Forty-Ninth Asilomar Conference on Signals, Systems, and Computers

November 8–11, 2015

FINAL PROGRAM & ABSTRACTS

Asilomar Hotel
Conference Grounds

FORTY-NINTH
ASILOMAR CONFERENCE ON
SIGNALS, SYSTEMS & COMPUTERS

Technical Co-sponsor

IEEE SIGNAL PROCESSING SOCIETY

CONFERENCE COMMITTEE

Welcome from the General Chair

Prof. Erik G. Larsson
Linköping University, Sweden

Welcome to the 49th Asilomar Conference on Signals, Systems, and Computers!

It is a privilege for me to serve as General Chair of the Asilomar conference this year. Asilomar is a unique conference and I believe what makes it so special is the combination of an exceptional quality of the technical presentations and papers, the congenial atmosphere that forms around the social events, and the opportunity for long outdoor walks along the California coast. For me personally, Asilomar stands out as the one conference that I have tried, and am trying to consistently attend since I first participated fifteen years ago.

We are looking forward to an exciting technical program that spans two and a half days. All credit for preparing the technical program goes to the Technical Chair, Prof. Timothy Davidson and his team of area chairs: Wei Yu, David Love, Randall Berry, Bhaskar Rao, Gerald Matz, Aleksandar Jeremic, Warren Gross, Shahram Shirani and Keshab Parhi (vice chair). I would like to thank Tim and his team for assembling the program, which this year consists of 363 papers, of which 158 are invited. Among these papers, 78 were submitted to the student paper contest and a list of finalists have been selected. The finalists in the student contest will present their contributions as posters to a committee of judges on Sunday afternoon and of course, everyone is invited to attend. The top-three ranked papers will then be awarded prizes at the Monday plenary session.

The plenary talk this year will be given by Prof. Frank R. Kschischang from the University of Toronto. Frank is an authority in information theory and coding with applications to wireline, wireless as well as optical communications. The topic of his talk is applications of the nonlinear Fourier transform, a signal analysis technique first introduced by mathematicians and physicists in the 1970s and now used to analyze optical communication links, where nonlinearities are present. I am greatly excited about this talk and the opportunity for us all to learn from a world-renowned expert about this advanced and useful tool.

It has been an honor to serve as General Chair, and I hope that you will all enjoy the conference.

Erik G. Larsson
Linköping University, Sweden, July 2015

Conference Steering Committee

2015 Asilomar Technical Program Committee

Chairman
Prof. Timothy Davidson
McMaster University

2015 Asilomar
Technical Program Committee Members

Track A: Communication Systems
Wei Yu
University of Toronto, Canada

Track B: MIMO Communications and Signal Processing
David Love
Purdue University, USA

Track C: Networks
Randall Berry
Northwestern University, USA

Track D: Signal Processing and Adaptive Systems
Bhaskar Rao
University of California,
San Diego, USA

Track E: Array Signal Processing
Gerald Matz
Technische Universität Wien, Austria

Track F: Biomedical Signal and Image Processing
Aleksandar Jeremic
McMaster University, Canada

Track G: Architecture and Implementation
Warren Gross
McGill University, Canada

Track H: Speech, Image and Video Processing
Shahram Shirani
McMaster University, Canada

Vice Track Chair
Keshab Parhi
University of Minnesota, USA

2014 Asilomar Conference Session Schedule

Sunday Afternoon, November 8, 2015

3:00–7:00 PM Registration — Merrill Hall
4:00–6:30 PM Student Paper Contest — Heather
7:00–9:00 PM Welcoming Dessert Reception — Merrill Hall

Monday Morning, November 9, 2015

7:30–9:00 AM Breakfast – Crocker Dining Hall
8:00 AM–6:00 PM Registration
8:15–9:45 AM MA1a — Conference Welcome and Plenary Session — Chapel
9:45–10:15 AM Coffee Social

10:15–11:55 AM MORNING SESSIONS

MA1b FANTASTIC-5G on MTC
MA2b Interference Management: New Techniques and Emerging Challenges
MA3b Optimization of Wireless Networks
MA4b Bayesian Methods for Compressed Sensing
MA5b Radar Signal Processing
MA6b Large Data Sets
MA7b Biological Communication
MA8b1 Cognitive Radio (Poster)
MA8b2 Parallel Processing (Poster)
MA8b3 Adaptive Filtering (Poster)
MA8b4 Synchronization and Localization (Poster)

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

Monday Afternoon, November 9, 2015

1:30–5:10 PM AFTERNOON SESSIONS

MP1a Underwater Acoustic Communications and Signal Processing
MP1b Physical Layer Security
MP2 Distributed Coherent Communication Systems
MP3 5G Cellular Networks
MP4a Distributed Signal Processing
MP4b Designing Sparse Sensing Structures
MP5a Co-Prime Arrays
MP5b MIMO Radar
MP6 Signal Processing and Optimization Methods for Big Data Analytics
MP7a Signal Processing in Biology: Theoretical Advances and Open Problems
MP7b ECG and EEG Signal Processing
MP8a1 Implementation of Digital Signal Processing Algorithms (Poster)
MP8a2 Sparsity and Compressed Sensing (Poster)
MP8a3 Applications of Adaptive Signal Processing (Poster)
MP8a4 Wireless and Sensor Networks (Poster)

Monday Evening, November 9, 2015

6:00–9:30 PM Conference Cocktail/Social — Merrill Hall
The Cocktail/Social takes the place of Monday's dinner. No charge for conference attendees and a guest.

2015 Asilomar Conference Session Schedule

(continued)

Tuesday Morning, November 10, 2015

7:30–9:00 AM Breakfast — Crocker Dining Hall
8:00 AM–5:00 PM Registration

8:15–11:55 AM MORNING SESSIONS

TA1a Topics in Communications
TA1b Coding and Signal Processing for Modern Memories
TA2a All About Spectrum
TA2b Methodologies for Signal Processing on Random Graphs
TA3a Estimation
TA3b Wearable and Body Area Networks
TA4 Workshop on Contributions of Louis Scharf
TA5a Smart Grid
TA5b Energy Management
TA6a Massive MIMO
TA7 Arithmetic
TA8a1 Biomedical Signal Processing I (Poster)
TA8a2 Relayed Communications I (Poster)
TA8b1 Sampling, Sensing and Detection (Poster)
TA8b2 Biomedical Signal Processing II (Poster)
TA8b3 Relayed Communications II (Poster)

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

Tuesday Afternoon, November 10, 2015

1:30–5:35 PM AFTERNOON SESSIONS

TP1 Coherent Optical Communications
TP2 Enabling Technologies for Future Wireless Networks
TP3a Social Networks
TP3b Caching in Wireless Networks
TP4 Workshop on Contributions of Louis Scharf
TP5a Interference Channels
TP5b Interference in Networks
TP6a Multi-Agent Systems and Optimization
TP6b Epidemic Control in Networks
TP7a Algorithm and Hardware Aspects for 5G Wireless Systems
TP7b VLSI Signal Processing
TP8a1 Multicarrier and DFE (Poster)
TP8a2 Speech and Image Processing (Poster)
TP8a3 Communication Techniques for the Downlink (Poster)
TP8a4 Estimation and Learning (Poster)
TP8b1 Radar Co-existence and Satellite Communications (Poster)
TP8b2 Video Processing (Poster)
TP8b3 MIMO Links and Uplink (Poster)

Tuesday Evening Open Evening — Enjoy the Monterey Peninsula

2015 Asilomar Conference Session Schedule

(continued)

Wednesday Morning, November 11, 2015

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.

8:15–11:55 AM MORNING SESSIONS

WA1a Communications with Low-Precision Analog-to-Digital Converters
WA1b Broadband Access Evolution
WA2a Cooperative Communications
WA2b 5G and mmWave
WA3 Sparsity in Signal Processing
WA4 Statistical Signal Processing for Social and Information Networks
WA5a Sparse Estimation
WA5b Compressive Beamforming and Sparsity-Based Techniques
WA6a Tracking
WA6b Structure in Adaptive Signal Processing Algorithms
WA7a Image Processing
WA7b Graph Signal Processing
WA8a1 Coding and Decoding (Poster)
WA8a2 Implementation of Communication Systems (Poster)
WA8a3 Array Signal Processing (Poster)
WA8a4 Parameter and Waveform Estimation (Poster)
WA8a5 Adaptive Signal Processing Techniques (Poster)

12:00–1:00 PM Lunch — Meal tickets may be purchased at registration desk. This meal is not included in the registration.

Student Paper Contest

Heather - Sunday, November 8, 2015, 4:00 - 6:30 PM

Track A *"A Tractable Model for Per User Rate in Multiuser Millimeter Wave Cellular Networks"*
Mandar Kulkarni, Ahmed Alkhateeb, Jeffrey Andrews, University of Texas at Austin, United States

Track B *"Interference Alignment-Aided Base Station Clustering using Coalition Formation"*
Rasmus Brandt, Rami Mochaourab, Mats Bengtsson, KTH Royal Institute of Technology, Sweden

Track C *"Sampling of Graph Signals: Successive Local Aggregations at a Single Node"*
Santiago Segarra, University of Pennsylvania, United States; Antonio Marques, King Juan Carlos University, Spain; Geert Leus, Delft University of Technology, Netherlands; Alejandro Ribeiro, University of Pennsylvania, United States

Track D *"Minimal Dictionaries for Spanning Periodic Signals"*
Srikanth V. Tenneti, P. P. Vaidyanathan, California Institute of Technology, United States

Track E *"SQR: Successive QCQP Refinement for MIMO Radar Waveform Design under Practical Constraints"*
Omar Aldayel, Vishal Monga, Pennsylvania State University, United States; Muralidhar Rangaswamy, Air Force Research Laboratory, United States

Track F *"Optimal Gene Regulatory Network Inference using the Boolean Kalman Filter and Multiple Model Adaptive Estimation"*
Mahdi Imani, Ulisses Braga-Neto, Texas A&M University, United States

Track G *"Architectures for Stochastic Normalized and Modified Lattice IIR Filters"*
Yin Liu, Keshab Parhi, University of Minnesota, Twin Cities, United States

Track H *"Screen Content Image Segmentation using Sparse-Smooth Decomposition"*
Shervin Minaee, Amirali Abdolrashidi, New York University, United States

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

Monday, November 9, 2015

CONFERENCE OPENING AND PLENARY SESSION 8:15 – 9:45 AM, LOCATED IN CHAPEL

1. Welcome from the General Chairperson:

Prof. Erik G. Larsson
Linköping University, Sweden

2. Session MA1a Distinguished Lecture for the 2015 Asilomar Conference

Fiber-Optic Communication via the Nonlinear Fourier Transform

Frank R. Kschischang
University of Toronto, Canada

Abstract
In this work we explore some of the potential fiber-optic data transmission applications of the nonlinear Fourier transform (NFT), a signal analysis technique introduced by mathematicians and physicists in the 1970s. Just as the usual Fourier transform converts linear convolution to multiplication, the NFT transforms the action of the ideal (noiseless, lossless) nonlinear Schrödinger equation (and other integrable evolution equations) to the action of a multiplicative filter in the nonlinear frequency domain. One potential application is a nonlinear analogue of linear frequency-division multiplexing that, unlike many other fiber-optic transmission strategies, deals with both dispersion and nonlinearity unconditionally, without the need for dispersion or nonlinearity compensation methods.

(Joint work with Mansoor I. Yousefi and Siddarth Hari.)

Biography
Frank R. Kschischang is the Distinguished Professor of Digital Communication in the Department of Electrical and Computer Engineering at the University of Toronto, where he has been a faculty member since 1991. He received the B.A.Sc. degree (with honors) from the University of British Columbia, Vancouver, BC, Canada, in 1985 and the M.A.Sc. and Ph.D. degrees from the University of Toronto, Toronto, ON, Canada, in 1988 and 1991, respectively, all in electrical engineering. During 1997-98, he was a visiting scientist at MIT, Cambridge, MA; in 2005 he was a visiting professor at the ETH, Zurich, and in 2011 and again in 2012-13 he was a visiting Hans Fischer Senior Fellow at the Institute for Advanced Study at the Technical University of Munich.

His research interests are focused primarily on the area of channel coding techniques, applied to wireline, wireless and optical communication systems and networks. In 1999 he was a recipient of the Ontario Premier's Excellence Research Award and in 2001 (renewed in 2008) he was awarded the Tier I Canada Research Chair in Communication Algorithms at the University of Toronto. In 2010 he was awarded the Killam Research Fellowship by the Canada Council for the Arts. Jointly with Ralf Koetter he received the 2010 Communications Society and Information Theory Society Joint Paper Award. He is a recipient of the 2012 Canadian Award in Telecommunications

Research. He is a Fellow of IEEE, of the Engineering Institute of Canada, and of the Royal Society of Canada.

During 1997-2000, he served as an Associate Editor for Coding Theory for the IEEE TRANSACTIONS ON INFORMATION THEORY, and since January 2014, he serves as this journal's Editor-in-Chief. He also served as technical program co-chair for the 2004 IEEE International Symposium on Information Theory (ISIT), Chicago, and as general co-chair for ISIT 2008, Toronto. He served as the 2010 President of the IEEE Information Theory Society.

Tuesday, November 10, 2015

WORKSHOP ON CONTRIBUTIONS OF LOUIS SCHARF

8:15–11:55 AM and 1:30–5:35 PM

Forty-Six Years (and counting) of Statistical Signal Processing - A workshop in recognition of the career contributions of Louis Scharf. This workshop will acknowledge the substantial influence of Louis Scharf's career contributions to statistical signal processing. It will feature presentations by a few of the many people whose work has been influenced by collaboration and other interactions with Professor Scharf over the past four decades.

Program of 2015
Asilomar Conference
on
Signals, Systems, and Computers

Technical Program Chairman
Prof. Timothy Davidson
McMaster University

Track A – Communications Systems

Session: MAb1 – FANTASTIC-5G on MTC

Chair: ***Gerhard Wunder,*** *Fraunhofer Heinrich-Hertz-Institut*

MA1b-1 **10:15 AM**

FBMC Based Asynchronous Uplink Access

Zhao Zhao, Qi Wang, Xitao Gong, Malte Schellmann, Martin Schubert, Huawei European Research Center, Germany

The 5th generation (5G) wireless communication network is expected to support up to 1000x more connections per cell with reduced latency below 1 ms. Maintaining uplink synchronization for each individual device as conventional 4G does, known as the Timing Advance adjustment, will lead to significant signaling overhead, especially for small traffic scenarios, like IoT services, “always-on-line” TCP connections, etc. This paper shows that the Timing Advance is not necessary if we introduce FBMC waveform in combination with suitable multiple access schemes. The resulting system is highly robust against timing misalignment while attaining high spectral efficiency.

MA1b-2 **10:40 AM**

Radio Access Protocols and Preamble Design for Machine-Type Communications in 5G

Stephan Saur, Andreas Weber, Gerhard Schreiber, Alcatel-Lucent, Germany

Machine-type communications is seen as one of the main drivers of 5G. In this paper we compare one-stage and two-stage radio access protocol options tailored for sporadic transmissions of small data packets in uplink with respect to throughput and delay requirements. An important aspect is robust and resource efficient preamble design to minimize missed detection and false alarm probabilities of service requests. Also the tradeoff between performance and necessary amount of downlink feedback bits is taken into account in our analysis. The final evaluation is done with computer simulation of a multi-cell system.

MA1b-3 **11:05 AM**

Compressive Coded Random Access for Massive MTC Traffic in 5G Systems

Gerhard Wunder, Heinrich Hertz Institut, Germany; Cedomir Stefanovic, Petar Popovski, Aalborg University, Denmark

In this paper we follow-up on recent massive MTC concepts combining advanced MAC protocols with Compressed Sensing (CS) based multiuser detection. Specifically, we introduce a concept for sparse joint activity, channel and data detection in the context of the Coded ALOHA (FDMA) protocol. In addition, we will improve on the performance of such Coded ALOHA protocols in terms of the resource efficiency. We will mathematically analyze the system accordingly and provide expressions for the capture probabilities of the underlying sparse multiuser detector. Finally, we will provide ‘structured’ CS algorithms for the joint estimation scheme and evaluate its performance.

MA1b-4 **11:30 AM**

A Potential Solution for MTC: Multi-Carrier Compressive Sensing Multi-User Detection

Fabian Monsees, Matthias Woltering, Carsten Bockelmann, Armin Dekorsy, University of Bremen, Germany

Massive Machine Type Communication characterized by low data-rates and low activity devices requires new physical layer solutions. Recently, we introduced the so-called Multi-Carrier Compressive Sensing Multi-User Detection (MCSM) combining Compressed Sensing Multi-User Detection (CS-MUD), a multi-carrier scheme and non-coherent modulation. The main benefits are low signaling overhead through both CS-MUD and non-coherent modulation, and high spectral efficiency enabled by overloaded CS-MUD. In this work, we extend the MCSM concept as follows: (i) a transmitter and receiver chain using tailored compressed sensing and channel coding algorithms; (ii) concepts for frequency diversity exploitation and (iii) a feasibility study on a hardware testbed.

Track A – Communications Systems

Session: MAb2 – Interference Management: New Techniques and Emerging Challenges

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

MA2b-1 **10:15 AM**

Interference Surge in Full-Duplex Wireless Systems

Ratheesh K. Mungara, Angel Lozano, Universitat Pompeu Fabra, Spain

Historically unfeasible because of self-interference, full duplexing has now been experimentally demonstrated and is on the verge of commercial feasibility thanks to advances in self-interference cancellation. This will disrupt the interference landscape in wireless networks, bringing about an unprecedented richness whereby every transmitter interferers with every receiver. This paper characterizes the actual increase in system spectral efficiency given all this interference, and in the process it identifies new needs in interference management.

MA2b-2 **10:40 AM**

Interference Mitigation Utilizing Antenna Mutual Coupling

Wonseok Jeon, Sae-Young Chung, KAIST, Republic of Korea

In this paper, we show interference can be removed almost perfectly if antenna mutual coupling is properly utilized. This holds even when the antennas are negligibly small in their physical sizes. We assume a Gaussian multiple access channel (MAC), where each transmitter has one antenna and the receiver can measure the electric field in a given spherical volume. We show that the capacity region is close to rectangular regardless of the physical size of the receiver, i.e., size of the spherical volume, and the position of the transmitters.

MA2b-3 **11:05 AM**

Optimality of Treating Interference As Noise in the IRC: A GDOF Perspective

Soheil Gherekhloo, Aydin Sezgin, Ruhr-University Bochum, Germany

The deployment of a relay in an interference channel can improve the performance, which might require complex receivers in general. A question which arises is whether the complexity at the receivers can be avoided without loss of optimality. In particular, this motivates the study of treating interference as noise (TIN) in the interference relay channel (IRC). To this end, we characterize regimes in which TIN is optimal for the IRC in terms of generalized degrees of freedom. In addition to some cases in the weak interference regimes, it is shown that TIN can be optimal in the strong interference regime.

MA2b-4 **11:30 AM**

Secure Degrees of Freedom of the Gaussian MIMO Interference Channel

Karim Banawan, Sennur Ulukus, University of Maryland, United States

We consider the two-user MIMO interference channel (IC) with confidential messages. We derive the exact secure degrees of freedom for any symmetric pair of users with arbitrary number of transmit and receive antennas. The converse is constructed by combining the broadcast channel with confidential messages cooperative bound, decodability of IC without secrecy constraints, and variants of secrecy penalty and role of a helper lemmas. For the achievability, we propose novel achievable scheme for the 2x2 ICCM, which combines asymptotic real interference alignment with spatial interference alignment. Using this scheme, we provide any other achievable scheme by proper vector space operations.

Track C – Networks

Session: MAb3 – Optimization of Wireless Networks

MA3b-1 **10:15 AM**

Frameless ALOHA with Multiple Base Stations

Shun Ogata, Koji Ishibashi, The University of Electro-Communications, Japan

We focus on frameless ALOHA; each user transmits a packet with the shared access probability calculated by a target degree and the receiver decodes the information from whole received packets by using successive interference cancellation. Our main contribution is two-fold; first, the target degree distribution is optimized using density evolution. Secondly, we study the

frameless ALOHA with several users who can communicate with multiple base stations (BSs) and optimize the target degree by extending the density evolution to that with multiple-edge types. Numerical results reveal that connections among BSs result in higher throughput than the original frameless ALOHA.

MA3b-2 10:40 AM

On the Delay Optimal User Association in Heterogeneous Wireless Networks

Narayan Prasad, NEC Labs America, United States; Vaibhav Singh, University of Maryland, United States; Sampath Rangarajan, NEC Labs America, United States

We consider the problem of delay minimization over the downlink of a heterogeneous wireless network by optimizing the association of users to transmission points (TPs) subject to per-user finite buffer or limited airtime constraints. We formulate the user association problem as a constrained set function minimization problem and our key result is to show that the set function is a supermodular set function. We then propose a simple combinatorial algorithm to solve the user association problem and comprehensively analyze its performance.

MA3b-3 11:05 AM

Scheduling for Compute and Forward Networks

David Ramirez, Behnaam Aazhang, Rice University, United States

Interference is a consequence of the broadcast nature of wireless communications. Compute and forward (CoF) leverages interfering signals to retrieve relevant information from concurrent transmissions. For a network where nodes must empty a queue in minimum time the use of CoF can outperform a traditional TDMA approach. We analyze the impact of compute and forward in minimizing the time to empty a wireless network. While a Linear Programing formulation is available, the minimization problem remains NP-hard. We propose two 2 Set strategies of distinct computational complexity and performance. Our strategies are evaluated against TDMA, the optimal solution, and alternative heuristics.

MA3b-4 11:30 AM

Carriers Allocation in Mobile Bacteria Network

Wei-Kang Hsu, Mark Bell, Xiaojun Lin, Purdue University, United States

This work combines the notion of a bacteria network with ad hoc mobile nodes. The average message delay is derived and is showed to form a convex function relation with respect to the number of available carriers in the environment. In the multiple pair scenario, bacteria serving as the medium of message transmission are a limited resource. We show that we can achieve optimal resource allocation to minimize the total delay and satisfy pair priorities by controlling the release probability at the source nodes. This suggests a guideline for communicating prioritized tasks in the ad hoc bacteria network.

Track D – Signal Processing and Adaptive Systems

Session: MAb4 – Bayesian Methods for Compressed Sensing

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

MA4b-1 10:15 AM

Hierarchical Bayesian Formulation of Sparse Signal Recovery Algorithms using Scale Mixture Priors

Ritwik Giri, Bhaskar D. Rao, University of California, San Diego, United States

In the recent past, the Sparse Signal Recovery (SSR) problem has been very well studied using penalized regression approaches with different choice of penalty functions. In this work we revisit these penalized regression formulations in a Bayesian framework with suitable choice of supergaussian prior distributions. We introduce a generalized scale mixture framework, and provide connections with well known norm minimization based SSR algorithms. The scale mixture representation allows us to formulate the corresponding Type II version of these algorithms, following the hierarchical bayesian framework of Sparse Bayesian Learning (SBL) and enable a comparison of Type I versus Type II approaches.

MA4b-2 10:40 AM

Understanding the MMSE of Compressed Sensing One Measurement at a Time

Galen Reeves, Henry Pfister, Duke University, United States

Recent research has shown that the asymptotic behavior of compressed sensing can be characterized by studying an appropriate sequence of scalar estimation problems. This relationship is elegant to state but tricky to prove. In some cases, it can be proved by analyzing approximate message passing algorithms. More generally, it can be derived using the replica method from statistical

physics. In this talk, we describe a new approach that analyzes the change in mutual information and MMSE associated with adding one measurement. Based on this change, we attempt to provide an information-theoretic derivation of the asymptotic MMSE.

MA4b-3 **11:05 AM**

Connecting Bayesian and Denoising-Based Approximate Message Passing

Christopher Metzler, Rice University, United States; Arian Maleki, Columbia University, United States; Richard Baraniuk, Rice University, United States

The recently developed D-AMP algorithm extends the approximate message passing (AMP) framework so as to enable the use of arbitrary denoisers within its iterations. This work explores the strengths and weaknesses of this approach on a variety of signal classes. It also explores the connections between D-AMP and Bayesian AMP, which employs a probabilistic model for the signal.

MA4b-4 **11:30 AM**

On Robust Approximate Message Passing

Philip Schniter, The Ohio State University, United States; Henry Pfister, Duke University, United States

The approximation message passing (AMP) approach is a recent breakthrough in Bayesian compressed sensing. With i.i.d. sub-Gaussian measurement matrices, AMP's performance in the large-system limit is completely characterized by a state evolution whose fixed points are Bayes-optimal performance when they are unique. When AMP is used with generic matrices, however, it may diverge. We present ongoing research that analyzes the performance of AMP with generic matrices and develops modifications with guaranteed convergence.

Track E – Array Signal Processing

Session: MAb5 – Radar Signal Processing

Chair: ***Hongbin Li,*** *Stevens Institute of Technology*

MA5b-1 **10:15 AM**

On Waveform Conditions and Range Compression in MIMO Radars using Matrix Completion

Shunqiao Sun, Athina Petropulu, Rutgers, The State University of New Jersey, United States

It was recently shown that MIMO radars with matrix completion (MC) can achieve high accuracy of target estimation with significantly fewer samples. For the scenario of targets falling in the same range bin, waveforms with a flat spatial spectrum were shown to be optimal in terms of requirement for good MC performance. In this paper, we conduct sensitive analysis of the optimized waveforms used in a MIMO-MC scenario in which targets fall in different range bins. We show that, for maximum target delay of the order of the pulse duration, the MC performance degrades slightly as the range delay increases.

MA5b-2 **10:40 AM**

Detection of Low-Signature Targets in Rough Surface Terrain for Forward-Looking Ground Penetrating Radar Imaging

Davide Comite, Fauzia Ahmad, Moeness Amin, Villanova University, United States; Traian Dogaru, US Army Research Lab, United States

We develop an image-domain target detector for forward-looking ground penetrating radar (FLGPR). An FLGPR offers the advantage of standoff sensing for detecting ground targets, but the target responses are more vulnerable to interference scattering arising from interface roughness and subsurface clutter. The proposed detection scheme does not assume prior knowledge on image statistics and draws all inferences from the data measurements. . More specifically, it iteratively adapts to the varying target/clutter statistics of the FLGPR images. Both single- and multi-aperture radar configurations are considered and the detection performance evaluation of each configuration is carried out using electromagnetic modeling data.

MA5b-3 **11:05 AM**

SQR: Successive QCQP Refinement for MIMO Radar Waveform Design under Practical Constraints

Omar Aldayel, Vishal Monga, Pennsylvania State University, United States; Muralidhar Rangaswamy, Air Force Research Laboratory, United States

We address the problem of designing a waveform for Multiple-Input Multiple-Output (MIMO) radar under the constant modulus and the waveform similarity constraints. Incorporating these constraints in an analytically tractable manner continues to be longstanding open challenge as the optimization problem subject to these constraints is a hard non-convex problem. We develop a new analytical approach that involves solving a sequence of convex Quadratic Constrained Quadratic Programing (QCQP) problems, which we prove converges to a sub-optimal solution. We call the method Successive QCQP Refinement (SQR). We evaluate SQR performance and show that it outperforms existing methods without a significant computational burden.

MA5b-4 **11:30 AM**

A Sparsity Based GLRT for Moving Target Detection in Distributed MIMO Radar on Moving Platforms

Zhe Wang, Hongbin Li, Stevens Institute of Technology, United States; Braham Himed, Air Force Research Laboratory/RYMD, United States

This paper examines moving target detection (MTD) in distributed multi-input multi-output (MIMO) radar with sensors placed on moving platforms. Unlike previous works which were focused on the case of stationary platforms, we consider explicitly the effects of platform motion, which exacerbate the location-induced clutter non-homogeneity inherent in such systems. We propose a sparsity based detector which, by exploiting a sparse representation of the clutter in the Doppler domain, adaptively estimates from the test signal the clutter subspace. The proposed detector requires no training signals and outerforms conentional covariance matrix based detectors which require training.

Track D – Signal Processing and Adaptive Systems

Session: MAb6 – Large Data Sets

MA6b-1 **10:15 AM**

Big Data Sketching with Model Mismatch

Sundeep Prabhakar Chepuri, Delft University of Technology, Netherlands; Yu Zhang, University of Minnesota, United States; Geert Leus, Delft University of Technology, Netherlands; Georgios B. Giannakis, University of Minnesota, United States

In this work, we will focus on a data-driven scheme for dimensionality reduction. In particular, we propose a framework for the big data sketching that is robust to possible model mismatch. Existing works on sketching or censoring is limited to perfectly known data models. However, for massive datasets, such an assumption is too ideal and impractical. We formulate the model-mismatch robust data sketching as a mixed integer min-max problem. We provide efficient algorithms to cope with large-scale data and apply the developed theory to synthetic as well as real datasets.

MA6b-2 **10:40 AM**

Change-Point Detection of High-Dimensional Streaming Data via Sketching

Yuejie Chi, The Ohio State University, United States; Yihong Wu, University of Illinois at Urbana-Champaign, United States

Change detection is greatly desired in applications such as target tracking and anomaly detection. Motivated by the unprecedented scale and rate of modern high-dimensional streaming data, we propose a data sketching scheme that only requires a single sketch per data vector, by cyclically applying a set of Gaussian sketching vectors. We propose a change-point detection procedure and demonstrate that when the underlying changes exhibit certain low-dimensional structures, and is not too small in magnitude, the change-points can be reliably detected and located. Our procedure can be implemented in an online fashion, since it sequentially operates on small windows of observations.

MA6b-3 **11:05 AM**

Large-Scale Subspace Clustering using Random Sketching and Validation

Panagiotis Traganitis, Konstantinos Slavakis, Georgios B. Giannakis, University of Minnesota, United States

While successful in clustering multiple types of high-dimensional data, subspace clustering algorithms do not scale well as the number of data increases. The present paper puts forth a novel randomized subspace clustering algorithm for high-dimensional data based on a random sketching and validation approach. Utilizing a computationally efficient random sketching technique to estimate the underlying data probability density function, the performance of the proposed method is assessed via simulations, and is compared with state-of-the-art sparse subspace clustering methods that rely on random sampling.

MA6b-4 **11:30 AM**

Improving Multiset Canonical Correlation Analysis in High Dimensional Sample Deficient Settings

Nicholas Asendorf, Raj Rao Nadakuditi, University of Michigan, United States

Today's technological landscape allows for practitioners to collect high dimensional datasets from multiple modalities. In this paper we show that the standard algorithm of multiset canonical correlation analysis (MCCA) fails to detect correlations when the number of training samples is limited. To overcome this enormous performance loss, we propose informative MCCA (IMCCA), which uses insights from random matrix theory to reliably detect correlations in multiple datasets in the sample deficient regime.

Track F – Biomedical Signal and Image Processing

Session: MAb7 – Biological Communication

Chair: ***Joerg Kliewer,*** *New Jersey Institute of Technology*

MA7b-1 **10:15 AM**

Information Theory of Intercellular Signal Transduction

Andrew Eckford, York University, Canada; Peter Thomas, Case Western Reserve University, United States

The cells in the human body use intercellular signal transduction to organize themselves and regulate their work; multicellular life would not exist without it. In this paper, we discuss why information theory provides a useful toolbox to approach this problem. We also discuss how to calculate the capacity of intercellular signal transduction in some specific examples. Finally, we describe the challenges and future prospects of this avenue of research.

MA7b-2 **10:40 AM**

Directed Information Measures for Assessing Perceived Audio Quality using EEG

Ketan Mehta, New Mexico State Univeristy, United States; Joerg Kliewer, New Jersey Institute of Technology, United States

We provide a novel method using directional information to examine the causal relationship between EEG data in response to audio stimulus. We conduct experiments wherein the EEG activity of subjects is recorded as they listen to audio with time-varying audio quality between two different levels. Different types of directed information measures are then used to quantify the information flow between EEG sensors, which are grouped into different regions of interest over the cortex. Further, we determine the analytical relationship between these different directional measures and compare how well they are able to distinguish between the perceived audio quality.

MA7b-3 **11:05 AM**

Molecular Communication and Signaling in Human Cells

Iman Habibi, Ali Abdi, New Jersey Institute of Technology, United States; Effat Emamian, Advanced Technologies for Novel Therapeutics, United States

Signaling networks in human cells convey signals from the cell membrane to specific target molecules via biochemical interactions, to control the cell function. We have modeled signaling networks as communication channels where molecules communicate with each other to transfer signals. We have defined and computed the fundamental parameters of transmission error probability and signaling capacity in signaling networks, and verified the findings using experimental cell signaling data. This systematic approach may be used to understand how cell signaling errors and malfunctioning molecules can contribute to the development of some complex human diseases whose molecular bases are not well understood.

MA7b-4 **11:30 AM**

A Stochastic Queuing Model of Quorum Sensing in Microbial Communities

Nicolo Michelusi, James Boedicker, Moh El-Naggar, Urbashi Mitra, University of Southern California, United States

Microbial communities regulate various collective functions using molecular signaling circuits in a process known as quorum sensing (QS). Regulation and prediction of QS dynamics may reveal new strategies to control virulence in infections without the use of antibiotics. To this end, models of QS are necessitated as tools for prediction and analysis. In this paper, a stochastic and dynamic queuing model of QS signaling in microbial communities is presented. The model provides an abstraction of the detailed and complex biological signals, yet it is accurate enough to capture the dynamics and correlations in QS activation in a population of microbes.

Track A – Communications Systems

Session: MAb8 – Cognitive Radio **10:15 AM–11:55 AM**

MA8b1-1

Efficient Wideband Spectrum Sensing using Random Projection

Soumendu Majee, Purdue University, United States; Priyadip Ray, Indian Institute of Technology Kharagpur, United States; Qi Cheng, Oklahoma State University, United States

Subspace based spectrum estimation is a powerful technique for wideband spectrum sensing. Typically, subspace based techniques require eigen-decomposition of the sample covariance matrix, which is computationally very expensive. In this paper, an efficient approach to perform subspace based spectrum sensing via random projection is proposed. In the proposed approach, spectral decomposition of a significantly lower order matrix is required for wideband spectrum sensing. In addition to improved time complexity, the regularization imposed via the low rank approximation, improves the spectrum sensing performance of the proposed approach over the conventional subspace based approach, especially with limited observations.

MA8b1-2

An Agile Wideband Interferers Identification Algorithm for Spectrum Sensing

Han Yan, Danijela Cabric, University of California, Los Angeles, United States

In a cognitive radio receiver, interferers degrade the performance of the spectrum sensing due to the hardware non-ideality and power leakage. Thus they need to be identified and removed. We propose a novel cognitive radio receiver system and algorithm using modulated pseudorandom codes to estimate the power of multiple interferers simultaneously over a wide band and identify strong ones. Such method is faster and uses less computational resources than traditional fast Fourier transformation based snapshot. We present theoretical analysis of the estimation performance and validate it with simulations.

MA8b1-3

Identifying the Presence and Footprints of Multiple Incumbent Transmitters

Mihir Laghate, Danijela Cabric, University of California, Los Angeles, United States

Cognitive networks share spectrum with incumbent, or pre-existing, networks by identifying their presence and not causing interference to them. Current methods to identify the presence of multiple incumbent transmitters require more information than is available to a cognitive network. In this paper, the energy received by cooperating CRs is used to identify the presence of multiple incumbent transmitters without knowledge of locations, channel model, and communication protocols. Incumbents are distinguished as components of a Gaussian mixture model of the energy received by CRs. Furthermore, the algorithm finds each incumbent's footprint, i.e., the CRs that can cause the incumbent interference.

MA8b1-4

Sequential Detection of Number of Primary Users in Cognitive Radio Networks

Liping Du, University of Science and Technology Beijing, China; Chun-Hao Liu, Mihir Laghate, Danijela Cabric, University of California, Los Angeles, United States

In the field of mobile cognitive radio networks, it is shown that a priori information on the number of primary users (PUs) is helpful to estimate more specific parameters of PUs' signal, such as the carrier frequency, direction of arrival, and location. We propose a sequential canonical correlation technique (S-CCT) method to estimate the number of active PUs quickly and accurately. In the proposed method, classical canonical correlation technique (CCT) is improved using multi-hypothesis sequential probability ratio test. Simulation results show that our proposed S-CCT method can achieve the better performance with less number of samples compared with classical CCT.

MA8b1-5
Determining User Specific Spectrum Usage via Sparse Channel Characteristics
Dennis Wieruch, Fraunhofer HHI, Germany; Peter Jung, Technische Universität Berlin, Germany; Thomas Wirth, Fraunhofer HHI, Germany

We target spectrum sensing as means to identify spectrum holes in order to identify spectrum allocations. The goal is to show that distinguishing the resource allocation of different users by only observing the received power spectral density (PSD) of an OFDM signal is possible. To achieve this, we take the sparsity of the channel into account. We show that by using the l1 –norm as a metric, the resource allocation of multiple orthogonal transmitters can be distinguished. Furthermore, as an additional result, we also obtain the PSD by using a transmit alphabet with constant amplitude.

MA8b1-6
Recognizing FM, BPSK and 16-QAM using Supervised and Unsupervised Learning Techniques
Mohammad Bari, George Washington University, United States; Awais Khawar, Virginia Tech, United States; Milos Doroslovacki, George Washington University, United States; Charles Clancy, Virginia Tech, United States

In this paper, we explore the use of supervised and unsupervised machine learning for signal classification in the joint presence of AWGN, carrier offset, asynchronous sampling and symbol intervals and correlated fast fading. Three simple features are studied to classify frequency modulation, binary phase shift keying and 16 point quadrature amplitude modulation. Support vector machines and self-organizing maps are used to classify the signals.

MA8b1-7
Design of Spectrally Shaped Binary Sequences via Randomized Convex Relaxations
Dian Mo, Marco Duarte, University of Massachusetts, United States

We consider the problem of designing binary sequences with a target spectral shape containing rejection and passing bands. The resulting sequences can be used in the design of custom-made filters and modulators that are simple to implement, provide rejection of interferers with known spectral content, and preserve messages at bandwidths of interest. While optimal selection of the binary sequence requires combinatorial complexity, we exploit previously proposed convex relaxations that rely on randomized projections to return feasible binary solutions. Experimental results show that the relaxation succeeds at finding optimal solutions to the spectrally shaped binary sequence design problem.

MA8b1-8
Dynamic Scheduling for Delay Guarantees for Heterogeneous Cognitive Radio Users
Ahmed Ewaisha, Cihan Tepedelenlioglu, Arizona State University, United States

We study an uplink multi secondary user (SU) system having statistical delay constraints, and an interference constraint to the primary user (PU). SUs with heterogeneous interference channel statistics, to the PU, will experience heterogeneous delay performances. This is because SUs causing low interference will be scheduled more frequently than those causing high interference. We propose a dynamic scheduling algorithm that can provide average delay guarantees to all SUs as well as protecting the PU. Using the Lyapunov technique, we show that our algorithm is, asymptotically, delay optimal and satisfies the delay and interference constraints.

Track G – Architecture and Implementation
Session: MAb8 – Parallel Processing 10:15 AM–11:55 AM

MA8b2-1
Implementing a Streaming Application on a Processor Array: A Case Study on the Epiphany Architecture
Jerry Linström, Stefan Nannesson, Jorn W. Janneck, Lund University, Sweden

The processing of streams of data characterizes a wide range of application areas, including signal processing, video coding, image analytics, cryptography, network routing, and network packet processing. This paper reports on a case study in which an at-size application is ported onto a commercially available processor array. Its purpose is threefold: (1) Determine the suitability of processor arrays for this kind of application. (2) Develop a runtime software infrastructure that supports streaming applications on processor arrays. (3) Gather data and insights into the resulting system performance, and the factors that affect it.

MA8b2-2
Extreme Multi-Core, Multi-Network Java Dataflow Machine (JavaFlow)
Robert Ascott, Earl E. Swartzlander, Jr., University of Texas at Austin, United States

JavaFlow is a static DataFlow Machine with multiple heterogeneous networks implementing a Java Virtual Machine addressing technology roadmap issues with the ability to effectively utilize and manage large numbers of processing cores. A baseline configuration is defined and then compared to multiple configurations of instruction assignments and clock relationships. Using methods from the SPEC benchmark, performance of the sparsely populated heterogeneous structure is 40% of the baseline. The average ratio of instructions to required nodes is 3.1. Innovative solutions to the loading and management of Java methods along with the translation from control flow to DataFlow structure are demonstrated.

MA8b2-3
Data-Parallel Implementation of Reconfigurable Digital Predistortion on a Mobile GPU
Amanullah Ghazi, Jani Boutellier, Markku Juntti, University of Oulu, Finland; Lauri Anttila, Mikko Valkama, Tampere University of Technology, Finland

3GPP LTE-A offers new technologies such as non-contiguous carrier allocation for improving radio spectrum utilization. However, implementation of these technologies is challenging because of intermodulation distortion caused by non-linearity of RF components. Digital Predistortion (DPD) offers a way for compensating these nonlinearities by modifying the digital baseband signal. Now that most consumer-oriented mobile devices are equipped with powerful Graphics Processing Units (GPUs), it has become possible to implement DPD functionality to such devices with no additional hardware cost. In this paper, we propose a data-parallel, reconfigurable DPD algorithm and measure its execution time on mobile GPUs such as Qualcomm Adreno.

MA8b2-4
A Software LDPC Decoder Implemented on a Many-Core Array of Programmable Processors
Brent Bohnenstiehl, Bevan Baas, University of California, Davis, United States

This paper presents the design and implementation of a software Low Density Parity Check (LDPC) decoder on the AsAP2 platform, which contains a 2D mesh of 164 programmable processors designed for general DSP applications. A software decoding algorithm is described which requires low memory overhead, and scalable methods are provided for parallelizing the computational workload across many cores. LDPC codes of length 4095 and 16129 are implemented, respectively using 152 or 156 processors, achieving 21.3 or 13.4~Mbps of throughput, and using 131 or 188~nJ per decoded bit over four decoding iterations.

Track D – Signal Processing and Adaptive Systems
Session: MAb8 – Adaptive Filtering 10:15 AM–11:55 AM

MA8b3-1
Transform Domain LMF Algorithm for Sparse System Identification under Low SNR
Murwan Bashir, Azzedine Zerguine, KFUPM, Saudi Arabia

In this work, a transform domain LMF adaptive filter for a sparse system identification in the case of low SNR is proposed. Unlike LMS algorithm, LMF algorithm performs very well in these environments. Moreover, its transform domain version has an outstanding performance in the correlated environment. However, it lacks sparse information capability. To overcome this limitation, a zero attractor mechanism, based on the l_1 norm is implemented to yield the ZA-TD-LMF algorithm that ensures fast convergence as well enforcing all the filter coefficients to zero. Simulation results are conducted to substantiate our claim and are found to be very effective.

MA8b3-2
Incorporating Signal History Into Transfer Logic for Two-Path Echo Cancelers
Jacob H. Gunther, Todd K. Moon, Utah State University, United States

Two-path echo cancelers offer an effective mechanism to deal with the double-talk problem. A fixed foreground (FG) filter cancels echo while an adaptive background (BG) filter learns the echo path response. The coefficients of the BG filter are transfered to the FG filter when a set of fitness conditions are satisfied. Whereas previous works used memoryless metrics in the

coefficient transfer logic, this paper demonstrates that historical information gives a more complete picture about the convergence and non-convergence of the BG filter. History- based transfer logic yields robust performance during double- talk and barge-in events.

MA8b3-3
Performance Comparisons of Three IIR Structures for Adaptive System Identification Based on Genetic Algorithms (GA)
Xin Shao, Guoxin Sun, William Jenkins, Pennsylvania State University, United States

Genetic Algorithms (GA's) are based on the principles of natural selection and natural genetics that originate in biology. The Genetic Algorithm (GA) has been used for IIR adaptive system identification to deal with its multimodal error surface. The Genetic Algorithm (GA) can perform well in many different IIR adaptive filter structures, while the Gradient Algorithm often does not perform well in these situations. This paper focuses on the performances of three different structures of IIR filters based on the conventional Genetic Algorithm (GA) and the more specialized Multi-Parents Genetic Algorithm (MPGA).

Track C – Networks
Session: MAb8 – Synchronization and Localization 10:15 AM–11:55 AM

MA8b4-1
Greedy Node Localization in Mobile Sensor Networks using Doppler Frequency Shift
Sudhir Kumar, Shriman Tiwari, Rajesh Hegde, Indian Institute of Technology, Kanpur, India, India

The principle of Doppler frequency shift can be utilized for node localization when mobile nodes are introduced into the sensor network. In this paper, a greedy method for mobile node localization using the principle of Doppler frequency shift is presented. A localization framework which accounts for multiple nodes and multiple reception paths is first developed. Subsequently, a greedy approach to anchor path guidance for maximal node localization is proposed. The method is advantageous both in terms of energy consumption and the number of nodes localized. Experiments on mobile node localization are conducted to illustrate the effectiveness of the proposed method.

MA8b4-2
Compressed Temporal Synchronization with Opportunistic Signals
Mohamed Ibrahim, Florian Roemer, Technische Universität Ilmenau, Germany; Niels Hadaschik, Fraunhofer Institute for Integrated Circuits IIS, Germany; Hans-Martin Tröger, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany; Benjamin Sackenreuter, Norbert Franke, Fraunhofer Institute for Integrated Circuits IIS, Germany; Joerg Robert, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany; Giovanni Del Galdo, Fraunhofer Institute for Integrated Circuits IIS, Germany

In this paper we propose a temporal synchronization method using opportunistic signals for wireless networks. Instead of broadcasting a broadband signal throughout the network for synchronization, high-bandwidth opportunistic signals existing in the environment can be used. Using ideas from the compressed sensing area, the high-bandwidth reference signal to be transmitted can be compressed before being sent to the other nodes, while still achieving an accurate correlation function compared to the low bandwidth reference signal scenario. Numerical results demonstrate that the proposed compressed technique achieves a similar performance at a much lower cost compared to using the high-bandwidth opportunistic signal directly.

MA8b4-3
Synchronization and Delay Estimation with Sub-Tick Resolution
Bernhard Etzlinger, Nino Palaoro, Andreas Springer, Johannes Kepler University, Linz, Austria, Austria

We consider the problem of clock synchronization between a pair of nodes using round-trip communication where only the initiating node collects time stamps, and where no time stamps are exchanged. In this work we deviate from the traditional model and propose a discrete-valued clock model, which is motivated by observations from real hardware. Employing the clock model allows us to find a new signaling model for round-trip time measurements, which enables us to simultaneously estimate clock skew, clock phase and propagation delay with a resolution below one clock tick period.

MA8b4-4

Single-Anchor Localization in Inductively Coupled Sensor Networks using Passive Relays and Load Switching

Eric Slottke, Armin Wittneben, ETH Zurich, Switzerland

Wireless physical layers based on inductive coupling are receiving a lot of attention in the context of RFID systems and more recently sensor networks and near field communication. We consider for the first time the localization of a passive agent node based on a single impedance measurement at a single anchor. To this end we propose using passive relay nodes to resolve the associated problem of localization ambiguity and show that load switching at these nodes vastly improves localization accuracy. Numerical results for random networks indicate that a median localization error in the sub-mm range is possible under realistic conditions.

Track A – Communications Systems

Session: MPa1 – Underwater Acoustic Communications and Signal Processing

Chair: ***Milica Stojanovic,*** *Northeastern University*

MP1a-1 **1:30 PM**

Challenges and Analysis of Adaptive Multichannel Equalization for Large-N Arrays

James Preisig, JPAnalytics LLC, United States

Hydrophone arrays with large numbers of elements (Large-N) offer the potential for significantly increasing the capabilities of underwater acoustic communications systems. However, the use of such arrays poses challenges as well. In the context of adaptive equalization in underwater acoustic communications, the primary of these challenges are the computational complexity of the adaptation algorithms and the long averaging intervals (memory) required by algorithms to effectively estimate optimal equalizer filter coefficients. This talk will present methods of addressing these challenges by working with both the array configuration and the equalizer adaptation algorithms and analyze the associated performance trade-offs.

MP1a-2 **1:55 PM**

Noise Variance Estimation for Signal and Noise Subspace Models

Magnus Nordenvaad, Swedish Defence Research Agency (FOI), Sweden

A noise variance estimator in complex-valued models with unknown signal subspace is proposed. Highlighted is that the conventional, maximum likelihood based, way of estimating the noise variance in this setting is highly biased, especially in low sample support and/or low SNR scenarios. The proposed estimator is derived by exploiting that the distribution of the sample covariance eigenvalues can be derived in closed form. By imposing the signal subspace structure, i.e., the multiplicity of the noise eigenvalue, the estimate is found through optimization of the considered likelihood. Simulations show that the presented approach, although slightly biased, vastly improves on standard techniques.

MP1a-3 **2:20 PM**

Experimental Results with HFModem for High Bandwidth Applications

Thomas Riedl, Andrew Bean, James Younce, OceanComm, Incorporated, United States; Toros Arikan, Andrew Singer, University of Illinois at Urbana Champaign, United States

Through leveraging the increased bandwidth available within ranges of 10 to 100m, an HF modem is explored with real time streaming video capability. This paper will discuss some of the challenges and successes in transmitting signals with bandwidths in excess of 400Khz and spectral efficiencies in excess of 6 b/s/Hz.

MP1a-4 **2:45 PM**

Structured Compressive Methods for Wideband Signal Localization

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

Wideband signals as acoustic underwater signaling experience distortion due to propagation delays and scaling from Doppler effects. Underwater acoustic channels are two dimensional. Here, novel compressive sensing approaches that exploit structural properties of communication signals are developed for estimation, localization and detection. For one such channel path isolation algorithm, sample complexity and recovery guarantees are developed. In particular, the effect of signal structure (e.g. rate of decay of the signal from its mode) on such signals is characterized. It is shown that exploiting such signal structure can result in a sample complexity reduction for path detection while maintaining strong performance.

Track A – Communications Systems

Session: MPb1 – Physical Layer Security

Chair: ***Rafael Schaefer,*** *Princeton University*

MP1b-1 **3:30 PM**

Can Linear Minimum Storage Regenerating Codes Be Universally Secure?

Sreechakra Goparaju, University of California, San Diego, United States; Salim El Rouayheb, Illinois Institute of Technology, United States; Robert Calderbank, Duke University, United States

We study the problem of making a distributed storage system information-theoretically secure against a passive eavesdropper, and aim to characterize coding schemes that are universally secure for up to a given number of eavesdropped nodes. Specifically, we consider minimum storage regenerating (MSR) codes and ask the following question: For an MSR code where a failed node is repaired using all the remaining nodes, is it possible to simultaneously be optimally secure using a single linear coding scheme? We define a pareto-optimality associated with this simultaneity and show that there exists at least one linear coding scheme that is pareto-optimal.

MP1b-2 **3:55 PM**

Secure Degrees of Freedom of the Gaussian MIMO Multiple Access Wiretap Channel

Pritam Mukherjee, Sennur Ulukus, University of Maryland, United States

We consider a two-user multiple-input multiple-output (MIMO) multiple access wiretap channel with N antennas at each transmitter, N antennas at the legitimate receiver, and K antennas at the eavesdropper. We determine the optimal sum secure degrees of freedom (s.d.o.f.) for this model for all values of N and K. We subdivide our problem into several regimes based on the values of N and K, and provide alignment based achievable schemes and matching converses for each regime. Our results show how the number of eavesdropper antennas affects the optimal sum s.d.o.f.~of the multiple access wiretap channel.

MP1b-3 **4:20 PM**

Strong Secrecy for Interference Channels from Channel Resolvability

Zhao Wang, Royal Institute of Technology (KTH), Sweden; Rafael F. Schaefer, Princeton University, United States; Mikael Skoglund, Royal Institute of Technology (KTH), Sweden; H. Vincent Poor, Princeton University, United States; Ming Xiao, Royal Institute of Technology (KTH), Sweden

The achievable rate region is studied for interference channels with confidential messages under strong secrecy constraints. The problem is studied based on the framework of the channel resolvability theory. The information-spectrum method introduced by Han and Verdu is first generalized to an arbitrary interference channel to obtain a direct channel resolvability result. The derived resolvability results are then shown to be the achievable strong secrecy rates for the stationary and memoryless interference channel. Our results provide further evidence that channel resolvability can be a powerful and general framework for strong secrecy analysis in multiuser networks.

MP1b-4 **4:45 PM**

The Multiple-Access Channel with an External Eavesdropper: Trusted vs. Untrusted Users

Mario Goldenbaum, Technische Universität Berlin, Germany; Rafael F. Schaefer, H. Vincent Poor, Princeton University, United States

The multiple-access channel with an external eavesdropper is considered. Depending on the trustworthiness of all transmitters, it is studied how the imposed secrecy criterion should be defined. The traditional joint secrecy criterion requires the information leakage from all messages jointly to be small. This is the strongest version and it is suitable for channels where certain transmitters might be compromised. If all transmitters are trustworthy, the secrecy criterion can be relaxed to the individual secrecy criterion which requires all information leakages to be individually small. It is shown that weakening the secrecy criterion lead to gains in achievable secrecy rates.

Session: MP2 – Distributed Coherent Communication Systems

Co-Chairs: ***D. Richard Brown III,*** *Worcester Polytechnic Institute* ***and Daniel Bliss,*** *Arizona State University*

MP2-1 1:30 PM

An Approach to Kalman Filtering for Oscillator Tracking

Sairam Goguri, Soura Dasgupta, University of Iowa, United States

A key impediment to distributed MIMO communications comes from the fact that each transceiver operates its own oscillator. These oscillators drift in both frequency and phase, and drift out of synchrony. Kalman filters can be used to track these drifts to maintain synchronization. A major challenge lies in the lack of precise knowledge of the process noise parameters. Existing algorithms for estimating these parameters are subject to significant bias unless they are run over very long periods of time. This paper proposes an alternative dead-beat approach that ameliorates this problem.

MP2-2 1:55 PM

Rate Adaptive Distributed Source Coding for Wireless Applications

Nicholas Chang, Anthony Triolo, Joseph Liberti, Applied Communication Sciences, United States

Distributed source coding techniques reduce the amount of network traffic required to relay information, by leveraging statistical correlations between different receivers' observations. Slepian-Wolf coding provides a compression bound and a method for distributed receivers to independently compress their own samples, without knowledge of the exact samples at other receivers. A complete abstract, describing the contributions of this work, will be submitted after approval.

MP2-3 2:20 PM

Wideband Retrodirective Distributed Transmit Beamforming with Endogenous Relative Calibration

Raghuraman Mudumbai, University of Iowa, United States; Patrick Bidigare, Raytheon BBN Technologies, United States; D. Richard Brown III, Worcester Polytechnic Institute, United States; Upamanyu Madhow, University of California, Santa Barbara, United States; Soura Dasgupta, Amy Kumar, Ben Peiffer, University of Iowa, United States

This paper describes two techniques for wideband retrodirective distributed transmit beamforming in a multi-input single-output wireless communication system. The techniques exploit channel reciprocity and use relative calibration techniques only among the nodes in the transmit cluster to compensate for non-reciprocal transceiver effects. The techniques are distinguished by whether the signal from the target node is known or unknown. While both techniques result in a coherent wideband beamforming at the target node, the spectrum of the retrodirective beam differs between the two cases. Numerical results are presented to demonstrate the efficacy of the techniques.

MP2-4 2:45 PM

Algorithms and Protocols for Wideband DMIMO

Muhammed Faruk Gencel, Maryam Eslami Rasekh, Upamanyu Madhow, University of California, Santa Barbara, United States

We consider distributed MIMO communication between a cluster of nodes and distant destinations, over a wideband dispersive channel. The goal is to use feedback to implement distributed transmit beamforming and nullforming, which form building blocks for SDMA. We consider FDD systems for which implicit feedback via channel reciprocity is not available. In order to design protocols which scale with cluster size, we restrict attention to aggregate feedback broadcast by each destination to the cluster. We consider OFDM, with the node cluster adapting its transmissions so that destinations can use standard procedures for channel estimation and demodulation.

BREAK **3:10 PM**

MP2-5 **3:30 PM**

Bounds on the Information Capacity of a Broadcast Channel with Quantizing Receivers

Christian Chapman, Arizona State University, United States; Adam Margetts, MIT Lincoln Laboratory, United States; Daniel Bliss, Arizona State University, United States

A `base' node wants to listen to a broadcast. The base is too far away to observe the broadcast itself, and instead listens to several `helper' nodes through a LAN. The helpers see the broadcast through channels occluded by additive white Gaussian noise. The helpers want to convey exactly what they see back to base, but the LAN is constrained in the sum rate from helpers to base, so they must send coarse information. Bounds on the capacity of such a system with channel state information available at the helpers and base are found, simulated and analyzed.

MP2-6 **3:55 PM**

Achieving Large Multiplexing Gain in Distributed Antenna Systems via Cooperation with pCell Technology

Antonio Forenza, Stephen Perlman, Fadi Saibi, Mario Di Dio, Roger Van Der Laan, Artemis Networks, United States; Giuseppe Caire, Technische Universität Berlin, Germany

In this paper we present pCell, the first commercial-grade wireless system that employs cooperation between distributed transceiver stations to create concurrent data links to multiple users in the same spectrum. First we describe the system architecture consisting of a GPP-based software defined radio (SDR) wireless platform implementing a real-time LTE protocol stack to communicate with off-the-shelf LTE devices. Then we present experimental results demonstrating up to 16 concurrent spatial channels for an aggregate downlink throughput of 200 Mbps in 5 MHz of TDD spectrum, yielding 35 times the average downlink spectral efficiency of current LTE networks.

MP2-7 **4:20 PM**

Coded Distributed Diversity with Physical Layer Network Coding

Andrew Marcum, David Love, James Krogmeier, Purdue University, United States

We consider a distributed reception scenario with physical layer network coding that consists of two user nodes, multiple geographically separated relays, and a fusion center. In the uplink time slot, each user transmits a signal that is observed by all relay nodes. The relays forward a few bits representing a processed version of the observed signal to the fusion center via high rate link. The fusion center then decodes the user transmissions and decides how to conduct the downlink (i.e., relay to use and signal). We show results using a USRP based physical layer network coding implementation.

MP2-8 **4:45 PM**

Distributed Nonlinear Filtering of Partially Observed Markov Chains over WSNs: Truncating the ADMM

Dionysios Kalogerias, Athina Petropulu, Rutgers, The State University of New Jersey, United States

As an iterative algorithm, the ADMM requires an infinite number of iterations in order to converge. However, in a dynamic filtering setup, it is impossible to let the ADMM converge in a large number of steps, due to the existence of the temporal update of the respective filter. The simplest solution to this issue is to truncate the iterations of the ADMM. In this work, under common assumptions, we analyze the behavior of this approach, showing that, under reasonable conditions, truncating the ADMM results in a stable distributed filtering scheme. Our simulations firmly support our theoretical investigation.

Track A – Communications Systems

Session: MP3 – 5G Cellular Networks

Co-Chairs: ***Matthew Valenti,*** *West Virginia University* ***and Jeffrey Andrews,*** *University of Texas, Austin*

MP3-1 **1:30 PM**

Directional Initial Access for Millimeter Wave Cellular Systems

C. Nicolas Barati, S. Amir Hosseini, Marco Mezzavilla, Parisa Amir-Eliasi, Sundeep Rangan, NYU Polytechnic School of Engineering, United States; Michele Zorzi, University of Padova, Italy; Thanasis Korakis, Shivendra S. Panwar, NYU Polytechnic School of Engineering, United States

A key challenge in designing millimeter wave (mmWave) cellular systems for is initial access -- the procedure by which a mobile establishes an initial link-layer connection to a base station cell. MmWave communication relies on highly directional transmissions and the initial access procedure must thus provide a mechanism by which initial directions of transmissions can be searched in a potentially large angular space. Design options are compared considering different scanning and signaling procedures to evaluate access delay and system overhead. The analysis demonstrates significant benefits of low-resolution fully digital architectures in comparison to single stream analog beamforming.

MP3-2 **1:55 PM**

Multiplexing-Diversity Tradeoffs in Single-Shot Noncoherent Wideband Massive MIMO Systems

Mainak Chowdhury, Alexandros Manolakos, Andrea Goldsmith, Stanford University, United States

We investigate, through a detection-theoretic framework, the effect of the number of antennas on the symbol error rate of a single-shot noncoherent MIMO system in which the terminals only know the channel statistics, and quantify the notions of diversity and multiplexing for large antenna systems. Our analysis indicates that increasing the number of receive antennas always helps even without instantaneous channel state information. On the other hand, in independent Rayleigh fading, having more than a single transmit antenna does not provide any gains. Yet, in scenarios with channel correlation or line of sight, having more transmit antennas could be beneficial.

MP3-3 **2:20 PM**

Spatial Modeling of Device-To-Device Networks: Poisson Cluster Process Meets Poisson Hole Process

Mehrnaz Afshang, Harpreet Dhillon, Virginia Tech, United States

This paper combines Poisson Cluster Process (PCP) and a Poisson Hole Process (PHP) to develop a new spatial model for integrated device-to-device (D2D) and cellular networks. In particular, the device locations are modeled by a modified Thomas cluster process in which the cluster centers are modeled by a PHP instead of a homogeneous PPP. While the clusters capture the inherent proximity in the devices engaging in D2D communications, the holes model exclusion zones where D2D communication is prohibited to protect cellular transmissions. For this setup, we characterize network performance in terms of coverage probability and area spectral efficiency.

MP3-4 **2:45 PM**

FDD Massive MIMO with Analog CSI Feedback

Kien Truong, Posts and Telecommunications Institute of Technologies, Viet Nam; Hosein Nikopour, Huawei Technologies Co., Ltd., Canada; Robert W. Heath Jr., University of Texas at Austin, United States

Prior work on massive MIMO assumes TDD operation to take advantage of channel reciprocity. Most current cellular systems, however, widely deploy FDD protocols. In this paper, we consider an FDD massive MIMO network where the base stations obtain downlink channel estimates via analog feedback from the users. We adopt a deterministic equivalent approach to analyze downlink achievable rates. The analysis is validated by numerical results in a multi-cell system. Depending on system parameters like the Doppler shift, it is desirable to shut off a subset of antennas at the base stations to maximize achievable downlink sum-rates.

BREAK **3:10 PM**

MP3-5 **3:30 PM**

A Tractable Model for Per User Rate in Multiuser Millimeter Wave Cellular Networks

Mandar Kulkarni, Ahmed Alkhateeb, Jeffrey Andrews, University of Texas at Austin, United States

We compare the coverage and rate performance of multiuser (MU) MIMO with single-user beamforming (SU-BF) in a dense millimeter-wave cellular network. We show that MU-MIMO has the potential to give significantly higher per user rates but at the cost of higher power consumption and reduced signal to interference plus noise ratio. However, if only the average power per unit area is preserved, it may turn out to be useful to deploy more base stations employing SU-BF versus introducing MU-MIMO on a less dense network. A stochastic geometry model that captures these trends for a large number of antennas is proposed.

MP3-6 **3:55 PM**

Frequency Hopping on a 5G Millimeter Wave Uplink

Salvatore Talarico, Matthew Valenti, West Virginia University, United States

Frequency hopping is optional for the 4G/LTE uplink, which implements it by assigning a different allocation of resource blocks during the second of two slots of a subframe. It is anticipated that 5G networks will make more aggressive use of frequency hopping. This paper demonstrates the potential of FH when used at millimeter wave frequencies. The signal model incorporates the effects of antenna directivity, blockage, fading, and partial power control. The analysis focuses on inter-cell interference. The impact of several design factors is considered, including using shorter slots, hopping more than just twice per subframe, and using variable-sized resource allocations.

MP3-7 **4:20 PM**

Towards a P2P Mobile Contents Trading

Sameh Hosny, Faisal Alotaibi, Hesham El Gamal, Atilla Eryilmaz, The Ohio State University, United States

In this paper, we study the possibility of data contents peer-to-peer trading. Motivated by our recent findings on proactive resource allocation, we focus on the scenario whereby end-users harness their predictable demands and the possibility of being connected together to pre-cache data contents and resell them in order to minimize their expected payments. The carrier, on the other hand, maximizes its profit by taking a commission from each trade and deploying a dynamic pricing scheme to spread-out the peak load and hence reduce the operational cost.

MP3-8 **4:45 PM**

Cell-Free Massive MIMO Versus Small Cells

Hien Ngo, Linköping University, Sweden; Alexei Ashikhmin, Hong Yang, Bell Labs, United States; Erik G. Larsson, Linköping University, Sweden; Thomas L. Marzetta, Bell Laboratories, Alcatel-Lucent, United States

We analyze the performance of Cell-Free Massive MIMO systems, where a large number of distributed access points simultaneously serve a much smaller number of users. Channel estimation, power control, and shadow fading correlation are taken into consideration in the analysis. A comparison between Cell-Free Massive MIMO systems and small-cell systems is also performed. We show that Cell-Free Massive MIMO systems outperform small-cell systems, particularly in correlated shadowing scenarios. The Cell-Free system can provide almost 10-fold respectively 100-fold increases in the 95\%-likely per-user throughputs in uncorrelated and correlated shadow fading, compared with the small-cell system.

Track C – Networks

Session: MPa4 – Distributed Signal Processing

Chair: ***Cihan Tepedelenlioglu,*** *Arizona State University*

MP4a-1 **1:30 PM**

Budgeted Kalman Filtering and Smoothing for Economical Tracking with Big Distributed Data

Dimitris Berberidis, Georgios B. Giannakis, University of Minnesota, United States

Tracking nonstationary state processes of dynamical systems is of paramount importance in various applications. In the context of big distributed data, accurate and economical state estimates over a fixed interval of observations are certainly well motivated. The goal of this paper is filtering and fixed-interval smoothing with reduced communication overhead and computational complexity. Building on the forward-backward iterative Kalman smoother, the novel approach leverages only ``sufficiently

informative'' measurements to develop a forward iteration that can be implemented in real time, followed by a backward smoothing iteration, both enjoying simple closed-form updates. Corroborating simulations illustrate the efficacy of the proposed scheme.

MP4a-2 1:55 PM

Detection of Data Injection Attacks in Decentralized Learning

Reinhard Gentz, Hoi-To Wai, Anna Scaglione, Arizona State University, United States; Amir Leshem, Bar-Ilan University, Israel

Gossip based optimization and learning are appealing methods solve big data learning problems sharing computation and network resources when data are distributed. The main advantage these methods offer is that they are fault tolerant. Their flat architecture, however, expands the attack surface in the case of a data injection attack. In this paper we analyze the effects of data injection on the asymptotic behavior of the network and draw a parallel with the case of opinion dynamics in a network where zealots inject opinions to mislead and bias a community. We further discuss the possible decentralized detection of such attacks.

MP4a-3 2:20 PM

Distributed Clustering Based on Message Passing

Songtao Lu, Zhengdao Wang, Iowa State University, United States

Clustering is an important task for many applications. Due to the size of the problems and the fact that in many applications the data are inherently distributed, many centralized clustering algorithms that have been developed before either have high complexity or are not directly applicable. In this work, we seek to develop distributed algorithms that can perform the clustering task by exchanging messages between distributed nodes. The goal is to achieve good local or global clustering performance at low complexity.

MP4a-4 2:45 PM

Distributed Node Counting in Wireless Sensor Networks

Sai Zhang, Cihan Tepedelenlioglu, Andreas Spanias, Arizona State University, United States; Mahesh Banavar, Clarkson University, United States

A distributed consensus algorithm for estimating the number of nodes in a wireless sensor network in the presence of communication noise is proposed. The idea is based on estimating the norm of available samples at nodes. Each node generates its own random initial measurements and updates its state by only communicating with its neighbors: the algorithm is a fully distributed algorithm that nodes require no information about the structure of the network. We show that there is a trade-off between the estimation error and the storage at each node: a more accurate estimate requires larger storage at each sensor node.

Track D – Signal Processing and Adaptive Systems

Session: MPb4 – Designing Sparse Sensing Structures

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

MP4b-1 3:30 PM

On Optimal Sensor Collaboration for Distributed Estimation with Individual Power Constraints

Sijia Liu, Syracuse University, United States; Swarnendu Kar, Intel Corporation, United States; Makan Fardad, Pramod Varshney, Syracuse University, United States

In the context of distributed estimation, we study the problem of sensor collaboration with individual power constraints, where inter-sensor collaboration refers to the act of sharing measurements with neighboring sensors prior to transmission to a fusion center. In order to find the optimal collaboration strategy consisting of power allocation scheme and collaboration topology, we propose a non-convex formulation in which the estimation distortion is minimized under power constraints. By exploiting problem structures, locally optimal collaboration strategies are found via bilinear relaxations and a convex-concave procedure. Numerical examples are provided to show the effectiveness of our approach.

MP4b-2 **3:55 PM**

Optimal Sensor and Actuator Selection for Large-Scale Dynamical Systems

Neil Dhingra, Mihailo Jovanovic, Zhi-Quan Luo, University of Minnesota, United States

We study the problem of selecting an optimal subset of available sensors or actuators for large-scale dynamical systems. By introducing a change of coordinates and a sparsity-promoting group ℓ_1 penalty, we cast this problem as a semidefinite program. The solution of the resulting convex optimization problem yields an estimator (respectively, controller) that achieves desired performance while using smaller number of sensors (actuators) than the optimal centralized Kalman filter (Linear Quadratic Regulator). We develop a customized algorithm, based on the alternating direction method of multipliers, that is well-suited for large-scale problems.

MP4b-3 **4:20 PM**

Information Discovery in Heterogeneous Sensor Networks via Regularized Canonical Correlations

Jia Chen, Ioannis Schizas, University of Texas at Arlington, United States

Heterogeneous sensing systems consisting of sensors with different types of sensing and communication capabilities offer flexibility in deployment, and the ability to provide different `views' of a sensed field by acquiring different types of measurements. The main challenge is that the often large amount of acquired raw sensed data does not provide any clue of `what lies beneath' the sensed field. This work focuses on deriving an algorithmic framework that has the ability to identify, cluster and match different types of sensor data based on their information content. To this end, a novel regularized canonical correlations framework is put forth.

MP4b-4 **4:45 PM**

Sparse Sensing for Estimation with Correlated Observations

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

Ubiquitous sensors generate prohibitively large datasets. In this era of data deluge, it is of paramount importance to gather only data that is informative for a specific task in order to limit the required sensing cost, as well as the related costs of processing, or communicating the data. In this paper, we propose a sparse sensing framework for non-linear parameter estimation with correlated observations. The solution is based on convex relaxation techniques. As a result, we show that the number sensors required reduces as the sensors become more coherent. We apply the developed theory to anchor placement problem in localization.

Track E – Array Signal Processing

Session: MPa5 – Co-Prime Arrays

MP5a-1 **1:30 PM**

Performance Breakdown in Parameter Estimation using Co-Prime Arrays

Pooria Pakrooh, Louis Scharf, Ali Pezeshki, Colorado State University, United States

We study performance breakdown of co-prime arrays for parameter estimation. The main source of performance breakdown in many parameter estimation methods is known to be the occurrence of a subspace swap, where some of the modes of the noise subspace better represent the measurements than some of the modes of the noise-free signal subspace. We consider a data model in which the parameters modulate the mean value function of multivariate normal measurements, and derive lower bounds on the probability of the subspace swap. These bounds may be used to predict the threshold signal-to-noise ratios for parameter estimation using co-prime arrays.

MP5a-2 **1:55 PM**

Detecting Gaussian Signals in the Presence of Interferers using the Coprime Sensor Arrays with the Min Processor

Yang Liu, John Buck, University of Massachusetts Dartmouth, United States

A coprime sensor array (CSA) requires fewer sensors to achieve equivalent spatial resolution as a fully populated ULA with the same aperture. CSAs commonly multiply the subarray beampatterns to resolve the ambiguities introduced by spatial aliasing. This paper proposes choosing the minimum between the CSA subarray output powers for each bearing to resolve the aliasing ambiguities. The resulting CSA-min detection PDFs for each bearing are weighted sums of products of exponential functions and Marcum Q-functions. The CSA-min processor improves the ROC performances in detecting Gaussian signals in the presence of interferers and noise in Monte Carlo simulations.

MP5a-3 **2:20 PM**

Multitapered Power Spectral Density Estimation for Co-Prime Sensor Arrays

Ian Rooney, John Buck, University of Massachusetts Dartmouth, United States

Thomson's multitaper method reduces the variance of power spectral density (PSD) estimates by averaging measurements weighted by orthogonal tapers at the expense of resolution. Co-prime sensing arrays match the resolution of a uniform linear array using fewer sensors by coherently combining interleaved spatially under-sampled sub-arrays for spatial PSD estimation. This research proposes an algorithm that combines both techniques to compute a spatial PSD estimate with reduced variance and resolution comparable to a uniform linear array. A multitapered co-prime sensing array reduces variance proportional to the number of tapers used and reduces sensors by at least 33%.

MP5a-4 **2:45 PM**

Co-Prime Array Processing with Sum and Difference Co-Array

Xiaomeng Wang, Xin Wang, Stony Brook University, United States; Xuehong Lin, Beijing University of Posts and Telecomm., China

The emerging co-prime array technique is found to be attractive. However, its potential of increasing the degree of freedom (DoF) is constrained due to the existence of holes in the difference co-array. Some attempts have been made to fill the holes at the cost of additional sensors and frequencies. We propose to exploit both sum and difference co-arrays to form a larger size of continuous virtual array while keeping the conventional co-prime array configuration for high detection performance. Compared to existing efforts, our scheme can use much smaller number of physical sensors while obtaining the same or even more degrees-of-freedom.

Track E – Array Signal Processing

Session: MPb5 – MIMO Radar

MP5b-1 **3:30 PM**

Reducing the Effects of Training Data Heterogeneity in Multistatic MIMO Radar

Tariq Qureshi, Muralidhar Rangaswamy, Air Force Research Laboratory, United States; Kristine Bell, Metron Inc., United States

A MIMO Multistatic radar system consists of multiple bistatic pairs working in potentially different configurations. Due to the relative motion between platforms, the clutter traces are, in general, non-overlapping, and the spectral centers are dispersed in the angle-Doppler domain. This makes the training samples non-representative which in turn increases AR parameter estimation error in the Parametric Adaptive Matched Filter (PAMF) that we consider. In this paper, we present techniques to compensate for this hetero- geneity, and characterize the performance of each technique based on the metrics of SINR loss, and the probability of detection as a function of SNR.

MP5b-2 **3:55 PM**

Coherent MIMO Radar with Sparse Recovery: Joint vs. Separate Range and Azimuth Estimation

Lorenz Weiland, Thomas Wiese, Wolfgang Utschick, Technische Universität München, Germany

We consider coherent MIMO radar imaging using a combination of sparse recovery for range estimation and high-resolution methods for azimuth estimation. By separating range and azimuth estimation, we circumvent the need for very coarse azimuth grids as imposed by RIP constraints. We recently proposed block sparse recovery for range-only imaging. In this work, we extend our previous work and use a high-resolution estimator on the estimated channel matrices to extract azimuth estimates. We compare our results with conventionally used joint sparse recovery for range and azimuth.

MP5b-3 **4:20 PM**

Three Dimensional Compressive Sensing in MIMO Radar

Yaqi Liu, Jun Tang, Ning Zhang, Wei Zhu, Tsinghua University, China

A compressive sensing based bistatic MIMO radar is proposed for joint direction of departure (DOD), direction of arrival (DOA) and Doppler frequency estimation, where random arrays are employed and the intervals between adjacent pulses are chosen randomly. A discretization mechanism for three-dimensional parameter space is established, based on which the least amount of random measurements required for faithful target parameter recovery is derived. The theoretical derivation indicates that remarkable reduction in measurement number can be achieved without degrading the estimation performance. Numerical results corroborate the effectiveness of the proposed sparse sensing framework as well as the corresponding recovery guarantees.

Session: MP6 – Signal Processing and Optimization Methods for Big Data Analytics

Chair: ***Gesualdo Scutari,*** *Purdue University*

MP6-1 **1:30 PM**

Fitting Graph Models to Big Data

Jonathan Mei, José M.F. Moura, Carnegie Mellon University, United States

Many big data applications collect large numbers of time series. A first task in analyzing such data is to find a low-dimensional representation, a graph, which faithfully describes relations among the measured processes and through time. The processes are often affected by a relatively small number of unmeasured trends. This paper presents a computationally tractable algorithm for jointly estimating these trends and underlying weighted, directed graph structure from the collected data. The algorithm is demonstrated on simulated and real time series datasets, and its performance is compared to that of related methods.

MP6-2 **1:55 PM**

Robust Low-Rank Optimization for Large Scale Problems

Licheng Zhao, Prabhu Babu, Daniel P. Palomar, Hong Kong University of Science and Technology, China

In this paper, we propose using smooth robust loss functions to formulate robust low-rank optimization problem in the presence of outliers. The objective of the problem is to recover a low-rank data matrix from noisy entries. Our main contributions are i) providing two smooth robust loss functions to handle respectively two different types of outliers, i.e., the universal outliers with unknown statistical distribution and the sparse spike-like outliers; ii) an efficient algorithm doing parallel minimization instead of alternating update. Numerical results show that the proposed algorithm obtains a better solution at a faster convergence rate than the state-of-art algorithms.

MP6-3 **2:20 PM**

Solvetime Complexity for Parallel Optimization

Peter Richtarik, University of Edinburgh, United Kingdom; Martin Takac, Lehigh University, United States

In much of the literature on iterative schemes it is customary to prove convergence results, sometimes with estimates of the rate of convergence. Often it is possible to obtain bounds on the number of iterations. In this work we propose a new and natural complexity model, “solve-time complexity”, where one is interested in obtaining a bound on the (expected) time for a method to solve a problem. We apply the idea to the parallel coordinate descent methods in optimization, which is a method suitable for solving big data problems.

MP6-4 **2:45 PM**

A Distributed Strategy for Computing Proximity Operators

Feriel Abboud, Emilie Chouzenoux, Jean-Christophe Pesquet, Universite Paris-Est Marne-la-Vallee, France; Jean-Hugues Chenot, Louis Laborelli, Institut national de l’audiovisuel, France

Various recent iterative optimization methods require to compute the proximity operator of a sum of functions. We address this problem by proposing a new distributed algorithm for a sum of convex non-necessarily smooth functions composed with arbitrary linear operators. In our approach, each function is associated with a node of a graph, which communicates with its neighbors. Our algorithm relies on a primal-dual splitting strategy that avoids to invert any linear operator, thus making it suitable for processing high-dimensional datasets. The proposed algorithm has a wide array of applications in signal/image processing and machine learning and its convergence is established.

BREAK **3:10 PM**

MP6-5 **3:30 PM**

Max-Min Feasible Point Pursuit for Nonconvex QCQP

Charilaos Kanatsoulis, Nicholas Sidiropoulos, University of Minnesota, United States

Quadratically constrained quadratic programming (QCQP) has a variety of applications in signal processing, communications, and networking – but in many cases the associated QCQP is non-convex and NP-hard. Semidefinite relaxation or successive convex approximation are typically used to approximate non-convex QCQP, but these fail when there are two-sided or indefinite constraints. Following up on recent work from our group on so-called feasible point pursuit (FPP), we revisit this problem from a different point of view and devise a new approximation strategy that is simpler and often meets or outperforms the original FPP.

MP6-6 **3:55 PM**

A Family of Friendly Proximals

Michael Friedlander, Gabriel Goh, University of California, Davis, United States

The convex proximal operator is a key computational kernel of many algorithms for sparse signal recovery. We show how an interior method can be used to compute the proximal operator of a convex function under different metrics, where both the metric and the function have simultaneous structure that allow the proximal map to be computed in time nearly linear in the input size. We describe how to use this approach to implement quasi-Newton methods for a rich class of nonsmooth problems that include important signal-processing applications.

MP6-7 **4:20 PM**

Decentralized Double Stochastic Averaging Gradient

Aryan Mokhtari, Alejandro Ribeiro, University of Pennsylvania, United States

This paper considers convex optimization problems where nodes of a network have access to summands of a global objective function. Each of these local objectives is further assumed to be an average of a finite set of functions. The decentralized double stochastic averaging gradient (DSA) algorithm is proposed as a solution alternative that relies on: (i) The use of local stochastic averaging gradients instead of local full gradients. (ii) Determination of descent steps as differences of consecutive stochastic averaging gradients. The algorithm is shown to approach the optimal argument at a linear rate. Numerical experiments verify linear convergence of DSA.

MP6-8 **4:45 PM**

Nonconvex Distributed Optimization over Graphs

Paolo Di Lorenzo, “Sapienza” University of Rome, Italy; Gesualdo Scutari, Purdue University, United States

We study nonconvex distributed optimization in multi-agent networks with time-varying (nonsymmetric) connectivity. We introduce the first algorithmic framework for the distributed minimization of the sum of a smooth (possibly nonconvex, nonseparable) function–the agents’ sum-utility–plus a convex (possibly nonsmooth, nonseparable) regularizer. The proposed method hinges on successive convex approximation techniques while leveraging dynamic consensus as a mechanism to distribute the computation among the agents. Asymptotic convergence to (stationary) solutions of the nonconvex problem is established. Our algorithmic framework is then customized to a variety of convex and nonconvex problems in several fields, including signal processing, networking, and machine learning.

Track F – Biomedical Signal and Image Processing

Session: MPa7 – Signal Processing in Biology: Theoretical Advances and Open Problems

Co-Chairs: ***Byung-Jun Yoon,*** *Texas A&M University* ***and Xiaoning Qian,*** *Texas A&M University*

MP7a-1 **1:30 PM**

A Risk-Based Approach to Optimal Clustering under Random Labeled Point Processes

Lori Dalton, The Ohio State University, United States

Typically, optimization in clustering is relative to a heuristic metric, rather than relative to a definition of error with respect to a probabilistic model to make clustering rigorously predictive. To address this, we develop a general risk-based formulation for clustering that parallels classical Bayes decision theory for classification, transforming clustering from a subjective activity to an objective operation. We develop a general analytic procedure to find an optimal clustering operator, called a Bayes clusterer, which corresponds to the Bayes classifier in classification theory. In particular, we address Gaussian models, and discuss fundamental limits of performance in clustering.

MP7a-2 **1:55 PM**

Small Data Is the Problem

Edward Dougherty, Texas A&M University, United States; Lori Dalton, Ohio State University, United States; Frank Alexander, Los Alamos National Laboratory, United States

Small data is limiting issue for signal processing and science in general, especially in the contemporary era of complex systems. Lack of data impacts system identification and the problem is compounded by having insufficient data for system validation. With biological systems, feature spaces for both classification and network representation contain thousands of potential

variables. Even when these spaces are dramatically reduced, owing to a paucity of data, the best one can do is identify an uncertainty class of distributions constructed via a combination of prior knowledge and data. We discuss the small sample conundrum and Baysesian approaches to address it.

MP7a-3 2:20 PM

Infinite Vocabulary Naive Bayes Classifiers

Mingyuan Zhou, University of Texas at Austin, United States

Using the gamma-Poisson, gamma-negative binomial, and beta negative binomial processes, we construct three infinite vocabulary naive-Bayes classifiers to categorize a count vector to one of several existing random count matrices of different categories. These classifiers support an unbounded number of features, and unlike most existing methods, they do not require a predefined finite vocabulary to be shared by all the categories, and need neither feature selection nor parameter tuning. Experimental results on document categorization demonstrate their competitive performance.

MP7a-4 2:45 PM

Optimal Gene Regulatory Network Inference using the Boolean Kalman Filter and Multiple Model Adaptive Estimation

Mahdi Imani, Ulisses Braga-Neto, Texas A&M University, United States

We propose a method for the inference of Boolean gene regulatory networks observed through noise. The algorithm is based on the optimal MMSE state estimator for a Boolean dynamical system, known as the Boolean Kalman filter (BKF). In the presence of partial knowledge about the network, a bank of BKFs representing the candidate models is run in parallel in a Bayesian framework known as a multiple model adaptive estimation (MMAE). Performance is investigated using a model of the p53-MDM2 negative feedback loop network, as well as application to a large number of random networks in order to estimate average performance.

Track F – Biomedical Signal and Image Processing

Session: MPb7 – ECG and EEG Signal Processing

MP7b-1 3:30 PM

Adaptive EEG Artifact Suppression using Gaussian Mixture Modeling

Francisco Solis, Alexander Maurer, Jiewei Jiang, Antonia Papandreou-Suppappola, Arizona State University, United States

Neural tracking using electroencephalography (EEG) recordings suffers from the presence of artifacts, such as eye movement or non-physiological activity. We propose an integrated method to adaptively track multiple neural sources while reducing the effects of artifacts. Specifically, time-frequency features are first extracted from EEG recordings without first pre-processing it to remove artifacts. The features for each signal type are parametarized using Gaussian mixture models, which are are incorporated into probability hypothesis density filter tracker. Simulation results demonstrate the effectiveness of the proposed algorithm in increasing the tracking accuracy performance for multiple dipole sources using recordings contaminated by artifacts.

MP7b-2 3:55 PM

Signal Denoising via Quadratic Semi-Infinite Programming

Carlos Davila, Southern Methodist University, United States

This paper has two main contributions, the first is an approach to signal denoising based on quadratic semi-infinite programming (QSIP). This approach offers some advantages over traditional discrete-time filtering, including sharper transition bands between passband and stopband and linear phase, while still enabling real-time processing (provided sufficient computational resources are available). The second contribution is a relatively efficient algorithm for solving QSIP. This algorithm offers some computational advantages over comparable algorithms based on semidefinite programming (SDP). We describe the application of this approach to notch filtering and the removal of high-frequency artifacts in ECG data.

MP7b-3 **4:20 PM**

Heart Rate Estimation from Photoplethysmogram During Intensive Physical Exercise using Non-Parametric Bayesian Factor Analysis

Sandeep Dsouza, Siddharth Jar, Indian Institute of Technology Kharagpur, India; Mahasweta Chakraborti, Anwesha Chatterjee, Jadavpur University, India; Priyadip Ray, Indian Institute of Technology Kharagpur, India

Estimating heart rate from PPG in the presence of motion artifacts is a challenging problem. Previous approaches have primarily relied on accelerometer data to remove motion artifacts. In this paper, we propose a factor analysis based approach to estimate heart rate from PPG, in the presence of motion artifacts. The novelty of our approach lies in the fact that it relies on a single channel PPG to estimate heart rate, and does not require accelerometer data. The accuracy and robustness of the proposed approach has been demonstrated on a range of datasets corresponding to different intensive physical exercise scenarios.

Track G – Architecture and Implementation

Session: MPa8 – Implementation of Digital Signal Processing Algorithms 1:30 PM–3:10 PM

MP8a1-1

CRT RSA Decryption: Modular Exponentiation Based Solely on Montgomery Multiplication

Joao Carlos Neto, University of Sao Paulo, Brazil; Alexandre Tenca, Synopsys, Inc., United States; Wilson Ruggiero, University of Sao Paulo, Brazil

An innovative hardware design is proposed to perform modular exponentiation using only Montgomery Multiplication for CRT RSA decryption. The same hardware used to perform exponentiation is also used to perform conversions. The proposed algorithm is described and provided a versatile hardware implementation. When compared to the classical sequential Radix-2 MM architecture from which it was derived, the new RSA architecture shows 44% average reduction in the energy consumption. The efficient design proposed is shown through an experimental synthesis with a 90nm CMOS technology. The results are compared with the state-of-art in the RSA 1024-bit implementations using non-RNS solutions.

MP8a1-2

Low Power Design of a Word-Level Finite Field Multiplier using Reordered Normal Basis

Parham Hosseinzadeh Namin, Roberto Muscedere, Majid Ahmadi, University of Windsor, Canada

A low power design for a finite field multiplier in GF(2^m) using reordered normal basis is presented. The main building block of the multiplier has been designed in domino logic. The basic idea is to reduce the contention between the keeper transistor and the pull-down network utilizing a new keeper control design to reduce the power dissipation. Simulation results in 65nm CMOS technology show that the proposed design offers 23.5% less power consumption compared to the previously presented design and 5% less than the static CMOS equivalent while preserving the maximum operating speed of the dynamic design.

MP8a1-3

Canonic Real-Valued Radix-2^n FFT Computations

Yingjie Lao, Keshab Parhi, University of Minnesota, Twin Cities, United States

Canonic real-valued FFT (RFFT) approach improves the computation performance by completely eliminating arithmetic redundancies. The major advantage of the canonic RFFTs is that these require the least butterfly operations and only involve real datapath when mapped to architectures. In this paper, we study the performances of canonic RFFT computations for different radix factorizations. We compare various radices RFFTs along with their canonic variants from both arithmetic and architectural perspectives. It is shown that decimation-in-frequency (DIF) RFFT structures require less twiddle factor operations than their decimation-in-time (DIT) counterparts.

MP8a1-4
A Low Power Radix-2 FFT Accelerator for FPGA
Soumak Mookherjee, Linda DeBrunner, Victor DeBrunner, Florida State University, United States

This paper presents a low power FFT accelerator using Radix-2 algorithm with 8-parallel multi-path delay commutator. A Radix-2 MDC architecture is designed with 8-parallel processing of input samples. The hardware utilization of the architecture is 100% requiring only 4 parallel butterflies. It increases throughput to eight times of the traditional R2MDC. We implement our design on Xilinx Virtex FPGA and measure area, frequency, latency, throughput and power. We show that our design can operate at a similar rate while reducing the power by 25% on FPGA compared to R2MDC.

MP8a1-5
Indoor Fall Detection using a Network of Seismic Sensors
Halil Ibrahim Sümer, Sevgi Zübeyde Gürbüz, TOBB University of Economics and Technology, Turkey

Falls present a great health threat as people get older, and is critical for decreasing fall-related mortality. The development of signal processing algorithms for biomedical applications involving assisted living has become an avid area of research. In this work, novel algorithm for activity classification and fall detection using a seismic sensor network is proposed. Classification of a variety of activities are considered. A new target detection and feature extraction algorithm based on wavelet coefficient characterization and spectral statistics is proposed. The algorithm offers a reduction of false alarms especially in the case of potentially easily confused sources of parasitic signals.

Track D – Signal Processing and Adaptive Systems
Session: MPa8 – Sparsity and Compressed Sensing 1:30 PM–3:10 PM

MP8a2-1
RSCS: Minimum Measurement MMV Deterministic Compressed Sensing Based on Complex Reed Solomon Coding
Tobias Schnier, Carsten Bockelmann, Armin Dekorsy, Universität Bremen, Germany

Compressed Sensing (CS) is an emerging field in mathematics that is used to measure few measurements of sparse vectors for lossless reconstruction. In this paper we use results from channel coding to create the recovery algorithm RSCS for CS in the Multiple Measurement Vector case (MMV) that can be used with a deterministic measurement matrix by using error correction schemes. In particular, we show that a modified Reed Solomon encoding-decoding structure can be used to measure sparsely representable vector systems down to the theoretical minimum number of measurements with guaranteed reconstruction, even in the low dimensional case.

MP8a2-2
Autoregressive Process Parameter Estimation from Compressed Sensing Measurements
Matteo Testa, Enrico Magli, Politecnico di Torino, Italy

In the paper we introduce a least squares estimator of the regression coefficients of an autoregressive process acquired by means of Compressed Sensing (CS). Unlike common CS problems in which we only know that the signal is sparse, using the proposed autoregressive model we can gain knowledge about the structure of the original signal without recovering it. This problem is addressed by introducing an ad-hoc sensing matrix that preserves the structure of the regression and whose performance is numerically validated. Moreover, we present applications that naturally exploit this additional information which can be directly obtained from the compressed data.

MP8a2-3
An Adaptive Greedy Pursuit Algorithm for Pulse-Doppler Radar
Abdur Rahman Maud, Mark Bell, Purdue University, United States

Pulse Doppler radar using matched filter often suffers from spurious targets because of the radar uncertainty principle. Recently, the application of sparse recovery techniques to pulse Doppler radar has been shown to yield improved target resolution when the radar waveform satisfies certain conditions. Unfortunately, many commonly used radar waveforms do not satisfy these conditions. In this paper, an adaptive greedy matching pursuit algorithm is proposed for estimating sparse target scenes. The recovery condition for the proposed algorithm is derived and it is shown that the proposed algorithm requires radar transmit signals to satisfy a more relaxed condition.

MP8a2-4
Dictionary Learning from Quadratic Measurements in Block Sparse Models
Piya Pal, University of Maryland, College Park, United States

This paper introduces the problem of dictionary learning from quadratic measurements of block-sparse observations. It is shown that learning the dictionary from certain quadratic products of these measurements can offer unique advantages, especially with respect to the size of identified sparse support. The proposed results are valid under some practical assumptions on the structure of the unknown sparse coefficient matrix. Given an $M \times L$ observation matrix, it is possible to recover supports of size $O(M^{2})$, along with the unknown dictionary, whereas existing literature in dictionary learning can only guarantee recovering sparse supports of size $O(M)$.

MP8a2-5
Signal Parameter Estimation Performance under a Sampling Rate Constraint
Andreas Lenz, Manuel Stein, Josef A. Nossek, Technische Universität München, Germany

Recently it has been found, that the receive filter design rule, known as the sampling theorem, does not necessarily lead to optimum signal parameter estimation performance. Here we extend the analysis with optimized ideal low-pass filters by considering arbitrary filter forms. We show how to solve for the best unconstrained filter with respect to the estimation performance with multiple parameters, by formulating a weighted optimization problem on the basis of the Fisher information matrix. The results give insides into favorable filter designs and allow to explore the theoretic performance limits of signal processing systems with sampling rate constraints.

MP8a2-6
On the Block-Sparse Solution of Single Measurement Vectors
Mohammad Shekaramiz, Todd K. Moon, Jacob H. Gunther, Utah State University, United States

Finding the exact solution of block-sparse single measurement vectors is considered. Here, we propose a sparse Bayesian learning (SBL) model based on approximate message passing. In order to encourage block-sparsity, we incorporate a parameter called Sigma-Delta which is a measure of contiguity in the supports of the solution. This approach has two main merits compared to the other algorithms. First, it has a sparse Bayesian learning structure and therefore it generally provides more exact solutions than the greedy-based algorithms. Second,due to the use of approximate message passing, it is computationally less complex and is faster than sparse Bayesian learning approaches.

MP8a2-7
Distributed Compression and Maximum Likelihood Reconstruction of Finite Autocorrelation Sequences
Aritra Konar, Nicholas Sidiropoulos, University of Minnesota, United States

Estimating the autocorrelation of time series is important for a wide range of signal processing and data analysis tasks. Distributed autocorrelation sensing strategies are of interest when multiple pieces or realizations of the time series are measured at different locations. This paper considers distributed autocorrelation sensing using randomly filtered power measurements, each compressed down to one bit. A Maximum Likelihood Estimator (MLE) is proposed and shown to work well, even at high compression ratios and with many bit errors. Whereas the MLE appears non-convex, it is proven that it possesses hidden convexity, enabling optimal estimation. Preliminary simulations illustrate the approach.

MP8a2-8
A Study on the Impact of the Fourier Transform on Hirschman Uncertainty
Kirandeep Ghuman, Victor DeBrunner, Florida State University, United States

Hirschman Uncertainty is defined by the average of the Shannon entropies of a discrete-time signal and its Fourier transform. The picket fence functions has been found to be the optimal basis for the Hirschman Uncertainty. In this paper, we study the effect of incorporating the discrete fractional fourier transfom (discrete FRT) instead of DFT and develop a new uncertainty measure. We explore how transfer order variation affects uncertainty of different discrete signals and study the effect of transfer order value variation on classification rate in an image classification experiment.

MP8a2-9
Minimal Dictionaries for Spanning Periodic Signals
Srikanth V. Tenneti, P. P. Vaidyanathan, California Institute of Technology, United States

Recently, several high dimensional dictionary representations were proposed for discrete time periodic signals. These dictionaries could span any periodic signal whose period lies in a given range $1 \leq P \leq P_{max}$. Such dictionaries were used in various ways to estimate unknown periods. In this work, we derive some fundamental properties that any such dictionary must satisfy. For example, we derive bounds on the minimum size of such dictionaries, necessary conditions on their composition, and so on. Our results also demonstrate a natural connection between the well-known Euler Totient function (ϕ-function) from number theory, and periodicity analysis.

Track D – Signal Processing and Adaptive Systems
Session: MPa8 – Applications of Adaptive Signal Processing 1:30 PM–3:10 PM

MP8a3-1
Dithered Multi-Pulsing and Non-Parametric Statistical Inference Algorithm for Time-of-Flight Mass Spectrometry
George Moore, Keysight Technologies, United States

Time-of-flight mass spectrometers have classically been limited in the maximum ion pulser firing rate by the flight time of the slowest analyte ion present. This paper describes a new randomly dithered ion pulser firing scheme that operates in conjunction with an iterated statistical inference algorithm, inspired by the Belief Propagation algorithm, to resolve the multiple aliased times of flight that result for firing rates above this classical limit. This algorithm readily exploits available a priori information and several acceleration techniques are applicable. Simulations of this method with a 10x firing rate increases show excellent fidelity with classically measured spectrums.

MP8a3-2
Correlated Maximum Likelihood Temperature/Emissivity Separation of Hyperspectral Images
David Neal, Todd K. Moon, Jacob H. Gunther, Utah State University, United States; Gustavious Williams, Brigham Young University, United States

In this paper, we examine temperature/emissivity separation (TES) of hyperspectral imagery that is blind, in the sense that no spectral library is employed. Our approach assumes a distribution for the downwelling component. In this structure, the emissivity contributes to the variance of the measurement as well as the mean, while the temperature contributes only to the mean. The downwelling radiance may be correlated across wavelengths. For a single wavelength, the likelihood equation for the emissivity is quadratic. For multiple wavelengths with correlated measurements, a set of multiple quadratic equations results, which may be solved in a round-robin fashion.

MP8a3-3
Probabilistic Low-Rank Matrix Recovery from Quantized Measurements: Application to Image Denoising
Sonia Bhaskar, Stanford University, United States

We consider the recovery of an image, represented by a low rank matrix M, given its noisy quantized measurements. We consider maximum likelihood estimation of M, under a constraint on the entry-wise infinity-norm of M and an exact rank constraint. We provide an upper bound on the matrix estimation error under this model. We propose a globally convergent optimization algorithm exploiting existing work on optimization based on low rank factorization of M and validate the method on synthetic and real images.

Session: MPa8 – Wireless and Sensor Networks 1:30 PM–3:10 PM

MP8a4-1
Implementation of Fog Computing for Reliable E-Health Applications

Razvan Craciunescu, Albena Mihovska, Mihail Mihaylov, Sofoklis Kyriazakos, Ramjee Prasad, Aalborg University, Denmark; Simona Halunga, University Politechnica of Bucharest, Romania

This research work investigates the possibility to offload data storage and data signal processing to the edge of the network, thus decreasing the latency associated with performing those tasks within the cloud. We propose real-time signal processing algorithms that are implemented in a fog node, closer to the sensing environment and are responsible for all the real-time processing of collected health-related data to enable a set of personalized services.The research scenario is an e-Health laboratory implementation where the real-time processing is performed by the home PC, while the extracted metadata is sent to the cloud for further processing.

MP8a4-2
Context-Aware D2D Peer Selection for Load Distribution in LTE Networks

Nima Namvar, Niloofar Bahadori, Fatemeh Afghah, North Carolina A&T State University, United States

In this paper we propose a novel context-aware peer-selection approach for load distribution in device to device (D2D) communication that exploits the information about the trajectory and velocity of the users to establish a stable D2D subnetwork for offloading the cellular traffic. The problem is modeled as a one-sided matching game in which the D2D users have strict preferences over their available D2D peers. To solve the game, a distributed algorithm is proposed that converges to an optimal and stable matching among the D2D users and optimizes the traffic offloading form the cellular network to D2D tier.

MP8a4-3
Using Mobility for Increasing the Energy Efficiency of Multihop Communications

Fernando Rosas, Mahdi Azari, Bertold Van den Bergh, KU Leuven, Belgium; Richard Demo Souza, Federal University of Technology - Paraná (UTFPR), Brazil; Sofie Pollin, Marian Verhelst, KU Leuven, Belgium

Mobile robots equipped with cameras and sensors produce large amounts of data, which needs to be transferred energy-efficiently due to their battery limitations. While most literature focuses on heterogeneous ad-hoc sensor networks, we use controlled robot mobility to reduce the energy cost per transmitted bit in a multihop link. In particular, we analyze the trade-off between hopping and movement cost. Our main conclusion is that, according to the parameters of the network, either the most efficient solution for large link distances is single hop with mobility or multiple hops without mobility, while a combination of both is never energy-optimal.

MP8a4-4
Instantaneous Relaying for the 3-Way Relay Channel with Circular Message Exchanges

Bho Matthiesen, Eduard A. Jorswieck, Technische Universität Dresden, Germany

The 3-user discrete memoryless multi-way relay channel with circular message exchange and instantaneous relaying is investigated. We first show that this channel is effectively a 3-user interference channel with receiver message side information for every fixed (and instantaneous) relay mapping. Then, we extend the Han-Kobayashi coding scheme to this channel. Finally, we apply these results to Gaussian channels with amplify-and-forward relaying and present numerical results showing the gain of the proposed scheme compared to the state of the art.

Track A – Communications Systems

Session: TAa1 – Topics in Communications

Chair: ***Fatemeh Afghah,*** *North Carolina A&T State University*

TA1a-1 **8:15 AM**

Covert Communication with the Help of an Uninformed Jammer Achieves Positive Rate

Tamara Sobers, Boulat Bash, Dennis Goeckel, University of Massachusetts Amherst, United States; Saikat Guha, Raytheon BBN Technologies, United States; Don Towsley, University of Massachusetts Amherst, United States

Covert communication involves transmission from Alice to legitimate receiver Bob without detection by warden Willie. Our previous work established the fundamental limits of such communication on additive white Gaussian noise (AWGN) channels: O(sqrt(n)) bits (and only O(sqrt(n)) bits) can be reliably transmitted covertly in n channel uses. Here, we show that an uninformed jammer, whom lacks knowledge of the codeword slot in which Alice will transmit, can help Alice and Bob to achieve positive rate (O(sqrt(n)) bits in n channel uses) covert communications.

TA1a-2 **8:40 AM**

Cooperative Power and DoT Estimation for a Directive Source

Sina Maleki, University of Luxembourg, Luxembourg; Philippe Ciblat, Telecom ParisTech, France; Symeon Chatzinotas, University of Luxembourg, Luxembourg; Dzevdan Kapetanovic, Ericsson, Sweden; Björn Ottersten, University of Luxembourg, Luxembourg

Reliable estimation of the source power as well as the direction of transmission (DoT) is required in a large number of applications, e.g. radio environment mapping for cognitive radios. In this paper, we develop a multi-sensor cooperative estimation algorithm for joint power and DoT estimation of a directive source with a known location and with a deterministic signal. Simulation results show that the developed algorithm can deliver a reliable estimation accuracy.

TA1a-3 **9:05 AM**

BER Analysis of High Speed Links with Nonlinearity

Gaurav Malhotra, Jalil Kamali, Samsung, United States

Analytical methods to predict performance of a high speed link use knowledge of channel models to calculate probability density function (PDF) of signal and impairments at the decision point, and use tail probability to predict BER. Such methods based on LTI system analysis have been studied extensively. A typical high speed system has significant nonlinearity in the signal path. We present a method to modify the PDF to account for nonlinearity in the path. Static, memory-less nonlinearities are modelled by polynomials in this paper. The methodology can also be adapted to deal with the time varying and frequency dependent nonlinearities.

Track A – Communications Systems

Session: TAb1 – Coding and Signal Processing for Modern Memories

Chair: ***Lara Dolecek,*** *University of California, Los Angeles*

TA1b-1 **10:15 AM**

Signal Processing Techniques for Ensuring Fidelity of Back-End Signal Transmission in Flash Memory Based Solid-State Drives

Ravi Motwani, Intel, United States

For ONFI-4 transmission rates, there is a notch in the channel frequency response. This leads to inter-symbol interference in the received signal. We propose methods based on filter banks to ensure that the contents of the signal in the channel notch are recoverable at the controller. The critically sampled signal is oversampled so that high frequency band is available. The signal content in the notch region is translated onto the high frequency band. The proposed technique show a virtually undistorted signal reconstructed in the back-end link. The proposed technique also combine performing equalization to get rid of any channel distortions.

TA1b-2 **10:40 AM**

Dynamic Voltage Allocation with Quantized Voltage Levels and Simplified Channel Modeling

Haobo Wang, Nathan Wong, Richard Wesel, University of California, Los Angeles, United States

Dynamically adjusting the write levels in FLASH memory has been shown to increase device lifetime under relatively idealistic conditions. Practical devices are constrained to a limited number of possible voltage levels and channel estimation that does not have the benefit of a perfect channel model. This paper explores how the benefits of dynamic voltage allocation with respect to device lifetime are affected by practical constraints on the limited set of available voltage levels and on imperfect modeling of the channel.

TA1b-3 **11:05 AM**

Compensating for Sneak Currents in Multi-Level Crossbar Resistive Memories

Tianqiong Luo, Purdue University, United States; Olgica Milenkovic, University of Illinois Urbana-Champaign, United States; Borja Peleato, Purdue University, United States

Crossbar architectures for ReRAM offer higher density, power efficiency, and endurance than most other emerging memory technologies, but they suffer sneak currents that cause significant write and read noise. Existing solutions limit the array size to ensure that the resulting noise falls within the margin between resistance levels but this might not be possible for MLC ReRAM memories. This paper models sneak currents in MLC-ReRAM arrays as a form of inter-cell-interference and proposes writing, reading, and constrained coding schemes to minimize the resulting BER. Specifically, it adjusts the read/write schedule and levels so as to compensate for the expected disturbances.

TA1b-4 **11:30 AM**

Asymmetric Error Control Coding Techniques for Flash Memories: Theory and Applications

Frederic Sala, Clayton Schoeny, Ahmed Hareedy, Dariush Divsalar, Lara Dolecek, University of California, Los Angeles, United States

It is well known that modern flash memories possess a large degree of asymmetry in terms of possible error patterns. This asymmetry is manifested both spatially, within a cell and across multiple cells, and temporally, over the duration of the memory lifetime. In this paper we explore various novel coding-theoretic approaches for exploiting this spatio-temporal asymmetry. We discuss both algebraic and graph-based constructions that are well suited for the correction of target error patterns, and demonstrate the benefits over conventional coding schemes that are based on symmetric error correction for several applications of interest.

Track A – Communications Systems

Session: TAa2 – All About Spectrum

Chair: ***Dongning Guo,*** *Northwestern University*

TA2a-1 **8:15 AM**

Spectrum Policy in 21st Century - Where are We Going, Why, and What are the Technology Implications?

Dennis Roberson, Illinois Institute of Technology, United States

Spectrum is the scarce natural resource that serves as the “life blood” of the wireless world. Since spectrum use has been fully allocated for decades, most new applications need to displace existing uses or find a way to share the allocated spectrum. Given the limited system retirement rate and the cost associated with clearing and relocating systems, sharing and specifically dynamic sharing dividing the users into prioritized tiers and using database driven systems to allocate spectrum use has become the preferred approach. This paper addresses some of the critical questions and implications of the transition to dynamic spectrum sharing.

TA2a-2 **8:40 AM**

Competition and Investment in Shared Spectrum

Chang Liu, Randall Berry, Northwestern University, United States

There has been much interest in new approaches for sharing wireless spectrum as a means to more effectively utilize this limited resource. Introducing such approaches impacts the competition among wireless service providers as well as their incentives to invest in infrastructure. In this paper, we discuss a number of different game theoretic models for studying these interactions.

TA2a-3 **9:05 AM**

Covariance Shaping for Interference Coordination in Cellular Wireless Communication Systems

Michael Newinger, Wolfgang Utschick, Technische Universität München, Germany

In this paper we consider interference covariance shaping for interference coordination in wireless communication systems. Commonly, non-orthogonal access to wireless resources is controlled via interference power management, so-called interference temperatures. Covariance shaping, however, facilitates a more efficient utilization of wireless resources by the reduction of uncertainty in the perceived interference at receive terminals. To this end, we propose a low complexity scheme for the design of suitable interference covariances. Our results are applicable to a variety of resource allocation problems in cellular networks, including Device-to-Device communication and Full-Duplex systems.

TA2a-4 **9:30 AM**

Optimal Resource Allocation in Ultra-Dense Networks with Many Carriers

Jialing Liu, Weimin Xiao, Huawei Technologies Co., Ltd., United States

In an ultra-dense network with many carriers, the network adaptively allocates the carrier resources among neighboring cells, according to traffic loads and interference situations of the users in those cells. An optimization problem is formulated to find the resource allocation that leads to the best overall user perceived performance. It is shown from performance evaluations that there can be significant performance gains with the approach.

Track D – Signal Processing and Adaptive Systems

Session: TAb2 – Methodologies for Signal Processing on Random Graphs

Chair: ***Laura Cottatellucci,*** *EURECOM*

TA2b-1 **10:15 AM**

Information Propagation in Clustered Multi-Layer Networks

Yong Zhuang, Osman Yagan, Carnegie Mellon University, United States

Individuals interact with each other in more complicated patterns than ever nowadays. Some individuals are connected via online social networks, while others communicate only through conventional ways, e.g., face-to-face. Therefore, understanding the dynamics of information propagation among humans calls for a multi-layer network model where online social networks are conjoined with a physical network. Here, we consider a multilayer network model, where all constituent networks are random graphs with high clustering. We assume that information propagates according to the SIR model and with different information transmissibility across the networks. We give results for condition, probability, and size of information epidemics.

TA2b-2 **10:40 AM**

Community Mining with Graph Wavelets for Correlation Matrices

Pierre Borgnat, Ecole normale supérieure de Lyon, CNRS, France; Paulo Gonçalves, Ecole normale supérieure de Lyon, Inria, France; Nicolas Tremblay, Ecole normale supérieure de Lyon, France

Graph wavelets can be used to detect communities in a network, thanks to the ego-centered view from each node encoded in the wavelets. When dealing with a network that derives from a correlation matrix, the weights assigned to the edges have properties different from usual adjacency matrices. It has been shown for instance that classical community detection methods based on modularity optimization are not consistent and that one needs to re-define modularity by taking into account the structure of the correlation from random matrix theory. We discuss here how to adapt the wavelet-based method to detect communities to correlation matrices.

TA2b-3 **11:05 AM**

An Exact Large System Analysis of Randomized Kaczmarz Methods

Chuang Wang, Yue Lu, Harvard University, United States

Randomized Kaczmarz algorithms are efficient methods for solving large-scale linear systems through random projections. Previous analyses consider systems with fixed sizes, and focus on establishing the exponential convergence of the algorithms. We work on a different regime, where the system sizes and the iteration steps go to infinity simultaneously, at fixed ratios. For random system matrices, we derive exact asymptotic formulas describing the dynamics of the algorithms, which are determined by the limiting singular value spectra of the measurement matrices. Our theoretical predictions match numerical simulations very well, even for a moderate system size of n = 50.

TA2b-4 **11:30 AM**

Characterization of Random Matrix Eigenvectors for Stochastic Block Model

Konstantin Avrachenkov, Inria, France; Laura Cottatellucci, EURECOM, France; Arun Kadavankandy, Inria, France

We consider an extension of Erdős-Rényi graph known in literature as Stochastic Block Model (SBM). The eigenvalue spectrum of the SBM adjacency matrix consists of two parts: a continuous limiting eigenvalue empirical distribution function and a finite discrete set of dominant eigenvalues. The cardinality of the latter set is equal to the number of blocks in the SBM adjacency matrix. In this work we rigorously characterize the properties of the dominant eigenvectors and provide a characterization of the eigenvectors corresponding to the continuous part of the spectrum. These results are related to spectral clustering.

Track C – Networks

Session: TAa3 – Estimation

TA3a-1 **8:15 AM**

High-Accuracy Vehicle Position Estimation using a Cooperative Algorithm with Anchors and Probe Vehicles

Ramez L. Gerges, John J. Shynk, University of California, Santa Barbara, United States; Suk-Seung Huang, Chosun University, Republic of Korea

This paper describes a method for achieving highway lane differentiation without requiring expensive global navigation receivers in every vehicle. Accurate lane identification can be used to optimize transportation network safety, by improving a vehicle's ability to avoid collision and to safely complete lane-change maneuvers. Using a cooperative technique, each vehicle communicates with road infrastructure and nearby connected vehicles to achieve sub-meter lane identification. We assume that a small subset of vehicles have high-accuracy GPS localization, which we refer to as probe vehicles. Other vehicles use location information from the probe vehicles and fixed infrastructure anchors to improve their position estimates.

TA3a-2 **8:40 AM**

Prediction-Correction Methods for Time-Varying Convex Optimization

Andrea Simonetto, Delft University of Technology, Netherlands; Alec Koppel, Aryan Mokhtari, University of Pennsylvania, United States; Geert Leus, Delft University of Technology, Netherlands; Alejandro Ribeiro, University of Pennsylvania, United States

We consider unconstrained convex optimization problems with objective functions varying continuously in time. We propose prediction-correction algorithms with a discrete time-sampling scheme to find and track the solution trajectory, while sampling the problem data at a constant rate of $1/h$. The prediction step is derived by analyzing the iso-residual dynamics of the optimality conditions, while the correction step consists either of one or multiple gradient steps or Newton's steps. Under suitable conditions, we establish that the asymptotic error behaves as $O(h^2)$, and in some cases as $O(h^4)$, which outperforms the state-of-the-art error bound of $O(h)$ for correction-only methods.

TA3a-3 **9:05 AM**

Improving Convergence of Distributed LMS Estimation by Enabling Propagation of Good Estimates Through Bad Nodes

Kevin Wagner, Naval Research Laboratory, United States; Milos Doroslovacki, The George Washington University, United States

A noisy node that is the only passage between two parts of a network can obstruct propagation of a good estimate through the network. Assuming adapt-then-combine diffusion based least mean square algorithm that uses combiners minimizing the mean square weight deviations, we found a sufficient condition for mean square weight deviation convergence that also guarantees propagation of good estimates through the whole connected part of the network. A practical algorithmic implementation of this condition is developed and compared in performance with several known algorithms for a nontrivial network. The proposed algorithm demonstrates improved performance.

TA3a-4 **9:30 AM**

Distributed Covariance Estimation for Compressive Signal Processing

Matteo Testa, Enrico Magli, Politecnico di Torino, Italy

We present a novel technique for the distributed estimation of the covariance matrix of an additive colored noise process affecting Compressed Sensing (CS) measurements. The main application is in wireless sensor networks, where nodes sense CS signals in order to save energy in the computation and transmission stages. The proposed technique enables various compressive signal processing operations to be performed at each node directly on the linear measurements, such as detection, exploiting the knowledge of the noise statistics, thereby achieving improved performance. The parametric approach we introduce promises to yield good results while keeping the communication cost low.

Track A – Communications Systems

Session: TAb3 – Wearable and Body Area Networks

Co-Chairs: ***Robert W. Heath, Jr.,*** *University of Texas at Austin* ***and Angel Lozano,*** *Universitat Pompeu Fabra*

TA3b-1 **10:15 AM**

Reducing Random Access Collisions via Machine Learning

Alexander Pyattaev, Tampere University of Technology, Finland; Kerstin Johnsson, Intel, United States; Olga Galinina, Sergey Andreev, Yevgeni Koucheryavy, Tampere University of Technology, Finland

It has become customary to think of random-access systems as wasteful, with collisions and idle slots taken for granted. In this paper we present a random-access protocol that achieves revolutionary improvements in channel utilization and collision rates. Inspired by reinforcement learning, it enables implicit negotiation of the channel access schedules in a distributed manner. With new protocol, collision rates below 5% with 95% channel utilization can be achieved. Further, an unprecedented number of concurrent users may be multiplexed effectively. The proposed algorithm is especially suitable for deployments where multiple disjoint networks are sharing the same channel, such as wearable computing.

TA3b-2 **10:40 AM**

Channel Dynamics in Body Area Networks: Recent Results and Challenges

Claude Oestges, UCLouvain, Belgium

Recent results about body area radio channel dynamics are analyzed, considering on-body and body-to-body area networks. Both investigations are based on experimental data around 4 GHz. Regarding the on-body case, the dynamics of cross-channel correlation are measured and analyzed for stationary periodic and non-stationary motions, with a clear impact of the walking mode being observed. For body-to-body scenarios, measurements conducted in room-to-room environments show again some strong non-stationary behaviors. In both cases, Markov chain-based models are developed to model the temporal behavior from one fading/correlation state to another state. Finally, remaining challenges in wireless body area propagation are highlighted.

TA3b-3 **11:05 AM**

Analysis of Millimeter-Wave Networked Wearables in Crowded Environments

Kiran Venugopal, University of Texas at Austin, United States; Matthew Valenti, University of West Virginia, United States; Robert W. Heath Jr., University of Texas at Austin, United States

The millimeter wave (mmWave) band can provide high throughput among wearable devices in a crowded environment like a train-car or bus. Previous work using stochastic geometry often assumes an infinite number of interfering nodes drawn from a Poisson Point Process (PPP). Since the indoor wearable setting will likely have a finite number of nodes, we leverage the stochastic geometry results to define a line-of-sight (LOS) ball and limit the interferers within it. The performance of wearables network is then studied in terms of the network density and antenna configuration while incorporating the effect of human-body blockage for the mmWave signals.

TA3b-4 **11:30 AM**

Characterizing Fading in Wearable Communications Channels using Composite Models

Simon Cotton, Seong Ki Yoo, Queen's University Belfast, United Kingdom; Paschalis Sofotasios, Tampere University of Technology, Finland

Characterizing and modeling the behavior of fading channels is critical for robust wireless systems design. This is especially the case for wireless devices designed to be positioned on the human body. So-called wearable communications are not only impacted by signal fluctuations caused by the propagation environment but also shadowed and envelope fading generated by the human body. In this paper we statistically characterize fading channels observed in wearable communications using a range of very general line of sight and multiplicative composite fading models such as κ–μ shadowed and κ–μ / Gamma.

Track C – Networks

Session: TAa5 – Smart Grid

Chair: ***Ermin Wei,*** *Northwestern University*

TA5a-1 **8:15 AM**

The Perils of Dynamic Electricity Pricing in the Presence of Retail Market Power

Mahnoosh Alizadeh, Andrea Goldsmith, Stanford University, United States; Anna Scaglione, Arizona State University, United States

Dynamic retail pricing of electricity is considered as the primary mechanism to tap into the inherent flexibility of end-use demand. In this paper, we show that the profit maximizing nature of electricity retailers, combined with limited retail competition, might induce physical operational problems for the power grid under dynamic retail pricing.

TA5a-2 **8:40 AM**

Value of Limited Communication in Voltage Regulation of Distribution Systems

Baosen Zhang, University of Washington, United States; Alejandro Dominguez-Garcia, University of Illinois at Urbana-Champaign, United States; David Tse, Stanford University, United States

Voltage regulation is a basic control problem in power distribution systems, especially under high penetration of renewables. However, the envisioned communication infrastructure that would control these resources has not yet been deployed, and most existing algorithms are based on purely local information. We first establish fundamental limits of these algorithms by showing that voltage cannot be regulated in certain networks using local control. Then we demonstrate the value of limited communication by showing that the capability of local control algorithms can be greatly enhanced by a few strategically placed communication links.

TA5a-3 **9:05 AM**

Learning Supply Function Equilibria in Constrained Power Networks

Weixuan Lin, Eilyan Bitar, Cornell University, United States

We consider a spot electricity market in which a finite number of generators compete in scalar-parameterized supply functions to satisfy an inelastic demand over a constrained transmission network. Payments are determined according to locational marginal prices. We examine a repeated game model with incomplete information and analyze several natural myopic learning dynamics. We show that such dynamics exhibit limiting behavior that is socially optimal when generators are price-taking, and near socially optimal when generators are price-anticipating.

TA5a-4 **9:30 AM**

Pricing Fairness in Networked Systems

Yuanzhang Xiao, Ermin Wei, Chaithanya Bandi, Northwestern University, United States

The optimal prices emerging from social welfare maximization problems for networked systems, such as power, water and transportation systems, often feature significant differences across different agents in the system. This work considers pricing fairness in these systems by augmenting the system objective with a price variation smoothing term. We analyze the resulting new system and interpret the required infrastructure modifications and policy implications.

Track C – Networks

Session: TAb5 – Energy Management

TA5b-1 **10:15 AM**

Risk-Averse Placement and Sizing of Photovoltaic Generators in Radial Distribution Networks

Mohammadhafez Bazrafshan, Nikolaos Gatsis, University of Texas at San Antonio, United States

A risk-averse optimal placement and sizing of photovoltaic (PV) inverters in radial distribution networks under solar irradiance and load uncertainty is presented. The objective is to minimize PV installation cost and a risk measure that penalizes high thermal losses in the operational phase. The uncertainty of solar irradiance and load profiles is modeled by a set with finite number of scenarios. The final optimization program is two-stage stochastic. First-stage decisions include binary placement variables, as well as the apparent and the real power capacity of the inverters. Second-stage decisions are reactive power injection of PV inverters and the power flows.

TA5b-2 **10:40 AM**

Towards Green Distributed Storage Systems

Abdelrahman Ibrahim, Ahmed Zewail, Aylin Yener, The Pennsylvania State University, United States

We consider a distributed storage system with F files stored distributively over energy harvesting nodes. We study file retrieval and node repair, under the energy causality constraints. In particular, we formulate two optimization problems: 1) maximizing the number of retrieved files given a deadline, and 2) minimizing the retrieval time of a number of stored files. First, we develop two algorithms to reduce them to a single feasibility problem. Next, we solve the feasibility problem using forward and backward algorithms. Finally, we provide numerical results that illustrate the system performance under the proposed algorithms.

TA5b-3 **11:05 AM**

Joint Real-Time Energy and Demand-Response Management using a Hybrid Coalitional-Noncooperative Game

Fulin He, Huazhong University of Science and Technology, United States; Yi Gu, Jun Hao, Jun Jason Zhang, University of Denver, United States; Jiaolong Wei, Huazhong University of Science and Technology, United States; Yingchen Zhang, National Renewable Energy Laboratory, United States

In order to model the interactions among utility companies, renewable energy generators (REGs), A hybrid coalitional-noncooperative game framework has been propose. We formulated a dynamic non-cooperative game to study the energy dispatch within multiple utility companies at higher level. While in DU level, we take a coalitional perspective on REGs and buildings demands. The building demands can self-organize into an ultimate coalition structure through a distributed hedonic shift algorithm. The interactive progress are implemented by distributed algorithms. Numerical results illustrate that the proposed hybrid coalitional-noncooperative game scheme may reduce the cost of both building demands and utility companies.

Session: TAa6 – Massive MIMO

TA6a-1 8:15 AM

Cell-Free Massive MIMO Systems

Elina Nayebi, Univesity of California, San Diego, United States; Alexei Ashikhmin, Thomas L. Marzetta, Hong Yang, Bell Laboratories, Alcatel-Lucent, United States

Cell-Free Massive MIMO Systems comprise of a large number of distributed, low cost, and low power access point antennas, connected to a network controller. The number of antennas is significantly larger than the number of users. The system is not partitioned into cells and each user is served by all antennas simultaneously. In this paper, we define cell-free systems and analyze algorithms for power optimization and linear pre-coding. Compared with the conventional small-cell scheme, Cell-Free Massive MIMO can yield more than ten-fold improvements in terms of 5%-outage rate.

TA6a-2 8:40 AM

Multi-Stage Beamforming for Interference Coordination in Massive MIMO Networks

Martin Kurras, Lars Thiele, Fraunhofer Institute for Telecommunications, Germany; Giuseppe Caire, Technische Universität Berlin, Germany

Recently we showed that the joint space division and multiplexing (JSDM) framework for ”massive MIMO” can applied to hybrid beamforming for interference coordination between multiple base station sites. JSDM explicitly distinguishes between pre-beamforming based on long-term channel (covariance) statistics (which is locally time-invariant) and precoding based on instantaneous channel state information. The idea of this work is to develop an algorithm to adapt interference coordination between multiple ”massive MIMO” BS sites with 3-dimensional pre-beamforming for heterogeneous changing user distributions, like moving hotspots. With the JSDM or multi-stage beamforming approach we decouple the problem of inter-cell interference coordination from multi-user beamforming.

TA6a-3 9:05 AM

Angle of Arrival Based Beamforming Schemes for Massive MIMO FDD Systems

Xing Zhang, John Tadrous, Evan Everett, Rice University, United States; Feng Xue, Intel Corporation, United States; Ashutosh Sabharwal, Rice University, United States

We propose two novel downlink multiuser beamforming schemes, AoAZF and 2AoAZF, to effectively realize FDD mode in massive MIMO systems. Proposed schemes hinge on the recent findings that angles of arrival of uplink and downlink bands are reciprocal. Such reciprocity is leveraged to enable massive MIMO gains in FDD with minimal CSI feedback overhead. We numerically compare both schemes with traditional zero-forcing beamforming (ZFBF) with analog CSI feedback. Results demonstrate that the two schemes attain increasing throughput with the number of antennas, an advantage over ZFBF which fails to maintain such increasing throughput due to its proportionally growing feedback requirements.

TA6a-4 9:30 AM

An Enhanced Threshold-Based Feedback Scheme for Massive MU-MIMO Downlink FDD Systems

Jinsoon Kim, Wonjae Shin, Yonghee Han, Jungwoo Lee, Seoul National University, Republic of Korea

In this paper, we propose an enhanced threshold-based feedback strategy in massive multiuser multiple-input multiple-output (MU-MIMO) downlink system adopting two-stage beamforming. The key idea lies in checking the semi-orthogonality at user terminal (UT) by utilizing the effective channel and average inter-group interference-plus-noise power (IGINP). Subsequently, the user determines whether UT feeds back the channel quality indicator (CQI) pair to base station (BS) or not, thereby alleviating the amount of feedback overhead. Numerical results show that the proposed scheme effectively reduces the number of feedback users while the sum rate is maintained compared to conventional feedback strategy.

Session: TA7 – Arithmetic

TA7-1 8:15 AM

24-Bit Significand Multiplier for FPGA Floating-Point Multiplication

E. George Walters III, Penn State Erie, United States

This paper presents a 24-bit significand multiplier for single-precision floating-point multiplication that is optimized for Xilinx FPGAs with 6-input LUTs. The design combines a 24x7 LUT-based multiplier and one embedded multiplier to implement a 24x24 unsigned multiplier. The proposed design uses 35% fewer LUTs and is 1.11 times faster than a LogiCORE multiplier that also uses one embedded multiplier. A truncated-matrix version that allows faithful rounding uses 78% fewer LUTs and is 1.17 times faster than a LogiCORE multiplier that uses one embedded multiplier. Both designs are comparable in speed to a LogiCORE multiplier that uses two embedded multipliers.

TA7-2 8:40 AM

Exploiting Asymmetry in Booth-Encoded Multipliers for Reduced Energy Multiplication

Mike O'Connor, NVIDIA / University of Texas at Austin, United States; Earl E. Swartzlander, Jr., University of Texas at Austin, United States

Modified Booth Encoding (MBE) is a common technique utilized in the design of high-speed multipliers. These MBE multipliers typically encode only one operand of the multiplier, and we observe this asymmetry results in different power characteristics as each input transitions to the next value in a pipelined design. Relative to the non-encoded input, changes on the MBE-encoded input induce more signal transitions requiring ~73% more multiplier array energy. We propose low-overhead architectural approaches to take advantage of this asymmetric behavior to reduce the energy of multiplication operations.

TA7-3 9:05 AM

A Parametric Error Analysis of Goldschmidt's Square Root Algorithm

Peter-Michael Seidel, University of Hawai'i at Manoa, United States

Goldschmidt's square root algorithm is a variation of Newton-Raphson's square root algorithm that is better suited for pipelining. The problem in using Goldschmidt's algorithm is to present an error analysis that enables one to save hardware by using just the right amount of precision for intermediate calculations while still providing correctly rounded results. We present a parametric error analysis of Goldschmidt's square root algorithm. This analysis sheds more light on the effect of the different parameters on the error of the square root implementations. In addition, we derive error formulae that help determine optimal parameter choices in practical implementation settings.

TA7-4 9:30 AM

Area Efficient Backprojection Computation with Reduced Floating-Point Word Width for SAR Image Formation

Jon Pimentel, Aaron Stillmaker, Brent Bohnenstiehl, Bevan Baas, University of California, Davis, United States

The widths of data words in digital processors have a direct impact on area in application-specific ICs (ASICs) and FPGAs. Circuit area impacts energy dissipation per workload and chip cost. Floating-point exponent and mantissa widths are independently varied for the seven major computational blocks of an airborne synthetic aperture radar (SAR) engine. The circuit area in 65nm CMOS and the PSNR and SSIM metrics are found for 572 design points. With word-width reductions of 48.4–81.3%, images with a 0.99 SSIM are created with imperceptible image quality degradation and a 2.7–15.9x area reduction.

BREAK **9:55 AM**

TA7-5 **10:15 AM**

Determining Fixed-Point Formats for a Digital Filter Implementation using the Worst-Case Peak Gain Measure

Anastasia Volkova, Thibault Hilaire, Christoph Lauter, University of Pierre and Marie Curie, France

In this article, we focus on the Fixed-Point implementation of Linear Time Invariant in state-space representation. For that purpose, we give an algorithm to determine the fixed-point formats of all the involved variables. The computational errors in the intermediate steps of the filter evaluation as well as their accumulation over time is fully taken into account. We handle several rounding modes for a two's-complement based Fixed-Point Arithmetic. Our approach is fully rigorous in the way that the output Fixed-Point formats are shown to avoid overflows and we do not use any filter simulation steps.

TA7-7 **11:05 AM**

Easing Development of Precision-Sensitive Applications with a Beyond-Quad-Precision Library

Christoph Lauter, Sorbonne Universités, UPMC Univ Paris 06, UMR 7606, LIP6, France

The IEEE754 Standard offers essentially two binary floating-point formats, binary32 and binary64, natively supported by current hardware. Whenever these precisions do not suffice, developers are restricted to arbitrary precision libraries, like MPFR. These libraries however leave a gap in the mid-precision range. Their very nature as object code to be linked in prevents compilers from inlining the code or optimizing it e.g. with loop unrolling. We propose the libwidefloat software meant to fill this gap. It offers precisions from 64 thru 512 bits. It supports all basic operations (+, -, *, /, sqrt, FMA, comparisons) It is fully implemented in header files for optimization.

TA7-8 **11:30 AM**

An Error-Compensated Piecewise Linear Logarithmic Arithmetic Unit for Phong Lighting Acceleration

Ching-En Lee, Milos Ercegovac, University of California, Los Angeles, United States

An error-compensated piecewise linear logarithmic arithmetic unit is presented for a single-cycle throughput Phong lighting hardware accelerator. A modified architecture is proposed by introducing an additional error compensation method. This method differentiates finer bounds within each piecewise linear (PWL) approximation interval, and applies compensation accordingly to achieve a lower absolute mean error rate. While consuming low additional area and power, this design is suitable for energy-efficient 3D graphic engines.

Track F – Biomedical Signal and Image Processing

Session: TAa8 – Biomedical Signal Processing I **8:15 AM–9:55 AM**

TA8a1-1

Regularization Parameter Trimming for Iterative Image Reconstruction

Haoyi Liang, Daniel Weller, University of Virginia, United States

Conventional automatic parameter choosing involves testing many parameter values, increasing computing time for iterative image reconstructions. The proposed approach first measures the image quality after each iteration and then predicts the convergence trend corresponding to each value of the parameter. Values unlikely to achieve the best quality upon convergence are trimmed from successive iterations to save time. Experimental results show that our parameter trimming method could reduce the running time of total variation parameter selection solved by Split Bregman iteration by more than 50% when the numbers of iterations and parameter candidates are large.

TA8a1-2
Iterative Reconstruction from Limited Angle, Limited View Projections for Cryo-Electron Tomography
Sally Wood, Santa Clara University, United States; Ernesto Fontenla, Baylor College of Medicine, United States; Chris Metzler, Rice University, United States; Wah Chiu, Baylor College of Medicine, United States; Richard Baraniuk, Rice University, United States

Improving accuracy of measurement models and iterative reconstruction algorithms would enhance cryo-electron tomography (cryo-ET) image quality. Filtered back-projection and related algorithms, successful in CT and MRI, assume a measurement model not well suited to the limited range of projection angles, large angular increments, and incomplete projections in cryo-ET. Iterative methods, such as compressed sensing, can include irregular measurement models and spatial extent constraints, and have great potential for solution of severely under-determined systems. This paper compares performance of source models using square and pyramid basis functions for both pencil beam and finite width aperture measurement in the context of cryo-ET.

TA8a1-3
A Parametric Model for Heart Sounds
Roilhi Frajo Ibarra, Miguel Angel Alonso, Salvador Villarreal, Carlos Ivan Nieblas, CICESE, Mexico

This paper presents a novel way to represent heart sound signals by using a harmonic plus noise model (HNM). A set of time-frequency waveforms are selected by the Matching Pursuit algorithm to form the harmonic part. The noise part is obtained after subtracting the harmonic part to the original signal and is modeled as an autorregresive process using linear predictive coding. The sum of both the harmonic and noise part models provides a highly accurate representation of the original heart sounds. The proposed model has many potential applications such as parametric low-bit rate coder, cardiac monitoring and heart disease identification.

TA8a1-4
Experimental Evaluations of Sequential Adaptive Processing for Fetal Electrocardiograms (ECGs)
Ziyan Yao, Yuqing Dong, 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 IIR comb filtering (CF) can effectively remove maternal interference from noninvasive fetal ECGs. This paper presents experimental results to show how LPC-ANC sequential processing can extract fetal signals from noninvasive abdominal measurements. Experimental results demonstrate how various combinations of time-domain and transform-domain adaptive filters an effectively extract the fetal component from noninvasive abdominal fetal ECG's. Experimental results also illustrate that sequential processing followed by single stage conventional comb filtering and zero-phase non-conventional comb filtering is an effective form of sequential processing.

TA8a1-5
Seizure Prediction using Cross-Correlation and Classification Tree
Zisheng Zhang, Thomas Henry, Keshab Parhi, Univerisity of Minnesota, United States

Reliable seizure prediction, which refers to anticipating epileptic seizures based on continuous electroencephalogram (EEG) recordings of epileptic patients, is important for improving the lives of epileptic patients. Dataset from the recent American Epilepsy Society Seizure Prediction Challenge are considered.Absolute value of the correlation coefficients between all possible pairs of the electrodes are extracted as features using a 10 seconds window with 50% overlap. Then the feature set is subjected to a feature selection step by classification and regression tree (CART). The regression tree achieves a sensitivity of 100% and an averaged AUC of 0.9907.

TA8a1-6
A New Approach for Automated Detection of Behavioral Task Onset for Patients with Parkinson's Disease using Subthalamic Nucleus Local Field Potentials
Nazanin Zaker, Jun Jason Zhang, University of Denver, United States; Sara Hanrahan, Joshua Nedrud, Adam Hebb, Colorado Neurological Institute, United States

We present a new automated onset detection approach for behavioral tasks of patients with Parkinson's disease (PD) using Local Field Potential (LFP) signals collected during Deep Brain Stimulation (DBS) implantation surgeries. Using time-frequency signal processing methods, features are extracted and clustered in the feature space. A supervised Discrete Hidden Markov

Models (DHMM) is employed and merged with Support Vector Machines (SVM) in a two-layer classifier, which boosted up the detection rate into 84% with delay of less than 1500 ms. We justified our methodology in the experiment results section, as well as detailed future directions to expand our work.

TA8a1-7
A Joint Sparsity and Linear Regression Based Method for Customization of Median Plane HRIR

Sandeep Reddy C, Rajesh M Hegde, Indian Institute of Technology Kanpur, India

In this paper, a joint sparsity and multiple linear regression(MLR) based method for computing customized median plane Head Related Impulse Response(HRIR) is proposed. A novel sparsity and MLR based method are first used to identify the dominant pinna parameters individually. Subsequently, parameters obtained by both these individual methods are combined to obtain smaller set of pinna parameters using the principle of majority voting. The HRIRs for an unknown subject are then customized using this meaningful subset of pinna parameters. Experiment on pinna spectral notch extraction and RMSE analysis are used to illustrate the improved performance provided by the proposed method.

TA8a1-8
Non-Contact Heart Rate Detection via Periodic Signal Detection Methods

Gizem Tabak, Andrew Singer, University of Illinois at Urbana-Champaign, United States

Real time non-contact heart rate detection is performed by using different methods for periodic signal detection in noise. Heart rate is estimated from a scalar signal formed from the average color values of the observed skin from videos recorded previously at first, and then captured in real time with a built-in laptop webcam. Cramer-Rao lower bounds are calculated as a function of SNR for an assumed parametric model, and heart rate is detected via autocorrelation, maximum likelihood and Fourier-based methods. The performance is evaluated by comparing the error rates for different detection techniques in each case.

Track B – MIMO Communications and Signal Processing
Session: TAa8 – Relayed Communications I 8:15 AM–9:55 AM

TA8a2-1
Optimal Equalization and Network Beamforming in Asynchronous Two-Way Relay Networks

Farzaneh Eshaghian Dorcheh, Shahram ShahbazPanahi, University of Ontario Institute of Technology, Canada

We consider an asynchronous two-way relay network, consisting of two transceivers and multiple relays, where due to the propagation delays of different transceiver-relay paths being different, inter-symbol-interference (ISI) exists at both transceivers. In this work, pre- and post-channel equalization blocks are used to combat ISI. The mean-squared error of the estimated received signals at both transceivers is minimized under a total transmit power budget by optimally obtaining the transceivers' powers and relay beamforming weight vectors as well as pre- and post-channel equalizers at the two transceivers. We prove that our proposed approach results in a certain relay selection scheme.

TA8a2-2
Symmetric Beamforming for Multi-Antenna Two-Way Relay Networks

Razgar Rahimi, Shahram ShahbazPanahi, University of Ontario Institute of Technology, Canada

We study the power minimization of a two-way relay network, where two single-antenna nodes exchange information through multiple multi-antenna relays with symmetric beamforming matrices. We consider the two-time-slot multiple access broadcast (MABC) scheme where signals are transmitted from the Transceivers to the relays and vice versa in two time-slots. We aim to minimize the total power under given signal-to-noise-ratio (SNR) requirements. We prove that this power minimization problem has a semi-closed form solution. That is, the symmetric beamforming matrices can be obtained in a closed form given a certain intermediate parameter. This parameter can also be obtained using Newton-Raphson method.

TA8a2-3
Maximum Likelihood Channel Estimation for Full Duplex Relay
Xiaofeng Li, Cihan Tepedelenlioglu, Arizona State University, United States

Maximum likelihood channel estimation for a full duplex relay is proposed. Log-likelihood function is maximized through quasi-Newton method. Alternative optimization and Euclidean projection are applied. The initial values of the quasi-Newton method are obtained from an MMSE estimator to avoid the local minima. The Cramer-Rao bounds are derived to evaluate the accuracy of the estimates.

TA8a2-4
Power Allocation for Three-Phase Two-Way Relay Networks with Simultaneous Wireless Information and Power Transfer
Shahab Farazi, D. Richard Brown III, Worcester Polytechnic Institute, United States; Andrew G. Klein, Western Washington University, United States

This paper considers a three-phase two-way relay system in which two single-antenna transceivers exchange data with the help of a multi-antenna energy harvesting relay. An SNR maximization problem is formulated under a fixed total power and a fairness constraint on the power and SNR of the transceivers, respectively. Given the fraction of energy harvested by the relay in the first two phases, a closed-form expression for the optimal power allocation between the transceivers is derived, which facilitates joint optimization of the power allocation and energy harvesting fraction numerically. An approximate SNR analysis is also developed to facilitate joint analytical optimization.

TA8a2-5
Online Power Control for Cooperative Relaying with Energy Harvesting
Fatemeh Amirnavaei, Min Dong, University of Ontario Institute of Technology, Canada

We consider a two-hop amplify and forward (AF) relay network with energy harvesting node over fading channels. We design an online power control strategy aiming at maximizing the long-term time-averaged data rate, given finite battery storage. Using Lyapunov optimization technique, we develop an algorithm to determine transmit power based on the current energy level of the battery and channel fade conditions. Our power algorithm does not rely on any knowledge of the statistics of energy arrivals and fading channels. It is provided in a closed-form. We further bound the performance of the proposed algorithm to that of the optimal solution.

TA8a2-6
Transmission Power Optimization for Energy Harvesting Wireless Nodes
Remun Koirala, Stefano Severi, Giuseppe Abreu, Jacobs University Bremen, Germany

We study the power optimization policy to maximize the average transmission rate in an energy harvesting wireless network. The addressed scenario considers an energy harvesting transmitting node where the energy arrives in discrete packets following a Poisson process. The challenge is then to optimally model the transmission period T according only to the statistical knowledge of the energy arrival process. A higher power would quickly empty the battery causing outage, while, a lower rate would inefficiently accumulate energy not to be used. A mathematical formulation of the optimal policy is derived, allowing the transmitting node to adaptively change its power.

Track A – Communications Systems
Session: TAb8 – Sampling, Sensing and Detection 10:15 AM–11:55 AM

TA8b1-1
On the Convergence Between Natural Sampling and Uniform Sampling
Noyan Sevuktekin, Andrew Singer, University of Illinois at Urbana-Champaign, United States

An analysis on the convergence between natural sampling and uniform sampling of a continuous, finite energy, band-limited signal is given. First, the natural sampling mechanism is discussed in a comparator with a periodic reference signal setting. Then, the necessary and sufficient conditions for lossless natural sampling are derived. For lossless sampling using a sawtooth reference signal, a geometrical framework is constructed to upper bound the deviation between uniform samples and natural samples and the corresponding uniform and natural sampling instances. For oversampling, the relation between deviation energy and oversampling factor is discussed. The results are tested with simulations.

TA8b1-2
Bayesian Interpretation of the Partial Area under the ROC with Applications to Spectrum Sensing
James Ritcey, University of Washington, United States

The Receiver Operating Characteristic is a concept in detection for spectrum sensing. The Area Under The Curve, AUC, integrated ROC, is a detection metric, derived from the ROC, that has been recently applied signal processing problems in cognitive radio. We present an interpretation of the partial AUC, where the a-priori probability of the false alarm probability is introduced, which generalizes the classical PAUC concept. Further, we show that adaptive threshold detectors, often introduced for holding a constant false alarm rate, have identical average detection performance as the PAUC. This provides a new interpretation of both the PAUC and CFAR tests.

TA8b1-3
Order Recognition of Continuous-Phase FSK
Mohammad Bari, Milos Doroslovacki, George Washington University, United States

In this paper we study a set of distinguishing features based on approximate entropy. The set identifies the order of continuous-time FSK in the joint presence of carrier offset, asynchronous sampling and symbol intervals, correlated fast fading and AWGN. Their performance is compared to wavelet-based feature's performance. For fair comparison of the features, both the approximate-entropy-based and wavelet-based features are classified by support vector machines. Major benefit of employing support vector machines is that they are able to train themselves using a very few realizations. Also, no a priori information is required about carrier phase, symbol rate and carrier amplitude.

TA8b1-4
Separation of Signals Consisting of Amplitude and Instantaneous Frequency RRC Pulses using SNR Uniform Training
Mohammad Bari, Milos Doroslovacki, George Washington University, United States

This work presents sample mean and sample variance based features that distinguish continuous phase FSK from QAM and PSK modulations. Root raised cosine pulses are used for signal generation. Support vector machines are employed for signals' separation. They are trained for only one value of SNR and used to classify the signals from a wide range of SNR. A priori information about carrier amplitude, carrier phase, carrier offset, roll-off factor and initial symbol phase is relaxed. Effectiveness of the method is tested by observing the joint effects of AWGN, carrier offset, lack of symbol and sampling synchronization, and fast fading.

Track F – Biomedical Signal and Image Processing
Session: TAb8 – Biomedical Signal Processing II 10:15 AM–11:55 AM

TA8b2-1
Causality Graph Learning on Cortical Information Flow in Parkinson's Disease Patients During Behaviour Tests
Abdulaziz Almalaq, Xiaoxiao Dai, Jun Jason Zhang, University of Denver, United States; Sara Hanrahan, Joshua Nedrud, Adam Hebb, Colorado Neurological Institute, United States

In this study, we assess cortical information flow in two subjects with Parkinson's disease. Causality graphs was generated by applying a Granger Causality connectivity analysis algorithm to electroencephalogram (EEG) data collected during a left and right hand movement task. And graph learning was exploited to classify movement classes. Our results demonstrate the ability to classify the flow of information in the brain. These methods can be applied in the future to identify pathological information flow for disease such as Parkinson's disease.

TA8b2-2
A Cortical Activity Localization Approach for Decoding Finger Movements from Human Electrocorticogram Signal
Seyede Mahya Safavi, Alireza S. Behbahani, Ahmed M. Eltawil, Zoran Nenadic, An H. Do, University of California, Irvine, United States

A novel approach for decoding the finger flexion and extension in the human Electrocorticogram is proposed. First, for different finger movements, we use projected MUltiple SIgnal Classification (projected MUSIC) as a source localization technique to estimate the active areas in primary motor cortex. Next, in order to distinguish between the flexion and extension, the results of the single-trial-based source localizations are fed as the input features to a classifier for decoding. The performance of different techniques such as Support Vector Machine (SVM), Perceptron, and the k-Nearest-Neighbor (kNN) are investigated and the resulting classification accuracies are 71.59, 79.1, and 86.33 respectively.

TA8b2-3
Momentum Measure for Quantifying Dendritic Cell Movement
Caroline Crockett, Elizabeth Orrico, University of Virginia, United States; Sara McArdle, University of California, United States; Klaus Ley, La Jolla Institute for Allergy and Immunology, United States; Scott Acton, University of Virginia, United States

Discovery is ongoing regarding the causes and onset of atherosclerosis. Studying the movement of dendritic cells may provide insight to disease mechanisms, which will eventually improve treatment. This paper develops a momentum-inspired approach to quantify the amount of quivering motion separately from translational motion. A simulation is developed to contrast the method performance against that of a graph-based approach. The resultant correlation coefficient between the simulated movement and the algorithm outcome is 0.85 for the proposed method, compared to 0.02 for the graph-based approach. In empirical tests, the momentum measure is shown to be robust to segmentation error.

TA8b2-4
Neurostimulation using Improved Focusing of Ultrasound
Ana Cruz, Pulkit Grover, Carnegie Mellon University, United States

Focused ultrasound has been known to be able to do neurostimulation for many decades. Most ultrasound focusing techniques in this context, however, use the “phased-array” technique where phases of multiple transducers are aligned so they interference constructively at the desired location. This paper explores the advantage of modulating ultrasound waves using pseudo-random sequences. We observe that sidelobes are reduced using peudo-random sequences, and this effect is more pronounced as the number of transducers increases.

TA8b2-5
Towards Achieving the Shannon-Capacity of EEG-Based Brain-Computer Interfaces
Pulkit Grover, Carnegie Mellon University, United States

We obtain a systematic framework for providing fundamental limits on information rates of EEG-based Brain Computer Interfaces, and insights on how to achieve these limits. We observe that to compute this limit, one needs to understand the spatial power spectral density of ``noise'' from sources both inside and outside the brain. Next, using existing experimental results, we argue that to exploit all available spatio-temporal degrees of freedom, the number of electrodes must increase from a few hundred today to a few thousand. Using example PSD functions, we estimate improvements in information-rates of EEG BCIs on using a few thousand electrodes.

TA8b2-6
Intra-Body Communication Model Based on Variable Biological Parameters
Ahmed Khorshid, Ahmed M. Eltawil, Fadi Kurdahi, University of California, Irvine, United States

This paper presents a simple, yet realistic and accurate model for signal transmission through the human body. The model is developed for intra-body communications, covering the range 100 KHz – 50 MHz. To gain a deeper insight about the body gain profile, biological parameters collected from statistical studies, were utilized when deriving the representative circuit model. The resulting model is the first to consider human age and weight as input parameters determining the models’ geometrical shape, and hence the different impedance values. Simulation results were compared with prior work using conventional modelling approaches as well as with previously published experimental results.

TA8b2-7
Controller Structure for Optimized Region of Attraction of Polynomial Systems
Zohaib Khalid Qazi, Cranos Williams, North Carolina State University, United States

We propose a feedback nonlinear controller structure to optimize the region of attraction (ROA) of polynomial system models while keeping the nature and position of the favorable fixed point unchanged. The control action allows us to manipulate positions of other fixed points, thus providing an increase in the ROA of the fixed point of interest. We show that an extension of the bi-level optimization algorithm presented by Matallana et al. can be used to optimize the parameters of the proposed controller. We compare the ROA of the controlled system with the uncontrolled system to assess the effectiveness of the approach.

Track B – MIMO Communications and Signal Processing
Session: TAb8 – Relayed Communications II 10:15 AM–11:55 AM

TA8b3-1
Jointly Optimal Distributed Beamforming and Power Control in Asynchronous Two-Way Relay Networks
Sahar Bastanirad, Shahram ShahbazPanahi, Ali Grami, University of Ontario Institute of Technology, Canada

We consider an \emph{asynchronous} two-way relay network where multiple single-antenna relay nodes enable a bi-directional communication between the two single-antenna transceivers using simple amplify-and-forward relaying protocol. In such a network, aiming to optimally obtain the relay beamforming weights and the transceiver transmit powers, we minimize the total consumed power in the network, subject to constraints on the transceiver`s data-rate. We show that our optimization problem leads to a certain relay selection scheme and present a semi-closed-form solution to find the optimal relay weight vector.

TA8b3-2
Sum-Rate Maximization for Asynchronous Two-Way Relay Networks
Mina Askari, Shahram ShahbazPanahi, University of Ontario Institute of Technology, Canada

We consider an asynchronous single-carrier bidirectional amplify-and-forward relaying scheme consisting of two single-antenna transceivers and several single-antenna relay nodes. We assume that the propagation delay of each relaying path is different from those of the other relaying paths. We solve for the optimum relay beamforming weights and transceiver's transmit powers which maximize the sum-rate subject to a total transmit power constraint. We show that this optimization problem leads to a relay selection scheme where only the relay(s) corresponding to one tap of the end-to-end channel impulse response are turned on and the remainder of relays are switched off.

TA8b3-3
Achievable Degrees of Freedom on K-user MIMO Multi-Way Relay Channel with Common and Private Messages
Mohamed Salah, Amr El-Keyi, Nile University, Egypt; Yahya Mohasseb, The Military Technical College, Egypt; Mohammed Nafie, Cairo University, Egypt

We investigate the achievable total degrees of freedom (DoF) of the K user MIMO multi-way relay channel where each user can exchange common and private messages with the remaining K-1 users via an intermediate relay. We derive cut-set bounds on the total DoF of the network and show that the network has DoF less than or equal to K min{M,N}, where M and N are the number of antennas at each user and the relay respectively. We show that introducing the common messages besides the private messages leads to achieving higher total DoF than using the private messages only.

TA8b3-4
Rate Maximization in Dense Interference Networks using Non-Cooperative Passively Loaded Relays
Yahia Hassan, Bernhard Gahr, Armin Wittneben, ETH Zurich, Switzerland

We consider a communication system with multiple single antenna transmitter-receiver pairs, forming an interference channel. The receivers are closely spaced and surrounded by a number of non-cooperative passively loaded relays. Utilizing antenna coupling between antennas of the receivers and relays, we adapt the relay loads as well as the receivers matching networks to

maximize the sum rate. Our results show huge performance enhancements in comparison to TDMA. In some cases, they are close to the ones having multiple antenna receivers that use the theoretically best multiport matching. Our proposed algorithm is relevant to modern communication systems with high node density.

TA8b3-5
Multi-User Beamforming-Aided AF Relaying: A Low-Complexity Adaptive Design Approach

Jiaxin Yang, McGill University, Canada; Yunlong Cai, Zhejiang University, China; Benoit Champagne, McGill University, Canada; Lajos Hanzo, University of Southampton, United Kingdom

The problem of cooperative multiple-input multiple-output amplify-and-forward relaying design for multi-user networks is studied. We aim for jointly optimizing the beamforming weights of different relays in order to minimize the total received power at all the destinations while a set of linear constraints are imposed to preserve the desired signals at each destination. In contrast to prior contributions, which optimize the relaying matrices in a batch processing mode, we propose a low-complexity adaptive update approach by designing a recursive algorithm for the relay beamforming weights. The efficacy of the adaptive scheme is demonstrated by computer simulations.

Track A – Communications Systems
Session: TP1 – Coherent Optical Communications

Chair: ***Shiva Kumar,*** *McMaster University*

TP1-1 1:30 PM
Group Delay Statistics and Management in Mode-Division Multiplexing

Sercan Arik, Stanford University, United States; Keang-Po Ho, SiBEAM and Silicon Image, United States; Joseph Kahn, Stanford University, United States

Reduction of the group delay (GD) spread is crucial for minimizing multi-input multi-output (MIMO) signal processing complexity in mode-division multiplexing (MDM). The GD spread obtained by optimized fiber design is not sufficiently small. Strong mode coupling and GD compensation (concatenating different fibers with opposing GD ordering) are two approaches for reducing the end-to-end GD spread. After reviewing multimode propagation models and the statistics of coupled GDs, we study the GD spread of systems in which both mode coupling and GD compensation are present. We provide design guidelines for minimizing MIMO signal processing complexity in MDM systems.

TP1-2 1:55 PM
Reduction of the Performance Effects of Kerr Nonlinearity in Single Mode Optical Coherent Transmission Systems

Maurice O'Sullivan, Michael Reimer, Qunbi Zhuge, Andrew Shiner, Andrzej Borowiec, Charles Laperle, Ciena incorporated, Canada

In WDM optical coherent transmission systems, the maximum capacity per spatial mode at a given reach is limited by optical fiber & amplifier properties as well as the actions of the Raman and Kerr effects. DSP strategies including dispersion compensation, spectral shaping, nonlinear pre-compensation and modulation design applied to the reduction of the effects of Kerr nonlinearity will be discussed together with supporting measurement.

TP1-3 2:20 PM
On the Nonlinear Shannon Limit of Optical Fibers in Networks with Reconfigurable Optical Add-Drop Multiplexers

René-Jean Essiambre, Bell Labs, Alacatel-Lucent, United States

The rate of transmission of information over single-mode optical fibers has increased by four orders of magnitude over the last three decades. A question naturally arises: Is there a fundamental limit to the capacity of single-mode fibers? In this presentation, I will introduce how Shannon's information theory and can be used to calculate an estimate of a fundamental capacity limit of single-mode fibers due to the Kerr nonlinear effect. I will also discuss how multicore and multimode fibers are foreseen to provide a capacity per fiber well beyond the capacity of single-mode fibers.

TP1-4 **2:45 PM**

100G DWDM Upgrades of Legacy Undersea and Terrestrial Fiber-Optic Systems

Sergey Burtsev, Do-il Chang, Wayne Pelouch, Xtera Communications, Inc., United States

DWDM Upgrades of Undersea and Terrestrial Fiber-Optic Systems with 100G PM-QPSK technology helped to increase significantly the capacity of legacy fiber-optic systems. To illustrate the upgrade issues from different angles, three different DWDM realistic upgrade applications were chosen: (1) undersea repeatered systems; (2) unrepeatered (UR) systems; (3) terrestrial multi-span long-haul systems. We also look into the upgrade design process with a focus on practical issues that a system engineer has to deal with in order to provide the quality upgrade design.

BREAK **3:10 PM**

TP1-5 **3:30 PM**

Flexible Transceiver Design for High Capacity Elastic Coherent Transport Systems

David Plant, McGill University, Canada

Next generation optical transport is expected to deliver data rates of 1 Tb/s per channel. Flexibility is required in order to satisfy the requirements of elastic optical networks. In order to maximize spectral efficiency transceiver bandwidths will be. Data rates will also be continuously adaptive in order to meet dynamic capacity demands. We describe transceivers designed to support such networks to tradeoff transmission distance and spectral efficiency.

TP1-6 **3:55 PM**

LDPC-Coded Orbital Angular Momentum Modulation Enabling Ultra-High-Speed Transmission over Free-Space Optical Links

Ivan B. Djordjevic, Zhen Qu, University of Arizona, United States

To simultaneously achieve high throughput and low energy consumption, in this invited paper we advocate the use of energy-efficient N-dimensional orbital angular momentum (OAM) LDPC-coded-modulation for ultra-high-speed optical transmission over free-space optical (FSO) links. OAM is associated with the azimuthal phase dependence of the complex electric field. Because its eigenvectors are orthogonal, they can be used as basis functions for multidimensional signaling. To deal with time-varying channel conditions, OAM modulation can be combined with rateless coding. Atmospheric turbulence effects can be handled, in addition to FSO-MIMO, through the use of the azimuthal phase correction methods including the adaptive optics approaches.

TP1-7 **4:20 PM**

Approaches for Nonlinear Interference Mitigation in Fiber-Optic Communication Systems

Ronen Dar, Bell Laboratories, Alcatel-Lucent, United States

Fiber's nonlinearity is known to be the most fundamental factor limiting the capacity of optical communication systems. In a Wavelength-Division-Multiplexed (WDM) transmission, it introduces nonlinear interference between the various WDM channels. While intra-channel distortions can be eliminated by means of digital back propagation, similar elimination of inter-channel distortions is considered to be impractical, particularly in a network environment. In this talk we review our recent work on the modeling of nonlinear propagation. We discuss the impact of these results on the prospects of inter-channel nonlinear interference mitigation in commercial systems and on the ultimate achievable gains of such schemes.

TP1-8 **4:45 PM**

Mitigation of Fiber Linear and Nonlinear Effects in Coherent Optical Communication Systems

Xiaojun Liang, Shiva Kumar, Jing Shao, McMaster University, Canada

Fiber dispersive and nonlinear effects lead to signal distortions in a fiber optic link, which limits the achievable transmission distance and system capacity. Digital and optical techniques have been proposed to mitigate propagation impairments. In this talk, we discuss three mitigation techniques: perturbation-based digital compensation, correlated digital back propagation (DBP), and ideal optical back propagation (OBP).

TP1-9 **5:10 PM**

QAM Quantum Noise Stream Cipher using Digital Coherent Optical Transmission

Masato Yoshida, Toshihiko Hirooka, Keisuke Kasai, Masataka Nakazawa, Tohoku University, Japan

Recently, a physical layer encryption technique using quantum shot noise has attracted a lot of attention with a view to realizing a high-speed and long-distance secure optical transmission system. In this scheme, a streamed data signal is hidden in quantum phase noise or amplitude noise, thus we refer to this as a "quantum noise stream cipher (QNSC)". In this paper, we present a high-security digital-coherent transmission scheme with a QAM-based two-dimensional QNSC employing amplitude and phase encryption simultaneously and multi-bit encoding with a multi-bit basis state. 40 Gbit/s-480 km and real-time 10 Gbit/s-320 km secure transmissions are demonstrated.

Track A – Communications Systems

Session: TP2 – Enabling Technologies for Future Wireless Networks

Chair: ***Lingjia Liu,*** *University of Kansas*

TP2-1 **1:30 PM**

Hardware Implementation of ADMM-Based LP Decoding

Mitch Wasson, Stark Draper, University of Toronto, Canada

The alternating directions method of multipliers (ADMM) is an optimization technique that can be used to solve large-scale factorable convex problem in an efficient distributed manner. One topical application is to linear programming (LP) relaxations of the maximum likelihood decoding problem for binary, linear error-correcting codes. In this paper we describe initial work exploring the hardware compatibility of this new algorithm on field-programmable gate-arrays (FPGAs).

TP2-2 **1:55 PM**

Directional Neighbor Discovery in Dual-Band Systems

Daoud Burghal, Arash Saber Tehrani, Andreas Molisch, University of Southern California, United States

This paper considers the problem of directional neighbor discovery in dual-band systems operating in both mm-wave and microwave bands employing antenna arrays. Due to the propagation loss, the set of neighbors in a direction at mm-wave frequencies is a subset of the neighbors at microwaves. This allows to greatly accelerate neighbor discovery. Specifically, we propose a distributed random scheme where each device maximizes the "local" probability of successful discovery at mm-waves given the prior info from microwaves. We verify our results through simulations and show that the total discovery time can be reduced significantly.

TP2-3 **2:20 PM**

SINR and Throughput Scaling Laws in Ultra Dense Urban Cellular Networks

Abhishek Gupta, University of Texas at Austin, United States; Xinchen Zhang, Qualcomm Inc., United States; Jeffrey Andrews, University of Texas at Austin, United States

We consider a densely deployed cellular network in an urban environment. Using a multi-slope path loss model that is well supported empirically, we extend recent results on the plane to 2.5 and 3 dimensions, and show that the 'critical near-field path loss' exponents where SINR and throughput decay to zero are proportionally larger than in the 2D case. Indeed in some cases the critical path loss exponent is larger than 2, which is quite realistic. This result implies that network densification will reach fundamental physical limits in the future, at which point further densification may not increase the sum throughput.

TP2-4 **2:45 PM**

Overview and Evaluation of Device-To-Device and Licensed Assisted Access for LTE-Advanced

Thomas Novlan, Boon Ng, Jianzhong (Charlie) Zhang, Samsung, United States

3GPP has been studying Licensed-Assisted Access (LAA) as a mechanism for LTE systems to utilize unlicensed spectrum paired with licensed spectrum. This work presents and evaluates procedures to achieve efficient operation and coexistence on unlicensed spectrum as a function of multiple factors, including traffic characteristics, deployment scenarios, and radio-access technologies. In addition, LTE-Advanced has also introduced device-to-device (D2D) discovery and communications for both commercial and public-safety applications and use cases. Different centralized and distributed resource allocation and synchronization mechanisms are presented which support operation inside and outside of network coverage.

BREAK **3:10 PM**

TP2-5 **3:30 PM**

Next Generation TDD for Future Wireless Systems

Yongxing Zhou, Huawei Technologies Co., Ltd., China

This presentation is focusing on the next generation TDD (NG TDD) system with low latency, high throughput and super resource utilization flexibility. Spectrum allocation and spectrum utilization technologies (e.g. spectrum sharing)for TDD are also discussed. In particular, the NG TDD design can be further tailored for the macro cell deployment, small cell deployment as well as device to device communications.

TP2-6 **3:55 PM**

Spectrum Management in 5G: A Tale of Two Timescales

Fei Teng, Dongning Guo, Northwestern University, United States

To attain the capacity promised by next generation (5G) cellular networks require dense deployment of small cells in addition to macro cells. Due to much more pronounced traffic and interference variations in small cells, dynamic radio resource management (RRM) is crucial in heterogeneous networks. This work addresses RRM on two timescales: a slow timescale (in seconds or minutes) and a fast timescale (in milliseconds). In particular, the effect of fast-timescale adaptation to traffic conditions of neighboring cells on centralized slow-timescale RRM is studied.

TP2-7 **4:20 PM**

A Minimax Distortion View of Differentially Private Query Release

Weina Wang, Lei Ying, Junshan Zhang, Arizona State University, United States

We devise query-set independent mechanisms for the problem of differentially private query release. Specifically, a differentially private mechanism is constructed to publish a synthetic database, and "customized" companion estimators are then derived to provide the best possible answers. Accordingly, the distortion corresponding to the best mechanism at the worst-case query, so called the minimax distortion, provides a fundamental characterization. For the general class of statistical queries, by deriving asymptotically sharp upper and lower bounds, we prove that the minimax distortion is O(1/n) as the database size n goes to infinity, with the squared-error distortion measure.

TP2-8 **4:45 PM**

Database- and Sensing-Based Distributed Spectrum Sharing

Mingming Cai, J Nicholas Laneman, University of Notre Dame, United States

This paper develops a database- and sensing-aided architecture for distributed spectrum sharing in a localized area and band of frequencies among secondary users. Scalability is enabled by having broadcast database updates to protect primary users and distributed spectrum sensing and access by the secondary users. We analyze and design protocols for multi-channel random access that allow the secondary users to settle into a period of collision-free transmission after a database update. We will also report on the results of protocol implementation and experimental validation of the architecture within an advanced software-defined radio (SDR) testbed.

TP2-9 **5:10 PM**

Resource Allocation for Sensing-Based D2D Networks

Hao Chen, Lingjia Liu, University of Kansas, United States

Resource allocation for sensing-based D2D networks is investigated in this paper. To be specific, we consider spatial spectrum sensing where D2D users can sense spatial spectrum opportunities in a cellular network. By modeling the location of base stations as a Poisson point process (PPP), the spatial spectrum sensing problem can be formulated using the framework of detection theory. The closed form expressions are obtained for the sensing threshold, probabilities of detection and probability of false alarm. Accordingly, the performance of sensing-based D2D networks with spatial spectrum sensing can be characterized using stochastic geometry.

Track C – Networks

Session: TPa3 – Social Networks

Chair: ***Vijay Subramanian,*** *University of Michigan*

TP3a-1 1:30 PM

On Rate of Learning in Social Networks

Anusha Lalitha, Tara Javidi, University of California, San Diego, United States; Anand Sarwate, Rutgers University, United States

We consider the problem of social learning, where individual nodes in a network receive noisy local observations whose distribution is parameterized by a discrete parameter. Conditional distributions are known locally but the true parameter is unknown to the nodes. We consider a class of learning rules where nodes first perform a Bayesian update of their belief of the parameter based on their local observations, communicate these local updates to their neighbors and then performs a ``non-Bayesian'' update using neighbors log-beliefs, (for instance, by taking linear consensus of neighbors log-beliefs). We characterize its asymptotic rate of learning and provide concentration results.

TP3a-2 1:55 PM

Achieving Exact Cluster Recovery Threshold via Semidefinite Programming under the Stochastic Block Model

Bruce Hajek, Yihong Wu, University of Illinois at Urbana-Champaign, United States; Jiaming Xu, University of Pennsylvania, United States

This talk focuses on the problem of finding the underlying communities within a network using only the knowledge of network topology. We consider the classical stochastic block model for generating a network with some underlying cluster structure, and derive a semidefinite programming (SDP) relaxation of the maximum likelihood estimator for recovering the clusters from the network. We show that the performance guarantee of the SDP exactly matches the necessary information bound, if there are two clusters of sizes proportional to the network size but not necessarily equal, or there are a fixed number of equal-sized clusters.

TP3a-3 2:20 PM

Generalized Hegselman-Krause Opinion Dynamics from Optimization Rules

Avhishek Chatterjee, University of Texas at Austin, United States; Anand Sarwate, Rutgers University, United States; Sriram Viswanath, University of Texas at Austin, United States

The Hegselman-Krause opinion dynamics model is a simple model for the evolution of opinions in a network of interacting agents. It uses iterated averaging of the current opinions of the agents. We interpret the update rule as each agent minimizing a cost function the depends on the disagreement between it and its neighbors. Averaging corresponds to quadratic costs. We generalize this rule to other convex cost functions and study the impact on the dynamics. We also investigate some natural control problems that emerge from these dynamics.

TP3a-4 2:45 PM

Incentive Design for Learning in User-Recommendation Systems

Deepanshu Vasal, Achilleas Anastasopoulos, Vijay Subramanian, University of Michigan, United States

We consider the problem of how strategic users can learn an underlying state in a user-recommendation system setup. We consider an ergodic setup (time-varying state) and first study the case of perfect cooperation, which can serve as a benchmark on the performance of any recommendation system with strategic agents. We then turn to the more interesting case of strategic agents and investigate incentive designs that induce agents to align their behavior with the socially optimal solution. Our initial results show that appropriately designed incentives can bridge the gap between the game and team setup.

Track C – Networks

Session: TPb3 – Caching in Wireless Networks

Chair: ***Edmund Yeh,*** *Northeastern University*

TP3b-1 **3:30 PM**

Caching in Combination Networks

Mingyue Ji, University of Southern California, United States; Antonia Tulino, Alcatel Lucent Bell Labs, United States; Giuseppe Caire, Technische Universität Berlin, Germany

We consider a network formed by one server, k "helpers" and K users. The users may request any file from a library of N files and can cache up to M files each. Each user can connect simultaneously to r helpers. This may model a wireless small-cell network where each user is simultaneously served by r base stations, or a content distribution network where each user can pull data simultaneously from r out of k possible "mirrors". We present a simple scheme that achieves a speed-up factor of $1/r$ with respect to a single shared link network (without helpers).

TP3b-2 **3:55 PM**

Physical Layer Caching for MIMO Relay Channels

Wei Han, An Liu, Vincent Lau, HKUST, Hong Kong SAR of China

In this talk, we propose a novel "physical layer caching scheme" and study the degree of freedom (DoF) gains in cached MIMO relay networks. The proposed PHY caching exploits the cache-induced cooperative MIMO gain. Specifically, the physical topology of the wireless access network changes dynamically between unfavorable PHY topologies (such as relay channels) and more favorable PHY topologies (such as MIMO broadcast channels) depending on the PHY cache state. Hence, physical layer caching can fully unleash the potential benefit of wireless relay that was never realised before.

TP3b-3 **4:20 PM**

Throughput-Delay Tradeoffs in Content-Centric Ad Hoc and Heterogeneous Wireless Networks

Milad Mahdian, Edmund Yeh, Northeastern University, United States

We study the throughput and delay characteristics of wireless networks based on a content-centric network architecture. Nodes are assumed to be uniformly distributed in the network area along with a number of base stations. Each node has a limited-capacity content store, which it uses to cache contents according to the proposed caching scheme. Requested content follows a general popularity distribution, and users employ multihop communication to retrieve the requested content from the closest cache or base station. We derive the throughput-delay tradeoff of the content-centric wireless network model and solve the caching optimization problem.

TP3b-4 **4:45 PM**

Distributed Caching in Device-To-Device Networks: A Stochastic Geometry Perspective

Shankar Krishnan, Harpreet Dhillon, Virginia Tech, United States

Increasing spatio-temporal correlation in the data demand makes it attractive to cache popular content on the user devices so that it can be delivered on demand to the neighboring devices through device-to-device (D2D) communications. Due to the limited storage capacity, each device can only cache a part of the popular content. With device locations modeled as a Poisson Point Process (PPP), we study the coverage and average delay for a typical device when the content of its interest is partitioned into K file portions with each device caching one of the portions randomly.

Track B – MIMO Communications and Signal Processing

Session: TPa5 – Interference Channels

TP5a-1 **1:30 PM**

Interference Alignment-Aided Base Station Clustering using Coalition Formation

Rasmus Brandt, Rami Mochaourab, Mats Bengtsson, KTH Royal Institute of Technology, Sweden

Base station clustering is necessary in large interference networks, where the channel state information (CSI) acquisition overhead otherwise would be overwhelming. In this paper, we propose a novel long-term throughput model for the clustered users which addresses the balance between interference mitigation capability and CSI acquisition overhead. The model only

depends on statistical CSI, thus enabling long-term clustering. Based on notions from coalitional game theory, we propose a low-complexity distributed clustering method. The algorithm converges in a couple of iterations, and only requires limited communication between base stations. Numerical simulations show the viability of the proposed approach.

TP5a-2 1:55 PM

Interference Alignment using Alignment Matrix

Jhanak Parajuli, Giuseppe Abreu, Jacobs University Bremen, Germany

In this article, we explore the application of alignment matrices as applied to non-linear dimensionality reduction [1] in the analysis and solution of interference alignment schemes for wireless communications systems. We propose an algorithm that achieves alignment in the correlated interference channel. It is also shown that the degrees of freedom (DoF) of an interfering channel can be characterized with the help of the dimension of the null space of the alignment matrix (AM). Indeed, we show that if AM can be built such that the null space N(AM) =I, full interference alignment is achieved.

TP5a-3 2:20 PM

Degrees of Freedom for K-user SISO Interference Channels with Blind Interference Alignment

Heecheol Yang, Wonjae Shin, Jungwoo Lee, Seoul National University, Republic of Korea

We derive the degrees of freedom (DoF) for K-user single-input single-output (SISO) interference channels (IC) with a blind interference alignment scheme. In this paper, the sum DoF for K-user SISO IC is generalized including the scenario when the number of preset modes, N, is greater than 2, while previous work only handles specific cases, i.e., N=2. We prove the DoF converse for the general K-user SISO IC, which shows that the sum DoF is upper-bounded by $\frac{n^{*}K}{K+n^{*}(n^{*}-1)}$ where n^{*} is determined by the (K,N) setting. Moreover, we propose the achievable scheme for a certain setting that achieves sum DoF upper-bound.

TP5a-4 2:45 PM

Interference-Floor Shaping for Liquid Coverage Zones in Coordinated 5G Networks

Lars Thiele, Martin Kurras, Stephan Jaeckel, Fraunhofer HHI, Germany; Wolfgang Zirwas, Nokia, Germany

Joint transmission CoMP is a combination of constructive and destructive superposition of several to potentially many signal components, with the goal to maximize the desired receive-signal and at the same time to minimize mutual interference. Especially the destructive superposition requires accurate alignment of phases and amplitudes. Therefore, a 5G clean slate approach needs to incorporate the following enablers: accurate channel estimation of all relevant channel components, channel prediction for time-aligned precoder design, proper setup of cooperation areas corresponding to user grouping and to limit feedback overhead as well as treatment of out-of-cluster interference (interference floor shaping).

Track B – MIMO Communications and Signal Processing

Session: TPb5 – Interference in Networks

Chair: ***Motjaba Vaezi,*** *Princeton University*

TP5b-1 3:30 PM

Nearly Optimal Non-Gaussian Codes for the Gaussian Interference Channel

Alex Dytso, Daniela Tuninetti, Natasha Devroye, University of Illinois at Chicago, United States

Recent work demonstrated that for the two-user Gaussian Interference Channel (G-IC) sub-optimal point-to-point codes can outperform optimal (Gaussian) point-to-point codes. However, it is not clear how far from capacity such sub-optimal codes operate. This work demonstrates a family of sub-optimal codes, generated from a mixture of Gaussian and discrete random-variables, is optimal up to an additive gap for the two-user G-IC. The developed tools are of interest on their own and applicable in a variety of settings. For example, capacity of the block-asynchronous G-IC is shown to be within a gap of the capacity of the classical fully synchronized G-IC.

TP5b-2 **3:55 PM**

On Limiting Expressions for the Capacity Regions of Gaussian Interference Channels

Mojtaba Vaezi, H. Vincent Poor, Princeton University, United States

With an explicit counterexample, we show that the restriction to Gaussian inputs in the limiting expression for the capacity region of memoryless Gaussian interference, falls short of achieving capacity in general. We then explain possible techniques that enable us make use of the limiting expression to obtain valid outer bounds for Gaussian interference channels. These techniques can be also used in other network information theory problems.

TP5b-3 **4:20 PM**

How Large Portion of K/2 DoF Can We Achieve at Finite SNR for the Gaussian Interference Channel?

Junyoung Nam, Young-Jo Ko, Electronics and Telecommunications Research Institute (ETRI), Republic of Korea

The K/2 degrees of freedom (DoF) of the K-user Gaussian interference channel (GIC) are well known to be achievable for almost all constant real channel coefficients. In this paper, we investigate the sum-rate behavior of the K-user complex-valued GIC at finite SNR. To this end, we derive closed-form upper bounds on the sum capacity for the symmetric real case. We further show that how large portion of K/2 DoF is achievable at practical values of SNR strongly depends on the phase difference between channel coefficients.

TP5b-4 **4:45 PM**

A Coordinated Uplink Scheduling and Power Control Algorithm for Multicell Networks

Kaiming Shen, Wei Yu, University of Toronto, Canada

This paper proposes a coordinated uplink joint scheduling and power control algorithm in a multi-cell network. The coordinated uplink scheduling problem is more challenging than downlink, because uplink scheduling decision affects the interference pattern in nearby cells. This paper considers a weighted sum-rates maximization problem across multiple cells and proposes a reformulation of the nonconvex mix-integer problem as a sum-linear-ratios problem. A novel quadratic algorithm is proposed to reach a stationary point of the problem through iterative distributed optimization of power levels and user schedules among the BSs. Simulation results show considerable performance improvement as compared to common heuristic approaches.

TP5b-5 **5:10 PM**

ITLinQ+: An Improved Spectrum Sharing Mechanism for Device-to-Device Communications

Xinping Yi, Giuseppe Caire, Technische Universität Berlin, Germany

The device-to-device (D2D) communications enable proximity-based applications by exchanging information directly between nearby devices without routing through cellular infrastructure. How to assist devices to share spectrum and deal with mutual interference is of practical importance. In this work, we propose a low-complexity distributed link scheduling and power control mechanism (ITLinQ+) for spectrum sharing in D2D networks, inspired by recent findings that power control and treating interference as noise is almost throughput-optimal in interference networks under some channel strength conditions. We show ITLinQ+ substantially improves the average sum-throughput over state-of-the-art mechanisms, such as FlashLinQ and ITLinQ, with much less power consumption.

Track C – Networks

Session: TPa6 – Multi-Agent Systems and Optimization

Co-Chairs: ***Alec Koppel,*** *University of Pennsylvania* ***and Alejandro Ribeiro,*** *University of Pennsylvania*

TP6a-1 **1:30 PM**

Sparsity Aware Dynamic Distributed Compressive Spectrum Sensing and Scheduling

Nicolo Michelusi, Urbashi Mitra, University of Southern California, United States

A cross-layer framework for resource constrained dynamic distributed spectrum sensing and scheduling is presented.A network of multiple agents opportunistically communicate over portions of the spectrum estimated to be unused by other systems.Sparsity in the network dynamics is exploited:if enough spectrum measurements are collected,as dictated by the expected level of sparsity in the estimate,then the spectrum is estimated without errors,and the agents are scheduled to communicate over the idle spectrum

bins; otherwise,the estimation uncertainty further increases,demanding more measurements to be collected in the future.The trade-off between achieving accurate spectrum estimates,high throughput, and low state information overhead, is optimized via dynamic programming.

TP6a-2 **1:55 PM**

A Stochastic Primal-Dual Algorithm for Task-Driven Dictionary Learning in Networks

Alec Koppel, University of Pennsylvania, United States; Garrett Warnell, Ethan Stump, U.S. Army Research Laboratory, United States

We task-driven dictionary learning in a decentralized dynamic setting: a network of agents aims to learn a common dictionary and model parameters while sequentially receiving local observations. This problem is a distributed stochastic program with a non-convex objective, which we solve with a block variant of the Arrow-Hurwicz saddle point algorithm and obtain a decentralized algorithm. We show this method asymptotically achieves a first-order stationarity condition of the formulated problem almost surely. Moreover, we demonstrate the proposed method's practical utility via a collaborative image classification task, illustrating that the performance is comparable to the centralized case.

TP6a-3 **2:20 PM**

On Asynchronous Implementations of Fictitious Play for Distributed Learning

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

Game-theoretic learning algorithms commonly assume that players act according to a global clock. This assumption is often infeasible in a distributed setting. The paper considers an asynchronous model of the well-known Fictitious Play (FP) learning algorithm. A sufficient condition is presented on the asymptotic pairwise frequency of players' strategy updates under which the asynchronous FP play process is shown to converge to Nash equilibrium in games known to possess the fictitious play property. The condition permits adaptive strategy-update rates, thus allowing for implementations in settings in which agent's individual clock rates are not synchronized apriori.

TP6a-4 **2:45 PM**

Intermittent Connectivity Control in Mobile Robot Networks

Yiannis Kantaros, Michael M. Zavlanos, Duke University, United States

In this paper, we consider networks of mobile robots that are responsible for accomplishing tasks captured by Linear Temporal Logic (LTL) formulas, in complex environments represented by appropriate transition systems (TS), while ensuring communication with all other robots in the network. We propose an intermittent communication framework, which is based on an LTL statement that enforces the robots to meet and exchange information at pre-determined points in the environment infinitely often. Our approach combines an existing model checking method with a novel technique that aims to reduce the state-space of the TS satisfying at the same time the LTL statement.

Track C – Networks

Session: TPb6 – Epidemic Control in Networks

Co-Chairs: ***Victor Preciado,*** *University of Pennsylvania* ***and Cameron Nowzari,*** *University of Pennsylvania*

TP6b-1 **3:30 PM**

Numerical Investigation of Metrics for Epidemic Processes on Graphs

Max Goering, Faryad Darabi Sahneh, Nathan Albin, Caterina Scoglio, Pietro Poggi-Corradini, Kansas State University, United States

This study develops a metric on graphs that measures the expected time an epidemic initiated at one node takes to reach another. A centrality measure is introduced and compared to degree, betweenness, spectral, and effective resistance centrality measures through exhaustive numerical simulations on several real-world network data-sets. We find two surprising observations: first, the epidemic centrality measure is much more delocalized compared to degree centrality and spectral centrality; and second, epidemic centrality is highly correlated with effective resistance centrality, suggesting that effective resistance is successful in identifying nodes that are influential with respect to epidemic spreading on real-world networks.

TP6b-2 **3:55 PM**

Sufficient Condition for Survival of the Fittest in a Bi-virus Epidemics

Augusto Santos, José M.F. Moura, Carnegie Mellon University, United States; Joao Xavier, Instituto Superior Tecnico, Portugal

We study the spread of two strains of virus in a network modeled by logistic ordinary differential equations. Qualitative analysis of these differential equations is challenging. We extend our prior work, to establish a sufficient condition for survival of the fittest in a bi-layer weighted digraph: the weaker strain dies out regardless of the initial conditions if its maximum in-flow rate of infection is smaller than the minimum in-flow rate of the stronger strain. We achieve this result by bounding the solution of the logistic ODE by 1D solutions over certain homogeneous networks for which the system is well understood.

TP6b-3 **4:20 PM**

Distributed stopping criteria for the Power Iteration applied to virus mitigation

Eduardo Ramirez-Llanos, Sonia Martinez, University of California, San Diego, United States

This paper proposes a novel distributed stopping criterion for the well-known Power Iteration method for symmetric and Metzler matrices. We provide a bound on the accuracy of the approximations for the maximum eigenvalue of the matrix and its corresponding eigenvector. We apply our result to mitigate virus spreading over a complex network. For that, we interconnect the Power Iteration algorithm together with our recently developed robust box-constrained gradient fairness algorithm. This distributed algorithm allows an interconnected group of agents to collectively minimize a global cost function subject to equality and inequality constraints.

TP6b-4 **4:45 PM**

Optimal Resource Allocation for Containing Epidemics on Time-Varying Networks

Cameron Nowzari, University of Pennsylvania, United States

This work considers an optimal resource allocation for spreading processes on time-varying networks. Unlike the vast majority of works that study the analysis and control of epidemics on static graphs, we allow the edge weights between nodes of the network to vary in time, possibly even disappearing and reappearing. We assume all edge weights (which can represent things like traffic between cities) are independently changing via Markov processes for which we are only able to control the upper limit (e.g., enforcing traffic restrictions). We formulate the optimization problem as a geometric program that can be solved efficiently in polynomial time.

Track A – Communications Systems

Session: TPa7 – Algorithm and Hardware Aspects for 5G Wireless Systems

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

TP7a-1 **1:30 PM**

Energy-Proportional Single-Carrier Frequency Domain Equalization for mmWave Wireless Communication

Nicholas Preyss, Sara Rodriguez Egea, Andreas Burg, École Polytechnique Fédérale de Lausanne, Switzerland

Wireless single-carrier communication at mmWave frequencies is considered to be an interesting solution to satisfy the growing demand for wireless connectivity. Unfortunately, the large bandwidth of mmWave systems leads to large variations of the inter-symbol-interference in non-line-of-sight environments. Such different requirements generally induce a loss in energy efficiency for receiver structures that are designed for worst-case situations. In this paper, we describe an adaptive equalization strategy that provides the right amount of ISI mitigation with the objective of power reduction. Hence, we propose and study a mix between cyclic-prefix frequency-domain-equalization and time-domain linear equalization realized in the frequency domain.

TP7a-2 **1:55 PM**

Low Resolution Adaptive Compressed Sensing with Oversampling for Low Power mmWave MIMO Receivers

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

One-bit compressed sensing has been recently considered as a solution for low power MIMO receivers at mmWave. In this paper we analyze first the use of one-bit adaptive compressed sensing strategies with oversampling, which introduces correlated noise in the quantized signal. Since using a slightly higher resolution comes at an approximately equal power consumption as

introducing oversampling, we also study low resolution mmWave receivers using highly coarsely quantized samples (2-3 bits) in a static and an adaptive fashion. Preliminary results show a significant performance improvement versus static one-bit receivers with no oversampling, while power consumption is kept reasonable low.

TP7a-3 **2:20 PM**

Algorithm and Hardware Aspects on Pre-Coding in Massive MIMO Systems

Hemanth Prabhu, Joachim Neves Rodrigues, Liang Liu, Ove Edfors, Lund University, Sweden

Massive Multiple-Input Multiple-Output (MIMO) systems have been shown to improve both spectral and radiated energy efficiencies by orders of magnitude. Despite being conceptually straight-forward, the new paradigm leads to new implementation challenges at the base station. Time-critical calculation of down-link pre-coders for hundreds of antennas, provides both challenges and opportunities. Fortunately, massive MIMO also provides many opportunities to improve processing efficiency. We focus on proposed implementations of pre-coder calculations, including those based on Neumann series expansions and modified QR decompositions, and compare their performance, complexity and hardware costs in different scenarios.

TP7a-4 **2:45 PM**

Large-Scale MIMO Detection for 5g Multi-Carrier Waveform Candidates

Michael Wu, Engin Tunali, Chris Dick, Xilinx Incorporated, United States; Christoph Studer, Cornell University, United States

5th generation wireless systems are expected to combine several novel technologies, such as large-scale MIMO and non-orthogonal multi-carrier waveforms, in order to improve the spectral efficiency. This paper investigates the efficacy of different multi-carrier waveform candidates, such as filter bank multi-carrier (FMBC) and generalized frequency division multiplexing (GFDM), in combination with large-scale MIMO. The non-orthogonality of these candidate waveforms increases the computational complexity of data detection considerably compared to conventional modulation schemes, such as OFDM and SC-FDMA. We therefore develop and compare efficient large-scale MIMO detection algorithms for several 5G multi-carrier waveform candidates and investigate the associated hardware complexity/performance trade-offs.

Track G – Architecture and Implementation

Session: TPb7 – VLSI Signal Processing

Chair: ***Keshab Parhi,*** *University of Minnesota*

TP7b-1 **3:30 PM**

Mixed-Signal Circuits for Machine Learning Applications

Boris Murmann, Stanford University, United States

Machine learning algorithms are emerging as attractive solutions for a number of problems in data analytics and sensor signal classification. However, in order to enable real-world applications, significant progress must be made to reduce the large power dissipation seen in current prototypes employing relatively inefficient GPU and FPGA platforms. Our work studies the trade-off between energy and accuracy in deep neural networks, and looks into the design of mixed-signal approximate computing circuits that achieve significantly lower power dissipation.

TP7b-2 **3:55 PM**

Cross-Layer Resilience

Yanjing Li, Intel, United States; Eric Cheng, Hyungmin Cho, Subhasish Mitra, Stanford University, United States

With enormous complexity and significantly increased vulnerability to failures, resilience to hardware failures becomes a key challenge for a large class of computing systems, from embedded systems to supercomputers. There is an urgent need to overcome this challenge due to explosive growth in our dependency on such systems. This talk advocates cross-layer resilience, where resilience techniques are considered from early design stages and implemented across multiple layers of system stack – from circuit/architecture to runtime/applications – such that they work together to achieve required degrees of resilience in a highly energy-efficient manner. Examples to demonstrate key aspects of cross-layer resilience are discussed.

TP7b-3 **4:20 PM**

List Sphere Decoding of Polar Codes

Seyyed Ali Hashemi, Warren J. Gross, McGill University, Canada

Sphere decoding (SD) has been shown to work well for short polar codes, however its decoding time is variable and depends on the channel conditions. In addition, the SD algorithm requires the choice of a radius that depends on a precise estimation of the channel noise level. We introduce a list SD algorithm for short polar codes that has a fixed time complexity and does not require knowledge of the channel noise level. The BER performance is tunable with the list size and the memory requirement is shown to be less than those of successive cancellation and list decoders.

TP7b-4 **4:45 PM**

Architectures for Stochastic Normalized and Modified Lattice IIR Filters

Yin Liu, Keshab Parhi, University of Minnesota, Twin Cities, United States

This paper presents novel architectures for lattice IIR filters using stochastic computing. The novelty lies in demonstrating that compared to the basic lattice structure, the normalized and proposed modified lattice structures are better suited for stochastic IIR filters. Two architectures are proposed. The first is based on the normalized lattice structure, where states are orthonormal. The performance of narrow-band IIR filter is reduced by more than two-third. The second is based on the modified lattice structure by choosing s_i=1-k_i in Schur Algorithm. The area and power consumptions are 90% and 80% less than the two's complement lattice filters, respectively.

Track A – Communications Systems

Session: TPa8 – Multicarrier and DFE **1:30 PM–3:10 PM**

TP8a1-1

A Low Complexity Algorithm for Successive Interference Cancellation in Large-Scale MIMO OFDM using Quadratic Programming Formulation

Ali Elghariani, Michael Zoltowski, Purdue University, United States

In this paper, a new low complexity successive interference cancellation (SIC) technique is proposed for a QPSK mapping multiple-input multiple-output (MIMO) spatial multiplexing system based on a Quadratic Programming detector. The proposed technique uses Log-Likelihood ratio (LLR) for reliability ordering of received symbols, and then formulates SIC procedures using a QP formulation. We also extend the application of this algorithm to Spread OFDM system and show it usefulness in reducing detection complexity. Simulation results show that the proposed scheme outperforms the conventional SIC schemes, especially for large-scale configuration, in both error performance and computational complexity saving.

TP8a1-2

CFO Mitigation using Adaptive Frequency-Domain Decision Feedback Equalization for Uplink SC-FDMA

Naveed Iqbal, Azzedine Zerguine, KFUPM, Saudi Arabia; Naofal Al-Dhahir, University of Texas at Dallas, United States

To mitigate Inter-Carrier Interference due to large Carrier Frequency Offset in an uplink Single-Carrier Frequency Division Multiple Access system, a 3-tap Adaptive Frequency Domain DFE is designed in this work by exploiting the banded and sparse structure of the equivalent channel matrix. The block RLS algorithm is used for adaptation and implemented in the frequency-domain. Consequently, the complexity of the block RLS is reduced substantially when compared to its time-domain counterpart. Ultimately, it will be shown that the proposed AFDDFE exhibits significant excellent performance improvement when compared to a 1-tap AFD-DFE while still enjoying a low computational complexity.

TP8a1-3

OFDM Channel Estimation via Phase Retrieval

Philipp Walk, Henning Becker, Technische Universität München, Germany; Peter Jung, Technische Universität Berlin, Germany

Channel estimation and PAPR reduction are the main challenges in OFDM. Pilot-aided signal schemes help to estimate the channel at the receiver and to reduce the PAPR, but decreases the data rate and demand full pilot knowledge at the receiver. Recently, the authors presented a phaseless pilot scheme to reconstruct the channel from symmetrized and zero-padded

magnitude Fourier measurements. Hence the unused pilot phases can be used to compensate for each data signal the PAPR. In this work we address the principal question of using sparse phase retrieval methods to reconstruct the channel only from its Fourier magnitude measurements.

TP8a1-4
Estimation of the Clipping Level in OFDM Systems
Ehsan Olfat, Mats Bengtsson, KTH Royal Institute of Technology, Sweden

We consider scenarios such as machine-to-cellular communications, where a low-cost transmitter communicates with a high-quality receiver. Then, digital pre-distortion of the non-linear power amplifier may be too expensive. In order to investigate the feasibility of receiver-side compensation of the transmitter RF impairments, we study estimation of the clipping level in OFDM systems. Both blind and pilot based estimators are proposed and numerical evaluations show that iterative decoding can be done using the estimated clipping level without any significant performance loss.

TP8a1-5
A Novel M-FSK Modem Architecture Based on Perfect Reconstruction NMDFBs
fred harris, Elettra Venosa, Xiaofei Chaen, San Diego State University, United States

M-FSK demodulators are implemented with a series of parallel filters, envelope detectors and a decision stage. The number of required matched filter and envelope detectors is the same as the number of complex sub-carriers. The bit error rate performance of the M-FSK system improves as the number of frequencies increases. This improvement is at the expense of transceiver size, weight and power consumption. We propose a new fully-digital M-FSK demodulator based on perfect reconstruction (PR) non-maximally decimated filter banks (NMDFBs) often referred to as polyphase channelizers. The efficacy of this architecture increases as the number of frequencies employed, M, increases.

TP8a1-6
Sub-Band Digital Predistortion for Noncontiguous Transmissions: Algorithm Development and Real-Time Prototype Implementation
Mahmoud Abdelaziz, Tampere University of Technology, Finland; Chance Tarver, Kaipeng Li, Rice University, United States; Lauri Anttila, Mikko Valkama, Tampere University of Technology, Finland; Joseph R. Cavallaro, Rice University, United States

This article proposes a novel reduced complexity block-adaptive digital predistortion(DPD) technique for mitigating the spurious emissions when amplifying spectrally noncontiguous signals with a nonlinear power amplifier(PA).Our DPD is designed for real-time scenarios where a loop delay exists in the DPD system,and is shown to be robust against arbitrarily long loop delays with reduced complexity while not sacrificing DPD linearization performance and convergence speed.Real-time FPGA implementations of the algorithm are developed with the tradeoff of robustness,performance and complexity.The simulations and experiments on WARP platform evidence excellent and robust performance in real-life situations with highly nonlinear PA’s and arbitrary loop delays.

Track H – Speech, Image and Video Processing
Session: TPa8 – Speech and Image Processing 1:30 PM–3:10 PM

TP8a2-1
Estimating Speaking Rate in Spontaneous Discourse
Yishan Jiao, Visar Berisha, Ming Tu, Julie Liss, Arizona State University, United States

In this paper we consider the problem of estimating the speaking rate directly from the speech waveform. We propose an algorithm that poses the speaking rate estimation problem as a convex optimization problem. In contrast to existing methods, we avoid the more difficult task of detecting individual syllables within the speech signal and we avoid heuristics like thresholding a loudness function. The algorithm will be evaluated on the ICSI Switchboard spontaneous speech corpus and a pathological speech corpus obtained from individuals with neurological disorders.

TP8a2-2
Image Interpolation Based on Weighting Function of Gaussian
Takuro Yamaguchi, Masaaki Ikehara, Yasuhiro Nakajima, Keio Univercity, Japan

In this paper, we propose a new image interpolation method based on a 2-D piecewise stationary autoregressive (PAR) model. SAI, which defined PAR model, is a state-of-the-art method in image interpolation. It produces good quality images but has high calculation cost because of solving the inverse matrix problem to estimate parameters. Our method uses Gaussian function instead and reduces the calculation cost. Moreover, parameters are estimated on pixel by pixel, while in SAI they are constant in a local window. By these improvements, the proposed method has equivalent quality to SAI with low calculation cost.

TP8a2-3
Conjointly Well Localized Modulated Lapped Orthogonal Transforms
Peter Tay, Yanjun Yan, Western Carolina University, United States

This paper proposes the particle swarm optimization method to determine conjointly time-frequency well localized filters that constitute a multi-channel perfect reconstruction. The time-frequency measure to determine optimality is the product of a filter's time and frequency variances. The optimization process involving multiple free parameters is computationally expensive. Optimization methods require long computation time that increases exponentially with the number of free parameters to achieve good results. The particle swarm optimization is an effective and efficient method to determine optimal complex modulated lapped transforms. We propose the use of the particle swarm optimization method to determine optimal modulated lapped transform filters.

TP8a2-4
Screen Content Image Segmentation using Sparse-Smooth Decomposition
Shervin Minaee, Amirali Abdolrashidi, Yao Wang, New York University, United States

Sparse decomposition has been extensively used for different applications including signal compression and denoising and document analysis. In this paper, sparse decomposition is used for image segmentation. The proposed algorithm separates the background and foreground using a sparse-smooth decomposition technique such that the smooth and sparse components correspond to the background and foreground respectively. This algorithm is tested on several test images from HEVC test sequences and is shown to have superior performance over other methods, such as the hierarchical k-means clustering in DjVu. This segmentation algorithm can also be used for text extraction, video compression and medical image segmentation.

Track B – MIMO Communications and Signal Processing
Session: TPa8 – Communication Techniques for the Downlink 1:30 PM–3:10 PM

TP8a3-1
Successive Convex Approximation for Simultaneous Linear TX/RX Design in MIMO BC
Jarkko Kaleva, Antti Tölli, Markku Juntti, University of Oulu, Finland

Weighted sum rate maximizing downlink beamformer design is considered for multiple-input multiple-output broadcast channel. As opposed to the conventional alternating optimization designs, the transmit beamformers are incorporated into the optimization objective and only the receive beamformers are explicitly solved. The non-convex rate maximization is approached via the corresponding mean-squared error minimization problem, which is further approximated to formulate a sequence of semidefinite programs. Furthermore, the algorithm is shown to have an improved rate of convergence in terms of the required number of beamformer iterations, when compared to recently published designs based on alternating transceiver optimization.

TP8a3-2
Per-User Outage-Constrained Power Loading Technique for Robust MISO Downlink
Mostafa Medra, Timothy Davidson, McMaster University, Canada

A low-complexity robust power loading technique is developed for multiple-input single-output (MISO) downlink systems. The technique uses insights from the Chebyshev inequality to develop a low-complexity iterative algorithm that provides control over the outage probability of each user. In the case of massive MIMO channels that harden, the iterations can be approximated in such a way that the computational cost per iteration becomes linear in the number of users. Preliminary simulation results suggest that the proposed technique provides significant improvements in outage performance over conventional techniques.

TP8a3-3
Pilot Length Optimization for Spatially Correlated Multi-User MIMO Channel Estimation
Beatrice Tomasi, Maxime Guillaud, Huawei Technologies Co., Ltd., France

We consider the problem of pilot sequence design for uplink channel state information (CSI) acquisition in multi-user massive MIMO systems, when the channel covariances of the individual users are assumed to be known and arbitrary (i.e. they can be either mutually orthogonal, or have partly or fully overlapping spans). We establish bounds on the length of the training sequences required to simultaneously learn all the users' channels, by deriving necessary and sufficient conditions for channel identifiability. In the final paper we will consider the minimization of the training sequence length, together with the corresponding pilot sequence design approaches.

TP8a3-4
Overcoming Conjugate Beamforming Limitations with Side-Channel Cooperative Decoders
Andrew Kwong, Ashutosh Sabharwal, Rice University, United States

The performance of conjugate beamforming systems is limited when inter-user interference is the dominant source of error. To overcome this limitation, we design simple schemes that utilize out-of-band, user-to-user links with cooperative decoders, such as decorrelators and MMSE receivers, to manage interference. We evaluate the bit error rate performance of this design through an experimental, proof of concept implementation. We then supplement the experiments with a simulation based evaluation for different scenarios. Both show that our scheme can reliably improve bit error rate for interference dominated situations.

TP8a3-5
Minimum Probability of Error Multiuser Transmit Beamforming
Majid Bavand, Steven Blostein, Queen's University, Canada

Motivated by the poor performance of the existing transmit beamforming methods in low signal to noise ratio (SNR) regime, and assuming that the knowledge of the modulation type could result in a more intelligent design of beamformer, this paper proposes a transmit beamforming method based on the concept of minimum probability of error (MPE) beamforming. We calculate the error probability of each user and design an objective function based on these error probabilities. It is shown that by minimizing this objective function, the performance of the system could be dramatically improved.

TP8a3-6
MIMO Power Minimization with Imperfect CSIT and Prescribed Outage
Samip Malla, Giuseppe Abreu, Jacobs University Bremen, Germany

The usage of perfect and instantaneous CSIT in a SINR-constrained transmit power minimization requires excessive resources to acquire and distribute channel information. Likewise, average CSIT suffers from quality fluctuation. Recent works relying on statistical SINR constraints designed under prescribed outage loosens the original constraint in converting statistical inequalities to deterministic convex equivalents. In this paper, we offer a simple solution to this problem, thereby deriving accurate models for true SINRs at the users subject to imperfect CSIT, conditioned on constraint matching estimates. Using these distributions, we design deterministic, instantaneous and convex SINR-constraints to compensate and meet the prescribed outage.

TP8a3-7
Downlink Transceiver Beamforming and Admission Control for Massive MIMO Cognitive Radio Networks
Shailesh Chaudhari, Danijela Cabric, University of California, Los Angeles, United States

In this paper, an optimization framework is proposed for joint transceiver beamforming and admission control in massive MIMO cognitive radio networks. The objective of the optimization problem is to support the maximum number of secondary users in downlink transmission with constraints on the rate achieved at secondary users and the interference at the primary nodes. The proposed framework takes into account the imperfect knowledge of the channels between secondary and primary nodes and also mitigates the interference caused by the primary transmission at the secondary receiver. A low complexity algorithm is proposed to solve the underlying NP-hard problem.

TP8a3-8
Optimal Feedback Rate Selection for Energy Harvesting with Distributed Transmit Beamforming
Rui Wang, D. Richard Brown III, Worcester Polytechnic Institute, United States

This paper considers the combination of feedback-based distributed transmit beamforming with wireless power transfer in a narrowband wireless communication system and analyzes the optimal feedback rate to maximize the amount of energy harvested by the receive node per unit of time. The analysis includes a two-state oscillator model with accurate long-term dynamics and the effect of non-zero feedback latency. A method to numerically calculate the optimal feedback rate is provided. The results demonstrate that the efficiency of wireless power transfer can be significantly improved with feedback-based distributed transmit beamforming and feedback rate optimization.

Track C – Networks
Session: TPa8 – Estimation and Learning 1:30 PM–3:10 PM

TP8a4-1
Causal Graph Inference
Simona Poilinca, Giuseppe Abreu, Jacobs University Bremen, Germany

We provide a framework to infer causal relationships in a system of multivariate, stochastic, delayed signals, with application to their prediction. First we address the dimensionality problem in information causality estimation and propose a method to improve the efficiency of calculations by retaining only the most essential components. The directed information between pairs of signals are then used to obtain a maximum spanning tree that captures the strongest causal relationships. Second, causal conditional information is applied to account for further dependencies and obtain the causal graph. Finally, based on this structure, we use delay estimation to accurately predict children signals.

TP8a4-2
A Real-Time Implementation of Precise Timestamp-Free Network Synchronization
Stefan Gvozdenovic, Alexander Ryan, Max Li, Radu David, D. Richard Brown III, Worcester Polytechnic Institute, United States; Andrew Klein, Western Washington University, United States

This paper describes a real-time implementation of precise timestamp-free network synchronization using audio-frequency signaling between a master and slave node. Rather than the conventional approach of exchanging digital timestamps through a dedicated synchronization protocol, timestamp-free synchronization is performed implicitly at the physical layer through the timing of the master node's responses to the slave node. The master and slave nodes were both implemented on Texas Instruments digital signal processing boards with real-time software implemented in C. Preliminary experimental results using modulated 100~Hz bandwidth sinc pulses demonstrate synchronization accuracies better than 0.33~μs.

TP8a4-3
Diffusion Distance for Signals Supported on Networks
Weiyu Huang, Santiago Segarra, Alejandro Ribeiro, University of Pennsylvania, United States

Diffusion distance is introduced as a metric to compare signals supported in a network. This metric considers signals as initial temperature distributions in the graph nodes and diffuses heat through the graph. The similarity between the given vectors is determined by the similarity of the respective diffusion profiles. We prove that diffusion distance defines a valid metric and is stable to perturbations in the underlying network. We illustrate its utility in classifying ovarian cancer histologies using gene mutation profiles of different patients. Diffusion distance is also as a label propagation method in semi-supervised learning to classify handwritten digits.

Session: TPb8 – Radar Co-existence and Satellite Communications 3:30 PM–5:10 PM

TP8b1-1
Digital Full-Band Linearization of Wideband Direct-Conversion Receiver for Radar and Communications Applications

Markus Allén, Jaakko Marttila, Mikko Valkama, Tampere University of Technology, Finland; Simran Singh, Michael Epp, Wolfgang Schlecker, Airbus Group, Germany

This paper proposes a fully digital post-processing solution for cancelling nonlinear distortion and mirror-frequency interference in wideband direct-conversion receivers (DCRs). Favorable cost, integrability, and power efficiency have made DCRs a popular choice in communication systems. It is also an emerging trend in radar systems since digital post-processing enables sufficient performance. The proposed method cancels the most essential distortion adaptively during normal operation without any prior information. Improved cancellation performance compared to the state-of-the-art is achieved considering inband and neighboring band distortion induced by the strong received signals. This is verified and demonstrated with extensive simulations and true RF hardware measurements.

TP8b1-2
Performance of Joint Radar-Communication System in Doubly-Selective Channels

Andrew D. Harper, Georgia Institute of Technology, United States; Jeremy T. Reed, Jonathan L. Odom, Georgia Tech Research Institute, United States; Aaron D. Lanterman, Georgia Institute of Technology, United States

When radar and communication systems are co-located and operating simultaneously in the same frequency band, interference can be addressed by designing the systems to share resources. This paper develops a framework for cooperative operation of bistatic radar and wireless communication systems. We adopt a low-complexity linear minimum mean square error (LMMSE) optimal pilot symbol aided modulation (PSAM) scheme, and show the achievability region of the joint radar-communication system designed for simultaneous operation in a wireless channel that is both frequency and time selective.

TP8b1-4
Constant Information Radar for Dynamic Shared Spectrum Access

Bryan Paul, Daniel Bliss, Arizona State University, United States

We derive the constant information radar, or CIR. Previous works developed the notion of a radar estimation rate, a measure of information shared between the true target range and range-rate, and the actual noisy measurement over time. This measure provided a means to compare various cooperative schemes for shared spectrum access for radar and communications (SSPARC). Since it provides a measure of target uncertainty and thus information transfer for a given tracking loop period, it can be used to modulate radar emission rate to minimize shared spectrum impact to communications networks.

TP8b1-5
Effect of Clutter on Joint Radar-Communications System Performance Inner Bounds

Alex Chiriyath, Daniel Bliss, Arizona State University, United States

We analyze the effects of clutter on inner bounds for the performance of a joint radar-communications system. Radar returns from clutter are often characterized by a randomly fluctuating cross section. Hence, statistical methods must be employed to model the clutter and its cross-section. In this paper we consider two clutter models and analyze their effect on the inner bounds on performance of a joint radar-communications system. Bounds on performance of the joint system are measured in terms of data information rate for communications, and radar estimation information rate for the radar.

Session: TPb8 – Video Processing 3:30 PM–5:10 PM

TP8b2-1
Object Recognition in Complex Video Scenes for Advertising Applications
Edward Ratner, Lyrical Labs, United States; Schuyler Cullen, Samsung, United States; James Quigley, Gener8 Inc., United States

Traditional image classifiers suffer from the so-called “Background clutter problem”, where they have to, simultaneously, localize and recognize an object of interest. In real-world video scenes, many objects appear at the same time and several objects of interest could be present. We decompose the problem into two stages. The first involves extracting a moving object from the video scene based on its coherent motion. This step makes no assumption about the nature of the object being tracked and extracted. We, then apply a classifier to the extracted object to determine if it falls into one of the classes of interest.

TP8b2-2
Fractal-Based Analysis for Foreground Detection
Daniel Raburn, Edward Ratner, Lyrical Labs, United States

We have developed a fractal-based analysis technique for use with foreground detection. In this technique, a modified form of the box-counting fractal dimension is used to identify meaningful structures when looking at pixels which change between frames in a video sequence. This technique is used along with a sophisticated variable-threshold approach to determine which segments are likely to be foreground in a given video sequence, provided reasonable image segmentation and registration for each frame.

TP8b2-3
Unsupervised Uncertainty Analysis for Video Saliency Detection
Tariq Alshawi, Zhiling Long, Ghassan AlRegib, Georgia Institue of Technology, United States

Numerous video saliency detection approaches proposed in literature have been typically evaluated using a handful of video datasets with eye-fixation tracking records as saliency groundtruth. However, this setup is subject to inconsistency due to variations in video sequences, dataset bias, and evaluation methodology. In this paper, we develop an unsupervised uncertainty estimation algorithm that can be used to provide additional performance evaluation of saliency detection algorithms by investigating spatial and temporal cues of saliency maps. Experimental results show promising performance that, on average, outperforms existing uncertainty estimation method.

TP8b2-4
Jitter Invariant Incremental Principal Component Pursuit for Video Background Modeling on the TK1
Paul Rodriguez, Pontifical Catholic University of Rio de Janeiro, Peru

While Principal Component Pursuit (PCP) is currently considered to be the state of the art method for video background modeling, it suffers from a number of limitations, including high computational cost, batch operating mode, and sensitivity to camera jitter. In this work we present a real-time, CUDA-aware C/C++ implementation of a novel and fully incremental PCP algorithm for video background modeling that can also deal with rigid transformation jitter. Our implementation has a computational complexity that allows (TK1 platform) a processing frame rate throughput (fixed camera case) of 27.8 and 9.4 f.p.s. for grayscale videos of 640x480 and 1920x088 respectively.

TP8b2-5
Robust and Reliable Counting of Footsteps by Mobile Phone Cameras
Koray Ozcan, Anvith Mahabalagiri, Senem Velipasalar, Syracuse University, United States

In this paper, we present a robust and reliable method for counting footsteps using onboard camera and processor of a Samsung Galaxy S4 smartphone. We propose a new vision based method of analyzing footstep patterns based on effective feature based tracking to compare its performance with existing accelerometer-based step counters. Through experimental results, we show show that the proposed method counts the steps accurately when the background is uniform in terms of texture. We then show how our proposed algorithm is made more robust by using techniques such as Optical Flow analysis and Kalman filter based tracking.

Track B – MIMO Communications and Signal Processing

Session: TPb8 – MIMO Links and Uplink 3:30 PM–5:10 PM

TP8b3-1

Performance of MIMO Enhanced Spatial Modulation under Imperfect Channel Information

Michael Carosino, James Ritcey, University of Washington, United States

Enhanced Spatial Modulation is a novel wireless scheme that uses combinations of antenna indexes and constellation types to increase the throughput compared to standard Spatial Modulation. An assumption of channel information at the receiver is required to allow for joint decoding of the symbol and antenna index. We analyze the performance of typical MIMO systems using Enhanced Spatial Modulation under imperfect channel information. We compare the performance loss with that realized in a spatially multiplexed system and find improved robustness against channel estimation errors. Additionally, the performance of the system over correlated fading channels is investigated.

TP8b3-2

Distributed Uplink CoMP for Small-Cell Networks

Shirish Nagaraj, M. R. Raghavendra, Chris Schmidt, Phil Rasky, Deepak Nayak, Xiaoyong Yu, Nokia, United States; Michael Honig, Northwestern University, United States

Uplink Co-ordinated Multi-Point (UL CoMP) is an important technique to significantly improve user performance, especially in dense small-cell networks. In such networks it is important that co-operation be (a) scalable {\em w.r.t.} number of cells (b) adaptable to different inter-connect bandwidths. In this paper, we propose near-optimal distributed mechanisms to enable uplink co-operation. We develop protocols for distributed helper-cell SINR measurement as well as adaptation algorithms to manage limited interconnect bandwidth. We show that the performance of the proposed {\em one-shot} bandwidth control algorithm is close to the optimal iterative algorithm proposed in [1].

Track A – Communications Systems

Session: WAa1 – Communications with Low-Precision Analog-to-Digital Converters

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

WA1a-1 8:15 AM

Hardware-Constrained Signal Processing for mm-wave LoS MIMO Links

Babak Mamandipoor, University of California, Santa Barbara, United States; Mahmoud Sawaby, Amin Arbabian, Stanford University, United States; Upamanyu Madhow, University of California, Santa Barbara, United States

At high carrier frequencies, spatial multiplexing gains can be obtained even in LoS environments with reasonable node form factors. We investigate design of a line of sight (LoS) MIMO link operating at millimeter wave frequencies beyond 100 GHz, with 4-fold spatial multiplexing, and bandwidth of 5-10 GHz, which holds the potential for data rates from 40-100 Gbps. In addition to the spatial processing required for demultiplexing at the receiver, even small misalignments lead to frequency selectivity. We investigate hardware-signal processing co-design in this setting, keeping in mind the difficulty of analog-to-digital conversion at high sampling rates.

WA1a-2 8:40 AM

Limited Feedback in Multiple-Antenna Systems with One-Bit Quantization

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

Communication systems with low-resolution analog-to-digital-converters (ADCs) can exploit channel state information at the transmitter (CSIT) and receiver. This paper presents initial results on codebook design and performance analysis for limited feedback systems with one-bit ADCs. Different from the high-resolution case, the absolute phase at the receiver is important to align the phase of the received signals when the received signal is sliced by one-bit ADCs. A new codebook design for the beamforming case is proposed that separately quantizes the channel direction and the residual phase.

WA1a-3 **9:05 AM**

Spectral Shaping with Low Resolution Signals

Amine Mezghani, Hela Jedda, Josef A. Nossek, Technische Universität München, Germany

We aim at investigating the impact of low resolution digital-to-analog converters at the transmitter on the required bandwidth. We consider the extreme case of only one bit resolution (with oversampling) and compare two different architectures and methods for minimizing the spectral occupation of 1-bit signals. The first method is a straightforward approach consisting of applying the 1-bit quantization after a standard pulse shaping technique. The second one is based on a discrete optimization in the frequency domain in a similar manner as the classical overlap-save method. Through simulations, we show that despite the coarse quantization, sufficient spectral confinement is achievable.

WA1a-4 **9:30 AM**

Detection of Communication Signals using Stochastic Quantization

Ryan Corey, Andrew Singer, University of Illinois at Urbana-Champaign, United States

We consider the problem of receiving a communication signal using a quantizer with uncertain quantization levels. Deeply scaled comparator circuits offer advantages in size and power, but exhibit random variations in their switching parameters. We can take advantage of these devices by incorporating the randomness of the receiver hardware into the channel model used for detection.

Track A – Communications Systems

Session: WAb1 – Broadband Access Evolution

Chair: ***George Ginis,*** *ASSIA, Inc.*

WA1b-1 **10:15 AM**

Improved Polling Strategies for Efficient Flow Control for Buffer Reduction in PON/xDSL Hybrid Access Networks

Anu Mercian, Arizona State University, United States; Elliott Gurrola, Michael McGarry, University of Texas, El Paso, United States; Martin Reisslein, Arizona State University, United States

Back-haul networks are fiber-based for its high bandwidth, but DSL is popular front-end network especially with the adoption of Vectored-DSL that reduces cross-talk, improves speed and is economical. With PON-xDSL Networks, the connecting drop-point(DP) has high buffer requirements due to the different data rates of Optical and DSL. Reducing the memory-capacity of the DP reduces the expenditure and energy-consumption of DP but can result in packet-losses and flow-control mechanisms are required to avoid them. In this paper we explore improvised upstream polling strategies to control data-flow from each CPE to its associated DP in order to reduce buffer occupancy.

WA1b-2 **10:40 AM**

Signal Processing for G.fast+

Mehdi Mohseni, Ken Kerpez, ASSIA, Inc., United States

The first version of G.fast uses relatively simple linear channel-inverting matrix precoders to cancel the crosstalk in a multi-pair telephone cable. However, to truly deliver Gbps+ speeds to most customers, even higher frequencies should be used; where the crosstalk can be stronger than the signal, and so more advanced signal processing is envisioned for "G.fast+." This paper examines optimal signal processing structures, such as the Generalized Decision Feedback Equalizer (GDFE) for G.fast+. The impacts of practical considerations are analyzed: line ordering, channel tracking, quantization effects, implications of power-saving TDD scheduling, upstream trellis decoding and downstream trellis shaping.

WA1b-3 **11:05 AM**

A New Approach to Traffic-Aware Real-Time Dynamic Spectrum Management

Chano Gomez, Marvell Semiconductor Inc, United States

Dynamic spectrum management (DSM) techniques have been used in the past to optimize performance in copper-based multi-user broadband networks. The traditional approach when using DSM has been optimizing system capacity independently of the actual amount of traffic demanded by network users. New standards (such as ITU-T G.9960) provide a new range of tools that system designers can use to take advantage of real-time variations in traffic in order to design DSM algorithms that dynamically match line capacity to traffic demands. The paper describes a generic framework for traffic-aware real-time dynamic spectrum management, and then presents some implementation examples.

WA1b-4 **11:30 AM**

Maintaining Harmony in the Vectoring xDSL Family by Spectral Coordination

Martin Wolkerstorfer, Driton Statovci, Sanda Drakulic, The Telecommunications Research Center Vienna, Austria

In future multi-line / multi-carrier xDSL access networks various technologies, with or without interference cancelation (Vectoring) capability, may be required to coexist. Spectral resource management is well-known for promoting collaboration among lines. However, the general resource allocation problem is complicated by per-transceiver and per-carrier power constraints coupled over multiple lines due to Vectoring, by residual interference due to imperfect cancelation, and by inter-carrier/inter-symbol interference arising from asynchronous transmission or differences in modulation parameters. Hence, in this contribution we propose tailored optimization approaches and compare their complexity and data-rate performance by mixed VDSL2/G.fast simulations using measured channel data.

Track A – Communications Systems

Session: WAa2 – Cooperative Communications

Co-Chairs: ***Tony Quek,*** *Singapore University of Technology and Design* ***and Shi Jin,*** *Southeast University*

WA2a-1 **8:15 AM**

Massive MIMO Feedback Methods under Limited CSI with User Cooperation

Haifan Yin, Laura Cottatellucci, David Gesbert, Eurecom, France

As is well known, the high cost of CSI acquisition and feedback hinders the application of promising massive MIMO technologies in the commercially dominant FDD mode, due to the non-reciprocity of the wireless channel. In this paper we propose novel methods that combine feedback design with terminal cooperation. We highlight a communication method over D2D links which allow users to substantially compress the channel state information to be fed back to the base station, helping enable massive MIMO in FDD deployments.

WA2a-2 **8:40 AM**

Coordinated Multicell Multiuser Precoding for Maximizing Resource Efficiency

Shiwen He, Ying Lu, Yongming Huang, Shi Jin, Wei Xu, Haiming Wang, Southeast University, China

Spectrum efficiency (SE) and energy efficiency (EE) have become two key performance measures for the future wireless communication system. In this paper, we focus on maximizing the resource efficiency of a coordinated multicell multiuser downlink system that is defined as the weighted sum of SE and EE, so as to achieve a desired tradeoff between the SE and the EE. To solve the considered optimization problem that is more complex than traditional ones, an effective algorithm with provable convergence is developed to reach an efficient solution. Extensive numerical results are finally provided to validate the effectiveness of the proposed algorithm.

WA2a-3 **9:05 AM**

Can Interference Alignment Impact Network Utility Maximization?

Gokul Sridharan, Wei Yu, University of Toronto, Canada

This paper examines the role of interference alignment (IA) in network utility maximization for cooperative cellular networks. We establish a feasibility condition for partial interference alignment in cellular networks, then propose a two-stage framework for utility maximization: the first stage nulls dominant interferers using IA; the second stage optimizes transmit and receive beamformers iteratively using IA as initial condition. Numerical evidence suggests that the impact of IA is limited. While IA is beneficial for isolated cluster of BSs for maximizing the minimum rate, it offers marginal gain for maximizing sum-rate, or when out-of-cluster interference

WA2a-4 **9:30 AM**

Towards System Cost Minimization in Cloud Radio Access Network

Jianhua Tang, Wee Peng Tay, Nanyang Technological University, Singapore; Tony Q. S. Quek, Singapore University of Technology and Design, Singapore; Ben Liang, University of Toronto, Canada

The key character of cloud radio access network (C-RAN) is migrating conventional distributed base station functionalities into a centralized cloud baseband unit (BBU) pool, which consists of many software defined virtual machines (VMs). In this paper, we take the joint consideration of VM activation in the BBU pool and joint transmission (JT) in the coordinated remote radio heads

(RRHs) cluster to minimize the system cost of C-RAN. We propose two different approaches to solve the problem, i.e., searching integer (SI) approach and joint optimization (JO) approach. Simulation results suggest that our proposed algorithm is more cost-effective than the benchmark algorithms.

Track A – Communications Systems
Session: WAb2 – 5G and mmWave

WA2b-1 10:15 AM
A Comparison of Waveform Candidates for 5G Millimeter Wave Systems
Christian Ibars, Utsaw Kumar, Huaning Niu, Hyejung Jung, Sameer Pawar, INTEL Corporation, United States

Availability of millimeter wave spectrum across the Globe, makes it an ideal candidate to be considered for the 5G systems. However, the mmWave propagation channel suffers from severe signal blockage and path-loss issues. In this paper, we address the problem of designing one of the fundamental mmWave system components, viz. the waveform. We first identify the waveform requirements, and then explore possible multi-carrier and single carrier options. Our analysis shows that design trade-offs are different from lower frequency bands. We propose using a DFTspread waveform as a balanced solution between the achieved spectral efficiency and robustness against RF impairments.

WA2b-2 10:40 AM
Ping-Pong Beam Training for Reciprocal Channels with Delay Spread
Elisabeth De Carvalho, Jørgen Bach Andersen, Aalborg University, Denmark

We present an iterative beam training procedure for a reciprocal channel with delay spread between two massive antenna arrays. The primary application is communication at millimeter wave frequencies. The procedure is based on ping pong transmissions. It tracks the left and right eigenvectors of each matricial channel coefficients. For channels with a sparse structure, the procedure converges within a few iterations. Based on the set of eigenvectors, we build transmit and receive equalizers. A simple equalization based on matched fitering is showed to be optimal provided that the channel contains a large number of independent links.

WA2b-3 11:05 AM
On Detection of Pilot Contamination Attack in Multiple Antenna Systems
Jitendra Tugnait, Auburn University, United States

In a TDD multiple antenna system, the CSI can be acquired using reverse training. A pilot contamination attack occurs when during the training phase, an adversary also sends identical training (pilot) signal as that of the legitimate receiver. This contaminates the channel estimation phase and can alter the legitimate precoder design, facilitating eavesdropping. In this paper we propose superimposing a random sequence on the training sequence at the legitimate receiver, allowing use of source enumeration methods to detect pilot contamination attack. The proposed method is analyzed and its detection performance is illustrated via simulations.

WA2b-4 11:30 AM
Cell Detection in High Frequency Band Small Cell Networks
Hyejung Jung, Qinghua Li, Pingping Zong, Intel Corporation, United States

In this paper, we investigate cell detection schemes for a new high frequency band (HFB) radio access technology (RAT) based small cell network, which employs much wider channel bandwidth (e.g. 100MHz~2 GHz) than current LTE-Advanced systems, in order to provide Gbps-level throughput. Cell detection performances are compared in terms of expected coverage and detection overhead/latency, considering various deployment scenarios and system parameter choices. Furthermore, a novel cell detection method, so called “UE polling based cell detection” is proposed to guarantee robust coverage and fast cell detection in HFB small cell networks.

Session: WA3 – Sparsity in Signal Processing

WA3-1 **8:15 AM**

Fundamental Limits of Singular Value Based Signal Detection from Randomly Compressed Signal-Plus-Noise Matrices

Nicholas Asendorf, Raj Rao Nadakuditi, University of Michigan, United States

The singular value spectrum of a data matrix is commonly used to detect high-dimensional signals. However, as the size of this data matrix grows, taking its SVD become intractable. We consider projecting the data matrix into a lower dimensional space and using the resulting singular value spectrum for signal detection. We derive the almost sure limit of the top singular values of the resulting projected matrix both when using a Gaussian and unitary projection matrix. We highlight our prediction accuracy and discuss the benefits and drawbacks of each projection matrix using numerical simulations.

WA3-2 **8:40 AM**

Joint Sparsity Pattern Recovery with 1-bit Compressive Sensing in Sensor Networks

Vipul Gupta, Indian Institute of Technology Kanpur, India; Bhavya Kailkhura, Thakshila Wimalajeewa, Pramod Varshney, Syracuse University, United States

We study the problem of jointly sparse support recovery with 1-bit compressive measurements in a sensor network. Sensors are assumed to observe sparse signals having the same but unknown sparse support. Each sensor quantizes its measurement vector element-wise to 1-bit and transmits the quantized observations to a fusion center. We develop a computationally tractable support recovery algorithm which minimizes a cost function defined in terms of the likelihood function and the $l_{1,\infty}$ norm. We observe that even with noisy 1-bit measurements, jointly sparse support can be recovered accurately with multiple sensors each collecting only a small number of measurements.

WA3-3 **9:05 AM**

A Mismatched Greedy Pursuit Algorithm for Sparse Spike Deconvolution

Abdur Rahman Maud, Mark Bell, Purdue University, United States

Matched filter output of pulse compression systems often suffers from sidelobes. In a multi-target environment, these sidelobes can cause false alarms and misdetection. In addition, these sidelobes make it particularly difficult to recover closely located spikes. In this paper, an iterative greedy algorithm is proposed that combines mismatched filtering with matching pursuit algorithm. Recovery bounds for the proposed algorithm are derived and used to show that the proposed algorithm can yield better resolution compared to matching pursuit algorithm.

WA3-4 **9:30 AM**

Joint Dictionary Learning and Recovery Algorithms in a Jointly Sparse Framework

Yacong Ding, Bhaskar D. Rao, University of California, San Diego, United States

We address the general multiple measurement vectors (MMV) problem where measured signals share a common sparse support, i.e. jointly sparse, but measured via different sensing matrices. We develop practical algorithms, which are extensions of existing sparse signal recovery algorithms, to implement joint sparse signal recovery and document their superiority over independent recovery. To deal with signals that can be jointly sparsely represented in appropriate combination of bases, we propose a joint dictionary learning algorithm in which the joint sparsity is enforced. Numerical results shows its improved performance in learning the multiple dictionaries and also to represent approximately sparse signals.

BREAK **9:55 AM**

WA3-5 **10:15 AM**

Distribution of the Fisher Information Loss Due to Random Compressed Sensing

Pooria Pakrooh, Ali Pezeshki, Louis Scharf, Colorado State University, United States; Douglas Cochran, Arizona State University, United States; Stephen D. Howard, Defence Science and Technology Organisation, Australia

In this work, we study the impact of compressive sampling with random matrices on Fisher information for nonlinear parameter estimation in a complex multivariate normal measurement model. We consider the class of random compression matrices whose distribution is invariant to right-unitary transformations. For this class of random compression matrices, we show that the

normalized Fisher information matrix after compression has a multivariate beta type one distribution, which is independent of the Fisher information matrix before compression and the values of the parameters. Our result can be used to quantify the amount of loss in Fisher information due to random compression.

WA3-6 **10:40 AM**

Nesterov's Proximal-Gradient Signal Recovery from Compressive Poisson Measurements

Renliang Gu, Aleksandar Dogandžic, Iowa State University, United States

We develop a fast proximal-gradient scheme for reconstructing sparse signals from Poisson measurements with a linear model. The objective function to be minimized is a sum of a negative log-likelihood (NLL) term and a convex regularization term. We consider (i) nonnegative and sparse regularizations and (ii) sparsity-only regularization. We apply the Nesterov's proximal-gradient (NPG) method with the proximal mapping computed by (i) ADMM and (ii) soft thresholding. To accelerate, we adopt the continuation and a step-size selection scheme accounting for the varying local Lipschitz of the NLL. In the numerical examples, we compare the proposed approach with existing methods.

WA3-7 **11:05 AM**

Exact Bayesian Test for a Common Rank-One Component in White Noise

Songsri Sirianunpiboon, Stephen D. Howard, Defence Science and Technology Organisation, Australia; Douglas Cochran, Arizona State University, United States

Unknown and arbitrary rank-one signals are collected by two arrays of sensors. This paper constructs an exact invariant Bayesian detector for deciding if the two sets of data are generated by the same rank-one signal. This detector is compared to the generalized likelihood ratio test (GLRT) and shown in simulation to give significantly better performance.

WA3-8 **11:30 AM**

Rank Deficiency and Sparsity in Partially Observed Multiple Measurement Vector Models

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

This paper considers the problem of recovering jointly sparse vectors using partially observed multiple measurement vector (MMV) model, in which only a few entries of the measurement vectors are observed. It is shown that when we have partial observations, seeking only the sparsest solution may not recover the original vectors, even if it succeeds when full observations are available. By simultaneously exploiting the low rank and joint-sparsity, a new reconstruction approach is proposed. Theoretical conditions for perfect recovery are also established. Simulations show that the proposed method outperforms the mixed l_{1}/l_{q} minimization and rank aware sparse reconstruction.

Track D – Signal Processing and Adaptive Systems

Session: WA4 – Statistical Signal Processing for Social and Information Networks

Co-Chairs: ***Nadya Bliss,*** *Arizona State University* ***and Benjamin Miller,*** *MIT Lincoln Laboratory*

WA4-1 **8:15 AM**

Counting Triangles in Real-World Graph Streams: Dealing with Repeated Edges and Time Windows

Madhav Jha, Zenefits, United States; C. Seshadhri, University of California, Santa Cruz, United States; Ali Pinar, Sandia National Laboratories, United States

Need for real-time analysis of large graph streams led to one-pass streaming algorithms, but these were designed for simple graphs (no repeated edges). Real graph streams however, are multigraphs. We describe a new algorithm for estimating triangle count of multigraph edge streams. We show that previous algorithms fail for multigraph streams, despite their accuracies for simple graphs. The bias created by duplicate edges leads these algorithms astray. Our algorithm avoids these biases through debiasing and has provable guarantees and excellent empirical performance. Our algorithm seamlessly handles multiple windows without committing to any window size(s) a priori.

WA4-2 **8:40 AM**

Inside the Atoms: Mining a Network of Networks and Beyond

Hanghang Tong, Arizona State University, United States

Networks (i.e., graphs) appears in many high-impact applications. Often these networks are collected from different sources, at different times, at different granularities. In this talk, I will present our recent work on mining such multiple networks. First, we will present two models - one on modeling a set of inter-connected networks (NoN); and the other on modeling a set of inter-connected co-evolving time series (NoT). Second, we will present some algorithmic examples on how to do mining with such new models, including ranking and imputation.

WA4-3 **9:05 AM**

Sampling and Filtering Operations on Big Data

Vijay Gadepally, Lauren Edwards, Luke Johnson, Maja Milosavljevic, Benjamin Miller, Massachusetts Institute of Technology, United States

The 3V's of Big Data continue to challenge a system's processing, memory and network capabilities. Performing analytics such as link prediction on data collected at the scale of TB/s requires specialized hardware or the ability to intelligently reduce the volume and/or velocity of data. In this article, we will describe a number of approached so sample large datasets. In order to quantify the effect of sampling on predictive analytics, we will describe the performance of these sampling methods on link prediction via local statistics and tensor factorization.

WA4-4 **9:30 AM**

Improved Hidden Clique Detection by Optimal Linear Fusion of Multiple Adjacency Matrices

Himanshu Nayar, University of Michigan, United States; Rajmonda Caceres, Kelly Geyer, Benjamin Miller, Steven Smith, MIT Lincoln Laboratory, United States; Raj Rao Nadakuditi, University of Michigan, United States

We consider the setting where we are a given multiple Erdos-Renyi modeled adjacency matrices containing a common hidden or planted clique. The objective is to combine them linearly so that the principal eigenvectors of the resulting matrix best reveal the vertices associated with the clique. We utilize recent results from random matrix theory to derive the optimal weighting coefficients and use these insights to develop a data-driven fusion algorithm. We demonstrate the improved performance of the algorithm relative to other simple heuristics.

BREAK **9:55 AM**

WA4-5 **10:15 AM**

Robust Kriged Kalman Filtering

Brian Baingana, University of Minnesota, United States; Emiliano Dall'Anese, National Renewable Energy Laboratory, United States; Gonzalo Mateos, University of Rochester, United States; Georgios B. Giannakis, University of Minnesota, United States

Although the kriged Kalman filter (KKF) has well-documented merits for prediction of spatial-temporal processes, its performance degrades in the presence of outliers due to anomalous events or measurement equipment failures. This work proposes a robust KKF model that explicitly accounts for outliers, and exploits the sparsity inherent to them to develop a joint estimator for both the unmeasured process and outliers. Preliminary experiments demonstrate the efficacy of the novel approach in the contexts of energy resource forecasting and network delay prediction.

WA4-6 **10:40 AM**

Residuals-Based Subgraph Detection with Cue Vertices

Benjamin Miller, Stephen Kelley, Rajmonda Caceres, Steven Smith, Massachusetts Institute of Technology, United States

A common problem in modern graph analysis is the detection of communities, an example of which is the detection of a single anomalously dense subgraph. Recent results have demonstrated a fundamental limit for this problem when using spectral analysis of modularity. In this paper, we demonstrate the implication of these results on community detection when a cue vertex is provided, indicating one of the vertices in the community of interest. Several recent algorithms for local community detection are applied in this context, and we compare their empirical performance to the theoretical spectral limits.

WA4-7 **11:05 AM**

Defining and Detecting Signatures of Innovation in Collaboration Networks

Nadya Bliss, Manfred Laubichler, Arizona State University, United States

Absence of truth data presents a significant challenge in developing detection algorithms for topological (connectivity-based) anomalies in large networks. Scientific collaborations and their temporal properties are well suited to network based techniques. Furthermore, leveraging well-studied periods of scientific innovation allows for definition of signal signatures. Leveraging previous work on detecting emergent subgraphs in large collaborations networks, we refine our algorithmic techniques leveraging temporal properties of known transformative collaboration networks to gain insight into patterns of innovation and emergence of new scientific knowledge with a goal of developing a general set of detectable innovation signals.

WA4-8 **11:30 AM**

Diffusion Dynamics in Social Networks of Arbitrary Structure

June Zhang, José M.F. Moura, Carnegie Mellon University, United States

To study signals on networks, to detect epidemics, or to predict blackouts, we need to understand network topology and its impact on the behavior of network processes. The high dimensionality of large networks presents significant analytical and computational challenges; only specific network structures have been studied without approximation. We consider the impact of network topology on the limiting behavior of a dynamical process obeying the stochastic rules of SIS (susceptible-infected-susceptible) epidemics using the scaled SIS process. We introduce the network effect ratio, which captures the preference of individual agents versus the preference of society (i.e., network) and investigate its effects.

Track D – Signal Processing and Adaptive Systems

Session: WAa5 – Sparse Estimation

Chair: ***Vitor Nascimento,*** *University of Sao Paulo*

WA5a-1 **8:15 AM**

Convex Cardinal Shape Composition and Object Recognition in Computer Vision

Alireza Aghasi, Justin Romberg, Georgia Institute of Technology, United States

This work mainly focuses on the segmentation and identification of objects present in an image, where the recovered objects can only be composed of given prototype shapes. Given a dictionary of prototype shapes, we define our problem as selecting a limited number of dictionary elements and geometrically composing them through basic set operations to characterize desired regions in the image. We propose a convex relaxation to this combinatorial problem and provide sufficient conditions for recovering a target composition. Aside from imaging applications such as shape-based characterization and optical character recognition, this problem is closely linked to the geometric packing problem.

WA5a-2 **8:40 AM**

An Optimized Proportionate Adaptive Algorithm for Sparse System Identification

Silviu Ciochina, Constantin Paleologu, University Politehnica of Bucharest, Romania; Jacob Benesty, University of Quebec, Canada; Steven Grant, Missouri University of Science and Technology, United States

The proportionate-type adaptive algorithms are commonly used for the identification of sparse impulse responses, like in network or acoustic echo cancellation. In this paper, we propose an optimized proportionate algorithm in the context of a state variable model. The algorithm follows an optimization criterion based on the minimization of the system misalignment and uses an iterative procedure for adjusting the system model parameter. Consequently, it achieves a proper compromise between the performance criteria, i.e., fast convergence/tracking and low misadjustment. Simulations performed in the context of sparse system identification indicate the good behavior of the proposed algorithm.

WA5a-3 **9:05 AM**

Adaptive Sparse Logistic Regression with Application to Neuronal Plasticity Analysis

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

We consider adaptive estimation of sparse parameters in a logistic regression model relating the occurrence of binary events to streaming covariates. Our setup is motivated by the sparsity and plasticity of the receptive fields of sensory neurons. We obtain recursive filters for solving the regularized maximum likelihood problem through proximal gradient techniques. We evaluate the performance of our algorithms on simulated and real spiking data recorded from ferret's primary auditory cortex during performance of a click-rate discrimination task. Our results reveal that the proposed adaptive filters significantly outperform existing filtering algorithms in terms of goodness-of-fit, mean square error and trackability.

WA5a-4 **9:30 AM**

Distributed Sparsity-Aware Diffusion Conjugate Gradient Algorithms for Sensor Networks

Tamara Miller, Rodrigo de Lamare, Pontifical Catholic University of Rio de Janeiro, Brazil; Vitor Nascimento, University of São Paulo, Brazil; Yuriy Zakharov, University of York, United Kingdom

This paper proposes distributed sparsity-aware adaptive algorithms based on the conjugate gradient (CG) method and the diffusion strategy for parameter estimation over sensor networks. In particular, we present a distributed CG algorithm and a distributed CG algorithm that exploits sparsity in the set of parameters using l1 and log-sum penalty functions using the diffusion strategy. The proposed distributed CG algorithms outperform several existing distributed least-mean square (LMS), conjugate gradient (CG) and recursive least-squares (RLS) algorithms and can effectively exploit sparse signals. Numerical results illustrate the performance of the proposed and existing algorithms in several scenarios

Track E – Array Signal Processing

Session: WAb5 – Compressive Beamforming and Sparsity-Based Techniques

WA5b-1 **10:15 AM**

Adaptive Measurement Matrix Design for Compressed DoA Estimation with Sensor Arrays

Berk Özer, Bilkent University, Turkey; Anastasia Lavrenko, Technische Universität Ilmenau, Germany; Sinan Gezici, Bilkent University, Turkey; Florian Römer, Giovanni Del Galdo, Technische Universität Ilmenau, Germany; Orhan Arikan, Bilkent University, Turkey

We propose a novel adaptive design technique for compressive 3-D Direction of Arrival (DoA) estimation with sensor arrays. Common CS measurement matrix designs do not necessarily yield the best performance in terms of a specific processing task. Therefore we apply a design technique based on the minimization of the Cramer-Rao Lower Bound (CRLB) and develop specific approaches for two distinct DoA applications: detection of the newly appearing targets (surveillance mode) and tracking of the previously detected targets (tracking mode). Numerical results suggest that the developed designs allow to provide near optimal performance in terms of the CRLB.

WA5b-2 **10:40 AM**

Multiple Snapshot Compressive Beamforming

Peter Gerstoft, Angeliki Xenaki, University of California, San Diego, United States; Christoph Mecklenbrauker, Erich Zoechmann, Technische Universität Wien, Austria

For sound fields observed on an array, compressive sensing (CS) reconstructs the multiple source signals at unknown directions-of-arrival (DOAs) using a sparsity constraint. The DOA estimation is posed as an underdetermined problem expressing the field at each sensor as a phase-lagged superposition of source amplitudes at all hypothetical DOAs. CS is applicable even for a single observation snapshot achieving a higher resolution than conventional beamforming. For multiple snapshots, CS outperforms conventional high-resolution methods, even with coherent arrivals and at low signal-to-noise ratio. Finally, the reconstruction results via convex optimization are compared to alternative methods, e.g. Sparse Bayesian Learning (SBL).

WA5b-3 **11:05 AM**

Blind Super-Resolution of Sparse Spike Signals

Yuejie Chi, The Ohio State University, United States

In many applications, the observations can be modeled as a superposition of a small number of scaled and shifted copies of a bandlimited point spread function, either determined by the nature or designed by the users. This paper proposes a convex optimization framework based on minimization of the atomic norm for jointly spectrally-sparse ensembles to simultaneously estimate the point spread function as well as the spike signal with provable performance guarantees, by mildly constraining the point spread function lies in a known low-dimensional subspace with an unknown orientation.

WA5b-4 **11:30 AM**

Tensor MUSIC in Multidimensional Sparse Arrays

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

Tensor-based MUSIC algorithms have been successfully applied to parameter estimation in array processing. In this paper, we apply these for sparse arrays, such as nested arrays and coprime arrays, which are known to boost the degrees of freedom to $O(N^2)$ given $O(N)$ sensors. We consider two tensor decomposition methods: CANDECOMP/PARAFAC (CP) and high

order singular value decomposition (HOSVD) to derive novel tensor MUSIC spectra for sparse arrays. It will be demonstrated that the tensor MUSIC spectrum via HOSVD suffers from cross-term issues while the tensor MUSIC spectrum via CP identifies sources unambiguously, even in high-dimensional tensors.

Track D – Signal Processing and Adaptive Systems
Session: WAa6 – Tracking

WA6a-1 8:15 AM
Supervised Online Subspace Tracking
Yao Xie, Qingbin Li, Sebastian Pokutta, Georgia Institute of Technology, United States

Existing subspace tracking algorithms for streaming data usually assume a supervised setting (including the GROUSE, PETRELS and MOUSSE algorithms). However, there are many scenarios where supervised subspace tracking is more appropriate, i.e., to incorporate side information which is captured by the response variables. We present a set of algorithms for the supervised setting, to track a subspace or a union-of-subspaces (used as an approximation to manifold structure) when there are two data streams: a high-dimensional predictor sequence and a response sequence. We demonstrate the good performance of our algorithms compared with unsupervised algorithms via simulated and real data.

WA6a-2 8:40 AM
Algorithms for Tracking with a Foveal Sensor
Gregory Spell, Douglas Cochran, Arizona State University, United States

A foveal sensor employs a small region of high acuity surrounded by a periphery of lesser acuity. This paper describes an approach for managing such a sensor for tracking a single target. This approach seeks to adaptively position the high-acuity region of the sensor to keep it centered on the target. This scheme is incorporated into a Kalman filter, suitably modified to account for the nonlinearity and spatial agility of the sensor. It is evaluated using simulations in a two-dimensional target tracking scenario.

WA6a-3 9:05 AM
Period Estimation and Tracking: Filter Bank Design using Truth Tables of Logic
Srikanth V. Tenneti, P. P. Vaidyanathan, California Institute of Technology, United States

Recently, a new filter bank known as the Ramanujan Filter Bank (RFB) was proposed to estimate and track periodic behavior in data, with several advantages over the traditional methods. Apart from estimating the period of a signal, an RFB can find multiple concurrent periods. But if our signal of interest is not a mixture of multiple periodic signals, we show here that one can design filterbanks with far fewer filters than the RFB for period estimation. Our new designs use ideas from digital logic analysis to reduce the number of filters in the RFB.

WA6a-4 9:30 AM
Vehicle Track Detection in CCD Imagery via Conditional Random Field
Rebecca Malinas, Tu-Thach Quach, Mark Koch, Sandia National Laboratories, United States

Coherent change detection (CCD) can be used to detect vehicle tracks in synthetic aperture radar (SAR) imagery; however, automatic detection of tracks in CCD imagery is difficult due to noise. Existing methods require user cues or modeling of parallel track structure. We present a detection algorithm based on a pixel-level labeling of the image via conditional random field (CRF), with features based on radial derivatives of local Radon transforms. Our approach does not rely on user input or modeling of track structure. Experiments show that our method successfully detects both parallel and single tracks in SAR CCD.

Track D – Signal Processing and Adaptive Systems
Session: WAb6 – Structure in Adaptive Signal Processing Algorithms

WA6b-1 10:15 AM
Fundamentals of Multirate Graph Signal Processing
Oguzhan Teke, P. P. Vaidyanathan, California Institute of Technology, United States

In this work, we will analyze the fundamental blocks of multirate signal processing on graphs.We define the decimator, and find the expander accordingly.Due to importance of noble identities in the classical theory, one of our goals is to construct those equations for the graph signals.After decimation or expansion, length of the signal changes which makes the original adjacency

matrix inapplicable.Hence, noble identities on graphs don't exist in general.We provide the necessary and sufficient conditions on the graph together with the adjusted adjacency matrix such that noble identities exist.We will also study polyphase representation of graph filters and filter banks.

WA6b-2 10:40 AM

Randomized Subspace Learning Approach for High Dimensional Low Rank Plus Sparse Matrix Decomposition

Mostafa Rahmani, George Atia, University of Central Florida, United States

In this paper, a randomized algorithm for high dimensional low rank plus sparse matrix decomposition is proposed. The existing decomposition methods are not applicable to big data applications since they are based on an optimization problem whose dimensionality is equal to the dimension of the given data. We reformulate the decomposition problem as a columns-rows subspace learning problem. It is shown that when the columns/rows subspace of the low rank matrix is incoherent with the standard basis, the columns/rows subspace can be obtained from a small random subset of the columns/rows of the given data matrix.

WA6b-3 11:05 AM

Social Media Data Assisted Inference with Application to Stock Prediction

Hao He, Arun Subramanian, Sora Choi, Pramod Varshney, Syracuse University, United States; Thyagaraju Damarla, US Army Research Lab, United States

The access to the massive amount of social media data provides a unique opportunity for extracting information that can be used to infer about events. It is desirable to investigate the convergence of sensor networks and social media in facilitating the data-to-decision making process. In this paper, we propose a copula-based joint characterization of multiple dependent time series from sensors and social media. As a proof-of-concept, this model is applied to the fusion of Google Trends (GT) data and stock price data of Apple Inc. for prediction. Superior prediction performance is demonstrated.

WA6b-4 11:30 AM

Improved Estimation of Canonical Vectors in Canonical Correlation Analysis

Nicholas Asendorf, Raj Rao Nadakuditi, University of Michigan, United States

Canonical Correlation Analysis (CCA) is a multidimensional algorithm for two datasets that finds linear transformations, called canonical vectors, that maximize the correlation between the transformed datasets. However, in the low-sample high-dimension regime these canonical vector estimates are terribly inaccurate. Here we use insights from random matrix theory to propose a new algorithm that can reliably estimate canonical vectors in the sample deficient regime. Through numerical simulations we showcase that our new algorithm is robust to both limited training data and overestimating the dimension of the signal subspaces.

Track H – Speech, Image and Video Processing

Session: WAa7 – Image Processing

WA7a-1 8:15 AM

No-Reference Synthetic Image Quality Assessment using Scene Statistics

Debarati Kundu, Brian Evans, University of Texas at Austin, United States

Significant progress has been made for assessing subjective quality of natural scenes. Natural Scene Statistics (NSS) is an important tool for no-reference visual quality assessment of natural images. Here we take an important step towards using NSS to automate visual quality assessment of photorealistic synthetic scenes. Our contributions are (1) conducting subjective tests on our ESPL Synthetic Image Database containing 500 distorted images (created from 25 original images) (2) evaluating the performance of 17 no-reference image quality assessment (IQA) algorithms using synthetic scene statistics. We find that similar to natural scenes, synthetic scene statistics can be successfully used for IQA.

WA7a-2 8:40 AM

Speckle Removal by Statistically-Driven Anisotropic Diffusion of SAR Temporal Stacks

Nazia Tabassum, Andrea Vaccari, Scott Acton, University of Virginia, United States

To allow for road and bridge quality assessment and tracking, a temporal stack of synthetic aperture radar (SAR) images are acquired. The SAR amplitude images are distorted by speckle, thereby reducing the potential for high-resolution spatial analysis. Traditionally, the mean of the time series is utilized to produce a single despeckled image that discards temporal information.

We propose a statistical approach to provide guidance to an anisotropic diffusion filter designed to reduce speckle noise in each image within the series. The new filter incorporates the temporal information essential to the detection of potential change events along roads and bridges.

WA7a-3 **9:05 AM**

Oil-Spill Forensics using Two-Dimensional Gas Chromatography: Differentiating Highly Correlated Petroleum Sources using Peak Manifold Clusters

Hamidreza Ghasemi Damavandi, Ananya Sen Gupta, University of Iowa, United States; Christopher Reddy, Robert Nelson, Woods Hole Oceanographic Institution, United States

This work proposes signal processing innovations that enhance recent methods in petroleum fingerprinting and related infometric applications. Specifically, we use top hat filtering techniques that achieve robust correction of baseline clutter and mitigate related interference in high-volume chromatographic datasets. Innovations proposed include: (i) Manifold clustering techniques for robust source differentiation; and (ii) Baseline interference mitigation that preserves biomarker distribution within complex mixtures. We validate our results over experimental field data and effectively differentiate between biomarker signatures from the Macondo well, source of the April 2010 Deepwater Horizon disaster in the Gulf of Mexico, and closely correlated sources from the area.

WA7a-4 **9:30 AM**

On the Power of Joint Wavelet-DCT Features for Multispectral Palmprint Recognition

Shervin Minaee, Amirali Abdolrashidi, New York University, United States

Biometric-based identification has drawn a lot of attention in the recent years. Among all biometrics, palmprint is known to possess a rich set of features. In this paper we have proposed to use DCT-based features in parallel with wavelet-based ones for palmprint identification. PCA is applied to the features to reduce their dimensionality and the majority voting algorithm is used to perform classification. The features introduced here result in a near-perfectly accurate identification. This method is tested on a well-known multispectral palmprint database and an accuracy rate of 99.97-100% is achieved, outperforming all previous methods in similar conditions.

Track C – Networks

Session: WAb7 – Graph Signal Processing

Chair: ***Antonio Marques,*** *Universidad Rey Juan Carlos*

WA7b-1 **10:15 AM**

Uncertainty Principle and Sampling of Signals Defined on Graphs

Mikhail Tsitsvero, Sergio Barbarossa, Paolo Di Lorenzo, Sapienza University of Rome, Italy

The goal of this paper is to derive an uncertainty principle for signals defined on a graph and show that there exists a fundamental link between uncertainty principle and sampling theory. Differently from continuous time signals, graph signals can be perfectly localized in both time and frequency domains. We derive the boundary of the uncertainty domain in closed form and show that these boundaries can be attained. Then, based on these findings, we derive a sampling theorem and an efficient recovery algorithm. Based on our theoy, we propose alternative sampling strategies, aimed at optimizing different performance metric.

WA7b-2 **10:40 AM**

Sampling of Graph Signals: Successive Local Aggregations at a Single Node

Santiago Segarra, University of Pennsylvania, United States; Antonio Marques, King Juan Carlos University, Spain; Geert Leus, Delft University of Technology, Netherlands; Alejandro Ribeiro, University of Pennsylvania, United States

A new scheme to sample bandlimited graph signals is proposed. Most of the existing works focused on using the value of the signal observed at a subset of nodes to recover the signal in the entire graph. Differently, the sampling scheme proposed here uses as input observations taken at a single node. The observations correspond to sequential applications of the graph-shift operator, which are linear combinations of the information gathered by the neighbors of the node. When the graph corresponds to a directed cycle, which is the support of time-varying signals, our method is equivalent to classical sampling.

WA7b-3 **11:05 AM**

Joint Filtering of Graph and Graph-Signals

Nicolas Tremblay, Pierre Borgnat, Ecole normale superieure de Lyon, CNRS, France

Joint-filtering of signals indexed on a graph is to filter not only the signal, but also the graph by an appropriate downsampling. A method for that, different from the existing ones (e.g., with approximate bipartition of graphs, or the nodal domains of the Laplacian), is introduced, based on the decomposition in subgraphs. Thanks to the works detecting meaningful subgraphs, e.g. communities in networks, we propose a method to downsample the graphs on such subgraphs and to jointly filter the signals. This leads to the design of a subgraph-based filterbank for graph signals. This design is tested on simple examples.

WA7b-4 **11:30 AM**

Taxi Data in New York City: A Network Perspective

Joya A. Deri, Carnegie Mellon University, United States; José M.F. Moura, Carnegie Mellon University; New York University (Visiting), United States

We work with the "NYC Taxi Data Set," a historical repository of 750 million taxi rides over four years (2010-2013) with about thirty data-fields including start- and end-times, start- and end-GPS coordinates, fare and tip, as well as (coded) id information on the driver and vehicle. This data set provides rich (batch) information on the movements in an urban network as its citizens go about their daily life. We present how to go from static information (e.g., start- and end-details) to a virtual imaging of the dynamic flows in the network and compute relevant statistics on the corresponding network processes.

Track A – Communications Systems

Session: WAa8 – Coding and Decoding **8:15 AM–9:55 AM**

WA8a1-1

Trapping Sets in Stochastic LDPC Decoders

Kuo-Lun Huang, Northeastern University, United States; Vincent Gaudet, University of Waterloo, Canada; Masoud Salehi, Northeastern University, United States

Stochastic decoding is a hardware and energy-efficient approach to implement iterative Low-Density Parity-Check (LDPC) decoders. However, stochastic decoding often has a performance loss compared to the sum-product algorithm and suffers from additional trapping sets, which limit the performance of LDPC codes in the error floor region. In this paper, we investigate the error patterns of stochastic LDPC decoding. We also report stochastic-decoding-specific trapping sets for the (1056,528) LDPC code used in WiMAX standard. This observation has a potential to guide code structure designs that lower the error floor in stochastic decoding.

WA8a1-2

Quantized Message Passing for LDPC Codes

Michael Meidlinger, Vienna University of Technology, Austria; Alexios Balatsoukas-Stimming, Andreas Burg, EPFL, Switzerland; Gerald Matz, Vienna University of Technology, Austria

We propose a novel algorithm for decoding low density parity-check codes. Our decoder is based on message quantization and replaces the variable node update rule of the min-sum algorithm with a look-up table (LUT) that is designed using an information-theoretic criterion. We show that even with very small message alphabets the proposed algorithm can achieve better error rates than a floating-point min-sum decoder. The paper further studies in detail the effect of decoder attributes like design signal-to-noise ratio and LUT tree structure on the performance of our decoder.

WA8a1-3

Partial Parallel Belief Propagation for Memory Reduction in Polar Code Decoding

Jingwei Xu, Tiben Che, Gwan Choi, Texas A&M University, United States

This paper presents a novel partial parallel architecture for decoding polar codes. The proposed design utilizes the property of polar codes to separate the factor graph into different layers. Connections between different layers are set up to guarantee the fidelity of the decoding. The memory allocation of the conventional BP decoding implementation is reduced by 45% with negligible reduction in decoding performance for a simple design illustration described in this abstract. An elaborate layering scheme is presented in the paper that judiciously trades off the memory allocation, latency, and coding gain.

WA8a1-4
Reduced Complexity Detection for Network-Coded Slotted ALOHA using Sphere Decoding
Terry Ferrett, Matthew Valenti, West Virginia University, United States

Network-coded slotted ALOHA (NCSA) is a technique which improves the throughput of the slotted ALOHA protocol by applying physical-layer network coding. Throughput is improved by allowing more than one source to transmit a packet during each ALOHA slot, deliberately interfering to form a network-coded packet. A fundamental component of implementing NCSA is a receiver capable of detecting the network-coded packet, which requires performing detection on symbol constellations having cardinality which grows exponentially in the number of sources. This work contributes a receiver capable of detecting the network coded packet with reduced complexity using sphere decoding.

Track G – Architecture and Implementation
Session: WAa8 – Implementation of Communication Systems 8:15 AM–9:55 AM

WA8a2-1
Parallel Processing Intensive Digital Front-End for IEEE 802.11ac Receiver
Mona AghababaeeTafreshi, Juha Yli-Kaakinen, Toni Levanen, Ville Korhonen, Pekka Jääskelainen, Markku Renfors, Mikko Valkama, Jarmo Takala, Tampere University of Technology, Finland

Modern computing platforms offer increasing levels of parallelism for fast execution of different signal processing tasks. In this paper, we develop and evaluate a digital front-end concept for an IEEE802.11ac receiver with 80MHz bandwidth where parallel processing is adopted in multiple ways. Both C and OpenCL software implementations of the processing are developed and simulated for comparison purposes on an Intel CPU, to demonstrate that the parallelism provided by the OpenCL will result in substantially faster realization. Furthermore, the final paper will also provide complete software implementation results on the ARM Mali Graphics Processing Units with half precision floating-point arithmetic.

WA8a2-2
The Impact of Faulty Memory Bit Cells on the Decoding of Spatially-Coupled LDPC Codes
Jiandong Mu, Aida Vosoughi, Rice University, United States; Joao Andrade, University of Coimbra, Portugal; Alexios Balatsoukas-Stimming, École Polytechnique Fédérale de Lausanne, Switzerland; Georgios Karakonstantis, Queen's University, United Kingdom; Andreas Burg, École Polytechnique Fédérale de Lausanne, Switzerland; Gabriel Falcao, Vitor Silva, University of Coimbra, Portugal; Joseph R. Cavallaro, Rice University, United States

In this paper, we investigate the decoding performance of spatially-coupled LDPC codes in the case of faulty memory bit-cells within the storage modules of the decoder. Our study deals with characterizing error resilience, by measuring the BER degradation from such errors and we focus on the application of error mitigation techniques that further aid the inherent error resilience. In particular, we propose mitigation strategies based on the use of appropriate decoding algorithms that consider the significance of each fault within any bit-cell, that help contain the errors introduced by the unreliable memories.

WA8a2-3
ASIC Implementation and Performance Comparison of Adaptive Detection for MIMO–OFDM System
Essi Suikkanen, Markku Juntti, University of Oulu, Finland

We consider application specific integrated circuit (ASIC) implementation of two detector algorithms for multiple-input multiple-output orthogonal frequency division multiplexing (MIMO–OFDM) systems. Higher data rate and lower power consumption requirements set new challenges for implementation. An optimal detector would be able to change the detection algorithm to suit the channel conditions in order to minimize the power consumption. The detectors are designed for 4×4 and 8×8 antenna systems and three different modulation schemes using 28 nm complementary metal oxide semiconductor (CMOS) technology. The performance of the chosen algorithms is evaluated in third generation (3G) long-term evolution (LTE) system.

WA8a2-4
Implementation of MU-MIMO Schedulers on SoC
Ganesh Venkatraman, Janne Janhunen, Markku Juntti, University of Oulu, Finland

To avail the benefits of a multi-antenna system, MU-MIMO systems multiplex different user streams spatially over time-frequency resources. However, serving dozens of users with spatial multiplexing increases the scheduler complexity significantly. In this paper, we demonstrate the computational requirements of different state-of-the-art MU-MIMO scheduling algorithms

and evaluate the number of users supported with the real-time requirements. Initially, we analyze the achievable sum rate of various scheduling algorithms using MATLAB for different antenna configurations. We also propose a modification to the existing scheduling algorithm for improved sum rate. We then implement the schedulers on ZYNQ-ZC702 SoC to illustrate the advantages.

Track E – Array Signal Processing

Session: WAa8 – Array Signal Processing 8:15 AM–9:55 AM

WA8a3-1
Multi-Frequency Array Self-Calibration
Benjamin Friedlander, University of California, Santa Cruz, United States

Self-calibration techniques typically use signals collected in a single channel. To operate properly they require multiple co-channel signals to be present. Here we develop a self-calibration technique which uses data collected simultaneously from multiple frequency channels to calibrate the array and provide direction estimates for the signals in the channel of interest. The probability that a sufficient number of signals will be present at any given time is dramatically increased when multiple channels are being used. This increases significantly the usefulness of self calibration in practical direction finding scenarios. The performance advantages of multi-frequency calibration are illustrated by numerical examples.

WA8a3-2
Iterative Thresholding for Blind Block Partitioned Tensor Decomposition
Christopher Mueller-Smith, Predrag Spasojevic, Rutgers University, United States

We consider a model where a single sensor observes a bandwidth of spectrum occupied by several non-orthogonal in both time and frequency signals. The sensor constructs a tensor based on the trispectrum and which can be modeled as a block partitioned tensor (BPT). By decomposing this tensor we can estimate signal activity in both time and frequency. We develop a partition-blind BPT decomposition algorithm using iterative thresholding and parallel coordinate descent. We test the algorithm in simulations and find that it succeeds in estimating received signal PSDs and time activity substantially faster than previous algorithms.

WA8a3-3
Passive Localization and Synchronization in the Presence of Affine Clocks
Bernhard Etzlinger, Christoph Pimminger, Stefan Fischereder, Andreas Springer, Johannes Kepler University, Linz, Austria, Austria

We consider the passive localization problem in a wireless network, where source nodes at unknown positions are emitting arbitrary signals at unknown time. The receiving asynchronous anchor nodes act passively as they do not cooperate with the source nodes. In order to localize the source nodes, the local receive times from the anchors are collected at a central processing unit. Here, we derive a low-complex iterative solution based on the expectation-maximization algorithm. In contrast to previous works, we consider asynchronity in clock offset and skew by using an affine clock model.

WA8a3-4
Lucky Ranging in Underwater Acoustic Environments Subject to Spatial Coherence Loss
Hongya Ge, New Jersey Institute of Technology, United States; Ivars P. Kirsteins, Naval Undersea Warfare Center, United States

Motivated by lucky imaging, we propose a new paradigm for wavefront curvature range estimation and array processing in underwater environments with poor spatial coherence. Empirical evidence suggests that even in environments with apparently low spatial coherence, when the data is analyzed at a much finer time scales, there are brief moments when the wave front has little distortion. We derive a lucky maximum likelihood range estimator where each collected data snapshot is either coherent, i.e., rank-1, or purely incoherent consisting of IID noise with some probability. This estimator has greatly improved robustness over the conventional estimator when coherence is low.

WA8a3-5
Unmanned Aerial Vehicle Based Passive Radar Agile Sensing for Computerized Ionospheric Tomography

Yishi Lee, Jun Jason Zhang, University of Denver, United States; Matthew Zettergren, Embry-Riddle Aeronautical University, United States; Kimon P. Valavanis, University of Denver, United States

This paper aims to address the technical challenges associated with traditional ground-based system by introducing a novel approach of using unmanned aerial vehicle (UAV) to perform tomographic sensing. This reconstruction algorithm uses the most recent development in auroral ionospheric modelling as a synthetic prior combined with an innovative reconstruction approach involving a multiscale Natural Pixel decomposition and a MAP-based penalty weighted least-squared (PWLR) Signal Reconstruction. This proposed algorithm will not only improve the existing CIT techniques by providing high resolution reconstructions of the space plasma density, but also generate a new array of research opportunities for modern space tomographic imaging.

WA8a3-6
Clutter Suppression in Synthetic Aperture Radar Targets using the DFRFT and Subspace Methods with Rank Reduction

Balu Santhanam, Jelili Adebello, University of New Mexico, United States

SAR based vibration estimation using discrete Fractional Fourier transform (DFRFT) analysis methods have gained attention in recent work. In the presence of significant clutter, this estimation becomes challenging due to the presence of clutter induced peaks in the vibration spectra. In this paper, we incorporate rank reduction and filtering into a subspace DFRFT approach that results in significant peak enhancement along with reduction in the mean square errors when applied to simulated SAR data. The approach is further applied to vibration data gathered from a real GA-Lynx system and shown to produce a corresponding peak enhancement and clutter suppression.

WA8a3-7
Multipath Effects on Nested Array Processing

Peter Vouras, Naval Research Lab, United States

Nonlinear adaptive processing using sparse nested arrays has received a lot of attention in the radar community recently because it is possible to exploit more spatial degrees of freedom for beamforming than a conventional linear processor would allow. However, the practical difficulties of nonlinear adaptive beamforming have received little attention in the literature. This paper will describe the deleterious impact of multipath on the nonlinearly adapted output of a nested array and show that nulling performance is severely degraded. Additional insight into the multipath problem will be derived by analyzing conceptual beamformers which suppress multipath residue at the adapted output.

WA8a3-8
Joint Frequency and DOA Estimation using Fourier Coefficient Interpolation

Songsri Sirianunpiboon, Stephen D. Elton, Stephen D. Howard, Defence Science and Technology Organisation, Australia

A high accuracy and low complexity estimator for the unknown frequency and direction of arrival (DOA) of a sinusoid incident on a sensor array is proposed. The approach is to extend an existing Fourier coefficient interpolation scheme of Quinn, to a multi-sensor array. Simulation results show a mean square error in frequency of approximately 1.3 times CRB, while for DOA it is approximately 1.1 times CRB. As the method estimates frequency and DOA separately, there is a loss in threshold of 2dB for frequency estimation and 3dB for DOA estimation compared to joint maximum likelihood.

WA8a4-1
PRIME: Phase Retrieval via Majorization-Minimization Technique
Tianyu Qiu, Prabhu Babu, Daniel Palomar, Hong Kong University of Science and Technology, Hong Kong SAR of China

This paper considers the phase retrieval problem where the observations consist of only the magnitude of several linear measurements of the unknown, e.g., spectral components of a time sequence. We develop low-complexity algorithms with excellent performance based on the majorization-minimization (MM) framework. The proposed algorithms are referred to as PRIME: Phase Retrieval vIa Majorization-minimization techniquE. They are preferred to existing benchmark methods since at each iteration a simple closed-form solution is computed using different majorization-minimization techniques.

WA8a4-2
Fast Sparse Compressive Phase Retrieval
Aditya Viswanathan, Mark Iwen, Michigan State University, United States

Compressive Phase Retrieval refers to the problem of recovering an unknown sparse signal given only a small number of phaseless (or magnitude) measurements. This problem finds application in certain molecular imaging modalities such as x-ray crystallography. We present here the first sub-linear time compressive phase retrieval algorithm. We show that it is possible to stably recover k-sparse signals $\x_0 \in \mathbb C^n$ from $\mathcal O\left(k \log^4 k \cdot \log n \right)$ measurements in only $\mathcal O \left(k \log^5 k \cdot \log n\right)$--time. Numerical experiments show that the method is not only fast, but also stable to measurement noise.

WA8a4-3
Asymptotically Efficient Estimators for Multidimensional Harmonic Retrieval Based on the Geometry of the Stiefel Manifold
Thomas Palka, Richard Vaccaro, University of Rhode Island, United States

Multidimensional harmonic retrieval problems are often addressed using R-dimensional subspace-based methods (e.g., R-D Unitary ESPRIT). Subspace estimation methods such as SVD with forward-backward averaging, higher-order-SVD (HO-SVD), and structured least-squares (SLS) do not satisfy the pertinent maximum likelihood (ML) criterion. Using a complex Steifel manifold formulation for the domain of the likelihood function we derive a quadratic ML criterion with a geometric constraint for the R-dimensional problem. We present two solution methods to this problem. The performance of the resulting estimators is compared with existing approaches, with the parameter space CRBs, and with the intrinsic subspace CRB.

WA8a4-4
Waveform Extraction from Reference Channels of Passive Multistatic Radar Systems
Pawan Setlur, Sandeep Gogineni, Wright State Research Institute, United States; Muralidhar Rangaswamy, Air Force Research Laboratory, United States

Multistatic passive radar systems utilize transmitters of opportunity. Modern illuminators both civilian and military are digital. Here, our focus is estimating the waveforms present in reference channels of passive radar systems. We consider three cases: (1) the waveform is unit rank, (2) the waveform for each transmission is randomly chosen from a P orthogonal waveform ensemble, and (3) that the waveform is an unknown linear combination of P unknown linearly independent vectors. maximum likelihood (ML) solutions are analyzed. In low SNR the bias of the ML solution may be explained from random matrix theory.

WA8a4-5
Methods and Bounds for Waveform Parameter Estimation with a Misspecified Model
Peter Parker, Los Alamos National Laboratory, United States

Parameter estimation for phase modulated signals is an important area of research as it is applicable to many application areas ranging from radar signal processing to gravity wave detection. However, in many of these applications, the phase model required to accurately model the phenomenology is either unknown or too complex to accurately estimate the parameters. This paper derives the Quasi-Maximum Likelihood estimator where the assumed model does not match the underlying phenomenology. The misspecified Cramér-Rao bound is also used to gain additional insight into the performance of the estimation algorithms.

Session: WAa8 – Adaptive Signal Processing Techniques 8:15 AM–9:55 AM

WA8a5-1
On Sample Generation and Weight Calculation in Importance Sampling

Victor Elvira, Universidad Carlos III de Madrid, Spain; Luca Martino, University of Helsinki, Finland; David Luengo, Universidad Politecnica de Madrid, Spain; Monica Bugallo, Stony Brook University, United States

We investigate various sampling and weight updating techniques, which are the two crucial steps of importance sampling. We discuss the standard mixture sampling that randomly draws samples from a set of proposals and the deterministic mixture sampling, where exactly one sample is drawn from each proposal. For weight calculation, we either compute the weights by considering the particular proposal used for each sample or by interpreting the proposal as a mixture formed by all available proposals. All combinations of sampling and weight calculation and some modifications that improve the performance and/or reduce the computational complexity are examined through computer simulations.

WA8a5-2
Multichannel Spectral Factorization Algorithm using Polynomial Matrix Eigenvalue Decomposition

Zeliang Wang, John G. McWhirter, Cardiff University, United Kingdom; Stephan Weiss, University of Strathclyde, United Kingdom

In this paper, we present a new multichannel spectral factorization algorithm which can be utilized to calculate the approximate spectral factor of any para-Hermitian polynomial matrix. The proposed algorithm is based on an iterative method for polynomial matrix eigenvalue decomposition (PEVD). By using the PEVD algorithm, multichannel spectral factorization problems are simply broken down to a set of single channel problems which can be solved by means of existing one dimensional spectral factorization algorithms. In effect, it transforms the multichannel spectral factorization problem into one which is much easier to solve.

WA8a5-3
Excision of a Discontinuous-Frequency Interference Signal with Harmonic Structure

Todd K. Moon, Jacob H. Gunther, McKay Bonham, Utah State University, United States; Gus William, Brigham Young University, United States

We consider the problem of excising a sinusoidal signal which is piecewise constant in frequency with random transition times, and which is duplicated at fixed frequency offsets. This signal interferes with a signal of interest. To remove this interfering signal, frequency transition times are estimated using a pair of frequency estimation windows obtained using compressed likelihood techniques, which account for all shifted versions of the interfering signals. This two-window approach avoids line broadening and allows accurate identification of the transition times. After identifying frequency transition times and the local interfering frequency, the interference is excised from the band of interest.

WA8a5-4
Characterization of Sonar Target Data using Gabor Wavelet Features

Daniel Schupp, Ananya Sen Gupta, University of Iowa, United States; Ivars Kirsteins, Naval Undersea Warfare Center, United States

We present a method of characterization of active sonar target response that makes use of physics-driven Gabor dictionaries. Key innovation is the combination of the useful characteristics of the Gabor wavelet (such as time/frequency localization) with an empirical approach to dictionary selection for underwater acoustics. We will demonstrate over experimental field data that these features are both visually distinct and ideal for separation and classification via SVM.

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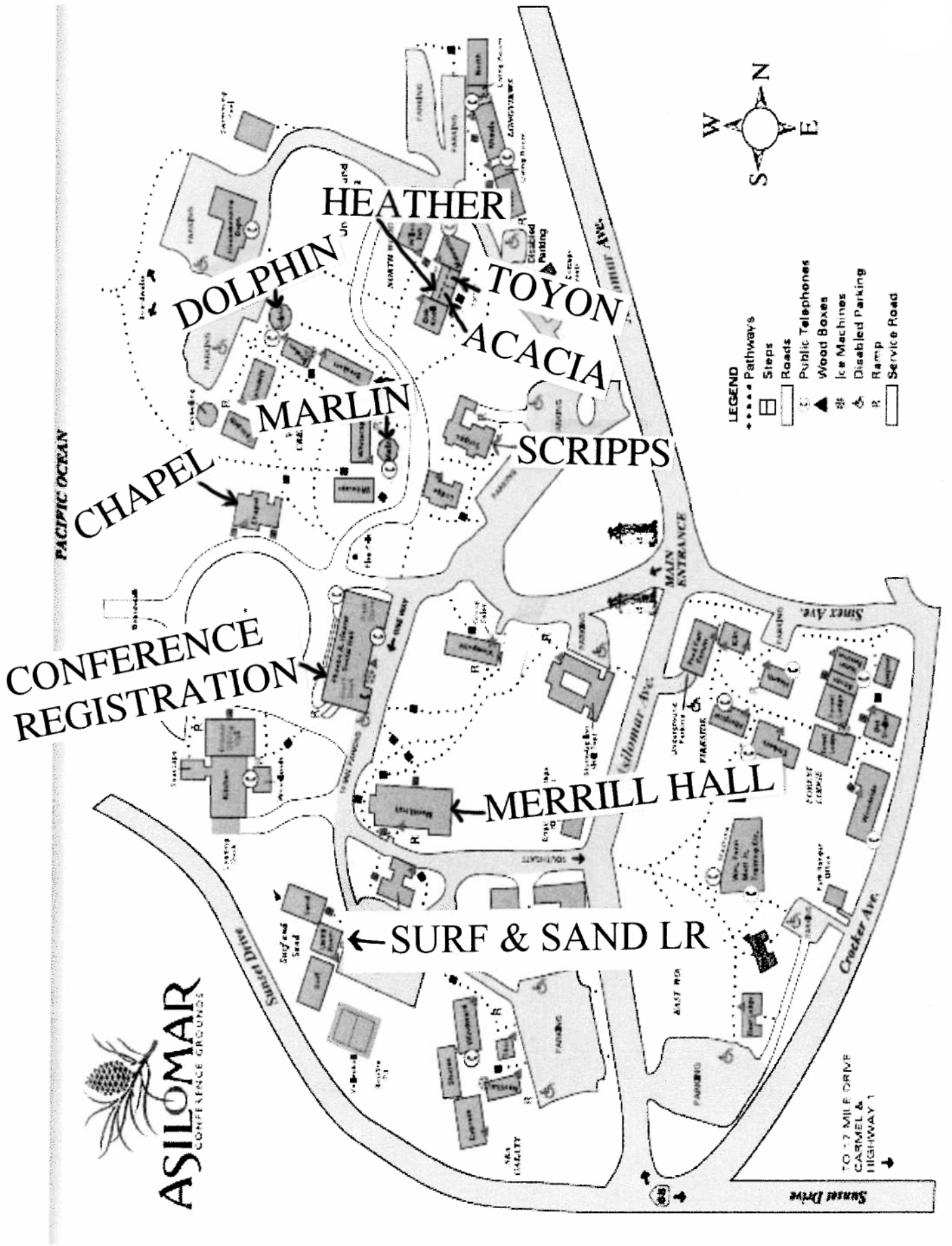
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