
Ruaridh Macdonald, Muriel Medard, Massachusetts Institute of Technology, United States

A novel method of data masking is presented which allows Poisson and some Gaussian datasets to be altered without changing the overall probability density function. The method consists of multiplying each entry by a random complex exponential function, i.e. a rotation in the complex plane, and exchanging imaginary components between entries. The transformation preserves the properties of the entire dataset, including all forms of entropy, while reducing correlations between the data entries of individual members. The transformation may be repeated to control the remaining strength of the individual correlations while always retaining the bulk data set properties.

MP8a4-7
Multiscale Tensor Decomposition
Alp Ozdemir, Mark A. Iwen, Selin Aviyente, Michigan State University, United States

Large datasets usually contain redundant information and summarizing these datasets is important for better data interpretation. Higher-order data reduction is usually achieved through low-rank tensor approximation which assumes that the data lies near a linear subspace across each mode. However, nonlinearities in the data cannot be captured well by linear methods. In this paper, we propose a multiscale tensor decomposition to better approximate local nonlinearities in tensors. The proposed approach constructs hierarchical low-rank structure by dividing the tensor into subtensors sequentially and fitting a low-rank model to each subtensor.

Track E – Array Signal Processing
Session: MP8b1 – Beamforming and Array-based Estimation II 3:30 PM–5:10 PM
Chair: ***Benjamin Friedlander,*** *Jack Baskin School of Engineering*

MP8b1-1
The Advanced TOA Trilateration Algorithms with Performance Analysis
Sajina Pradhan, Seokjoo Shin, Goo-Rak Kwon, Jae-young Pyun, Suk-seung Hwang, Chosun University, Nepal

The TOA trilateration determines the MS location at a single intersecting point of three circles based on distances between MS and BSs, but three estimated circles may not generally meet at a single point. In this paper, we present the advanced TOA trilateration algorithms for solving this problem, such as the line intersection algorithm and the comparison approach of intersection distances. In addition, we analytically prove that the comparison approach of intersection distances has better performance than that of the line intersection algorithm, in the specific case where a small circle is located in the area of two large circles.

MP8b1-2
Design and Implementation of a Three-layer Cognitive Radar Architecture
Stefan Brueggenwirth, Fraunhofer FHR, Germany

In the paper we describe a novel concept for an integrated cognitive radar architecture developed at Fraunhofer FHR that is based on the Rasmussen model of human performance and incorporates ideas from three-layer robotic control architectures. We give simulative and experimental examples for cognitive radar behavior generated on each of the three abstraction layers.

MP8b1-3
Real-Time Underdetermined Source Separation for Low-Latency Speech Enhancement
Ryan Corey, Andrew Singer, University of Illinois at Urbana-Champaign, United States

Modern source separation algorithms can significantly improve speech intelligibility in noisy environments, but are unsuitable for latency-critical applications, such as digital hearing aids. We propose a hybrid architecture that combines high-latency source localization with low-latency beamforming. Because speech is nonstationary and sparse in the time-frequency domain, we use a different beamformer in each time-frequency bin. Estimated mixing parameters are used to design a set of frequency-domain beamformers, each of which suppresses one interfering source, and a classifier switches between them. Given an accurate estimate of the mixing parameters, the nonstationary beamformer can outperform conventional beamformers for underdetermined speech separation.

MP8b1-4
On the Resolution of Diversely Polarized Arrays
Benjamin Friedlander, University of California, Santa Cruz, United States

A self-calibration algorithm is presented for direction finding in the presence of unknown complex sensor gains for diversely polarized arrays. The method jointly estimates the directions of arrival and polarizations of all the sources as well as the unknown gains. Existing self-calibration techniques are ineffective in the presence of large calibration errors which cause loss of resolution. The method presented here is does not require initial direction estimates and has better convergence properties in the presence of large calibration errors than previously reported algorithms.

MP8b1-5
Super-resolution Direction-of-Arrival Estimation Using a Coprime Sensor Array With the Min Processor
Yang Liu, John R. Buck, University of Massachusetts Dartmouth, United States

This paper proposes a super-resolution direction-of-arrival (DOA) estimator using coprime sensor arrays (CSAs) with the min processor. The min processor resolves the aliased CSA subarrays while achieving lower sidelobes than the product processor and maintaining a positive semi-definite spatial power spectral density (PSD) estimation. The spatial correlation function implied by the CSAmin PSD populates a Hermitian Toeplitz augmented covariance matrix, which MUSIC processes to estimate source DOAs. The proposed approach outperforms the previously proposed coprime MUSIC DOA estimation from spatial smoothing of pairwise sensor correlation estimates in low SNR scenarios with limited numbers of snapshots.

MP8b1-6
Dynamic Formulation of Co-prime Array for DOA Estimation
Xiaomeng Wang, Xin Wang, Stony Brook University, United States

Among various sparse-array techniques, co-prime array is found to be more attractive because of its higher DoF with a smaller number of sensing elements. However, it requires physically non-uniform linear structure, which would require the availability of co-prime hardware. It is also costly to implement different arrays for varying detection scenarios. Instead, we propose to exploit the current ULA to dynamically formulate a co-prime array infrastructure based on the sensing scenarios and quality. Our proposed scheme can keep the sensing performance the same while taking advantage of the properties of co-prime array to significantly reduce the energy and cost.

MP8b1-7
Alternating Optimization Low-Rank Expansion Algorithm to Estimate a Linear Combination of Separable Filters to Approximate 2D Filter Banks
Paul Rodriguez, Pontifical Catholic University of Peru, Peru

Learn 2D filter banks are currently being used in high-impact applications such convolutional neural networks, convolutional sparse representations, etc. However such filter banks usually have plentiful filters, each being non-separable, accounting for a large portion of the overall computational cost. In this paper we propose a novel and computationally appealing alternating optimization based algorithm to estimate a linear combination of separable (rank-1) filters to approximate 2D filter banks. Our computational results show that the proposed method can be faster than (state-of-the-art) tensor Canonical Polyadic decomposition (CPD) method to obtain an approximation of comparable accuracy.

Track A – Communications Systems
Session: MP8b2 – Communication Theory **3:30 PM–5:10 PM**
Chair: ***James A. Ritcey,*** *University of Washington*

MP8b2-1
Fundamental BER Performance Trade-off in Cooperative Cognitive Radio Systems with Random Number of Secondary Users
Ruochen Zeng, Cihan Tepedelenlioglu, Arizona State University, United States

A cooperative underlay cognitive radio system with an instantaneous interference constraint at the primary receiver is considered. Secondary users (SU) whose interference above this threshold will relay primary user's (PU) signal, and the rest will fulfill their own underlay transmissions. Hence the numbers of relay and underlay SUs are random at a time instant. As the mean number of relay SUs increases, the PU's performance will be improved which causes degradation of underlay SUs' performance concurrently. We will quantify this fundamental performance trade-off by deriving the optimal ratio between the mean number of relay and underlay SUs in closed form.

MP8b2-2
Performance of OFDM Systems with Adaptive DFT-Precoding
Yusaku Yamashita, Hideki Ochiai, Yokohama National University, Japan

In this work, we propose an adaptive use of DFT-precoding for OFDM where the DFT operation is applied only when the generated OFDM symbol has large dynamic range and thus causes severe nonlinear in-band distortion after clipping and filtering. It is shown that a good trade-off in terms of bit error rate performance can be achieved while maintaining the amount of out-of-band radiation lower than the specified level.

MP8b2-3
Physical Layer Security Analysis for Cooperative Communications with Full-Duplex Relaying under Nakagami-m Fading Model
Yohannes Jote Tolossa, Abreu Giuseppe, Jacobs University Bremen, Germany

We characterized the physical layer security analysis of cooperative network with full-duplex (FD) relaying under Nakagami-m fading channel. Eavesdropper that tends to wiretap the transmission from the source and relay is assumed to coexist within the system. The closed form expression for the secrecy outage probabilities of the relevant communication links that constitutes the overall expression are derived analytically. For comparison the outage probability with half-duplex (HD) relay is also derived. It can be generalized from the results that cooperative communication with FD relaying has less secrecy outage even with the presence of residual self-interference as compared to HD relay.

MP8b2-4
On Zero-Forcing Equalization for Short-Filtered Multicarrier Faster-than-Nyquist Signaling
Albert Abelló, Damien Roque, ISAE-Supaéro, France; Cyrille Siclet, Alexandre Marquet, GIPSA-lab, France

Within the context of faster-than-Nyquist transmission, a low-complexity multicarrier transceiver based on short-length filters and zero-forcing turbo equalization is introduced. The short filters assumption allows reduced-size block processing and zero-forcing equalization yielding a reduced complexity implementation. Furthermore, tight frames pulse shaping allows competitive performance results over an additive white Gaussian noise channel while keeping a lower computational cost than other faster-than-Nyquist systems.

MP8b2-5
Secret Communication on Z-Channel with Cooperative Receivers
Abdallah M.Fayed, Tamer Khattab, Qatar University, Qatar; Lifeng Lai, Worcester Polytechnic Institute, United States

The discrete memoryless Z-channel with a confidential message and one-sided noiseless cooperation link is considered. Three messages are transmitted; encoder 1 sends a message to be decoded by decoder 1. Encoder 2 sends two messages, one of them is intended for getting decoded by decoder 1(a cross-message). The second message is to be decoded by decoder 2 and to be kept secret from decoder 1. The secrecy level is measured by the equivocation rate. A one-sided noiseless cooperation link between the two decoders conveys information about the cross-message to decoder 1, without violating the secrecy of the confidential message.

MP8b2-6
Joint Precoding and Transmit Antenna Selection for Spatial Modulation
Michael Carosino, James Ritcey, University of Washington, United States

Spatial Modulation is a recent wireless transmission scheme wherein bits are transmitted via not only the over-the-air symbols but as well as via the antenna index on which the symbol is sent. Channel information at the receiver is assumed to allow for joint decoding of the symbol and antenna index. In order to further improve the performance and provide transmit diversity, work in this area has focused on transmit antenna selection and precoding. We investigate some of these individual techniques and show that a joint optimization further improves the system performance.

Track G – Architecture and Implementation
Session: MP8b3 – Implementations of DSP Kernels 3:30 PM–5:10 PM
Chair: ***Alexios Balatsoukas-Stimming,*** *EPFL*

MP8b3-1
Hardware Architecture for Positive Definite Matrix Inversion Based on LDL Decomposition and Back-Substitution
Carl Ingemarsson, Oscar Gustafsson, Linköping University, Sweden

In this paper we propose an efficient hardware architecture for computation of matrix inversion of positive definite matrices. The architecture combines a high throughput with an efficient utilization of its hardware units. We also report FPGA implementation results that show that the architecture is well tailored for implementation in real-time applications.

MP8b3-2
A Scalable Architecture for Massive MIMO Base Stations Using Distributed Processing
Erik Bertilsson, Oscar Gustafsson, Erik G. Larsson, Linköping University, Sweden

Massive MIMO-systems have received considerable attention in recent years. As the idea is based on having a large number of antennas at the base station it is important to have both a scalable and distributed realization of such a system to ease deployment. In this work, we propose a base station architecture based on connecting the processing nodes in a K-ary tree, allowing simple scalability. Furthermore, it is shown that most of the processing can be performed locally in each node and that each node contains one or two complex multipliers operating at some hundred MHz.

MP8b3-3
Interpolated FIR Based Practically Perfect Reconstruction Filter Bank
Jorge Cadena, A.A. (Louis) Beex, Virginia Tech, United States

A new filter bank structure or channelizer is developed, named the IFIR-FB, as it is the result of combining the concepts of interpolated FIR filters (IFIR) and filter banks (FB). The filter design procedures for the IFIR-FB are developed and explained. The resulting IFIR-FB structure is shown to be competitive with the state-of-the-art non-maximally-decimated filter bank [1], in terms of the number of multiplications required per input sample and overall distortion introduced by the system when operating with Nyquist prototype filters.

MP8b3-4
Design of a Multi-Core Hardware Architecture for Consensus-based MIMO Detection Algorithms
Konstantin Tscherkaschin, Benjamin Knoop, Jochen Rust, Steffen Paul, University of Bremen, Germany

Consensus-based algorithms are one approach to establish Cooperative Communication Systems. In this work, this approach has been utilized to present a hardware architecture for distributed data detection as an example in a receiver with several sensor nodes on an easily scalable regular network. Additionally, it is capable to detect the transmitted message even when a single sensor node fails to operate. On top of that, the processing is executed on vector-based Application Specific Instruction Set Processors (ASIP) as processing cores. This makes is very flexible for reconfiguration of the network and reprogramming of the algorithm, though being highly performant.

MP8b3-5
Dynamically-Loaded Hardware Libraries (HLL) Technology for Audio Applications
Andrea Lomuscio, Angelo Esposito, Gian Carlo Cardarilli, Leonardo Di Carlo, University of Rome Tor Vergata, Italy; Alberto Nannarelli, Technical University of Denmark, Denmark; Marco Re, University of Rome Tor Vergata, Italy

Hardware acceleration is a viable solution to obtain energy efficiency for computers, such as those used in data centers. In this work, we apply hardware acceleration to embedded systems running audio applications. We present a new framework, Dynamically-Loaded Hardware Libraries or HLL, to dynamically load hardware libraries on reconfigurable platforms (FPGAs). Provided a library of application-specific processors, we load on-the-fly the specific processor in the FPGA, and we transfer the execution from the CPU to the FPGA-based accelerator. The proposed architecture provides excellent flexibility with respect to the different audio applications implemented, high quality audio, and an energy efficient solution.

Track A – Communications Systems
Session: TA1b – Biological Communications
Co-Chairs: ***Ubli Mitra,*** *University of Southern California* ***and Nicolo Michelusi,*** *Purdue University*

TA1b-1 10:15 AM
Model and Analysis of Population Density Estimation via Quorum Sensing
Nicolo Michelusi, Purdue University, United States; Urbashi Mitra, University of Southern California, United States

Microbial communities regulate various collective functions using molecular signaling circuits known as quorum sensing. Understanding and modeling of quorum sensing regulation is essential to designing nano-networks and enable communication and coordination among nano-machines, inspired by the biological world. We develop a model of quorum sensing, and we provide some analytical results on the accuracy achieved by quorum sensing to estimate the population density.

TA1b-2 **10:40 AM**

A Fundamental Approach to Communication using Individual Molecules

Christopher Rose, Brown University, United States

Using individual molecule release/capture timing/payload as a signaling methodology holds promise as an extremely low power communication scheme with theoretical efficiencies on the order of attojoules per bit. A molecular timing/payload approach encompass more blunt methods based on signaling agent concentration and can be used to bound molecular channel capacity.

TA1b-3 **11:05 AM**

Multicellular Information Relays

Ilya Nemenman, Emory University, United States; Andrew Mugler, Purdue University, United States; Andre Levchenko, Yale University, United States; Tyler Smith, Emory University, United States; Sean Fancher, Purdue University, United States

Recent experiments have shown that cells in a multicellular organ (specifically, in a developing mammary duct) sense external sensory cues and change direction of their motion collectively. A key component of this collective sensing phenomenon is an information relay that allows cells on different sides of the organ to communicate their locally sensed concentration to each other. I will present results of our analysis of channel capacity of such relays, show experimental demonstration of their existence, and argue that shape of the growing mammary duct is governed by the need to accurately sense and communicate the sensory information.

Track B – MIMO Communications and Signal Processing

Session: TA2b – Recent Advances in Massive MIMO

Chair: ***Erik G. Larsson,*** *Linkoping University*

TA2b-1 **10:15 AM**

Dual-regularized Precoding: A Robust Approach for D2D-Enabled Massive MIMO

Junting Chen, Haifan Yin, Laura Cottatellucci, David Gesbert, EURECOM, France

Channel state information (CSI) feedback is one of the most challenging problems in massive MIMO systems under FDD mode. A precoder feedback scheme for feedback reduction was proposed in the literature by exploiting the device-to-device (D2D) communication for perfect CSI sharing among users. However, it is not known what to feedback when the D2D communication is poor. In this paper, we develop an adaptive feedback and precoding scheme to exploit the gains over all D2D capability scenarios. In particular, when there is no D2D, the proposed adaptive scheme degenerates to classical precoding scheme where users feedback the CSI.

TA2b-2 **10:40 AM**

FD-MIMO versus Massive MIMO Performance: What do the Data Say?

Jose Flordelis, Fredrik Rusek, Fredrik Tufvesson, Ove Edfors, Lund University, Sweden; Erik G. Larsson, Linkoping University, Sweden

Downlink beamforming in Massive MIMO either relies on uplink pilot measurements---exploiting reciprocity and TDD operation, or on the use of a predefined grid-of-beams with terminals reporting their preferred beams, in FDD operation. Massive MIMO in its originally conceived form uses the first strategy, with uplink pilots, whereas FD-MIMO uses the second, grid-of-beams. It has been analytically shown that both in isotropic scattering (independent Rayleigh fading) and in Line-of-Sight the first approach outperforms the second. Nevertheless there remains controversy regarding their relative performance in practice. In this contribution, the performances of these two strategies are compared using measured data.

TA2b-3 **11:05 AM**

Massive MIMO with Imperfect Channel Covariance Information

Luca Sanguinetti, University of Pisa, Italy; Emil Bjornson, Linkoping University, Sweden; Merouane Debbah, CentraleSupelec, France

This work focuses on multi-cell massive MIMO systems and aims at maximizing the network-wide minimum supported rate in the downlink. Three configurations are considered: coordinated beamforming (only channel state information is shared among base stations), network MIMO (channel state and data cooperation), and single cell beamforming. The analysis is conducted assuming that the number of antennas per base station and the number of users per cell grow large with a non trivial ratio and data transmission is affected by channel estimation errors, pilot contamination and limited backhaul. Numerical results are used to validate the asymptotic analysis and to make comparisons.

TA2b-4 **11:30 AM**

Pilot Decontamination Through Compressive Wideband Channel Estimation

Saeid Haghighatshoar, Giuseppe Caire, Technische Universität Berlin, Germany

Pilot contamination refers to the case where, in a TDD system with UL-DL reciprocity, the UL pilot dimensions are overloaded, such that multiple users transmits the same pilot signal. In the conventional narrowband (i.e., frequency non-selective) channel model, the base station cannot separate the corresponding channel estimates and in massive MIMO this causes interference that does not vanish even in the large antenna limit. Here, we consider channel estimation with frequency-selective channels. When the signal bandwidth is large enough to resolve a sufficient number of multipath delays, then it is possible to greatly mitigate or even completely eliminate pilot contamination.

Track C – Networks

Session: TA3b – Distributed Signal Processing

Chair: ***Qing Ling,*** *University of Science and Technology of China*

TA3b-1 **10:15 AM**

Doubly Partial-Diffusion LMS over Adaptive Networks

Ibrahim El Khalil Harrane, Rémi Flamary, Cédric Richard, University Nice Sophia Antipolis, France

Diffusion LMS is an efficient strategy for solving distributed optimization problems with cooperating agents. Nodes are interested in estimating the same parameter vector and exchange information with their neighbors to improve their local estimates. However, successful implementation of such applications depends on a substantial amount of communication resources. In this paper, we introduce diffusion algorithms that have a significantly reduced communication load without compromising performance. We also perform analyses in the mean and mean-square sense. Simulations results are provided to confirm the theoretical findings.

TA3b-2 **10:40 AM**

Decentralized Consensus Optimization with Asynchrony and Delay

Tianyu Wu, Kun Yuan, University of California, Los Angeles, United States; Qing Ling, University of Science and Technology of China, China; Wotao Yin, Ali H. Sayed, University of California, Los Angeles, United States

We propose an asynchronous, decentralized algorithm for consensus optimization. The algorithm runs in a network where agents perform local computation and communicate with neighbors. Our algorithm allows agents to compute and communicate independently, at different times, for different durations. This reduces the waiting time for the slowest agent or longest communication delay and eliminates the need for a global clock. Mathematically, our algorithm involves primal and dual variables, uses fixed parameters, and has convergence guarantees under a bounded delay and a random agent assumption. Through simulations, we demonstrate that our asynchronous algorithm converges much faster that it does under synchronization.

TA3b-3 **11:05 AM**

Thermodynamic Limit of Interacting Particle Systems over Dynamical Networks

Augusto Santos, Soummya Kar, José M. F. Moura, Carnegie Mellon University, United States; João Xavier, University of Lisbon, Portugal

We establish a functional weak law of large numbers on a macroscopic state variable of interacting particle systems (e.g., voter and contact processes) over fast evolving sparse networks. We show that, as the number of agents grows large, the proportion of agents at a certain state converges (weakly with respect to the uniform topology on the space of càdlàg sample paths) to the solution of a differential equation. We note that each process~$\left(\overline{Y}^{N}(t)\right)$ in the sequence is not Markov as they are tied to the \emph{high-dimensional} microscopic state of the system (Kurtz Theorem does not apply). The limit is Markov.

TA3b-4 **11:30 AM**

Distributed Dictionary Learning

Amir Daneshmand, Gesualdo Scutari, Purdue University, United States; Francisco Facchinei, University of Rome, Italy

We study distributed (nonconvex) Dictionary Learning (DL) problems where the learning task is distributed over a multi-agent network with time-varying connectivity. This formulation is relevant, e.g., in scenarios where massive amounts of data are collected/stored in different locations and it's unfeasible to aggregate/process all data in a fusion center. We develop a distributed

algorithm for the DL problem and establish its convergence. The new method hinges on successive convex approximation techniques while leveraging dynamic consensus to distribute the computations among agents. To the best of our knowledge, this is the first distributed algorithm with provable convergence for the DL problem.

Track D – Signal Processing and Adaptive Systems

Session: TA4b – Sketching and Optimizing for Big Data

Co-Chairs: ***Georgios Giannakis,*** *University of Minnesota* ***and Gonzalo Mateos,*** *University of Rochester*

TA4b-1 10:15 AM

Parallel Asynchronous Lock-free Algorithms for Nonconvex Big-Data Optimization

Loris Cannelli, Gesualdo Scutari, Purdue University, United States; Francisco Facchinei, University of Rome, La Sapienza, Italy; Vyacheslav Kungurtsev, Czech Technical University in Prague, Czech Republic

This paper proposes the first lock-free parallel asynchronous algorithm for the minimization of the sum of a smooth nonconvex function and a convex nonsmooth regularizer. This class of problems arises from many big-data applications, including deep learning, matrix completions, tensor factorization, etc. A key feature of the proposed asynchronous model is that it is lock-free: components of the vector variables may be written by some cores while being simultaneously read by others. Almost sure convergence to stationary solutions is proved. Numerical results show that our method compares favorably to existing synchronous and asynchronous algorithms on both convex and nonconvex problems.

TA4b-2 10:40 AM

Sketching for Numerical Linear Algebra and Recent Developments

David P. Woodruff, IBM Almaden Research Center, United States

We survey recent near optimal algorithms for regression, low rank approximation, and robust variants of these problems. Our results are based on the sketch and solve paradigm, which is a tool for quickly compressing a problem to a smaller version of itself, for which one can then run a slow algorithm on the smaller problem. These lead to the fastest known algorithms for fundamental machine learning and numerical linear algebra problems, which run in time proportional to the number of non-zero entries of the input. We also touch upon communication-efficient solutions to these problems in distributed environments.

TA4b-3 11:05 AM

Large Scale Subspace Clustering Algorithms

Chong You, Claire Donnat, Daniel Robinson, Rene Vidal, Johns Hopkins University, United States

State-of-the-art methods for clustering data into multiple low-dimensional subspaces typically adopt a two-step procedure. In the first step, an affinity among data points is constructed, usually by exploiting data self-representation with proper regularization on the representation coefficients. In the second step, spectral clustering is applied to the affinity. Such methods are broadly applicable to mid-size datasets with 10,000 data points in 10,000 variables. This paper presents a comparative study of various large scale subspace clustering techniques, including divide and conquer, greedy, and active set strategies, as well as theoretical results that guarantee the correctness of some of these methods.

TA4b-4 11:30 AM

Randomized Approaches to Large-Scale Subspace Clustering

Panagiotis Traganitis, Georgios Giannakis, University of Minnesota, United States

Clustering plays an important role in a gamut of signal processing, machine learning, and data mining applications. Subspace clustering in particular, accounts for low-dimensional structures present in high-dimensional data that are captured by a union of subspaces model. Recent advances in subspace clustering have yielded high-performance algorithms that suffer however from prohibitively high complexity, especially when massive data are involved. The present paper introduces randomized approaches capable of reducing the complexity of subspace clustering methods, while maintaining their high-performance. Simulated and real-data tests confirm the merits of the proposed approaches in comparison with state-of-the-art subspace clustering algorithms on large-scale datasets.

Track G – Architecture and Implementation

Session: TA5b – Hardware Aspects for Compressive Sensing and Analog-to-Information Conversion

Chair: ***Christoph Studer,*** *Cornell University*

TA5b-1 **10:15 AM**

Exploiting System Configurability Towards Dynamic Accuracy-Performance Trade-Offs in AIC and CS Front-ends

Laura Isabel Galindez Olascoaga, Steven Lauwereins, Komail Badami, Juan-Carlos Pena, KU Leuven, Belgium; Rajesh Venkata, Marian Verhelst, KU Leuven and IMEC, Belgium

Analog-to-information converters and compressed sensing front-ends try to only extract the relevant, information-bearing elements of an incoming sensory signal. Feature extraction/recognition tasks can run directly on this compressed data stream without full signal reconstruction. The accuracy of the classification result is however strongly determined by the analog and digital settings, as well as the tolerated level of hardware impairments. Exploiting this relationship allows to dynamically tune accuracy for power consumption. This paper will discuss how to dynamically control this relationship, illustrated with two circuit realizations: 1.) an AIC for acoustic event detection, and .b) CS PPG heart rate extraction.

TA5b-2 **10:40 AM**

Band-Pass Compressive Sampling As an Enabling Technology for Rapid Wideband RF Spectrum Sensing

Rabia Tugce Yazicigil, Tanbir Haque, John Wright, Peter R. Kinget, Columbia University, United States

The ’data storm’ driven by the emerging technologies like Internet of Things, video over wireless will lead to a pressing ’artificial’ spectrum scarcity. Future “smart” terminals will need to quickly assess the spectrum usage and opportunistically use the available spectrum to overcome this challenge. They require energy-efficient spectrum scanning capabilities. We developed a rapid interferer detector with a Quadrature Analog-to-Information Converter (QAIC) that uniquely exploits compressed sampling (CS) together with RF architecture innovations. The band-pass CS QAIC system offers a novel approach to attack the search for the quick detection of interferers in a wideband spectrum in an energy-efficient way.

TA5b-3 **11:05 AM**

Adaptive Compressive Sensing for Radio-Frequency Receivers

Michael Pelissier, CEA,LETI, MINATEC Campus & Cornell University, France; Christoph Studer, Cornell University, United States

In recent years, a number of promising compressive sensing (CS) solutions for analog-to-information (A2I) conversion have been proposed in the field of RF. For spectrum sensing, for example, the most promising techniques rely on non-uniform sampling, random demodulation, or variable sub-Nyquist rate sampling. These techniques, however, suffer from stringent RF hardware requirements, such as sensitivity, jitter constraints, filter accuracy, and power consumption, as well as the excessive complexity of real-time signal recovery. This paper reviews the state-of-the-art of CS-based A2I for RF applications, and proposes a novel adaptive CS solution that enables real-time RF signal processing at relaxed hardware constraints.

TA5b-4 **11:30 AM**

Compressed Sampling for Astrophysical Signal Processing

Patrick Loumeau, Yosra Gargouri, Hervé Petit, Telecom ParisTech Institut Mines-Telecom, France; Baptiste Cecconi, Observatoire de Paris, France; Patricia Desgreys, Telecom ParisTech Institut Mines-Telecom, France

To reduce the amount of data acquired and stored for astrophysical signals, Compressed Sensing (CS) and compressed sampling can be potentially an efficient solution. The design of radio receiver architecture based on CS requires, first of all, the knowledge of the sparsifying basis. In this paper, we analyze an astrophysical signal (Jovian signal with a bandwidth of 40MHz) by extracting its relevant information and we study its compressibility. Experimental results demonstrate that our signal is sparse in the frequency domain with a compressibility level of 10%. Key words: compressed sensing, compressed sampling, compressibility, astrophysical signal, sparsifying basis.

Session: TA6b – Phase Retrieval for Imaging: Theory and Methods

Chair: ***Daniel Weller,*** *University of Virginia*

TA6b-1 10:15 AM

Nonconvex Phase Retrieval: From Theory to Physical Implementation

Mahdi Soltanolkotabi, University of Southern California, United States

In this talk we consider the problem of recovering the seemingly hidden phase of an object from intensity-only measurements, a problem which naturally appears in X-ray crystallography and related disciplines. I will discuss new guarantees for a class of novel non-convex optimization schemes dubbed Wirtinger flows, demonstrating that these fast algorithms are effective without the need for any sophisticated initialization/truncation schemes. These results apply to a wide variety of settings of significant interest in actual imaging implementations. Time permitting, I will also demonstrate how these new algorithms improve a variety of imaging tasks ranging from optics to chip design.

TA6b-2 10:40 AM

Robust PhaseLift for Phase Retrieval under Corruptions

Paul Hand, Rice University, United States; Thang Huynh, New York University, United States

Phase retrieval is a challenging mathematical task that appears in X-ray crystallography. As with any physical measurements, the phase retrieval measurements are typically contaminated by noise. In the cases of sensor saturation, sensor failure, or occlusions, such measurements may contain significant corruptions. In this talk we will show that a variant of the semidefinite program PhaseLift is provably tolerant of data corruptions, in the case that there are enough measurements, that there is a sufficient quantity of uncorrupted measurements, and that the underlying measurement model is random.

TA6b-3 11:05 AM

Solving Random Quadratic Systems of Equations Is Nearly As Easy As Solving Linear Systems

Yuxin Chen, Emmanuel Candes, Stanford University, United States

We consider the fundamental problem of solving quadratic systems of equations. We propose a novel method, which starting with an initial guess computed via a careful spectral method, proceeds by minimizing a nonconvex functional as in the Wirtinger flow approach. There are several distinguishing features, most notably, a novel update rule which operate in an adaptive fashion and drop terms bearing too much influence on the search direction. We demonstrate that for certain unstructured quadratic systems, our algorithms return the correct solution in linear time as soon the ratio between the number equations and unknowns exceeds a fixed numerical constant.

TA6b-4 11:30 AM

Robust Phase Retrieval with Sparsity under Nonnegativity Constraints

Daniel Weller, University of Virginia, United States

Phase retrieval for high-resolution imaging is challenging due to the low signal-to-noise ratio of magnitude measurements prevalent in such applications. This work describes a generalizable framework and reconstruction algorithm that utilizes a tight convex majorizer to construct a dual optimization problem that incorporates sparsity and nonnegativity constraints to resolve an image from such data. This talk will derive this framework and describe its application on a variety of image examples, demonstrating the robustness and scalability of the approach.

Session: TA7b – Biological Neural Systems

Chair: ***Francisco Solis,*** *Arizona State University*

TA7b-1 **10:15 AM**

A Pulse-Gated, Predictive Neural Circuit

Yuxiu Shao, Peking University, China; Andrew Sornborger, University of California, Davis, United States; Louis Tao, Peking University, China

Recent evidence suggests that neural information is encoded in packets and may be flexibly routed. We have hypothesized that neural circuits are split into sub-circuits where one controls information propagation via pulse-gating and a second processes information under the control of the first. We have shown how information may be processed by such circuits and also how decisions can be made. Here, we demonstrate how Hebbian plasticity may be used in this framework to implement a machine learning algorithm. The resulting neural circuit is similar to biological neural systems, including a layered structure and dynamics with a complex frequency spectrum.

TA7b-2 **10:40 AM**

A Multitaper, Causal Decomposition for Stochastic, Multivariate Time Series: Application to High-Frequency Calcium Imaging Data

Andrew Sornborger, University of California, Davis, United States; James D Lauderdale, University of Georgia, United States

Neural data analysis has increasingly incorporated information concerning causality between neurons in order to understand circuit connectivity. Dimensional reductions form the basis of most analyses of large multivariate time series. Here, we present a new, multitaper-based decomposition for stochastic, multivariate time series that acts on the covariance of the time series at all lags, $C(\tau)$, as opposed to standard methods that decompose the time series, $\mathbf{X}(t)$, using only information at zero-lag. In both simulated and neural imaging examples, we demonstrate that methods that neglect the full causal structure may be discarding important dynamical information in a time series.

TA7b-3 **11:05 AM**

The Neural Basis for Sleep Regulation - Data Assimilation from Animal to Model

Fatemeh Bahari, Camila Tulyaganova, Myles Billard, Kevin Alloway, Bruce Gluckman, Pennsylvania State University, United States

The likely neurophysiolgical basis of sleep regulation has been identified utilizing an array of techniques that include electrical measurements of neuronal activities, stimulation, local pharmacological manipulations, and lesion studies. From these have developed models of the interactions between the cell groups involved, and mathematical embodiments of those models. We have extended our computational demonstration that such models can be utilized in a data assimilation framework to fit model state and parameters from observed data, and are currently applying this to both long time series of observed behavioral state as well unit recordings from the cell groups modeled.

TA7b-4 **11:30 AM**

Neuronal Network Models for Sensory Discrimination

Mohammad Samavat, Genevieve Toutain, Sharon Crook, Arizona State University, United States

Previous modeling studies have demonstrated that lateral inhibition contributes to enhanced precision in sensory networks. That is, inhibitory connections reduce the spread of activity and repress neighboring cells, increasing the reliability of a sensory response. However, much less is understood about how excitatory connections might contribute to the processing of sensory stimuli in the context of a sensory discrimination task. In this work, we describe the role of excitation in determining network dynamics and contributing to sensory discrimination.

Session: TA8b1 – Array Processing and Wireless Communications 10:15 AM–11:55 AM

Chair: ***Xavier Leturc,*** *Telecom ParisTech*

TA8b1-1
An Exact Bayesian Detector for Multistatic Passive Radar

Stephen D. Howard, Songsri Sirianunpiboon, DST Group Australia, Australia; Douglas Cochran, Arizona State University, United States

An exact Bayesian likelihood ratio is derived for detecting the presence of a rank-2 signal in M>2 channels of noisy receiver data under the assumption that the signal is known to be present on K=2 of the channels (reference channels). The objective of the test is thus to ascertain whether the signal is also present on the other channels (surveillance channels). The performance of the Bayesian detector is compared to that of the generalized likelihood ratio test (GLRT). In this scenario, the Bayesian detector is found to be quite significantly better than the GLRT.

TA8b1-2
Compressive Direction-of-Arrival Estimation Off The Grid

Shermin Hamzehei, Marco Duarte, University of Massachusetts, United States

We consider the problem of direction-of-arrival (DOA) estimation from compressive sensing measurements taken at each sensor in a receiver array. While most existing literature assumes the DOAs are contained within a grid to obtain sparsity, we consider arbitrary resolution in the DOA parameter space. Our first approach uses a multiple measurement vector model for a sequence of snapshots and a subsequent parametric estimation algorithm. Our second approach integrates such parametric estimation within a denoiser for approximate message passing. Numerical experiments show that the proposed algorithms can significantly outperform existing approaches in terms of the average DOA estimation error.

TA8b1-3
Bandpass Signal Design for Passive Time Delay Estimation

Jeffrey Nanzer, Matthew Sharp, Johns Hopkins Applied Physics Laboratory, United States; Donald Brown, Worcester Polytechnic Institute, United States

This paper analyzes the performance of passive time delay estimation with bandpass signals and generalizes the results of Weiss and Weinstein by considering a more general bandpass signal model with a parameter that allows for increasing the mean-squared bandwidth of the bandpass signal with respect to conventional flat bandpass signals. Analysis of the modified Ziv-Zakai lower bound shows (i) performance is typically improved at moderate to high signal to noise ratios due to the increased mean-squared bandwidth of the split bandpass signal but (ii) performance is typically worse at moderate to low signal to noise ratios due to increased ambiguities.

TA8b1-4
Estimation of the Ricean K-Factor from Noisy Complex Channel Coefficients

Xavier Leturc, Thales Communications and Security, France; Philippe Ciblat, Télécom Paristech, France; Christophe Le Martret, Thales Communications and Security, France

The estimation of the Ricean K factor in case of noisy complex channel coefficients is addressed. A new deterministic estimator is designed, and the relevant deterministic Cramer-Rao Lower Bound (CRLB) is derived. It is shown by simulation that the new estimator outperforms the existing ones in term of both bias and Normalized Mean Square Error (NMSE), and is close to the CRLB. We also design two Bayesian estimators, which outperform the deterministic ones and are robust to small sample size (<=30 samples), but as a drawback are more complex.

TA8b1-5
A Novel Non-Linear Equalizer Structure for Single Carrier Wideband Communication

fredric harris, Xiaofei Chen, San Diego State University, United States; Elettra Venosa, SpaceMicro, United States

We present a non-linear equalization method for wideband single carrier communications. The equalization is performed efficiently in the domain of analysis filter bank channelized output signals. The received signal is partitioned into a collection of narrow band components by a Non-Maximally Decimated Perfect Reconstruction Filter Bank. The polyphase form of the bank

offers efficient channelization and permits the signal processing to be performed at the channelized down sampled rate. The architecture enables reduced cost hardware implementation of wideband signal processing tasks [1]. We show how the filter bank based non-linear equalizer implements an Inter Symbol Interference (ISI) canceller.

Track A – Communications Systems

Session: TA8b2 – Communication System Theory 10:15 AM–11:55 AM

Chair: ***Lara Dolecek,*** *UCLA*

TA8b2-1

From Dedicated Redundant Subcarriers to Distributed Redundancy in UW-OFDM

Christian Hofbauer, Linz Center of Mechatronics, Austria; Carl Böck, Mario Huemer, Johannes Kepler University, Austria

Unique word (UW)-OFDM is based on introducing redundancy, either on dedicated redundant subcarriers leading to systematically encoded UW-OFDM, or spread over the entire bandwidth, resulting in the significantly better performing non-systematically encoded UW-OFDM concept. The waveform design of the latter has originally been optimized by incorporating transmitter as well as receiver processing steps, while the optimization of the systematic approach primarily focuses on the mean redundant energy minimization of the transmit symbols. This work closes the gap between both approaches by introducing a design procedure for non-systematically encoded UW-OFDM that is also solely based on redundant energy arguments.

TA8b2-2

Coordinated Medium Access in Wireless Industrial D2D Networks: Fast Handshake Procedures Based on Stable Matching Variants

Bernd Holfeld, Thomas Wirth, Fraunhofer Heinrich Hertz Institute, Germany

We study the medium access of wireless device-to-device links in industrial factory environments characterized by high reliability and low latency communication requirements. We propose fast handshake procedures between the devices and a coordinator which allows several transmitter-receiver pairs to access the same frequency resource within a cell. Our framework relies on game-theoretic stable matching. We exploit many-to-one and many-to-many matching variants together with truncated schemes to achieve low-complex implementations. Furthermore, we consider power allocation with SINR guarantees to ensure reliable data transmission on resources under frequency reuse. Performance results for industrial indoor propagation at 5.2 GHz complement previous analytical work.

TA8b2-3

Delay-Optimal Scheduling and Power Control for Instantaneous-Interference-Limited CRs

Ahmed Ewaisha, Cihan Tepedelenligolu, Arizona State University, United States

We study an uplink multi secondary user (SU) cognitive radio system suffering statistical heterogeneity among SUs' channels. This heterogeneity may result in differentiated delay performances to these SUs and result in harmful interference to the PU. We first derive an explicit closed-form expression for the average delay in terms of an arbitrary power-control policy. Then, we propose a delay-optimal closed-form scheduling and power-control policy that can provide the required average delay guarantees to all SUs besides protecting the PU from harmful interference. We support our findings by extensive system simulations and show that it outperforms existing policies substantially.

TA8b2-4

Non-Orthogonal Multiple Access with Sub-Constellation Alignment

Sanjeewa Herath, Afshin Haghighat, InterDigital Communications, Inc., Canada

A non-orthogonal multiple access (NOMA) technique is presented where the information bits of a user are carried by the least significant bits (LSBs) of other users' symbols. It is shown that the user performance is improved by a receiver combining that relies on sub-constellation alignment. Corresponding rate outage analysis shows that the proposed technique exploits the full diversity of the system and therefore, a significant performance boost can be achieved despite the LSBs being allocated a small fraction of the transmit power.

TA8b2-5
On the Capacity of Diffusion-Based Molecular Timing Channels with Diversity
Nariman Farsad, Yonathan Murin, Milind Rao, Andrea Goldsmith, Stanford University, United States

This work introduces bounds on the capacity of molecular timing (MT) channels, where information is modulated on the release timing of {\em multiple indistinguishable} information particles, and decoded from the times of arrival at the receiver. It is shown that for diffusion-based MT channels, the capacity scales linearly in the number of particles. This is analogous to receiver diversity as each particle takes a random independent path. However, unlike receiver diversity in wireless channels, which mitigates fading, this form of diversity in MT channels can be used to significantly increase data rate.

TA8b2-6
On Global Channel State Estimation and Dissemination in Ring Networks
Shahab Farazi, Donald Brown, Worcester Polytechnic Institute, United States; Andrew Klein, Western Washington University, United States

This paper studies global channel state information (CSI) in time-slotted wireless ring networks with time-varying reciprocal channels. Lower bounds on maximum and average staleness of global CSI are derived, and efficient protocols that achieve the bounds are developed. Two extreme scenarios are considered with either (i) one node transmitting at a time or (ii) the maximum number of nodes transmitting at a time without collisions. In addition, the amount of CSI disseminated per packet is varied between two extremes. Simulation results confirm the analysis and quantify staleness in terms of the network parameters.

TA8b2-7
Spatially-Coupled LDPC Codes Optimized for 1-D Magnetic Recording Channels
Homa Esfahanizadeh, Ahmed Hareedy, Lara Dolecek, University of California, Los Angeles, United States

Spatially-coupled codes have recently attracted significant attention due to their capability to achieve capacity-approaching performance. The analysis of spatially-coupled codes for non-AWGN channels is highly important because of the nature of channels in modern storage systems. Absorbing sets are objects in the Tanner graph of LDPC codes causing performance degradation in the error floor region. In this paper, we identify detrimental absorbing sets of spatially-coupled codes for 1-D magnetic recording channels. First, we show that balanced absorbing sets, which are detrimental absorbing sets, share a common substructure. Then, we propose an algorithm for minimizing the number of these structures.

Track E – Array Signal Processing
Session: TA8b3 – MIMO and Multistatic Radars 10:15 AM–11:55 AM
Chair: ***Braham Himed,*** *Air Force Research Laboratory*

TA8b3-1
Analyzing and Improving MIMO Radar Detection Performance in the Presence of Cybersecurity Attacks
Hao Chen, Boise State University, United States; Braham Himed, Air Force Research Laboratory, United States

Abstract As a complicated distributed system, distributed MIMO radars are vulnerable to cybersecurity attacks against its three key components: the transmitters, the receivers, and the communication links that connect them and the fusion center. In this paper, we investigate the impact of cybersecurity attacks on detection performance of a distributed MIMO radar. We show that the detection performance degrades significantly if the MIMO radar is not aware of the attacks. To mitigate the attacks, we develop robust detection schemes which can greatly improve detection performance when the radar is under attack.

TA8b3-2
Direct Tracking of Multiple Targets in MIMO Radar
Phuoc Vu, Alexander Haimovich, New Jersey Institute of Technology, United States; Braham Himed, Air Force Research Lab (AFRL/RYMD), United States

We consider the problem of tracking multiple moving targets by MIMO radar systems with widely distributed antennas and non-coherent processing. Two tracking algorithms based on the extended Kalman filter are proposed to estimate locations and velocities of multiple targets.With indirect tracking, the tracker observations model consists of time delay and velocity estimates and nearest-neighbor data association, whereas direct tracking is performed on the radar observations, and data association is implicit. A Bayesian Cramer-Rao bound is developed for direct tracking of multiple targets. The analysis shows that for multiple targets, direct tracking outperforms indirect tracking at all signal-to-noise ratio values.

TA8b3-3

Super-Resolution in Position and Velocity Estimation for Short-Range mmWave Radar

Anant Gupta, Upamanyu Madhow, University of California, Santa Barbara, United States; Amin Arbabian, Stanford University, United States

Arrays of low-cost, short-range millimeter wave radar sensors have significant potential for emerging applications such as vehicular situational awareness. In this paper, we take a first step towards understanding this potential. We compute estimation-theoretic bounds for typical geometries and link budgets, showing that position resolution better than 0.1 m and velocity resolution better than 1cm/s are possible using a small number of monostatic sensors. We also show that recently developed super-resolution algorithms can approach single-sensor estimation-theoretic bounds for range and Doppler estimation. In addition to these preliminary results, results on tracking multiple targets will be included in the final paper.

TA8b3-4

High Resolution Geolocation with a Multi-Static Radar

Benjamin Friedlander, University of California, Santa Cruz, United States

We consider a multi-static radar where the transmitted signal is reflected from scatterers on the ground and received by multiple widely spaced sensors. Conventional geolocation algorithms are based on variants of the maximum likelihood estimator optimized for a single reflector. These algorithms have a natural resolution limit determined by the time-bandwidth product of the signal and the sensor-reflector geometry. Here we present a localization algorithm capable of resolving reflectors whose separation is less than this limit. The algorithm requires knowledge of the illuminating waveform. Two different algorithms are derived for the single snapshot and the multiple snapshot cases.

TA8b3-5

Using WCP-OFDM Signals with Time-Frequency Localized Pulses for Radar Sensing

Damien Roque, Stephanie Bidon, University of Toulouse, ISAE-SUPAERO, France

In this paper performance of a symbol-based WCP-OFDM radar estimation algorithm is studied. Particularly, benefits of using orthogonal time-frequency localized pulses rather than biorthogonal rectangular pulses (traditionally used in CP-OFDM receiver) is investigated in presence of white Gaussian noise. Numerical examples show that the former provide better dynamic range and tolerance to Doppler for short ranges.

TA8b3-6

Canonical Correlations for Target Detection in a Passive Radar Network

Yuan Wang, Washington State University, United States; Louis Scharf, Colorado State University, United States; Ignacio Santamaria, University of Cantabria, Spain; Haonan Wang, Colorado State University, United States

This work considers a passive radar system with non-cooperative transmitters and receivers with no prior knowledge of the transmitted signal. The objective is to detect the presence of a target. The system has a reference channel and a surveillance channel that separate the transmitter-to-receiver and transmitter-to-target-to-receiver signals. We consider a second-order detection problem where the transmitted signal is a P-dimensional unknown random vector. We derive the generalized likelihood ratio test under three different structures for the noise covariance matrix. In the most general case, the test statistic is a monotone function of canonical correlations between the reference and surveillance channels.

TA8b3-7

Compressive Radar Sensing via One-Bit Sampling with Time-Varying Thresholds

Jian Li, University of Florida, United States; Mohammad Mahdi Naghsh, Sayed Jala Zahabi, Mahmoud Modarres-Hashemi, Isfahan University of Technology, Iran

We propose a compressive radar that uses single bit quantization of the received noisy signal. The one-bit quantization is performed by a comparator with a time-varying level. The problem is studied through a sparse method, leading to an optimization problem which can be solved numerically. Simulation results show that the proposed method has a promising performance.

Track A – Communications Systems

Session: TP1a – Millimeter Wave Cellular Systems

Co-Chairs: ***Robert Heath,*** *University of Texas at Austin* ***and Nuria Gonzalez Prelcic,*** *University of Vigo*

TP1a-1 **1:30 PM**

mmWave Overlaid 5G Heterogeneous Cellular Networks - From Central Resource Management to Distributed Edge Cloud

Kei Sakaguchi, Tokyo Institute of Technology / Fraunhofer HHI, Germany; Gia Khanh Tran, Tokyo Institute of Technology, Japan; Thomas Haustein, Fraunhofer Heinrich Hertz Institute, Germany

This paper firstly shows the importance of mmWave access in 5G cellular networks to achieve 5G KPIs such as system capacity, user throughput, and energy efficiency. Secondly, novel resource management algorithms utilizing C/U splitting architecture are introduced for efficient operation of the network. Lastly, user and application centric extension by combining with edge cloud is introduced for further evolution of 5G systems.

TP1a-2 **1:55 PM**

On the Design and Performance of Initial Access in mmWave Cellular Networks

Yingzhe Li, Jeffrey Andrews, Francois Baccelli, University of Texas at Austin, United States; Thomas Novlan, Charlie Zhang, Samsung Research America, United States

Initial access is the process whereby a mobile user connects to the cellular system since it is switched on, wherein cell search (CS) over the downlink and random access (RA) on the uplink are the two major steps. The narrow beam communication in millimeter wave systems requires the user and base station to not only establish a connection, but also find a suitable beamforming direction from a large angular search space. By leveraging stochastic geometry, the success probability for CS and RA, as well as the user-perceived throughput, are derived and compared for several initial access protocol options.

TP1a-3 **2:20 PM**

On the Feasibility of Interference Alignment in Ultra-Dense Millimeter-Wave Cellular Networks

Jian Song, Thanh Tu Lam, Marco Di Renzo, Paris-Saclay University / CNRS, France

Recent studies have demonstrated that millimeter-wave cellular networks may operate either in the noise- or in the interference-limited regime, depending on several parameters, which include the density of base stations, the density and size of obstacles/blockages, the antenna beamwidth, and the transmission bandwidth. The objective of the present paper is to exploit tools from stochastic geometry for obtaining a mathematically tractable framework that allows us to assess the potential advantages of interference alignment, by taking into account the overhead cost of base station cooperation due to the estimation of channel state information.

TP1a-4 **2:45 PM**

Performance Characteristics of 5G mmWave Wireless To-the-Home

Frederick Vook, Eugene Visotsky, Timothy Thomas, Amitava Ghosh, Nokia Bell Labs, United States

Next generation broadband wireless systems are expected to operate on carrier frequencies up to 100GHz and provide extremely high data rates. A use case being considered for these systems is the wireless delivery of high bit rate services to a residential neighborhood. We investigate the performance characteristics of this “5G-to-the-Home” scenario in the 28GHz and 39GHz bands which are both being considered for 5G services. We leverage the latest path loss and multipath models at these frequencies and show how the system performance is affected by the antenna array and MIMO configuration at the base station and user equipment.

Session: TP1b – 5G Cellular Theory

Chair: ***Robert Heath,*** *University of Texas at Austin*

TP1b-1 3:30 PM

5G New Radio and Ultra Low Latency Applications: A PHY Implementation Perspective

Thomas Wirth, Bernd Holfeld, Matthias Mehlhose, Jens Pilz, Dennis Wieruch, Fraunhofer Heinrich Hertz Institute, Germany

Industry fora foresee a gigabit experience with zero latency for 5G new radio. Besides throughput enhancements and reduction of cost and power requirements of devices, latency and reliability requirements are among the key performance indicators (KPIs) targeted in the 5G research pyramid. While cellular 4G technologies have been designed for a 10 ms delay on the air interface, the user-experienced latency in most public cellular networks today is in a range of 30-50 ms. The proposed parameterized CP-OFDM waveform and its real-time implementation on a SDR platform achieves E2E delays below 1ms with further potentials by a factor of 10.

TP1b-2 3:55 PM

Fundamental Limits of Secure Device-to-Device Coded Caching

Ahmed A. Zewail, Aylin Yener, Pennsylvania State University, United States

We consider a device-to-device coded caching system, where each user should recover only its requested file and be kept completely ignorant of the remaining files, i.e., is viewed as an eavesdropper on the remaining files. We jointly optimize the cache placement and delivery policies such that a set of end users are able to satisfy their requests while preserving the confidentiality constraints. We develop an upper bound utilizing secret sharing schemes and one-time pad keying as well as a lower bound on the required transmission rate. Numerical results indicate that the gap between the bounds vanishes with increasing memory size.

TP1b-3 4:20 PM

On the Impact of Blockage on the Throughput of Multi-tier Millimeter-Wave Networks

Shuqiao Jia, David Ramirez, Rice University, United States; Lei Huang, Yi Wang, Huawei Technologies Co. Ltd., China; Behnaam Aazhang, Rice University, United States

We characterize upper bounds on the throughput capacity of a multi-tier millimeter wave (mmWave) network with diverse blockage probability, p(n), scaling scenarios. Communication links in the network are divided into three communication tiers sharing a single mmWave frequency. The bottom tier considers transmissions between n terminals and M(n) access points (APs). The top tier includes links between the APs and the backhaul. The bottom tier and the top tier are connected by the AP tier, referring to the communications between APs. Our results show that the network performance degradation caused by blockage can be avoided with certain p(n) and M(n).

TP1b-4 4:45 PM

Spatial Channel Covariance Estimation for mmWave Hybrid MIMO Architecture

Sungwoo Park, Robert Heath, University of Texas at Austin, United States

Instead of full CSI, spatial channel covariance can be used to design the analog part of mmWave hybrid MIMO systems. The problem is that the hybrid MIMO architecture makes it challenging to estimate the spatial channel covariance matrix because the estimator in the baseband can only see the low-dimensional projections of the original channel itself. In this paper, we propose two key ideas for developing the covariance estimation techniques based on compressive sensing techniques. One is to use the Hermitian property of the covariance, and the other is to use time-varying analog combining matrices to effectively extend the measurement size.

TP1b-5 5:10 PM

Joint User Association and Resource Allocation in Small Cells with Limited Backhaul Capacity

Jong Gyu Jang, Woojin Park, Hyun Jong Yang, Ulsan National Institute of Science and Technology, Republic of Korea; Hye Gyung Jwa, Electronics and Telecommunications Research Institute, Republic of Korea

User association and resource allocation for downlink orthogonal frequency division multiplexing are jointly optimized in small cells networks with limited backhaul. In particular, per resource block resource allocation under the backhaul constraint is formulated in pursuit of maximizing proportional fairness, which leads to an integer problem requiring prohibitive computational

complexity to solve. We propose two suboptimal methods to solve the problem with feasible complexity. The sum-rate and computational complexity of the two proposed schemes are evaluated via numerical simulations and mathematical analysis, respectively, showing the trade-off between the sum-rate and complexity

Track G – Architecture and Implementation

Session: TP2a – Implementation of Decoders for Polar Codes

Co-Chairs: ***Alexios Balatsoukas-Stimming,*** *EPFL* ***and Pascal Giard,*** *McGill University & EPFL*

TP2a-1 1:30 PM

Low Complexity SC Stack Polar Decoder Based on Segmented CRC Scheme

Yi Zhao, Chuan Zhang, Southeast University, China; Shunqing Zhang, Intel Labs, China; Xiaohu You, Southeast University, China

To reduce the complexity of SC list (SCL) polar decoder, SC stack (SCS) decoder has been proposed by existing literatures. However, with low SNR conditions or correlated channels, SCS decoder still suffers from the overwhelming complexity. To lower such complexity and the storage resources, this paper proposes a low complexity SCS decoder with segmented CRC scheme. This decoder reduces the complexity especially for low SNR regime without performance degradation. Results have shown that for (1024, 512) polar code, it achieves more than 25% complexity reduction at SNR of 0.5 dB. Also, the storage consumption has been reduced by 50%.

TP2a-2 1:55 PM

Low Memory Complexity Successive Cancellation Decoder for Very Long Polar Codes

Bertrand Le Gal, Camille Leroux, Christophe Jego, University of Bordeaux, France

This paper proposes a low memory complexity hardware successive cancellation decoder for very long polar codes. The decoder combines several hardware optimizations in terms of memory complexity and computational logic. A flexible controller can manage the decoding of any polar code for a given frozen bit vector. The resulting decoder is implemented on FPGA devices and favorably compares with state of the art architectures in terms of throughput and computational complexity.

TP2a-3 2:20 PM

A Multi-Gbps Unrolled Hardware List Decoder

Pascal Giard, McGill University, Canada; Alexios Balatsoukas-Stimming, Thomas Christoph Müller, Andreas Burg, École polytechnique fédérale de Lausanne, Switzerland; Claude Thibeault, École de technologie supérieure, Canada; Warren J. Gross, McGill University, Canada

Polar codes provably achieve capacity, even with the low-complexity successive-cancellation (SC) decoding algorithm. Yet, the more complex list-based decoding algorithms are gathering a lot of attention as they significantly improve the error-correction performance of short- to moderate-length polar codes, especially when they are concatenated with a CRC code. However, as list decoding explores several decoding paths, existing hardware implementations tend to be an order of magnitude slower than SC-based decoders. In this paper, we show how the unrolling technique can be adapted to list decoding yielding a multi-Gbps list-based polar decoder with competitive error-correction performance. ASIC results are also provided.

TP2a-4 2:45 PM

Error Patterns in Belief Propagation Decoding of Polar Codes and Their Mitigation Methods

Shuanghong Sun, Sung-Gun Cho, Zhengya Zhang, University of Michigan, United States

Belief propagation (BP) is a high-throughput decoding algorithm for polar codes, but it is known to underperform successive cancellation decoding and list decoding in error-correcting performance. In this work, we study the error patterns of BP decoding of polar codes to uncover the error mechanisms, as well as the influence of channel condition and decoding parameters. Based on the insights, we design new methods to detect, prevent and overcome the decoding errors. The methods are implemented as simple add-ons to a BP decoder, and evaluated by FPGA prototyping.

Session: TP2b – Beamforming and Linear Processing

Chair: ***Mojtaba Soltanalian,*** *University of Illinois at Chicago*

TP2b-1 **3:30 PM**

Max-Min Transmit Beamforming via Iterative Regularization

Ahmad Gharanjik, University of Luxembourg / KTH Royal Institute of Technology, Luxembourg; Bhavani Shankar, University of Luxembourg, Luxembourg; Mojtaba Soltanalian, University of Illinois at Chicago, United States Virgin Islands; Björn Ottersten, University of Luxembourg / KTH Royal Institute of Technology, Luxembourg

This work introduces an iterative optimization framework to tackle the multi-group multicast Max-Min transmit beamforming problem. In each iteration, the optimization problem is decomposed into four sub-problems, all of which can be solved using computationally efficient algorithms. The advantage of the proposed method lies in its ability to handle different types of signal constraints like total power and unimodularity, a feature not exhibited by other techniques. The proposed technique outperforms the well-known semidefinite relaxation method both in terms of quality of solutions and run-time.

TP2b-2 **3:55 PM**

Two-Stage Downlink Beamforming in MISO Multicell Networks with Limited Backhaul Signaling

Youjin Kim, Hyun Jong Yang, Ulsan National Institute of Science and Technology, Republic of Korea

A two-stage downlink beamforming design is proposed for multicell multi-input single-output channels with limited backhaul capacity and local channel state information (CSI). The first stage is to maximize the signal-to-leakage-plus-noise ratio with local CSI. Each base station (BS) then calculates the corresponding channel gains and shares them with all other BSs, which typically requires low-rate backhaul signaling. Finally, all the BSs design their beamforming vectors in pursuit of increasing the sum-rate with the shared information. Simulation results show that the proposed scheme shows the sum-rate close to that of the scheme with global CSI even without vector channel information.

TP2b-3 **4:20 PM**

A Class of Scalable Feedback Algorithms for Beam and Null-forming from Distributed Arrays

Sairam Goguri, Ben Peiffer, Raghu Mudumbai, Soura Dasgupta, University of Iowa, United States

We describe a class of scalable algorithms for shaping the transmission pattern of a distributed antenna array to steer beams and nulls to cooperating receivers. The key distinguishing feature of these algorithms is that no explicit channel state feedback from the receiver to individual transmitters, no channel reciprocity and minimal coordination between the transmitters is required. Instead, these algorithms are iterative, whereby the transmitters periodically make small adjustments to their transmit array weights, and the intended beam or null target responds by sending a common feedback message every period to all the transmitters.

TP2b-4 **4:45 PM**

Dirty Paper Coding versus Beamforming in Multi-user MIMO under OFDM

Ajay Mohanan, Arjun Nadh, Andrew Thangaraj, Radha Krishna Ganti, Indian Institute of Technology, Madras, India

Consider a two-user MIMO Gaussian Broadcast Channel with two antennas at the transmitter and two single-antenna receivers. While Dirty Paper Coding (DPC) achieves capacity, its practical adoption needs a precise comparison with the popular method of Zero Forcing Beam Forming (ZFBF). In this work, we obtain a simplified expression for the exact difference in sum rate between DPC and ZFBF at all SNRs. Using this expression, we obtain the distribution of the difference under block fading, and show a significant improvement in rate in wideband OFDM transmission by using DPC for only a small fraction of subcarriers.

TP2b-5 **5:10 PM**

Linear Detection Schemes for MIMO UW-OFDM

Sher Ali Cheema, Jianshu Zhang, Ilmenau University of Technology, Germany; Mario Huemer, Johannes Kepler University, Austria; Martin Haardt, Ilmenau University of Technology, Germany

UW-OFDM is a novel signaling concept where the usual cyclic prefixes are replaced by deterministic sequences, the so-called unique words. This is achieved by adding redundancy in the frequency domain with the help of a code generator matrix. A superior BER performance is achieved if the code generator matrix is utilized efficiently in the detection procedure. So far, the

performance of UW-OFDM has been well investigated for SISO systems. In this work, we expand our investigation of UW-OFDM to MIMO systems and propose two detection approaches. The results show that UW-OFDM outperforms CP-OFDM significantly but requires a higher computational complexity.

Track C – Networks

Session: TP3a – Multiagent Systems and Game Theory

Chair: ***Ceyhun Eksin,*** *Georgia Tech*

TP3a-1 **1:30 PM**

Strategic Communication in Multi-Agent Systems

Emrah Akyol, Cedric Langbort, Tamer Basar, University of Illinois at Urbana Champaign, United States

This paper analyses the strategic communication paradigm over a sensor network. Each sensor is strategic and aims to minimize its own objective which involves type and source random variables. The objective of the receiver is to minimize the estimation error associated with the source. The orthogonal multiple access channel model and two notions of equilibrium, Nash and herding equilibria, are considered. The optimal communication strategies achieving these equilibria and pay-offs at the equilibria are characterized for both noiseless and noisy channel models.

TP3a-2 **1:55 PM**

A Decentralized Algorithm with Signaling for Learning Nash Equilibria in Bilinear Graphical Games

Ceyhun Eksin, Georgia Institute of Technology, United States; Jeff S. Shama, King Abdullah University of Science and Technology, Saudi Arabia

This paper considers learning Nash equilibria in bilinear graphical games. In a bilinear graphical game each player is a node on the graph, and the utility function of each player is a bilinear function of its own action and the actions of its neighbors. We propose a decentralized best-response type learning algorithm with signaling based on the process of iterated elimination of dominated strategies. We show the algorithm converges to a Nash equilibrium in at most 2n iterations. Lastly, numerical examples are presented that motivate the class of games considered.

TP3a-3 **2:20 PM**

Computationally Efficient Learning in Large-Scale Games: Sampled Fictitious Play Revisited

Brian Swenson, Soummya Kar, Carnegie Mellon University, United States; Joao Xavier, Instituto Superior Tecnico, Portugal

This paper focuses on learning in large-scale games. The Fictitious Play (FP) algorithm is a popular algorithm known to achieve Nash equilibrium learning in certain important classes of games. However, in general, the complexity of deploying FP increases exponentially in the number of players. Sampled FP (SFP) is a variant of FP that mitigates computational demands via a Monte-Carlo approach. While SFP does significantly mitigate the complexity of FP, it can be shown that SFP still uses information in an inefficient manner. The paper generalizes the SFP convergence result and studies a variant that significantly reduces its complexity.

TP3a-4 **2:45 PM**

Equivalence Between Dynamic Games and its Effect on Equilibrium Characterization

Dhruva Kartik, Ashutosh Nayyar, University of Southern California, United States

We consider a general model of dynamic games where players may have asymmetric information. In such games, we can have signaling between the players, that is, the actions of one player may affect the future observations of other players. This kind of signaling effect makes it difficult to characterize and compute Nash equilibria. Based on some results in team theory, we show that such games are equivalent to games without signaling but with more complicated cost/utility functions. This equivalence may be helpful for equilibrium identification.

Track C – Networks

Session: TP3b – Graph Signal Processing

Co-Chairs: ***Mike Rabbat,*** *McGill University* ***and Antonio Ortega,*** *University of Southern California*

TP3b-1 **3:30 PM**

Network Topology Identification from Imperfect Spectral Templates

Santiago Segarra, University of Pennsylvania, United States; Antonio Marques, King Juan Carlos University, Spain; Gonzalo Mateos, University of Rochester, United States; Alejandro Ribeiro, University of Pennsylvania, United States

This paper studies network topology inference, a cornerstone problem in statistical analysis of complex systems. We build on results from convex optimization and graph signal processing to identify the graph-shift operator (encoding the network topology) given its eigenvectors. These spectral templates can be obtained, e.g., from the covariance of a set of graph signals defined on the network. We develop efficient inference algorithms stemming from provably-tight convex relaxations of non-convex criteria for cases when the eigenbasis is perfectly known and where an imperfect eigenbasis is available. Numerical tests showcase the effectiveness of the algorithms in recovering real-world social networks.

TP3b-2 **3:55 PM**

Models that Generate Approximately Band-limited Graph Signals

Takeshi Musgrave, Michael Rabbat, McGill University, Canada

Many modern signal processing methods are based on the assumption (or prior) that the signal of interest has most of its energy in a low-dimensional subspace. In the domain of graph signal processing there has specifically been interest in methods for sampling, reconstructing, and approximating signals that are (exactly or approximately) band-limited. In this work we consider the question: \emph{Are there processes for generating approximately band-limited graph signals?} In particular we are interested in processes motivated by physical phenomena and models commonly adopted in other signal processing applications.

TP3b-3 **4:20 PM**

Representations for Localized Signals on Graphs

Rohan Varma, Siheng Chen, Jelena Kovacevic, Carnegie Mellon University, United States

We propose representations based on the graph vertex domain to analyze localized signals on graphs that are widely observed in the real world. Inspired by an uncertainty principle that shows that graph signals can be jointly localized over the vertex-frequency space unlike in classical signal processing, we develop representations for such localized signals by constructing local Fourier bases over local sets. We show theoretical results for different classes of localized graph signals and show connections to graph-based uncertainty principles. We further present experimental results on real world data including real-time traffic and brain network data.

TP3b-4 **4:45 PM**

Graph Learning with Laplacian Constraints: Modeling Attractive Gaussian Markov Random Fields

Hilmi Enes Egilmez, Eduardo Pavez, Antonio Ortega, University of Southern California, United States

In this paper, we propose a novel framework for learning graphs from data. Our framework formulates various graph learning problems and develops efficient algorithms solving them. We specifically focus on graphs associated with graph Laplacian matrices which leads to modeling attractive Gaussian Markov Random Fields under specific statistical assumptions. Several applications of the proposed framework in signal processing and machine learning are also discussed and some experimental results are presented.

TP3b-5 **5:10 PM**

Discrete Uncertainty Principles on Graphs

Oguzhan Teke, Palghat Vaidyanathan, California Institute of Technology, United States

This paper advances a new way to formulate the uncertainty principle for graphs, by using a non-local measure based on the notion of sparsity. The uncertainty principle is formulated based on the total number of nonzero elements in the signal and its corresponding graph Fourier transform (GFT).By providing a lower bound for this total number, it is shown that a nonzero graph signal and its GFT cannot be arbitrarily sparse simultaneously.The theoretical bound on total sparsity is derived. For several real-world graphs this bound can actually be achieved by choosing the graph signals to be appropriate eigenvectors of the graph.

Session: TP4a – Bilinear Inverse Problems

Chair: ***Yuejie Chi,*** *The Ohio State University*

TP4a-1 1:30 PM

Simultaneous Blind Deconvolution and Blind Demixing via Convex Programming

Shuyang Ling, Thomas Strohmer, University of California, Davis, United States

Suppose that one receives the superposition of several signals and each of them goes through an unknown channel, can we correctly recover the signals and their corresponding channels simultaneously? This talk presents a robust, reliable and efficient approach to solve this challenging problem, which intertwines blind deconvolution with blind demixing, via convex optimization under mild assumptions. The problem is closely related to a variety of applications including the Internet-of-Things. Numerical experiments demonstrate remarkable performance of our algorithm.

TP4a-2 1:55 PM

Ambiguities of Convolutions with Application to Phase Retrieval Problems

Philipp Walk, California Institute of Technology, United States; Peter Jung, Technische Universität Berlin, Germany; Goetz E. Pfander, Philipps-University Marburg, Germany

The convolution output of two finite dimensional vectors x and y can also be obtained by the convolution of different input vectors $\tilde{x}$ and $\tilde{y}$. They are called non-trivial ambiguities if they are not collinear to x and y. We will show that for each convolution output there exists finitely many non-trivial ambiguity pairs which can be seen as factorization ambiguities obtained in the z-domain by polynomial factorization. This result can even be extended to multi-dimensional convolutions and signals over any integral domain. As an application we design domain restrictions which allow exact recovery up to sign in Phase Retrieval.

TP4a-3 2:20 PM

Blind Deconvolution with Sparsity: Optimal Identifiabiliy Conditions and Efficient Recovery

Yanjun Li, University of Illinois at Urbana-Champaign, United States; Kiryung Lee, Georgia Institute of Technology, United States; Yoram Bresler, University of Illinois at Urbana-Champaign, United States

Blind deconvolution (BD) is a ubiquitous inverse problem but does not admit a unique solution even up to inherent ambiguities. In practice, imposing subspace or sparsity constraints met with some empirical success. However, corresponding theoretical analysis is limited. We derive the first results on sample complexity for BD with sparsity constraints that guarantee unique and stable recovery under minimal requirements. Some of these results generalize to a universal framework for bilinear inverse problems. These theoretical results are complemented by a polynomial-time BD algorithm achieving nearly optimal scaling of the sample complexity, both in theoretical guarantee and in numerical experiments.

TP4a-4 2:45 PM

Time-Varying Narrowband Channel Estimation: Exploiting Low-Rank and Sparsity Structures in Delay-Doppler Domain via Bilinear Representation

Sajjad Beygi, Urbashi Mitra, University of Southern California, United States

In this paper, the estimation of time-varying channels under finite block-length and finite transmission-bandwidth is investigated. It is shown that channel estimation problem can be represented as a bilinear inverse problem. A novel method based on low-rank matrix recovery with structural constraints is proposed to estimate the channel. Furthermore, the sparsity of time-varying channel coefficients is exploited. The proposed recovery algorithm takes advantage of alternating-direction method and powerFactorization algorithm to reduce the computational complexity. Numerical simulations show that the proposed method offers about 5 dB and 15 dB improvement over prior structured methods (e.g., LASSO) and unstructured methods, respectively.

Track D – Signal Processing and Adaptive Systems

Session: TP4b – Five Puzzles and Euclid's Bag of Tricks

Co-Chairs: ***Ivan Dokmanic,*** *Ecole Polytechnique Fédérale de Lausanne* ***and Martin Vetterli,*** *Ecole Polytechnique Fédérale de Lausanne*

TP4b-1 **3:30 PM**

Recovering Spatial Organization of Genomes from Hi-C Contact Maps: High-Dimensional Statistical Estimation and Optimization with Euclidean Distance Matrices

Aleksandr Aravkin, University of Washington, United States; Stephen Becker, University of Colorado at Boulder, United States; Dmitriy Drusvyatskiy, University of Washington, United States; Aurelie Lozano, IBM T.J. Watson Research Center, United States

Understanding how chromosomes fold is a central question in biology. Recently developed Hi-C technology is able to identify interactions between pairs of genomic loci at large scale and fine resolution. Transforming Hi-C data to a 3D structure map requires making a leap from noisy large-scale contact matrices to Euclidean distances, while overcoming several uncertainties. We propose a principled approach to recovering 3D chromosome structure by bringing together tools from statistical modeling, convex optimization, and distance geometry. Euclidean distance matrices are key to our approach. We present convex formulations and non-convex accelerations and demonstrate their efficacy on simulated and Hi-C datasets.

TP4b-2 **3:55 PM**

Graph Rigidity, Unassigned Distance Geometry and the Nanostructure Problem

Phillip Duxbury, Michigan State University, United States; Simon Billinge, Columbia University, United States

In many applications the primitive experimental data is a list of interpoint distances where the vertices at the ends of each distance are unknown. Reconstruction of an embedding from such an unassigned distance list requires discovery of the underlying graph as well as the graph realization. New algorithms for this unassigned distance geometry problem (uDGP) use build up procedures starting with a substructure that is known. These algorithms will be introduced, uniqueness will be discussed, and solution to uDGPs that have missing distances and/or distance imprecision will be demonstrated.

TP4b-3 **4:20 PM**

Biologically Inspired Unsupervised Algorithms for Streaming Data Analysis

Dmitri Chklovskii, Simons Center for Data Analysis, United States

Conventionally, online algorithms that reduce dimensionality, cluster and discover features in streamed data are derived by minimizing the representation, or encoding, error. Here, inspired by neuroscience observations, we derive a family of such algorithms by using a multidimensional scaling objective. But, unlike conventionally considered offline setting, our algorithms are derived for the online (streaming) setting. Our algorithms are competitive with state-of-the art dimensionality reduction and feature discovery algorithms. Finally, neural network implementations of our algorithms resemble brain circuits and provide insight into how the brain processes sensory input streams.

TP4b-4 **4:45 PM**

Look, no beacons! Optimal all-in-one EchoSLAM

Miranda Krekovic, Ivan Dokmanic, Martin Vetterli, École polytechnique fédérale de Lausanne, Switzerland

We study the problem of simultaneously reconstructing a polyhedral room and a trajectory of a device equipped with collocated omnidirectional source and receiver. The device measures arrival times of echoes of pulses emitted by the source and picked up by the receiver. Most existing approaches addressing this problem assume multiple sources or receivers, or they assume that some of these are static---they serve as beacons. Still differently from earlier approaches, we take into account the measurement noise and various constraints on the geometry by formulating the solution as a minimizer of a cost function similar to stress in multidimensional scaling.

TP4b-5 **5:10 PM**

Eternity II Insoluble: Damn You, Monckton

Jon Dattorro, Systems Optimization Laboratory, United States

A tessellation puzzle game, and $2M USD award for its solution (expiry 2010), was introduced in London by Christopher Walter Monckton in July 2007. Called Eternity II, its name derives from passage of time while trying all allowable puzzle-piece tilings before obtaining a complete solution. The prize remains unclaimed, and solution is yet to be found. This work provides linear/binary program statements for Eternity II, and posits several different methods for solution: quantum, Lagrangian, distance geometry. But its sparse A matrix has little discernible structure. Question looms as to whether solution exists at all.

Track E – Array Signal Processing

Session: TP5a – Detection over Very Large Datasets

Co-Chairs: ***Vincent H. Poor,*** *Princeton University* ***and Yingbin Liang,*** *Syracuse University*

TP5a-1 **1:30 PM**

Detection of Sparse Mixtures: the Finite Alphabet Case

Jonathan Ligo, University of Illinois at Urbana-Champaign, United States; George Moustakides, University of Patras, Greece; Venugopal Veeravalli, University of Illinois at Urbana-Champaign, United States

We study the problem of testing between a sparse signal in noise, modeled as a mixture distribution, versus pure noise with finite alphabet observations. We study the consistency and adaptivity of tests as the mixture proportion tends to zero with number of observations. The finite alphabet assumption allows for application to inherently categorical data, where no useful relationship on the alphabet typically exists. This is in contrast to the conventional sparse mixture problem on real-valued data, where popular tests (e.g. Higher Criticism) rely on linear ordering. We construct and analyze divergence-based adaptive tests for finite alphabets via combinatorial techniques.

TP5a-2 **1:55 PM**

Quickest Hub Discovery in Correlation Graphs

Taposh Banerjee, Massachusetts Institute of Technology, United States; Alfred Hero, University of Michigan, Ann Arbor, United States

The problem of quickest hubs discovery in correlation graphs is considered. Hubs in a correlation graph of a random vector are variables that have a high degree of correlation with other variables. The random vectors are high-dimensional and have nonparametric elliptical densities. A test is proposed to detect sudden appearance of hubs in a sequence of random vectors. The test employs a set of novel local summary statistics generated from small samples of the data. The sequential test is optimal in a well-defined sense, and the optimality is established via a detailed performance analysis of the proposed test.

TP5a-3 **2:20 PM**

Quickest Combined Anomaly Detection and Estimation in Networked Data

Javad Heydari, Ali Tajer, Rensselaer Polytechnic Institute, United States

Outlier detection arises in many application domains as a pre-processing stage or the ultimate objective. Consider a collection of data streams, which are distributed according to one of the normal and outlier distributions. Due to some underlying physical couplings, the generations of data streams follow an unknown dependency kernel. With the ultimate objective of finding one data stream distributed according to the outlier distribution as well as forming a sufficiently reliable estimate of the dependency kernel, this paper designs a sequential data-adaptive strategy that minimizes the average delay for forming the two combined inferential decisions.

TP5a-4 **2:45 PM**

Nonparametric Composite Outlier Detection

Weiguang Wang, Yingbin Liang, Syracuse University, United States; H. Vincent Poor, Princeton University, United States

A composite outlier detection problem is studied, the goal of which is to distinguish between the hypothesis that all data streams are generated by a typical distribution and the alternative hypothesis that some data streams are generated by an outlying distribution while others are generated by the typical distribution. A semi-parametric scenario is first studied, where only the typical distribution is known. A consistent test is constructed, and the optimal error exponent is obtained. Nonparametric scenario is further studied, where neither typical nor outlying distribution is known, and consistent test is also constructed.

Session: TP5b – Source Localization and Sparse Array Design

Chair: ***Marco Lops,*** *University of Cassino*

TP5b-1 3:30 PM

An Ideal-Theoretic Criterion for Localization of an Unknown Number of Sources

Matthew W. Morency, Delft University of Technology, Netherlands; Sergiy A. Vorobyov, Aalto University, Finland; Geert Leus, Delft University of Technology, Netherlands

Source localization is among the most fundamental problems in statistical signal processing. Methods which rely on the orthogonality of the signal and noise subspaces, such as Pisarenko's method, MUSIC, and root-MUSIC are some of the most widely used algorithms to solve this problem. As a common feature, these methods require both a-priori knowledge of the number of sources, and an estimate of the noise subspace. In this paper, we propose a new localization criterion based on the algebraic structure of the noise subspace. An algorithm is proposed which adaptively learns the number of sources and estimates their locations.

TP5b-2 3:55 PM

Exact Localization of Correlated Sources using 2D Harmonics Retrieval

Ali Koochakzadeh, Piya Pal, University of Maryland, College Park, United States

This paper considers the problem of DOA estimation of correlated sources using sparse arrays, where the number of sources can exceed the number of sensors. Depending on the magnitude of the cross correlation terms, our algorithm either treats them as additive noise (small correlation) or estimates them jointly with the DOAs (large correlation). In the latter case, the problem is cast as an equivalent 2D harmonics retrieval problem and the DOAs are estimated by solving the corresponding dual problem via sum-of-squares relaxation. Simulations show the possibility of identifying more correlated sources than the number of sensors using a nested array.

TP5b-3 4:20 PM

Two-Dimensional Sparse Arrays with Hole-Free Coarray and Reduced Mutual Coupling

Chun-Lin Liu, Palghat Vaidyanathan, California Institute of Technology, United States

Two-dimensional sparse arrays with hole-free difference coarrays, like billboard arrays and open box arrays, can identify $O(N^2)$ uncorrelated source directions (DOA) using N sensors. These arrays contain some dense ULA segments, leading to many sensor pairs separated by $\lambda/2$. The DOA estimation performance often suffers degradation due to mutual coupling between such closely-spaced sensor pairs. This paper introduces a new 2D array called the half open box array. For a given N, this array has the same hole-free coarray as an open box array. At the same time, the number of sensor pairs with small separation is significantly reduced.

TP5b-4 4:45 PM

Multiple Source Detection Performance of Linear Sparse Arrays

Yu Rong, Daniel Bliss, Arizona State University, United States

This paper considers detection performance of linear sparse arrays in the presence of multiple source Direction-Of-Arrivals (DOA). A number of source DOAs greater than the number of physical array elements are randomly generated, without restriction on the angular separation. Two augmentation algorithms are considered before application of traditional spatial spectrum estimation algorithms: MVDR and MUSIC. Detection and false alarm statistics are generated from the spatial spectrum. Monte Carlo simulations are performed to validate this detection scheme.

TP5b-5 5:10 PM

Gridless Super-Resolution Direction Finding for Strictly Non-Circular Sources Based on Atomic Norm Minimization

Jens Steinwandt, Florian Roemer, Ilmenau University of Technology, Germany; Christian Steffens, Technische Universität Darmstadt, Germany; Martin Haardt, Ilmenau University of Technology, Germany; Marius Pesavento, Technische Universität Darmstadt, Germany

The recently developed super-resolution framework by Candes enables the direction-of-arrival (DOA) estimation from a sparse spatial power spectrum in the continuous domain with infinite precision. By means of atomic norm minimization (ANM), the discretization of the spatial domain is no longer required, which overcomes the basis mismatch problem in conventional

compressed sensing (CS)-based DOA estimation. In this abstract, we incorporate additional signal structure, i.e., the strict non-circularity (NC) of the signals, into the ANM framework. We propose a novel NC ANM procedure based on the multiple measurement vector (MMV) model that exploits the NC signal structure. Simulations demonstrate the performance.

Track H – Speech, Image and Video Processing

Session: TP6a – Big Data Analytics for Image and Video Processing

Chair: ***Marios Pattichis,*** *University of New Mexico*

TP6a-1 1:30 PM

Food Image Analysis: the Big Data Problem You Can Eat!

Yu Wang, Chang Liu, Shaobo Fang, Fengqing Zhu, Purdue University, United States; Deborah Kerr, Curtin University, Australia; Carol Boushey, University of Hawaii, United States; Edward Delp, Purdue University, United States

Six of the ten leading causes of death in the United States can be directly linked to diet. Measuring accurate dietary intake is considered to be an open research problem in the nutrition and health fields. We have developed a novel food record method using a mobile device and the embedded camera. This is known as Mobile Food Record (mFR). Images acquired before and after foods are eaten can be used to estimate the amount of food consumed. This paper will describe the current status of the TADA project and overview problems that still need to be addressed.

TP6a-2 1:55 PM

Automated Monitoring by Behavior Classification of Healthcare Providers using Big Data Analysis

Nasrin Sadeghzadehyazdi, Laura Barnes, Scott Acton, University of Virginia, United States

It has been established that certain behaviors of health care providers can affect the transmission of antibiotic-resistant infections in hospital systems. Using hundreds of hours of videos, recorded from staff behavior, a video search engine has been designed that extracts proper image descriptors. The solution involves a novel combination of graph signal processing and spatiotemporal video segmentation. The extracted feature vectors are then applied to a machine learning classifier to characterize different events in each video. The activities mined from the video data are then correlated with localized statistics of infectious disease.

TP6a-3 2:20 PM

Building a Living Atlas of the Earth in the Cloud

Daniela I. Moody, Steven P. Brumby, Michael S. Warren, Samuel W. Skillman, Ryan Keisler, Rick Chartrand, Tim Kelton, Mark Mathis, Descartes Labs, United States

The recent computing performance revolution has driven improvements in sensor, communication, and storage technology. Multi-decadal remote sensing datasets are now available in commercial clouds, with new satellite constellations generating petabytes/year of daily high-resolution global coverage imagery. Cloud computing and storage, combined with recent advances in machine learning are enabling understanding of the world at a scale and at a level of detail never before feasible. We show data processing at rates of terabytes to petabytes per day using multi-modal sensor data and use the calibrated, georeferenced imagery to build videos of the Earth at varying temporal and spatial resolutions.

TP6a-4 2:45 PM

A Review of Big Data Technologies and Challenges in Image and Video Analytics in Healthcare

Andreas Panayides, University of New Mexico, United States; Constantinos Pattichis, University of Cyprus, Cyprus; Marios Pattichis, University of New Mexico, United States

There is a growing need for developing fast and scalable methods for storing and processing large databases of healthcare images and videos. The paper reviews current image and video analysis approaches, scalable approaches based on big data technologies and architectures (e.g., Openstack and Hadoop), and discusses the networking limitations that arise from distributing these large-scale datasets for parallel processing over heterogeneous compute nodes. Finally, it underlines the potential of capitalizing the wealth of patient's big healthcare data such as EHR, genetic, and sensing data to allow personalized interventions for improving quality of care.

Session: TP6b – Optimization and Adaptive Methods

Chair: ***Philip Schniter,*** *Ohio State University*

TP6b-1 3:30 PM

A New Formulation of Generalized Approximate Message Passing

Subrata Sarkar, Philip Schniter, The Ohio State University, United States; Alyson Fletcher, University of California, Los Angeles, United States; Sundeep Rangan, New York University, United States

The Approximate Message Passing (AMP) algorithm is a computationally efficient al- gorithm for linear regression under additive white Gaussian noise (AWGN). The General- ized AMP (GAMP) algorithm extends AMP to non-AWGN (e.g., quantized or phaseless) measurements. With a large i.i.d. sub-Gaussian transform, both AMP and GAMP obey a state-evolution whose fixed points, when unique, are optimal. But algorithmically, GAMP is much more complicated than AMP. We propose a new formulation of GAMP that mimics AMP, and we analyze its convergence, fixed-points, and free-energy interpretation.

TP6b-2 3:55 PM

Mean-Reverting Portfolio Design via Majorization-Minimization Method

Ziping Zhao, Daniel P. Palomar, Hong Kong University of Science and Technology, Hong Kong SAR of China

This paper considers the mean-reverting portfolio design problem arising from statistical arbitrage in financial markets. The problem is formulated by optimizing a criterion characterizing the mean-reversion strength of the portfolio and taking into consideration the variance of the portfolio and the investment budget constraint at the same time. An efficient algorithm based on the majorization-minimization (MM) method is proposed to solve the problem. Numerical results show that our proposed mean-reverting portfolio design method can significantly outperform naive investment strategies like single asset investment and the benchmark method in the literature.

TP6b-3 4:20 PM

Online Kernel Dictionary Learning on a Budget

Jeon Lee, University of Texas Southwestern Medical Center, United States; Seung-Jun Kim, University of Maryland, Baltimore County, United States

Online kernel-based dictionary learning (DL) algorithms are considered, which perform DL on training data lifted to a high-dimensional feature space via a nonlinear mapping. Compared to batch alternatives, the online algorithms require low computational complexity, essential for processing the Big Data, based on the stochastic gradient descent method. However, as with any kernel-based learning algorithms, the number of parameters needed to represent the desired dictionary is equal to the number of training samples, which incurs prohibitive memory requirement for large-scale datasets. In this work, appropriate sparsification and pruning strategies are combined with online kernel DL to mitigate this issue.

TP6b-4 4:45 PM

A New Strategy for Effective Learning in Population Monte Carlo

Monica Bugallo, Stony Brook University, United States; Victor Elvira, Universidad Carlos III de Madrid, Spain; Luca Martino, Universidad de Valencia, Spain

Adaptive importance sampling is a methodology that iteratively approximates distributions by sets of samples and associated weights. It exploits learning from samples and weights obtained from past iterations so that the sampling system can move from parts of the sampling space that are less important to parts that contain more information. We aim at investigating a novel strategy for adaptive learning with the objective of obtaining improved proposals applicable to problems with large amounts of unknowns and/or observed data. The new strategy will be examined and compared to existing ones in terms of performance and computational complexity through computer simulations.

TP6b-5 5:10 PM

A Bayesian Framework for Robust Kalman Filtering Under Uncertain Noise Statistics

Roozbeh Dehghannasiri, Texas A&M University, United States; Mohammad Shahrokh Esfahani, Stanford School of Medicine, United States; Edward Dougherty, Texas A&M University, United States

In this paper, we propose a Bayesian framework for robust Kalman filtering when noise statistics are unknown. The proposed intrinsically Bayesian robust Kalman filter is robust in the Bayesian sense meaning that it guarantees the best average performance relative to the prior distribution governing unknown noise parameters. The basics of Kalman filtering such as the

projection theorem and the innovation process are revisited and extended to their Bayesian counterparts. These enable us to design the intrinsically Bayesian robust Kalman filter in a similar way that one can find the classical Kalman filter for a known model.

Track F – Biomedical Signal and Image Processing

Session: TP7a – Signal Processing for Dynamic Functional Brain Network Analysis

Chair: ***Seline Aviyente,*** *Michigan State University*

TP7a-1 1:30 PM

Connectivity Dynamics from Wakefulness to Sleep

Eswar Damaraju, Robyn Miller, Devon Hjelm, Vince Calhoun, Mind Research Network, United States

It has become evident that resting state functional connectivity is dynamic in nature and hence methodology assuming static metrics of interregional brain connectivity can be inappropriate. One approach to assessing connectivity dynamics uses sliding-window correlations. One limitation of estimating connectivity based on relatively short time courses using sliding windows is a potentially low signal-to-noise ratio. We use simultaneous EEG-resting functional magnetic imaging data collected continuously over 50 minutes while subjects transitioned between wakefulness and sleep stages (EEG-based sleep scoring) and assessed the ability of sliding-window based dynamic functional network connectivity measures to track the changes across these different wakefulness states.

TP7a-2 1:55 PM

An EEG and fTCD based BCI for Control

Matthew Sybeldon, Aya Khalaf, Ervin Sejdic, Murat Akcakaya, University of Pittsburgh, United States

Brain-computer interfaces (BCIs) promise to promote a novel access channel for functional independence for individuals with severe speech and physical impairment (SSPI) that can occur as a result of numerous neurological diseases and injuries. Current BCI systems lack the robustness and accuracy to allow individuals with SSPI to complete tasks required for independent living (e.g. communication or navigation). We aim to develop a noninvasive hybrid BCI relying on two imaging modalities: Electroencephalography (EEG) and functional transcranial Doppler sonography (fTCD). We will show that such a hybrid BCI will be sufficiently robust and accurate to be operated in a real-life environment.

TP7a-3 2:20 PM

Source-Informed Segmentation: Towards Capturing the Dynamics of Brain Functional Networks Through Eeg

Ali Haddad, Laleh Najafizadeh, Rutgers University, United States

We propose a data-driven framework to objectively evaluate the dynamics of brain functional connectivity from electroencephalography (EEG) recordings. The proposed framework consists of two main steps: first, EEG recordings are segmented into intervals during which the spatial distribution of functionally connected networks in the source space stays fixed. Second, recordings within each segment are transformed into the source domain, where functionally connected cortical points are localized based on their correlation to the dominant right singular vectors of the source matrix. Theoretical derivations are presented, and the framework is used to examine the temporal evolution of functional networks during task execution.

TP7a-4 2:45 PM

Functional Connectivity Metrics for Wavelet Clustering of rs-fMRI Data

Alessio Medda, Georgia Tech Research Institute, United States; Jacob Billings, Emory University, United States; Shella Keilholz, Georgia Institute of Technology and Emory University, United States

In this paper we compare several functional connectivity metrics for wavelet-based clustering of resting state fMRI data. Recent advent of fast imaging techniques for MRI application allow whole brain coverage with sub-second resolution. The use of wavelet based spectral decomposition and hierarchical clustering for resting-state functional MRI was shown to refine functional network over specific subbands. Here, functional connectivity metrics are compared with the results obtained from the wavelet clustering technique.

Session: TP7b – Implementation of Full-Duplex Radio Transceivers

Co-Chairs: ***Joseph Cavallaro,*** *Rice University* ***and Ashutosh Sabharwal,*** *Rice University*

TP7b-1 **3:30 PM**

Advanced Architectures for Self-Interference Cancellation in Full-Duplex Radios: Algorithms and Measurements

Dani Korpi, Mona Aghababaeetafreshi, Mauno Piililä, Lauri Anttila, Mikko Valkama, Tampere University of Technology, Finland

In this paper, we propose advanced cancellation architectures for efficient digital-domain suppression of self-interference in inband full-duplex devices. The digital canceller architectures and associated signal processing algorithms are derived for a generic MIMO full-duplex transceiver, and take also into account the nonlinear distortion produced by the transmitter power amplifiers. In addition to presenting the advanced cancellation architectures, they are also evaluated using real-time processing implementations building on modern computing platforms, such as graphics processing units (GPUs) and field-programmable gate arrays (FPGAs). The obtained results demonstrate the practical real-time feasibility and high cancellation performance of the proposed advanced cancellation solutions.

TP7b-2 **3:55 PM**

Self-Interference Cancellation for Full-Duplex Wireless Communications

Tho Le-Ngoc, Robert Morawski, Ahmed Masmoudi, McGill University, Canada

The main problem of full-duplex (FD) operation is the large power difference between the self-interference (SI) and the intended signal from the other distant transmitter. This paper addresses the SI-cancellation for FD operation in presence of imperfect transceiver components. After a discussion on SI-channel characteristics, and FD transceiver structure, the paper will show that the SI can be gradually reduced by a combination of analog and digital radio-frequency (RF) and baseband (BB) cancellation stages using various signal processing and estimation techniques. In addition to analysis and simulation, experimental results on a 2x2 FD MIMO prototype system will also be discussed.

TP7b-3 **4:20 PM**

Real Time Adaptive RF and Digital Self-Interference Cancellation for Full-Duplex Transceivers

Visa Tapio, Markku Juntti, Aarno Pärssinen, Kari Rikkinen, University of Oulu, Finland

The main challenge in the FD transceiver design is the self-interference (SI). The SI cancellation requirement can be well over 100 dB necessitating both analog and digital processing. Because the SI channel can vary in time, both analog and digital SI cancellation must be adaptive. We consider both adaptive analog and baseband SI cancellation. If additional pilot symbols are used for SI cancellation, the potential gain offered by the FD transmission is compromised. We use the transmitted data signal as a pilot in the adaptation of RF cancellation and for SI channel estimation at baseband.

TP7b-4 **4:45 PM**

Full-Duplex in a Hand-held Device - From Fundamental Physics to Complex Integrated Circuits, Systems and Networks: An Overview of the Columbia FlexICoN project

Harish Krishnaswamy, Gil Zussman, Jin Zhou, Jelena Marasevic, Tolga Dinc, Negar Reiskarimian, Tingjun Chen, Columbia University, United States

Full duplex wireless is an exciting emerging communication paradigm that also poses tremendous challenges at every layer: from the antenna interface and integrated circuits and systems to the network layer. This paper covers recent advances at Columbia University across all these dimensions. Specific advances include (i) a novel CMOS passive non-reciprocal circulator, (ii) a reconfigurable polarization-based antenna cancellation technique that achieves very wideband isolation, (iii) several generations of RF/analog self-interference cancellation circuits that combat noise, distortion and bandwidth limitations, (iv) higher-layer resource allocation algorithms and evaluation of rate gains given realistic physical-layer models, and (v) demonstrations using realistic IC-based nodes.

TP7b-5 **5:10 PM**

Integrating Full-duplex Capabilities in Heterogeneous Spectrum Sharing

Wessam Afifi, Marwan Krunz, Mohammed Hirzallah, University of Arizona, United States

Driven by a persistent increase in wireless demand, spectrum sharing between heterogeneous systems has recently been the focus of extensive research. A key common concern is how to address coexistence-related interference, especially when the systems involved exhibit different protocols. In this paper, we outline a framework for exploiting full-duplex (FD) capabilities to support coexistence in a spectrum sharing environment. Besides the traditional simultaneous transmission/reception (STAR), we advocate a simultaneous transmission and sensing (STAS) mode that allows for rapid interference detection and migration to other channels. Specific examples of Wi-Fi/LTE-U coexistence and opportunistic systems are used to demonstrate the idea.

Track C – Networks

Session: TP8a1 – Network Data Analysis **1:30 PM–3:10 PM**

Chair: ***Usman Khan,*** *Tufts University*

TP8a1-1

A New Approach to Distributed Hypothesis Testing

Gil Katz, Pablo Piantanida, Merouane Debbah, CentraleSupelec, France

A distributed hypothesis testing problem is considered, where the goal is to declare the distribution of two random variables, based on their observations. Defining two error events, the error exponent of Type II is studied under a fixed constraint over the error of type I. A novel approach is presented, based on random binning. The benefits of this approach are demonstrated through an example, compared to a more traditional approach, as well as to a different binned decoding method. These performance gains are then generalized to a large set of probability distributions.

TP8a1-2

Worst-case Robust Attacks by Limited Adversaries Against Electricity Markets

Mengheng Xue, Ali Tajer, Rensselaer Polytechnic Institute, United States

False data injection attacks (FDIAs) on real-time electricity market are studied. In particular, with {\em complete information} of power network topology, adversaries can bypass the detection system and manipulates the state estimation data in order to shift the locational marginal prices (LMPs) in a desired way and make profit via virtual bidding. This paper focuses on limited adversaries with {\em imperfect information} which is modeled with bounded uncertainties and offers a framework for analyzing the attack strategies for such limited adversaries to guarantee the attacker's profitability.

TP8a1-3

Efficent and Cooperative Smart Grid Failure Control with Low Communication Overhead

Jose Cordova-Garcia, Xin Wang, Stony Brook University, United States

Failures in the transmission network compromise the proper delivery of energy in power grids. Control planned solely by an operator whose domain contains the failure cannot provide a strategy that guarantees the global stability of the grid. In this paper, we propose a distributed failure control mechanism based on cooperation agreements between different regions of a Smart Grid. Our design generates low communication overhead and makes use of only local information to enable the system to reach the global stability. Our algorithm also ensures the system to cooperate to deliver as much energy as possible to meet the global demand.

TP8a1-4

A Distributed Range-Based Algorithm for Localization in Mobile Networks

Sam Safavi, Usman Khan, Tufts University, United States

In this paper, we provide a distributed algorithm to locate an arbitrary number of agents moving in a bounded region. Assuming that each agent can estimate a noisy version of its motion and the distances to the nearby nodes, we provide a linear update to find the locations of an arbitrary number of mobile agents when they follow some convexity in their deployment and motion. We abstract the corresponding localization algorithm as a Linear Time-Varying (LTV) system and show that it asymptotically converges to the true locations of the agents under different noise conditions.

TP8a1-5
Random Matrix Improved Community Detection in Heterogeneous Networks
Hafiz Tiomoko Ali, Romain Couillet, CentraleSupelec, University of Paris-Saclay, France

A new spectral method is proposed for community detection in large dense heterogeneous networks. Our approach is based on a novel ``$ \alpha $-regularization" of the modularity matrix. We provide a consistent estimator for the choice of α inducing the most favorable community detection in worst case scenarios. We further prove that spectral clustering ought to be performed on a $1-\alpha$ regularization of the dominant eigenvectors to compensate for biases due to degree heterogeneity. Our clustering method is shown to be very promising on real world networks with competitive performances versus state-of-the-art spectral techniques developed for sparse homogeneous networks.

TP8a1-6
Distributed Learning over Multitask Networks with Linearly Related Tasks
Roula Nassif, Cédric Richard, André Ferrari, University of Nice-Sophia-Antipolis, France; Ali H. Sayed, University of California, Los Angeles, United States

Distributed optimization over networks enables agents to cooperate locally to estimate a common parameter vector, or multiple related parameter vectors. We consider multitask estimation problems over mean-square-error networks where each agent is interested in estimating its own parameter vector (task) and where the tasks are related according to a set of linear equality constraints. We assume that each agent possesses its own cost and that the constraint set is distributed over the agents. To solve the problem, a diffusion algorithm is used to estimate the optimal dual variable in a distributed manner. Simulation results show the efficiency of the strategy.

TP8a1-7
Distributed Linear Prediction of a Single Source
Kevin Wagner, Naval Research Laboratory, United States; Milos Doroslovacki, George Washington University, United States

Adaptive learning across a distributed network is an ongoing area of research. It is typically assumed that each node in the network is trying to estimate the same unknown impulse response by using its own probing signal. However, many real world applications do not fit this paradigm. In this manuscript, estimation of a signal structure produced by single source and received by distributed nodes is presented. This scenario is of great interest in speech detection, sonar, and radar applications. In this scenario, the received signals will be time-delayed and amplitude scaled versions with independent additive noises at different receivers.

TP8a1-8
A Latent Variable Clustering Method for Wireless Sensor Networks
Vladislav Vasilev, Georgi Iliev, Vladimir Poulkov, Technical University of Sofia, Bulgaria; Albena Mihovska, Aalborg University, Denmark

We develop a decentralized clustering method that can be used by individual sensors to predict the behavior of groups of sensors. The main idea behind our method is to define a specific set system (hypergraph) that has an isomorphism that is easy to detect. Because clustering is in essence an integration of elements and their relations, then detecting the isomorphism allow us to detect the appropriate integrations and, hence, clusters. The performance of the proposed method is compared with other graph clustering methods. The simulation results show that the proposed method outperforms the comparison algorithms.

Track B – MIMO Communications and Signal Processing
Session: TP8a2 – Relaying and Full Duplex Communications 1:30 PM–3:10 PM
Chair: ***Min Dong,*** *University of Ontario Institute of Technology*

TP8a2-1
Robust Message Recovery for Non-Cooperative Compute-And-Forward Relaying
Miruna Raceala-Motoc, Jan Schreck, Peter Jung, Slawomir Stanczak, Fraunhofer Heinrich Hertz Institute, Germany

Compute-and-Forward transforms collisions into decodable linear equations. Choosing those equation coefficients which maximize the computation rate at each relay is not always optimal from network perspective. A receiver may fail to recover the individual messages even when the relays successfully decoded linear combinations of the messages. We introduce an easy to implement non-cooperative practical scheme for short linear codes that focuses on the end-to-end rate and guarantees message recovery at the receiver given a successful recovery of linear combinations.

TP8a2-2
Performance Analysis for Multi-Source Multi-Relay Transmission over κ-μ Fading Channels
Shen Qian, Japan Advanced Institute of Science and Technology, Japan; Jiguang He, Markku Juntti, University of Oulu, Finland; Tad Matsumoto, Japan Advanced Institute of Science and Technology, Japan

We derive the outage probability of a multi-source multi-relay transmission system, where all the links experience κ-μ fading variations. The source-relay links are assumed to be multiple access channels. Two transmission schemes are considered for relay-destination transmission, i.e., non-orthogonal maximum ratio transmission (MRT) and orthogonal transmission with joint-decoding (JD). With or without the impact of line-of-sight component or the number of multipath clusters in channels, the outage performance of the system with JD is superior to that with MRT. Furthermore, we investigate the impact of the geometric gain based relay location and power allocation for relays on the performance.

TP8a2-3
Randomized Space-Time Codes with Imperfect Channel Estimation
Behrouz Shayesteh, Birsen Sirkeci, San Jose State University, United States

This work studies the average probability of error for randomized space-time codes (RSTCs) when channel state information (CSI) is not perfect. We show that the diversity order of RSTC using an ML(Maximum Likelihood) channel estimation technique is the same as that of RSTC with perfect CSI. However, the coding gain is affected by a factor which converges to 1 as the signal-to-noise ratio (SNR) or the number of pilot symbols utilized in the channel estimation increases. In addition, we show that as the number of relays increases the performance improves.

TP8a2-4
Joint Relay Beamforming and Receiver Processing for Multi-way Multi-antenna Relaying
Wen Li, Min Dong, University of Ontario Institute of Technology, Canada

We consider multiple users exchanging information with each other via a multi-way multi-antenna relaying. To design both relay beamforming and receiver linear processing, we formulate the joint optimization problem to maximize the minimum SINR under the relay power budget. We solve the problem by iteratively designing relay beam matrices and receiver processing matrix at each user. For the latter, both MRC receiver and ZF receiver are designed, with the MRC receiver leads to the optimal solution while the ZF receiver has lower complexity. Simulation shows that the proposed algorithm yields higher achievable sum-rate than the existing partial ZF method.

TP8a2-5
Spatial Half-duplex: Precoder Design and Experimental Evaluation
Niranjan M Gowda, Ashutosh Sabharwal, Rice University, United States

In this paper, we study spatial half-duplex, where an antenna array is partitioned such that a subset of antennas is used for transmission, and others for reception in the same time and frequency. We use transmit-precoders to partition the antennas and design optimal precoders under two approaches. In one approach, precoder minimizes self-interference, for fixed downlink-rate. In another approach, precoder maximizes downlink-rate, for fixed self-interference power. For both approaches, the problems are modeled as convex programs. We characterize the performance of precoders using over-the-air channel measurements and identify the regimes in which spatial half-duplex strictly outperforms time or frequency half-duplex.

TP8a2-6
Degrees of Freedom of Spatial Self-Interference Suppression for In-Band Full-Duplex with Inter-node Interference
Yujun Chen, Ashutosh Sabharwal, Rice University, United States

We study a three-node network with a full-duplex base-station communicating with one uplink and one downlink half-duplex node. In this network, both self-interference and inter-node interference are present. We use an antenna-theory-based channel model to study the spatial degrees of freedom of such network, and study if and how much does spatial isolation outperforms time-division (i.e. half-duplex) counterpart. Using degrees of freedom analysis, we show that spatial isolation outperforms time division, unless the angular spread of the objects that scatters to the intended users is overlapped by the spread of objects that back scatters to the receivers.

TP8a2-7
On the Achievability of Interference Alignment for Full-Duplex Cellular Networks with Multiple Antennas
Wonjae Shin, Seoul National University, Republic of Korea; Jong-Bu Lim, Samsung Electronics, Republic of Korea; Hyun-Ho Choi, Hankyong National University, Republic of Korea; Jungwoo Lee, Seoul National University, Republic of Korea

This paper studies full-duplex (FD) cellular networks, where a base station (BS) that operates in FD mode supports a set of half-duplex (HD) uplink and downlink users simultaneously. For the FD cellular networks, we develop a novel method for finding the closed-form interference alignment solution, called circular IA. The core idea behind our approach is to construct a set of loop-equations enabling interference alignment, so that beamforming vectors are sequentially determined by solving an eigenvalue problem. We show that the proposed circular IA can achieve the optimal degrees-of-freedom when the numbers of users' antennas are enough to meet derived conditions.

Track D – Signal Processing and Adaptive Systems
Session: TP8a3 – Subspaces, Covariances and Tensors 1:30 PM–3:10 PM
Chair: ***Louis Scharf,*** *Colorado State University*

TP8a3-1
Covariance Estimation in Terms of Stokes Parameters with Application to Vector Sensor Imaging
Ryan Volz, Mary Knapp, Frank Lind, Frank Robey, Massachusetts Institute of Technology, United States

Vector sensor imaging presents a challenging problem in covariance estimation when allowing arbitrarily polarized sources. We propose a Stokes parameter representation of the source covariance matrix which is both qualitatively and computationally convenient. Using this formulation, we adapt the proximal gradient and expectation maximization (EM) algorithms and apply them to multiple variants of the maximum likelihood and least squares problems. We also show how EM can be cast as gradient descent on the Riemannian manifold of positive-semidefinite matrices, enabling a new accelerated EM algorithm. Finally, we demonstrate the convergence benefits of the proximal gradient approach through implementation of acceleration methods.

TP8a3-2
Principal Subspace Estimation for Low-rank Toeplitz Covariance Matrices with Binary Sensing
Haoyu Fu, Yuejie Chi, The Ohio State University, United States

We consider estimating the principal subspace of data in decentralized sensing systems with resource constraints, where the sensors only transmit a single bit to the fusion center to minimize communication costs. In particular, the data covariance matrix is modeled as a low-rank Toeplitz positive semidefinite (PSD) matrix, which arises in many applications. Our algorithm is based on convex regularization using carefully designed one-bit measurements based on comparing the energy projections of the data seen at each sensor onto pairs of randomly selected Gaussian vectors. Numerical experiments demonstrate the method outperforms existing approaches that do not consider the Toeplitz structure.

TP8a3-3
Complexity and Search Space Reduction in Cyclic-by-Row PEVD Algorithms
Fraser Coutts, Jamie Corr, Keith Thompson, Stephan Weiss, University of Strathclyde, United Kingdom; Ian Proudler, Loughborough University, United Kingdom; John McWhirter, Cardiff University, United Kingdom

In recent years, several algorithms for the iterative calculation of a polynomial matrix eigenvalue decomposition (PEVD) have been introduced. The PEVD is a generalisation of the ordinary EVD and uses paraunitary operations to diagonalise a parahermitian matrix. This paper addresses potential computational savings that can be applied to existing cyclic-by-row approaches for the PEVD. These savings are found during the search and rotation stages, and do not significantly impact on algorithm accuracy. We demonstrate that with the proposed techniques, computations can be significantly reduced. The benefits of this are important for a number of broadband multichannel problems.

TP8a3-4
Investigation of a Polynomial Matrix Generalised EVD for Multi-Channel Wiener Filtering
Jamie Corr, Jennifer Pestana, Stephan Weiss, University of Strathclyde, United Kingdom; Soydan Redif, European University of Lefke, Cyprus; Marc Moonen, KU Leuven, Belgium

State of the art narrowband noise cancellation techniques utilise the generalised eigenvalue decomposition (GEVD) for multichannel Wiener filtering which can be applied to independent frequency bins in order to achieve broadband processing. Here we investigate the extension of the GEVD to broadband, polynomial matrices, akin to strategies that have already been developed by McWhirter et. al on the polynomial matrix eigenvalue decomposition (PEVD).

TP8a3-5
Maximum Likelihood Identification of an Information Matrix Under Constraints in a Corresponding Graphical Model
Randy Paffenroth, Nan Li, Worcester Polytechnic Institute, United States; Louis Scharf, Colorado State University, United States; Myung Hee Lee, Weill Cornell Medical College, United States

This paper is addressed to the problem of identifying the neighborhood structure of an undirected graph, whose nodes are labeled with the elements of a multivariate normal (MVN) random vector. A semi-definite program is given for estimating the information matrix under arbitrary constraints on its elements. More importantly, a closed-form expression is given for the maximum likelihood (ML) estimator of the information matrix, under the constraint that the information matrix has pre-specified elements in a given pattern (e.g., in a principal submatrix). The results apply to the identification of dependency labels in a graphical model with neighborhood constraints.

Track G – Architecture and Implementation
Session: TP8b1 – Computer Arithmetic II **3:30 PM–5:35 PM**
Chair: ***Pascal Giard,*** *EPFL*

TP8b1-1
Optimized Memristor-Based Ripple Carry Adders
Lauren Guckert, Earl Swartzlander, Jr., University of Texas at Austin, United States

This work presents improved implementations of memristor-based ripple carry adders using three different approaches: the IMPLY operation, hybrid-CMOS gates, and threshold gates. The designs are optimized by performing parallel operations, leveraging computational redundancies, and recognizing Boolean simplifications. The proposed IMPLY N-bit ripple carry adder decreases the area by 2N-1 components and latency by 3N-1 as compared to the previous state-of-the-art. The hybrid approach improves upon the area in prior work by 4N memristors and 8N MOSFETs while maintaining the same delay. The threshold gate approach is novel and requires only N+1 gate delays and 7N memristors.

TP8b1-2
Computing Subtraction and Polynomial Computation using Unipolar Stochastic Logic
Yin Liu, Keshab Parhi, University of Minnesota, Twin Cities, United States

This paper addresses subtraction and polynomial computations using unipolar stochastic logic. This paper makes two major contributions. First, two approaches are proposed to compute subtraction in stochastic unipolar representation. In the first approach, the subtraction operation is approximated by cascading multi-levels of OR and AND gates. The accuracy of the approximation is improved with the increase in the number of stages. In the second approach, the stochastic subtraction is implemented using a multiplexer and a stochastic divider. Second, polynomial computation in stochastic unipolar format is addressed based on the proposed implementations of stochastic subtraction.

TP8b1-3
Precise Digital Implementations of Hyperbolic Tanh and Sigmoid Function
Shaghayegh Gomar, Mitra Mirhassani, Majid Ahmadi, University of Windsor, Canada

Sigmoid and Hyperbolic Tangent are widely used as activation functions in artificial neural networks. Exponential term and division are basic building blocks of these functions. This paper proposes precise and efficient hardware implementations for sigmoid and hyperbolic tangent functions using exponential function approximation. The performance of both functions has been verified which shows that the proposed implementations have up to 99.97% similarity with the ideal transfer functions while the circuits take maximum 2% of logic resources when implemented on a Vertex IV FPGA .

TP8b1-4
Optimized Multipartite Table Methods for Elementary Functions Computation
James Stine, Masoud Sadeghian, Oklahoma State University, United States

This paper presents an optimization method for computing an optimum lookup table size for two well-known look up table elementary function approximation methods; Symmetric Table Additional Method (STAM) and Multipartite Table Method (MTM). Using a discrete optimization algorithm called Leapfrogging, this paper utilizes a method to find the best decomposition of the coefficients to optimize look up table sizes.

TP8b1-5
Radix-4 Energy Efficient Carry-Free Truncated Multiplier
Wen Yan, Beijing Institute of Technology, China; Milos Ercegovac, University of California, Los Angeles, United States

A radix-4 energy efficient carry-free truncated multiplier is proposed and designed. The final product is obtained in parallel with the reduction of partial products in carry-save form using an improved on-the-fly conversion of O(n) size based on conditional adders. In addition to the proposed multiplier, several right-to-left, left-to-right multipliers and a Dadda tree multiplier for various precisions are designed, synthesized in 90nm technology and compared, demonstrating the advantages of the proposed design. Our proposed multiplier has lower delay (except a tree multiplier), area, power and energy than other types of multipliers, and this advantage grows with the increase in precision.

Track H – Speech, Image and Video Processing
Session: TP8b2 – Image and Video Sensor Processing and Communications
3:30 PM–5:35 PM

Chair: ***Sally Wood,*** *Santa Clara University*

TP8b2-1
Focal Plane Processing for HOG Detection with Bayer Pattern Sensors
Allen Rush, Sally Wood, Santa Clara University, United States

The efficiency and accuracy of keypoint detection can potentially be improved using filters designed to operate directly on the raw Bayer pattern image using Histogram of Oriented Gradients (HOG). In applications where the objective is detection and identification of image content rather than the production of an image for human viewing, demosaicing would not be necessary. For focal plane processing, filter structures can be mapped to the Bayer pattern, and take into account the subsampling of the pixel data prior to full demosaic interpolation. The results show the similarity of HOG descriptors compared to standard common rendering techniques.

TP8b2-2
Performance of Maximum Likelihood Temperature/Emissivity Separation of Hyperspectral Images with Correlated Gaussian Downwelling Radiance
David Neal, Todd Moon, Jacob Gunther, Utah State University, United States; Gus Williams, Brigham Young University, United States

Temperature/Emissivity separation is desirable in hyperspectral image processing in order to extract the emissivity spectra and temperature of the materials in the image. We review a model for the hyperspectral image pixels for which a maximum likelihood estimator can be used for temperature and emissivity separation. We report on the performance of this model, including estimation bias. A natural solution to bias of increasing the amount of data supplied to the model shows that this bias can be reduced.

TP8b2-3
Spatially Scalable Video Broadcasting in Multiple Antenna Systems
Arash Vosoughi, LG Electronics, United States; Seok-Ho Chang, Dankook University, Republic of Korea; Sang-Hyo Kim, Sungkyunkwan University, Republic of Korea; Pamela Cosman, Laurence Milstein, University of California, San Diego, United States

We propose an efficient multiple-input multiple-output video broadcasting technique that well serves different types of users residing inside the service area. We consider a scenario in which heterogeneous users with different display resolutions, different operating bit rates, and different numbers of receive antennas are present. Our proposed scheme adopts spatially scalable

video coding, and makes use of both spatial diversity and spatial multiplexing techniques. We compare the performance of our proposed scheme with that of a non-scalable video transmission scheme. Simulation results show that our proposed scheme significantly outperforms the non-scalable video broadcasting strategy.

Track F – Biomedical Signal and Image Processing

Session: TP8b3 – Processing of Physiological Signals 3:30 PM–5:35 PM

Chair: ***Antonia Papandreou-Suppappola,*** *Arizona State University*

TP8b3-1

Modeling the P300-based Brain-computer Interface as a Channel with Memory

Vaishakhi Mayya, Boyla Mainsah, Galen Reeves, Duke University, United States

The P300 speller is a brain-computer interface (BCI) that enables people with severe neuromuscular disorders communicate based on electroencephalography (EEG) measurements. One of the challenges to fast and reliable communication is the fact that the P300-based event related potential has a refractory period that induces temporal dependence in the user's EEG responses. The contribution of this paper is to model the P300 speller as finite-state communication channel with memory and to design flash patterns that maximize the mutual information rate between the target characters and the measured EEG responses.

TP8b3-2

The Addition of Adaptive Comb Filtering to Sequential Adaptive Processing for Fetal Electrocardiograms (ECGs)

Yuqing Dong, Jacob Kovarskiy, William Jenkins, Pennsylvania State University, United States

Previously published results demonstrated that a sequential combination of adaptive linear prediction (LPC), adaptive noise cancellation (ANC), and non-adaptive (fixed) IIR comb filtering (CF) can effectively remove maternal interference from noninvasive fetal ECGs. This paper presents results obtained by replacing the third stage fixed IIR comb filtering (CF) with adaptive comb filtering (ACF). In this work the fixed IIR comb filtering is replaced by FIR adaptive comb filtering based on two distinct forms of the ACF adaptive algorithms. Experimental results illustrate that sequential LPC-ANC processing followed by the newly proposed adaptive comb filtering is an effective form of sequential processing.

TP8b3-3

Fast Respiratory Rate Estimation from PPG Signal Using Sparse Signal Reconstruction Based on Orthogonal Matching Pursuit

Xiaorong Zhang, San Francisco State University, United States; Quan Ding, The Home Depot Techshed, United States

Fast and accurate respiratory rate (RR) estimation from photoplethysmography (PPG) signal is still a challenging problem. In this paper, we propose a real-time algorithm for RR estimation from PPG signal using sparse signal reconstruction (SSR) based on orthogonal matching pursuit (OMP). This algorithm greatly reduces the computational complexity of the original sparse signal reconstruction and respiratory rate tracking (S2R3T) algorithm. While the proposed algorithm and a state-of-the-art real-time algorithm based on smart fusion of RR estimates from three respiratory modulations have similar estimation accuracy, the proposed algorithm outperforms the smart fusion algorithm in number of RR estimates.

TP8b3-4

Modeling of Oxygen Saturation and Respiration for Sleep Apnea Detection

Sandeep Gutta, Qi Cheng, Oklahoma State University, United States

Sleep apnea is a serious sleep disorder affecting millions of people. With the availability of several low-cost physiological sensors, there is a growing research interest to develop a low-cost sleep apnea detection system. Existing sleep apnea detection methods are data-driven and process different sensor information independently, which is not optimal. Combining different sensor data with the cardiorespiratory system models can greatly help to create a better sleep apnea detection system. In this paper, we propose a mathematical model relating the oxygen saturation level to the respiration signal. The model parameters are estimated by solving a nonlinear least squares optimization problem.

TP8b3-5
Do Retinal Ganglion Cells Project Natural Scenes to Their Principal Subspace?
Reza Abbasi-Asl, University of California, Berkeley, United States; Cengiz Pehlevan, Simons Foundation, United States; Bin Yu, University of California, Berkeley, United States; Dmitri B. Chklovskii, Simons Foundation, United States

Retinal ganglion cells reduce the dimensionality of input signal from photoreceptors, as evidenced by their significantly (~10-100 times) lower numbers. However, the nature of this dimensionality reduction is poorly understood. Here we test a normative theory that the activity of ganglion cell population represents a projection of visual stimulus onto its principal subspace (PS). To test the theory, we use recordings from 152 ganglion cells in salamander retina responding to natural movies. The theory of PS projection predicts the matching of the right singular vectors of stimulus and response covariance matrices and explains the relationship between their singular values.

TP8b3-6
Surface charge method for the forward EEG problem
Francisco J. Solis, Antonia Papandreou-Suppappola, Arizona State University, United States

Many electroencephalographic (EEG) studies can be interpreted assuming the presence of localized sources in the brain. Filtering methods for the determination of the sources require the solution of the associated forward problem, finding the electric potential due to prescribed sources. This presentation will show that the forward problem can be solved for arbitrary head shapes using an integral equation for the excess charge at physiological interfaces. This formulation leads to algorithms that are efficient and robust. In particular, these avoid the deflation requirement of currently available methods based on the Geselowitz integral equations for the electric potential.

Track G – Architecture and Implementation
Session: WA1a – Approximate Computing and Fault Tolerance
Co-Chairs: ***Andrew Singer,*** *University of Illinois at Urbana Champaign* ***and Pulkit Grover,*** *Carnegie Mellon University*

WA1a-1 8:15 AM
Approximate and Error-Tolerant Computing: From Shannon-Theory to Circuits
Pulkit Grover, Carnegie Mellon University, United States; Andrew Singer, University of Illinois at Urbana Champaign, United States

What is the minimum energy required to compute reliably using error-prone nanofabrics, given an energy-reliability tradeoff for any single nanofunction? With saturation of Moore's law (and Dennard's scaling), this question is becoming increasingly important as researchers seek alternatives to ultra-reliabe CMOS devices. This paper reviews recent progress on the question from a theoretical perspective, developed in conjunction with progress in device design.

WA1a-2 8:40 AM
Energy Efficiency Limits in Approximate Computing: A Fundamental Physical Perspective
Neal Anderson, University of Massachusetts Amherst, United States

Approximate computing offers pathways to increased energy efficiency in computational settings where absolute precision is not required. In this work, we explore fundamental links between computational precision, information loss, and limiting energy efficiency. We show how imprecision in digital information processing—whether of deterministic or non-deterministic origin—is properly described at a fundamental physical level, and how it can be quantified in physical-information-theoretic measures that directly link loss of input information to energy dissipation. We then present fundamental energy efficiency bounds, expressed in terms of these measures, and illustrate their evaluation for simple scenarios relevant to approximate computing.

WA1a-3 **9:05 AM**

Flash Memories in High Radiation Environments: LDPC Decoder Study

Frederic Sala, Clayton Schoeny, Shahroze Kabir, University of California, Los Angeles, United States; Dariush Divsalar, NASA Jet Propulsion Laboratory, United States; Lara Dolecek, University of California, Los Angeles, United States

Flash memories are now being used as onboard memory in satellites and space probes. In deep space applications, high levels of radiation can have severe effects on memory operation. In this work, we study the feasibility of LDPC codes in Flash when subjected to high levels of radiation. We derive fundamental performance limits of such noisy decoders. Our results can have immediate applications on the system design and deployment of Flash memories in deep space technologies.

WA1a-4 **9:30 AM**

Analog Processing to Enable Scalable High-Throughput mm-Wave Wireless Fiber Systems

Mahmoud Sawaby, Stanford University, United States; Babak Mamandipour, Upamanyu Madhow, University of California, Santa Barbara, United States; Amin Arbabian, Stanford University, United States

Commercial mm-wave systems are addressing a variety of applications in communication and radar. However, scaling of these systems to larger throughputs and spatial coverage is limited by hardware constraints. This work explores challenges in the silicon integration of scalable high-throughput "Wireless Fiber" links that use the spatial and spectral degrees of freedom by exploiting multiplexing in LoS MIMO environments and at extremely high bandwidths. We examine tradeoffs in the partitioning of functionality between the transmitter and receiver as well as the analog and digital domains and investigate a new scalable analog processing architecture for the receiver network.

Track A – Communications Systems

Session: WA1b – Communication System Development

Chair: ***Raghuraman Mudumbai,*** *University of Iowa*

WA1b-1 **10:15 AM**

Maximizing Wireless Power Transfer using Distributed Beamforming

Sairam Goguri, University of Iowa, United States; Dennis Ogbe, Purdue University, United States; Raghuraman Mudumbai, University of Iowa, United States; David Love, Purdue University, United States; Soura Dasgupta, University of Iowa, United States; Patrick Bidigare, BBN Technologies, United States

We consider the problem of maximizing wireless signal power delivered by a distributed antenna array to a receiver, where nodes have known frequency-selective channels to the receiver and are subject to individual transmit power constraints. This problem is mathematically different from the power maximization problems involving single transmitters or narrowband systems. We show that the maximization involves the nodes performing distributed beamforming while concentrating their power in a small, finite set of frequencies. We derive properties and describe an iterative algorithm to compute the solution. We show using simulations that power maximization problem yields larger power compared to alternatives.

WA1b-2 **10:40 AM**

Digitally Enhanced Inter-modulation Distortion Compensation in Wideband Spectrum Sensing

Han Yan, Danijela Cabric, University of California, Los Angeles, United States

The wideband spectrum sensing is vulnerable to interferers and blockers due to inter-modulation distortion (IMD) that arises in nonlinear front-end. Traditional DSP-enhanced receivers use least mean squares (LMS) filters to mitigate IMD. We theoretically study the performance of LMS-based algorithm and give expression of its residual distortion power. We then propose a novel compensation algorithm that outperforms LMS. Compared with LMS, our algorithm improves the effective spurious-free dynamic range by 10 dB. In sensing signals under 0 dB SNR, receivers with our solution tolerate 5 dB stronger interferers than those adopting LMS.

WA1b-3 **11:05 AM**

Hybrid Analog-Digital Transceiver Designs for Cognitive Radio Millimiter Wave Systems

Christos G. Tsinos, Sina Maleki, Symeon Chatzinotas, Bjorn Ottersten, University of luxembourg, Luxembourg

Recent advances in Milimeter wave (mmWave) band mobile communications provide solutions to the increasing traffic demand by extending the available spectrum. However, such a system needs to coexist with the incumbent services in this band. Two underlay cognitive hybrid transceiver designs are considered in this paper in order to gain access to the mmWave spectrum

without interfering the incumbent users. As it is shown by indicative simulations, the proposed approaches achieve close performance to the one of the corresponding digital only transceiver while having lower requirements in hardware and power consumption.

Track A – Communications Systems

Session: WA2a – Physical Layer Security

Co-Chairs: ***Rafael Schaefer,*** *TU Berlin* ***and Mario Goldenbaum,*** *Princeton University*

WA2a-1 8:15 AM

Keyless Authentication over Noisy Channel

Wenwen Tu, Lifeng Lai, Worcester Polytechnic Institute, United States

We consider the problem of keyless message authentication over noisy channels in the presence of active adversaries. In our model, the legitimate users do not have any pre-shared key for authentication. Instead, we use the noisy channel connecting the legitimate users for authentication. The main idea is to utilize the noisy channel to generate an output that is difficult for the adversary to replicate, and then use this output to distinguish legitimate messages from fake messages. For a given message rate, we investigate the speed at which the optimal successful attack probability can be driven to zero.

WA2a-2 8:40 AM

Secure Computation of Linear Functions over Linear Discrete Multiple-Access Wiretap Channels

Mario Goldenbaum, Princeton University, United States; Holger Boche, Technical University of Munich, Germany; H. Vincent Poor, Princeton University, United States

In this paper, a joint source-channel coding approach is taken to the problem of securely computing a function of distributed sources over a multiple-access wiretap channel that is linear with respect to a finite field. It is shown that if the joint source distribution fulfills certain conditions and the function to be computed matches the linear structure of the channel, secrecy comes for free in the sense that the fundamental limit (i.e., the secrecy computation capacity) is achieved without the need for stochastic encoding. Furthermore, the legitimate receiver does not need any advantage over the eavesdropper.

WA2a-3 9:05 AM

Physical Layer Based Authentication Without Phase Detection

Sarah Rumpel, Anne Wolf, Eduard A. Jorswieck, Technische Universität Dresden, Germany

Authentication on the physical layer is proposed to enhance the security of communication. Some authentication techniques assume high SNR to use the phase of the received signal for the hypothesis test. We study the probability of errors of the hypothesis test under the assumption that the phase of the received signal cannot be measured accurately. Thus the decision is based on the absolute value of the received signal. As the test does not necessarily need a high SNR for the detection of the correct phase, it is more robust. We compare this approach with recent approaches, which consider the phase.

WA2a-4 9:30 AM

Private Authentication with Controllable Measurement

Kittipong Kittichokechai, Rafael F. Schaefer, Giuseppe Caire, Technische Universität Berlin, Germany

We consider the problem of secret key-based authentication under a privacy constraint on the enrolled source data. The user's measurement in the authentication phase is assumed to be controllable through a cost-constrained ``action" sequence. We provide a single-letter characterization of the optimal tradeoff among the communication rate, leakage rate, secret key rate and action cost. The result can be relevant for several user authentication scenarios including hardware-based authentication and biometric authentication with multiple measurements.

Track B – MIMO Communications and Signal Processing

Session: WA2b – Massive MIMO in the Field

Chair: ***Lars Thiele,*** *Fraunhofer Heinrich Hertz Institute*

WA2b-1 **10:15 AM**

Massive MIMO Proof-of-Concept: Emulations and Hardware-in-the-Loop Field Trials at 3.5 GHz

Thomas Wirth, Lars Thiele, Martin Kurras, Matthias Mehlhose, Thomas Haustein, Fraunhofer Heinrich Hertz Institute, Germany

Massive MIMO (M-MIMO) is commonly considered as one of the key technology enablers for 5G to solve the 10,000-fold capacity increase in use cases such as eMBB. The gains of M-MIMO heavily depends on the user distribution and movement, as well as on the deployment of the M-MIMO antennas. In order to better understand the achievable M-MIMO benefits and to measure the performance gains for individual users in a multi-user scenario, a new evaluation methodology is required. Therefore, a combination of hardware proof-of concept combined with radio network evaluations is a key to show benefits of the M-MIMO technology.

WA2b-2 **10:40 AM**

Directional Propagation Measurements and Modeling in an Urban Environment at 3.7 GHz

Leszek Raschkowski, Stephan Jaeckel, Fabian Undi, Lars Thiele, Wilhelm Keusgen, Fraunhofer Heinrich Hertz Institute, Germany; Boonsarn Pitakdumrongkija, Masayuki Ariyoshi, NEC Corporation, Japan

In order to realistically model urban micro-cell environments with low base station heights, a measurement campaign has been conducted in the 3.5 - 3.8 GHz frequency band. The two scenarios of interest are the Urban Micro (UMi) Campus and Open Square scenarios. The findings of this campaign led to a parameter set for the quasi deterministic radio channel generator (QUADRIGA) channel model and shall be used to improve accuracy in small-cell network design and evaluation towards 5G. This report includes details about the measurement array antenna as well as the approach of data analysis and postprocessing.

WA2b-3 **11:05 AM**

Massive MIMO Properties based on Measured Channels: Channel Hardening, User Decorrelation and Channel Sparsity

Alex Oliveras Martinez, Elisabeth De Carvalho, Jesper Ødum Nielsen, Aalborg University, Denmark

Three prominent features of massive MIMO are studied using channel measurements. Those features are extensively exploited in signal processing methods for massive MIMO and have been only partially, or not at all, validated. First, channel hardening is characterized as a function of the number of antennas. Second, user decorrelation is evaluated as a function of the distance between users. At last, the sparsity of the channel, proposed as a basis for pilot contamination and frequency division duplexing operation, is assessed. The whole study is based in two measurement campaigns involving a base station with 64 antennas and 128 antennas.

Track C – Networks

Session: WA3a – Cognitive Networking

Chair: ***Tara Javidi,*** *University of California, San Diego*

WA3a-1 **8:15 AM**

On the Equivalence Between Information Acquisition-Utilization and Generalized Tracking

Tara Javidi, University of California, San Diego, United States

This paper focuses on the problem of information acquisition and utilization where a decision maker, by carefully controlling a sequence of actions with uncertain outcomes, dynamically refines his/her belief about stochastically time-varying state in order to utilize a system of interest as efficiently as possible. It is shown that in the special case of Markovian dynamics, this problem can be mapped to a generalized tracking of a Markov source in Noise. Furthermore, under regularity conditions on the observation noise, the optimal information acquisition is shown to solve a dynamic programming equation and to ensure stochastically stationary of the belief state.

WA3a-2 **8:40 AM**

Correlation-Aware Sensing in Active and Passive Modes for Source Localization

Ali Koochakzadeh, Heng Qiao, Pia Pal, University of Maryland, College Park, United States

It has been recently shown that the idea of "correlation-aware" sensing can enhance the performance of traditional sparse estimation, by exploiting the correlation of signals alongside their sparse representation. In this paper, we will investigate the benefits of correlation-aware sensing for active sensor arrays (e.g. those used in the tracking mode of a radar) that transmit electromagnetic waveforms (often specially designed) and collect their reflections from targets of interest. In this case, a combination of sum and difference sets will determine the effective aperture and degrees–of-freedom of the correlation-aware active sensor array, leading to new spatial sampling geometries.

WA3a-3 **9:05 AM**

Approximate K-Means++ in Sublinear Time

Hamed Hassani, ETH, Switzerland

The quality of K-Means clustering is extremely sensitive to proper initialization. The classic remedy, called K-means++, uses a seeding procedure to obtain an initial set of centers that is provably competitive with the optimal solution. Unfortunately, K-means++ requires K full passes over the data. We propose simple and efficient seeding algorithms for K-Means based on Markov Chain Monte Carlo sampling. Under mild assumptions, the proposed algorithms retain the full theoretical guarantees of K-means++ with a computational complexity that is only sublinear in K. As a corolary, for any dataset a provably good clustering with sublinear complexity can be obtained.

WA3a-4 **9:30 AM**

A POMDP Approach for Active Collision Detection via Networked Sensors

Daphney-Stavroula Zois, University of Illinois, Urbana Champaign, United States

Accidents, construction zone closures and weather hazards exacerbate the already congested transportation network. Timely detection of such events can offer an unprecedented opportunity. In this paper, a partially observable Markov decision process (POMDP) framework is proposed for continuous active collision detection in a road segment equipped with spatially distributed speed sensors of variable accuracy. To this end, sensor selection strategies in combination with a Kalman-like filter are designed and proposed that can quickly estimate the existence of a collision. The efficacy of the proposed strategies is shown on real data collected on the 405 freeway in the Los Angeles County.

Track E – Array Signal Processing

Session: WA3b – Signal Processing with Lattices

Chair: ***Vaughan Clarkson,*** *University of Queensland*

WA3b-1 **10:15 AM**

Convolutional Lattices

Joseph Boutros, Nicola Di Pietro, Texas A&M University at Qatar, Qatar; Fanny Jardel, Télécom Paristech, France

Real convolutional lattices over the ring of integers Z are considered in this paper. A new family of convolutional lattices is proposed. Why are we considering convolutional lattice structures? Their main interesting property is causality. Convolutional lattices allow for causal encoding and causal decoding, hence they are suited to control applications where feedback should be produced almost in real time. Previous work on convolutional lattices was made over complex fields. Also, turbo-like lattices were proposed for low spectral efficiency. Our target is to build high spectral efficiency coded modulations (based on lattices) for control and communication systems.

WA3b-2 **10:40 AM**

Typical Sumsets of Lattice Points

Jingge Zhu, Michael Gastpar, École polytechnique fédérale de Lausanne, Switzerland

From a given subset of n-dimensional integer lattices, we independently pick two points uniformly at random. A sumset is formed by adding these two points component-wise and a sumset is called typical, if the sum falls inside this set with high probability. In this paper we characterize the asymptotic size of the typical sumsets for large n, and show that the typical sumset size exhibits a phase transition when the density of the subset exceeds certain value. We also comment on how these results connect to certain channel coding schemes with linear codes.

WA3b-3 **11:05 AM**

Lattice Parameter Estimation from Sparse, Noisy Measurements

Vaughan Clarkson, University of Queensland, Australia; Robby McKilliam, Myriota Pty Ltd, Australia; Barry Quinn, Macquarie University, Australia

We consider a situation in which a number of points are observed in n-dimensional space, each point arising from an underlying lattice or translate. Each observation is noisy in that it is randomly, additively displaced from a lattice point. The observations are sparse in the sense that a ball containing all observations contains many more lattice points than observations. Our problem is to estimate the lattice parameters accurately. This problem is important, for instance, in blind detection for communications. We present initial results in which the parameters of a square lattice are estimated using a generalisation of Bartlett's point-process periodogram.

Track D – Signal Processing and Adaptive Systems

Session: WA4a – Decentralized Optimization and Learning

Co-Chairs: ***Cédric Richard,*** *Université de Nice Sophia-Antipolis* ***and Pascal Bianchi,*** *Telecom ParisTech*

WA4a-1 **8:15 AM**

Doubly Stochastic Algorithms for Large-Scale Optimization

Alec Koppel, Aryan Mokhtari, Alejandro Ribeiro, University of Pennsylvania, United States

This paper considers a class of parallel doubly stochastic algorithms for solving large-scale optimization problems that arise in machine learning. The proposed methods are doubly stochastic since at each iteration they use stochastic approximations of gradients instead of gradients -- a subset of samples -- and update only a subset of coordinates of the optimization variable in parallel instead of the full vector -- a subset of features. We establish the convergence of these methods and demonstrate their utility on a logistic regression example. Further, we observe performance gains relative to methods which are not stochastic either in gradient evaluation or coordinate updates.

WA4a-2 **8:40 AM**

On Hypothesis Testing in Networks

Angelia Nedich, Alexander Olshevsky, Cesar Uribe, University of Illinois, United States

We consider a hypothesis testing problem in a network of agents. We propose a distributed algorithm for solving the problem by combining Bayes rule with consensus technique. The algorithm is motivated by an optimization formulation of the hypothesis testing problem. We also investigate convergence rate properties of the proposed algorithm. We also provide some simulation results that illustrate the behavior of the algorithm.

WA4a-3 **9:05 AM**

Expander Graph and Communication-Efficient Decentralized Optimization

Yat-Tin Chow, University of California, Los Angeles, United States; Wei Shi, University of Illinois at Urbana Champaign, United States; W Yin, University of California, Los Angeles, United States

This paper discusses how to perform decentralized optimization with the least amount of communication. Our goal is to minimize the total communication that is needed to achieve a prescribed accuracy. Our answer is expander graphs. Based on the relationship between total communication cost and graph topology, we deduce the (near) optimality of expander graphs. We propose to apply three approaches to construct expander graphs corresponding to different restrictions allowed to make on the graphs. We numerically demonstrate the significantly improved performance using the generated expander graphs for decentralized optimization, over using the graphs that are recommended for consensus averaging.

WA4a-4 **9:30 AM**

An Empirical Comparison of Multi-Agent Optimization Methods for Distributed Learning

Mahmoud Assran, Michael Rabbat, McGill University, Canada

The past decade has seen intense research in the development of multi-agent methods for distributed convex optimization. This includes both the development of a variety of algorithms, as well as theoretical analysis of their convergence behaviour. These analyses are based on assumptions which do not always hold in practice. In this paper we aim to understand how different methods in the literature behave when implemented in a practical environment. We will report the results of experiments on a cluster using multi-agent optimization methods for a variety of benchmark problems, ranging from quadratic programs to models drawn from machine learning.

Track D – Signal Processing and Adaptive Systems

Session: WA4b – Modelling and Inference with Graphs

Chair: ***Georgios Giannakis,*** *University of Minnesota*

WA4b-1 **10:15 AM**

Semi-parametric Reconstruction of Signals over Graphs

Vassilis N. Ioannidis, Daniel Romero, Georgios B. Giannakis, University of Minnesota, United States

Signals evolving over graphs emerge naturally in a number of network science related applications. A frequently encountered challenge pertains to reconstructing such signals given their values over a subset of vertices. Existing approaches either employ parametric estimators under a bandlimited signal model, or, they pursue general nonparametric kernel-based approaches. Whereas the former are not tailored for non-bandlimited signals, the latter cannot readily accommodate prior information. This contribution develops a semi-parametric approach capable of estimating non-bandlimited signals, while efficiently capturing a priori known structure. Numerical tests with synthetic and real data corroborate that judiciously incorporating prior information markedly improves reconstruction performance.

WA4b-2 **10:40 AM**

Hierarchical Representations of Network Data with Optimal Distortion Bounds

Zane Smith, Samir Chowdhury, Facundo Memoli, The Ohio State University, United States

Single linkage hierarchical clustering is a tool in unsupervised learning which has been fully characterized for finite metric spaces, but not for the unrestricted setting of general networks. We follow a recent line of work to complete the characterization for general networks, and moreover, we provide quantitative bounds on how much information is lost when applying our method to network data. These bounds are novel even in the setting of finite metric spaces. Finally, we propose a construction called a treegram that provides a visual summary of the result of applying our method to a network data set.

WA4b-3 **11:05 AM**

Efficient Graph Signal Recovery over Big Networks

Gabor Hannak, Peter Berger, Gerald Matz, Vienna University of Technology, Austria; Alexander Jung, Aalto University, Finland

We consider the problem of recovering a smooth graph signal from noisy samples taken at a small number of graph nodes. The recovery problem is formulated as a convex optimization problem which minimizes the total variation (accounting for the smoothness of the graph signal) while controlling the empirical error. We solve this total variation minimization problem efficiently by applying a recent algorithm proposed by Nesterov for non-smooth optimization problems. Furthermore, we develop a distributed implementation of our algorithm and verify the performance of our scheme on a large-scale real-world dataset.

Track E – Array Signal Processing

Session: WA5 – Tensor Signal Processing

Chair: ***Nicholas D. Sidiropoulos,*** *University of Minnesota*

WA5-1 **8:15 AM**

First-Order Perturbation Analysis of Low-Rank Tensor Approximations Based on the Truncated HOSVD

Emilio Rafael Balda, Sher Ali Cheema, Jens Steinwandt, Martin Haardt, Ilmenau University of Technology, Germany; Amir Weiss, Arie Yeredor, Tel-Aviv University, Israel

The truncated version of the HOSVD has a great significance in multi-dimensional tensor-based signal processing. It allows to extract the principal components from noisy observations in order to find a low-rank approximation of the multi-dimensional data. In this paper, we address the question of how good the approximation is by analytically quantifying the tensor reconstruction error introduced by the truncated HOSVD. We present a first-order perturbation analysis of the truncated HOSVD to obtain analytical expressions for the signal subspace error in each dimension as well as the tensor reconstruction error induced by the low-rank approximation of the noise corrupted tensor.

WA5-2 **8:40 AM**

Extension of the Semi-Algebraic Framework for Approximate CP Decompositions via Simultaneous Matrix Diagonalization to the Efficient Calculation of Coupled CP Decompositions

Kristina Naskovska, Martin Haardt, Ilmenau University of Technology, Germany

Several combined signal processing applications such as the joint processing of EEG and MEG data can benefit from coupled tensor decompositions. The coupled CP (Canonical Polyadic) decomposition jointly decomposes tensors that have at least one factor matrix in common. The SECSI (Semi-Algebraic framework for approximate CP decomposition via SImultaneaous matrix diagonalization) framework is an efficient tool for the calculation of the CP decomposition based on matrix diagonalizations. In this paper, we present an extension of the SECSI framework to the efficient calculation of coupled CP decompositions and show its advantages compared to the traditional solution via alternating least squares (ALS).

WA5-3 **9:05 AM**

Tensorlab 3.0 – Numerical Optimization Strategies for Large-Scale (Constrained, Coupled) Matrix/Tensor Factorization

Nico Vervliet, Otto Debals, Lieven De Lathauwer, KU Leuven, Belgium

We give an overview of recent developments in numerical optimization-based computation of tensor decompositions supporting Tensorlab 3.0 (www.tensorlab.net). By careful exploitation of tensor product structure in methods such as quasi-Newton and nonlinear least squares, good convergence is combined with fast computation. A modular approach extends the computation to coupled factorizations and structured factors. In the case of large data sets, compact representations (polyadic, Tucker, ...) may be obtained by stochastic optimization, randomization, compressed sensing, ... Careful exploitation of the representation structure allows us to scale the algorithms for constrained/coupled factorizations to large problem size. The discussion is illustrated with application examples.

WA5-4 **9:30 AM**

Inferring Directed Network Topologies via Tensor Factorization

Yanning Shen, Brian Baingana, Georgios Giannakis, University of Minnesota, United States

Complex directed networks underlie many biological, social, and financial phenomena, to name just a few. With often hidden network structures, topology inference approaches capitalizing on measurable nodal processes abound, with structural equation models (SEMs) playing a prominent role. Although SEMs can resolve directional ambiguities by incorporating exogenous inputs, this assumes full knowledge of such inputs, which may not be practically possible. This paper advocates a tensor-based approach that leverages the PARAFAC decomposition, using only second-order statistics of exogenous variables. Leveraging uniqueness properties of high-order tensor factorizations, it is empirically shown that topology identification is possible under reasonably mild conditions.

BREAK **9:55 AM**

WA5-5 **10:15 AM**

Robust PCA via Tensor Outlier Pursuit

Jineng Ren, Xingguo Li, University of Minnesota, United States; Jarvis Haupt, University of Minnesota, Twin Cities, United States

Robust principle component analysis (RPCA) on tensor, as a generalization of RPCA on matrices, has become increasing important to modern data analysis. In this paper, we study the robust tensor principle component analysis (RTPCA), when frame-wise outliers exist. Theoretically, we guarantee that exact subspace recovery and outlier identification may be achieved under mild model assumptions. Besides, we demonstrate that our approach can handle higher ranks and proportion of outliers than entry-wise outlier pursuit and naive matricization of tensor when there is slice-wise corruption. Extensive numerical studies on both synthetic and real data are provided to support our model.

WA5-6 **10:40 AM**

Tensor Completion via Group-Sparse Regularization

Bo Yang, Gang Wang, Nikos Sidiropoulos, University of Minnesota, United States

To enable low-rank tensor completion/decomposition, this paper puts forth a novel tensor rank regularization method using the l_{1,2}-norm of the PARAFAC decomposition factors. For an N-way tensor, the resultant regularizer is able to control the tensor's rank by inducing sparsity in the vector comprising magnitudes of its rank-1 components through an l_{1/N}(pseudo)-norm regularization. To efficiently process high-dimensional tensor data, a block-coordinate descent solver is developed. Preliminary numerical tests on synthetic data demonstrate that the proposed method improves upon its competing alternatives.

WA5-7 **11:05 AM**

Coupled Graph Tensor Factorization

Ahmed S. Zamzam, Vassilis Ioannidis, Nikos D. Sidiropoulos, University of Minnesota, United States

Factorization of a single matrix or tensor has been used widely to predict missing data. In many cases side information may be available, like social network activities. In these situations, coupled matrix tensor factorization (CMTF) can be employed to account for additional sources of information. When the side information comes in the form of item-correlation matrices, CMTF algorithms do not apply. Instead, a novel approach to model the correlation matrices is proposed here, using symmetric nonnegative matrix factorization. The multiple sources of information are fused by fitting outer-product models for the tensor and the correlation matrices in a coupled manner.

Track F – Biomedical Signal and Image Processing

Session: WA6a – Emerging Sensing Technologies for Assisted Living

Co-Chairs: ***Yimin D. Zhang,*** *Temple University* ***and Fauzia Ahmad,*** *Villanova University*

WA6a-1 **8:15 AM**

Continuous-Wave Sensors for Non-contact Physiological Monitoring and Human-Aware Localization

Changzhi Li, Texas Tech University, United States

Wireless sensors with embedded control ensure human well-being in assisted living environment by tracking users' location, vital signs, and gesture information. This paper presents our research on smart radio frequency sensors aided with advanced technologies including beamforming, inverse synthetic aperture radar, and flexible electronics. The scope of applications ranges from sleep study, vital signs monitoring, to human-aware localization. Specifically, our recent efforts on portable sensors operating in a hybrid FMCW-interferometry mode will be discussed. The focus will be real-time signal processing in range-Doppler domain, hybrid mode operation, and software-configured architecture. Experimental results will demonstrate the efficacy of our solutions.

WA6a-2 **8:40 AM**

Training-Free Sleep Behavior Monitoring using Smartphones

Rui Wang, Dartmouth College, United States; Saeed Abdullah, Cornell University, United States; Fazlay Rabbi, Xiao Zeng, Mi Zhang, Michigan State University, United States

Sleep is one of the most important activities related to our health. The smartphone is an ideal tool to detect sleep behavior. The conventional sleep detection method trains a supervised sleep classifier to detect sleep period. We argue that this method cannot scale because its performance heavily relies on selecting proper training data. We propose a training-free sleep detection method based on the intuition that sleep is the longest sedentary period in a person's day and the sensor data should show a uniform pattern during a sleep period. Compared with a supervised method, our training-free method achieves superior sleep-detection results.

WA6a-3 **9:05 AM**

Breathing Detection Based on the Topological Features of IR Sensor and Accelerometer Signals

Fatih Erden, Atilim University, Turkey; Ahmet Enis Cetin, Bilkent University, Turkey

This paper describes a non-contact breathing detection system to monitor the respiratory variations and sleeping patterns of an adult or a baby. PIR sensors placed onto a stand near a bed and accelerometer on the mattress produce almost periodic signals due to body movements associated with the breathing activity. Sensor signals are processed using a topological approach. Point

clouds are constructed from the delay-coordinate embeddings of sensor data samples. Then, presence of the periodic structures is detected using persistent homology. It is shown that the sensors with the proposed method complement each other to produce more accurate decisions.

WA6a-4 **9:30 AM**

Wideband Radar Based Fall Motion Detection for a Generic Elderly

Baris Erol, Moeness Amin, Fauzia Ahmad, Villanova University, United States; Yimin Zhang, Temple University, United States

Falls are a major cause of injuries in the elderly population (those aged 65 years and above). Doppler radar based fall detection has drawn much attention in recent years, wherein micro-Doppler signatures are exploited to discriminate between falls and other human motion articulations. However, the micro-Doppler signature of a fall may resemble that of a sitting motion when using discriminative features. In this work, we consider a fall detector based on wideband radar technology that aids in reducing such confusions.

Track H – Speech, Image and Video Processing

Session: WA6b – Image and Video Quality Assessment

Chair: ***Balasubramaniam Santhanam,*** *University of New Mexico*

WA6b-1 **10:15 AM**

No-Reference Image Quality Assessment for High Dynamic Range Images

Debarati Kundu, Deepti Ghadiyaram, Alan Bovik, Brian Evans, University of Texas at Austin, United States

Measuring visual quality is important in many applications in which humans are ultimate consumers of visual information. Standard dynamic range (SDR) images provide 8 bits/color/pixel. High dynamic range (HDR) images can provide 16 or 32 bits/color/pixel by combining multiple exposures of the same scene. For HDR images, we propose (1) a new no-reference image quality assessment (NR-IQA) algorithm based on natural scene statistics using features extracted in the spatial and gradient domains, (2) evaluate the method on a large-scale crowdsourced HDR image database, and (3) show that it performs well on legacy natural SDR images.

WA6b-2 **10:40 AM**

A Multi-Stage Temporal Pooling Mechanism for Video Quality Assessment

Venkata Phani Kumar M, Sudipta Mahapatra, Indian Institute of Technology, Kharagpur, India

Based on the results of recent subjective studies on time-varying quality of experience (QoE), a multi-stage temporal pooling mechanism is proposed in this paper for improving the prediction capability of an objective quality metric for video quality assessment (VQA). The experimental results obtained from four publicly available video quality databases demonstrate that the proposed pooling mechanism can significantly improve the prediction capability of an objective quality metric for VQA and can be adopted for predicting the video level quality scores of longer duration sequences with varying video qualities.

WA6b-3 **11:05 AM**

Sparsity Based Stereoscopic Image Quality Assessment

Sameeulla Khan, Sumohana Channappayya, Indian Institute of Technology, Hyderabad, India

—In this work, we present a full-reference stereo image quality assessment algorithm that is based on the sparse representations of luminance images and depth maps. The primary challenge lies in dealing with the sparsity of disparity maps in conjunction with the sparsity of luminance images. Although analysing the sparsity of images is sufficient to bring out the quality of luminance images, the effectiveness of sparsity in quantifying depth quality is yet to be fully understood. We present a full reference Sparsity-based Quality Assessment of Stereo Images (SQASI) that is aimed at this understanding.

Track E – Array Signal Processing

Session: WA7 – Cognitive Radar

Co-Chairs: ***Hugh Griffiths,*** *University College London* ***and Muralidhar Rangaswamy,*** *Air Force Research Laboratory*

WA7-1 **8:15 AM**

Semi-Cognitive Angle Estimation for Adaptive Array Radars

Michal Meller, PIT-RADWAR S.A., Poland

The problem of angle estimation in an adaptive array radars is considered. We aim at improving efficacy of the radar system by achieving the required amount of performance, while keeping power radiated into sidelobes at a low level. This is somewhat in contrast to previous contributions on cognitive radar, which emphasized achieving the best possible performance. Furthermore, performance specification is made on the plot, rather than track, level. The proposed solution employs a performance predictor and a computationally cheap optimization mechanism. Simulation experiments demonstrate that the desired level of performance is indeed achieved and that the controller makes reasonable decisions.

WA7-2 **8:40 AM**

Challenge Problems in Cognitive Radar

Hugh Griffiths, University College London, United Kingdom; Alex Charlish, Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE), Germany; Nathan Goodman, University of Oklahoma, United States

Cognitive Radar represents an exciting set of techniques with the potential to significantly influence the design of future sensor systems. However, despite the great interest, as shown by the large volume of publications, there is not yet complete agreement over the precise definitions and the potential benefits. This contribution provides an introduction of the work of the NATO SET-227 Task Group, which represents a collaboration of more than thirty scientists and engineers from ten countries, and introduces and describes some of the major themes that the Task Group is pursuing.

WA7-3 **9:05 AM**

Joint Design of Waveform and Receive Filter for MIMO Radar using Parametric Programming

Bosung Kang, Omar Aldayel, Vishal Monga, Pennsylvania State University, United States; Muralidhar Rangaswamy, Air Force Research Laboratory, United States

We address the problem of jointly designing a waveform and a receiver filter for multiple-input multiple-output (MIMO) radar. Incorporating the constant modulus constraint and the similarity constraint jointly with the interference constraint in an analytically tractable manner is an open challenge. We formulate a joint waveform and filter optimization problem with both the constant modulus and the similarity constraints and provide an approach to obtain the optimal transmit waveform. We solve the resulting non-convex fractional quadratic optimization problem by employing the parametric programming approach and the successive quadratically constrained quadratic programming (QCQP) refinement (SQR) method.

WA7-4 **9:30 AM**

Experimental Validation of Cognitive Radar Anticipation using Stochastic Control

Colin Horne, Matthew Ritchie, Hugh Griffiths, University College London, United Kingdom; Folker Hoffmann, Alex Charlish, Fraunhofer Institute for Communication, Information Processing and Ergonomics (FKIE), Germany

Cognition applied to radar systems is a growing area of research. The majority of cognitive radar research is focused on theory and simulation with little experimental validation. Prior research proposed the application of anticipation within a cognitive radar, demonstrating by simulation that this can provide significant improvements in performance for cognitive radar systems. The approach applied a POMDP algorithm to control track updates for a target with and without anticipating a lack of measurements within a known region. This work aims to expand on this concept by using real radar data to validate these findings.

BREAK **9:55 AM**

WA7-5 **10:15 AM**

Learning Radar for Airborne Maritime Surveillance Applications

Myriam Nouvel, Stéphane Kemkemian, THALES Airborne Systems, France

The paper discusses the case of maritime surveillance radars aiming to detect very slow moving targets, such as in the case of a Search and Rescue mission. Indeed, the detection of very slow or even stationary targets cannot be helped using the Doppler shift to isolate the relevant targets from the areas contaminated by the sea clutter. Thus, the detection of such targets is directly confronted with the properties of sea clutter in terms of Power Spectrum Density.

WA7-6 **10:40 AM**

Cognitive Radar Testbed Development

Roland Oechslin, armasuisse, Science and Technology, Switzerland; Graeme Smith, The Ohio State University, United States; Uwe Aulenbacher, Klaus Rech, Sebastian Hinrichsen, Ingenieurbüro für Sensorik und Signalverarbeitung, Germany; Kristine Bell, Metron, Inc., United States; Peter Wellig, armasuisse, Science and Technology, Switzerland

This paper describes the development of the Cognitive Detection, Identification, and Ranging (CODIR) testbed by Armasuisse. The hardware configuration is presented and the cognitive algorithm development process is discussed, including simulation, “after the fact” processing of collected data, and real-time processing. The CODIR is similar in many respects to the Cognitive Radar Engineering Workspace (CREW) developed at The Ohio State University. Similarities and differences between the systems are discussed, as well as lessons learned and plans for further development.

WA7-7 **11:05 AM**

Big Data Capon Beamforming: Random Matrix Theory Perspectives

Pawan Setlur, AFRL/WSRI, United States; Muralidhar Rangaswamy, Air Force Research Laboratory, United States

We study the behavior of the Capon beamformer for a DOA estimation problem considering multiple sources. The Capon beamformer is analyzed assuming the number of sensors and the number of snapshots to be large. Random matrix theory is utilized as a tool in the analysis and almost sure convergence limits are provided for the amplitudes of the capon spectrum at the corresponding direction of arrivals. It is common folklore that the Capon spectrum does not estimate the powers of the sources correctly. As a consequence of this research, for the first time in the literature, this behavior is explained analytically.

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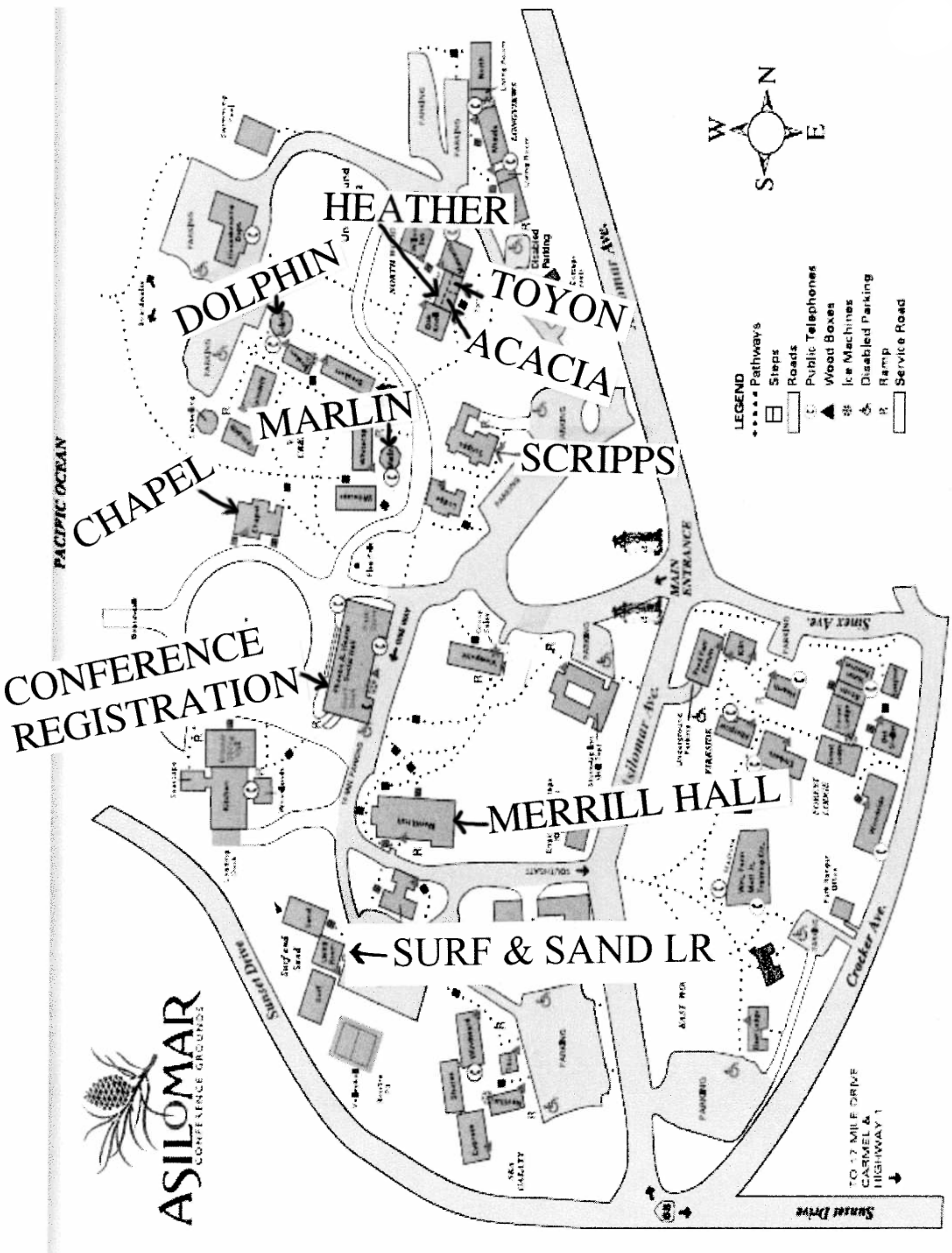
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