Fifty-First
Asilomar Conference on
Signals, Systems, and Computers

October 29–November 1, 2017

FINAL PROGRAM & ABSTRACTS

Asilomar Hotel
Conference Grounds

FIFTY-FIRST
ASILOMAR CONFERENCE ON
SIGNALS, SYSTEMS & COMPUTERS

Technical Co-sponsor

IEEE SIGNAL PROCESSING SOCIETY

CONFERENCE COMMITTEE

General Chair
Geert Leus
Delft University of Technology
Mekelweg 4, 2628 CD
Delft, The Netherlands
G.J.T.Leus@tudelft.nl

Technical Program Chair
Joseph Cavallaro
Dept. of Electrical and Computer Engineering, Center for Multimedia Communication
Rice University
6100 Main Street, MS 380
Houston, TX 77005, USA
cavallar@rice.edu

Conference Coordinator
Monique P. Fargues*
Department of Electrical & Computer Engineering
Naval Postgraduate School
Monterey, CA 93943
fargues@asilomarssc.org

Publications Chair
Michael B. Matthews
NorthWest Research Associates
301 Webster Street
Monterey, CA 93940
michael.b.matthews@ieee.org

Publicity Chair
Linda S. DeBrunner
Department of Electrical & Computer Engineering
Florida State University
Tallahassee, FL 32310-6046
Linda.debrunner@eng.fsu.edu

Finance Chair
Ric Romero*
Department of Electrical & Computer Engineering
Naval Postgraduate School
Monterey, CA 93943-5121
treasurer@asilomarssc.org

Electronic Media Chair
Marios Pattichis
Department of Electrical & Computer Engineering
MSC01 1100, 1
University of New Mexico
Albuquerque, NM 87131-0001
pattichi@unm.edu

Student Paper Contest Chair
Scott Acton
Electrical & Computer Eng. Dept.
University of Virginia
P.O. Box 400743
Charlottesville, VA 22904-4743
acton@virginia.edu

Student Paper Contest Co-Chair
Anna Scaglione
Ira A. Fulton Schools of Engineering, School of Electrical, Computer, and Energy Engineering
Arizona State University
Tempe, AZ 85287-5706
Anna.Scaglione@asu.edu

*participating in his or her personal capacity

Welcome from the General Chairman

Prof. Geert Leus
Delft University of Technology

Welcome to the 51st Asilomar Conference on Signals, Systems, and Computers! This is the first edition after Asilomar's golden jubilee, and I am really honored to serve as General Chair this year. Asilomar is well known in the community as a high-quality conference where world-renowned researchers present their most recent results, in some cases even just a few days old. Some of the greatest achievements in our field were presented first at Asilomar. For me personally, Asilomar has always been this place where you can combine great lectures on exciting emerging topics, with relaxing walks, runs and bike rides in the most beautiful natural environment. The first time I was at Asilomar was as a PhD student back in 1999 and ever since I try to make it to this one-of-a-kind conference.

We have a very strong technical program for you this year with a good mix of invited, regular and poster sessions. I would like to sincerely thank the Technical Program Chair Prof. Joseph R. Cavallaro and his team of Technical Area Chairs: Urbashi Mitra, Elza Erkip, Antonio G. Marques, Marco Duarte, Piya Pal, Behtash Babadi, Christoph Studer, Tokunbo Ogunfunmi, and Markku Juntti (Vice Track Chair). They all did an outstanding job in coordinating the technical aspects of this conference. This year's program consists of 432 accepted papers, of which 191 were invited. Among these papers, 88 were submitted to the student paper contest, from which a list of 12 finalists were selected. These finalists will present their papers in a poster session to a committee of judges on Sunday afternoon, and everybody is of course welcome to attend. The top three papers will be awarded at the Monday plenary session.

I am really pleased that this year's plenary speaker will be Prof. Robert W. Heath Jr. from the University of Texas at Austin. Robert is a lifelong attendee of Asilomar and has been actively involved in the organization for many years. Robert is an authority in millimetre wave communications for fifth generation (5G) wireless technology. He is one of the few researchers in this area who spans a bridge between theoretical foundations and practical implementation aspects. Furthermore, Robert is well-anchored in the field of signal processing and can enlighten us on this exciting area from a signal processing point of view, overviewing past achievements and pinpointing future challenges. I am greatly looking forward to this plenary.

Serving as General Chair for this conference was a great journey. I hope you will enjoy the conference and please take some time to experience the special environment and atmosphere that Asilomar has to offer.

Prof. Geert Leus
Delft University of Technology

Conference Steering Committee

PROF. MONIQUE P. FARGUES*
President & Chair
Electrical & Computer Eng. Dept.
Code EC/Fa
Naval Postgraduate School
Monterey, CA 93943-5121
fargues@asilomarssc.org

PROF. VICTOR DEBRUNNER
Vice Chair/President
Electrical & Computer Eng. Dept.
Florida State University
2525 Pottsdamer Street, Room A-341-A
Tallahassee, FL 32310-6046
victor.debrunner@eng.fsu.edu

PROF. SHERIF MICHAEL*
Secretary
Electrical & Computer Eng. Dept.
Code EC/Mi
Naval Postgraduate School
Monterey, CA 93943-5121
michael@nps.edu

PROF. RIC ROMERO*
Treasurer
Electrical & Computer Eng. Dept.
Code EC/Rr
Naval Postgraduate School
Monterey, CA 93943-5121
treasurer@asilomarssc.org

PROF. SCOTT ACTON
Electrical & Computer Eng. Dept.
University of Virginia
P.O. Box 400743
Charlottesville, VA 22904-4743
acton@virginia.edu

PROF. LINDA DEBRUNNER
Publicity Chair
Electrical & Computer Eng. Dept.
Florida State University
2525 Pottsdamer Street, Room A-341-A
Tallahassee, FL 32310-6046
linda.debrunner@eng.fsu.edu

PROF. MILOS ERCEGOVAC
Computer Science Dept.
University of California at Los Angeles
Los Angeles, CA 90095
milos@cs.ucla.edu

PROF. BENJAMIN FRIEDLANDER
Computer Eng. Dept.
University of California
1156 High Street, MS:SOE2
Santa Cruz, CA 95064
Benjamin.friedlander@gmail.com

PROF. FREDRIC J. HARRIS
Electrical Eng. Dept.
San Diego State University
San Diego, CA 92182
fred.harris@sdsu.edu

PROF. W. KENNETH JENKINS
Electrical Eng. Dept.
The Pennsylvania State University
209C Electrical Engineering West
University Park, PA 16802-2705
jenkins@engr.psu.edu

PROF. FRANK KRAGH*
Electrical & Computer Eng. Dept.
Code EC/Kr
Naval Postgraduate School
Monterey, CA 93943-5121
frank.kragh@gmail.com

DR. MICHAEL B. MATTHEWS
Publications Chair
NorthWest Research Associates
301 Webster Street
Monterey, CA 93940
michael.b.matthews@ieee.org

DR. MARIOS PATTICHIS
Electronic Media Chair
Electrical & Computer Eng. Dept.
MSC01 1100
1 University of New Mexico
ECE Bldg., Room: 229A
Albuquerque, NM 87131-000
Pattichis@ece.unm.edu

PROF. JAMES A. RITCEY
Nominating Committee Chair
Electrical Eng. Dept.
Box 352500
University of Washington
Seattle, Washington 98195
ritcey@ee.washington.edu

DR. BALU SANTHANAM
ECE Dept
University of New Mexico
Albuquerque, NM 87131-1356
Bsanthan@unm.edu

DR. MICHAEL SCHULTE
AMD Research
7171 Southwest Parkway
Austin, TX 78739
Michael.schulte@amd.com

PROF. EARL E. SWARTZLANDER, JR.
Electrical & Computer Eng. Dept.
University of Texas at Austin
Austin, TX 78712
eswartzla@aol.com

PROF. KEITH A. TEAGUE
School Electrical & Computer Eng. / 202ES
Oklahoma State University
Stillwater, OK 74078
Keith.teague@okstate.edu

PROF. PHIL SCHNITER
General Program Chair (ex officio)
Year 2016
ECE Department
Ohio State University
616 Dreese Laboratories
2015 Neil Ave
Columbus, OH 43210
schniter.1@osu.edu

PROF. GEERT LEUS
General Program Chair (ex officio)
Year 2017
Faculty EEMCS
Delft University of Technology
Mekelweg 4, 2628 CD
Delft, The Netherlands
g.j.t.leus@tudelft.nl

PROF. VISA KOIVUNEN
General Program Chair (ex officio)
Year 2018
Dept. of Signal Processing and Acoustics
School of Electrical Engineering, Aalto University
P.O. Box 13000
FIN-00076 AALTO, FINLAND
visa@wooster.hut.fi

*participating in his or her personal capacity

2017 Asilomar Technical Program Committee

Technical Chairman
Prof. Joseph Cavallaro
Rice University

2017 Asilomar
Technical Program Committee Members

Track A: Communication Systems
Urbashi Mitra
University of Southern California, USA
ubli@usc.edu

Track B: MIMO Communications and Signal Processing
Elza Erkip
NYU Tandon School of Engineering, USA
elza@nyu.edu

Track C: Networks
Antonio G. Marques
King Juan Carlos University, Spain
antonio.garcia.marques@urjc.es

Track D: Signal Processing and Adaptive Systems
Marco Duarte
University of Massachusetts Amherst, USA
mduarte@ecs.umass.edu

Track E: Array Signal Processing
Piya Pal
University of California San Diego, USA
pipal@eng.ucsd.edu

Track F: Biomedical Signal and Image Processing
Behtash Babadi
University of Maryland, College Park, USA
behtash@umd.edu

Track G: Architecture and Implementation
Christoph Studer
Cornell University, USA
studer@cornell.edu

Track H: Speech Image and Video Processing
Tokunbo Ogunfunmi
Santa Clara University, USA
togunfunmi@scu.edu

Vice Track Chair
Markku Juntti
University of Oulu, Finland
markku.juntti@oulu.fi

2017 Asilomar Conference Session Schedule

Sunday Afternoon, October 29, 2017

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

Monday Morning, October 30, 2017

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 — Chapel

10:15–11:55 AM MORNING SESSIONS

MA1b	Securing Crowded and Open Networks: Physical-Layer Security in 5G (Invited)
MA2b	Dirty-RF for Multi-User Massive-MIMO (Invited)
MA3b	Graph Signal Processing (Invited)
MA4b	Nonconvex Optimization (Invited)
MA5b	Theory for Next Generation Radar Systems (Invited)
MA6b	Signal Processing-Enhanced Biomedical Instrumentation
MA7b	Dynamically Scheduled High-Level Synthesis (Invited)
MA8b1	Detection, Classification, and Tracking (Poster)
MA8b2	Video and Image Processing (Poster)
MA8b3	Multimedia Processing Systems (Poster)

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

Monday Afternoon, October 30, 2017

1:30–5:10 PM AFTERNOON SESSIONS

MP1a	Network Inference (Invited)
MP1b	DNA Storage (Invited)
MP2a	Massive MIMO: Vision and Reality (Invited)
MP2b	Cloud and Fog-Assisted 5G (Invited)
MP3a	Distributed Methods for Large-scale Optimization (Invited)
MP3b	Dynamic Control in Wireless Networks (Invited)
MP4a	Low-dimensional Models for Big Data (Invited)
MP4b	High-dimensional Estimation: Theory and Algorithms (Invited)
MP5a	Mathematics of Super-Resolution (Invited)
MP5b	Waveform and Array Optimization for Multistatic/MIMO Radar (Invited)
MP6a	Identification and Control of Neural Dynamics (Invited)
MP6b	Statistical Signal Processing and Learning in Neuroscience (Invited)
MP7a	Machine Learning for Information Retrieval, Speech, and Image Processing (Invited)
MP7b	Testbed-Based 5G Research (Invited)
MP8a1	Large-Scale Data (Poster)
MP8a2	Message Passing and Matrix Factorization Algorithms (Poster)
MP8a3	Computer Arithmetic II (Poster)
MP8a4	Computer Architecture II (Poster)

Monday Evening, October 30, 2017

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.

2017 Asilomar Conference Session Schedule
(continued)

Tuesday Morning, October 31, 2017

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

8:15–11:55 AM MORNING SESSIONS

TA1a	Interface of Communications and Control (Invited)
TA1b	Cognitive Networks (Invited)
TA2a	Video Delivery Over Wireless Caching Networks: Theory and Practice (Invited)
TA2b	Millimeter-Wave MIMO Wireless Systems (Invited)
TA3a	Smart Networked Infrastructure (Invited)
TA3b	Networks and Society (Invited)
TA4a	Structured and Covariance Matrix Recovery (Invited)
TA4b	Adaptive Sensing (Invited)
TA5	Tensor Methods (Invited)
TA6a	Signal Processing for Neuroimaging (Invited)
TA6b	Computational Ultrasound Imaging (Invited)
TA7a	Computer Arithmetic (Invited)
TA7b	Computer Arithmetic Algorithms
TA8a1	Statistical Signal Processing (Poster)
TA8a2	Adaptive Signal Processing II (Poster)
TA8a3	Compressed Sensing (Poster)
TA8a4	Information Theoretic and Networked Signal Processing (Poster)
TA8b1	Massive MIMO Communication Systems (Poster)
TA8b2	Issues in MIMO System Design (Poster)
TA8b3	Array Processing Algorithms for Radar (Poster)
TA8b4	Source Localization (Poster)

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

Tuesday Afternoon, October 31, 2017

1:30–5:35 PM AFTERNOON SESSIONS

TP1a	Fundamentals of mmWave Communications
TP1b	Hardware Designs for 5G Wireless Systems (Invited)
TP2a	Noncoherent Wireless Communications (Invited)
TP2b	Massive MIMO Systems
TP3a	Medical Image Acquisition and Reconstruction (Invited)
TP3b	Networks of the Brain (Invited)
TP4a	Crowdsourcing (Invited)
TP4b	Adaptive Signal Processing I
TP5a	Array Processing for Spectrum Sharing (Invited)
TP5b	Sparsity and Structure in Human Bio-Imaging (Invited)
TP6a	Biomedical Signal Processing and Information Extraction (Invited)
TP6b	Asynchronous and Neural Computing (Invited)
TP7a	Computer Architecture
TP7b	Optimization Methods for Image Processing (Invited)
TP8a1	Networks and Graphs (Poster)
TP8a2	Biomedical Signal Processing (Poster)
TP8a3	Networks and Applications (Poster)
TP8a4	Networks for Communication Systems (Poster)
TP8b1	Privacy, Secrecy and Channel Capacity (Poster)
TP8b2	Communication System Design and Resource Allocation (Poster)
TP8b3	Coding Theory and Sequences (Poster)
TP8b4	Detection Methods and mmWave Systems (Poster)

Tuesday Evening Open Evening — Enjoy the Monterey Peninsula

2017 Asilomar Conference Session Schedule
(continued)

Wednesday Morning, November 1, 2017

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

8:15 AM–11:30 PM MORNING SESSIONS

WA1a	Theory of Wireless Systems
WA1b	Theory of Structured Waveforms
WA2a	MIMO Channel Estimation
WA2b	Speech Processing
WA3a	Wireless Networks
WA3b	Signal Processing over Graphs and Networks
WA4a	Computational Imaging (Invited)
WA4b	Deep Learning and Applications
WA5a	Information Limits and Signals Representations (Invited)
WA5b	Array Signal Processing Algorithms
WA6a	Signal Processing for Hearing Aids (Invited)
WA6b	Neural Signal Processing
WA7a	Hardware Design for Machine Learning (Invited)
WA7b	Video Processing

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

Student Paper Contest

HEATHER HALL – SUNDAY, OCTOBER 29, 2017, 4:00–6:30 PM

Track A *"Lossless Natural Sampling for PWM Generation"*

Noyan Sevuktekin, Andrew Singer, University of Illinois at Urbana-Champaign, United States

"5G Millimeter Wave Cellular System Capacity with Fully Digital Beamforming"

Sourjya Dutta, C. Nicolas Barati, Aditya Dhananjay, Sundeep Rangan, New York University, Tandon School of Engineering, United States

Track B *"The Impact of Impedance Matching on Channel Estimation in Compact MIMO Receivers"*

Wuyuan Li, Brian Hughes, North Carolina State University, United States

Track C *"Beyond Consensus and Synchrony in Decentralized Online Optimization using Saddle Point Method"*

Amrit Singh Bedi, Indian Institute of Technology Kanpur, India; Alec Koppel, University of Pennsylvania, United States; Ketan Rajawat, Indian Institute of Technology Kanpur, India

"Online Learning for "Thing-Adaptive" Fog Computing in IoT"

Tianyi Chen, Yanning Shen, University of Minnesota, United States; Qing Ling, University of Science and Technology of China, China; Georgios B. Giannakis, University of Minnesota, United States

Track D *"Recovery Conditions and Sampling Strategies for Network Lasso"*

Alexandru Mara, Alexander Jung, Aalto University, Finland

"Target-Based Hyperspectral Demixing via Generalized Robust PCA"

Sirisha Rambhatla, Xingguo Li, Jarvis Haupt, University of Minnesota-Twin Cities, United States

Track E *"Adaptive Sequential Refinement: A Tractable Approach for Ambiguity Function Shaping in Cognitive Radar"*

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

"Multiple-Antenna Multiple-Access Joint Radar and Communications Systems Performance Bounds"

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

Track F *"On Developing an FPGA Based System for Real Time Seizure Prediction"*

Sarah Hooper, Erik Biegert, Marissa Levy, Justin Pensock, Luke Van der Spoel, Xiaoran Zhang, Tianyi Zhang, Rice University, United States; Nitin Tandon, University of Texas Health Science Center, United States; Behnaam Aazhang, Rice University, United States

Track G *"Performance Comparison of AES-GCM-SIV and AES-GCM Algorithms for Authenticated Encryption on FPGA Platforms"*

Sandhya Koteshwara, University of Minnesota, United States; Amitabh Das, Intel Corporation, United States; Keshab K. Parhi, University of Minnesota, United States

Track H *"Multi-Object Detection and Tracking via Kernel Covariance Factorization in Thermal Video"*

Guohua Ren, Ioannis Schizas, University of Texas at Arlington, United States

2017 Asilomar Conference Session Schedule

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

Monday, October 30, 2017

CONFERENCE WELCOME AND PLENARY SESSION 8:15–9:45 AM — CHAPEL

1. Welcome from the General Chair

Prof. Geert Leus
Delft University of Technology, The Netherlands

2. Session MA1a Distinguished Lecture for the 2017 Asilomar Conference

Millimeter Wave MIMO Signal Processing

Prof. Robert Heath
University of Texas at Austin, USA

Abstract
Millimeter wave has become an incubator for the rebirth of MIMO communication. It has many applications, as a core 5G technology, and also as a conduit for emerging applications of wireless to fixed access, vehicular, aerial, and wearable networks. In this talk, I explain why communication at millimeter wave — and even higher frequencies — is interesting from a signal processing perspective. I first describe the three differentiating features of communication at millimeter wave: larger arrays, new channel models, and power constraints. Then I explain how these features impact the formulation and solution of traditional MIMO signal processing problems like beamforming, precoding, and channel estimation. I describe the signal processing challenges associated with fast antenna array configuration. In particular, I highlight how out-of-band information, sensing, and machine learning algorithms can reduce the overhead in tasks such as adaptive channel estimation and beamforming. I conclude with directions for future research.

Biography
Robert W. Heath Jr. received the Ph.D. in EE from Stanford University. He is a Cullen Trust for Higher Education Endowed Professor in the Department of Electrical and Computer Engineering at The University of Texas at Austin and a Member of the Wireless Networking and Communications Group. He is also the President and CEO of MIMO Wireless Inc and Chief Innovation Officer at Kuma Signals LLC. Prof. Heath is a recipient of the 2012 Signal Processing Magazine Best Paper award, a 2013 Signal Processing Society best paper award, the 2014 EURASIP Journal on Advances in Signal Processing best paper award, and the 2014 Journal of Communications and Networks best paper award, the 2016 IEEE Communications Society Fred W. Ellersick Prize, and the 2016 IEEE Communications Society and Information Theory Society Joint Paper Award. He authored "Introduction to Wireless Digital Communication" (Prentice Hall in 2017), co-authored "Millimeter Wave Wireless Communications" (Prentice Hall in 2014), and authored "Digital Wireless Communication: Physical Layer Exploration Lab Using the NI USRP" (National Technology and Science Press in 2012). He is a licensed Amateur Radio Operator, a registered Professional Engineer in Texas, and is a Fellow of the IEEE.

Program of the
2017 Asilomar Conference on
Signals, Systems, and Computers

Technical Program Chairman
Prof. Joseph Cavallaro
Rice University

Track A – Communications Systems

Session: MA1b – Securing Crowded and Open Networks: Physical-Layer Security in 5G

Chair: ***Matthieu Bloch,*** *Georgia Tech*

MA1b-1 10:15 AM

Physical Layer Security in Massive MIMO Systems

Rafael F. Schaefer, Technische Universität Berlin, Germany; Gayan Amarasuriya, Southern Illinois University, United States; H. Vincent Poor, Princeton University, United States

In this paper, physical layer security for massive multiple-input multiple-output (MIMO) systems is considered. In such a system, an eavesdropper can either passively eavesdrop upon the confidential communication or actively attack the communication. While massive MIMO systems are shown to be inherently robust against passive eavesdropping, the situation changes significantly for active attacks. This paper reviews recent developments and results for passive and active attacks on massive MIMO systems.

MA1b-2 10:40 AM

Implementing a Real-Time Capable WPLS Testbed for Independent Performance and Security Analyses

Christian Zenger, Mario Pietersz, Andreas Rex, Jeremy Brauer, Falk-Peter Dressler, Christian Baiker, Daniel Theis, Christof Paar, Ruhr Universität Bochum, Germany

In this paper, we present a Wireless Physical Layer Security (WPLS) testbed implementation to evaluate the performance and security of Channel-Reciprocity based Key Extraction (CRKE). The testbed is based on off-the-shelf hardware and utilizes the IEEE 802.15.4 communication standard for key extraction and secret key rate estimation in real-time. The testbed can include generically multiple transceivers to simulate legitimate parties or eavesdropper. We believe the testbed is a good first step to provide a way to compare WPLS research results. As an example, we present evaluation results of several test cases we performed, while we are focusing on attack scenarios.

MA1b-3 11:05 AM

Learning and Secrecy in 5G Networks

Matthieu Bloch, Georgia Institute of Technology, United States; Aylin Yener, The Penn State University, United States

In this paper, we study how learning the wireless environment, e.g., through the deployment of sensor nodes, helps achieve secrecy at the physical-layer of 5G wireless networks. In particular, we show that secrecy is achievable even in the presence of active attackers subject to mild constraints on the channel model.

MA1b-4 11:30 AM

A Complete Stealthy Communication System

Pin-Hsun Lin, Carsten R. Janda, TU Dresden, Germany; Rafael F. Schaefer, Technische Universität Berlin, Germany; Eduard A. Jorswieck, TU Dresden, Germany

In this talk we will discuss how to construct a stealthy communication system when Bob's channel is worse than Charlie's. In this model, additional keys are needed to guarantee the stealth communication. Given such channel conditions, we analyze the achievable stealth communication rate and the required key rate. To construct a complete stealthy system, normal secret key generation (SKG) scheme is not feasible since normal public discussion will raise Charlie's attention. In contrast, we investigate a secret key generation scheme with an additional stealth constraint. Both rate-unlimited and rate-limited public discussion are considered. By such a construction, we can attain a completely stealthy communication even there is no channel advantage for the legitimate users over Charlie.

Track B – MIMO Communications and Signal Processing

Session: MA2b – Dirty-RF for Multi-User Massive-MIMO

Chair: ***Inbar Fijalkow,*** *ENSEA*

MA2b-1 10:15 AM

On Out-of-Band Emissions of Quantized Precoding in Massive MU-MIMO-OFDM

Sven Jacobsson, Giuseppe Durisi, Chalmers University of Technology, Sweden; Mikael Coldrey, Ericsson, Sweden; Christoph Studer, Cornell University, United States

Massive multi-user multiple-input multiple-output (MU-MIMO) is expected to be a core technology for fifth-generation (5G) wireless systems. In order to reduce the power and costs of the required radio-frequency (RF) circuitry in MU-MIMO base-stations with hundreds or thousands of antennas, a number of recent papers suggested the use of low-precision digital-to-analog converters (DACs). Such low-precision DACs, however, cause out-of-band (OOB) emissions which may interfere with other systems that communicate in nearby frequencies or even violate spectrum regulations. In this paper, we analyze the impact of the DAC resolution and the oversampling ratio on OOB emissions in orthogonal frequency-division multiplexing (OFDM)-based massive MU-MIMO systems.

MA2b-2 10:40 AM

Per-Antenna Hardware Optimization and Mixed Resolution ADCs in Uplink Massive MIMO

Daniel Verenzuela, Emil Björnson, Linköping University, Sweden; Michail Matthaiou, Queen's University Belfast, United Kingdom

Massive MIMO is a key candidate for 5G wireless communication systems for its ability to increase the spectral efficiency (SE) and energy efficiency (EE) by virtue of spatial multiplexing. Due to the large number of antennas at the base stations (BSs), the use of low quality hardware is essential for scalability, low-cost implementation, and low power consumption. It has been shown that the distortions introduced by low quality hardware can be mitigated by increasing the number of BS antennas. The use of low resolution analog-to-digital converters (ADCs) reduces the power consumption while introducing undesired distortions and a trade-off exists between the number of BS antennas and the ADC resolution. This work analyzes the effect of having mixed resolution ADCs across the BS antenna elements in terms of SE and EE. A closed-form achievable rate is derived and used to optimize the ADC resolution at each radio frequency chain.

MA2b-3 11:05 AM

Predistortion Techniques for Vector Perturbation Precoding of One-Bit Massive-MIMO

Inbar Fijalkow, ETIS, Université Paris Seine, Université de Cergy-Pontoise, ENSEA, CNRS, France; A. Lee Swindlehurst, University of California, Irvine, United States

Massive MIMO (mMIMO) aims to build wireless base stations with hundreds of coherently operating antennas serving tens of single antenna users in order to improve the capacity by a factor 10-50 and the energy-efficiency trade-off by up to a thousand times. One-bit quantized precoding has been proposed to efficiently handle the RF front-end when the array is implemented with so many antennas. In this paper, we generalize peak power reduction techniques such as active constellation extension (ACE) to perform symbol vector perturbation prior to the one-bit quantization. The resulting one-bit quantization of the perturbed vector provides a non-linear precoding with low complexity. Our simulations show that it outperforms both one-bit quantized Zero-Forcing and the much more complex vector perturbation precoding.

MA2b-4 11:30 AM

Directional Timing Synchronization in Wideband Millimeter Wave Cellular Systems with Low-Resolution ADCs

Dalin Zhu, Robert Heath, University of Texas at Austin, United States

In this paper, a new multi-beam probing strategy is proposed and evaluated for directional timing synchronization in wideband millimeter-wave (mmWave) cellular systems with low-resolution analog-to-digital converters (ADCs). The synchronization signals for the timing position estimation are beamformed by the base station to provide sufficient link margin. The corresponding quantization loss is formulated by accounting for both the spatial correlation induced by the directional beamforming and the distribution of the synchronization signals samples. To improve the synchronization performance, the synchronization signals are custom designed and transmitted across a cluster of simultaneously probed beams using multiple transmit radio frequency (RF) chains. Specifically, the beam cluster consists of an anchor beam and a plurality of auxiliary beams, which are selected from the beam codebook to maximize the corresponding received signal-to-noise-plus-quantization ratio (SNQR). A low-complexity trellis

exploration algorithm is developed as well for practical implementation of the proposed algorithm. Numerical results reveal that for wideband mmWave cellular systems with low-resolution ADCs, the timing synchronization performance of the proposed approach outperforms the conventional directional synchronization method for various system assumptions.

Track C – Networks

Session: MA3b – Graph Signal Processing

Co-Chairs: ***Pierre Borgnat,*** *Centre National de la Recherche Scientifique* ***and Nicolas Tremblay,*** *GIPSA-lab Grenoble Images Parole Signal Automatique*

MA3b-1 10:15 AM

Analyzing the Approximation Error of the Fast Graph Fourier Transform

Luc Le Magoarou, b<>com, France; Nicolas Tremblay, CNRS, France; Rémi Gribonval, INRIA Rennes Bretagne-Atlantique, France

The graph Fourier transform (GFT) is in general dense and requires O(N^2) time to compute and O(N^2) memory space to store. In this paper, we pursue our previous work on the approximate fast graph Fourier transform (FGFT). The FGFT is computed via a truncated Jacobi algorithm, and is defined as the product of J Givens rotations (very sparse orthogonal matrices with only 4 non-null elements). The truncation parameter, J, represents a trade-off between precision of the transform and time of computation (and storage space): for instance, if J = O(N^2), the FGFT is exactly the GFT, but there is no computational gain compared to the GFT. We will here explore the case of J = O(N log N) (mimicking the classical FFT), and study, on different types of graphs, the approximation error caused by the truncation.

MA3b-2 10:40 AM

Tropical Graph Signal Processing

Vincent Gripon, IMT Atlantique, France

For the past few years, the domain of graph signal processing has extended classical Fourier analysis to domains described by graphs. Most of the results were obtained by analogy with the study of heat propagation. We propose to perform a similar analysis in the context of tropical algebra, widely used in theoretical computer science to monitor propagation processes over graphs of distances. We introduce a Tropical Graph Fourier Transform and prove a few results on graph inference and the existence of a tropical uncertainty principle. Index Terms—graph signal processing, tropical algebra, graph

MA3b-3 11:05 AM

Tree-structured filter banks for M-block cyclic graphs

Aamir Anis, University of Southern California, United States; David B.H. Tay, LaTrobe University, Australia; Antonio Ortega, University of Southern California, United States

In this paper, we consider the problems of sampling and reconstruction of signals on M-block cyclic graphs. These graphs arise naturally in various applications to model periodic Markov chains and decision processes. The special structure in the adjacency matrix of such graphs results in the existence of modulation behavior in the eigenvalues and eigenvectors. We exploit this property to identify signals and sampling sets that allow perfect recovery, along with efficient methods for reconstruction. The proposed approach is experimentally evaluated for approximate value iteration techniques on periodic Markov decision processes.

MA3b-4 11:30 AM

Predicting the Evolution of Stationary Graph Signals

Andreas Loukas, École Polytechnique Fédérale de Lausanne, Switzerland; Elvin Isufi, TU Delft, Netherlands; Nathanael Perraudin, École Polytechnique Fédérale de Lausanne, Switzerland

A recent way of tackling the dimensionality issues arising in the modeling of a multivariate process is to assume that the inherent data structure can be captured by a graph. We here focus on the problem of predicting the evolution of a process that is time and graph stationary, i.e., a time-varying signal whose first two statistical moments are invariant over time and correlated to a known graph topology. This stationarity assumption allows us to regularize the estimation problem, reducing the variance and computational complexity, two common issues plaguing standard vector autoregressive (VAR) models. In addition, our method compares favorably to state-of-the-art graph- and time-based methods: it yields similar accuracy to a linear mean squared error estimator at a lower complexity, and outperforms previous graph causal models, as well as a purely time-based method.

Track D – Signal Processing and Adaptive Systems

Session: MA4b – Nonconvex Optimization

Chair: ***Gongguo Tang,*** *Colorado School of Mines*

MA4b-1 — 10:15 AM

When and Why are Nonconvex Optimization Problems Not Scary?

Ju Sun, Stanford University, United States; Qing Qu, John Wright, Columbia University, United States

Nonconvex optimization plays an important role in problem-solving across science and engineering. In theory, even guaranteeing a local minimizer is NP-hard. In practice, more often than not, simple iterative methods work surprisingly well in specific applications. In this talk, I will describe a family of nonconvex problems that can be solved to global optimality using simple iterative methods, which are ``initialization-free''. This family has the characteristic structure that (1) all local minimizers are global, and (2) all saddle points have non-degenerate Hessians. Examples lying in this family arise from applications such as learning sparsifying basis for signals (aka sparse dictionary learning), and recovery of images from phaseless measurements (aka generalized phase retrieval). In both examples, the benign global structure allows us to derive novel performance guarantees. Completing and enriching this framework is an active research endeavor undertaken by several research communities. The ultimate goal is to enable practitioners to deploy the theory and computational tools with a minimal amount of efforts, paralleling convex analysis and optimization. I will highlight open problems to be tackled to move forward. Joint work with Qing Qu (Columbia) and John Wright (Columbia). More details can be found in my PhD thesis under the same title.

MA4b-2 — 10:40 AM

Matrix Completion, Saddlepoints, and Gradient Descent

Jason Lee, University of Southern California, United States

Matrix completion is a fundamental machine learning problem with wide applications in collaborative filtering and recommender systems. Typically, matrix completion are solved by non-convex optimization procedures, which are empirically extremely successful. We prove that the symmetric matrix completion problem has no spurious local minima, meaning all local minima are also global. Thus the matrix completion objective has only saddlepoints an global minima. Next, we show that saddlepoints are easy to avoid for even Gradient Descent -- arguably the simplest optimization procedure. We prove that with probability 1, randomly initialized Gradient Descent converges to a local minimizer. The same result holds for a large class of optimization algorithms including proximal point, mirror descent, and coordinate descent.

MA4b-3 — 11:05 AM

Regularized Gradient Descent: A Nonconvex Recipe for Fast Joint Blind Deconvolution and Demixing

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

We study the question of extracting a sequence of functions $\{f_i,g_i\}_{i=1}^s$ from observing only the sum of their convolutions, i.e., from $y=\sum_{i=1}^s = f_i\ast g_i$. While convex optimization techniques are able to solve this joint blind deconvolution-demixing problem provably and robustly under certain conditions, for medium-size or large-size problems we need computationally faster methods without sacrificing the benefits of mathematical rigor that come with convex methods.
In this paper, we present a non-convex algorithm which guarantees exact recovery under conditions that are competitive with convex optimization methods, with the additional advantage of being computationally much more efficient. Our two-step algorithm converges to the global minimum linearly and is also robust in the presence of additive noise. While the derived performance bounds are suboptimal in terms of the information-theoretic limit, numerical simulations show remarkable performance even if the number of measurements is close to the number of degrees of freedom. We discuss an application of the proposed framework in wireless communications in connection with the Internet-of-Things.

MA4b-4 — 11:30 AM

A Provable Method for Sparse CPD/PARAFAC Tensor Decomposition

Sirisha Rambhatla, Di Xiao, Jarvis Haupt, Nicholas D. Sidiropoulos, University of Minnesota-Twin Cities, United States

Recent provable algorithms for dictionary learning offer promising approaches for analyzing non-convex objectives arising in other application domains. In this work, we present a provable dictionary learning based algorithm for exact recovery of the canonical polyadic decomposition (CPD)/PARAFAC factors of a 3-way tensor, wherein two of the factors are assumed sparse. Specifically, we model tensor decomposition as a sparse coding problem, and analyze the conditions on sparsity, incoherence and sample complexity, under which these factors can be recovered exactly.

Session: MA5b – Theory for Next Generation Radar Systems

Chair: ***Waheed Bajwa,*** *Rutgers University*

MA5b-1 10:15 AM

Joint Radar-Communications Waveform Multiple Access and Synthetic Aperture Radar Receiver

Andrew Herschfelt, Daniel Bliss, Arizona State University, United States

Radar and communications systems are often deployed in already crowded environments. The growing demand for additional communications users in frequency bands previously reserved for radar users motivates cooperation between these systems. One solution to the problem of radar-communications coexistence is to develop joint systems that simultaneously perform both tasks. One aspect of this co-design solution is to design waveforms simultaneously suitable for both systems' goals. Using a joint radar-communications waveform promises mutually beneficial performance gains while limiting spectral impact. We develop and simulate an example multiple access channel topology in which users simultaneously communicate and perform synthetic aperture radar imaging with a joint waveform. A joint radar-communications receiver is designed in the context of this example and shown to feasibly accomplish both systems' goals with a single waveform.

MA5b-2 10:40 AM

Demonstrating Significant Passive Radar Performance Increase Through using Known Communication Signal Format

Yonggang Wu, Qian He, Jianbin Hu, University of Electronic Science and Technology of China, China; Rick Blum, Lehigh University, United States

In order to determine if passive radar performance can be good enough to allow passive radars to take the place of active radars, we seek the ultimate limits of passive radar performance. The focus is on the case where the radars are employed for estimating the position and velocity of a target. Further, the passive radar employs several dispersed existing communication transmitters, which could be cellular base stations. We compare the Cramer-Rao bound (CRB) for an active radar with the CRB for a passive radar under various amounts of prior information concerning the transmitted signals. The mean-square-error of maximum likelihood estimation is presented to provide the threshold at which the estimation performance approaches the CRB. One important result shows that if we know the employed transmitted signals are of known form, for example those coming from GSM base stations, but contain unknown bits, then under reasonable models the passive radar can estimate the bits and ultimately achieve target estimation performance that is very close to that of the active radar. Estimation performance for a number of other interesting cases with less information shows considerable performance loss.

MA5b-3 11:05 AM

Weighted Sparse Bayesian Learning (WSBL) with Application to MIMO Radar Using Sparse Sensing

Ahmed Al Hilli, Rutgers University, USA and Al furat Al Awsat Technical Collage, Iraq; Athina Petropulu, Rutgers, The State University of New Jersey, United States

Sparse Bayesian Estimation (SBE) methods estimate a sparse vector by maximizing the posterior distribution and using sparsity inducing priors. In prior SBE works, all hyper-parameters priors are assumed to follow the product of Gamma distributions with the same parameters. In this paper, we propose to assign different parameters to each hyper-parameter, giving more importance to some hyper-parameters over others. The relative importance of the hyper-parameters is determined based on an approximation of the underlying sparse vector, for example, based on a low resolution estimate of it. We call the proposed approach Weighted Sparse Bayesian Learning (WSBL) approach. We apply WSBL for target tracking in MIMO radar with sparse sensing. Simulations show improved performance as compared to the traditional SBL in terms of probability of detection and false alarm.

MA5b-4 11:30 AM

Through-The-Wall Radar Imaging using a Distributed Quasi-Newton Method

Haroon Raja, Waheed U. Bajwa, Rutgers University, United States; Fauzia Ahmad, Temple University, United States

This paper considers a distributed network of radars for accurate indoor scene reconstruction in the presence of multipath propagation. A sparsity based method is proposed for eliminating ghost targets under imperfect knowledge of interior wall locations. Instead of aggregating and processing the observations at a central fusion station, joint scene reconstruction and estimation of interior wall locations is carried out in a distributed manner across the network. In centralized settings, quasi-Newton method has been shown to work well for solving wall location estimation problem. Recently, extensions of quasi-Newton methods have been proposed for nonconvex optimization problems and a distributed variant of quasi-Newton method has been

proposed for convex optimization problems. In this paper we will use ideas from both these directions and develop a distributed variant of quasi-Newton method to obtain global solution of the wall location estimation problem which is a nonconvex optimization problem. Finally, we will provide simulations for TWRI problem to show the efficacy of proposed algorithm.

Track F – Biomedical Signal and Image Processing

Session: MA6b – Signal Processing-Enhanced Biomedical Instrumentation

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

MA6b-1 10:15 AM

A Real-Time Rodent Neural Interface for Deciphering Acute Pain Signals from Neuronal Ensemble Spike Activity

Sile Hu, Zhejiang University, China; Qiaosheng Zhang, Jing Wang, Zhe Chen, New York University School of Medicine, United States

In recent years, brain machine interfaces have attracted accumulating interest with goals to map, assist, augment or repair the cognitive or sensory-motor functions of human and animal brains. Pain is a common experience in our daily lives. Developing a demand-based pain management or modulation system requires timely detection of pain signals and temporally precise, effective neuromodulation. To improve our understanding of neural mechanisms of nociceptive pain, we developed a novel rodent neural interface to study the role of neural circuits for encoding acute pain. Our neural interface is aimed at integrating (i) the detection of acute pain signals based on simultaneously recorded ensemble spike activity from multiple brain areas and (ii) neuromodulation based on the closed-loop feedback. The current paper focuses on the detection of pain signals using neural ensemble spike activity.

MA6b-2 10:40 AM

Real-Time, Data-Driven Algorithm and System to Learn Parameters for Pacemaker Beat Detection

Yamin Arefeen, Philip Taffet, Daniel Zdeblick, Jorge Quintero, Greg Harper, Behnaam Aazhang, Joseph Cavallaro, Rice University, United States; Mehdi Razavi, Texas Heart Institute, United States

While beat detection in a Cardiac Electrical Signal (CES) is a well-studied problem, we propose a novel algorithm for implementation in pacemakers that learns the heights and widths of atrial and ventricular peaks from processing a few seconds of cardiac data sampled at 1 kHz. This purely data-driven solution to learn the parameters of atrial and ventricular peaks will allow pacemakers to set their own detection parameters and adaptively tune the parameters over time for that specific patient. We have validated our algorithm on one minute of cardiac electrical signal data from 51 separate channels, coming from 17 electrodes connected directly to cardiac tissue on each of three separate animals. Additionally, we have implemented the algorithm on a Field Programmable Gate Array and tested it on an ex-vivo rat heart to illustrate that our algorithm can run in real-time on commodity hardware.

MA6b-3 11:05 AM

On Developing an FPGA Based System for Real Time Seizure Prediction

Sarah Hooper, Erik Biegert, Marissa Levy, Justin Pensock, Luke Van der Spoel, Xiaoran Zhang, Tianyi Zhang, Rice University, United States; Nitin Tandon, University of Texas Health Science Center, United States; Behnaam Aazhang, Rice University, United States

For the purposes of designing a neurostimulator system meant to predict and suppress seizures in patients with epilepsy, we have developed a one-class support vector machine (SVM) learning algorithm that accurately predicts upcoming seizures. Trained on patient intracranial electroencephalography (iEEG) data, our algorithm has a high seizure prediction sensitivity while maintaining an acceptably low number of false positives. In order to transition this algorithm to an implantable clinical device, the hardware solution must draw minimal power and conform to a small form factor. With the end goal of designing and fabricating an application specific integrated circuit (ASIC), we have implemented our machine learning algorithmic pipeline on a field programmable gate array (FPGA). This FPGA implementation runs on real-time patient data and maintains all performance specifications.

MA6b-4 11:30 AM

Use of Adaptive Filtering for Improved Performance in Digital Stethoscopes

Donald Hall, Mathew Mctaggart, William Jenkins, Pennsylvania State University, United States

This paper proposes the use of adaptive filtering in digital stethoscopes to lay the foundation towards future growth of heart rate calculations on an LPCXpresso54608 board. The incorporation of the developed algorithms on the device shall lead to an accurate digital stethoscope for the medical industry, at a more reasonable price point at $140. In turn, the device will alleviate noisiness accompanied by the traditional stethoscope and lead towards more precise readings of the components associated with a user's heart, generated in real-time. The implementation of the developed algorithm for adaptive noise cancellations within the digital stethoscope will be a groundbreaking solution to a problem that industry has yet to solve.

Track G – Architecture and Implementation

Session: MA7b – Dynamically Scheduled High-Level Synthesis

Co-Chairs: ***Paolo Ienne,*** *EPFL, Switzerland* ***and Philip Brisk,*** *University of California, Riverside*

MA7b-1 10:15 AM

A Hierarchical Mathematical Model for Automatic Pipelining and Allocation using Elastic Systems

Jordi Cortadella, Jordi Petit, Universitat Politècnica de Catalunya, Spain

Elasticity enables the use of handshake signals to implement computing systems with variations in computation and communication delays. This flexibility also enables the exploration of different architectures for the implementation of a system with different area-performance metrics. The presentation will show how elastic transformations can be applied to optimize timing and area by automatically pipelining the system and selecting the most efficient functional unit for each computation. A hierarchical MILP model is proposed to perform the exploration and find optimial solutions according to different area-performance trade-offs.

MA7b-2 10:40 AM

From C to Elastic Circuits

Lana Josipovic, École Polytechnique Fédérale de Lausanne, Switzerland; Philip Brisk, University of California, Riverside, Switzerland; Paolo Ienne, École Polytechnique Fédérale de Lausanne, Switzerland

Most high-level synthesis tools rely on static scheduling techniques. However, when the disambiguation of memory accesses is not possible before execution, static methods must assume that a dependency exists and produce an inferior schedule, even though, perhaps, there is rarely or even never an actual dependence. In contrast, circuit design techniques that apply dynamic scheduling allow analyzing data dependencies at runtime and stalling the execution only in the presence of effective data or control hazards. In this work, we discuss the challenges of synthesizing dynamic (latency-insensitive) designs from high-level circuit specifications and compare our circuit generation strategy to traditional HLS.

MA7b-3 11:05 AM

Run Fast When You Can: Loop Pipelining with Uncertain and Non-uniform Memory Dependencies

Junyi Liu, John Wickerson, Imperial College London, United Kingdom; Samuel Bayliss, Xilinx, United States; George Constantinides, Imperial College London, United States

As a key optimization method in high-level synthesis (HLS), high-performance loop pipelining is enabled by the static scheduling algorithm. When there are non-trivial memory dependencies in the loop, current HLS tools have to apply conservative pipeline schedule that also leads to nearly sequential execution. In this paper, we demonstrate using parametric polyhedral model to mathematically capture uncertain (i.e., parameterised by an undetermined variable) and/or non-uniform (i.e., varying between loop iterations) memory dependence patterns. According to this static analysis, if we always execute the loop with an aggressive (fast) pipeline schedule, we can generate the parameter conditions in which this execution is safe and the parametric break points when the execution encounters memory conflicts. Then, we apply these information into an automated source-to-source code transformation, which implements parametric loop pipelining and loop splitting. The transformed loop is synthesised by Vivado HLS and its execution speed can be adjusted at runtime to avoid memory conflicts. The experiments over a set of benchmark loops show that our optimization can improve the runtime pipeline performance significantly with a reasonable overhead of hardware resources.

MA7b-4 **11:30 AM**

Adaptive Loop Pipelining in High-Level Synthesis

Zhiru Zhang, Steve Dai, Gai Liu, Ritchie Zhao, Cornell University, United States

Loop pipelining is extensively used in modern high-level synthesis (HLS) tools to achieve high performance by overlapping execution of successive loop iterations. Conventional loop pipelining techniques in HLS replies on compile-time analysis to generate a pipeline that operates with a fixed, statically determined schedule. However, this approach must conservatively assume the worst-case scenario of any data-dependent compute or data access behavior, which may result in unnecessary degradation in performance and resource utilization. To address this challenge, we are investigating a set of new synthesis techniques to enable adaptive pipelining which can effectively handle (1) variable-latency memory accesses, (2) work imbalance due to dynamic loop bounds, and (3) infrequent data and structural hazards. Our experiments targeting FPGA platforms have led to promising improvement in quality of results of across a suite of application kernels and real-life designs.

Track D – Signal Processing and Adaptive Systems

Session: MA8b1 – Detection, Classification, and Tracking 10:15 AM–11:55 AM

Chair: ***Marco Duarte,*** *University of Massachusetts Amherst*

MA8b1-1

Scheduling Variable Field-of-View Sensors for Tracking Multiple Objects

Joao Cabrera, BAE Systems, United States

We propose the field-of-view of a sensor as a parameter to be controlled in real time to improve tracking performance. In contrast to earlier contributions, we take into account the measurement origin uncertainty in selecting the on-line sensor schedule. Two objects and two viewing modes are considered. The trace of the sum of approximations to the predicted covariances of the objects are used to select the mode at each instant of time; these approximations take into account the probability of target detection and the probability of false alarm. Simulations illustrate the superiority of the policy in comparison with fixed policies.

MA8b1-2

Automatic Modulation Classification Via Symbolic Representations of Complex Time Series Data

Eric Ruzomberka, Purdue University, United States; Gary H. Whipple, Laboratory for Telecommunication Sciences, United States; Catherine M. Keller, Bruce MacLeod, MIT Lincoln Laboratory, United States

Automatic modulation classification (AMC) is of interest for spectrum sensing and network coexistence applications, and it is desirable to find AMC techniques that work with limited computational complexity and memory. This work is an initial exploration of how to apply existing dimensionality reduction symbolic representation approaches for real-valued time series, that claim computational and memory efficiency in data mining and other applications, to feature-based automatic modulation classification of complex-valued time series data. This initial investigation shows that it is feasible to apply these symbolic representation techniques to automatic modulation classification problems with promising performance. Future work needs to be done to refine the approach and to compare the computational complexity and storage efficiency to other techniques.

MA8b1-3

Resolving Occlusion Ambiguity by Combining Kalman Tracking with Feature Tracking for Image Sequences

Mark Heimbach, Kamak Ebadi, Sally Wood, Santa Clara University, United States

Although object tracking based on Histogram-of-Oriented-Gradients (HOG) descriptors is highly successful, it may fail to track an object that is partially or fully obscured. Multiple objects of similar appearance in a scene may cause the feature detector to mistakenly capture a second occluding object. Adding a Kalman filter to track the motion of the desired object will target the area for highest probability of reacquisition when visibility of the object is reduced. The probability of capturing another object on a different trajectory is reduced also. Models of HOG measurement noise based on detection confidence are developed for the Kalman filter.

MA8b1-4

Detector design using Item Response Theory with applications to Active Insider Threat Detection

Jayakrishnan Unnikrishnan, Zhihui Yang, Satish Iyengar, General Electric Global Research, United States; Susan Embretson, Georgia Institute of Technology, United States

Item response theory (IRT) is a paradigm traditionally used in the design, analysis and scoring of tests and questionnaires. We adapt advanced techniques in IRT to design detectors that monitor discrete measurements from entities and changes in the measurements as a response to an event occurring at a known time. These detectors have the added advantage that they can explicitly model the context in which different measurements are obtained, and can quantify the response of each entity in relation to others in the study. We apply this method to an active insider threat detection system and demonstrate their effectiveness as a detector for detecting behavioral responses to external events.

MA8b1-5

Efficient and Robust Classification of Seismic Data using Nonlinear Support Vector Machines

Kyle Hickmann, Jeffrey Hyman, Gowri Srinivasan, Los Alamos National Laboratory, United States

We characterize the robustness and scalability of nonlinear Support Vector Machines (SVM) combined with kernel Principal Component Analysis (kPCA) for the classification of nonlinearly correlated data within the context of geo-structure identification using seismic data. Classification through pattern recognition using supervised learning algorithms such as SVM is popular in many fields. However, the suitability of such methods for classifying seismic data is severely hampered by assumptions of linearity (linear SVM), which affects accuracy, or computational limitations with increases in data dimension (nonlinear SVM). We propose a classification method for seismic data that is accurate with low computational burden. We quantify trade off between accuracy and required computational time of this approach to classify nonlinearly correlated seismic data which performs nonlinear SVM in a reduced dimensional space determined using kPCA. The utility of the method is demonstrated by characterizing the geologic structure using synthetically generated seismograms. We observe that our method produced a more efficient and robust classifier for seismic data than standard nonlinear SVM with only 10% of the entire feature space used for the training set. We also observe a greater than five times speedup in computational time between the optimal performance and standard nonlinear SVM.

MA8b1-6

Feature Based Order Recognition of Continuous-Phase FSK using Principal Component Analysis

Ambaw Ambaw, Miloš Doroslovacki, George Washington University, United States

Principal component analysis (PCA) is a technique that performs a linear transformation on the input space to align directions of maximum variation with the directions of the axises. In this paper, we study the feasibility of principal component analysis based order recognition of continuous phase FSK. The approximate entropy (ApEn) of the received signal, ApEn of the phase of the received signal, and ApEn of the instantaneous frequency of the received signal are used as a set of distinguishing features. The work aims in devising an unsupervised learning algorithm under noisy, carrier frequency offset and fast fading channel conditions. Performance of principal component based method is compared to stacked autoencoder (SAE) based approach which is more computationally complex technique that can model relatively complicated relationships and non-linearities. For fair comparison both the PCA and SAE based methods use approximate entropy features. The benefit of employing PCA is that after PCA transformations the computation cost can really be decreased a lot. Also, no a priori information is required about carrier phase, symbol rate and carrier amplitude.

MA8b1-7

Nonstationary Linear Discriminant Analysis

Shuilian Xie, Mahdi Imani, Edward Dougherty, Ulisses Braga-Neto, Texas A&M University, United States

Changes in population distributions over time are common in many applications. However, the vast majority of statistical learning theory takes place under the assumption that all points in the training data are identically distributed (and independent), that is, nonstationarity of the data is disregarded. In this paper, a version of the classic Linear Discriminant Analysis (LDA) classification rule is proposed for for nonstationary data, using a linear-Gaussian state space model. This Nonstationary LDA (NSLDA) classification rule is based on the Kalman Smoother algorithm to estimate the evolving population parameters. In the case the dynamics of the system are not fully known, a combination of the Expectation- Maximization (EM) algorithm and the Kalman Smoother is employed to simultaneously estimate population and state- space equation parameters. Performance is

assessed in a set of numerical experiments using simulated data, where the average error rates obtained by NSLDA are compared to the error produced by a naive application of LDA to the pooled nonstationary data. Results demonstrate the promise of the proposed NSLDA classification rule.

MA8b1-8
Bayesian Kalman Filtering in the Presence of Unknown Noise Statistics Using Factor Graphs

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

We propose an optimal Bayesian Kalman filtering framework that provides optimal performance relative to the posterior distribution of unknown noise parameters obtained from incorporating data into the prior distribution. The structure of the proposed filter is similar to that of classical Kalman filtering except the use of posterior effective noise statistics. We introduce a factor-graph-based approach to compute the likelihood function required for computing the posterior effective statistics. The performance of the proposed method is verified by applying it to a target tracking example.

Track H – Speech, Image and Video Processing

Session: MA8b2 – Video and Image Processing 10:15 AM–11:55 AM

Chair: ***Sally Wood,*** *Santa Clara University*

MA8b2-1
Adaptive Search Pattern for Fast Motion Estimation in Video

Pavel Arnaudov, Tokunbo Ogunfunmi, Santa Clara University, United States

Motion estimation consumes the major part of time and power in both video compression standards – HEVC and H.264. This paper presents a Fast Motion Estimation algorithm, which learns the best search pattern depending on the video sequence. That maximizes the quality of the Motion Vectors, while preserving the speed of Fast Motion Estimation without any memory usage. The algorithm is not HEVC or H.264 specific and thus can be used by either one.

MA8b2-2
Monocular Vehicle Distance Sensor Using HOG and Kalman Tracking

Marcos Gonzalez, Jerry Hsu, Robert Christiansen, Sally Wood, Santa Clara University, United States

Reliable measurement of the ground distance between a host vehicle and nearby vehicles is needed for driver assistance and collision avoidance systems. Although LIDAR sensors provide accurate information over a narrow field-of-view, a single camera system could provide a more versatile, lower cost alternative. A trained HOG feature detector locates vehicles in each image frame and bounding box information provides measurement input to a Kalman filter tracker. Measurement variance for a specific camera and a feature detector is modeled as a Gaussian distribution, confirmed by comparison with LIDAR measurements, combined with a wide distribution due to feature detector error.

MA8b2-3
Human Activity Classification from Wearable Devices with Cameras

Yantao Lu, Senem Velipasalar, Syracuse University, United States

There have been many approaches for human activity classification relying on accelerometer sensors, or cameras installed in the environment. There are relatively less works using egocentric videos. Accelerometer-only systems, although computationally efficient, are limited in the variety and complexity of the activities that they can detect. For instance, we can detect a sitting event by using accelerometer data from a smart phone, but cannot determine whether the user has sat on a chair or sofa, or what type of environment the user is in. In order to detect activities with more details and context, in this paper, we present a robust and autonomous method using both accelerometer and camera data obtained from a smart phone. A multi-class SVM is used to classify activities by using accelerometer data and optical flow vectors. Objects in the scene are detected from camera data by using an ACF-based detector. Another multi-class SVM is used to detect approaching different objects. Then, an HMM is employed to detect more complex activities. Experiments have been performed with subjects performing activities of sitting on chairs, sitting on sofas, and walking through doorways. The proposed method achieves overall precision and recall rates of 95% and 89%, respectively.

MA8b2-4

Bayer Feature Map Approximation through Spatial Pyramid Convolution

Allen Rush, Sally Wood, Santa Clara University, United States

Feature extraction is a key element of object detection and classification. In Convolutional Neural Networks, feature maps are used to identify and successively refine candidate features in order to ultimately determine classification results. When using just raw bayer data we show that a set of suitable kernels can be designed to create the first layer feature maps based on the pyramid representation of the image data. We show that this version of estimating feature maps based on original ground truth data reduces the need for finding full resolution, interpolated color plane versions of the image (demosaic). Index Terms—HOG, Bayer Pattern, Keypoints, Edge Detection, CNN, Feature Maps, Region Proposal Net, Receptive fields

MA8b2-5

Photometric Warp-based SFSR with Application to Infrared Image Processing

James Glenn-Anderson, Supercomputer Systems, Inc., United States

In this paper we consider a new Single Frame Super-Resolution (SFSR) algorithm targeting streaming infrared video applications. Here, use of SFSR facilitates preservation of image-sharpness across scale. This is of particular relevance to far-infrared imaging where source images are characteristically of low resolution, low contrast, and possessed of diffraction limited acutance. Under circumstances where SFSR is effective, advantage may be gained with tradeoff of algorithmic scaling properties whereby processing at high resolution is instead performed at low resolution followed by substitution of an SFSR kernel possessed of a lower time-space complexity. The SFSR formalism described in this work is based upon a photometric similarity principle uniformly applied to image edge-content per an assumed structural model. The associated algorithmic kernel is further characterized by a set of operators each of which is equivalent to a nonlinear filter parametrically dependent upon local diffeomorphic structure, the precise calculation of which is critical to SFSR performance. In what follows, this photometric warp based SFSR is shown highly effective when applied to upscaling of infrared camera capture data. Overall paper organization is as follows; (1) SFSR theoretical development, (2) algorithmic design, (3) implementation, (4) performance testbench design, and (5) discussion and summary.

MA8b2-6

Fast and Compact Kronecker-structured Dictionary Learning for Image Classification

Ishan Jindal, Matthew Nokleby, Wayne State University, United States

Kronecker-structured subspace models have proven efficient for representing and denoising multidimensional signals like images, tomographic data, and videos, but their use for signal classification has not received as much attention. In this paper, we develop a Kronecker-structured dictionary learning framework for representation and classification purposes that exploit the structure of the multidimensional signals. We evaluate the performance of proposed framework on Extended YaleB face recognition dataset and compare the results with standard dictionary learning models. The Kronecker-structured dictionaries improve the classification performance by around 5% over general subspace models, and are competitive with dictionaries learned from SIFT features even without feature extraction. Furthermore, Kronecker-structured dictionaries offer a more compact representation of signal classes, packing in more atoms with no more than 5% of the storage requirements of standard subspace models.

MA8b2-7

Automatic Fog Detection in Day and Night Images to Improve Highway Driving Conditions

Victor DeBrunner, Jigar Patel, Florida State University, United States

We present a computationally simple approach for using a local sharpness measure obtained from a highway camera image to estimate the visibility an automobile driver would have in fog. Our intention is for the system to use already existing cameras to reduce traffic accidents. We normalize the images for ambient lighting (night and day images), and examine the performance for different scales. Our approach significantly simplifies the 9 statistics used by Choi, You, and Bovik in their approach to this problem, and we appear to achieve similar performance.

MA8b2-8
Superpixels Based Marker Tracking Vs. Hue Thresholding In Rodent Biomechanics Application
Omid Haji Maghsoudi, Annie Vahedipour Tabrizi, Benjamin Robetrson, Andrew Spence, Temple University, United States

Examining locomotion has improved our basic understanding of motor control and aided in treating motor impairment. Mice and rats are premier models of human disease and increasingly the model systems of choice for basic neuroscience. High frame rates (250 Hz) are needed to quantify the kinematics of these running rodents. Manual tracking, especially for multiple markers, becomes time-consuming and impossible for large sample sizes. Therefore, the need for automatic segmentation of these markers has grown in recent years. We propose two methods to segment and track these markers: first, using SLIC superpixels segmentation with a tracker based on position, speed, shape, and color information of the segmented region in the previous frame; second, using a thresholding on hue channel following up with the same tracker. The comparison showed that the SLIC superpixels method was superior because the segmentation was more reliable and based on both color and spacial information.

Track H – Speech, Image and Video Processing

Session: MA8b3 – Multimedia Processing Systems 10:15 AM–11:55 AM

Chair: ***Tokunbo Ogunfunmi,*** *Santa Clara University*

MA8b3-1
3D Mesh Robust Watermarking Technique for Ownership Protection
Farhan Alenizi, Prince Sattam bin Abdulaziz University, Saudi Arabia; Fadi Kurdahi, Ahmed Eltaweel, University of California, Irvine, United States

A 3d mesh blind optimized watermarking technique is proposed in this paper. The technique relies on the displacement process of the vertices locations depending on the modification of the variances of the vertices's norms. Statistical analysis were performed to establish the proper distributions that best fit each mesh, and hence establishing the bins sizes. Several optimizing approaches were introduces in the realms of mesh local roughness, the statistical distributions of the norms, and the displacements in the mesh centers. Experimental results showed that the approach is robust in terms of both the perceptual and the quantitative qualities. Moreover, it was also robust against both the geometry and connectivity attacks.

MA8b3-2
Fast Stochastic Hierarchical Bayesian MAP for Tomographic Imaging
John McKay, Pennsylvania State University, United States; Raghu Raj, Naval Research Laboratory, United States; Vishal Monga, Pennsylvania State University, United States

Any image recovery algorithm attempts to achieve the highest quality reconstruction in a timely manner. The former can be achieved in several ways, among which are by incorporating Bayesian priors that exploit natural image tendencies to cue in on relevant phenomena. The Hierarchical Bayesian MAP (HB-MAP) is one such approach which is known to produce compelling results albeit at a substantial computational cost. We look to provide further analysis and insights into what makes the HB-MAP work. While retaining the proficient nature of HB-MAP's Type-I estimation, we propose a stochastic approximation-based approach to Type-II estimation. The resulting algorithm, fast stochastic HB-MAP (fsHBMAP), takes dramatically fewer operations while retaining high reconstruction quality. We employ our fsHBMAP scheme towards the problem of tomographic imaging and demonstrate that fsHBMAP furnishes promising results when compared to many competing methods.

MA8b3-3
Nonlinear Image Interpolation via Deep Neural Network
Wentian Zhou, Xin Li, Daryl Reynolds, West Virginia University, United States

Model-based approaches toward image interpolation attempt to predict unknown pixels at the high-resolution (HR) from a given low-resolution (LR) image. In the past decade, various adaptive image interpolation methods have been develop aiming at better recovering important image structures such as edges and textures. However, those methods are all based on an implicit assumption about the linear relationship between LR and HR pixels partially due to the difficulty with modeling nonlinear relationship. In this paper, we propose to take an explicit learning-based approach toward modeling the nonlinear relationship between LR an HR pixels. A six-layer convolutional neural network with rectified linear units (ReLU) is presented and trained to learn the targeted nonlinear mapping from training data for image interpolation. Our experimental results have shown the proposed learning-based approach is often capable of achieving superior performance both subjectively and objectively to existing model-based methods.

MA8b3-4

On the Effects of Windowing on the Discretization of the Fractional Fourier Transform

Balu Santhanam, University of New Mexico, United States; Thalanayar Santhanam, Saint Louis University, United States; Satish Mandal, University of New Mexico, United States

The eigenvalue degeneracy problem inherent in the {\em discrete Fourier transform} (DFT) matrix operator and the development of a full basis of orthogonal eigenvectors have been addressed via a commuting matrix, devoid of the aforementioned eigenvalue degeneracy problem, that also serves as a discrete version of the Gauss-Hermite (G-H) differential operator. This G-H operator is however, is not bandlimited, and existing discretization efforts run into distortion problems that manifest as deviation from the ideal linear eigenvalue spectrum, aliasing in the eigenvectors, and as a non-invertible peak to parameter mapping associated with the discretization restricting its ability to uniquely represent multicomponent chirp signals. Existing approaches do not account for the effects of windowing on discretization. In this paper, we focus on distortion issues associated with the discretization of the G-H operator and their sources. We specifically analyze the discrete version of the G-H operator based on quantum mechanics in finite dimensions (QMFD), by computing its underlying peak to parameter mapping and its invertibility to subsequently present a representation of the operator with improved mapping invertibility via use of suitable windowing of the eigenvalue spectrum.

MA8b3-6

Effect of Random Vertical Orientation for Mobile Users in Visible Light Communications

Yusuf Said Eroglu, Yavuz Yapici, Ismail Guvenc, North Carolina State University, United States

In this paper, we study the effect of vertical user orientation in the error performance of point-to-point visible light communication (VLC) systems with randomly deployed mobile users. The random fluctuations in the vertical orientation is modeled statistically, and the corresponding channel distribution is derived analytically for both fixed and mobile user settings. Extensive Monte Carlo simulations verify our analytical framework by achieving a perfect match between the analytical and the simulation data in terms of both the statistical channel distribution and the resulting bit error rate (BER).

MA8b3-7

A Best-Features based Digital Rotoscope

Iain Murphy, Tyler Norlund, Vivek K. Pallipuram, University of the Pacific, United States

The paper presents a best-features based digital rotoscope to animate a video sequence. We assert that corners in an image are viable feature points for animation because they move appreciably across frames. The rotoscope processes a video sequence one frame at a time and comprises four stages namely, the background subtraction stage, two-phase Shi-Tomasi feature extraction stage, watershed segmentation stage, and the color palette stage. The background subtraction stage subtracts the background from the input image, isolating the foreground colors and producing an inverted image. The two-phase feature extraction stage performs two passes of corner detection on the inverted image to identify a user-defined number of best-features. The watershed segmentation stage uses the best-features as markers to segment the input frame. The color palette stage colors each one of the segments with the average of the input frame's color values in that segment, creating a rotoscoped frame. After processing all of the video frames, the digital rotoscope produces an animated movie. We study the impact of choosing different numbers of best-features on the animation quality. For a frame-size of 480x640x3, 1000 features or more produce effective animation. Our four-stage digital rotoscope also provides opportunities for parallel implementations for fast analysis.

MA8b3-8

Automatic Blind Source Separation of Speech Sources in an Auditory Scene

Kenneth Faller II, Jason Riddley, Elijah Grubbs, California State University, Fullerton, United States

Hearing-impaired individuals have much more difficulty, then normal hearing individuals, with speech intelligibility in cocktail party situations. Hence, the overall research goal is to improve intelligibility of speech and to enhance spatial hearing of hearing aids in these situations. It is known that spatial audio leads to improved speech intelligibility. As a step towards this goal, source separation algorithms were investigated. In particular, the DUET Blind Source Separation (BSS) algorithm was modified to automatically extract speech sources in a simulated auditory scene.

Track A – Communications Systems

Session: MP1a – Network Inference

Chair: ***Negar Kiyavash,*** *University of Illinois, Urbana-Champaign*

MP1a-1 1:30 PM

Seeded Graph Matching: Efficient Algorithms and Theoretical Guarantees

Farhard Shirani, NYU Tandon School of Engineneering, United States; Siddharth Garg, New York University, United States; Elza Erkip, NYU Tandon School of Engineneering, United States

The well-known graph isomorphism problem asks the following question: Given two unlabeled graphs, is there a permutation between the node sets of the graphs such that edges perfectly align? The imperfect alignment problem, often called graph matching, attempts to find a permutation that minimizes a defined distance between the adjacency matrices of the two graphs, where the distance is commonly taken as the number of edge mismatches. Graph matching has numerous applications including de-anonymization attacks on social networks and computer vision. The problem, in its original form, is NP-hard therefore heuristic approximate algorithms have been proposed in the literature many of which have found usage especially in pattern recognition. The focus of this paper is relaxation algorithms that are formulated as the minimization of a distance function over a superset of all permutations, usually both convex. A survey of theoretical guarantees for such relaxations are provided and the results are investigated in the context of random graphs.

MP1a-2 1:55 PM

Towards Provably Invisible Network Flow Fingerprints

Ramin Soltani, Dennis Goeckel, Don Towsley, Amir Houmansadr, University of Massachusetts Amherst, United States

Traffic analysis reveals important information even when messages are encrypted. We consider an active traffic analysis method, flow fingerprinting, which works by embedding information into packet timings of flows. Assume Alice wishes to embed fingerprints into network flows by altering their packet timings, and Bob, who receives a set of fingerprinted flows after they pass through a noisy network, wishes to infer Alice's embedded fingerprints from the observed flows. We model the noisy network as a single $M/M/1$ queue, a series of $M/M/1$ queues in tandem, and a Jackson's network.

MP1a-3 2:20 PM

Efficient Neighborhood Selection for Walk Summable Gaussian Graphical Models

Yingxang Yang, Jalal Etesami, Negar Kiyavash, UIUC, United States

This paper addresses the problem of learning Gaussian graphical models using a threshold-based greedy neighborhood selection and pruning algorithm. The algorithm leverages the fact that the maximum conditional covariance between a node and its undiscovered neighbors given any estimated neighborhood is always bounded away from zero. We provide theoretical guarantees for the efficiency and accuracy of our algorithm for the class of walk summable Gaussian graphical models. We verify the performance of the algorithm through simulations.

MP1a-4 2:45 PM

Assembling a Graph from Many Small Unlabeled Subgraphs

Matthias Grossglauser, Lyudmila Yartseva, École Polytechnique Fédérale de Lausanne, Switzerland

We consider the problem of recovering a graph from a collection of unlabeled subgraphs. More specifically, we assume that we are given small neighborhoods of every node in the graph. We develop achievability bounds in terms of the size, density, and transitivity of the original graph. These results are based on a novel random-graph model, where we superpose multiple dense Erdős–Rényi random graphs over small random subsets of nodes, to result in a sparse graph with high transitivity. We show that in this model, small subgraphs can be reassembled into the original graph under fairly loose conditions. The results have applications in network privacy, graph mining, and network inference.

Track A – Communications Systems

Session: MP1b – DNA Storage

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

MP1b-1 3:30 PM

Storing Information in Short DNA Molecules

Ilan Shomorony, Reinhard Heckel, Kannan Ramchandran, University of California, Berkeley, United States; David Tse, Stanford University, United States

Recent advances in DNA synthesis and sequencing technologies have allowed several laboratories to demonstrate the feasibility of DNA-based storage systems. In this work, we propose a model to study the fundamental limits of these systems. Our model aims to capture two key aspects dictated by current technological constraints: (1) the data is written onto many short DNA molecules that are stored in an unordered way and (2) the data is read by randomly sampling from the DNA pool. We study the storage capacity of this system under an asymptotic regime where the DNA molecules are short with respect to the amount of data to be written.

MP1b-2 3:55 PM

Coding Techniques for Emerging DNA-Based Storage Systems

Ryan Gabrys, Olgica Milenkovic, University of Illinois at Urbana-Champaign, United States

In the following work, we begin by reviewing the two fundamental processes involved in any DNA storage system: a) synthesis or the process of encoding information, and b) sequencing or retrieving the stored information. We then discuss some of the technical challenges related to the synthesis and sequencing processes and show how existing DNA storage architectures have overcome these issues using coding techniques. We then propose a number of new coding schemes addressing limitations of DNA-based data storage systems and show how they can be successfully integrated into a practical implementation platform.

MP1b-3 4:20 PM

Faster Reconstruction Through Coding for DNA Storage

Frederic Sala, Clayton Schoeny, Lara Dolecek, University of California, Los Angeles, United States

Recent efforts have shown DNA to be a very promising medium for long-term data storage. Like all media, DNA storage offers a number of features and challenges. One major issue involves reading stored data from DNA devices: to read, sequencing must be performed. The sequencing process involves accessing a large number of short, overlapping DNA subsequences, placing them in order, and stitching them to reassemble the original sequence, a slow and computationally-complex process. In this paper, we develop efficient methods for writing and reading data when limits are placed on read latency/complexity. Our methods are based on tools from sequence reconstruction and burst-deletion correcting codes.

MP1b-4 4:45 PM

Multidimensional DNA-Based Data Storage

Hossein Tabatabaei Yazdi, Ryan Gabrys, Olgica Milenkovic, UIUC, United States

We propose a new coding paradigm for DNA-based data storage that uses, in addition to the sequence composition, secondary properties of the strands to perform encoding. This form of coding produces the highest known information rates and significantly reduces the cost associated with synthesis. The error-correction problems at hand amount to designing codewords resilient to “mass shift” errors and have not been studied previously.

Track B – MIMO Communications and Signal Processing

Session: MP2a – Massive MIMO: Vision and Reality

Chair: ***Thomas Marzetta,*** *Nokia Bell Labs*

MP2a-1 1:30 PM

Scaling Up Distributed Massive MIMO: Why and How

Sofie Pollin, KU Leuven, Belgium

Massive MIMO is widely seen a s promising candidate for 5G as it promises high throughput, long range, low cost or power consumption, and perfect fairness among users. Distributed massive MIMO gives a higher spectral efficiency and enhanced coverage area, compared to collocated massive MIMO. Scaling up massive MIMO by using distributed antennas arrays however brings some unique challenges in terms of implementation complexity, from antenna design to calibration to synchronization.

In this paper, we will illustrate some of the advantages of distributed massive MIMO, and highlight the main implementation challenges. By looking at the real measured performance as function of various implementation choices, such as the antenna elements, we will shed some new light on massive MIMO compared to distributed massive MIMO.

MP2a-2 1:55 PM

mmWave Massive MIMO with Simple RF and Advanced DSP

Amine Mezghani, A. Lee Swindlehurst, University of California, Irvine, United States

There is considerable interest in the combined use of millimeter-wave (mmwave) frequencies and arrays of massive numbers of antennas (massive MIMO) for next-generation wireless communications systems. A symbiotic relationship exists between these two factors: mmwave frequencies allow for densely packed antenna arrays, and hence massive MIMO can be achieved with a small form factor; low SNR due to path loss or shadowing can be overcome with a large array gain; steering narrow beams or nulls with a large array is a good match for the line-of-sight (LOS) or near-LOS mmwave propagation environments, etc. However, the cost and power consumption for standard implementations of massive MIMO arrays at mmwave frequencies is a significant drawback to rapid adoption and deployment. In this talk, we examine a number of possible approaches to reduce cost and power at both the basestation and user terminal, making up for it with signal processing and additional (cheap) antennas. These approaches include low- and mixed-resolution sampling, direct-detection architectures, blind channel estimation, pico-cell deployments, etc. We will examine the potential of these approaches in making mmwave massive MIMO a reality.

MP2a-3 2:20 PM

Analysis of Nonlinear Low-Noise Amplifiers in Massive MIMO Base Stations

Christopher Mollén, Linköpings Universitet, Sweden; Ulf Gustavsson, Ericsson, Sweden; Thomas Eriksson, Chalmers, Sweden; Erik G. Larsson, Linköpings Universitet, Sweden

In a massive MIMO base station, the power amplifier of the downlink signal is not necessarily the main power consumer. As the radiated power from each antenna grows smaller, other hardware components, whose total power consumption scales with the number of antennas, will account for larger shares of the total power consumption. One such component is the low-noise amplifier (LNA), which is required to amplify the weak received signal before further signal processing. Since the low-noise amplifier is an inherently nonlinear hardware component, it introduces signal distortion, which is mitigated by requiring the LNA to meet certain linearity constraints. The higher constraints, the more expensive and power-hungry the hardware becomes however. Because of the large number of radio chains and hardware in massive MIMO base stations, which are known to be robust against various hardware imperfections and signal distortion, it is desirable to lower the linearity constraints. To study the feasibility of a low-power massive MIMO base station that uses inexpensive, power efficient LNAs at the base station, we investigate how the linearity constraint of the LNAs affects the performance of the massive MIMO uplink.

MP2a-4 2:45 PM

Future Cell - An End to End Massive MIMO Fronthauling System

Andreas Pascht, Nokia Bell Labs, Germany

Future cell is a fundamental breakthrough for small cell deployment, comprising a wireless hub fronthauling to 16 energy autonomous small cells. No wiring or alignment is required to deploy the small cells, thus minimizing installation effort and deployment cost. After cell insertion LTE service can be started within a minute. The hub enables 2.1 GHz wireless non line of sight (NLOS) fronthauling operation with its frequency division duplex (FDD) 64-antenna array and fully fledged closed-loop massive MIMO (MMIMO). The small cells are designed for 10x reduction in power consumption and energy autonomous operation by solar power. The extremely versatile system concept also supports implementation of simultaneous fronthauling- and access-operation in FDD or time division duplex (TDD) mode.

Session: MP2b – Cloud and Fog-Assisted 5G

Co-Chairs: ***Osvaldo Simeone,*** *Newark College of Engineering* **and *Ravi Tandon,*** *University of Arizona*

MP2b-1 3:30 PM

Dynamic Wireless Computing Network Control

Hao Feng, University of Southern California, United States; Jaime Llorca, Nokia Bell Labs, United States; Antonia Tulino, Bell Labs & Università di Napoli Federico II, United States; Andreas Molisch, University of Southern California, United States

We consider the problem of optimal delivery of digital services, described by a chain of service functions, over wireless computing networks, in which nodes are equipped with both communication and computing resources. We characterize the wireless computing network capacity region and design a dynamic control policy that makes local transmission and processing decisions with arbitrarily close to minimum network cost, with a tradeoff in network delay. Our solution captures the unique chaining and flow scaling aspects of next generation digital services, while exploiting the use of the broadcast approach over the wireless channel.

MP2b-2 3:55 PM

Topological Edge Caching with no CSI at the Edge

Wei-Ting Chang, Ravi Tandon, University of Arizona, United States; Osvaldo Simeone, King's College, United Kingdom

In this paper, we consider the role of edge caching in partially connected wireless networks with no channel state information (CSI) at the edge transmitters. The goal of this work is to understand the interplay between cache storage at the transmitters and the delivery latency as a function of the underlying network topology. To this end, we focus on a special class of partially connected networks, namely the cyclic Wyner channel model, in which each receiver is connected to exactly d transmitters in a cyclic manner. We present a novel MDS-coded caching and interference avoidance based delivery scheme for the operating point of minimum storage, and also compare the resulting delivery latency with the ideal case when all the edge transmitters have full storage. Finally, we provide a novel lower bound on the delivery latency as a function of the network topology and cache storage per edge transmitter and compare it with the proposed delivery scheme.

MP2b-3 4:20 PM

Multicast for Cloud Radio-Access Networks with Heterogeneous Backhaul

Ya-Feng Liu, Chinese Academy of Sciences, China; Wei Yu, University of Toronto, Canada

Cooperative communication in which multiple base-stations jointly transmit to mobile users is a major advantage of cloud radio-access networks (C-RAN). This paper considers C-RAN with heterogeneous and possibly combined wireless and wireline backhaul, and examines the optimization of backhaul transmission for multicast to multiple base-stations for cooperation purposes. In particular, to combat fading and path-loss of the wireless backhaul channels, this paper proposes an optimized rate allocation strategy of the wireline backhaul to smooth out the wireless channel disparity. This paper reveals the structure of the optimization problem and shows that the proposed strategy can significantly improve the effective backhaul transmission rate.

MP2b-4 4:45 PM

Coding for Edge-Facilitated Wireless Distributed Computing with Heterogeneous Users

Mehrdad Kiamari, University of Southern California, United States; Chenwei Wang, DOCOMO Labs, United States; Salman Avestimehr, University of Southern California, United States

We consider an edge-facilitated wireless distributed computing scenario in which several mobile users collaborate with each other for computing via communication through an access point. It has recently been shown that by utilizing a particular repetitive structure of computation assignments at the users, one can enable coding opportunities that reduce the required communication by a multiplicative factor that grows linearly with the number of users; hence resulting in a scalable design, in which the required communication load is fixed and independent of the number of users. In this paper, we discuss the generalization of this framework to heterogenous networks, in which different users may have different storage and processing capabilities.

Session: MP3a – Distributed Methods for Large-scale Optimization

Co-Chairs: ***Alejandro Ribeiro,*** *University of Pennsylvania* ***and Aryan Mokhtari,*** *University of Pennsylvania*

MP3a-1 1:30 PM

Optimal Algorithms for Smooth and Strongly Convex Distributed Optimization in Networks

Kevin Scaman, MSR-INRIA Joint Center, France; Francis Bach, INRIA, Ecole Normale Supérieure, France; Sébastien Bubeck, Yin Tat Lee, Microsoft Research, United States; Laurent Massoulié, MSR-INRIA Joint Center, France

In this paper, we determine the optimal convergence rates for strongly convex and smooth distributed optimization in two settings: centralized and decentralized communications over a network. For centralized (i.e. master/slave) algorithms, we show that distributing Nesterov's accelerated gradient descent is optimal and achieves a precision $\varepsilon > 0$ in time $O(\sqrt{\kappa_g}(1+\Delta\tau)\ln(1/\varepsilon))$, where κ_g is the condition number of the (global) function to optimize, Δ is the diameter of the network, and τ (resp. 1) is the time needed to communicate values between two neighbors (resp. perform local computations). For decentralized algorithms based on gossip, we provide the first optimal algorithm, called the multi-step dual accelerated (MSDA) method, that achieves a precision $\varepsilon > 0$ in time $O(\sqrt{\kappa_l}(1+\frac{\tau}{\sqrt{\gamma}})\ln(1/\varepsilon))$, where κ_l is the condition number of the local functions and γ is the (normalized) eigengap of the gossip matrix used for communication between nodes. We then verify the efficiency of MSDA against state-of-the-art methods for two problems: least-squares regression and classification by logistic regression.

MP3a-2 1:55 PM

Beyond Consensus and Synchrony in Decentralized Online Optimization using Saddle Point Method

Amrit Singh Bedi, Indian Institute of Technology Kanpur, India; Alec Koppel, University of Pennsylvania, United States; Ketan Rajawat, Indian Institute of Technology Kanpur, India

We consider online learning problems in multi-agent systems where each agent is charged with minimizing the global regret. This regret is sum of the instantaneous sub-optimality of each agent's actions with respect to a fixed global clairvoyant actor with access to all costs across the network for full time-horizon T. Since agents are not assumed to be of the same type, the hypothesis that all agents seek a common action is violated, and thus we instead introduce a notion of network discrepancy as a measure of how well agents coordinate their behavior while retaining distinct local behavior. Moreover, agents are not assumed to receive the sequentially arriving costs on a common time index, and thus seek to learn in an asynchronous manner. A variant of Arrow-Hurwicz saddle point algorithm is proposed to control the growth of global regret and network discrepancy. This algorithm uses Lagrange multipliers to penalize the discrepancies between agents and leads to an implementation that relies on local operations and exchange of variables between neighbors. Decisions made with this method lead to regret whose order is $\ccalO(\sqrt{T})$ and network discrepancy $\ccalO(T^{3/4})$. Empirical evaluation is conducted on an asynchronously operating sensor network estimating a spatially correlated random field.

MP3a-3 2:20 PM

A Doubly Quasi-Newton Method for Decentralized Consensus Optimization

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

In this paper, we study consensus optimization problems in which nodes of a network have access to a local cost function and seek the argument that minimizes the aggregate cost function over the network. We consider the augmented Lagrangian formulation of the dual function, while incorporating a curvature correction inspired by the Broyden-Fletcher-Goldfarb-Shanno (BFGS) quasi-Newton method. By applying the curvature correction in both the primal and dual updates, we develop a doubly quasi-Newton method that is fully distributed across the network. We are able to give an exact linear convergence performance guarantee in both the primal and dual domain and we additionally demonstrate performance advantages over existing decentralized methods through numerical simulations.

MP3a-4 **2:45 PM**

Coded Shuffling for Distributed Machine Learning: Theory and Practice

Jichan Chung, Kangwook Lee, Korea Advanced Institute of Science & Technology (KAIST), Republic of Korea; Ramtin Pedarsani, University of California, Santa Barbara, United States; Dimitris Papailiopoulos, University of Wisconsin-Madison, United States; Kannan Ramchandran, University of California, Berkeley, United States

Large-scale machine learning and data analytics tasks are increasingly being run on massive distributed computational platforms. A major bottleneck in distributed machine learning is the communication bandwidth required for data shuffling. In this talk, we introduce a _coded shuffling_ framework, where we use codes to significantly reduce the communication bottleneck for shuffling the data. More precisely, we show that when a constant fraction of the data can be cached at each worker node, and n is the number of workers, coded shuffling reduces the communication cost by a factor of O(n). We further show extensive simulations and experimental results that corroborate our theoretical results.

Track C – Networks

Session: MP3b – Dynamic Control in Wireless Networks

Chair: ***Nicolò Michelusi,*** *Purdue University*

MP3b-1 **3:30 PM**

Contextual Combinatorial Bandits in Wireless Distributed Computing

Pranav Sakulkar, Bhaskar Krishnamachari, University of Southern California, United States

With Wireless Distributed Computing (WDC), multiple resource-constrained mobile devices connected wirelessly can collaborate to enable a variety of applications involving complex tasks that one device cannot support individually. It is important to consider the application task graph, the features of the instantaneous data-frame, availability of the computing resources, the link connectivity to these devices, and determine the task assignments to balance the trade-off between energy costs of the devices and overall task execution latency. Considering the time-varying nature of the resource availability and the link conditions, we model the online task assignment problem as a Contextual Combinatorial Bandit. Since each incoming data-frame may have different features and affect the optimal task assignment, the data-frame features act as context for each frame. We propose a novel online learning algorithm called PMF Learning algorithm that learns the distributions of the internal random variables of the system over time and uses the empirical distributions to make task allocations for each data-frame. We prove that the regret of PMF Learning algorithm scales logarithmically over time and linearly in the number of connected devices, which is a substantial improvement over the standard combinatorial bandit algorithms.

MP3b-2 **3:55 PM**

Learning-Guided Network Resource Allocation: A Closed-Loop Approach

Xueying Guo, Huasen Wu, Xiaoxiao Wang, Xin Liu, University of California, Davis, United States

Based on network measurement and user behavior data, much recent work has studied the modeling and prediction of network utility and user experience using machine learning techniques. While it provides important insights, prediction itself is often not the ultimate goal in networks. Ideally, a network could identify users with poor experience and take proper actions to proactively improve the overall performance. To achieve this goal, the paper advocates a closed-loop approach that uses learning-aided utility model to explicitly guide resource allocation in networks and uses feedback to (in)validate and improve the learned utility model.

MP3b-3 **4:20 PM**

Active Spectrum Sensing with Sequential Sub-Nyquist Sampling

Lorenzo Ferrari, Anna Scaglione, Arizona State University, United States

In this paper we propose a new framework that allows to optimize a sub-Nyquist sampling front-end. We design an active sequential sensing algorithm that draws insight from group testing to solve sparse recovery problems sequetially. Our optimization problem maximizes a utility function that trades off the cost of each sub-Nyqusit sample with a utility that balances the reward of the right decision with the cost of a detection error. This situation can model dynamic spectrum access as well as RF sensing, allowing to switch between these two sensing modalities optimally. In general our utility represents the trade-off between exploration and exploitation that is characteristic of the spectrum sensing problem. In the paper we explore the performance of a sub-optimal greedy algorithm and derive an ad-hoc factor approximation that extends the results in the literature for the optimization of non monotone sub-modular functions. We then provide the details of our analog front-end architecture, mapping the measurement model into the abstract optimization problem proposed and analyzed in the first part of the paper. Numerical simulations corroborate our claims and show the benefits of active sensing and sub-Nyquist sampling. The sensing matrix must be sparse in order to achieve good performance.

MP3b-4 4:45 PM

Topology-Agnostic Average Consensus in Sensor Networks with Limited Data Rate

Chang-Shen Lee, Nicolo Michelusi, Gesualdo Scutari, Purdue University, United States

In this paper, the distributed average consensus problem in sensor networks with limited data rate communication is studied. Unlike standard average consensus, only quantized signals with finite support are adopted for the communications among agents. To tackle this problem, a novel distributed algorithm is proposed, where each agent iteratively updates a local estimate based on quantized signals received by its neighbors. The proposed algorithm differs from the existing schemes dealing with limited data rate in the following key features: 1) each agent is not required to have information on spectral properties of the graph associated with the communication topology; 2) the initial measurements are not required to be bounded within a known interval; and 3) exact consensus to the average can be achieved asymptotically. Thus, it is more favorable for practical implementations, especially for large networks. The proposed algorithm is proved to achieve average consensus asymptotically, with probability one. Finally, numerical results validate our theoretical findings, and demonstrate the superior performance of the proposed algorithm compared to the state-of-the-art topology-agnostic consensus schemes with limited data rate.

Track D – Signal Processing and Adaptive Systems

Session: MP4a – Low-dimensional Models for Big Data

Chair: ***Chinmay Hegde,*** *Iowa State University*

MP4a-1 1:30 PM

Memory-Limited Subspace Tracking with Poisson Data

Liming Wang, Yuejie Chi, The Ohio State University, United States

Poisson noise is ubiquitously encountered in applications including medical and photon-limited imaging. We consider the problem of recovering and tracking the underlying Poisson rate, where the rate vector is assumed to lie in a low-dimensional subspace, with possibly missing entries. A stochastic approximation (SA) algorithm is proposed to solve the problem. This algorithm alternates between two steps. It sequentially identifies the underlying subspace, and recovers coefficients associated with the subspace. The SA algorithm is then modified to obtain a memory-efficient algorithm without storing all historic data. Two theoretical performance guarantees are establish regarding the convergence of SA algorithm. Numerical experiments are provided to demonstrate all proposed algorithms for Poisson video. The memorylimited SA algorithm is shown to empirically yield similar performances to the original SA algorithm.

MP4a-2 1:55 PM

Sharp Asymptotics for Blind Estimation with Geometric Constraints

Yue Lu, Harvard University, United States

We consider the problem of estimating a high-dimensional vector from random linear measurements subject to an unknown nonlinear mapping. The target vector is estimated from a simple two-step approach, where an initial linear estimate is refined after projection onto a subset capturing the prior information of the unknown vector. In this paper, we derive sharp asymptotics for the performance of this two-step estimator, in the limit that the signal dimension and the number of measurements both tend to infinity, with their ratio fixed at a positive constant.

MP4a-3 2:20 PM

Efficient Signal Detection on Graphs

Venkatesh Saligrama, Boston University, United States

We propose a novel, computationally efficient optimization framework for subgraph detection in graph-structured data, where we aim to discover anomalous patterns present in a connected subgraph of a given graph. This problem arises in many applications such as detection of network intrusions, community detection, detection of anomalous events in surveillance videos or disease outbreaks. Since optimization over connected subgraphs is a combinatorial and computationally difficult problem, we propose a convex relaxation that offers a principled approach to incorporating connectivity and conductance constraints on candidate subgraphs. We develop a novel efficient algorithm to solve the relaxed problem, establish convergence and consistency guarantees and demonstrate its feasibility and performance with experiments on real and very large simulated networks

MP4a-4 **2:45 PM**

The Convex and Nonconvex Geometries of Tensor Factorization

Qiuwei Li, Gongguo Tang, Colorado School of Mines, United States

Tensors provide natural representations for massive multi-mode datasets and tensor methods also form the backbone of many machine learning, signal processing, and statistical algorithms. This work develops theories and computational methods for guaranteed overcomplete, non-orthogonal tensor factorization using convex and nonconvex optimizations. In particular, we derive conditons to provably extract rank-one tensor factors using convex atomic norm minimization. To design scalable polynomial-time algorithms, we apply a low-rank parameterization to reformuate the atomic norm regularized tensor optimization as a nonconvex program. We analyze the geometry of this nonconvex optimization to ensure global convergence of many local search algorithms.

Track D – Signal Processing and Adaptive Systems

Session: MP4b – High-dimensional Estimation: Theory and Algorithms

Chair: ***Yue Lu,*** *Harvard University*

MP4b-1 **3:30 PM**

Discrete Submodular Optimization via Continuous Nonconvex Optimization

Mahdi Soltanolkotabi, University of Southern California, United States

Discrete submodular optimization problems emerge in a variety of areas in machine learning. Examples include potential functions of graphical models, utility functions in active learning and sensing, matrix approximations and network inference, and structured sparse estimation. In this talk I will discuss how to cast the highly discrete problem of submodular maximization as a continuous nonconvex optimization problem. I will then discuss new local search heuristics based on this continuous formulations that lead to significant speed up for such problems. Despite the apparent lack of convexity in such optimization problems I will show that these new local search heuristics lead to approximation guarantees on par (or sometimes better) than state of the art on submodular maximization. This talk is based on joint work with Hamed Hassani and Amin Karbasi.

MP4b-2 **3:55 PM**

Some Sharp Asymptotics for Spectral Initialization Methods for Nonconvex Optimization

Yue Lu, Harvard University, United States

We present some sharp asymptotic results characterizing, in the high-dimensional limit, the exact performance of several spectral methods that serve a key role in recent work on efficient signal estimation via nonconvex optimizations. Our analysis also reveals a sharp phase transition phenomenon that takes place at critical values of the sampling ratio.

MP4b-3 **4:20 PM**

Nonconvex Sparse Blind Deconvolution: Global Geometry and Efficient Methods

Yuqian Zhang, Han-Wen Kuo, John Wright, Columbia University, United States

Sparse blind deconvolution is a recurring problem in imaging, neuroscience, computer vision, and related areas. Despite much recent progress, general algorithmic theory on this problem remains elusive; natural formulations are nonconvex, and analyzing them globally is challenging. In this paper, we consider the problem of recovering a short kernel and a random sparse signal from their convolution. We describe two algorithmic approaches which yield provable, efficient algorithms. The first is based on polynomial optimization over the sphere; the second is based on minimizing the optimal Lasso cost with respect to the (unknown) filter. In both cases, we prove that when the activiation map is sufficiently sparse, local minima are signed shift-truncations of the ground truth, and that simple descent methods efficiently produce minimizers. We illustrate this results on problems from blind deblurring and the interpretation of microscopy data.

MP4b-4 **4:45 PM**

Implicit Regularization in Nonconvex Statistical Optimization

Yuxin Chen, Princeton University, United States

Logistic regression is widely used for modeling the associations between binary response variables and a certain number of features of interest. In many applications, one would like to determine whether a feature is associated with the response or not, for which the likelihood ratio tests are most commonly deployed. The classical chi-square approximation to the distribution of the test statistic --- which is invoked in standard statistical softwares --- becomes remarkably imprecise when the number of features is proportional to the number of samples. In this work, we characterize the behavior of the log-likelihood test statistic in the high dimensional asymptotics, which offers a correction to the classical chi-square approximation.

Track E – Array Signal Processing

Session: MP5a – Mathematics of Super-Resolution

Chair: ***Gongguo Tang,*** *Colorado School of Mines*

MP5a-1 1:30 PM

Information and Resolution

Albert Fannjiang, University of California, Davis, United States

We review recent development in resolution for imaging problems. We discuss how noise, prior information, numbers and types of measurements affect the performance of imaging systems.

MP5a-2 1:55 PM

A Sampling Theorem for Robust Deconvolution

Brett Bernstein, Courant Institute, New York University, United States; Carlos Fernandez-Granda, Courant Institute and Center for Data Science, NYU, United States

In the 70s and 80s geophysicists proposed using l1-norm regularization for deconvolution problems in the context of reflection seismology. Since then such methods have had a great impact in high-dimensional statistics and in signal-processing applications, but until recently their performance on the original deconvolution problem was not well understood theoretically. In this talk we provide an analysis of optimization-based methods for the deconvolution problem, including results on irregular sampling and sparse corruptions that highlight the modeling flexibility of these techniques.

MP5a-3 2:20 PM

Sampling Patterns for Off-The-Grid Spectral Estimation

Maxime Ferreira Da Costa, Wei Dai, Imperial College London, United Kingdom

Line spectral estimation theory aims to estimate the off-the-grid spectral components of a time signal with optimal precision. Recent results have shown that it is possible to recover signals having sparse line spectra from few temporal observations via the use of convex programming. However, the computational cost of such approaches remains the major flaw to their use in practical system. We propose to reduce the complexity of the spectral estimation by taking compressive measurement in the time domain. We study the feasibility and the resolution limits of different sub-sampling patterns and present an efficient algorithm working up to poly-logarithmic order that is guaranteed the recover the original signal.

MP5a-4 2:45 PM

A Super-resolution Algorithm for Multiband Signal Identification

Zhihui Zhu, Dehui Yang, Michael Wakin, Gongguo Tang, Colorado School of Mines, United States

Recent advances in convex optimization have led to super-resolution algorithms that provide exact frequency localization in multi-tone signals from limited time-domain samples. Such localization is accomplished by minimizing a certain atomic norm, which can be implemented in a semidefinite program. In this work, we consider the identification of multi-band signals, which are comprised of multiple, unknown narrow bands of frequency content at multiple carrier frequencies. Integrating a basis of modulated Slepian sequences into the atomic norm minimization framework, we introduce a technique for estimating the unknown band positions based on limited time-domain samples of the signal.

Track E – Array Signal Processing

Session: MP5b – Waveform and Array Optimization for Multistatic/MIMO Radar

Co-Chairs: ***Maria S. Greco,*** *University of Pisa* **and *Shannon Blunt,*** *University of Kansas*

MP5b-1 3:30 PM

Antenna and Pulse Selection for Colocated MIMO Radar

Ehsan Tohidi, Hamid Behroozi, Sharif University, Iran; Geert Leus, Delft University of Technology, Netherlands

Multiple input multiple output (MIMO) radar is known for its superiority over conventional radar due to its antenna-waveform diversity. However, the increased power (due to multiple transmitters and receivers) and computational complexity (due to numerous pulses) are the drawbacks of MIMO radar. On one hand, a higher estimation accuracy is required, but on the other hand, a lower number of active antennas/pulses is desirable. Therefore, in this paper, we will minimize the total number of

active antennas/pulses in order to guarantee a prescribed performance accuracy. The performance measure we will optimize is the Cramer-Rao lower bound (CRLB) for the angle and velocity estimation accuracy of two targets, which provides a trade-off between the main beam width and the side lobe level of the ambiguity function.

MP5b-2 **3:55 PM**

Joint Design for Co-existence of MIMO Radar and MIMO Communication System

Junhui Qian, University of Electronic Science and Technology of China, China; Marco lops, University of Cassino and Southern Latium, Italy; Le Zheng, Xiaodong Wang, Columbia University, United States

The authors design a scenario in which a multiple-input multiple-output (MIMO) radar coexists with a MIMO wireless communication system in the presence of clutter. The radar space-time transmit code, the radar space-time receive filter, and the communication space-time transmit covariance matrix are jointly optimized. An iterative procedure is devised to maximize the radar output signal to interference plus noise ratio (SINR) accounting for communication capacity, radar code similarity and power constraints. Each iteration of the algorithm involves the solution of hidden convex problems that can be solved in polynomial time. Numerical results show that the proposed algorithm improves the SINR of the radar, while maintaining certain average capacity for the communication system.

MP5b-3 **4:20 PM**

Adaptive Sequential Refinement: A Tractable Approach for Ambiguity Function Shaping in Cognitive Radar

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

Ambiguity function shaping continues to be one of the most challenging open problems in cognitive radar. Analytically, a complex quartic function should be optimized as a function of the radar waveform code. Practical considerations further require that the waveform be constant modulus, which exacerbates the issue and leads to a hard non-convex problem. We develop a new approach called Adaptive Sequential Refinement (ASR) to suppress the clutter returns for a desired range-Doppler, i.e. ambiguity function response. ASR solves the aforementioned optimization problem in a unique iterative manner such that the formulation is updated depending on the iteration index. We establish formally that: 1.) the problem in each step of the iteration has a closed form solution, and 2.) monotonic decrease of the cost function until convergence is guaranteed. Experimental validation shows that ASR produces a radar waveform with higher Signal to Interference Ratio (SIR) and superior ambiguity function shaping than state of the art alternatives even as its computational burden is orders of magnitude lower.

MP5b-4 **4:45 PM**

MIMO Radar Beampattern Optimization with Ripple Control Using Sum-of-squares Representation

Tuomas Aittomaki, Visa Koivunen, Aalto University, Finland

In this paper, we examine MIMO radar beampattern optimization with control on the peak sidelobe level, as well as the ripple and the minimum power of the focus region. Using the sum-of-squares representation for inequalities, the optimization can be done without discretizing the angle domain. The disadvantage of this method is that the desired beampattern has to be a piece-wise constant or a piece-wise trigonometric polynomial.

Track F – Biomedical Signal and Image Processing

Session: MP6a – Identification and Control of Neural Dynamics

Chair: ***ShiNung Ching,*** *Washington University in St. Louis*

MP6a-1 **1:30 PM**

Latent Variable Models for Uncovering Motor Cortical Ensemble Dynamics

Zhe Chen, New York University School of Medicine, United States; Jose Iriarte-Diaz, University of Illinois at Chicago, United States; Nicholas Hatsopoulos, Callum Ross, Kazutaka Takhashi, University of Chicago, United States

Neural activity is dynamic at various spatiotemporal scales. We consider a general class of latent variable models for analyses of neuronal ensemble spikes. Specifically, the latent variable follows a Markovian dynamics, and the observations are modulated by the latent variable through an assumed or unknown mapping function. The inference of latent variable models lead to novel solutions for unsupervised decoding analysis or data visualization. We assess the validity of the proposed models by simulated data and experimental ensemble spike data recorded from monkeys' primary motor cortices during arm or orofacial movement. We also discuss the challenges in result interpretation.

MP6a-2 1:55 PM

Neural System Identification for Optimizing Stimulation-Enhanced, Sleep- Mediated, Memory Consolidation

Kyle Lepage, Allen Institute for Brain Science, United States; Sujith Vijayan, Boston University, United States

The coordination of fast spindle activity (12-15 Hz) with hippocampal ripples and slow oscillations (SO, < 1 Hz) is important for sleep-mediated memory consolidation. Studies have shown that auditory pink-noise stimulation, timed to SO during sleep, results in enhanced and extended trains of SO, a greater prevalence of spindles, and improved memory performance upon awakening. Auditory pulse train stimulation conferred the same phenomenological enhancement. Further, shorter two-pulse trains produced the same results, suggesting the presence of a synchrony-limiting mechanism. Both phenomenological time-series and mean-field models of neural activity inform the current work, in which three methods of system identification (pink-noise stimulation-based identification, response curve analysis, and iterative, narrowband stimulation-based system identification) are compared both in simulation and in theory. The results are expected to inform real-time system identification and optimal neural stimulation for the purposes of elucidating scientific theories and optimizing memory performance.

MP6a-3 2:20 PM

Spike Sorting Requirements for Sensory Neurocontrol

Jason Ritt, Samuel Brown, Boston University, United States

Stimulating neural interfaces that drive population activity towards dynamic multineuronal patterns, such as for sensory neuroprostheses, face a number of challenging physical limitations. Control strategies must contend with significant underactuation and limited observability. In a typical application using extracellular electrodes, individual neuron identity must be inferred from action potential waveform shape, or ``spike sorting'', possibly augmented with other indirect information. Errors in spike sorting, while problematic in general, can especially contribute to misidentification in neurocontrol applications. For example, due to waveform overlap of broader neural recruitment at higher stimulation strengths, basic measures of neural responsiveness, such as strength-duration curves, likely exhibit input-dependent bias derived from spike sort errors. We summarize these issues in models and data from cortex in anesthetized mice, and discuss possible strategies to mitigate these concerns in the context of the larger underactuated neurocontrol problem.

MP6a-4 2:45 PM

Identifying Disruptions in Brain Network Control Properties Due to Focal Injury

Sina Khanmohammadi, Terrance Kummer, ShiNung Ching, Washington University in St. Louis, United States

Recent studies suggest that disruptions in resting state functional connectivity –- a measure of stationary statistical association between brain regions -- can be used as an objective marker of brain injury. However, fewer characterizations have examined the effect of connectivity changes on the temporal dynamics of the networks in question. Here, we examine this issue using electroencephalographic (EEG) data from brain-injured patients, together with a control analysis wherein we quantify the effect of the injury on the ability of functional networks to traverse their respective state spaces. More specifically, we fit a dynamical model for each measured channel of EEG and deploy a series of systems-theoretic metrics to assay the overall reachability of the subsequent network with respect to a constrained set of afferent inputs. We show how such an approach may reveal basic spatial properties such as focality of the underlying injury and, further, may suggest focal interventions to ameliorate aberrant dynamics.

Track F – Biomedical Signal and Image Processing

Session: MP6b – Statistical Signal Processing and Learning in Neuroscience

Chair: ***Dmitri Chklovskii,*** *Simons Foundation*

MP6b-1 3:30 PM

Fully Automated Spike Sorting of Large-Scale Multi-Day Neural Recordings

Jeremy Magland, Flatiron Institute, United States; Jason Chung, University of California, San Francisco, United States; Alex Barnett, Dartmouth College, United States; Loren Frank, University of California, San Francisco, United States; Leslie Greengard, Flatiron Institute, United States

Improvements in hardware and data acquisition methodology have enabled the simultaneous extracellular detection of individual neural events from hundreds of neurons tracked over hours, days, and even weeks. The process of extracting spike times and neuron labels from these continuously samples signals is known as spike sorting. Standard approaches have traditionally relied on manual input, which is prohibitively time consuming for such large-scale datasets. Fully automated approaches have therefore become necessary. Other advantages of full automation include reproducibility, objectivity, and scientific transparency. We describe an automated clustering approach, cluster quality metrics, and an associated software package that addresses these

problems. Our accuracy matches or exceeds that of manual or semi-manual techniques in real time. Moreover, a single choice of parameters in the algorithm is effective for a variety of electrode geometries and across multiple brain regions. This technique enables reproducible and fully automated spike sorting of much larger scale recordings than is currently possible.

MP6b-2 3:55 PM

Distance Covariance Analysis

Benjamin Cowley, Joao Semedo, Carnegie Mellon University, United States; Douglas Ruff, University of PIttsburgh, United States; Amin Zandvakili, Brown University, United States; Marlene Cohen, Matthew Smith, University of Pittsburgh, United States; Adam Kohn, Albert Einstein College of Medicine, United States; Byron Yu, Carnegie Mellon University, United States

Linear dimensionality reduction methods, such as canonical correlation analysis, are widely used for their interpretability, but do not detect nonlinear relationships. We propose distance covariance analysis (DCA), a linear dimensionality reduction method that detects linear and nonlinear interactions between two or more sets of variables. DCA optimizes a correlational statistic called distance covariance, which can detect if two sets of variables are related. We extend distance covariance to detect interactions between multiple sets of variables, and then optimize the extended distance covariance with respect to linear projection vectors (i.e., dimensions) for each set of variables. DCA can be applied to continuous and categorical variables, orders identified dimensions based on the strength of interaction, and can take dependent variables into account. Computationally, DCA is fast and scales to hundreds of variables and tens of thousands of samples. With a novel testbed, we systematically assess the ability of DCA to detect both linear and nonlinear interactions, and find that DCA performs better than or comparable to existing methods, while being one of the fastest methods. We demonstrate the utility of DCA by applying it to neural activity recorded from populations of neurons.

MP6b-3 4:20 PM

Deconstructing Odorant Identity via Primacy in Dual Networks

Daniel Kepple, Hamza Giaffar, Cold Spring Harbor Laboratory, United States; Dmitry Rinberg, New York University, United States; Alexei Koulakov, Cold Spring Harbor Laboratory, United States

In the olfactory system, odor percepts retain their identity despite substantial variations in concentration, timing, and background. We propose a novel strategy for encoding intensity-invariant stimuli identity that is based on representing relative rather than absolute values of the stimulus features. Because, in this scheme, stimulus identity depends on relative amplitudes of stimulus features, identity becomes invariant with respect to variations in intensity and monotonous non-linearities of neuronal responses. In the olfactory system, stimulus identity can be represented by the identities of the p strongest responding odorant receptor types out of a species dependent complement. We show that this information is sufficient to recover sparse stimuli (odorants) via elastic net loss minimization. Such a minimization has to be performed under constraints imposed by the relationships between stimulus features. We map this problem onto the dual problem of minimizing a functional of Lagrange multipliers. The dual problem, in turn, can be solved by a neural network whose Lyapunov function represents the dual Lagrangian. We thus propose that networks in the piriform cortex compute odorant identity and implement dual computations with the sparse activities of individual neurons representing the Lagrange multipliers.

MP6b-4 4:45 PM

Biological Learning Through Min-Max Dynamics of Synaptic Plasticity

Cengiz Pehlevan, Flatiron Institute, United States

The brain learns to build useful representations of data streams from its sensory organs. We show that representation learning is the result of an adversarial game between feedforward and lateral synapses of a neural circuit. Many representation learning problems, e.g. dimensionality reduction, clustering and feature discovery, can be formulated as similarity alignment between inputs and outputs. We show that certain similarity alignment objectives are dual to min-max objectives whose variables can be interpreted as synaptic weights of a neural circuit and optimization dynamics can be interpreted as biological, Hebbian synaptic plasticity. While feedforward plasticity promotes maximal correlations between pre- and post synaptic neural activity, lateral plasticity reduces the redundancy between neurons. The intutition that such competition would lead to rich and useful representations in the brain is an old one. We formalize this intuition in terms of a min-max game.

Session: MP7a – Machine Learning for Information Retrieval, Speech, and Image Processing

Chair: ***Tokunbo Ogunfunmi,*** *Santa Clara University*

MP7a-1 1:30 PM

Using Information Theoretic Learning Techniques to Train Neural Networks

Manas Deb, Tokunbo Ogunfunmi, Santa Clara University, United States

Given a set of features of the input vector and a corresponding target value, the multilayer perceptron (MLP) utilizes a supervised learning technique called backpropagation to adapt the input weights of each neuron. Based on MSE, it relies on second order statistics of the error and ignores all higher order statistics that may be contained in the error. Using Information Theoretic Learning (ITL) techniques with higher order statistics of the error, we adapt the weights of the MLP during the backpropagation process. This results in faster convergence of the weights during the training process. Specifically, the MSE is replaced by minimum error entropy (MEE) of Renyi's quadratic entropy which involves the probability density function (PDF) of the error samples. All higher order statistics of the error are taken into consideration in this backpropagation technique. Renyi's quadratic entropy out-performs Shannon's entropy in terms of convergence speed where backpropagation implementations use cross-entropy as the loss function. Using simulations and standard MNIST handwriting data sets, we compare MLP using the typical backpropagation algorithm (using MSE, Shannon's cross-entropy, Renyi's quadratic entropy) and also one using ITL methods in terms of convergence speed of the weights, prediction accuracy and the residual error

MP7a-2 1:55 PM

What to Play Next? A RNN-Based Music Recommendation System

Miao Jiang, Ziyi Yang, Indiana University, United States; Chen Zhao, University of Tsukuba, Japan

Recent years, development of music recommendation system has been a more heated problem due to a higher level of digital songs consumption and the advancement of machine learning techniques. Some traditional approaches such as collaborator filtering, has been improved by algorithms based on deep neural network because traditional methods may difficult to make recommendations in a large system by "understand" the content of songs. In this paper, we propose an end-end model, which is based on recurrent neural network to predict user's next most possible song by similarity. We will make experiments and evaluations based on Million Song Dataset and demonstrate how it outperformed the traditional methods.

MP7a-3 2:20 PM

Transfer Learning with Variational Auto-Encoders

Suthee Chaidaroon, Yi Fang, Santa Clara University, United States

Human learners appear to have inherent ways to transfer knowledge between tasks. The core idea of transfer learning is that experience gained in learning to perform one task can help improve learning performance in a related, but different, task. Transfer learning allows us to leverage the already existing labeled data of some related task or domain. It has demonstrated great effectiveness in many applications. On the other hand, Variational autoencoders (VAEs) are a class of deep generative models based on variational inference. They provide a powerful framework for learning representations for unlabeled data. In this paper, we aim to bridge transfer learning with variational autoencoders. We propose deep generative models to transfer knowledge learned in one or more source tasks and use it to improve learning in a related target task. The experiments are conducted on public testbeds with competitive baselines. The preliminary results show the promise of the proposed approach.

MP7a-4 2:45 PM

Preference Elicitation in Recommender Systems using Matrix Factorization with Non-Personalized and Personalized Steps

Kirk Iserman, Yuhong Liu, Santa Clara University, United States

The prevalence of recommender systems is increasing with the growing number of online marketplaces. Recommender systems are an effective way to find items of interest among the many available items. It is important to have an efficient and effective way to introduce new users into a system so they can start receiving accurate recommendations. We seek to provide a new method to build an initial user profile while minimizing user effort through a series of non-personalized algorithmic steps and personalized steps based on user feedback. We use matrix factorization to extract latent factors and reduce the dimensionality of the problem. We elicit these latent factor values by iteratively selecting a set of representative movies for a given latent factor for the new user to rate. With each iteration, we cluster the existing users and place our new user in a cluster to determine the

next most important latent factor. We use a MovieLens dataset for testing by leaving a target user out as the ground truth, and building an initial profile for that user. In comparison with two alternative approaches, our method requires less user effort while improving the accuracy of the initial profile with respect to the ground truth.

Track G – Architecture and Implementation

Session: MP7b – Testbed-Based 5G Research

Chair: ***Ove Edfors,*** *Lund University, Sweden*

MP7b-1 3:30 PM

Building and Operating a Real-Time Massive MIMO Testbed - Lessons Learned

Steffen Malkowsky, Liang Liu, Viktor Öwall, Ove Edfors, Lund University, Sweden

We present lessons learned from building and operating a real-time massive MIMO testbed with LTE-like physical layer, based on tightly coordinated software-defined radio units. Learned lessons include both those related to building flexible testbeds, as well as those related to how massive MIMO base stations should be designed in terms of system architecture and baseband processing hardware. Recent massive MIMO system performance tests and their relation to system design will also be discussed.

MP7b-2 3:55 PM

ArgosNet: A Multi-Cell Many-Antenna MU-MIMO Platform

Clayton Shepard, Rahman Doost-Mohammady, Jian Ding, Ryan Guerra, Lin Zhong, Rice University, United States

We designed and built a custom hardware platform from scratch to support practical massive MIMO. Leveraging this platform we deployed a multi-cell network across Rice University campus, called ArgosNet. While the platform is highly configurable, its default configuration employs three outdoor 100-antenna base stations to serve 40 battery-powered mobile clients at 3.7 GHz. The base stations are time-frequency synchronized using both GPS and Synchronous Ethernet (SyncE) with Precision Time Protocol (PTP). Additionally, the base stations have direct fiber connections to a small server cluster, enabling advanced wireless techniques such as coordinated multipoint. We extended the Argos channel measurement system to support multi-cell topologies, then conducted a measurement campaign. These measurements are made freely available online.

MP7b-3 4:20 PM

SBXG - A City-Scale Software-Defined Wireless Network

J. Nicholas Laneman, University of Notre Dame, United States

The City of South Bend and the University of Notre Dame are creating SBXG, a city-scale testbed for advanced wireless research and development. The SBXG testbed will focus on next-generation (5G+) cellular architectures; network-scale channel measurements across multiple frequency bands; radio prototyping at millimeter wave frequencies; and futuristic applications not enabled by today's wireless networks, such as connected cars and drones and augmented reality. Because of the desired flexibility and evolvability of the testbed, its base design heavily emphasizes software-defined radios and software-defined networking. SBXG will also provide a resource center with outreach and educational programs for the research community as well as the local community. Taken together, the testbed, resource center, and user community they support will be a platform for advanced wireless research and development projects across the wireless "stack" for the next decade or more.

MP7b-4 4:45 PM

From massive MIMO to C-RAN: the OpenAirInterface 5G testbed

Florian Kaltenberger, Xiwen Jiang, Raymond Knopp, Eurecom, France

5G will be much more than just a new radio interface - 5G will fundamentally change the way networks are operated. Traditional telecom equipment will be replaced successively with general purpose computing platforms. This change will affect both the core network and the radio network, where it is also called cloud-RAN (C-RAN). The C-RAN architecture allows for flexible splits between different processing elements in the radio network, for an optimal tradeoff between processing in the cloud or in the remote radio unit. OpenAirInterface (OAI) is an open source initiative that today provides Rel-8/Rel-10 3GPP compliant reference implementation of eNodeB, UE, RRH and EPC that runs on general purpose computing platforms. Already today OAI offers several functional splits for its 4G radio stack, for example between the remote cloud center (RCC) and a Remote Radio Unit (RRU). Moreover, Eurecom is currently deploying a C-RAN network at its premises in Sophia-Antipolis, France using a low-cost solution for RRU based on off-the-shelf equipment. In this paper we are going to describe the OAI C-RAN architecture with a special emphasis on the possibilities to do multi-cell distributed MIMO processing. In particular we will show how to enable reciprocity-based multi-user MIMO processing in such a setting.

MP7b-5 5:10 PM

Scalable 5G MPSoC Architecture

Gerhard P. Fettweis, Emil Matus, TU Dresden, Germany

5G radio access networks impose high demands on flexible software defined radio (SDR) platforms. They must cope with a large number of heterogeneous access technologies and must meet a variety of application requirements in term of throughput, latency and reliability. In order to address these issues, this work proposes a heterogeneous SDR MPSoC. It has a scalable resilient network-on-chip (NoC) connecting heterogeneous processing modules composed as a clusters of general purpose and application specific processing cores with local cluster memory. Furthermore, it features data processing modules for general DSP algorithms and a baseband processing modules supporting iterative multiple-input multiple-output (MIMO) and channel decoding techniques. The reconfigurable NoC provides increased diversity and resiliency and enables the system scalability. We implemented this in a 5G concept MPSoC: the 28nm Tomahawk-4 chip comprising four data processing and single baseband module achieves a throughput of 232 Mbit/s and processing latency of 20 us while consuming 414 mW at 570MHz for a LTE UL 4 × 4 MIMO application scenario and thus outperforming the state-of-the-art platforms in terms of throughput by a factor of 4. And, it achieves resilience and latency requirements for applications of the 5G Tactile Internet.

Track D – Signal Processing and Adaptive Systems

Session: MP8a1 – Large-Scale Data 1:30 PM–3:10 PM

Chair: ***Maya Kabkab,*** *University of Maryland*

MP8a1-1

The Case for Spatial Pooling in Deep Convolutional Sparse Coding

Maya Kabkab, University of Maryland, College Park, United States

The sparse representation framework is a popular approach due to its desirable theoretical guarantees and the use of sparse representations as feature vectors in machine learning problems. Another seemingly unrelated line of research is deep learning and, in particular, convolutional neural networks (CNNs) which perform extremely well on various machine learning benchmarks. Recently, a connection between CNNs and convolutional sparse coding (CSC) was established using a simplified CNN model. Motivated by the use of spatial pooling in practical CNN implementations, we investigate the effect of using spatial pooling in the CSC model. We show that the spatial pooling operations do not hinder the performance and can introduce additional benefits.

MP8a1-2

Grid-less Estimation of Saturated Signals

Filip Elvander, Johan Swärd, Andreas Jakobsson, Lund University, Sweden

This work proposes a frequency and amplitude estimator tailored for noise corrupted signals that have been clipped. Formulated as a sparse reconstruction problem, the proposed algorithm estimates the signal parameters by solving an atomic norm minimization problem. The estimator also exploits the waveform information provided by the clipped samples, incorporated in the form of linear constraints that have been augmented by slack variables as to provide robustness to noise. Numerical examples indicate that the algorithm offers preferable performance as compared to methods not exploiting the saturated samples.

MP8a1-3

Learning Graph Evolutions from Cut Sketches: Faster Algorithms with Fewer Samples

Chinmay Hegde, Iowa State University, United States

We consider the problem of reconstructing graphs from a small number of observed cuts. This problem naturally arises in applications involving dynamically varying graphs where the goal is to learn the evolution of edge structure over a set of nodes. We describe a fast, provably efficient non-convex algorithm for solving this problem that can leverage the intrinsic structure of the underlying evolution. Our algorithm fuses ideas from sparse recovery and graph optimization, and exhibits asymptotic improvements over sample complexity over existing approaches. We supplement our analysis with several numerical results.

MP8a1-4

Transform-Based Compression for Quadratic Similarity Queries

Hanwei Wu, Markus Flierl, KTH Royal Institute of Technology, Sweden

This paper considers the problem of compression for similarity queries and discusses transform-based compression schemes. Here, the focus is on the tradeoff between the rate of the compressed data and the reliability of the answers to a given query. We consider compression schemes that do not allow false negatives when answering queries. Hence, classical compression techniques need to be modified. We propose transform-based compression schemes which decorrelate original data and regard

each transform component as a distinct D-admissible system. Both compression and retrieval will be performed in the transform domain. The transform-based schemes show advantages in terms of encoding speed and the ability of handling high-dimensional correlated data. In particular, we discuss component-based and vector-based schemes. We use P{maybe}, a probability that is related to the occurrence of false positives to assess our scheme. Our experiments show that component-based schemes offer both good performance and low search complexity.

MP8a1-5

Geometric Description and Characterization of Time Series Signals

Lauren Crider, Douglas Cochran, Arizona State University, United States

This paper considers time series signals in $\R^n$ as samples of an embedded space curve and proceeds to characterize such signals in terms of differential-geometric descriptors of their associated curves. In particular, a method of estimating curvature as a function of arc length is presented. Because arc length is invariant to reparameterization of a space curve, this approach provides a representation of the evolution of the time series that is invariant to local variations in the rate of the time series as well as displacement and rotation of the curve in space. The focus here is on ascertaining structural similarity of time series signals by measuring similarity of their curvatures, though extension to other applications and other geometric descriptors (e.g., torsion) is envisioned.

MP8a1-6

Bayesian Top Scoring Pairs for Feature Selection

Emre Arslan, Ulisses Braga-Neto, Texas A&M University, United States

We proposed a novel feature selection method, based on the Bayesian Top Scoring Pairs method, and compare its performance against well-known feature selection methods with SVM, k-NN and NB classification rules, by means of an extensive numerical experiment using real genomic data sets.Results demonstrate the promise of the proposed feature selection method in the analysis of high-dimensional biological data.

MP8a1-7

Random and Localized Random Projections for Radar: Statistical and Performance Analysis

Pawan Setlur, Tariq Qureshi, AFRL / WSRI, United States; Muralidhar Rangaswamy, Air Force Research Laboratory, United States

Multisensor radar data is high-dimensional and suffers from the curse of dimensionality. For example, in radar space time adaptive processing, training data from neighboring range cells is limited. This precludes implementation of the full-dimension optimal detectors, i.e. the minimum variance distortionless response filter. In this paper we reduce the dimension of the problem by random sampling, i.e. by projecting the data into a random d-dimensional subspace. The Johnson-Lindenstrauss theorem provides theoretical guarantees which explicitly state that the low dimensional data after random projections is only very slightly perturbed when compared to the data from the original problem in an L2 norm sense. Random projections offers two advantages, first, it permits implementation of classical detectors in the small sample size regime. Second, it offers significant computational savings permitting possible real time solutions. Both these advantages are however at the cost of reducing the clairvoyant output SINR for radar STAP. To ameliorate over this SINR loss, we propose another technique which is localized random projections for radar. In this technique, the lower dimension subspace is not entirely random, but is broken down into both a random and a deterministic part. The performance of both these approaches will be quantified using probabilistic bounds.

MP8a1-8

Cache-Aided Private Information Retrieval

Minchul Kim, Heecheol Yang, Jungwoo Lee, Seoul National University, Republic of Korea

We present a cache-aided private information retrieval (PIR) problem for a replication-based storage system, where a user caches parts of messages in advance. We propose a new PIR scheme from non-colluding databases with cached data at the user. The main idea of our scheme is to exploit cached data as a side information in a specific way to maximize the rate of PIR. The rate of our scheme is within a constant multiplicative factor from the upper bound for the considered PIR problem. Furthermore, we show that the achievable rate meets the upper-bound for a specific range of cache size.

Track D – Signal Processing and Adaptive Systems

Session: MP8a2 – Message Passing and Matrix Factorization Algorithms 1:30 PM–3:10 PM

Chair: ***Dror Baron,*** *North Carolina State University*

MP8a2-1

Recovery Conditions and Sampling Strategies for Network Lasso

Alexandru Mara, Alexander Jung, Aalto University, Finland

The network Lasso is a recently proposed convex optimization method for machine learning from massive network structured datasets, i.e., big data over networks. It is a variant of the well-known least absolute shrinkage and selection operator (Lasso), which is underlying many methods in learning and signal processing involving sparse models. Highly scalable implementations of the network Lasso can be obtained by state-of-the art proximal methods, e.g., the alternating direction method of multipliers (ADMM). By generalizing the concept of the compatibility condition put forward by van de Geer and B¨uhlmann in the analysis of plain Lasso, we derive a sufficient condition, i.e., the network compatibility condition, on the underlying network topology such that network Lasso accurately learns a clustered underlying graph signal. This network compatibility condition, relates the the location of the sampled nodes with the clustering structure of the network. In particular, the NCC informs the choice of which nodes to sample, or in machine learning terms, which data points provide most information if labeled.

MP8a2-2

Sketched Clustering via Hybrid Approximate Message Passing

Evan Byrne, Philip Schniter, The Ohio State University, United States; Remi Gribonval, INRIA, France

In the traditional approach to clustering, an algorithm like K-means is run on a dataset of, say, T samples of dimension N. The complexity and memory of this approach becomes impractical as T becomes very large, as in the "big data" regime. An alternative is to "sketch" the dataset down to an M- dimensional vector y, where $M = O(KN) \ll TN$ suffices when the data is well described by K cluster centers. The sketching process typically involves a random projection followed by a componentwise nonlinearity. The process of recovering the K centroids from y is known as "sketched clustering." We attack the sketched clustering problem using the "simplified hybrid" variant of generalized approximate message passing (SHyGAMP). We numerically demonstrate that our approach is significantly more accurate, and almost an order-of-magnitude more computationally efficient, than the state-of-the-art CLOMPR method recently proposed by Kerivan et al.

MP8a2-3

Robust Matrix Factorization for Collaborative Filtering in Recommender Systems

Christos Bampis, University of Texas at Austin, United States; Cristian Rusu, University of Edinburgh, United Kingdom; Hazem Hajj, American University of Beirut, Lebanon; Alan Bovik, University of Texas at Austin, United States

Recently, matrix factorization has produced state-of-the-art results in recommender systems. However, given the typical sparsity of ratings, the often large problem scale, and the large number of free parameters that are often implied, developing robust and efficient models remains a challenge. Previous works rely on dense and/or sparse factor matrices to estimate unavailable user ratings. In this work we develop a new formulation for recommender systems that is based on projective non-negative matrix factorization, but relaxes the non-negativity constraint. Driven by a simple yet instructive intuition, the proposed formulation delivers promising and stable results that depend on a minimal number of parameters. Experiments that we conducted on two popular recommender system datasets demonstrate the efficiency and promise of our proposed method. We make available our code and datasets at https://drive.google.com/open?id=0B_jpZEoWXKvQNmVkdnVyc0FsYVU.

MP8a2-4

Target-Based Hyperspectral Demixing via Generalized Robust PCA

Sirisha Rambhatla, Xingguo Li, Jarvis Haupt, University of Minnesota-Twin Cities, United States

Localizing targets of interest in a given hyperspectral (HS) image has applications ranging from remote sensing to surveillance. This task of target detection leverages the fact that each material/object possesses its own characteristic spectral response, depending upon its composition. As signatures of different materials are often correlated, matched filtering based approaches may not be appropriate in this case. In this work, we present a technique to localize targets of interest based on their spectral signatures. We also present the corresponding recovery guarantees, leveraging our recent theoretical results. To this end, we model a HS image as a superposition of a low-rank component and a dictionary sparse component, wherein the dictionary

consists of the a priori known characteristic spectral responses of the target we wish to localize. Finally, we analyze the performance of the proposed approach via experimental validation on real HS data for a classification task, and compare it with related techniques.

MP8a2-5

Iterative Re-weighted L1-Norm Principal-Component Analysis

Ying Liu, State University of New York at Buffalo, United States; Dimitris A. Pados, Stella Batalama, Florida Atlantic University, United States; Michael Medley, AFRL / RITE, United States

We consider the problem of principal-component analysis of a given set of data samples. When the data set contains faulty measurements/outliers, the performance of classic L2 principal-component analysis (L2-PCA) deteriorates drastically. Instead, L1 principal-component analysis (L1-PCA) offers outlier resistance due to the L1-norm maximization criterion it adopts to compute the principal subspace. In this work, we present an iterative re-weighted L1-PCA method (IRW L1-PCA) that generates a sequence of L1-norm subspaces. In each iteration, the data set comformity of each sample is measured by the L1 subspace calculated in the previous iteration and used to weigh the data sample before the L1 subspace update. The approach automatically suppresses outliers in each iteration resulting in increasingly accurate subspace calculation. We provide convergence analysis and compare the proposed algorithm against benchmark algorithms in the literature. Experimental studies demonstrate the superiority of the proposed IRW L1-PCA procedure.

MP8a2-6

Conditional Approximate Message Passing with Side Information

Dror Baron, North Carolina State University, United States; Anna Ma, Claremont Graduate University, United States; Deanna Needell, Claremont McKenna College, United States; Cynthia Rush, Columbia University, United States; Tina Woolf, Claremont Graduate University, United States

In information theory, side information is often used to increase the efficiency of communication systems. This work presents a class of Bayes-optimal signal reconstruction algorithms based on conditional approximate message passing (CAMP) in the presence of side information. Despite having a simple and straightforward derivation, our CAMP algorithm obtains lower mean squared error than other signal reconstruction algorithms that have been proposed to incorporate side information.

MP8a2-7

Analysis of a GAMP Based Algorithm with Hierarchical Priors for Recovering Non-Negative Sparse Signals

Maher Al-Shoukairi, Bhaskar Rao, University of California, San Diego, United States

We explore the advantages of addressing the sparse non-negative least squares (NNLS) problem using a rectified Gaussian scale mixture approach combined with the generalized approximate message passing algorithm (GAMP). The approach uses a hierarchical representation based on the scale mixture prior and a chosen mixing density. The expectation maximization algorithm is used to perform type II estimation of the hyper-parameters that are then used to obtain a point estimate of the unknown signal. In this work, the GAMP algorithm is used to implement the E-step. Compared to existing GAMP based NNLS algorithms, this approach enhances convergence when the transformation matrix in non-i.i.d.-Gaussian. Other advantages include significant reduction in derivation complexity of the algorithm, and the ability to impose different sparsity promoting priors on the signal simply by changing the less computationally demanding M-step.

MP8a2-8

Radix-4 Modular Pipeline Fast Fourier Transform Algorithm

Alekhya Lakkadi, Linda S. DeBrunner, Florida State University, United States

In this work, we describe the design and implementation of the Radix-4 Modular Pipeline FFT, as well as the results of implementing the previously proposed Radix-2 Modular Pipeline FFT. We present the Radix-4 algorithm including all the needed theoretical development. The Modular Pipeline algorithm differs from the Conventional FFT in terms of the storage of center elements to significantly reduce the computations requirements without significant change in performance. We present a comparison between the Conventional FFT and Modular Pipeline FFT implementations, for both Radix-2 and Radix-4, in terms of the number of computations, latency and hardware utilization, which are substantiated by our implementations using Xilinx Virtex 5, Virtex 6 devices and Quartus Stratix IV, Stratix V devices. As the size of FFT increases from 16 to 1024 points, the efficiency in terms of number of multiplications required increases from 21.8% to 31.23% for Radix-2 and from 12.5% to 25% for Radix-4. Estimated delay to compute the Modular algorithm shows an increased efficiency of 37.7% for Radix-2 and 24.08% for Radix-4 implementation when compared to Conventional FFT. Both Radix-2 and Radix-4 Modular Pipeline implementations show about 2 times the hardware utilization of the conventional FFT implementation.

Session: MP8a3 – Computer Arithmetic II **1:30 PM–3:10 PM**

Chair: ***Linda DeBrunner,*** *Florida State University*

MP8a3-1
Hyper-Threaded Multiplier for HECC

Gabriel Gallin, Arnaud Tisserand, CNRS, France

Modular multiplication is the most costly and common operation in Hyper-Elliptic Curve Cryptography over prime fields. It is based on dependent partial products and reduction steps, which make hardware implementation using FPGA pipelined DSPs difficult to optimize. We propose a new modular multiplier designed to manage several independent multiplications in parallel in order to efficiently fill the pipeline of this hyper-threaded multiplier. It increases the silicon efficiency and leads to a better area cost / computation time tradeoff than the current state-of-the-art in hardware implementation of finite fields multipliers.

MP8a3-2
An Efficient Software Implementation of Correctly Rounded Operations Extending FMA: a + b + c and a * b + c * d

Christoph Lauter, Sorbonne Universités, France

In its 2008 revision, the IEEE754 Standard for Floating-Point Arithmetic added the Fused-Multiply-And-Add (FMA) operation, computing a * b + c without intermediate rounding. This operation enables faster scalar products and doubled-precision arithmetic. The IEEE754 Standard is again undergoing revision. We propose an efficient software implementation of two additional operations: Fused-Multiply-Twice-And-Add, a * b + c * d and Fused-Add-Add a + b + c. Our implementation guarantees correct rounding in all rounding modes and IEEE754 compliant signaling. Although intended for reference purposes, with a 107 cycle latency, our implementation is pretty fast.

MP8a3-3
Rigorous Determination of Recursive Filter Fixed-Point Implementation with Input Signal Frequency Specifications

Anastasia Volkova, Christoph Lauter, Thibault Hilaire, Marc Mezzarobba, Sorbonne Universités, Université Pierre et Marie Curie, France

We give an algorithm to rigorously determine the Fixed-Point formats for the variables in an implementation of a Linear Time Invariant (LTI) filter taking into account information on the spectrum of the input signal. The Worst-Case Peak Gain (WCPG) theorem enables determination of rigorous bounds on the output of a stable filter, and thus of the Most Significant Bit of each internal variable. However, for systems with input signals that have constrained dynamics and hence bounded spectra, this magnitude upper-bound is rigorous but quite overestimated. In this paper we adapt the classical approach to the situation when information on the shape of the spectrum of the input signal is given. Exploiting this information, this allows a rigorous lower upper-bound to be determined, resulting in significant gain. Our approach still rigorously preserves from overflows occurring in internal computations. We illustrate our algorithm with several numerical examples.

MP8a3-4
Truncated Multiply-and-Accumulate Units for FIR Filter Implementation with Reduced Coefficient Length

Linda DeBrunner, Florida State University, United States

For FIR filter implementation and many other signal processing algorithms, significant error can be tolerated in the multiply-and-accumulate process. We consider the error introduced by the truncated multiply-and-add unit in light of coefficient rounding and internal rounding. This leads to designs with increased filter length and shorter coefficients to give better performance with lower power requirements. Our results show that our approach leads to reduced MSE by more than 2 orders of magnitude compared to an implementation using the C5515 DSP.

MP8a3-5
High-Performance Relative Position Rounding
Peter-Michael Seidel, University of Hawai'i at Manoa, United States

In conventional implementations of binary rounding, a binary value needs to be conditionally incremented or truncated at a predetermined rounding position setting an upper bound on the absolute rounding error. In relative position rounding, the rounding position is not fixed, but it is determined relative to the value of the rounding argument, setting bounds on the relative rounding error. We propose high-performance implementations for relative position rounding both for the case that the rounding argument is represented in binary or in carry-save form. These implementations can be useful as modules for implementing FP addition and FMA operations.

MP8a3-6
Digital Predistortion with Low Precision ADCs
Chance Tarver, Joseph Cavallaro, Rice University, United States

Digital Predistortion (DPD) is a popular technique for linearizing a power amplifier (PA) to help reduce the spurious emissions and spectral regrowth. DPD requires the learning of the inverse PA nonlinearities by training on the output of the PA. In practical systems, the analog output of the PA will have to go through an analog-to-digital converter (ADC) so that training can be done on a digital processor. The quantization degrades signal quality and may limit the performance of a DPD learning algorithm. However, a lower resolution ADC may cost less and allow for less computational complexity in the digital processing. We study this trade-off to try to find how much precision is needed in DPD systems and discover that for a full-band DPD as few as 6 bits can reliably be used. For sub-band DPD, a single bit ADC can be used.

MP8a3-7
Computation Limited Matrix Inversion Using Neumann Series Expansion for Massive MIMO
Erik Bertilsson, Oscar Gustafsson, Johannes Klasson, Erik G. Larsson, Linkoping University, Sweden

Neumann series expansion is a popular method for performing matrix inversion in massive MIMO systems. However, it has recently been shown that the computational complexity of the Neumann methods is larger than for exact matrix inversion algorithms, such as LDL, when the number of terms in the series is three or more. In this paper, the Neumann series expansion is analyzed from a computational perspective for cases when the complexity of performing exact matrix inversion is too high. By partially computing the third term of the Neumann series, the computational complexity can be reduced. Additionally, if only parts of the third term is computed, how to select which part to compute is analyzed in the context of correlated terminal channels.

Track G – Architecture and Implementation

Session: MP8a4 – Computer Architecture II **1:30 PM–3:10 PM**

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

MP8a4-1
A Comparison of Efficient First Stage Decimation Filters for Delta Sigma Modulators
Christopher Felton, Barry Gilbert, Clifton Haider, Mayo Clinic, United States

Low power and high signal to noise ratio analog-to-digital converters with high decimation rate digital filters are frequently required for biomedical applications. The traditional cascaded integrated-comb structure is a multiplier-less recursive running sum decimation filter, but requires large word lengths for high decimation rates. Alternately, the cascaded minimum polyphase structure is a non-recursive multiplier-less running sum filter with reduced word lengths. This paper quantifies the power consumption of the two filter structures that are suitable for the first stage decimation, paired with high oversample rate delta-sigma modulators.

MP8a4-2
Molecular Computation of Complex Markov Chains with Self-Loop State Transitions
Sayed Ahmad Salehi, Utah Valley University, United States; Marc Riedel, Keshab K. Parhi, University of Minnesota, United States

This paper describes a systematic method for molecular implementation of complex Markov chain processes with self-loop transitions. Markov chains consist of two parts: a set of states, and state transition probabilities. Each state is modeled by a unique molecular type, referred to as a data molecule. Each state transition is modeled by a unique molecular type, referred

to as a control molecule, and a unique molecular reaction. Each reaction consumes data molecules of one state and produces data molecules of another state. As we show in this paper, although the reactions corresponding to self-loop transitions do not change the molecular concentrations of the data molecules, they are required in order for the system to compute probabilities correctly. The concentrations of control molecules are initialized according to the probabilities of corresponding state transitions in the chain. The steady-state probability of Markov chain is computed by the equilibrium concentration of data molecules. We demonstrate our method for a molecular design of a seven-point Markov with self-loop state transitions. The molecular reactions are then mapped to DNA strand-displacement reactions. The error in the computed probabilities is shown to be less than 2% .

MP8a4-3
A Dataflow Compiler for Code-Generation, Mapping and Partitioning in Many-Core Processor Arrays

Vivek Sabbineni, Gustav Cedersjö, Jörn Janneck, LTH, Sweden

As single-core speed has ceased to increase in recent years, performance improvements are now mainly the result of increased parallelism. Processor array architectures provide scalable parallel performance suitable for a wide range of applications. However, while these hardware architectures themselves scale, their programming model usually does not, requiring designers to explicitly reflect the structure of the platform in their software. In this paper, we address this problem in a compiler that allows applications to be developed and debugged independent of platform considerations. Once functional correctness has been achieved, using the data which comes from application profiling, applications are mapped flexibly to the processing elements of the target platform.

MP8a4-4
Functional Encryption of Integrated Circuits by Key-Based Dynamical Obfuscation

Sandhya Koteshwara, Chris H. Kim, Keshab K. Parhi, University of Minnesota, United States

Hardware obfuscation refers to a set of countermeasures used against counterfeiting and illegal overproduction by modification of circuits and application of secret keys. In this paper, we introduce a novel technique of obfuscation termed dynamic obfuscation where the system works in a dynamic manner. When the secret key input to the system is not correct, it operates inconsistently by working correctly sometimes and failing sometimes. Since the circuit will eventually fail during its operation, it makes it unusable by unauthorized parties without access to the correct keys. The time complexity of deciphering the correct key is large enough to prevent a brute-force attack from being computationally feasible. The dynamic nature of these circuits also makes them resistant to tool based or reverse engineering based attacks. In this paper, a complete design of the obfuscation technique using counters is presented. A demonstration of obfuscation on sequential circuits implementing FFT algorithm shows low overall area and power-delay overheads of 0.32% and 0.92%, respectively. Security in terms of time to attack (for a key size of 30 bits and a system operating at 100 MHz) is increased to 5,961,440 years using dynamic obfuscation, compared to only 5.36 s using fixed obfuscation schemes.

MP8a4-5
MIMO Detector Implementation Comparison Using High-level Synthesis Tools from Different Generations

Tuomo Hänninen, Muhammad Saad Saud, Ganesh Venkatraman, Markku Juntti, University of Oulu, Finland

We compared different multiple-input multiple-output (MIMO) receiver algorithms and structures for single-carrier frequency-division multiple access (SC-FDMA) uplink transmission to get a good understanding of the performance and complexity of these algorithms and their suitability for practical realization. One of those structures, namely the frequency domain MMSE equalization with sphere detection (SD) using K-best SD is implemented on an field programmable gate array (FPGA). High-level Synthesis (HLS) tools from two different generations are used for the implementation. The results are compared and evolution of HLS tools is discussed.

MP8a4-6
Execution Trace Graph Based Interface Synthesis of Signal Processing Dataflow Programs for Heterogeneous MPSoCs

Endri Bezati, Simone Casale Brunet, SIB Vital-IT, Switzerland; Marco Mattavelli, École Polytechnique Fédérale de Lausanne, Switzerland

Heterogeneous multiprocessor system-on-chip (MPSoCs) platforms may provide effective implementation solutions for a wide range of applications. This kind of chip provides low-power massive parallelism but with the cost of being difficult to program. Dataflow programming, and specifically the CAL dynamic dataflow programming language, provides a solution for effectively programming both the reconfigurable (such as an FPGA) and the sequential (multi-core CPU) part. One of the toughest part of

such platforms is the interface synthesis, which is to decide the number and kind of interfaces for the communication between the reconfigurable and the sequential part of MPSoCs. In this paper, we propose a methodology that automatically inserts the necessary interface after partitioning based on the Execution Trace Graph.

MP8a4-7
Wideband Spectrum Sensing Measurement Results using Tunable Front-End and FPGA Implementation

Xusong Wang, Shailesh Chaudhari, Mihir Laghate, Danijela Cabric, University of California, Los Angeles, United States

In this work, we will present field measurement results of an energy detection based wideband spectrum sensor. The sensor uses an Analog Devices AD9361 RF frontend that can be tuned to frequencies from 70MHz to 6GHz with bandwidth up to 56MHz. The occupied frequency bins are detected by thresholding an 8192-point power spectrum computed on a Xilinx Kintex-7 FPGA. Contiguous occupied frequency bins are grouped together to estimate the center frequency and bandwidth of up to 8 non-overlapping frequency bands. The proposed design provides spectrum sensing results every 13.079ms, i.e., 230x faster than currently reported spectrum sensors.

MP8a4-8
Profiling of Dynamic Dataflow Programs on MPSoC Multi-Core Architectures

Simone Casale Brunet, Endri Bezati, Swiss Institute of Bioinformatics, Switzerland; Aurelien Bloch, Marco Mattavelli, École Polytechnique Fédérale de Lausanne, Switzerland

This paper describes a profiling methodology and its implementation applied to dynamic dataflow programs running on embedded heterogeneous platforms. Starting from an high-level and platform independent representation of the program, the approach automatically generates low-level platform-specific source code including specific profiling capabilities. Profiling information is then collected during the profiling execution and successively used during the design space exploration stages. The methodology has been developed and validated using different application designs based on dynamic dataflow program implementations running on a multi-core ARM MPSoC architecture.

Track A – Communications Systems
Session: TA1a – Interface of Communications and Control

Chair: ***Victoria Kostina,*** *California Institute of Technology*

TA1a-1 8:15 AM
The Value of Information in Event Triggering: Can We Beat the Data-Rate Theorem?

Khojasteh Mohammad Javad, University of California, San Diego, United States; Pavankumar Tallapragada, Indian Institute of Science, India; Jorge Cortes, Massimo Franceschetti, University of California, San Diego, United States

In cyber-physical systems (CPS), data-rate theorems relate the amount of information that the feedback channel between estimator and controller must be able to supply to guarantee stability, to the amount of information requested by the plant. The need to use distributed resources efficiently has led to event-triggering control techniques based on the idea of sending information in an opportunistic manner between the controller and the plant. We illustrate how data-rate theorems are modified in the presence of an event-triggered implementation. The act of triggering reveals information about the system's state and can be exploited for stabilization, thus effectively invalidating "classic" formulations of the theorem. The extended formulation reveals a phase transition behavior of the transmission rate required for stabilization as a function of the communication delay. It is shown that for low values of the delay the timing information carried by the triggering events is large and the system can be stabilized with any positive rate. On the other hand, when the delay exceeds a certain threshold that depends on the given triggering strategy, the timing information alone is not enough to achieve stabilization and the rate must begin to grow. Results for both scalar and vector systems are considered.

TA1a-2 8:40 AM
Exploring Unpredictability in Control

Gireeja Ranade, Microsoft Research, United States

Scalar control systems with multiplicative actuation noise exhibit surprising behavior: while a system might not be stabilizable in the second-moment sense, and the second-moment control capacity is zero, the system can be stabilizable in probability. However, it is not clear whether the same phenomenon is true for vector systems. Does a second-moment control capacity of zero imply that a vector system also cannot be stabilized in probability or can an alternative control strategy stabilize the system?

TA1a-3 9:05 AM

Finite-Horizon Rationally Inattentive Markov Decision Processes

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

The framework of Rationally Inattentive Markov Decision Processes (RIMDPs) is an extension of Partially Observable Markov Decision Processes (POMDP) to the case when the observation kernel that governs the information gathering process is also selected by the decision maker at each time subject to a constraint on Shannon's conditional mutual information between the current state and the current observation given the history of past observations. This set-up naturally arises in the context of networked control systems, artificial intelligence, and economic decision-making by boundedly rational agents. We show that, under certain structural assumptions on the information pattern and on the optimal policies, Bellman's Principle of Optimality can be used to derive a general dynamic programming recursion that reduces to solving a sequence of conditional rate-distortion problems. As an illustrative example, we analyze the information-constrained Linear Quadratic Gaussian (LQG) problem.

TA1a-4 9:30 AM

Rate-Cost Tradeoffs over Lossy Channels

Anatoly Khina, Victoria Kostina, Babak Hassibi, California Institute of Technology, United States; Ashish Khisti, University of Toronto, Canada

We consider a discrete-time linear quadratic networked control setting where the observer and controller are separated by a rate-limited, time-varying, noiseless channel. More specifically, at time t such a channel can noiselessly transmit R_t bits, where R_t is a random variable. An important special case is the stationary packet drop channel, which conveys its input packet error-free with probability $1 - p$, and loses it with probability p. The required conditions to stabilize such systems have been well studied. In this work we take one step further by deriving bounds on the optimal cost that can be achieved, which is of great theoretical and practical significance. To that end, we employ classical information theoretic tools to derive lower bounds on the optimal achievable cost. For the variable-rate quantization setting we then show that entropy coded lattice-based techniques approach these bounds when the resolution is high. All the results are shown to be useful outside the realm of noiseless channels.

Track A – Communications Systems

Session: TA1b – Cognitive Networks

Chair: ***Marco Levorato,*** *University of California, Irvine*

TA1b-1 10:15 AM

Deep Neural Network Architectures for Modulation Classification

Xiaoyu Liu, Diyu Yang, Aly El Gamal, Purdue University, United States

In this work, we test various deep neural network architectures for the task of classifying the modulation of received wireless signals. We find that among all tested networks, using convolutional neural layers on top (close to the input layer) and densely connected neural layers at the bottom (close to the output layer) is most efficient. We use both simulated and experimental received signals to test our architectures and show enhancement in performance compared to the state of the art.

TA1b-2 10:40 AM

Non-parametric Learning to Infer Wireless Relays, Routes and Traffic Patterns from Time Series of Spectrum Activity

Silvija Kokalj-Filipovic, Vencore Labs, Inc., United States; Predrag Spasojevic, Winlab, Rutgers University, United States; Alex Poylisher, Vencore Labs, Inc., United States

We analyze several generative models of sequential data consisting of spectral activity indicators of network nodes, in their capacity to uncover the latent network structure and characterize the information flow between spectrally monitored nodes. The practical aspect of learning is to aid the reasoning of a cognitive network about its dynamic spectrum environment where coexisting networks are unknown or adaptive. For example, learning network patterns could help mitigate interference in hospital area and other mission-critical communications in the unlicensed spectrum. Using learned statistics, such as Granger-causality between time series of per-node activity indicators, we can trace the impact of one node's traffic to another. We consider unsupervised learning, through approaches based on either state-space models or multivariate point-process models. The latter is more successful in learning information flow graphs while less interpretable in terms of latent structures. Moreover, learning can be made more resilient to the activity noise (ubiquitous maintenance and status packets), if state-space models are used to extract low-dimensional sequential features. The latter are next fed into a point-process such as Hawkes in order to extract information graphs. Finally, non-parametric linear state models and deep (non-linear) Markov models are compared in terms of interpretability under simple wireless scenarios.

TA1b-3 11:05 AM

Intelligent Data Filtering in Constrained IoT Systems

Igor Burago, Davide Callegaro, Marco Levorato, Sameer Singh, University of California, Irvine, United States

A novel semantic approach to data selection and compression is presented for the dynamic adaptation of IoT data processing and transmission within wireless islands, where a set of sensing devices (sensors) are interconnected through one-hop wireless links to a computational resource via a local access point. The core of the proposed technique is a cooperative framework where local classifiers used as filters at the mobile nodes are dynamically crafted and updated based on the current state of the observed system, the global processing objective, the energy and bandwidth resources available and the characteristics of the data streams. In this architecture, the edge processor plays a key role by establishing a link between content and operations within the distributed system. The local classifiers are designed to filter the data streams and provide only the needed information to the global classifier at the edge processor, thus minimizing bandwidth usage. However, the better the accuracy of these local classifiers, the larger the energy necessary to run them at the individual sensors.

TA1b-4 11:30 AM

Modulation Classification using Convolutional Neural Networks and Spatial Transformer Networks

Danijela Cabric, Moein Mirmohammadsadeghi, University of California, Los Angeles, United States

In this paper, we studied new approach for modulation classification. We take advantage of recent methods in deep learning such as Convolutional Neural Network and Spatial Transformer Networks to build a classifier model in supervised fashion by using raw baseband I/Q samples as input for classifier. We compared the accuracy of proposed classifier with two popular methods for modulation classification. Results shows that proposed classifier has better classification accuracy on the same dataset even with multipath channel. In addition, sample complexity of proposed approach is about one order of magnitude less than state of the art methods.

Track B – MIMO Communications and Signal Processing

Session: TA2a – Video Delivery Over Wireless Caching Networks: Theory and Practice

Co-Chairs: ***Antonia Tulino,*** *Nokia Bell Labs* ***and Jaime Llorca,*** *Nokia Bell Labs*

TA2a-1 8:15 AM

Coded Caching Main Technical Barriers: Finite Packetization and Channel Heterogeneity

Karthikeyan Shanmugam, IBM Research, T. J. Watson Research Center, United States; Alexandros G. Dimakis, University of Texas at Austin, United States; Jaime Llorca, Bell Labs, United States; Antonia Tulino, Bell Labs & Università di Napoli Federico II, United States

In a broadcast channel serving K receivers, each storing a constant fraction of a file library, from which requests are issued, it has been shown that one can get a coding gain of O(K) over the naïve scheme that does not use coding for delivery. Two important bottlenecks to translate this gain in practice are: a) the number of packets per file needed to achieve this coding gain, and b) the heterogeneity of the channel strengths. We review recent developments that address these critical technical barriers.

TA2a-2 8:40 AM

Algorithms for Asynchronous Coded Caching

Hooshang Ghasemi, Aditya Ramamoorthy, Iowa State University, United States

Coded caching has largely been studied in the setting when file requests from the users to the server are synchronized. Furthermore, while it is well recognized that coded caching offers significant reductions in the overall rate of transmission from the server, its performance in presence of end user delay constraints is much less understood. In this work we consider a problem setting where users have arrive in an asynchronous fashion and also have deadlines by which they expect their requests to be completed. In the offline case the server is assumed to have knowledge of the arrival times and deadlines in advance. In this case we present fast algorithms for solving the problem that rely on dual decomposition of an appropriate linear program. Our algorithm outputs a schedule for the transmissions from the server that minimizes the overall rate, subject to the constraint that each user meets their delay constraint. We also present some preliminary observations and results on online algorithms with good performance.

TA2a-3 9:05 AM

Combination Networks with Caches: Improved Achievable Scheme based on Interference Alignment

Kai Wan, Laboratoire des Signaux et Systèmes, France; Mingyue Ji, University of Utah, United States; Pablo Piantanida, Laboratoire des Signaux et Systèmes, France; Daniela Tuninetti, University of Illinois at Chicago, United States

Caching is an efficient way to reduce peak hour network traffic congestion by storing some content at the user's cache, without knowledge of later demands. This paper studies the tradeoff between cache size and download time in combination networks, i.e., caching systems with a server connected to intermediate relays, which in turns connect to the end users equipped with a cache, that is symmetric with respect to any user and any relay. Assuming symmetric uncoded cache placement, this paper proposes an delivery method based on topological interference alignment. Numerical evaluations show that the proposed scheme outperforms known state of the art schemes. For some ranges of parameters the scheme is shown to be actually optimal under the restriction of uncoded cache placement.

TA2a-4 9:30 AM

Improved Caching Gains in Fast-Fading Downlinks

Shirin Saeedi Bidokhti, Stanford University, United States; Michele Wigger, Telecom ParisTech, United States; Aylin Yener, Pennsylvania State University, United States

A new coding scheme for cellular downlink is proposed. Our scheme improves over previous schemes in dynamic environments where the channel fadings vary faster than file download times. A new coding scheme for cellular downlink is proposed. Our scheme improves over previous schemes in dynamic environments where the channel fadings vary faster than file download times.

Track B – MIMO Communications and Signal Processing

Session: TA2b – Millimeter-Wave MIMO Wireless Systems

Chair: ***Akbar Sayeed,*** *University of Wisconsin-Madison*

TA2b-1 10:15 AM

Multi-Aperture Phased Arrays Versus Multi-beam Lens Arrays for mmW Multiuser MIMO

Akbar Sayeed, University of Wisconsin, United States

Multi-beamforming and data multiplexing is a key functionality for realizing the spatial multiplexing gains in multiuser massive MIMO systems at millimeter-wave (mmW) frequencies. Due to the prohibitive complexity of conventional digital beamforming, two main approaches to hybrid analog-digital beamforming are being investigated that employ the use of phased arrays or lens arrays for analog beamforming. While the two approaches are equivalent from a purely communication-theoretic perspective, they offer very different tradeoffs in terms of performance, complexity and power consumption. In particular, all existing phased array-based prototypes are limited to a single beam per aperture, due to hardware constraints, thereby necessitating the use of multiple smaller sub-arrays for multi-beam operation. On the other hand, the beam switching network presents a hardware challenge in lens array-based systems, thereby limiting the coverage achieved by particular radio-frequency chain. In this paper, we use beamspace MIOM framework to compare the achievable sum-rates in a small cell served by an access point AP using a lens array-based or phased array-based architecture. Our results characterize the optimum configurations for the two architectures from a sum-rate perspective. We also quantify the hardware complexity of the two architectures to enable performance-complexity optimization.

TA2b-2 10:40 AM

Millimeter Wave Communications: from Point-to-Point Links to Agile Network Connections

Haitham Hassanieh, University of Illinois at Urbana-Champaign, United States; Omid Abari, Dina Katabi, Massachusetts Institute of Technology, United States

Millimeter wave (mmWave) technologies promise to revolutionize wireless networks by enabling multi-gigabit data rates. However, they suffer from high attenuation, and hence have to use highly directional antennas to focus their power on the receiver. Existing radios have to scan the space to find the best alignment between the transmitter's and receiver's beams, a process that takes up to a few seconds. This delay is problematic in a network setting, where the base station needs to quickly switch between users and accommodate mobile clients. We present Agile-Link, the first mmWave beam steering system that is

demonstrated to find the correct beam alignment without scanning the space. Instead of scanning, AgileLink hashes the beam directions using a few carefully chosen hash functions. It then identifies the correct alignment by tracking how the energy changes across different hash functions. Our results show that Agile-Link reduces beam steering delay by orders of magnitude.

TA2b-3 11:05 AM

A Split TCP Proxy Architecture for 5G mmWave Cellular Systems

Michele Polese, University of Padova, Italy; Menglei Zhang, Marco Mezzavilla, New York University, United States; Jing Zhu, Intel, United States; Sundeep Rangan, Shivendra Panwar, New York University, United States; Michele Zorzi, University of Padova, Italy

TCP is the most used transport protocol in the internet. However, it offers a suboptimal performance when operating over high bandwidth mmWave links. The main issues introduced by communications at such high frequencies are (i) the sensitivity to blockage and (ii) the high bandwidth fluctuations due to LOS to NLOS transitions and vice versa. In particular, TCP has an abstract view of the end-to-end connection, which does not properly capture the dynamics of the wireless mmWave link. The consequence is a suboptimal utilization of the available resources. In this paper we propose a split TCP proxy architecture that improves the performance of TCP flows without any modification at the remote sender side. The proxy is installed in the Radio Access Network, and it exploits information available at the eNB in order to maximize the throughput and minimize the latency.

TA2b-4 11:30 AM

Non-Orthogonal Multiple Access for mmWave Drones with Multi-Antenna Transmission

Nadisanka Rupasinghe, Yavuz Yapici, Ismail Guvenc, North Carolina State University, United States; Yuichi Kakishima, Docomo Innovations, Inc., United States

In this paper, we consider the use of non-orthogonal multiple access (NOMA) technique with millimeter-wave (mmWave) drones, serving as flying base stations (BSs) to deliver broadband rates in a large and densely populated stadium. While in conventional NOMA scenarios the users can be differentiated based on their link qualities at different distances to a BS, we argue that, by generating directional beams using multi-antenna arrays, a similar link quality difference can be expected for those users who are within the same beam but located at different angular offsets from the boresight of the beam. Then, by introducing NOMA techniques, multiple users within the same beam but with different angular offsets can be served simultaneously. To provide broadband rates to users, we deploy multiple drone BSs each providing coverage to users within equal size angular sectors. We evaluate outage probability and achievable sum-rate with NOMA considering different beam widths and user densities at various mmWave frequencies. We also conduct ray tracing simulations using Wireless InSite to capture realistic mmWave propagation in a stadium environment.

Track C – Networks

Session: TA3a – Smart Networked Infrastructure

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

TA3a-1 8:15 AM

Wholesale Electricity Pricing in the Presence of Geographical Load Balancing

Mohammed A. Abdelghany, Mahnoosh Alizadeh, University of California, Santa Barbara, United States; Hamed Mohsenian-Rad, University of California, Riverside, United States

Data centers and cloud computing providers currently represent over two percent of the total energy consumption in the US. Hence, power management in data centers has gained much attention in the literature. Geographical load-balancing (GLB) is one such power management method, which exploits data centers' workload flexibility and spatial diversity to minimize electricity cost by geographically shifting workload. However, under such forms of geographical load shifting, conventional wholesale electricity market clearing mechanisms would face many difficulties, particularly with regards to bidding. In this paper, we provide a distributed market clearing algorithm in the presence of GLB. We calculate the cost of stopping the distributed algorithm before convergence, and showcase the dangers of employing dynamic pricing programs in the absence of appropriately updated market clearing mechanisms.

TA3a-2 8:40 AM

Distribution System Voltage Control under Uncertainties

Pan Li, Baosen Zhang, University of Washington, United States

Voltage control plays an important role in the operation of electricity distribution networks, especially with high penetration of distributed energy resources. These resources introduces significant and fast varying uncertainties. In this paper, we focus on reactive power compensation to control voltage in the presence of uncertainties. We adopt a probabilistic approach that accounts for arbitrary correlations between renewable resources at each of the buses and we use the linearized DistFlow equations to

model the distribution network. We then show that this optimization problem is convex for a wide variety of probabilistic distributions. Compared to conventional per-bus chance constraints, our formulation is more robust to uncertainty and more computationally tractable. We illustrate the results using standard IEEE distribution test feeders.

TA3a-3 9:05 AM

A Prediction-Correction Method for Dynamic Distribution State Estimation

Emiliano Dall'Anese, National Renewable Energy Laboratory, United States; Andrea Simonetto, IBM Research Ireland, Ireland; Hao Zhu, University of Illinois at Urbana-Champaign, United States

This paper focuses on dynamic state estimation for multiphase power distribution networks. The proposed technical approach involves casting the state estimation task within the time-varying optimization realm, and it leverages the prediction-correction method to develop an online algorithm that provably tracks the state of a distribution system -- in the form of voltage profiles and power flows -- from heterogenous measurements. The online algorithm is computationally efficient in the sense that it relies on the Hessian of the cost function, which does not require the matrix-inversion computations. In addition, it can account for the operational constraints on pertinent electrical quantities of interest, while being suitable for settings where measurements are collected at a fast time scale to maintain comprehensive situational awareness of the system state. Convergence and bounds on the estimation errors of proposed algorithm are analytically established.

TA3a-4 9:30 AM

Online Learning for "Thing-Adaptive" Fog Computing in IoT

Tianyi Chen, Yanning Shen, University of Minnesota, United States; Qing Ling, University of Science and Technology of China, China; Georgios B. Giannakis, University of Minnesota, United States

The present paper deals with online convex optimization involving time-varying loss functions and time-varying constraints. The constraints are revealed after making decisions, and allow instantaneous violations yet they must be satisfied in the long term. This setting is motivated by emerging online tasks such as fog computing, where online decisions need to flexibly adapt to the temporally unpredictable availability of resources. Tailored for heterogeneous systems such as those involved in the Internet of Things (IoT), a ``thing-adaptive'' online saddle-point (TAOSP) scheme is developed, which automatically adjusts the stepsize to offer desirable task-specific learning rates. Performance here is assessed by: i) dynamic regret that generalizes the widely used static regret; and, ii) dynamic fit that captures the accumulated amount of constraint violations. Specifically, TAOSP is proved to simultaneously yield sub-linear dynamic regret and fit, provided that the best dynamic solutions vary slowly over time. Numerical tests in fog computation offloading tasks corroborate that our proposed TAOSP approach outperforms the state-of-the-art.

Track C – Networks

Session: TA3b – Networks and Society

Chair: ***Santiago Segarra,*** *Massachusetts Institute of Technology*

TA3b-1 10:15 AM

Estimation of Vertex Degrees in a Sampled Network

Apratim Ganguly, Natera Inc., United States; Eric Kolaczyk, Boston University, United States

The need to produce accurate estimates of vertex degree in a large network, based on observation of a subnetwork, arises in a number of practical settings. We study a formalized version of this problem, wherein the goal is, given a randomly sampled subnetwork from a large parent network, to estimate the actual degree of the sampled nodes. Depending on the sampling scheme, trivial method of moments estimators (MMEs) can be used. However, the MME is not expected, in general, to use all relevant network information. In this study, we propose a handful of novel estimators derived from a risk-theoretic perspective, which make more sophisticated use of the information in the sampled network. Theoretical assessment of the new estimators characterizes under what conditions they can offer improvement over the MME, while numerical comparisons show that when such improvement obtains, it can be substantial. Illustration is provided on a human trafficking network.

TA3b-2 10:40 AM

Joint Inference of Networks from Stationary Graph Signals

Santiago Segarra, Yuhao Wang, Caroline Uhler, Massachusetts Institute of Technology, United States; Antonio Marques, King Juan Carlos University, Spain

We investigate the identification of the topology of a collection of undirected weighted graphs from the observation of signals defined on a common set of nodes. To address this problem two main assumptions are considered: (i) the topology of the different networks is related, so that joint identification of them is beneficial; and (ii) the edges in the graph encode direct relationships between the corresponding nodes, which render the values of the observed signals correlated. To model the relationship between

the observations and the underlying graph it is assumed that the signals are graph-stationary. The joint network topology inference problem is formulated as a constrained sparse recovery problem, where the sought graphs are sparse and different metrics to assess the similarity among them are analyzed. Theoretical guarantees for exact joint recovery of sparse graphs are presented and the developed algorithms are tested in both synthetic and real-world data.

TA3b-3 11:05 AM

Soft Unveiling of Communities via Egonet Tensors

Fatemeh Sheikholeslami, Georgios B. Giannakis, University of Minnesota, United States

The task of community detection over a network pertains to identifying the underlying \emph{groups} of nodes whose \emph{often-hidden association} has manifested itself in dense connections among the members, and sparse inter-community links. The present works introduces a novel tensor-based graph representation, in which tensors are utilized as multi-way data structures, capturing \emph{higher-order} statistics of nodes, i.e., egonet connectivity patterns. Capturing such higher-order statistics will in turn induce a reinforced structure in the representation, which can potentially increase the robustness of community detection algorithms against overlapping nodes as well as highly-mixing communities. To this end, constrained PARAFAC decomposition is put forth in which physical characteristics of the networks are utilized as constraints, providing the factorization with community-revealing components. Preliminary tests on synthetic and real-word networks corroborate the envisioned advances over conventional matrix-based as well as state-of-the-art competitors.

TA3b-4 11:30 AM

Aggregate Learning in Networked Dynamic Games with Strategic Agents

Amir Ajorlou, Ali Jadbabaie, Massachusetts Institute of Technology, United States

We study the quality of information aggregation in a dynamic quadratic game of incomplete information. Agents in each generation have access to a public history of noisy aggregate actions in previous generations. Each agent also receives a private noisy signal about the state. We quantify the quality of information aggregation as the asymptotic precision of the publicly learned signal about the state, and study how the interactions among the agents affect the quality of aggregate learning. Characterizing the precision of aggregate learning for slow walks, we show the inefficiency of learning from the public history: while for a static state, public history fully reveals the state, a small perturbation in the state from generation to generation significantly degrades the quality of learning. As for the effect of interactions, we show that the quality of learning for slow walks is mainly determined by the local network structure: the denser the locality, the higher the quality of information aggregation. For fast dynamics, on the other hand, the quality of aggregate learning is positively affected by the average Bonacich centrality, and is negatively affected by its variance. As a result, we may observe phase transition in quality of learning between different network structures.

Track D – Signal Processing and Adaptive Systems

Session: TA4a – Structured and Covariance Matrix Recovery

Co-Chairs: ***Greg Ongie,*** *University of Michigan* ***and Laura Balzano,*** *University of Michigan*

TA4a-1 8:15 AM

Learning the Second-Moment Matrix of a Smooth Function From Point Samples

Armin Eftekhari, Alan Turing Institute, United Kingdom; Michael Wakin, Colorado School of Mines, United States; Ping Li, Rutgers University, United States; Paul Constantine, Colorado School of Mines, United States; Rachel Ward, University of Texas at Austin, United States

Consider an open set $D\subseteq \mathbb{R}^n$ equipped with a probability measure μ. An important characteristic of a smooth function $f:D\rightarrow\mathbb{R}$ is its second-moment matrix $\Sigma_{\mu} = \int \nabla f(x) \nabla f(x)^\ast \mu(dx)$, where $\nabla f(x)\in\mathbb{R}^n$ is the gradient of $f(\cdot)$ at $x\in D$. For instance, the span of the leading r eigenvectors of Σ_μ forms an active subspace of $f(\cdot)$, thereby extending the concept of principal component analysis to the problem of ridge approximation. In this work, we propose a simple algorithm for estimating Σ_μ from point values of $f(\cdot)$ without imposing structural assumptions on $f(\cdot)$---e.g., that $f(\cdot)$ is a ridge function. Theoretical guarantees for this algorithm are provided with the aid of the same technical tools that have proved valuable in the context of covariance matrix estimation from partial measurements.

TA4a-2 8:40 AM

Sketched Covariance Testing: A Compression-Statistics Tradeoff

Gautam Dasarathy, Rice University, United States; Parikshit Shah, Yahoo Research, United States; Richard Baraniuk, Rice University, United States

Hypothesis testing of covariance matrices is an important problem in multivariate analysis. Given n data samples and a covariance matrix, the goal is to determine whether or not the data is consistent with the matrix. In this paper we introduce a framework that we call Sketched Covariance Testing, where the data is provided after being compressed by multiplying by a "sketching" matrix. We propose a statistical test in this setting and quantify an achievable sample complexity as a function of the amount of compression. Our result reveals an intriguing tradeoff between the compression ratio and the statistical information required for reliable hypothesis testing; the sample complexity increases as the fourth power of the amount of compression.

TA4a-3 9:05 AM

Performance Limits of Covariance-Driven Super Resolution Imaging

Heng Qiao, Piya Pal, University of California, San Diego, United States

This paper considers the problem of super-resolution fluorescence microscopy for cellular and molecular imaging. Unlike prior works that restrict the emitters to lie on a known high-resolution grid, we consider the actual off-grid super-resolution model where the target resolution is not restricted by the size of the grid. We reformulate super-resolution cellular imaging as a two-dimensional source localization problem, and propose two algorithms that exploit the correlation structure of the measurements. One algorithm is based on 2D MUSIC and the other is inspired by atomic norm minimization, where the atom set differs from commonly used Fourier atoms. We also study sufficient conditions for perfectly recovering the emitter locations which highlight the role of the Point Spread Function (PSF) and the correlation between brightness functions of different emitters.

TA4a-4 9:30 AM

Super-Resolution with Quantization Compressive Sensing

Haoyu Fu, Yuejie Chi, The Ohio State University, United States

Efficient estimation of wideband spectrum is of great importance for applications such as cognitive radio. Recently, sub-Nyquist sampling schemes based on compressed sensing have been proposed to greatly reduce the sampling rate. However, the important issue of quantization has not been fully addressed, particularly for high-resolution spectrum estimation. In this paper, we aim to recover spectrally-sparse signals from quantizations of their complex-valued random linear measurements, for example only the quadrant information. We propose a new algorithm based on atomic norm soft thresholding (AST) with provable performance guarantees under the Gaussian measurement model. Moreover, the Cramer-Rao bound is studied to characterize the trade-off between bit depth and sample complexity, as well as provide a benchmark for performance.

Track D – Signal Processing and Adaptive Systems

Session: TA4b – Adaptive Sensing

Co-Chairs: ***Mark Davenport,*** *Georgia Institute of Technology* ***and Marco Duarte,*** *University of Massachusetts Amherst*

TA4b-1 10:15 AM

Enhanced Online Robust PCA via Adaptive Sensing

Greg Ongie, Laura Balzano, University of Michigan, United States

Robust principal component analysis (RPCA) is a technique for efficiently decomposing a matrix of data into sparse and low-rank additive components from possibly missing or compressive measurements. Online extensions of RPCA have been proposed that estimate low-rank and sparse components of time series data at each time instant. However, current online RPCA approaches focus on random sampling models similar to static situation. In this work we show it is possible to leverage adaptive sampling in online RPCA to better estimate future low-rank and sparse components from current estimates. In particular, we propose a sampling scheme that optimally samples the sparse part given a good estimate of the low-rank component. As an application, we illustrate the potential of such an adaptive strategy for compressed sensing of dynamic magnetic resonance imaging data.

TA4b-2 10:40 AM

Active Learning of Linear Separators under Asymmetric Noise

Pranjal Awasthi, Rutgers University, United States; Maria-Florina Balcan, Nika Haghtalab, Hongyang Zhang, Carnegie Mellon University, United States

We study the learnability of linear separators in R^d in the presence of asymmetric bounded noise. We provide the first polynomial-time algorithm that learns linear separators to arbitrarily small excess error in this noise model under log-concave distribution, for some constant value of noise level. While widely studied in the statistical learning theory in the context of getting faster convergence rates, computationally efficient algorithms in this model had remained elusive. Our work provides the first evidence that one can design algorithms achieving arbitrarily small excess error in polynomial time. We additionally provide lower bounds showing that popular algorithms such as hinge loss minimization cannot lead to arbitrarily small excess error under bounded noise, even under the uniform distribution. Our work instead, makes use of a margin-based technique developed in the context of active learning. So our algorithm has label complexity that is only a logarithmic the desired excess error.

TA4b-3 11:05 AM

Global Testing Against Sparse Alternatives under Ising Models

Rajarshi Mukherjee, Stanford University, United States; Sumit Mukherjee, Columbia University, United States; Ming Yuan, University of Wisconsin-Madison, United States

We study the effect of dependence on detecting sparse signals. In particular, we focus on global testing against sparse alternatives for the means of binary outcomes following an Ising model and establish how the interplay between the strength and sparsity of a signal determines its detectability under various notions of dependence. The profound impact of dependence is best illustrated under the Curie-Weiss model where we observe the effect of a “thermodynamic” phase transition. In particular, the critical state exhibits a subtle “blessing of dependence” phenomenon in that one can detect much weaker signals at criticality than otherwise. Furthermore, we develop a testing procedure that is broadly applicable to account for dependence and show that it is asymptotically minimax optimal under fairly general regularity conditions.

TA4b-4 11:30 AM

A framework for Multi-A(rmed)/B(andit) testing with online FDR control

Fanny Yang, University of California, Berkeley, United States

We propose a an alternative framework to existing setups for controlling false alarms when multiple A/B tests are run over time. This setup arises in many practical applications, e.g. when pharmaceutical companies test new treatment options against control pills for different diseases, or when internet companies test their default webpages versus various alternatives over time. Our framework proposes to replace a sequence of A/B tests by a sequence of best-arm MAB instances, where each instance corresponds to an adaptive test of a single hypothesis which can be continuously monitored by the data scientist and stopped at any time. To control for multiple testing, we demonstrate how to interleave the MAB tests with an online false discovery rate (FDR) algorithm so that we can obtain the best of both worlds: low sample complexity and any time online FDR control. Our main contributions are: (i) to propose reasonable definitions of a null hypothesis for MAB instances; (ii) to demonstrate how one can derive an always-valid sequential p-value that allows continuous monitoring of each MAB test; and (iii) to show that using the rejection thresholds of online-FDR algorithms as confidence levels for the MAB algorithms results in both sample-optimality, high power and low FDR at any point in time. We run extensive simulations to verify our claims, and also report results on real data collected from the New Yorker Cartoon Caption contest.

Track E – Array Signal Processing

Session: TA5 – Tensor Methods

Chair: ***Lieven De Lathauwer,*** *KU Leuven*

TA5-1 8:15 AM

Kullback-Leibler Principal Component for Tensors is not NP-hard

Kejun Huang, Nicholas D. Sidiropoulos, University of Minnesota, United States

We study the problem of nonnegative rank-one approximation of a nonnegative tensor, and show that the globally optimal solution that minimizes the generalized Kullback-Leibler divergence can be efficiently obtained in closed form. This result works for arbitrary nonnegative tensors with arbitrary number of modes (including two, i.e., matrices), and any (partial) mode symmetry can be seamlessly incorporated as well. We achieve this via re-parameterizing the nonnegative entries of the rank-one factors, which transforms the problem into an unconstrained and convex one. An interesting sparsity promoting regularization is naturally suggested by this re-parameterization, which does not hinder the convexity of the reformulation. Implications of this result for higher-rank nonnegative tensor approximations are also discussed.

TA5-2 8:40 AM

Directed Network Topology Inference via Sparse Joint Diagonalization

Yanning Shen, Xiao Fu, Georgios B. Giannakis, Nicholas D. Sidiropoulos, University of Minnesota, United States

Discovering the connectivity patterns of directed networks is a crucial step towards understanding complex systems such as human brains and financial markets. Network inference approaches aim at estimating the hidden topology given nodal observations. Existing approaches relying on structural equation models (SEMs) require full knowledge of exogenous inputs, which may be impossible to obtain in certain applications. Recent tensor based alternatives advocate reformulation of SEMs as a three-way tensor decomposition task that only requires second-order statistics of exogenous inputs for identifying the hidden topology. However, the tensor-based methods are computationally expensive, and do not facilitate accounting for prior information about the network structure (e.g., sparsity and local smoothness), that is important for enhancing performance. The present work puts forth a joint diagonalizaiton (JD)-based formulation for directed network inference. JD can be viewed as a tensor decomposition, but can afford more efficient algorithms and can readily incorporate prior information about the network topology. Topology identification guarantees are established, and simulated tests are presented to showcase the effectiveness of the novel approach.

TA5-3 9:05 AM

Joint Extended Factor Analysis

Ahmad Mouri Sardarabadi, Groningen University, Netherlands; Alle-Jan van der Veen, TU Delft, Netherlands

Many subspace-based array signal processing algorithms assume that the noise is spatially white. In this case the noise covariance matrix is a multiple of the identity and the eigenvectors of the data covariance matrix are not affected by the noise. If the noise covariance is an unknown arbitrary diagonal (e.g., for an uncalibrated array), the eigenvalue decomposition leads to biased results and it has to be replaced by a more general ``Factor Analysis'' decomposition, which then reveals all relevant information. In this paper we consider this data model and several extensions where the noise covariance matrix has a more general structure, such as banded, sparse, block-diagonal, and cases where we have multiple data covariance matrices that share the same noise covariance matrix. We propose new estimation algorithms that have much faster numerical convergence and lower complexity compared to existing algorithms for factor analysis. The new algorithms scale well to large dimensions and can replace eigenvalue decompositions in many applications even if the noise can be assumed to be white.

TA5-4 9:30 AM

Analytical Performance Analysis of the Semi-Algebraic Framework for Approximate CP Decompositions via Simultaneous Matrix Diagonalizations (SECSI)

Sher Ali Cheema, Emilo Rafael Balda, Technical University Ilmenau, Germany; Amir Weiss, Arie Yeredor, Tel-Aviv University Israel, Israel; Martin Haardt, Technical University Ilmenau, Germany

The Semi-Algebraic framework for approximate Canonical Polyadic (CP) decomposition via SImultaneaous matrix diagonalization (SECSI) is an efficient tool for the computation of the CP decomposition, which is based on matrix diagonalizations. The SECSI framework reformulates the CP decomposition into a set of joint eigenvalue decomposition (JEVD) problems. Solving all JEVDs, we obtain multiple estimates of the factor matrices and the best estimate is chosen in a subsequent step. Moreover, the SECSI framework retains the option of choosing the number of JEVDs to be solved and to adopt various strategies for the selection of the final solution out of the multiple estimates. In this work, we provide an analytical performance analysis of the SECSI framework for the computation of the approximate CP decomposition of a noise corrupted low-rank tensor, where we provide closed-form expressions of the relative mean square error for each of the estimated factor matrices. These expressions are derived using a first-order perturbation analysis and are formulated in terms of the second-order moments of the noise, such that apart from a zero mean, no assumptions on the noise statistics are required. Simulation results exhibit an excellent match between the obtained closed-form expressions and the empirical results.

BREAK 9:55 AM

TA5-5 10:15 AM

Balancing Interpretability and Predictive Accuracy for Unsupervised Tensor Mining

Ishmam Zabir, Evangelos Papalexakis, University of California, Riverside, United States

The PARAFAC tensor decomposition has enjoyed an increasing success in exploratory multi-aspect data mining scenarios. A major challenge remains the estimation of the number of latent factors (i.e., the rank) of the decomposition, which yields high-quality, interpretable results. Previously, we have proposed an automated tensor mining method which leverages a well-known quality heuristic from the field of Chemometrics, the Core Consistency Diagnostic (CORCONDIA), in order to automatically determine the rank for the PARAFAC decomposition. In this work we set out to explore the trade-off between 1)

the interpretability/quality of the results (as expressed by CORCONDIA), and 2) the predictive accuracy of the results, in order to further improve the rank estimation quality. Our preliminary results indicate that striking a good balance in that trade-off benefits rank estimation.

TA5-6 10:40 AM

Coupled Matrix-Tensor Factorizations - The Case of Partially Shared Factors

Lieven De Lathauwer, KU Leuven, Belgium; Eleftherios Kofidis, University of Piraeus, Greece

Coupled matrix-tensor factorizations have proved to be a powerful tool for data fusion problems in a variety of applications. Uniqueness conditions for such coupled decompositions have only recently been reported, demonstrating that coupling through a common factor can ensure uniqueness beyond what is possible when considering separate decompositions. In view of the increasing interest in application scenarios involving more general notions of coupling, we revisit in this paper the uniqueness question for the important case where the factors common to the tensor and the matrix only share some of their columns. Related computational aspects and numerical examples are also discussed.

TA5-7 11:05 AM

Tensor Decomposition for Crowdsourced Clustering

Ramya Korlakai Vinayak, Babak Hassibi, California Institute of Technology, United States

We consider the problem of clustering a set of unlabeled items using a crowd of non-expert workers who can answer "triangle queries" — similarity queries involving three items and the workers provide noisy clustering of the three items. In previous work, we showed that for a fixed query budget, it outperforms clustering based on edge queries (i.e, comparing pairs of objects). However, the clustering algorithms treated the responses from triangle queries as 3 separate edge responses and embedded them into an adjacency matrix. In this work we exploit the triangle structure of the responses by embedding them into a 3-way tensor. Since there are 5 possible responses to each triangle query, it is a priori not clear how best to embed them into the tensor. We give sufficient conditions on non-trivial embedding such that the resulting tensor has a rank equal to the underlying number of clusters (akin to what happens with the rank of the adjacency matrix). We then use an alternating least squares tensor decomposition algorithm to cluster a noisy and partially observed tensor and show, through extensive numerical simulations, that it outperforms methods that make use only of the adjacency matrix.

TA5-8 11:30 AM

Linear Systems with a CPD Constrained Solution

Martijn Boussé, Nico Vervliet, Otto Debals, Ignat Domanov, Lieven De Lathauwer, KU Leuven, Belgium

The solution of (large-scale) linear systems often exhibit some structure and/or sparsity, allowing one to use compact models for representation and approximation. Well-known models are low-rank matrix and tensor decompositions such as the (multilinear) singular value decomposition (SVD), canonical polyadic decomposition (CPD), tensor train (TT), and hierachical Tucker (hT) model. In this talk we focus on a framework for linear systems with a CPD constrained solution consisting of optimization-based and algebraic methods as well as a generic uniqueness condition. This has wide applicability in domains such as classification, multilinear algebra, and signal processing.

Track F – Biomedical Signal and Image Processing

Session: TA6a – Signal Processing for Neuroimaging

Chair: ***Laleh Najafizadeh,*** *Rutgers University*

TA6a-1 8:15 AM

Integrative Signal Processing Approaches for Neuroimaging Problems

Wei Wu, Stanford University, United States; Zhe Chen, New York University, United States

The past decades have witnessed the development of a number of novel neuroimaging tools for basic neuroscience as well as clinical research. While these new tools provide unprecedented opportunities to study the brain, they also produce complex data sets not amenable to traditional signal processing methods. In this paper, we highlight how modern signal processing, machine learning, and powerful computing strategies can be integrated to address this challenge. For human neuroimaging, we illustrate our recent work on concurrent transcranial magnetic stimulation (TMS) and EEG (TMS-EEG) recordings, which are contaminated by enormous stimulation-induced artifacts. Use of TMS-EEG in brain circuit mapping, close-loop applications, or clinical settings requires fully automated processing of the EEG data without tedious human intervention. For animal neuroimaging, we review recent progresses on the combination of two-photon microscopy and calcium imaging, which is aimed to simultaneously record order of thousands of neurons at a reasonably fast timescale. How to efficiently process these data (detection, deconvolution, parallelization) remains a challenge. Finally, we outline a few emerging challenges and research directions where further development of signal processing approaches is needed.

TA6a-2 8:40 AM

Multiscale Modeling of High-Dimensional Neural Activity

Hamidreza Abbaspourazad, Han-Lin Hsieh, Maryam Shanechi, University of Southern California, United States

Measuring and modeling the brain at multiple spatiotemporal scales are essential for understanding brain function and developing high-performance brain-machine interfaces. Multiscale modeling is challenging because of the different statistical characteristics and time-scales of multiscale neural signals consisting of electrocorticogram (ECoG), local field potentials (LFP) and spikes. Here, we construct a multiscale state-space model for high-dimensional neural activity and develop a learning algorithm to train this model using neural data. We show that the learning algorithm accurately identifies the state-space model parameters. We also demonstrate that the learned model improves the estimation accuracy of hidden brain states using multiscale decoding.

TA6a-3 9:05 AM

Latent Variable Models for Hippocampal Sequence Analysis

Etienne Ackermann, Rice University, United States; Kourosh Maboudi, Kamran Diba, University of Wisconsin-Milwaukee, United States; Caleb Kemere, Rice University, United States

The activity of ensembles of neurons within the hippocampus is thought to enable memory formation, storage, and recall. During offline states (associated with sharp wave ripples, quiescence, or sleep), some of these neurons are reactivated in temporally-ordered sequences which may enable associations across time and episodic memories spanning longer periods. However, analyzing these sequences remains challenging for several reasons, including the (i) lack of animal behavior, and (ii) limitations of prevailing analysis techniques to analyze sequential activity. Here we build on recent approaches using latent variable models for hippocampal population codes, to detect and score so-called "replay events", and to model hippocampal sequences independent of animal behavior. We demonstrate that these latent variable models are comparable to state-of-the-art Bayesian methods for detecting replay, but more importantly, they provide an alternative "sequential" view of hippocampal activity that may help clarify how memories are formed, stored, and recalled.

TA6a-4 9:30 AM

On Robust Detection of Brain Stimuli with Ramanujan Periodicity Transforms

Pouria Saidi, George Atia, Azadeh Vosoughi, University of Central Florida, United States

Visual Evoked Potentials (VEPs) are the brain responses to repetitive visual stimuli. The ability to detect the underlying frequencies of VEPs is crucial to advancing Brain Computer Interfaces (BCIs). This paper considers the detection of such frequencies using a Ramanujan Periodicity Transform based model. We analyze the performance of a generalized likelihood ratio detector and derive the distributions of the sufficient statistics under hypotheses corresponding to different stimulus frequencies using confluent hypergeometric functions. Choosing stimulation periods with non-overlapping divisors is shown to enhance the detection performance. Our analysis provides guidelines for efficient design of stimulus waveforms for BCIs.

Track F – Biomedical Signal and Image Processing

Session: TA6b – Computational Ultrasound Imaging

Chair: ***Pieter Kruizinga,*** *Erasmus University Medical Center*

TA6b-1 10:15 AM

Image Reconstruction from Coded Excitation Transmit Schemes Using a Linear Model Approach

John Flynn, Lauren Pflugrath, Sinan Li, Ron Daigle, Verasonics, Inc., United States

Coded excitation for array imaging increases SNR over uncoded bursts. Though matched filtering is optimal for isolated targets, a linear statistical model (LSM) generalizes to distributed targets, and can balance image bias against precision. We illustrate an LSM scheme that first estimates the medium impulse response, then computes retrospective transmission and imaging. Space-time diversity codes permit trading frame rate, SNR, resolution, and contrast. The estimation computational cost is linear in array size and independent of pixel density. We compare conventional compact-burst pulse-echo acquisition against a scheme having multiple bursts in-flight, and demonstrate B-Mode and Doppler imagery using captured ultrasound data.

TA6b-2 10:40 AM

Inverse Problem Approaches for Coded High Frame Rate Ultrasound Imaging

Denis Bujoreanu, Barbara Nicolas, Denis Friboulet, Hervé Liebgott, University of Lyon, CREATIS, France

Numerous applications where frame rate and SNR were key issues have been solved with high frame rate (HFR) medical ultrasound imaging. In HFR imaging single focused transmissions are replaced by broad insonifications (plane/diverging waves) or simultaneous focused beams emitted in different directions (MLT). In both these approaches the emission focus is either nonexistent or multiple, the origin of the backscattered echoes is ambiguous, thus these techniques yield lower image qualities. In PW/DW this can be compensated for by coherent compounding of several transmitted waves. The main drawback of compounding is the frame rate decrease. This can be overcome thanks to simultaneous transmission of multiple coded broad insonifications. However simultaneous emission increases even more the ambiguity, each element of the array receiving superposed echoes backscattered by the medium in response to the concurrent transmissions. We propose to reconstruct the final ultrasound image from such original transmission sequences using inverse problem approaches. First we will establish the model of the direct problem, linking the transmission of several encoded signals and their interaction with the medium to the received signals by the probe elements. Then we will focus on the methodologies that allow recovering the final image of the medium without quality loss.

TA6b-3 11:05 AM

Physics and Data Driven Models for Ultrasound Image Reconstruction

Brett Byram, Kazuyuki Dei, Adam Luchies, Vanderbilt University, United States

We previously demonstrated that model-based beamforming methods can substantially improve ultrasound B-Mode image quality. We developed a method called Aperture Domain Model Image Reconstruction (ADMIRE), that explicitly models ultrasound signals based on the physics of wave propagation. ADMIRE can address sources of B-mode image degradation, such as reverberation, that are hard to address with conventional beamforming strategies. Furthermore, the development of ADMIRE demonstrated that beamforming could be posed as a regularized nonlinear regression problem, which suggests that a deep neural network (DNN) might be used to accomplish the same task. In contrast to ADMIRE, deep networks represent a data based approach. As part of this work, we will discuss performance issues of these two beamforming approaches and how our experience developing a physical model based method guided our decisions when developing our data based approach.

TA6b-4 11:30 AM

Spatial Compression in Ultrasound Imaging

Pim van der Meulen, Delft University of Technology, Netherlands; Pieter Kruizinga, Johannes G. Bosch, Erasmus MC, Netherlands; Geert Leus, Delft University of Technology, Netherlands

High quality 3D ultrasound imaging is typically attained by increasing the amount of sensors, often resulting in complex hardware. Compressing measurements before sensing addresses this problem, and could enable new clinical applications. We have developed an analogue compression technique, by positioning a plastic coding mask across the aperture, inducing varying local echo delays. This results in a compression of the spatial ultrasound field across the sensor surface, while retaining sufficient information for 3D imaging. We discuss the signal processing principles of this technique, optimal mask design, and demonstrate a particular case of 3D imaging using only a single ultrasound sensor.

Track G – Architecture and Implementation

Session: TA7a – Computer Arithmetic

Chair: ***Milos Ercegovac,*** *University of California, Los Angeles*

TA7a-1 8:15 AM

On the Relative Error of Computing Complex Square Roots in Floating-Point Arithmetic

Claude-Pierre Jeannerod, INRIA, laboratoire LIP, Universite de Lyon, France; Jean-Michel Muller, CNRS, laboratoire LIP, Universite de Lyon, France

We study the accuracy of classic algorithms for evaluating computing complex square-roots in floating-point arithmetic. We also consider the problem of scaling the input variables for avoiding spurious overflows or underflows. Our analyses are done in binary floating-point arithmetic in precision p, and we assume that the elementary arithmetic operations are rounded to nearest, so that the roundoff unit is u = 2^{-p}. We find a relative error bound sqrt(37)/2 u for the complex square root (showing that order-2 terms are not needed in a bound previously obtained by Hull, Fairgrieve, and Tang), and build examples that show that that bound is reasonably sharp when using the three basic binary interchange formats (binary32, binary64, and binary128) of the IEEE-754 Standard for Floating-Point Arithmetic.

TA7a-2 8:40 AM

Optimized Leading Zero Anticipators for Faster Fused Multiply-Adds

David Lutz, ARM, United States

Leading zero anticipators (LZAs) predict the number of leading zeros in a difference, and have long been used to speed up floating-point add and fused multiply-add operations. Typically the LZA prediction must be corrected for small exponents and possible carries, and only the corrected value is useful for normalizing the difference and computing rounding. We present new techniques for LZA correction and rounding, improving our logic depth by 67% and our double-precision latency by 50%.

TA7a-3 9:05 AM

The Future of Computing - Arithmetic Circuits Implemented with Memristors

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

Memristors have recently become a promising candidate for the future of non-volatile memory due to their fast, low power read/write operations and compatibility with CMOS. In applications like mem-computing, where memory acts both as a site for storing data and logic computations, memristors provide a promising future. This paper describes multiple techniques of using memristors to build adders and multipliers. Designs are presented based on material implication, MAD, and current mirror logic to provide a comparative analysis of the described techniques in the context of carry look-ahead adders and array multipliers. Area, power and latency are compared to previous works.

TA7a-4 9:30 AM

On Left-to-Right Arithmetic

Milos Ercegovac, University of California, Los Angeles, United States

Doing arithmetic most significant digits first provides opportunities to circumvent or reduce data dependencies in recursive computations. It also enables digit-level parallelism, and allows variable precision computations with unbiased truncation. Moreover, there are benefits at the design level: precision-independent cycle time, lower energy since digits are used only when needed, and minimal interconnection. We present an integrated view of the main left-to-right arithmetic features in the context of solving linear systems of equations, recursive filters, and inner-product designs.

Track G – Architecture and Implementation

Session: TA7b – Computer Arithmetic Algorithms

Co-Chairs: ***Earl Swartzlander,*** *University of Texas at Austin* ***and Milos Ercegovac,*** *University of California, Los Angeles*

TA7b-1 10:15 AM

Complex Block Floating-Point Format with Box Encoding For Wordlength Reduction in Communication Systems

Yeong Foong Choo, Brian L. Evans, University of Texas at Austin, United States; Alan Gatherer, Huawei Technologies, United States

We propose a new complex block floating-point format to reduce implementation complexity. The new format achieves wordlength reduction by sharing an exponent across the block of samples, and uses box encoding for the shared exponent to reduce quantization error. Arithmetic operations are performed on blocks of samples at time, which can also reduce implementation complexity. For a case study of a baseband quadrature amplitude modulation (QAM) transmitter and receiver, we quantify the tradeoffs in signal quality vs. implementation complexity using the new approach to represent IQ samples. Signal quality is measured using error vector magnitude (EVM) in the receiver, and implementation complexity is measured in terms of arithmetic complexity as well as memory allocation and memory input/output rates. The primary contributions of this paper are (1) a complex block floating-point format with box encoding of the shared exponent to reduce quantization error, (2) arithmetic operations using the new complex block floating-point format, and (3) a QAM transceiver case study to quantify signal quality vs. implementation complexity tradeoffs using the new format and arithmetic operations.

TA7b-2 **10:40 AM**

Parallel GF(2n) Multipliers

Trenton Grale, Earl Swartzlander, University of Texas at Austin, United States

Operations over polynomial Galois finite fields GF(2n) are employed in some cryptographic systems. These operations include multiplication and reduction with respect to an irreducible polynomial. Fast parallel multipliers can be designed at the cost of higher die area. Building on prior work, two fully parallel polynomial n×n multipliers are presented with O(log2n) latency, and which use lookup tables to store modular reduction terms.

TA7b-3 **11:05 AM**

Twiddle Factor Complexity Analysis of Radix-2 FFT Algorithms for Pipelined Architectures

Fahad Qureshi, Jarmo Takala, Tampere University of Technology, Finland

In this paper, we show that fast Fourier transform (FFT) algorithms can be derived in various ways resulting in algorithms, which can be implemented with different number of general complex-valued multipliers in pipelined FFT architectures. Those algorithms have different range of twiddle factor complexity, which have an effect on the twiddle factor coefficient memory and multiplier cost when many of the multipliers can be implemented with inexpensive shift-and-add circuits instead of general complex multipliers. We analyze those algorithms to investigate the total cost of those algorithms. The trade-off between adder cost of multiplier and coefficient memory can be observed from the results.

TA7b-4 **11:30 AM**

A Combined IEEE Half-Precision and Single-Precision Floating Point Multipliers for Deep Learning

Tuan Nguyen, James Stine, Oklahoma State University, United States

In deep learning, single-precision floating point multipliers are widely used and the most power-hungry arithmetic operators. In this paper, we propose a novel combined IEEE half-precision (float16) and single-precision (float32) floating point multipliers for deep learning. Our design can be easily configured to run in the half-precision mode for power saving or in the single-precision mode for accuracy. Compared to conventional IEEE single-precision multipliers, the combined multipliers require only a small amount of additional area and delay, while offer a significant reduction in power dissipation.

Track D – Signal Processing and Adaptive Systems

Session: TA8a1 – Statistical Signal Processing **8:15 AM–9:55 AM**

Chair: ***Jitendra Tugnait,*** *Auburn University*

TA8a1-1

Spectrum-Based Comparison of Multivariate Complex Random Signals of Unequal Lengths

Jitendra Tugnait, Auburn University, United States

We consider the problem of comparing two complex multivariate random signal realizations of unequal lengths, to ascertain whether they have identical power spectral densities. A binary hypothesis testing approach is formulated and a generalized likelihood ratio test (GLRT) is derived. An asymptotic analytical solution for calculating the test threshold is provided. The results are illustrated via computer simulations. Past work on this problem is limited to either complex or real signals of equal lengths, or to real-valued scalar signals of unequal lengths. The proposed test has applications in diverse areas including user authentication in wireless networks with multiantenna receivers.

TA8a1-2

SNR Threshold Region Prediction via Singular Value Decomposition of the Barankin Bound Kernel

John Kota, Systems & Technology Research, United States; Antonia Papandreou-Suppappola, Arizona State University, United States

As signal-to-noise-ratio (SNR) directly impacts sensing performance, it is important to be able to determine a threshold value past which the performance of a maximum likelihood estimator (MLE) of a deterministic parameter rapidly deviates from the Cramer-Rao lower bound (CRLB). One approach for predicting the SNR threshold is based on the computation of the Barankin bound (BB) that can provide a tighter bound than the CRLB on the estimator’s performance. As direct computation of the BB

is quite challenging, we propose a new approach for predicting the SNR threshold based on the effective rank of the BB kernel matrix. The effective rank is computed using singular value decomposition (SVD) and likelihood function ratios evaluated on a uniformly sampled parameter space without requiring optimal test-point selection. We demonstrate the algorithm on common nonlinear estimation problems.

TA8a1-3
Period Estimation with Linear Complexity of Sparse Time Varying Point Processes

Hans-Peter Bernhard, Bernhard Etzlinger, Andreas Springer, Johannes Kepler University Linz, Austria

For sparse time-varying point processes we present a period estimator, which is relevant in many applications such as time synchronization of wireless networks in harsh environments. The proposed estimator has a significantly reduced computational complexity while maintaining the same estimation accuracy compared to state-of-the-art methods that are available only for stationary processes. By the novel approach of estimating the period in time domain, analytical expressions of the lower bound on the mean square error (MSE) are presented for the first time in this work. In numerical analysis we show that the proposed algorithm attains these bounds.

TA8a1-4
Estimation of Real Valued Impulse Responses based on Noisy Magnitude and Phase Measurements

Oliver Lang, Mario Huemer, Johannes Kepler University, Austria; Victor Elvira, IMT Lille Douai, France

We discuss the task of estimating real valued impulse responses based on frequency response measurements. These measurements are available in form of noisy magnitude and phase measurements conducted at discrete frequencies. While this is in general a non-linear estimation problem, it can also be approximated by a linear model, however with noise statistics that depend on the unknown parameters to be estimated. We investigate and compare different types of newly proposed as well as standard classical and Bayesian estimators such as widely linear, maximum likelihood, maximum a posteriori and Monte Carlo based estimators.

TA8a1-5
On the Theoretical Analysis of Box-Constrained Adaptive Filters

Vitor Nascimento, Leilson Araujo, University of Sao Paulo, Brazil; Yuriy Zakharov, University of York, United Kingdom

Theoretical models for adaptive filters are traditionally obtained through the introduction of approximations that make the analysis mathematically tractable. Usual approximations are independence between regressor and parameter estimate (the so-called “independence theory”) and Gaussianity of the error. In this paper we propose a new class of approximations for adaptive filters with nonlinear constraints on the parameters, such as box constraints on the parameters. The new class of approximations is based on assuming a family of distributions for the unknown variables (e.g., uniform), and finding approximate updates for the parameters describing the distribution (e.g., upper and lower bounds for a uniform distribution).

TA8a1-6
Distribution Results for a Multi-Rank Version of the Reed-Yu Detector

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

In this paper we revisit a detector first derived by Reed and Yu, generalized by Bliss and Parker, and recently studied by Hiltunen, Loubaton, and Chevalier. The problem is to detect a known signal transmitted over an unknown MIMO channel of unknown complex gains and unknown additive noise covariance. The probability distribution of a CFAR detector for this problem was first derived for the SIMO channel by Reed and Yu. We generalize this distribution for the case of a MIMO channel. Our results, based on the theory of beta distributed random matrices, hold for M symbols transmitted from p transmitters and received at L receivers, in contrast to the asymptotic results of Hiltunen, Loubaton, and Chevalier, based on large random matrix theory, which assume L and M to be unbounded. The CFAR detector is shown to be distributed as the product of independent scalar beta random variables, for which the probability density may be derived. This is our main result.

TA8a1-7
Statistical Two-Dimensional Edge Linear Prediction With Fast Algorithm

Lawrence Marple, Signal Research, United States

Two-dimensional linear prediction algorithms the past 30 years have predicted to a single point. A more proper approach that fully utilizes the two-dimensional statistical information in the 2- autocorrelation is to make a 2-D linear prediction based on an edge prediction rather than a point prediction. This paper introduces this 2-D linear prediction edge approach and integrates it

into a computationally fast full 2-D minimum variance spectral technique. The improvement in edge-based 2-D linear prediction is illustrated with an actual data source of complex synthetic aperture radar data. It is shown that the new edge approach creates a fully 2-D white residual from the 2-D linear prediction algorithm.

TA8a1-8
An Objective-Based Experimental Design Framework for Signal Processing in the Context of Canonical Expansions
Roozbeh Dehghannasiri, Xiaoning Qian, Edward Dougherty, Texas A&M University, United States

This work presents an objective-based experimental design framework for uncertainty reduction in filtering and signal processing when the underlying random processes are expressed in terms of canonical expansions. Canonical expansions are convenient representations for random processes that pave the way for finding closed-form solutions for operators (filters). In the proposed experimental design framework, uncertainty is quantified based on the concept of mean objective cost of uncertainty, which measures uncertainty by taking into account the ultimate modeling objective, which is optimal filtering.

Track D – Signal Processing and Adaptive Systems

Session: TA8a2 – Adaptive Signal Processing II 8:15 AM–9:55 AM

Co-Chairs: ***Thomas Paul,*** *Orbital ATK Inc.* ***and Azzedine Zerguine,*** *King Fahd University of Petroleum and Minerals, Saudi Arabia*

TA8a2-1
On the use of Spectro-Temporal Modulation in Assisting Adaptive Feedback Cancellation for Hearing Aid Applications
Meng Guo, Oticon A/S, Denmark; Bernhard Kuenzle, Bernafon AG, Switzerland

Acoustic feedback cancellation in modern hearing aids is often performed using adaptive filters, in which the convergence rate has typically to be limited in order to maintain satisfactory steady-state performance. This can lead to insufficiently slow feedback cancellation upon rapid feedback path changes, e.g., when a phone is placed next to the user's ear. In this work, we introduce a novel method by using spectro-temporal modulation in combination with an adaptive filter. We demonstrate through simulation experiments that when the traditional adaptive filter approach has an insufficient convergence rate and thereby fails to cancel feedback upon rapid feedback path changes, the proposed system removes feedback immediately.

TA8a2-2
Nonlinear Least-Mean-Square Type Algorithm for Second-Order Interference Cancellation in LTE-A RF Transceivers
Andreas Gebhard, Christian Motz, Johannes Kepler University, Austria; Ram Sunil Kanumalli, Harald Pretl, Danube Mobile Communications Engineering GmbH & Co KG, Austria; Mario Huemer, Johannes Kepler University, Austria

Direct conversion receivers are sensitive to the second-order intermodulation distortion (IMD2) which falls directly into the baseband, thereby interfering with the wanted receive signal. In frequency division duplex receivers the transmit signal leaks through the duplexer and experiences a second-order nonlinearity in the receiver. In this contribution a nonlinear least-mean-square type adaptive filter to cancel the transmitter induced IMD2 self-interference is developed which outperforms existing adaptive solutions despite its low complexity.

TA8a2-3
Adaptive Echo Cancellation Using Deep Cerebellar Model Articulation Controller
Lan Shih-Wei, Yuan Ze University, Taiwan; Yu Tsao, Academia Sinica, Taiwan; Junghsi Lee, Yuan Ze University, Taiwan

In this paper, we propose to adopt the deep cerebellar model articulation controller (DCMAC) model for adaptive echo cancelation (AEC). The DCMAC model is formed by stacking multiple CMAC models. With the deep structure, the DCMAC model can characterize nonlinear transformations more effectively when compared with the conventional CMAC model. To estimate the parameters in DCMAC, we have derived a modified backpropagation training algorithm. Experimental results showed that the DCMAC outperforms the CMAC in terms of AEC capability, confirming that DCMAC yields improved capability of modeling channel characteristics.

TA8a2-4

Adaptive Algorithm Based on a New Hyperbolic Sine Cost Function

Ahmad Khalifi, Qadri Mayyala, Naveed Iqbal, Azzedine Zerguine, King Fahd University of Petroleum & Minerals, Saudi Arabia; Karim Abed-Meraim, University of Orléans, PRISME Lab, France

This paper introduces a stochastic gradient algorithm, which uses an exclusive hyperbolic sine objective function. The algorithm belongs to the variable step size (VSS) class. The algorithms in this class are shown to be very stable and effective in many applications, e.g., echo-cancellation, equalization, and others. In this algorithm, as opposed to other existing VSS algorithms, only one tuning parameter is needed. Experimental results show that with a sub-optimal selection of the tuning parameter, the algorithm provides very promising results in both stationary and tracking situations. Analytic convergence and steady state error performance analysis are provided to demonstrate the excellent performance. Also, an optimal solution, based on the least hyperbolic sine error, is derived to confirm the convergence of the proposed algorithm towards the Wiener solution.

TA8a2-5

Adaptive Digital Filtering using the Bio-Inspired Firefly Algorithm (FFA)

William Jenkins, Magni Hussain, Pennsylvania State University, United States

The L'evy Flights variation of the bio-inspired Firefly Algorithm (LFFA) combines the Firefly Algorithm based on how fireflies interact through flashes and a random-step function based on the L'evy distribution. The LFFA, the Genetic Algorithm (GA), and the Particle Swarm Optimization Algorithm (PSOA) are compared when used for adaptive IIR system identification. Comparisons of the LFFA in direct, cascade, and parallel form structures suggest that 1) the LFFA is more effective than the GA and PSOA, 2) the LFFA adaptive algorithm works well for all structures that were experimentally tested, including a nonlinear Volterra structure, and 3) the LFFA appears to perform most effectively.

TA8a2-6

Optimal Blind-Adaptive Compensator for Time-Varying Frequency Selective IQ Imbalance

Durga Laxmi Narayana Swamy Inti, A. A. (Louis) Beex, Virginia Tech, United States

Limited precision and stability of front-end RF components lead to imbalances in the I/Q paths of wireless transceivers, limiting their image rejection capabilities. In wide-band multi-channel systems, slight variations in I/Q low-pass filters lead to significant differences in signal to image strengths across the Nyquist range. SER performance improvement for a widely linear blind-adaptive IQ imbalance compensator is shown by using the (near) optimal number of taps for the adaptive filter. While the (near) optimal number of taps depends on the unknown I/Q low-pass filter imbalances in effect, a method is proposed to estimate that optimal number by experiment.

TA8a2-7

On Quaternion Kernel Adaptive Filtering of Nonwhite, Noncircular, and Non-Gaussian Inputs

Tokunbo Ogunfunmi, Santa Clara University, United States; Thomas Paul, Orbital ATK Inc., United States

Much work has been done recently on exploring the use of quaternions for applications such as pattern recognition and robotics. Towards this goal, methods for designing adaptive filters with quaternions have been developed. Additionally, adaptive algorithms that optimally consider the various possible forms of input diversity are being considered. Specifically, input characteristics of nonwhiteness, noncircularity, and non-Gaussianity have been studied. This paper expands on recent work exploring these forms of input diversity by considering their use with quaternions for adaptive filtering. The results are algorithms designed to optimally perform quaternion adaptive filtering under these types of input signal diversity. Simulations verify the quaternion filtering performance.

TA8a2-8

Learning Robust General Radio Signal Detection using Computer Vision Methods

Timothy O'Shea, Tamoghna Roy, T. Charles Clancy, Virginia Tech, United States

We introduce a new method for radio signal detection and localization in the time-frequency spectrum based on the use of convolutional neural networks. In the past several years this approach has surpassed human-level performance in computer vision benchmarks, but has yet to be adopted within the radio signal domain. We explain how such a system can leverage a labeled training dataset of wideband spectrum annotated with masks and bounding boxes in order to train a highly effective radio signal detector which achieves higher levels of contextual understanding and improved sensitivity performance vs more traditional naïve energy thresholding based signal detection schemes while maintaining a compact low-complexity architecture which can be

deployed on low power sensing platforms. We extend prior work from the vision domain employing a variation of the You Only Look Once (YOLO) architecture which is a fast and accurate visual object detector. Results from our leading entry in the DARPA "Battle-of-the-ModRecs" competition are discussed.

Track D – Signal Processing and Adaptive Systems

Session: TA8a3 – Compressed Sensing 8:15 AM–9:55 AM

Chair: ***Johan Swärd,*** *Lund University, Sweden*

TA8a3-1

Efficient Online Dictionary Adaptation and Image Reconstruction for Dynamic MRI

Saiprasad Ravishankar, Brian E. Moore, Raj Rao Nadakuditi, Jeffrey A. Fessler, University of Michigan, United States

Sparsity-based techniques have yielded promising results for dynamic MRI reconstruction. Data-driven methods involving dictionary learning have become increasingly popular, but involve expensive computation and memory requirements. We propose a new framework for online or time-sequential data-driven reconstruction of dynamic MRI sequences from measurements. The spatiotemporal patches of the underlying image sequence are modeled as sparse in a DIctioNary with lOw-ranK AToms (DINO-KAT), and the proposed method estimates the dictionary, sparse coefficients, and images sequentially and efficiently from the time series of MRI measurements. Our experiments demonstrate the promising performance of our schemes for online reconstruction from limited data.

TA8a3-2

Modified Orthogonal Matching Pursuit for Multiple Measurement Vector with Joint Sparsity in Super-Resolution Compressed Sensing

Xuan Vinh Nguyen, Klaus Hartmann, Wolfgang Weihs, Otmar Loffeld, University of Siegen, Germany

The mismatch model errors incur after discretization in the compressive sensing (CS) applications such as target discrimination or direction-of-arrival (DOA) estimation since the true parameters do not lie on the discretized grid. The sensing matrix design with a refined grid system becomes a current research approach, namely relaxed super-resolution compressed sensing. An alternative relaxed metric for gauging the quality of support recovery is used with the level of tolerance for support offset. However, without the hardware modification, a large refinement factor will lead to the high coherence of the sensing matrix and eventually the bad reconstruction quality. To improve the recovery results, Multiple Measurement Vector (MMV) model with joint sparsity will be analyzed in this paper with a new variant of Orthogonal Matching Pursuit (OMP) algorithm. Besides, the atom update module of the Cyclic OMP will be also inserted to enhance the reconstruction quality. The results will be proven through the numerical experiments.

TA8a3-3

Sparse Recovery With Quantized Multiple Measurement Vectors

Yacong Ding, Sung-En Chiu, Bhaskar D. Rao, University of California, San Diego, United States

We address the quantized sparse recovery problem with multiple measurement vectors, where each measurement is represented using a finite number of bits. The source signals are sparse and share the same sparse support, and the goal is to recover that support. A general framework based on sparse Bayesian learning is developed, which is applicable to both 1-bit and multi-bit scalar quantization. We show through numerical simulations that as the number of measurements increases, the proposed algorithm can provide support recovery performance similar to that when the measurements are unquantized.

TA8a3-4

Designing Optimal Sampling Schemes for Multi-Dimensional Data

Johan Swärd, Filip Elvander, Andreas Jakobsson, Lund University, Sweden

In this work, we propose a method for determining an optimal, non-uniform, sampling scheme for multi-dimensional signals by solving a convex optimization problem reminiscent of the sensor selection problem. The optimal sampling scheme is determined given a suitable estimation bound on the parameters of interest, as well as incorporating any imprecise a priori knowledge of the locations of the parameters. Numerical examples illustrate the efficiency of the proposed scheme.

TA8a3-5
Hyperparameter-Selection for Sparse Regression: A Probablistic Approach
Ted Kronvall, Andreas Jakobsson, Lund University, Sweden

The choice of hyperparameter(s) notably affects the support recovery in LASSO-like sparse regression problems, acting as an implicit model order selection. Parameters are typically selected using cross-validation or various ad hoc approaches. These often overestimates the resulting model order, aiming to minimize the prediction error rather than maximizing the support recovery. In this work, we propose a probabilistic approach to selecting hyperparameters in order to maximize the support recovery, quantifying the type I error (false positive rate) using extreme value analysis, such that the regularization level is selected as an appropriate quantile. By instead solving the scaled LASSO problem, the proposed choice of hyperparameter becomes almost independent of the noise variance. Simulation examples illustrate how the proposed method outperforms both cross-validation and the Bayesian Information Criterion in terms of computational complexity and support recovery.

TA8a3-6
Sparse Bayesian Learning using Variational Bayes Inference Based on a Greedy-Based Criterion
Mohammad Shekaramiz, Todd Moon, Jacob Gunther, Utah State University, United States

We propose a new sparse Bayesian learning (SBL) algorithm inferred via variational Bayes (VB) to perform sparse signal recovery in the compressive sensing (CS) problem. The algorithm uses a simple greedy-based criterion to remove the non-sparse issue of the support of the solution when using VB for low number of measurements. Such criterion forces the solution to become sparse and then works in a lower dimension to estimate the signal based on the available resources. Simulations show encouraging performance in detecting the supports and diminishing the over-fitting issue of the model parameters when having low number of measurements. We will provide a comprehensive study to compare the overall performance of the algorithm with the other existing algorithms in the CS area. Furthermore, we show the duality that exist between the parameter estimation update rules using fully hierarchical Bayesian approach via Markov chain Monte Carlo (MCMC), expectation-maximization (EM) algorithm, and the VB inference. Also, we will provide some simulation results to compare the performance of such algorithms for the CS problems.

TA8a3-7
Reconstruction from Periodic Nonlinearities, With Applications to HDR Imaging
Viraj Shah, Mohammadreza Soltani, Chinmay Hegde, Iowa State University, United States

We consider the problem of reconstructing signals and images from periodic nonlinearities. For such problems, we design a measurement scheme that supports efficient reconstruction; moreover, our method can be adapted to extend to compressive sensing-based signal and image acquisition systems. Our techniques can be potentially useful for reducing the measurement complexity of high dynamic range (HDR) imaging systems, with little loss in reconstruction quality. Several numerical experiments on real data demonstrate the effectiveness of our approach.

TA8a3-8
Non-tensor Wavelet Sparse Basis for Random Hirschman Sensing Matrices
Peng Xi, Victor DeBrunner, Florida State University, United States

The RHSMs (Random Hirschman Sensing Matrices) are newly developed sensing structures based on Hirschman Transform. The RHSMs are superior in computational efficiency and recovery precision to DFT sensing structures and the other DFT-like sensing structures. However, the RHSMs require a high level of incoherence between the sensing structures and the sparse basis. In this paper, we introduce a non-tensor wavelet as the sparse basis for RHSMs. Compare to the traditional Discrete Wavelet Transform (DWT) sparse basis, the non-tensor wavelet has nearly the same sparsification performance but much lower incoherence for RHSMs as well as for all the other DFT based sensing structures.

Session: TA8a4 – Information Theoretic and Networked Signal Processing 8:15 AM–9:55 AM

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

TA8a4-1
Improved Finite-Sample Estimate of a Nonparametric f-Divergence

Prad Kadambi, Alan Wisler, Visar Berisha, Arizona State University, United States

Information divergence functions allow us to measure distances between probability density functions. We focus on the case where we only have data from the two distributions and have no knowledge of the underlying models from which the data is sampled. In this scenario, we consider an f-divergence for which there exists an asymptotically consistent, nonparametric estimator based on minimum spanning trees, the Dp divergence. Nonparametric estimators are known to have slow convergence rates in higher dimensions ($d > 4$), resulting in a large bias for small datasets. Based on experimental validation, we conjecture that the original estimator follows a power law convergence model and introduce a new estimator based on a bootstrap sampling scheme that results in a reduced bias. Experiments on real and artificial data show that the new estimator results in improved estimates of the Dp divergence when compared against the original estimator.

TA8a4-2
Target Tracking via Recursive Bayesian State Estimation in Radar Networks

Yijian Xiang, Washington University in St. Louis, United States; Murat Akcakaya, University of Pittsburgh, United States; Satyabrata Sen, Oak Ridge National Laboratory, United States; Arye Nehorai, Washington University in St. Louis, United States

Modern cognitive radar networks incorporating intelligent and cognitive support-modules can actively adjust the radar-target geometry and optimally select a subset of radars to track the target of interest. We propose a framework for single target tracking in radar networks, considering path planning and radar selection. We formulate the tracking procedure as two iterative steps: (i) solving a combinatorial problem based on the expected cross-entropy measure to select the optimal subset of radars and their locations, and (ii) tracking the target using recursive Bayesian state estimation technique. We simulate the proposed framework using an illustrative example in 2-D space and demonstrate the tracking performance.

TA8a4-3
Exploration and Data Refinement via Multiple Mobile Sensors Based on Gaussian Processes

Mohammad Shekaramiz, Todd Moon, Jacob Gunther, Utah State University, United States

We consider configuration of multiple mobile sensors to explore and refine knowledge in an unknown field. After some initial discovery, it is desired to collect data from the regions that are far away from the current sensor trajectories in order to favor the exploration purposes, while simultaneously, exploring the vicinity of known interesting phenomena to refine the measurements. Since the collected data only provide us with local information, there is no optimal solution to be sought for the next trajectory of sensors. Using Gaussian process regression, we provide a simple framework that accounts for both the conflicting data refinement and exploration goals, and to make reasonable decisions for the trajectories of mobile sensors.

TA8a4-4
Robust Estimation of the Magnitude Squared Coherence based on Kernel Signal Processing

Ferran de Cabrera Estanyol, Jaume Riba Sagarra, Gregori Vázquez Grau, Technical University of Catalonia, Spain

A new outlier-robust approach to estimate the magnitude squared coherence of a random vector sequence, a common task required in a variety of estimation and detection problems, is proposed. The proposed estimator is based on Rényi’s entropy, an information theoretic kernel-based measure that proves to be inversely proportional to the determinant of a regularized version of the covariance matrix in the proper Gaussian case. The trade-off between accuracy and robustness in terms of bias and variance is analytically and numerically characterized, showing a dependence on the relative kernel bandwidth and the available data size.

TA8a4-5
Multilevel Group Testing via Sparse-Graph Codes
Pedro Abdalla, Amirhossein Reisizadeh, Ramtin Pedarsani, University of California, Santa Barbara, United States

We consider the problem of multi-level group testing, where the goal is to recover a set of K defective items in a set of n items by pooling groups of items and observing the result of each test. The main difference of multilevel group testing with the classical non-adaptive group testing problem is that the result of each test is an integer in the set $[L]=\{0,1,..,L\}$: if there are $i \leq L$ defective iterms in the pool, the result of the test is i, and if there are more than L items in the pool, the result of the test is L. We develop a multi-level group testing algorithm using sparse-graph codes that has low sample and computational complexity. More precisely, with high probability, our algorithm provably recovers $(1-\epsilon)$ fraction of the defective items using $C(\epsilon,L)K \log(n)$ tests, where $C(\epsilon,L)$ is a constant that only depends on ϵ and the number of levels L, and it can be precisely characterized for arbitrary L and ϵ. Furthermore, the computational complexity of our algorithm is $\mathcal{O} (K \log(n))$. As an example, our algorithm is able to recover $(1- 10^{-3})$ fraction of the defective items with only $13.8 K \log(n)$ measurements for $L=2$.

TA8a4-6
Multipulse Subspace Detectors
Pooria Pakrooh, Louis Scharf, Colorado State University, United States

Matched subspace detectors have found widespread use in radar, sonar, instrumentation, and hyperspectral imaging. In this paper we extend these results to multipulse or multi-snapshot experiments consisting of M temporal measurements of a spatial field. In so doing we consider a number of models for how the spatial covariance matrix for additive noise in a sensor array changes with time. Each of these models leads to a different set of detectors. Within each of these sets there is a detector for the case where the basis for the signal subspace is known and for the case where it is unknown.

TA8a4-7
Image-Sourced Fingerprinting for LED-Based Indoor Tracking
Zafer Vatansever, Maite Brandt-Pearce, University of Virginia, United States

We propose a fingerprinting-based algorithm for an indoor tracking system that uses light-emitting diodes (LED) equipped with imaging sensors. The LEDs have created an opportunity to use visible light for communications and positioning. The location-based services have created a necessity for indoor positioning and tracking. The accuracy of the LED-based indoor positioning can be measured in decimeters while RF-based systems like LTE operate in meters. This supports the need for more accurate alternatives to RF-based systems. We approach the LED-based indoor tracking problem using imaging sensors mounted on the LED arrays to capture the images of the power distribution on the room floor. The images used to estimate the light intensity map that serves as the fingerprints for positioning. Linear and nonlinear regression and artificial neural networks are used for mapping from the grayscale pixel values to theoretically-computed power levels. A photodetector on the user equipment measures the light intensity in real-time and these measurements are used in an extended Kalman filter for tracking. The estimated fingerprint map forms the basis for the linearization of these measurements for the filter. The results show that we can reach an accuracy on the order of the resolution of the fingerprint map.

TA8a4-8
Penalty-Based Multitask Distributed Adaptation over Networks with Constraints
Fei Hua, Roula Nassif, Cédric Richard, Université Nice Sophia Antipolis, France; Haiyan Wang, Jianguo Huang, Northwestern Polytechnical University, China

Multitask distributed optimization over networks enables the agents to cooperate locally to estimate multiple related parameter vectors. In this work, we consider multitask estimation problems over mean-square-error (MSE) networks where each agent is interested in estimating its own parameter vector, also called task, and where the tasks are related according to a set of linear equality constraints. We assume that each agent possesses its own cost and that the set of constraints is distributed among the agents. In order to solve the multitask problem, a cooperative algorithm based on penalty method is derived. Some results on its stability and convergence properties are also provided. Simulations are conducted to illustrate the theoretical results and show the efficiency of the strategy.

Session: TA8b1 – Massive MIMO Communication Systems 10:15 AM–11:55 AM

Chair: ***Oscar Gustafsson,*** *Linköping University, Sweden*

TA8b1-2

A Joint Combiner and Bit Allocation Design for Massive MIMO Using Genetic Algorithm

Fnu I. Zakir Ahmed, Hamid Sadjadpour, University of California, Santa Cruz, United States; Shahram Yousefi, Queen's University, Canada

In this paper, we derive a closed-form expression for the combiner of a multiple-input-multiple-output receiver equipped with a minimum-mean-square-error (MMSE) estimator. We propose using variable-bit-resolution analog-to-digital converters across radio frequency (RF) paths. The combiner designed is a function of the quantization errors across each RF path. Under a power constraint, we propose a Genetic Algorithm to arrive at an optimal bit allocation framework with significant reduction in computational complexity.

TA8b1-3

Sectoring in Multi-cell Massive MIMO Systems

Shahram Shahsavari, Parisa Hassanzadeh, New York University, United States; Alexei Ashikhmin, Nokia Bell Labs, United States; Elza Erkip, NYU Tandon School of Engineneering, United States

In this paper, the downlink of a massive MIMO system is studied when each base station is composed of three antenna arrays with directional antenna elements serving 120° of the two-dimensional space. A lower bound for the achievable rate is provided. A power optimization problem is formulated and as a result, centralized and decentralized power allocation schemes are proposed. The simulation results reveal that using directional antennas at base stations along with sectoring can lead to more than 5-fold gain in the achievable rates by increasing the received signal power and decreasing `pilot contamination' interference in multi-cell massive MIMO systems. Moreover, it is shown that using optimized power allocation can increase 0.95-likely rate in the system significantly.

TA8b1-4

On Channel Estimation for One-Bit Massive MIMO Systems with Fixed and Time-Varying Thresholds

Pu Wang, Mitsubishi Electric Research Laboratories, United States; Jian Li, University of Florida, United States; Milutin Pajovic, Petros Boufounos, Philip Orlik, Mitsubishi Electric Research Laboratories, United States

This paper considers angular-domain channel estimation for massive MIMO systems with one-bit analog-to-digital converters (ADCs) equipped at base stations for the sake of lower power consumption and reduced hardware cost. We characterize analytical performance in term of the Cramer-Rao bound (CRB) on estimating the two-dimensional channel matrix (including angle-of-departure, angle-of-arrival and associated channel path gain) in the angular-domain representation. Our analysis provides a simple tool to compare the channel estimation performance among several one-bit quantization schemes. Particularly, we study the performance trade-off between fixed (zero-threshold) and time-varying one-bit quantization schemes. Numerical results are provided for preliminary performance verification.

TA8b1-5

A Study on Channel Block Sparsity in Massive MIMO Systems based on Channel Measurements

Elisabeth De Carvalho, Anders Kastersen, Alex Oliveras Martinez, Jesper Ødum Nielsen, Patrick Eggers, Aalborg University, Denmark

The assumption that the channel is block sparse in massive MIMO systems below 6 GHz is central to many research study. It is the key factor to enable frequency division duplexing and has also been proposed as a basis for pilot decontamination and for improved channel estimation. Yet, this assumption remains controversial as it is essentially not verified by channel measurements. Based on two measurement campaigns with 64 and 128 antennas at the base station, we examine the directional properties of the channel and examine its level of sparsity.

TA8b1-6

Proof-of-Concept of Sparse Massive MIMO Beamforming at 3.5 GHz

Thomas Wirth, Fraunhofer Heinrich Hertz Institute, Germany

Massive-MIMO (M-MIMO) and beamforming is commonly considered as one of the key technologies for future cel- lular communications. It is targeted to solve the capacity requirements for enhanced mobile broadband services, which is predicted to increase by a factor of 10,000 for 5G networks. Furthermore, M-MIMO can be an enabler for new services in other fields of communications such as massive machine type communication (mMTC) or the enabler for directed commu- nication for autonomous driving in vehicular scenarios. The latter can comprise of classical vehicular-to-vehicular (V2V) or vehicular-to-infrastructure (V2I) scenarios. The goal of this work is to estimate the number of active transceiver branches required to achieve a given system per- formance in a specified multi-user scenario. Sparse M-MIMO refers to reducing the number of active transceiver branches by adaptive selection of a set of antenna elements from a larger array antenna. The system concept will be evaluated by means of system-level simulations on measurement data collected in a real proof-of-concept scenario as well was by means of measurement results collected from implemented direction-of-arrival (DoA) and beamforming algorithms on a real SDR platform.

TA8b1-7

Pilot Decontamination Under Imperfect Power Control

Jitendra Tugnait, Auburn University, United States

In a time-division duplex (TDD) multiple antenna system the channel state information (CSI) can be estimated using reverse training. In multicell multiuser massive MIMO systems, pilot contamination degrades CSI estimation performance and adversely affects massive MIMO system performance. In this paper we consider a subspace-based semi-blind approach where we have training data as well as information bearing data from various users (both in-cell and neighboring cells) at the base station (BS). Existing subspace approaches assume that the interfering users from neighboring cells are always at distinctly lower power levels at the BS compared to the in-cell users. This requires (perfect) power control particularly if the interfering users are at the cell edge. In this paper we do not make any such assumption: the interfering users from neighboring cells can be at higher power levels at the BS compared to the in-cell users. Unlike existing approaches, the BS estimates the channels of all users: in-cell and significant neighboring cell users, i.e., ones with comparable power levels at the BS. We exploit both subspace method using correlation as well as blind source separation using higher-order statistics. The proposed approach is illustrated via simulation examples and compared with existing subspace methods.

TA8b1-8

Large-Scale Antenna-Assisted Grant-Free Non-Orthogonal Multiple Access via Compressed Sensing

Hanyu Wang, Yanlun Wu, Jun Fang, University of Electronic Science and Technology, China

In this paper, we propose a multi-antenna-assisted grant-free non-orthogonal multiple access scheme. The proposed grant-free scheme does not require complex handshaking procedure, and allows simultaneous user detection, channel estimation and data decoding in a single shot, thus leading to a significant reduction in the signalling overhead. Different from previous studies, we consider the deployment of large-scale antennas at the receiver. By exploiting the asymptotic orthogonality among channel vectors, we show that the user detection accuracy can be significantly improved. Simulation results are provided to illustrate the performance of the proposed scheme.

Track B – MIMO Communications and Signal Processing

Session: TA8b2 – Issues in MIMO System Design 10:15 AM–11:55 AM

Chair: ***Sofie Pollin,*** *KU Leuven, Belgium*

TA8b2-1

Delay-Aware Routing and Data Transmission for Multi-Hop D2D Communications Under Stochastic Interference Constraints

Sireesha Madabhushi, Chandra Murthy, Indian Institute of Science, India

In this paper, we determine the multi-hop route that maximizes the throughput between a given Device-to-Device (D2D) source-destination pair for delay sensitive applications. We solve the routing problem under per-link target rate and delay constraints, in addition to the stochastic interference constraint from the cellular network. We derive closed-form expressions for the achievable end-to-end throughput, delay and packet drop probability. Based on this analysis, we develop an optimal routing algorithm for throughput maximization. We confirm the accuracy of our analysis using Monte Carlo simulations and illustrate the tradeoff

between delay and throughput. Further, we show that multi-hop route offers significant gains in end-to-end data rates compared to the direct link communication under the stochastic interference constraint imposed by the cellular network and the maximum delay constraint on the transmitted packets.

TA8b2-2

Layered Graph-Merged Detection and Decoding of Non-Binary LDPC Coded Massive MIMO Systems

Shusen Jing, Junmei Yang, Huayi Zhou, Southeast University, China; Yeong-Luh Ueng, National Tsing Hua University, Taiwan; Xiaohu You, Chuan Zhang, Southeast University, China

In order to improve the spectral efficiency and reliability of communication systems, both the multiple-input multiple-output (MIMO) technique and non-binary low-density parity-check (NB-LDPC) codes are considered as powerful tools to meet the requirements. In order to further optimize the MIMO NB-LDPC systems and adapt to massive MIMO scenarios, a new joint detection and decoding (JDD) method of massive MIMO with NB-LDPC codes, called layered graph-merged detection and decoding (GMDD), is proposed. In this paper, factor graphs associated to symbol-based belief propagation (BP) MIMO detection and NB-LDPC decoding are merged into a single graph. For massive MIMO condition, a MIMO detection graph is attached to several NB-LDPC decoding graphs, which makes the methods unique to existed ones. Compared with separated detection and decoding (SDD), for BER less than 5x10^{-2} the proposed method can achieve nearly 7 dB gain with same or even fewer iterations. Corresponding hardware architecture and complexity analysis are also given in this paper.

TA8b2-3

A Greedy Approach for mmWave Hybrid Precoding with Subarray Architectures

Marcin Iwanow, Nikola Vucic, Samer Bazzi, Jian Luo, Huawei Technologies Duesseldorf GmbH, Germany; Wolfgang Utschick, Technical University of Munich, Germany

We consider a single mmWave link with hybrid digital-analog transceivers. Moreover, we restrict the analog processing network such that disjoint antenna subarrays are processed separately in the analog domain. The algorithm presented in the paper aims on designing the analog processing stage in a greedy manner. Subsequent streams are allocated to selected transmitter-receiver subarray pairs and the cooperation between the subarrays allows to manage the inter-stream interference. Simulation results show that with low computational complexity, the algorithm achieves better performance than the baseline solutions.

TA8b2-4

Criterion of Adaptively Scaled Belief for PDA in Overloaded MIMO Channels

Takumi Takahashi, Shinsuke Ibi, Seiichi Sampei, Osaka University, Japan

This paper proposes a new design criterion of adaptively scaled belief (ASB) in probabilistic data association (PDA), especially for overloaded multi-user multi-input multi-output (MU-MIMO) detection. The most vital issue with regard to improving the convergence property of PDA is how to deal with the soft symbol outliers in each iteration, which are caused by modeling errors of the prior belief. As the simplest way to mitigate the harmful impacts of outliers, adaptive belief scaling is proposed while stabilizing dynamics of random MIMO channels. Finally, we verify the validity of ASB regarding suppressions of the bit error rate (BER) floor level.

TA8b2-5

Scheduling and Power Optimization in Full-Duplex Small Cells with Successive Interference Cancellation

Shahram Shahsavari, David Ramirez, New York University, United States; Elza Erkip, NYU Tandon School of Engineneering, United States

Successive interference cancellation facilitates mitigation of uplink-downlink interference in full-duplex networks. In this paper a novel full-duplex opportunistic scheduler is proposed to improve throughput of small cell wireless networks. Downlink (uplink) primary users are scheduled based on a half-duplex opportunistic temporal fair strategy; then a full-duplex base station simultaneously schedules secondary users in uplink (downlink) on the frequency of the primary user if throughput increases and the rate of the primary user does not decrease beyond a fixed threshold. In a single cell scenario, we show that successive interference cancellation and full-duplex can favorably address downlink-uplink demand asymmetry while simultaneously increasing network throughput. Power optimization is shown to improve the performance further.

TA8b2-6

On Beam Design for Sparse Arrays of Subarrays using Multi-Objective Optimization and Estimation-Theoretic Criteria

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

Compact antenna arrays with a moderately large number of elements (e.g. 16 elements in a 4x4 planar configuration) can be realized at low cost at millimeter wave frequencies. This provides the opportunity for cost-effective synthesis of large aperture antenna arrays using sparse placement of such compact “subarrays”. In this paper, we investigate the design of arrays of subarrays constructed in this fashion, constraining the number of subarrays and the size of the area over which they are placed, with a view to mitigating the grating lobes created by multi-wavelength separation of the subarrays. We consider multi-objective optimization of directivity, beamwidth, maximum sidelobe level and beam eccentricity: while exhaustive search for the space of optimal solutions is computationally infeasible, we obtain intuitively plausible configurations using simple search strategies for finding local minima. We compare example configurations using bounds on the performance Direction of Arrival (DoA) estimation using such arrays.

TA8b2-7

Single Carrier Frequency Domain Compressed Training Adaptive Equalization

Baki Berkay Yilmaz, Georgia Institute of Technology, United States; Alper T. Erdogan, Koc University, Turkey

Decreasing the number of training symbols in a communication packet is one of the concerns of researchers to increase the efficiency of available bandwidth. In this respect, we propose single carrier frequency domain compressed training adaptive equalization (SC-FDE CoTA) which combines cost functions regarding reconstruction error of training symbols and infinity norm of equalizer outputs with the knowledge of magnitude boundedness of digital communication symbols. Due to exploitation of both training and information symbols for channel equalization, it is categorized in semi-blind algorithms. We provide examples to demonstrate the effectiveness of the algorithm in terms of training reduction and performance improvement.

TA8b2-8

Impact of Interference Correlation on the Decoding Error Statistics

Fernando Rosas, Imperial College London, United Kingdom; Konstantinos Manolakis, Huawei Technologies, Germany; Christian Oberli, Pontificia Universidad Catolica de Chile, Chile; Marian Verhelst, Sofie Pollin, Mahdi Azari, KU Leuven, Belgium

Scenarios where interference is in some way correlated with useful signals are often met in communications systems. Interestingly, even though uncorrelated interference mitigation has been extensively studied by the literature, there is still lack of insight into how correlation can affects information transfer processes. In this paper we formally address this issue and show how a positive correlation between the interference and useful signal power introduces a non-intuitive increase in the diversity gain, improving the error statistics with respect to the uncorrelated case. In contrast, the diversity gain decreases under negative correlation, degrading the system performance. Findings are confirmed by simulations for scenarios of practical relevance and mechanisms are discussed.

Track E – Array Signal Processing

Session: TA8b3 – Array Processing Algorithms for Radar 10:15 AM–11:55 AM

Chair: ***Yimin Zhang,*** *Temple University*

TA8b3-1

Time and Frequency Corrections in a Distributed Network using Gnu Public Radio

Sam Whiting, Dana Sorensen, Todd Moon, Jacob Gunther, Utah State University, United States

In software defined radio hardware, coherency between multiple low-cost ADCs is often difficult to achieve. The general movement of software defined radio is to have less hardware and instead rely on software to correct for these problems. A lack of coherency in receivers results in three main offsets: a sample offset, frequency offsets, and phase offsets that are introduced when the sampling begins. In this paper, an adaptive method for correcting these offsets using software feedback loops is presented. The system is implemented in Gnuradio with low-cost RTL-SDR receivers as a proof-of-concept.

TA8b3-2

Joint Radar-Communications System Implementation Using Software Defined Radios: Feasibility and Results

Richard M. Gutierrez, Andrew Herschfelt, Hanguang Yu, Daniel Bliss, Hyunseok Lee, Arizona State University, United States

Joint radar-communications systems attempt to address spectral congestion with cooperative spectrum sharing architectures. These architectures include co-existence, in which both systems agree to operate cooperatively, and co-design, in which both systems are designed together to achieve more efficient cooperation. We demonstrate the feasibility of a co-design architecture using a multiple-input, single-output (MISO) channel topology. This system architecture is implemented with a network of commercially available software defined radios (SDRs). The communications system uses a quadrature phase-shift keying (QPSK) modulation scheme. The radar system uses a standard linear frequency modulated (LFM) chirp. We demonstrate that a high-resolution radar return can be extracted from a simultaneous, multiple access reception using successive interference cancellation (SIC). Furthermore, we show that the high-resolution radar return can achieve similar estimation performance when compared to a radar only system.

TA8b3-3

Frequency Invariance Beamforming for Arbitrary Planar Arrays

Alessio Medda, Georgia Tech Research Institute, United States; Arjun Patel, Georgia Institute of Technology, United States

In this paper, we present the adaptation to the least-square solution for frequency invariant beamforming to arbitrary planar arrays. The resulting formulation is easily steerable thanks to the decoupling of spatial and frequency constraints. This is achieved with a basis of spherical harmonics polynomials, which parametrize the array response in a term dependent on frequency and a term dependent on the array geometry. Furthermore, the parametrization of the array response Bessel functions decouples the frequency term, which becomes independent of the geometry of the planar array, and allows steering in azimuth and elevation independently. Preliminary results are shown for a 9-element square and circular array

TA8b3-4

Time-Decentralized DOA Estimation for Electronic Surveillance

Songsri Sirianunpiboon, Stephen D. Howard, Stephen D. Elton, Defence Science & Technology Group, Australia

Due to high data rates necessary in multi-channel Electronic Surveillance systems, the full multi-channel data collected on each radar pulse is data compressed to a pulse descriptor word (PDW), which conventionally contains a DOA estimate for the pulse. It is only in down steam processing that the PDWs are clustered into groups identified as originating from single radar. A combined DOA estimate for the radar is conventionally achieved by some form of averaging over the individual pulse DOAs. If one could retain all of the multi-channel IQ data for all of the pulses in a cluster, one could optimally estimate a DOA for the radar using, for example, a maximum likelihood (ML) estimate. In this paper we propose a modification to the initial data compression and subsequent processing which, while adding only a modest amount of data to each PDW, allows estimation of the radar's DOA with performance approaching that which could be achieved by ML estimation using the full multi-channel data records for all the pulses in the cluster. The method is computationally efficient and also allows the optimal beamforming of each pulse without the need to explicitly estimate its DOA.

TA8b3-5

One-Bit Digital Radar

Jiaying Ren, Jian Li, University of Science and Technology of China, China

This paper introduces a one-bit digital radar involving direct one-bit sampling with unknown dithering of the received radio frequency (RF) signal. Due to avoiding the analog mixer and the down-conversion of the RF signal, the digital radar can be energy-efficient and low-priced. The use of unknown dithering allows for the one-bit samples to be processed efficiently using conventional algorithms. A computationally efficient range-Doppler estimation method based on fractional Fourier transform (FRFT) and fast Fourier transform (FFT) is used for linear frequency modulated continuous wave (LFMCW) transmissions, and the CLEAN algorithm is used for target parameter estimation.

TA8b3-6

Analysis of Sparse Co-Prime Sensing Array Performance Using Wideband Noise Signals

David Alexander, Ram Narayanan, The Pennsylvania State University, United States; Braham Himed, US Air Force Research Laboratory, United States

A pair of co-prime phased arrays are capable of sampling a wide sense stationary signal at a set of points densely relative to the sparse inter-element spacing. In this paper, the attractive properties of both one- and two-dimensional co-prime arrays are exploited for application to noise radar systems. A performance comparison was made of wideband noise waveforms to more traditional chirp waveforms through simulation of peak cross-correlation of transmitted and received waveforms and direction-of-arrival (DOA) estimation with the co-prime sensor arrays.

TA8b3-7

Joint Transmit-Receive Beamspace Design for Colocated MIMO Radar in the Presence of Deliberate Jammers

Jiawei Liu, Saquib Mohammad, University of Texas at Dallas, United States

An iterative joint transmit-receive beamspace design method based on convex optimization is proposed for colocated multiple-input-multiple-output (MIMO) radar. Interfering sources and powerful jammers are considered. The performance gain of the proposed scheme is demonstrated using several performance metrics such as signal-to-interference-plus-jammer-plus-noise-ratio (SIJNR) and out-of-sector power attenuation etc. The convergence analysis and SIJNR gain of our iterative scheme are also reported.

TA8b3-8

Radar Detection in K-Distributed Clutter using Multiple Order-Statistics combining

James Ritcey, University of Washington, United States

Detection in long-tailed clutter is a challenging problem. Recently, GLRT in K-distributed clutter plus noise has been addressed. It has been shown that order-statistics detectors work well to sort nonfluctuating point targets from clutter. We extend this work to show that, at little additional computational cost, linear combining of sorted values, L-statistics, can provide additional performance gains. We show methods for optimizing within the class of L-statistic combiners. Results are given primarily through simulation, but additionally with some approximate theoretical models.

Track E – Array Signal Processing

Session: TA8b4 – Source Localization 10:15 AM–11:55 AM

Chair: ***Benjamin Friedlander,*** *University of California, Santa Cruz*

TA8b4-1

Distributed Beamforming with High Altitude Balloon Relays

Ameya Agaskar, Keith Forsythe, Navid Yazdani, MIT Lincoln Laboratory, United States

In this paper, we propose an aerial relay layer composed of a swarm of high altitude balloon nodes. These nodes are deployed as a large distributed array, allowing spatial reuse of precious bandwidth through adaptive beamforming. creating multi-fold increases in spectrum efficiency using the distributed sparse array requires advanced adaptive processing at a ground station. In this paper, we will develop the fundamental limits of such a system, show simulation results for scenarios of interest, and provide flight test results from the system.

TA8b4-2

On the Accuracy of Array Manifold Models

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

The antenna array manifold plays a pivotal role in array processing. Achieving super-resolution requires highly accurate knowledge of this manifold. We compare the mathematical model of the manifolds commonly used in the array signal processing literature to the model derived from electromagnetic antenna theory and note some important differences. In particular, a constant (direction independent) mutual coupling matrix is used in array signal processing, while electromagnetic theory indicates that it should be direction dependent. Furthermore, different mutual coupling matrices need to be used for vertical and horizontal polarization. The effects of these inaccuracies are investigated and shown to be of potential concern for frequently used array structures.

TA8b4-3

The Role of Difference Coarrays in Correlation Subspaces

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

The concept of correlation subspaces was recently introduced in array processing literature by Rahmani and Atia. Given a sensor array, its geometry determines the correlation subspace completely, and the covariance matrix of the array output is constrained in a certain way by the correlation subspace. It has been shown by Rahmani and Atia that this knowledge about the covariance constraint can be exploited to improve the performance of DOA estimators. In this paper, it is shown that there is a simple closed form expression for the basis vectors of the correlation subspace. Thus, computation of this subspace is greatly simplified. Another fundamental observation is that, this expression is closely related to the difference coarray. Thirdly, the paper also shows an interesting logical connection between correlation subspaces and the method of redundancy averaging, which is popularly used in DOA estimation.

TA8b4-4

A Newton-type Forward Backward Greedy Method for Multi-Snapshot Compressed Sensing

Ahmad Bazzi, RivieraWaves-CEVA and EURECOM, France; Dirk Slock, Lisa Meilhac, EURECOM, France

Parameter estimation has applications in many applications of signal processing, such as Angle-of-Arrival (AoA) estimation. Compressed sensing is a widely growing paradigm that can be applied to parameter estimation via sparse recovery. In this paper, we propose a Newton-type Forward Backward Greedy method that performs sparse recovery, given the observed data over multiple snapshots. This method is applied to the AoA estimation problem, where we have observed better performance, in terms of Mean-Squared Error and faster convergence when compared to existing methods. More information can be found in the conclusions section.

TA8b4-5

DOA Estimation with k-Times Extended Co-prime Arrays

Xiaomeng Wang, Xin Wang, Stony Brook University, United States

Sparse arrays such as co-prime arrays, nested arrays and minimum redundancy arrays (MRAs) can achieve larger number of degrees-of-freedom (DoFs) with fewer sensors by exploring their difference co-arrays. Co-prime arrays become more attractive, as there exist no exact expressions of MRA configurations for an arbitrary number of sensors and the nested arrays suffer greatly from mutual coupling. However, in order to achieve a large number of DoFs, traditional extended coprime arrays have a large array aperture compared to the DoFs gained. In this paper, we propose a novel advanced co-prime array geometry that can not only further reduce the number of required sensors but also significantly reduce the array aperture while achieving the same number of DoFs. On the other hand, it has better performance than nested arrays in the presence of mutual coupling. Simulation results demonstrate the feasibility and effectiveness of our proposed array geometry in achieving higher quality direction-of-arrival (DOA) estimation.

TA8b4-6

Cumulant-Based Direction-of-Arrival Estimation Using Multiple Co-Prime Frequencies

Ammar Ahmed, Yimin D. Zhang, Temple University, United States; Braham Himed, Air Force Research Laboratory, United States

In this paper, we propose a novel direction-of-arrival (DOA) estimation technique based on multiple co-prime frequencies and fourth-order statistics of received signals. The utilization of multiple frequencies provides virtual sensors at the receiver array, thereby resulting in extended aperture, higher number of degrees-of-freedom, and greater flexibility compared to the commonly used single frequency-based methods. The set of lags achieved from the resulting virtual antenna elements is further extended by exploiting higher-order statistics-based difference co-array approach. The proposed scheme yields the fourth-order difference co-array which offers a significantly greater number of lags compared to the sparse array techniques used by existing DOA estimation methods. Simulation results verify the effectiveness of the proposed technique.

TA8b4-7

Analog Beam Tracking in Linear Antenna Arrays: Convergence and Optimality

Jiahui Li, Tsinghua University, China; Yin Sun, The Ohio State University, United States; Limin Xiao, Shidong Zhou, Tsinghua University, China; C. Emre Koksal, The Ohio State University, United States

Fast and accurate analog beam tracking is an important and yet challenging issue in 5G wireless networks, due to the inherent non-convexity of the problem. In this paper, we develop a low-complexity recursive beam tracking algorithm. In static beam tracking scenarios, this algorithm converges to the Cramer-Rao lower bound (CRLB) with very high probability. In dynamic

beam tracking scenarios, if combined with a simple TDMA pilot pattern, this algorithm has the potential to track hundreds of independent beams, generated by highly-mobile transmitters/reflectors, with low pilot overhead. Simulations are provided to illustrate the performance gain of this algorithm.

TA8b4-8
Array Calibration in the Presence of Linear Manifold Distortion
Benjamin Friedlander, University of California, Santa Cruz, United States

We consider a linear distortion model to parameterize the mismatch between the true and assumed array manifolds in a direction finding system. This model corrects certain issues arising in prior work on self-calibration. An algorithm is presented for the joint estimation of the directions of arrival (DOAs) and the distortion parameters based on data from multiple collection intervals. A closed form solution for the distortion parameters conditioned on the DOAs is derived. The DOAs are estimated separately in each collection interval using the MUSIC algorithm. Simulation results are provided to validate the self-calibration algorithm and illustrate its performance.

Track A – Communications Systems
Session: TP1a – Fundamentals of mmWave Communications
Co-Chairs: ***Aditya Dhananjay,*** *NYU Tandon School of Engineering* ***and David Ramirez,*** *NYU Tandon School of Engineering*

TP1a-1 1:30 PM
Rate-Optimal Power and Bandwidth Allocation in an Integrated RF-Millimeter Wave Communications System
Morteza Hashemi, C. Emre Koksal, Ness B. Shroff, The Ohio State University, United States

In millimeter wave (mmWave) systems, energy is a scarce resource due to the large channel losses and high energy usage by analog-to-digital converters. To mitigate this issue, we propose an integrated architecture that combines RF (i.e., sub-6~GHz) and mmWave technologies. We investigate the power and bandwidth allocation jointly across the interfaces in order to maximize the achievable sum rate under power constraints. Our optimization formulation explicitly takes the components energy consumption into account, and our results show that despite the availability of huge mmWave bandwidth, it is optimal to utilize it partially under some circumstances.

TP1a-2 1:55 PM
Managing Analog Beams in mmWave Networks
Yasaman Ghasempour, Rice University, United States; Narayan Prasad, Mohammad Khojastepour, Sampath Rangarajan, NEC Labs, United States

We consider multi-cell mmWave networks wherein each cell can employ a group of analog beams to serve its associated users, while each such user can employ a single analog beam. A key problem over such a network is to determine the set of users that each cell should serve, the group of beams it should employ, as well as their attributes such as how often and with how much power should each beam be used. This problem becomes harder since the choice of beam at any user is coupled to the cell it is assigned to and the latter's choice of beams. Moreover, practical considerations demand that each transmitting and receiving beam and their attributes be selected from finite codebooks. We adopt the generalized Quality-of-Service (QoS) ProportionalFairness (PF) network utility which is particularly relevant for coverage constrained mmWave systems. We prove that, remarkably, the user association problem under this QoS-PF utility can be formulated as a constrained submodular set function maximization problem. We then propose a simple distributed algorithm to optimize the choice of beams and their attributes, and prove that it converges to a social equilibrium even in the presence a non-ideal communication channel between cells.

TP1a-3 2:20 PM
Energy Efficient Beam Alignment in Millimeter Wave Networks
Muddassar Hussain, Nicolo Michelusi, Purdue University, United States

Millimeter wave communications rely on narrow- beam transmissions to cope with the strong signal attenuation at these frequencies, thus demanding precise beam alignment between transmitter and receiver. This need may entail a significant loss in transmission efficiency due to the associated signaling overhead, especially in mobile environments. This paper addresses the energy efficient design of the beam alignment protocol, with the goal of minimizing power consumption under a constraint on the transmission rate. It is proved that a fractional search method is optimal, which allocates a given fraction of the beam in each slot during beam alignment. The fractional value is determined in closed form and is shown to be a function of the sensing-

communication energy ratio: when this ratio is small (the sensing energy is small), a wider beam is selected and the fractional value approaches 1/2 (bisection); in contrast, when it is large, a narrower beam is used to reduce the energy cost of sensing. It is proved that fractional search strictly outperforms a bisection search algorithm. Numerical results demonstrate a reduction in the average power consumption by a factor 2 with respect to bisection, for a wide range of rates.

TP1a-4 2:45 PM

5G Millimeter Wave Cellular System Capacity with Fully Digital Beamforming

Sourjya Dutta, C. Nicolas Barati, Aditya Dhananjay, Sundeep Rangan, New York University, Tandon School of Engineering, United States

Due to heavy reliance of millimeter-wave (mmWave) wireless systems on directional links, Beamforming (BF) with high-dimensional arrays is essential for cellular systems in these frequencies. How to perform the array processing in a power efficient manner is a fundamental challenge. Analog and hybrid BF require fewer analog-to-digital converters (ADCs), but can only communicate in a small number of directions at a time, limiting directional search, spatial multiplexing and control signaling. Digital BF enables flexible spatial processing, but must be operated at a low quantization resolution to stay within reasonable power levels.This paper presents a simple additive white Gaussian noise (AWGN) model to assess the effect of low-resolution quantization of cellular system capacity. Simulations with this model reveal that at moderate resolutions (3-4 bits per ADC), there is negligible loss in downlink cellular capacity from quantization. In essence, the low-resolution ADCs limit the high SNR, where cellular systems typically do not operate. The findings suggest that low-resolution fully digital BF architectures can be power efficient, offer greatly enhanced control plane functionality and comparable data plane performance to analog BF.

Track G – Architecture and Implementation

Session: TP1b – Hardware Designs for 5G Wireless Systems

Chair: ***Zhengya Zhang,*** *University of Michigan*

TP1b-1 3:30 PM

Adaptive and Multi-Mode Baseband Systems for Next Generation Wireless Communication

Farhana Sheikh, Mehnaz Rahman, Dongmin Yoon, Alexios Balatsoukas-Stimming, Oskar Andersson, Deepak Dasalukunte, Ankit Sharma, Anthony Chun, Intel Corporation, United States

System adaptivity has been studied since the mid-60s and recently there has been a surge in interest in self-adaptive systems, especially in the software engineering community, with its main application to cybernetics. In this work, we apply self-adaptivity to multi-mode baseband processing systems for 5G wireless communications to exploit channel characteristics to modify the computation of digital baseband processing subsystems for energy savings. The gains from self-adaptivity are exemplified in the design of lattice reduction aided MIMO detection and extended out to other baseband subsystems such as multi-mode FIR filters, and multi-point FFT computation.

TP1b-2 3:55 PM

VLSI Design of a Nonparametric Equalizer for Massive MU-MIMO

Gulnar Mirza, Ramina Ghods, Charles Jeon, Arian Maleki, Christoph Studer, Cornell University, United States

Optimal data detection for massive multi-user (MU) multiple-input multiple-output (MIMO) wireless systems requires prohibitive computational complexity. Hence, practical data-detector designs typically rely on near-optimal algorithms, such as linear minimum mean-square error (L-MMSE) equalization. This method, however, requires accurate knowledge of the signal and noise variances, which is difficult to acquire in practice due to the time-variant nature of wireless channels. We propose a VLSI design of a novel, nonparametric data-detection algorithm for massive MU-MIMO systems that provably achieves the error-rate performance of the L-MMSE equalizer without requiring knowledge of the signal and noise variances. The algorithm, referred to as NOnParametric Equalizer (NOPE), is robust to a broad range of system impairments and exhibits lower complexity than traditional L-MMSE data detectors that require costly matrix inverses and tedious parameter tuning. To demonstrate the effectiveness of NOPE, we develop a coarsely-pipelined VLSI architecture and provide implementation results in 28nm CMOS for a massive MU-MIMO system in which 16 single-antenna users transmit data to a 64-antenna base-station.

TP1b-3 4:20 PM

An Area-Efficient Parallel Memory for Massive MIMO using Channel State Information Compression

Yangxurui Liu, Ove Edfors, Liang Liu, Viktor Öwall, Lund University, Sweden

Massive multiple-input-multiple-output (MIMO) has been proven to have significant improvement regarding both spectral and energy efficiency. While the number of antennas at the base station is up scaling, the size of channel state information (CSI) also grows dramatically and its huge storage room requirement becomes an implementation bottleneck. This paper presents an area-efficient memory system for massive MIMO baseband processing. It exploits the data-level parallelism method, which is mapped on a parallel memory system to provide high access bandwidth and flexible matrix access pattern, i.e., row- column-, and diagonal-access. To further improve the area efficiency, the spatial correlation property in massive MIMO channel is explored together with on-chip data compression method that the amount of stored CSI can be reduced with small system performance degradation. We evaluated the proposed methods using real-measured massive MIMO channel with 128 base station antenna setup. Evaluation results show that 75% of the CSI memory can be saved with less than 1 db performance loss in line-of-sight scenarios.

TP1b-4 4:45 PM

Segmented Successive Cancellation List Polar Decoding with Joint BCH-CRC Codes

Xiao Liang, Huayi Zhou, Southeast University, China; Zhongfeng Wang, Nanjing University, China; Xiaohu You, Chuan Zhang, Southeast University, China

Polar codes, which have been adopted as the channel code for 3GPP eMBB control channel, are the first codes achieving the capacity of symmetric binary-input discrete memoryless channels (B-DMCs). For short length polar codes, which are favorable for control channels, CRC-aided segmented successive cancellation list (SCL) decoding can reduce the hardware complexity and memory cost. However, CRC brings no performance gain in segmented decoding. In this paper, an efficient joint decoding scheme called BCH-CRC-aided segmented SCL decoding (BC-SCL) is firstly proposed. Its HARQ refined version is also given. BCH and CRC are employed in different segments to maximize their own correction or check advantages. Numerical results on binary-input additive white Gaussian noise (BI-AWGN) channel have shown the performance gain of the proposed BC-SCL decoder. The corresponding hardware architecture is also proposed. Short-length BC-SCL decoder with (N=128, K=64, L=2) is implemented with Altera Stratix V FPGA. Compared to the CRC-aided decoder, the proposed decoder requires only 76.12% ALMs with slightly increased latency. Therefore, BC-SCL scheme can highly demonstrate advantages of both BCH and CRC in polar segmented decoding.

Track B – MIMO Communications and Signal Processing

Session: TP2a – Noncoherent Wireless Communications

Co-Chairs: ***Dirk Slock,*** *EURECOM, France* ***and Maxime Guillaud,*** *Huawei Technologies Co. Ltd, France*

TP2a-1 1:30 PM

Large Antenna Arrays for Direction Finding using Phaseless Non-Coherent Measurements

Mainak Chowdhury, Milind Rao, Andrea Goldsmith, Stanford University, United States

Building an all-digital large antenna array with coherent radio chains at each antenna element has many engineering challenges. In this work, direction finding based on array elements capable of acquiring only phaseless non-coherent measurements is considered. Fundamental limits on the angle estimation error for a finite number of planar wavefronts impinging on the array as a function of the number of antennas are derived through a characterization of the Fisher information matrix. The performance of sparsity-based computationally efficient algorithms for direction finding from recent advances in the phase retrieval literature are also presented. Finally, performance comparisons of non-coherent direction finding with that under perfectly coherent measurements are drawn.

TP2a-2 1:55 PM

Design and Analysis of a Practical Codebook for Non-Coherent Communications

Khac-Hoang Ngo, Alexis Decurninge, Maxime Guillaud, Huawei Technologies France SASU, France; Sheng Yang, LSS, CentraleSupelec, France

In this paper, we introduce and analyze a practical codebook construction for single-antenna non-coherent communications, with codewords belonging to the Grassmannian of lines defined on the complex vector space. This codebook is structurally generated by partitioning the Grassmannian of lines with a collection of bent grids and mapping the codewords' coordinates in the Euclidean space onto one of these bent grids. Leveraging the structured nature of the codebook, we design a systematic decoder

which does not require exhaustive search, has low complexity and hence can be easily implemented in practice. We characterize analytically and by simulation the error probability of this decoder and compare with the available benchmarks (maximum likelihood decoding and analytical error bounds)

TP2a-3 2:20 PM

Hierarchical Coherent and Noncoherent Communication

Ramy Gohary, Carleton University, Canada; Kareem Attiah, University of Alexandia, Egypt; Karim Seddik, American University in Cairo, Egypt

In this paper we propose a method for simultaneous communication of three types of information: two nested layers of coarse and medium information to be communicated noncoherently using Grassmannian constellations and a layer of fine information to be communicated coherently using unitary constellations. The layered architecture gives rise to four classes of receivers: coherent and noncoherent receivers, each operating in one of two distinct SNR regions. An operational bottleneck of this architecture is the detection complexity of the medium and fine information layers. To overcome this difficulty, two sequential detectors are developed. These detectors enable a performance comparable with that of their optimal maximum likelihood counterparts but with a significantly less computational cost.

TP2a-4 2:45 PM

Noncoherent Multi-User MIMO Communications using Covariance CSIT

Christo Kurisummoottil Thomas, Wassim Tabikh, Dirk Slock, EURECOM, France; Yi Yuan-Wu, Orange Labs, France

The Multi-User downlink, particularly in a Multi-Cell Massive MIMO setting, requires enormous amounts of CSIT (Channel State Information at the Transmitter(s) (Tx)). Here we consider various splits of channel estimates (mean CSIT) and channel covariance CSIT. In particular multipath induced structured low rank covariances are considered that arise in Massive MIMO and mmWave settings. These non-Kronecker covariance structures lead to a split between the roles of transmitters and receivers in MIMO systems. For the beamforming optimization, we consider the Expected Weighted Sum Unbiased MSE (EWSUMSE) criterion, which allows to accommodate also uncertain multipath information.

Track B – MIMO Communications and Signal Processing

Session: TP2b – Massive MIMO Systems

Chair: ***Elza Erkip,*** *NYU Tandon School of Engineering, USA*

TP2b-1 3:30 PM

Cell-Free Massive MIMO Systems Utilizing Multi-Antenna Access Points

Ahmad Ibrahim, Purdue University, United States; Alexei Ashikhmin, Thomas Marzetta, Bell Labs, United States; David Love, Purdue University, United States

Cell-free massive MIMO (CFmM) was recently proposed as an alternative to partitioning coverage area into cells. The main idea is to have many access points (APs) distributed over the coverage area to serve a smaller number of users. Users are served by all APs simultaneously sharing time and frequency resources. In this paper, we study the deployment of multi-antenna APs in CFmM systems. In particular, we study the advantages and disadvantages of using multi-antenna APs with respect to the achievable rates, the backhauling traffic, and the infrastructure cost to give results on how disperse antennas should be among APs.

TP2b-2 3:55 PM

Greed is Good: Leveraging Submodularity for Antenna Selection in Massive MIMO

Aritra Konar, Nicholas D. Sidiropoulos, University of Minnesota-Twin Cities, United States

We consider the NP-Hard problem of performing antenna selection in the downlink of a single cell, multi-user Massive MIMO system by maximizing the downlink channel capacity with a specified power allocation matrix subject to a cardinality constraint on the number of selected antennas. Prior work has focused on using convex relaxation coupled with fractional rounding in an attempt to obtain high quality sub-optimal solutions for this problem in polynomial-time. However, one cannot quantify the sub-optimality of the solution obtained via this approach for an arbitrary problem instance, which, in addition, is also computationally demanding to determine for a large-scale antenna system. In this paper, we show that the objective function of the antenna selection problem is monotone submodular, which implies that a simple greedy algorithm can be used to guarantee a constant (1-1/e)-factor approximation for all problem instances. The merits of using this approach are illustrated via simulations where the greedy algorithm returns high quality solutions in all cases at significantly lower complexity relative to convex relaxation based approaches.

TP2b-3 4:20 PM

Massive MIMO Functionality Splits based on Hybrid Analog-Digital Precoding in a C-RAN Architecture

Dong Min Kim, Jihong Park, Elisabeth De Carvalho, Carles Navarro Manchón, Aalborg University, Denmark

The paper addresses the integration of base stations with massive antenna arrays in a Cloud-RAN architecture. One major obstacle in a successful integration is the transport of huge data volumes between the massive arrays and the base band unit (BBU). The general idea relies on a split of the functionalities in the massive array processing between the base station and the BBU. In order to ensure a flexible and low cost deployment, the functionality split is based on hybrid analog-digital precoding where the cheaper analog processing is left at the remote radio head (RRH) and more expensive digital processing is migrated to the BBU. Analog beamforming at the RRH provides a data compression step significantly reducing the number of data streams to be transported to the BBU. The analog precoder, computed at the BBU, relies only on long term statistics. In addition, all the quantities related to beamforming coefficient computation correspond to either long term statistics of the channel or benefit from channel hardening hence providing robustness towards delays due to the fronthaul data transfer.

TP2b-4 4:45 PM

On the Hardware Efficiency of Decentralized Equalization in Massive MU-MIMO Systems

Kaipeng Li, Rice University, United States; Charles Jeon, Cornell University, United States; Joseph Cavallaro, Rice University, United States; Christoph Studer, Cornell University, United States

Massive multi-user multiple-input multiple-output (MU-MIMO) achieves higher spectral efficiency and link reliability than traditional small-scale MIMO while posing significant challenges on efficient system design and implementation. In an uplink system, conventional linear equalization algorithms can cause excessively high computational complexity and interconnection bandwidth beyond modern hardware capabilities. This paper presents a decentralized equalization architecture integrated with both linear and non-linear equalization algorithms, enabling near-optimal error-rate performance and high system scalability. We demonstrate the hardware efficiency of our decentralized equalization method using GPU and FPGA implementations and further analyze associated design trade-offs and performance models.

Track H – Speech, Image and Video Processing

Session: TP3a – Medical Image Acquisition and Reconstruction

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

TP3a-1 1:30 PM

Reconstructing High-Resolution Cardiac MR Movies from Low-Resolution Frames

Liam Cattell, Craig H. Meyer, Frederick H. Epstein, Gustavo K. Rohde, University of Virginia, United States

In medicine, high-resolution magnetic resonance imaging can aid accurate diagnosis. However, high-resolution magnetic resonance imaging usually necessitates a longer acquisition time than low-resolution imaging, since the resolution of magnetic resonance images is determined by the extent of k-space that is sampled. Long scan times can induce motion artifacts in the images and lead to patient discomfort, and therefore, scan times should be kept as low as possible. Although a short acquisition time comes at the expense of spatial resolution, the resolution of magnetic resonance images can be increased using post-processing methods. In this work, we present one such method designed for cardiac magnetic resonance movies. Our method uses diffeomorphic deformable image registration to capture the motion of the heart, and an additional term to account for changes in pixel intensity. We demonstrate that our method has the potential to reconstruct high-resolution cardiac magnetic resonance movies from very low-resolution movies, using only a single high-resolution frame.

TP3a-2 1:55 PM

Whole Brain Reconstruction from Multilayered Sections of a Mouse Model of Status Epilepticus

Haoyi Liang, Natalia Dabrowska, Jaideep Kapur, Daniel Weller, University of Virginia, United States

This research concerns two-photon fluorescence microscopy imaging of the whole brain of C57BL/6 mice with single-cell resolution. These brains are too large for specimen holders in available 3D microscopes, so this research develops a set of volume reconstruction methods to reproduce a whole brain from multilayered, thin sections of the brain imaged using a confocal microscope. As the sections are in solution during imaging, their shapes warp differently, and their structures no longer align. The proposed two-stage reconstruction procedure consists of single-section correction and section-to-section alignment, towards producing a whole brain volume. In the first stage, the proposed method carefully unwarps the distorted shapes of each section. The second stage aligns prominent features between the layers of neighboring sections. This paper also newly considers how

these stages influence each other in the broader context of whole brain volume reconstruction. Experimental results portraying each stage with real image data suggest that the proposed approach can produce consistent 3D volumes and largely correct the observed distortions.

TP3a-3 2:20 PM

Improved Efficiency for Microstructure Imaging using High-Dimensional MR Correlation Spectroscopic Imaging

Daeun Kim, Justin Haldar, University of Southern California, United States

Magnetic Resonance Correlation Spectroscopic Imaging (MR-CSI) is a high-dimensional data acquisition/modeling approach for studying microstructure. MR-CSI uses imaging data that is simultaneously encoded with multiple MR contrast mechanisms (e.g., diffusion and relaxation), and applies a spatial-spectral reconstruction framework to estimate a spectroscopic image with a unique high-dimensional correlation spectrum for every spatial location. While MR-CSI enables powerful new capabilities for spatially mapping sub-voxel microstructural compartments, the contrast encoding is slow due to the curse of dimensionality. This paper reviews MR-CSI and investigates principled estimation theoretic approaches for more efficient experiment design.

TP3a-4 2:45 PM

Multi-Dimensional Flow MRI for Single Sequence Pediatric Exams

Joseph Cheng, Marcus T. Alley, Stanford University, United States; Michael Lustig, University of California, Berkeley, United States; John M. Pauly, Shreyas S. Vasanawala, Stanford University, United States

The cardiac and respiratory systems have most commonly been evaluated separately through multiple exams: CT or MRI for the cardiac system and nuclear scintigraphy for the respiratory system. However, diseases of one system will eventually impact the other; thus, a more comprehensive imaging exam is ideal for proper patient management. Here, we propose to extend velocity MRI to higher-order tensor space that may include cardiac motion, respiratory motion, temporal dynamics and volumetric spatial. Such a sequence is enabled through advancements in motion monitoring with intrinsic MR navigators, pseudo-random data sampling, and compressed-sensing-based image reconstructions. We explore the feasibility of such an approach in pediatric patients with congenital heart defects.

Track C – Networks

Session: TP3b – Networks of the Brain

Chair: ***Georgios Giannakis,*** *University of Minnesota*

TP3b-1 3:30 PM

Graph Slepians to Probe Into Large-Scale Network Organization of Resting-State Functional Connectivity

Maria Giulia Preti, Dimitri Van De Ville, Ecole Polytechnique Fédérale de Lausanne and University of Geneva, Switzerland

Functional magnetic resonance imaging (fMRI) is providing large amounts of data about brain function. Spontaneous fluctuations of activity measured using resting-state fMRI have intrigued neuroscientists for more than a decade now, as correlations between spatially distant regions reveal large-scale network organization. One common approach in functional connectivity analysis is to build a brain graph where nodes are spatial positions in the brain and edge weights are given by pairwise correlations between the associated time courses measured during resting state. In this work, we propose to apply a new approach from graph signal processing to these functional connectomes, where we build upon the novel concept of graph Slepian signals. These signals are band-limited (i.e., they are built from graph Laplacian eigenvectors with low eigenvalues) with maximal energy concentration in a predefined subgraph. In particular, we apply this methodology to probe into the organization of the posterior medial cortex (PMC), an important hub of the brain. We find that at a critical bandwidth, the PMC is showing specific subdivisions that interact differently with large-scale networks. Therefore, the proposed method can direct the analysis to specific parts of the network and bring to light interactions between local and global aspects of network organization.

TP3b-2 3:55 PM

Robust Tensor Decomposition of Resting Brain Networks in Stereotactic EEG

Jian Li, University of Southern California, United States; John Mosher, Dileep Nair, Jorge Gonzalez-Martinez, Cleveland Clinic, United States; Richard Leahy, University of Southern California, United States

Stereotactically implanted EEG (SEEG) in epileptic patients provides a unique insight into spontaneous human brain activity. We describe a Robust Sequential Canonical Polyadic Decomposition (RSCPD) algorithm that can simultaneously identify brain networks between large (100-200) numbers of implanted SEEG electrodes. Our approach uses a combination of smoothness, sparsity and positivity constraints to sequentially and robustly identify tensor models of successively higher order. We demonstrate consistency of the resulting networks across time and subjects and compare connectivity patterns with those obtained with resting functional MRI.

TP3b-3 4:20 PM

Multiscale network analysis through tail-greedy bottom-up approximation, with applications in neuroscience

Piotr Fryzlewicz, London School of Economics, United Kingdom; Xinyu Kang, Boston University, United States; Catherine Chu, Massachusetts General Hospital, United States; Mark Kramer, Eric D. Kolaczyk, Boston University, United States

We will discuss a novel method to model non-stationary multivariate time series using dynamic causal networks. This newly proposed method combines traditional multi-scale modeling and network based neighborhood selection, aiming at capturing the temporally local structure of the data while maintaining the sparsity of the potential network interactions. Our multi-scale framework is based on recursive dyadic partitioning, which recursively splits the temporal axis into finer intervals and allows us to detect local network structural changes at varying temporal resolutions. The dynamic neighborhood selection is achieved through penalized likelihood estimation, where the penalty seeks to limit the number of neighbors used to model the data. We present theoretical and numerical results describing the performance of our method, including an application to task-based MEG data.

TP3b-4 4:45 PM

Multi-kernel Change Detection for Dynamic Functional Connectivity Graphs

Georgios Vasileios Karanikolas, University of Minnesota, United States; Olaf Sporns, Indiana University, United States; Georgios B. Giannakis, University of Minnesota, United States

Dynamic functional connectivity (dFC) analyses of fMRI time-courses typically rely on sliding-window based schemes, which inherently confine analysis to a single time-scale, and also do not generally lend themselves to accurate change-time estimation of the underlying dynamically evolving graph topology. Change-point detection methods offer the potential to overcome both limitations. However, the approaches employed so far in the dFC context are limited to detecting changes in the linear relationships among time-courses corresponding to brain regions. The present work introduces a novel multi-kernel change-point detection approach with the goal of capturing changes in the generally nonlinear relationships among time-courses, and thus in the topologies of the corresponding FC graphs. The approach is tested on both synthetic and real resting-state fMRI data.

Track D – Signal Processing and Adaptive Systems

Session: TP4a – Crowdsourcing

Co-Chairs: ***Lav Varshney,*** *University of Illinois Urbana-Champaign* ***and Mark Hasegawa-Johnson,*** *University of Illinois Urbana-Champaign*

TP4a-1 1:30 PM

Permutation-based Models for Crowdsourcing: Optimal Estimation and Robustness

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

The aggregation and denoising of crowd-labeled data has gained increased significance with the advent of crowdsourcing platforms and requirements of massive labeled datasets. We propose a permutation-based model for crowd-labeled data that is a significant generalization of the popular "Dawid-Skene" model. Working in a high-dimensional non-asymptotic framework, we derive optimal rates of convergence for the permutation-based model. We show that the permutation-based model offers significant robustness in estimation due to its richness, while surprisingly incurring only a small statistical penalty as compared to the Dawid-Skene model. Finally, we propose a polynomial-time computable algorithm, called OBI-WAN, for provably efficient estimation.

TP4a-2 1:55 PM

Incentive Design in Crowdsourcing with Strategic Agents

Donya Ghavidel Dobhakhshari, Kewei Chen, University of Notre Dame, United States; Lav Varshney, University of Illinois at Urbana-Champaign, United States; Yih-Fang Huang, Vijay Gupta, University of Notre Dame, United States

Crowdsourcing for various applications has both a vast literature and several practical implementations by now. We consider a few case studies to understand design of incentives for crowdsourcing when agents are strategic and possibly malicious. We design suitable mechanisms for these examples and point out open questions for future work.

TP4a-3 2:20 PM

Mismatched Crowdsourcing: Mining Latent Skills to Acquire Speech Transcriptions

Mark Hasegawa-Johnson, University of Illinois at Urbana-Champaign, United States; Preethi Jyothi, Indian Institute of Technology Bombay, United States; Wenda Chen, University of Illinois at Urbana-Champaign, United States; Van Hai-Do, Advanced Digital Sciences Center, Singapore

Automatic speech recognition (ASR) converts audio to text. ASR is usually trained using a large quantity of labeled data, i.e., audio with transcriptions. In many resource-constrained languages, however, transcriptions are hard to find, e.g., languages such as Hokkien and Dinka. Fortunately, speech in every language is produced by human mouths, and designed to be interpreted by human ears. Speakers of a majority language (English, say, or Mandarin Chinese) are therefore able to make some sense of even the strangest language (Zulu, say, or Cantonese): language-unique distinctions are mostly lost, but universal distinctions such as consonant versus vowel are, for the most part, correctly transmitted. We can decode such mismatched transcripts using an information-theoretic decoder, resulting in a low-entropy probability distribution over the possible native-language transcriptions. Mismatched transcripts can be used to train ASR. Combining ten hours of mismatched transcripts with 12-48 minutes of native transcripts, if available, results in lower phone error rate. On the other hand, if we don't even know the native phoneme inventory, mismatched transcripts in two or more annotation languages can be used to infer the native phoneme inventory (with entropy depending on the distinctive feature inventory of the annotation languages).

TP4a-4 2:45 PM

Crowdsourced Clustering via Triangle Queries

Ramya Korlakai Vinayak, Babak Hassibi, California Institute of Technology, United States

We consider the task of clustering unlabeled items using answers from non-expert crowd workers. Workers are often not able to label the items directly, however, they can compare them and judge whether they are of the same category. As the workers are not experts, the answers obtained are noisy. It is crucial to design queries that can reduce the noise levels in the responses. We compare two types of random queries: edge queries, where a pair of items is revealed, and triangle queries, where a triple is. Under natural modeling assumptions, we show that the triangle queries provide more reliable data. We complement our theoretical results with experiments on real datasets on Amazon Mechanical Turk. Our experiments suggest that the triangle queries not only provide more reliable edges but also reveal many more of them for a fixed budget. We also provide a sufficient condition on the number of observations, edge densities inside and outside the clusters and the minimum cluster size required for the exact recovery of the true adjacency matrix via triangle queries using a convex optimization-based clustering algorithm.

Track D – Signal Processing and Adaptive Systems

Session: TP4b – Adaptive Signal Processing I

Chair: ***Peter Tuuk,*** *Georgia Institute of Technology*

TP4b-1 3:30 PM

Using Random Matrix Theory to Improve Radar Space-Time Adaptive Processing

Peter Tuuk, James McClellan, Georgia Institute of Technology, United States

Space-time adaptive radar processing finds widespread use filtering clutter and other structured interference to detect targets. One key challenge in this approach is estimating the interference statistics. Two techniques regularly used to improve the estimate are diagonal loading and rank reduction. But the optimal diagonal loading weights and rank reduction vary by application and some values can result in poor performance. This work identifies relevant results in random matrix theory related to Wishart matrix eigenspectra, applies them to the adaptive filter context, and develops criteria for selecting filtering parameters.

TP4b-2 **3:55 PM**

Reliable Conjugate Gradient Method with applications in Adaptive Filtering and Machine Learning

Chandrasekhar Radhakrishnan, Andrew Singer, University of Illinois at Urbana-Champaign, United States

Reliable execution of optimization algorithms is an essential requirement in both digital signal processing (DSP) and machine learning applications. DSP systems designed using nanoscale process technologies are susceptible to transient errors. These errors can considerably slow down the convergence speed of the chosen algorithm. Distributed and Federated learning strategies have been proposed in machine learning to leverage the computational power of independent devices. In such a scenario, incorrect parameter updates from independent nodes can have significant impact on global learning. In this work we explore the behavior of Conjugate Gradient algorithm under stochastic computational errors. The expanding subspace property and the orthogonality of the gradient and direction vectors is exploited to develop a robust conjugate gradient based method with applications in adaptive filtering and machine learning.

TP4b-3 **4:20 PM**

Invariance and the Bayesian Approach to Generalized Coherence Tests

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

This paper considers the problem of testing for mutual independence of multiple sets of complex Gaussian vectors. This problem has classical roots in statistics and has been of recent interest in the signal processing literature in connection with multi-channel signal detection. The probability distribution of the maximal invariants, under the action of a subgroup of the full invariance group of the problem, is derived for both hypotheses. It is shown that for the parameter space, the maximal invariants under the action of this subgroup form a compact space on which proper non-informative prior distributions can be constructed. Bayesian likelihood ratios for the maximal invariants are derived for various proper prior distributions. Previously, Bayesian likelihood ratios associated with non-informative prior distributions for this problem could only be constructed through considerably less satisfactory limiting techniques.

TP4b-4 **4:45 PM**

Hilbert Space Geometry of Quadratic Covariance Bounds

Stephen Howard, Defense Science and Technology Group, Australia; William Moran, Royal Melbourne Institute of Technology, Australia; Pooria Pakrooh, Louis Scharf, Colorado State University, United States

In this paper, we study the geometry of quadratic covariance bounds on the estimation error covariance, in a properly defined Hilbert space of random variables. We show that a lower bound on the error covariance may be represented by the Grammian of the error score after projection onto the space orthogonal to the subspace spanned by the measurement scores. The Grammian is defined with respect to inner products in a Hilbert space of second order random variables. This geometric result holds for a large class of quadratic covariance bounds including the Barankin, Cram´er-Rao, and Bhattacharyya bounds, where each bound is characterized by its corresponding measurement scores. In two examples, we show that for complex multivariate normal measurements with parameterized mean or covariance, there exist well-known Euclidean space geometries for the general Hilbert space geometry derived in this paper.

Track E – Array Signal Processing

Session: TP5a – Array Processing for Spectrum Sharing

Chair: ***Yimin D. Zhang,*** *Temple University*

TP5a-1 **1:30 PM**

Spectrum Sharing Between Radar and Communication systems: Can The Privacy Of the Radar Be Preserved?

Bo Li, Shunqiao Sun, Rutgers, The State University of New Jersey, United States; Matthew Clark, Konstantinos Psounis, University of Southern California, United States; Athina Petropulu, Rutgers, The State University of New Jersey, United States

Cooperative spectrum sharing between a radar and a communication system requires the collection by a controller of channel state information (CSI) from both the radar system and the communication systems. The controller collects CSI, solves an optimization problem and then distributes signaling information (e.g., precoders) back to the radar and communication systems. In this work, we consider the scenario in which an adversary may get access to the communication system, by, for example, hacking into a user equipment (UE), e.g. a smartphone, and attempt to reverse engineer the spectrum sharing system to get information about the radar CSI. This paper addresses operational security/privacy challenges, and focuses on a scenario in which

the adversary seeks to learn information about the radar without being detected. At every time slot, the adversary will observe the assignments that the controller decides for the communication system, e.g. precoders. After several assignment observations, the adversary can estimate the probability that any arbitrary candidate sequence of the radar CSI corresponds to the true CSI sequence as a standard Bayesian inference problem. The closeness of the adversary estimates to the ground truth will be a measure of the degree of privacy of the radar.

TP5a-2 1:55 PM

Interference Alignment based Precoder-Decoder Design for Radar-Communication Co-Existence

Yuanhao Cui, Aalto University and Beijing University of Posts and Telecommunications, Finland; Visa Koivunen, Aalto University, Finland; Xiaojun Jing, Beijing University of Posts and Telecommunications, China

Co-existence of radar and communications systems is needed to facilitate new wireless systems and services due to shortage of useful radio spectrum. Moreover, changes in spectrum regulation will be introduced in which different radio systems need to share the spectrum. For example LTE, Wi-Fi and 5G systems will have to share spectrum with S-band radars. Managing interferences is a key task in co-existence scenarios. Cognitive Radar and Radio technologies facilitate using the spectrum in a flexible manner and sharing channel awareness between the two subsystems. In this paper we propose a joint Precoder-Decoder design for co-existing radar and communication systems. Multiantenna transceiver structures are assumed. Max-SINR criterion and Interference Alignment (IA) constraints are employed in finding the optimal Precoder and Decoder. Our simulation studies demonstrate that the interference can be practically fully cancelled in both the communication and radar system. This leads to better detection performance in radar and higher rate in communication subsystem. Significant performance gains over subspace-based Precoder design are obtained as well.

TP5a-3 2:20 PM

Multiple-Antenna Multiple-Access Joint Radar and Communications Systems Performance Bounds

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

We investigate joint radar-communications convergence for multiple-antenna radar and communications systems and develop novel radar-communications sharing schemes in the spatial domain. In this paper, we develop a multiple-antenna in-band radar and communications system model and provide a set of multiple-access performance bounds, which can be used as a system design tool based on a novel parameterization of the radar system performance. Time domain and spatial domain approaches are proposed, and the resulting joint system performance bounds are compared and analysed. Throughout the formulation of these performance bounds, we consider the angle and range as target parameters of interest. We utilize the radar estimation rate and data information rate to measure radar and communications system performance respectively.

TP5a-4 2:45 PM

Robust Astronomical Imaging under Coexistence with Wireless Communications

Shuimei Zhang, Yujie Gu, Ben Wang, Yimin D. Zhang, Temple University, United States

Radio astronomy provides many benefits to the society in exploring, understanding, and explaining the origin and nature of life in the universe. Astronomical signals are extremely weak and vulnerable to radio frequency interference (RFI). To protect astronomical signals from RFI with the consideration of the fact that the frequencies used to measure many space parameters are dictated by the physical processes and cannot be chosen arbitrarily, certain frequency bands are protected by international agreements for exclusive use of radio astronomy. To meet the increasing demand for spectrum resources, however, development of spectrum-sharing and interference-immune radio astronomical technologies become very important and emerging. In this work, we develop robust astronomical imaging techniques in the presence of wireless communication signals, bearing in mind of many particularities involved in radio astronomy that differ from terrestrial communication and radar applications. Our particular focus is the effective mitigation of the sidelobe interference from nearby downlink wireless signals through robust beamforming. The proposed techniques utilize the shared structure of spatial interference covariance matrix during the Earth's rotation and, at the same time, account for various perturbations factors arising from imperfect calibration of the mainlobe and sidelobe antenna patterns and propagation channel distortions.

Session: TP5b – Sparsity and Structure in Human Bio-Imaging

Chair: ***Bhaskar D. Rao,*** *University of California, San Diego*

TP5b-1 3:30 PM

Using Spatial Sparsity in Electrophysiological Source Localization

Zeynep Akalin Acar, Scott Makeig, University of California, San Diego, United States

In this study, we used a Sparse, Compact, Smooth (SCS) source localization method (Cao et al., 2012; Akalin Acar et al., 2016) and we compared patch-based Sparse Bayesian Learning (Akalin Acar et al., 2009) and Sparse, Compact, Smooth (SCS) (Cao et al., 2012) source localization methods for cortical distributed source localization to estimate simulated and actual distributed cortical source areas returned by independent component analysis (ICA) decomposition of high-density scalp EEG data (Makeig et al., 1996, 2002). Both methods give compact, high-resolution source distribution estimates. Likely because of the additional compactness and smoothness constraints, SCS returned better fitting and more realistic estimates.

TP5b-2 3:55 PM

MEG Spatio-temporal L1 Minimum-norm Source Images as Potential Biomarkers for Mild Traumatic Brain Injury and Post-traumatic Stress Disorder

Mingxiong Huang, Ashley Robb-Swan, Annemarie Angeles-Quinto, Sharon Nichols, Dewleen Baker, Deborah Harrington, Charles Huang, Roland Lee, University of California, San Diego, United States

Mild traumatic brain injury (mTBI) is a leading cause of physical, cognitive, and emotional deficits in military members and the general public. MTBI also substantially increases the risk of post-traumatic stress disorder (PTSD). The pathophysiology of mTBI is not completely understood, and the neuronal mechanisms by which mTBI enhances the likelihood of PTSD even less clear. A series of studies from our lab cover resting-state magnetoencephalography (rs-MEG) research of mTBI and PTSD using spatio-temporal minimum L1-norm source images. Main findings are: 1) MEG slow-wave (delta-band, 1-4Hz) L1-norm source magnitude imaging provides mTBI diagnosis on a single-subject basis, with new findings about the neurophysiology of slow-wave generation. 2) Resting-state MEG L1-norm functional connectivity measures reveal abnormality in individuals with mTBI. 3) In individuals with PTSD, MEG L1-norm source imaging identifies neural oscillatory dysfunction in emotion processing neurocircuitry (i.e., amygdala, ventro-medial prefrontal cortex (vmPFC), and hippocampus), with rs-MEG results consistent with resting-state fMRI default mode network findings in PTSD. 4) New evidences of using rs-MEG L1-norm source imaging and behavioral measures for assessing transcranial electrical stimulation as an effective treatment for mTBI. Overall, this presentation highlights rs-MEG Spatio-temporal minimum L1-norm source imaging as a potential imaging marker for mTBI and PTSD.

TP5b-3 4:20 PM

Sampling theorems for Three Dimensional Zero Time of Echo (ZTE) Magnetic Resonance Imaging

Ali Koochakzadeh, Piya Pal, Eric Ahrens, University of California, San Diego, United States

Many Magnetic Resonance Imaging (MRI) applications demand an ultra short time of echo, as the subjects can have significantly small transverse relaxation (T2) times. In recent times, ZTE/UTE techniques have been proposed as solutions to these imaging applications. In ZTE, the read-out gradient and radio-frequency excitation pulses are simultaneously activated, resulting in center-out 3D radial trajectories. Despite promising experimental results in applications such as bone, teeth and lung imaging, a mathematical analysis of 3D radial sampling is not available in the literature. In this paper, we provide closed form expressions characterizing the aliasing caused by such samplers. We also propose an explicit interpolation formula for image reconstruction.

TP5b-4 4:45 PM

SPECT Image Reconstruction under Imaging Time Constraints

Igor Fedorov, Sebastian Obrzut, Bongyong Song, Bhaskar Rao, University of California, San Diego, United States

In this paper, we review single-photon emission computed tomography (SPECT) and the role of sparsity in image reconstruction. SPECT imaging involves injecting a patient with a radioactive pharmaceutical and then measuring the emitted radiation using a rotating camera system. The imaging task reduces to a linear inverse problem, i.e. inferring the radio-pharmaceutical density within the patient's body from a limited number of compressive measurements. The difficulty of the inverse problem hinges on the number of photon counts detected by the camera system, which is directly proportional to the imaging time. We aim to review effective solutions for reducing the imaging time by imposing various signal priors as well as how to estimate regularization parameters of interest. In addition, we propose a class of novel sparsity promoting priors on the image variation and detail an evidence maximization framework for performing inference in this regime.

Track F – Biomedical Signal and Image Processing

Session: TP6a – Biomedical Signal Processing and Information Extraction

Co-Chairs: ***Antonia Papandreou-Suppappola,*** *Arizona State University* ***and Francisco Solis,*** *Arizona State University*

TP6a-1 1:30 PM

Brain Language: Uncovering Functional Connectivity Codes

Victor Vergara, Vince Calhoun, The Mind Research Network, United States

The functional connectivity within a specific set of brain networks (or domain) can assume different configurations known as domain states that change with time. Recently, we proposed an information theoretical framework that models the finite set of domain states as elements of an alphabet. Significant bits of information were found to be shared among domains, but specific domain codification was not explored. This work describes a method to identify code words used to transmit and receive information between the cerebrum and the cerebellum based on dynamic domain connectivity estimated from functional magnetic resonance imaging (fMRI). Following the theory of jointly typical sets, the developed method identifies the codeword length and the specific combination of domain states on each codeword. Resting state fMRI data was taken from 121 subjects with no significant age difference between males and females. Group independent component analysis was utilized to identify important brain networks and group them in a cerebellum and six other domains representing the cerebrum. The amount information between the cerebellum, the executive control and sensorimotor domains showed a statistically significant number of bits. Proposed method uncovered specific code words, temporal sequences of domain states, behind the bits shared between cerebellum and cerebrum.

TP6a-2 1:55 PM

Predicting Postoperative Delirium in Patients Undergoing Deep Hypothermia Circulatory Arrest

Owen Ma, Arindam Dutta, Arizona State University, United States; Amy Crepeau, Mayo Clinic, United States; Daniel Bliss, Arizona State University, United States

Cardiac surgeries involving deep hypothermia circulatory arrest present a risk of cognitive impairment. This study attempts to uncover biomarkers within intraoperative electroencephalogram (EEG) signals that may be predictive of postoperative delirium, which is associated with long term health complications. We analyze EEG data recorded from 16 patients while undergoing such surgeries using spatiotemporal eigenspectra, and predict results of delirium assessments performed by intensive care unit nurses. Artifact detection and normalization schemes are developed to facilitate this. At most 14 cases were correctly predicted with a p-value of 0.0015. An area under the receiver operating characteristics (ROC) curve of 0.8364 was achieved--0.9091 when considering the convex hull.

TP6a-3 2:20 PM

Understanding Fetal Heart Rate Series by Hidden Markov Models and Nonparametric Bayesian Theory

Kezi Yu, J. Gerald Quirk, Petar Djuric, Stony Brook University, United States

Fetal heart rate (FHR) signals are routinely monitored for assessing fetal status by obstetricians in most hospitals. There are guidelines for visual inspections of FHR signals, but their implementation is prone to subjectivity and inaccurate interpretation. This has motivated research in their computerized analysis. In this paper, we propose to process FHR signals by hidden Markov models (HMMs) and to associate their hidden states with patterns of the signals. Furthermore, we propose to employ a nonparametric Bayesian approach in the processing. With the approach, we do not define the number of hidden states beforehand, but instead we let the data determine the most appropriate number of states. Our nonparametric HMM resolves the issue of creating redundant states and rapid switching rate of basic nonparametric models. In our work, we aim at capturing different hidden states, as well as different state switching patterns between FHR signals labeled as healthy and unhealthy. Our goal is to find the states that indicate pathological FHR patterns. We demonstrate the performance of our method on real data FHR signals.

TP6a-4 2:45 PM

Multiple Interface Brain and Head Models for EEG: A Surface Charge Approach

Francisco J. Solis, Antonia Papandreou-Suppappola, Arizona State University, United States

Analysis of electroencephalographic (EEG) studies can be carried out using forward methods where the scalp potential is first determined for given localized dipolar sources. The recently introduced surface charge method (SCM) can be used to solve the forward problem by means of integral equations where the accumulated charge at the boundaries between homogeneous

regions is taken as the basic variable. These equations can be efficiently solved without the deflation steps required in alternative approaches. We demonstrate the application of the SCM to the case of realistic head shapes with multiple homogenous regions and discuss the use of these results to source tracking problems.

Track G – Architecture and Implementation

Session: TP6b – Asynchronous and Neural Computing

Chair: ***Rajit Manohar,*** *Yale University*

TP6b-1 3:30 PM

How to Think About Asynchronous Computing

Marly Roncken, Ivan Sutherland, Portland State University, United States

Most people imagine that entire computing devices pass instantly from one state to another. This "finite state machine" model is the basis of nearly every existing digital system. A "clock" signal aligns all actions in time much as the beat of a drum keeps marching soldiers in step. This "clocked" or "synchronous" design paradigm is ubiquitous in today's computer industry. What alternative can we offer? At the Asynchronous Research Center of Portland State University we use a "Link and Joint" alternative paradigm. Our paradigm gives equal importance to communication and computation. Our Links connect actions distributed over space in our Joints. A system is a directed graph of Joints connected by Links. A Link stores a data item and transports it over distance from input to output. A Joint acts when it has FULL input Links and EMPTY output Links and it computes, draining input Links and filling output Links. A global clock is unnecessary because the local FULL and EMPTY states of Links suffice to sequence Joint actions. External control of the actions of each Joint and of the states of each Link offers at-speed test methods superior to any now in use for either synchronous or self-timed systems.

TP6b-2 3:55 PM

The Benefits and Pitfalls of Asynchrony in Computer Systems

Rajit Manohar, Yale University, United States

Large-scale computer systems designed using the synchronous paradigm expend enormous effort to ensure that the entire system behaves as a single finite state machine. Asynchronous computing provides an alternative, decentralized approach to system design. This talk highlights the differences between the two approaches, providing case studies that illustrate the benefits as well as the drawbacks of adopting an asynchronous design approach.

TP6b-3 4:20 PM

Digital Signal Processing in the Continuous-Time Domain Using Asynchronous Techniques

Yu Chen, Yannis Tsividis, Columbia University, United States

Conventional digital signal processors are all clock based. According to the Nyquist sampling theorem, the system has to operate at a clock rate that is determined by the maximum input frequency. On the other hand, input signals in many applications are often sporadic and exhibit timing-varying activities; this is the case, for example, with speech signals, and electrocardiogram (ECG) signals. If a constant clock rate determined by the highest input frequency component has to be used all the time, substantial amount of power is wasted when the input changes slowly or is constant. In this talk, we review continuous-time digital signal processors (CT-DSP), whose power consumption can closely track the input activity. We will discuss two major subsystems: continuous-time data converters and continuous-time digital signal processors, followed by several design examples. The implementations of CT DSPs in integrated circuit form will also be briefly discussed.

TP6b-4 4:45 PM

Neuromorphic Event-Driven Multi-Scale Synaptic Connectivity and Plasticity

Gert Cauwenberghs, University of California, San Diego, United States

Neural computation and communication in the brain are partitioned into the grey matter of dense local synaptic connectivity in tightly knit neuronal networks, and the white matter of sparse long-range connectivity over axonal fiber bundles across distant brain regions. This exquisite distributed multiscale organization provides inspiration to the design of scalable neuromorphic systems for deep learning and inference, with hierarchical address event-routing of neural spike events and multiscale synaptic connectivity and plasticity, and their efficient implementation in low-power mixed-signal VLSI circuits.

TP6b-5 5:10 PM

Efficient Online Learning with Low-Precision Synaptic Variables

Marcus K. Benna, Stefano Fusi, Columbia University, United States

In the biological brain, synaptic memory consolidation following one-shot learning relies on a complex network of highly diverse biochemical processes. Here we construct a broad class of steady-state synaptic models with tightly bounded dynamical variables that can store and preserve a large number of memories, which grows almost linearly with the number of synapses. This constitutes a substantial improvement over the square root scaling of previous models, especially when large neural systems are considered. In addition, the initial memory strength is also high in these models, and scales approximately like the square root of the number of synapses. These favorable properties are achieved by combining together multiple dynamical processes that operate on different timescales, to ensure the memory strength decays as slowly as the inverse square root of the age of the corresponding synaptic modification. This decay curve implements an optimal compromise between large memory strengths and long lifetimes. Memories are initially stored in fast variables and then progressively transferred to slower ones. Importantly, the interactions between fast and slow variables are bidirectional. Each synapse only requires a small number of variables that can have very limited precision. We discuss efficient implementations using binary switches suitable for neuromorphic hardware.

Track G – Architecture and Implementation

Session: TP7a – Computer Architecture

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

TP7a-1 1:30 PM

Performance Comparison of AES-GCM-SIV and AES-GCM Algorithms for Authenticated Encryption on FPGA Platforms

Sandhya Koteshwara, University of Minnesota, United States; Amitabh Das, Intel Corporation, United States; Keshab K. Parhi, University of Minnesota, United States

Authenticated encryption schemes achieve both authentication and encryption in one algorithm and are a must for ensuring security of devices today. In this regard, we investigate architectures for a recently proposed algorithm, AES-GCM-SIV, which achieves complete nonce-misuse resistance. We present detailed architectures for AES-GCM-SIV and contrast with that of an existing standard, AES-GCM. We use modern FPGA platforms for our implementation and discuss the hardware performance in terms of area, throughput, power and energy. Proposed optimizations are implemented and compared with unoptimized architectures. Our observations show that AES-GCM-SIV is able to achieve around 95% of the performance of AES-GCM in terms of throughput while consuming only around 4% more area in terms of LUT count and energy per bit. For this added overhead, it provides better security in terms of nonce misuse resistance and greater flexibility with respect to reusability of main components of AES-GCM. To the best of our knowledge, this is the first paper which discusses a hardware implementation of AES-GCM-SIV.

TP7a-2 1:55 PM

An Efficient Reconfigurable Hardware Accelerator for Convolutional Neural Networks

Anaam Ansari, Kiran Gunnam, Tokunbo Ogunfunmi, Santa Clara University, United States

Convolutional Neural Networks (CNN) have proven to be very effective in image and speech recognition. The increasing usage of such applications in mobile devices and data centers have led the researchers to explore application specific hardware accelerators for CNN. However, most of these approaches are limited to specific networks such as AlexNet. We propose a truly reconfigurable network-agnostic architecture that supports various computational-intensive networks such as AlexNet, GoogleNet, Microsoft's ResidualNet in a fast and power efficient way. The technique described in this paper aims at developing a reconfigurable accelerator that uses basic processing elements (PE) as building blocks of its computational engine. In our design, we control the configuration of each layer using a switching control logic and a Benes network. In addition to supporting all the various CNN architectures, our design has 5% improvement in execution time for AlexNet compared to the state-of- the-art architecture that only supports AlexNet. We expect that the savings in execution time on our proposed hardware architecture for CNNs other than AlexNet would be 20% or more.

TP7a-3 2:20 PM

A Low-Power Digital ASIC for Detecting Heart-rate and Missing Beat

Sepideh Nouri, Behnaam Aazhang, Rice University, United States; Mehdi Razavi, Texas Heart Institute, United States; Joseph Cavallaro, Rice University, United States

This paper presents a low power Application Specific Integrated Circuit (ASIC) to detect the heart-rate and missing beats. This design is implemented without using any computationally intensive operation. This approach has resulted in a total power consumption of 318nW for the entire circuit at a clock frequency of 1KHz and a supply voltage of 5V. The ASIC occupies an area of 785µm by 744µm and is implemented in a 0.5µm AMI technology. The low power consumption of the ASIC and its small size make it possible to utilize it on an implantable pacemaker chip that can be powered wirelessly with electromagnetic waves.

TP7a-4 2:45 PM

An Effective Hardware Implementation of 1024-point Convolution Based on the Fast Hirschman Transform

Linda S. DeBrunner, Dingli Xue, Florida State University, United States

In this work, we present a general structure for the Fast Hirschman Transform (FHT) that is suitable for implementation using Field Programmable Gate Arrays or ASICs. A general hardware implementation of convolution based on the Hirschman Optimal Transform (HOT) is proposed. The FHT is superior to the FFT in terms of computational complexity, latency and area requirements. We explore the implementation requirements and tradeoffs for larger transforms, which face some unique implementation issues. We determine throughput, accuracy, Mean Square Area (MSE) and area requirements for Field Programmable Gate Arrays and explore some of the tradeoffs between these measures. The FHT is particularly well-suited to implementations of convolution, compressive sensing, and Orthogonal Frequency Division Multiplexing (OFDM).

Track H – Speech, Image and Video Processing

Session: TP7b – Optimization Methods for Image Processing

Chair: ***Thomas Goldstein,*** *University of Maryland*

TP7b-1 3:30 PM

Approximate Semidefinite Programming Methods for Image Reconstruction and Segmentation.

Tom Goldstein, University of Maryland, United States; Christoph Studer, Cornell University, United States

Many imaging applications require the solution of non-convex optimization problems that can be convexified by “lifting” methods. Such methods enable global optimization without getting trapped at local minimizers, but they also square the dimensionality of the problem. We present low-complexity alternatives to lifting that handle extremely large problems efficiently. We consider two approaches. First, we discuss bi-convex methods as a low-complexity alternative to fully convex semidefinite programs. Second, we consider a new method, called PhaseMax, that convexifies certain problems without lifting.

TP7b-2 3:55 PM

BranchHull: Convex Bilinear Inversion from the Entrywise Product of Signals with Known Signs

Alireza Aghasi, IBM, United States; Ali Ahmed, Information Technology University, Pakistan; Paul Hand, Rice University, United States

We consider the bilinear inverse problem of recovering two vectors, x and w, in RL from their en- trywise product. For the case where the vectors have known signs and belong to known subspaces, we introduce the convex program BranchHull, which is posed in the natural parameter space and does not require an approximate solution or initialization in order to be stated or solved. Under the structural assumptions that x and w are the members of known K and N dimensional ran- dom subspaces, we prove that BranchHull recovers x and w up to the inherent scaling ambiguity with high probability whenever L >> K + N . This program is motivated by sweep-distortion removal, blind deconvolution and self-calibration.

TP7b-3 4:20 PM

Computational Microscopy

Laura Waller, University of California, Berkeley, United States

Computational imaging involves the joint design of imaging system hardware and software, optimizing across the entire pipeline from acquisition to reconstruction. This talk will describe new methods for computational microscopy with coded illumination, based on a simple and inexpensive hardware modification of a commercial microscope, combined with advanced image reconstruction algorithms. In conventional microscopes and cameras, one must trade off field-of-view and resolution. Our methods allow both simultaneously by using multiple images, resulting in Gigapixel-scale reconstructions with resolution beyond the diffraction limit of the system. Our algorithms are based on large-scale nonlinear non-convex optimization procedures for phase retrieval, with appropriate priors.

TP7b-4 4:45 PM

Information, Invariance and Generalization in Deep Representation Learning

Alessandro Achille, Stefano Soatto, University of California, Los Angeles, United States

We describe an information-theoretic approach to modeling and learning representations. Starting from desirable properties of representations (sufficiency, or informational equivalence to the training set; minimality; invariance to nuisance factors affecting the test set) we show how an optimal representation can be determined by minimizing the Information Bottleneck Lagrangian. We then show that there is a connection between minimal sufficiency of the representation of the training set (encoded in the weights of a deep network) and invariance of the representation of the test datum (encoded in the activations). The framework allows predicting the information content to be stored in the weight to avoid overfitting, and empirical evaluation matches the prediction surprisingly well, suggesting that the bounds are tight. In the case of random data, there is a phase transition between underfitting and overfitting that is predicted by the framework. We also show connections to optimization and regularization, including computing the information content of a local minimum, and relation to the generalization abilities of so-called 'flat minima', or lack thereof. To the best of our knowledge, this is the first work to connect representation issues (invariance, sufficiency, minimality) to optimization (regularization) in an information framework.

TP7b-5 5:10 PM

Efficient Convex Optimization for Low-Rank Matrix Recovery

Michael Friedlander, University of British Columbia, Canada

Convex formulations of phase retrieval and blind deconvolution give rise to large spectral optimization problems with strong statistical guarantees for correctly reconstructing certain signals. A significant criticism leveled at these relaxation approaches is that they lead to problems that are too difficult to be useful in practice. However, carefully constructed dual approaches lead to remarkably efficient algorithms that can be as efficient as nonconvex recovery algorithms, and have the benefit of greater stability. I will describe this dual approach and its applicability to a range of low-rank spectral optimization problems.

Track C – Networks

Session: TP8a1 – Networks and Graphs 1:30 PM–3:10 PM

Chair: ***Santiago Segarra,*** *MIT, USA*

TP8a1-1

Distributed Convergence Verification for Gaussian Belief Propagation

Jian Du, Soummya Kar, Jose' M. F. Moura, Carnegie Mellon University, United States

Gaussian belief propagation (BP) has been widely used for distributed estimation in large-scale networks such as the smart grid, sensor networks, and social networks, where local measurements/observations are scattered over a wide geographical area. However, the convergence of Gaussian BP is still an open issue. In this paper, we propose a novel sufficient convergence condition for Gaussian BP with pairwise linear model and we show analytically that this sufficient convergence can be easily verified in a distributed way that satisfies the network topology constraint.

TP8a1-2

Mobility and Decision-making on Graphs: Utility Maximization for Cabs

Augusto Santos, Soummya Kar, Ramayya Krishnan, Jose' M. F. Moura, Carnegie Mellon University, United States

We devise a model for a single-cab transporting passengers on a graph. We assume that some nodes in the graph are dedicated to passengers pick up, referred to as terminals. Whenever the cab is empty, it must choose a terminal to pick a passenger, and each hop traversed in the graph until it reaches the terminal will incur a cost. The passenger must be dropped at a random position obeying a distribution law that depends on the terminal chosen. Each hop traversed with the passenger leads to a unit revenue.

After dropping the passenger, the agent must choose another terminal and the process continues. The cab must devise a decision-making policy on choosing the terminals, as a function of its current position, so to maximize its long term profit. We show that there is always an optimal pure-strategy -- i.e., deterministic. For certain drop-off distribution laws and graph topologies, it can be characterized in closed form.

TP8a1-3
Control of Networked Systems in the Graph-Frequency Domain

Juan Andres Bazerque, Pablo Monzon, Universidad de la Republica - Uruguay, Uruguay

This paper studies the stability and control of networked systems from the perspective of the new field of signal processing over graphs. Specifically, we reformulate the linear quadratic optimal controller as a graph filter by demonstrating that it becomes separable when applying the graph Fourier transform. Accordingly, the graph-frequency components of the input signal are processed independently by a set of parallel controllers which are given in closed form by solving their Riccati equations. Additionally, we prove that the \emph{joint graph-and-temporal}-frequency transfer function of the controlled system satisfies the condition for stability, that is, that the complement of its region of convergence fits inside a cylinder of unit radius. The results are universal in the sense that they hold true for any graph-frequency and do not depend on the specific eigenvalues of the network shift operator. Numerical tests in an directed circulant graph show that the unstable poles corresponding to graph-frequencies larger than one are shrunk towards the origin.

TP8a1-4
Broadcast Caching Networks with Two Receivers and Multiple Correlated Sources

Parisa Hassanzadeh, New York University, Tandon School of Engineering, United States; Antonia Tulino, Bell Labs & Università di Napoli Federico II, United States; Jaime Llorca, Bell Labs, United States; Elza Erkip, NYU Tandon School of Engineneering, United States

This paper studies the fundamental limits of cache- aided communication systems under the assumption of correlated content for a two-user multiple-file network. Lower bounds on the optimal peak and average rate-memory trade-offs are derived, and a class of schemes based on a two-step source coding approach is proposed to exploit the content correlation and reduce the delivery rate. Files are first compressed using Gray-Wyner-type source coding, and then cached and delivered using a combination of existing correlation-unaware cached aided coded multicast schemes. It is shown that the rate achieved by the proposed scheme matches or performs very close to the lower bound.

TP8a1-5
Distributed Inference with Multiple Decision Makers

Wenwen Zhao, Lifeng Lai, University of California, Davis, United States

In this paper, we consider the distributed testing against independence problem with multiple terminals, in which each terminal has data only related to one random variable. Different with usual cases with multiple senders and one decision maker, we investigate the cases with one sender and multiple decision makers, which needs a trade-off of the performance of each terminal. In this case, the sender broadcasts compressed message and each terminal makes a decision about whether it is independent with the sender or not. Subject to type 1 error probability and communication rate constraint, we characterize the rate-exponent region for the type 2 error probability.

TP8a1-6
Self-Accelerating Consensus Filter Design for Stochastic Networks

Stephen Kruzick, Jose' M. F. Moura, Carnegie Mellon University, United States

Coordination of multi-agent network systems often requires that node-agents reach agreement through local communications, a problem known as distributed consensus. In distributed average consensus, the nodes implement linear dynamics with states that iteratively approach the node data mean. Filters that incorporate previous state values can significantly improve the convergence rate of the dynamics, improving accuracy or reducing the number of iterations. This work focuses on distributed design of acceleration filter coefficients for networks described by stationary graph stochastic processes. The paper proposes an algorithm based on a self-accelerating consensus process in which nodes pursue consensus on updated filter coefficients.

TP8a1-8

Representation of Positive Alpha-Stable Network Traffic Through Levy Mixtures

Chad Bollmann, Murali Tummala, John McEachen, Naval Postgraduate School, United States

Aspects of network traffic, among other time series, can be more accurately represented using the family of stable distributions. Simple, closed form solutions for stable distributions do not exist, other than special cases. Mixtures of one of these special cases, the Levy (or Pearson V) distribution, can be used to provide a closed-form approximation of a positive alpha-stable (PaS) distribution. We show that accurate, closed-form approximations of PaS time series can be obtained with eight or fewer mixture components, providing a computationally-tractable method for estimating real, positive time series, such as network traffic, and facilitating the real-time application of proven detection algorithms to the problem of detecting anomalies in network traffic.

Track F – Biomedical Signal and Image Processing

Session: TP8a2 – Biomedical Signal Processing 1:30 PM–3:10 PM

Chair: ***Siamak K. Sorooshyari,*** *Ellipsis Health*

TP8a2-1

Toward Depth Estimation using Mask-Based Lensless Camera

M. Salman Asif, University of California, Riverside, United States

Recently, coded masks have been used to demonstrate a thin form-factor lensless camera, FlatCam, in which a mask is placed immediately on top of a bare, conventional image sensor. In this paper, we present an algorithm to jointly estimate depth and intensity information in the scene from a single or multiple images of FlatCam. We present a greedy pursuit algorithm to estimate the depth and intensity of each pixel. We use a light field representation in which light rays from different depths yield different modulation patterns. We use this light field representation to analyze the sensitivity of FlatCam against depth mismatch.

TP8a2-2

Glaucoma Detection using Texture Features Extraction

Kavya N, Dr Padmaja K V, RV College of Engineering, India

Glaucoma is a second leading cause of the disease in the world. The World Health Organization has estimated that by 2020, about 80 million people would suffer from glaucoma. As the disease progresses, it leads to structural changes in the Optic Nerve Head (ONH). Optic Nerve Head is the region which consists of Optic Cup and Optic Disc. The region of interest is extracted from the fundus image by using Hough Transformation. It is an automated way of segmentation used to obtain the accurate results and it replaces the manual segmentation. The k-mean clustering also used for segmentation which is another approach. From the segmented ONH, the different features like Gray Level Co-occurrence Matrix (GLCM) and Markov Random Field (MRF) are extracted. As the structural changes taken place in ONH, the texture and the intensity values also changes. The features are used to classify the images as normal and glaucoma. The algorithm speed increases by applying the technique on region of interest instead of using complete image directly. Hence the algorithm results about 94% of accuracy in segmentation using Hough Transform, 84% for segmentation using k-means clustering and about 86% for classification using support vector machine.

TP8a2-5

ECG Segmentation Using Adaptive Hermite Functions

Péter Kovács, Eötvös L. University, Hungary; Carl Böck, Johannes Kepler University, Austria; Jens Meier, Kepler University Hospital, Austria; Mario Huemer, Johannes Kepler University, Austria

Electrical activity of the heart can be measured via electrodes placed on the human body resulting in the physiological signal called electrocardiogram (ECG). Each heart beat contains elementary waves (P,QRS,T), which represent different phases of a cardiac cycle. The main characteristics of these waves such as amplitudes, durations or shapes are of great importance for medical experts. In this article, we develop an ECG delineation algorithm which extracts these features and additionally is able to track subtle variations of the elementary waves. To this end we propose an adaptive signal model based on Hermite functions, optimized for each heartbeat.

TP8a2-6

Optimal Finite-Horizon Sensor Selection for Boolean Kalman Filter

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

Partially-observed Boolean dynamical systems (POBDS) are large and complex dynamical systems capable of being monitored through various sensors. However, limitations such as time-limit constraints, the availability of physical or storage space, and economical constraints impede the use of all sensors for estimation purposes. Thus, developing a procedure for selecting a subset of the sensors is essential. The optimal minimum mean-square error (MMSE) POBDS state estimator is the Boolean Kalman

Filter (BKF) and Smoother (BKS). Naturally, the performance of these estimators strongly depends on the choice of sensors. Given a finite subsets of sensors, for a POBDS with a finite observation space, we introduce the optimal procedure to select the best subset which leads to the smallest expected mean-square error (MSE) of the BKF over a finite horizon. The performance of the proposed sensor selection methodology is demonstrated by numerical experiments with a p53-MDM2 negative-feedback loop gene regulatory network observed through Bernoulli noise.

TP8a2-7
Variational Principle for Ultracoustic Artifact Correction and Signal Segmentation
Jue Wang, Union College, United States; Yongjian Yu, University of Virginia, United States

We present a generic variational framework, titled BLA (Backscatter-Levelset-Attenuation joint estimation model), to correct attenuation artifacts and automatically segment structures in ultracoustic signals. The BLA is posed as a mathematical inverse problem and solved via functional minimization with region-based isotropic regularizations. The echoes are modeled using acoustic backscatter and attenuation of structures. We formulate a weak form model using level set functions over irregular image domains to seek structure boundaries. It eliminates the need of solving PDEs over irregular domains, thus leading to the remarkable computational efficiency for multiple objects. We provide numerical algorithms along with discretization schemes. The efficacy of the method is demonstrated using simulated and clinical ultrasound data.

TP8a2-8
Model-Based Decoding of Time-Varying Visual Information during Saccadic Eye Movements using Population-Level Information
Kaiser Niknam, Amir Akbarian, Behrad Noudoost, Neda Nategh, Montana State University, United States

Our visual system scans the environment by directed ballistic movements of the eyes known as saccades to bring the location of interest to the fovea for further visual processing. Accurately characterizing visual responses in the perisaccadic period is an important step toward understanding how the visual world is represented during saccades and therefore how the brain maintains the stability of visual perception across saccades. Here we use our recently developed probabilistic model in the generalized linear model framework to extract time varying visual information from both spiking response and local field potential of individual middle temporal neurons during rapid eye movements. Our results indicate that the optimal model-based decoding that exploits the response correlation structure between neurons or the network state of population of neurons or both extracts significantly more information about the visual scene than decoding based on the single neuron spiking activity. This model-based approach reveals the role of several external and internal covariates and their modulatory effects in the extrastriate coding of visual stimuli during eye movements. Moreover, the model-based decoding provides a general framework for testing the contribution of specific perisaccadic changes in neuronal responses to the representation of the visual scene during eye movements.

Track C – Networks
Session: TP8a3 – Networks and Applications 1:30 PM–3:10 PM
Co-Chairs: ***David Ramirez,*** *Carlos III University of Madrid, Spain* **and *Hao Zhu,*** *University of Texas at Austin, USA*

TP8a3-1
Distributed Center and Coverage Region Estimation in Wireless Sensor Networks Using Diffusion Adaptation
Sai Zhang, Cihan Tepedelenlioglu, Andreas Spanias, Arizona State University, United States

A fully distributed algorithm for estimating the center and coverage region of a wireless sensor network (WSN) is proposed. The proposed algorithm is useful in many applications, such as finding the required power for a certain level of connectivity in WSNs and localizing a service center in a network. The network coverage region is defined to be the smallest sphere that covers all the sensor nodes. The center and radius of the smallest covering sphere are estimated. The center estimation is formulated as a convex optimization problem using soft-max approximation. Then, diffusion adaptation is used for distributed optimization to estimate the center. After all the sensors obtain the center estimates, max consensus is used to calculate the radius distributively. The performance analysis of the proposed algorithm is provided, as a function of a design parameter controls the trade-off between the center estimation error and the convergence speed of the algorithm. Simulation results are provided.

TP8a3-2

Load Forecasting Based Distribution System Network Reconfiguration–A Distributed Data-Driven Approach

Yi Gu, University of Denver, United States; Huaiguang Jiang, National Renewable Energy Laboratory, United States; Jun Jason Zhang, University of Denver, United States; Yingchen Zhang, Eduard Muljadi, National Renewable Energy Laboratory, United States

In the traditional study, the optimal network reconfigurations are operated with the measured load data at every scheduled time point, which ignores the future load deviations in the periods between two scheduled time points. To overcome this shortage, a support vector regression (SVR) based short- term load forecasting approach is designed to provide an accurate load prediction and benefit the network reconfiguration. Because of the nonconvexity of the three-phase unbalanced AC optimal power flow, a second-order cone program (SOCP) based approach is used to relax the AC optimal power flow problem. Then, the alternating direction method of multipliers (ADMM) is used to compute the AC optimal power flow in distributed manner. The preliminary results demonstrate the feasible and effectiveness of the proposed approach.

TP8a3-3

Chance-Constrained Day-Ahead Hourly Scheduling in Distribution System Operation

Yi Gu, University of Denver, United States; Huaiguang Jiang, National Renewable Energy Laboratory, United States; Jun Jason Zhang, University of Denver, United States; Yingchen Zhang, Eduard Muljadi, National Renewable Energy Laboratory, United States

This paper aims to propose a two-step approach for day-ahead hourly scheduling in a distribution system operation, which contains two operation costs, the operation cost at substation level and feeder level. In the first step, the objective is to minimize the electric power purchase from the day-ahead market with the stochastic optimization. The historical data of day-ahead hourly electric power consumption is used to provide the forecast results with the forecasting error, which is presented by a chance constraint and formulated into a deterministic form by Gaussian Mixture Model (GMM). In the second step, the objective is to minimize the system loss. Considering the nonconvexity of the three-phase unbalanced AC optimal power flow problem in distribution systems, the second-order cone program (SOCP) is used to relax the problem. Then, a distributed optimization approach is built based on the Alternating Direction Method of Multiplier (ADMM). The numerical results demonstrate the effectiveness and validity of the proposed method.

TP8a3-4

Modeling and Optimization of Complex Building Energy Systems with Deep Neural Networks

Yize Chen, Yuanyuan Shi, Baosen Zhang, University of Washington, United States

Modern building encompasses complex dynamics of multiple electrical, mechanical, meteorological and control systems. One of the biggest hurdles in applying conventional model-based optimization and control methods to building energy management is the huge cost and effort of capturing the diverse building dynamics. Here we propose an alternative approach which is model-free and data-driven. By utilizing high volume of data coming from advanced sensors, we train a deep neural network which could accurately represent the operation dynamics of building complexes. The trained network is then directly fitted into a constrained optimization problem to find the optimal control strategies.

TP8a3-5

Optimal Measurement Policy for Predicting UAV Network Topology

Abolfazl Razi, Fatemeh Afghah, Northern Arizona University, United States; Jacob Chakareski, University of Alabama, United States

An important challenge in realizing Unmanned Aerial Vehicles (UAV) networks is the need for a communication platform that accommodates rapidly changing dynamic network topologies. In this work, we develop an optimal tracking policy for each UAV to perceive its surrounding network configuration in order to facilitate more efficient communication protocols. More specifically, we develop an algorithm based on particle swarm optimization and Kalman filtering with intermittent observations to find a set of optimal tracking policies for each UAV under timevarying channel qualities and constrained tracking resources such that the network estimation error is minimized.

TP8a3-6

Sensor Selection and Power Allocation via Maximizing Bayesian Fisher Information for Distributed Vector Estimation

Mojtaba Shirazi, Alireza Sani, Azadeh Vosoughi, University of Central Florida, United States

In this paper we consider the problem of distributed estimation of a Gaussian vector with linear observation model in a wireless sensor network (WSN). Sensors transmit their modulated quantized observations over orthogonal erroneous wireless channels (subject to fading and noise) to a fusion center, which estimates the unknown vector. We consider the problem of sensor selection and transmit power allocation that maximizes the trace of Bayesian Fisher Information Matrix (FIM) under total network power constraint, and propose three algorithms to solve it. Simulation results compare the performances of these algorithms.

TP8a3-7

Detecting Adversaries in Distributed Estimation

Yuan Chen, Soummya Kar, Jose' M. F. Moura, Carnegie Mellon University, United States

Distributed estimation algorithms are crucial to many practical applications, such as power grid state estimation, inference in wireless sensor networks, and control of multi-agent systems. Since there are many agents involved in distributed estimation setups, there is a good chance that some of them will be compromised. Due to the possible presence of compromised agents, it is necessary to develop distributed estimation algorithms that are resilient to adversarial behavior. This paper considers the Flag Raising Distributed Estimation (FRDE) algorithm, a consensus+innovations distributed algorithm for the non-compromised agents to simultaneously perform parameter estimation and detect the presence of adversaries. So long as the non-compromised agents form a connected network and are globally observable, then, we can show that the FRDE algorithm either leads the non compromised agents to correctly estimate the parameter or detect the adversarial activity preventing correct estimation. We demonstrate the performance of the FRDE algorithm through numerical examples.

TP8a3-8

Authentication of Parties in Piggy Bank Cryptography

Prashanth Busireddygari, Subhash Kak, Oklahoma State University, United States

This paper considers authentication issues and security analysis of a CA-based authentication of parties using the Piggy Bank paradigm of cryptography. The PB paradigm as originally described did not deal with the question of how Alice and Bob authenticate each other. This problem is considered in this paper and an advanced protocol is proposed for authentication using a certification authority (CA). A formal proof of the protocol is modeled using input-output finite automata.

Track C – Networks

Session: TP8a4 – Networks for Communication Systems 1:30 PM–3:10 PM

Chair: ***Nicolo Michelusi,*** *Purdue University, USA*

TP8a4-1

A Distributed Admission Control Algorithm for Multicell MISO Downlink Systems

Shashika Manosha Kapuruhamy Badalge, Satya Joshi, Marian Codreanu, Nandana Rajatheva, Matti Latva-aho, University of Oulu, Center for Wireless Communications, Finland

The problem of admission control in a multicell downlink multiple-input single-output system is considered. The objective is to maximize the number of admitted users subject to a signal-to-interference-plus-noise ratio constraint at each admitted user and a transmit power constraint at each base station. We cast the admission control problem as an $\ell 0$ minimization problem. This problem is known to be combinatorial, NP-hard. Hence, we have to rely on suboptimal algorithms to solve it. We first approximate the $\ell 0$ minimization problem via a noncombinatorial one. Then, we propose centralized and distributed algorithms to solve the non-combinatorial problem. To develop the centralized algorithm we use sequential convex programming method. The distributed algorithm is derived by using alternating direction method of multipliers in conjunction with sequential convex programming.

TP8a4-2

Fractional Frequency Reuse Scheme for Interference Mitigation in Device-To-Device Communication Underlying LTE-A Networks

Devarani Ningombam, Jae-young Pyun, Suk-seung Hwang, Seokjoo Shin, Chosun University, Republic of Korea

Device-to-Device (D2D) communication underlying LTE-A cellular networks is becoming a promising technology for the next generation cellular networks. D2D communication in cellular systems addresses two main challenges of interference and spectral inefficiency. In this paper, we propose a fractional frequency reuse (FFR) scheme as a promising solution to mitigate the co-channel interference between D2D pairs and cellular users as well as to improve the spectral efficiency of the network. For such system, to safeguard the outage probabilities in terms of signal-to-interference noise ratio (SINR) of both cellular users and D2D users, we proposed the location based channel reusing scheme in which D2D users in the cell inner region are able to reuse the channel resources of the cellular users in the outer cell region and vice versa. We calculate the boundaries of accessible regions and compared our simulation results against those of the results available in literature.

TP8a4-3

Semi-distributed Conflict-free Multichannel TDMA Link Scheduling for 5G

Zahra Naghsh, Shahrokh Valaee, University of Toronto, Canada

Conflict-free TDMA link scheduling assigns separate resources to conflicting links while taking advantage of possible resource reuse opportunities. This important \textit{resource management} problem is shown to be NP-hard. In this paper, a novel \textit{semi-distributed} algorithm, called SD-MUCS, is proposed for the multichannel conflict-free TDMA link scheduling. SD-MUCS is designed based on the semi-distributed architecture as one of the most promising proposed network structures for 5G. Thus, it takes advantage of parallel processing while imposing a tolerable overhead on the network. Compared to the existing link schedulers, SD-MUCS offers a more spectrally efficient solution which well suits massive expected demand in 5G.

TP8a4-4

Trajectory Optimization for Mobile Access Point

Rajeev Gangula, Paul de Kerret, Omid Esrafilian, David Gesbert, EURECOM, France

We consider the problem of trajectory optimization for an Unmanned Air Vehicle (UAV) equipped with an wireless access point (AP) that collects data from the ground users. Different from few previous works that considered a similar problem, we focus on finding a constant altitude path and velocity of the UAV during the mission time such that the weighted sum-rate of the users is maximized. The formulated problem is a non-convex functional optimization problem, that is difficult to solve in general. By discretizing the time, it can be reformulated as a discrete time optimal control problem, where dynamic programming (DP) is used to obtain the optimal trajectory. This optimal solution does not have a closed form expression and is computationally expensive. Based on the monotonicity of user's rate on its distance from the AP, we provide some analytical properties that help in reducing the complexity of DP algorithm.

TP8a4-5

Identifying Coverage Holes: Where To Densify?

Rebal Jurdi, Jeffrey Andrews, University of Texas at Austin, United States; Dave Parsons, Crown Castle, United States; Robert Heath, University of Texas at Austin, United States

We develop a methodology to identify coverage holes in cellular markets, given demographic and socio-economic information of the population, detailed knowledge of the current macro-cellular infrastructure, and the spectrum capabilities of a cellular operator. Coverage holes are defined as spatial locations in which users contending for macro BS resources outnumber those who eventually get serviced with minimum acceptable average rates. We develop a model that begins with filtering out users who connect to the Internet through small cells and Wi-Fi. We then generate an SINR heat map. Since the rate observed by a user is a function of their own SINR as well as the SINR of other connected users, we introduce a fairness-based method that computes the effective load on a BS as a number of users. By comparing the cell load to the number of users with acceptable rates, we obtain a coverage map that identifies holes that should be targeted by further densification.

TP8a4-6

Optimal Power Control and Scheduling under Hard Deadline Constraints for Continuous Fading Channels

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

We consider a joint scheduling-and-power-allocation problem of a downlink cellular system. The system consists of two groups of users: real-time (RT) and non-real-time (NRT) users. Given an average power constraint on the base station, the problem is to find an algorithm that satisfies the RT hard deadline constraint and NRT queue stability constraint. We propose a sum-rate-

maximizing algorithm that satisfies these constraints. We also show, through simulations, that the proposed algorithm has an average complexity that is close-to-linear in the number of RT users. The power allocation policy in the proposed algorithm has a closed-form expression for the two groups of users. However, interestingly, the power policy of the RT users differ in structure from that of the NRT users. We also show the superiority of the proposed algorithms over existing approaches using extensive simulations.

TP8a4-7

The Role of Transmitter Cooperation in Linear Interference Networks with Block Erasures

Yasemin Karacora, Tolunay Seyfi, Aly El Gamal, Purdue University, United States

We study transmitter cooperation in interference networks with block erasures that capture long-term fluctuations (deep fading). We consider large interference networks where each transmitter can be connected to its corresponding receiver and one following receiver and every link can be erased with probability p. Each message can be assigned to two transmitters. We present an algorithm to find message assignments that lead to achieving the optimal average per user DoF at every value of p. The role of cooperation is found to shift from interference cancellation to increasing the probability of delivering a message as p increases.

TP8a4-8

Exploring Spatial Motifs for Device-to-Device Network Analysis (DNA) in 5G Networks

Tengchan Zeng, Omid Semiari, Walid Saad, Virginia Tech, United States

Device-to-device (D2D) communication is a promising approach to efficiently disseminate critical or viral information across 5G cellular networks. Reaping the benefits of D2D-enabled networks is contingent upon choosing the optimal dissemination policy (number of co-channel D2D links) subject to resource, topology, and user distribution constraints. In this paper, a novel D2D network analysis (DNA) framework is proposed to explore frequent communication patterns across D2D users, known as spatial motifs, to optimize content dissemination in D2D-enabled networks. Preliminary results show that exploring motifs for DNA provides insightful guidelines for devising optimal D2D dissemination policies to maximize the average per user throughput.

Track A – Communications Systems

Session: TP8b1 – Privacy, Secrecy and Channel Capacity 3:30 PM–5:35 PM

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

TP8b1-1

Detection and Mitigation of Pilot Spoofing Attack

Jitendra Tugnait, Auburn University, United States

In a time-division duplex (TDD) multiple antenna system, the channel state information (CSI) can be estimated using reverse training. A pilot contamination (spoofing) attack occurs when during the training phase, an adversary (spoofer) also sends identical training (pilot) signal as that of the legitimate receiver. This contaminates channel estimation and alters the legitimate beamformimg design, facilitating eavesdropping. A recent approach proposed superimposing a random sequence on the training sequence at the legitimate receiver and then using the minimum description length (MDL) criterion to detect pilot contamination attack. In this paper we augment this approach with joint estimation of both legitimate receiver and eavesdropper channels, and secure beamforming, to mitigate the effects of pilot spoofing. We consider two cases: (i) the spoofer also adds a random sequence to its pilot, (ii) the spoofer transmits only the pilot signal. The proposed mitigation approach is illustrated via simulations.

TP8b1-2

Function Computation with Privacy Constraints

Wenwen Tu, Lifeng Lai, University of California, Davis, United States

In this manuscript, the problem of function computing with rate distortion under privacy constraints is considered. The problem consists of two legitimate nodes Alice and Bob, and an eavesdropper Eve. Bob would like to compute a function within given rate distortion, and the arguments of the function are two source observation sequences that are distributed over the legitimate nodes respectively. To make the function computable at Bob, Alice is allowed to transmit a message to Bob via a public noiseless channel, which Eve have full access to. Under this model, we study the relationship among the message rate, private information leakage to Bob, equivocation of Alice's source observations at Eve and the rate distortion, and fully single-letter characterize the region of these achievable parameter tuples.

TP8b1-3
Bayesian Time Series Matching and Privacy
Ke Li, Hossein Pishro-Nik, Dennis Goeckel, University of Massachusetts Amherst, United States

A user's privacy can be compromised by matching the statistical characteristics of an anonymized trace of interest to prior behavior of the user. Here, we address this matching problem from first principles in the Bayesian case, where user parameters are drawn from a known distribution, to understand the relationship between the length of the observed traces, the characteristics of the distribution defining the differences between user behavior, and user privacy. First, we establish optimal tests (of two hypotheses and extended to multiple hypotheses as well) for the cases with: 1) continuous alphabets, in particular i.i.d. Gaussian observations with a different (unknown) mean for each user, where the means are drawn from a general a priori distribution; 2) binary alphabets where i.i.d. observations are drawn from a Bernoulli distribution, with each user having an (unknown) probability of being in the "0" state drawn from some certain a priori distribution. Next, for the case with Gaussian observations, we provide general (non-asymptotic) bounds to the performance of the tests and also employ these to show the scaling behavior of privacy. Finally, we present simulation results to demonstrate the accuracy of our analytical bounds.

TP8b1-4
Full-Duplex Communications for Wireless Links with Asymmetric Capacity Requirements
Orion Afisiadis, École Polytechnique Fédérale de Lausanne, Switzerland; Andrew C. M. Austin, University of Auckland, New Zealand; Alexios Balatsoukas-Stimming, Andreas Burg, École Polytechnique Fédérale de Lausanne, Switzerland

Asymmetric capacity requirements between the up-link and down-link channels are common in many communication standards and are usually satisfied by using time-division or frequency-division duplexing with asymmetric resource allocation. In-band full-duplex communication can reduce the overhead associated with the aforementioned duplexing methods, but, unfortunately, practical full-duplex systems suffer from residual self-interference. However, in asymmetric links the impact of residual self-interference can be partially mitigated by reducing the transmit powers with the goal of maximising the down-link capacity. Compared to time-division half-duplex systems, it is found that power-adjusted full-duplex operation can improve the down-link capacity of an asymmetric IEEE 802.11 system by 20% at a link distance of 10 m, even with pessimistic assumptions on the achievable amount of self-interference suppression. For highly asymmetric traffic, the operation range where a full-duplex system outperforms a corresponding time-division half-duplex system can extend up to 2 km, covering a typical urban LTE macro-cell.

TP8b1-5
MIMO Wiretap Channel with ISI Heterogeneity– Achieving Secure DoF with no CSI
Jean Mutangana, Deepak Kumar, Ravi Tandon, University of Arizona, United States

We consider the multiple-input multiple-output (MIMO) wiretap channel with intersymbol interference (ISI) in which a multi-antenna transmitter (Alice) wishes to securely communicate to a multi-antenna receiver (Bob) in presence of a multi-antenna eavesdropper (Eve). We focus on the practically relevant setting in which there is no channel state information (CSI) at Alice about either of the channels to Bob or Eve, except statistical information about the ISI channels (i.e., Alice only knows the effective number of ISI taps). The key contribution of this work is to show that even with no channel knowledge at Alice, positive secure degrees of freedom (SDoF) are achievable by carefully exploiting a) the heterogeneity of the ISI links to Bob and Eve, and b) the relative number of antennas at all the three terminals. To this end, we propose a novel achievable scheme that carefully mixes information and artificial noise symbol in order to exploit the ISI heterogeneity to achieve positive SDoF. To the best of our knowledge, this is the first work to explore the idea of exploiting ISI channel length heterogeneity to achieve positive SDoF for the MIMO wiretap channel with no CSI at the legitimate transmitter.

TP8b1-6
Covert Active Sensing of Linear Systems
Dennis Goeckel, University of Massachusetts, United States; Boulat Bash, Saikat Guha, Raytheon BBN Technologies, United States; Don Towsley, University of Massachusetts, United States

A significant drawback of active sensing is that it can reveal the sensor's presence and location to an attentive adversary. We leverage recent work on the fundamental limits of covert communications to consider active sensing of a linear filter that acts on the transmitted signal. Motivated by channel estimation applications, we first consider the ability to sense a filter that changes M times per second. We then consider sensing of wide-sense stationary random processes and demonstrate the limits of covert sensing on such a model. The final paper will explore the seeming contradiction between these two results and the impact in applications.

TP8b1-7

Covert Communications on Continuous-Time Channels in the Presence of Jamming

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

Covert wireless communication is achieved if transmitter (Alice) sends messages to legitimate receiver (Bob) without detection by an attentive warden Willie. Employing a discrete-time model, prior research demonstrates that adding a jammer to the model allows Alice to achieve covert communication at positive rate. However, the discrete-time model only models the covert communications environment if Alice and the jammer have identical symbol timing at Willie. Here, we assume the symbol timing is offset and construct a detector that severely limits Alice's covert communication capabilities if previous jamming approaches are employed, and consider strategies for Alice to thwart such a detector.

TP8b1-8

On the Combined Effect of Directional Antennas and Imperfect Spectrum Sensing upon Ergodic Capacity of Cognitive Radio Systems

Hassan Yazdani, Azadeh Vosoughi, University of Central Florida, United States

We consider a cognitive radio system, consisting of a primary user (PU), a secondary user transmitter (SUtx), and a SU receiver (SUrx). The SUs are equipped with steerable directional antennas. The SUtx first performs spectrum sensing and then transmits data at two power levels, according to the result of sensing. We assume the SUs and PU coexist and the SUtx does not know the realizations of the fading channels between SUtx and PU, PU and SUrx, SUtx and SUrx and it only knows the statistics of these fading channels. We find the ergodic capacity of the channel between SUtx and SUrx, and study how spectrum sensing errors affect the capacity. Furthermore, we explore the optimal SUtx power levels and the optimal directions of SUtx and SUrx antennas, such that the capacity is maximized, subject to average transmit power and average interference power constraints. For study the effect of fading channels, we considered two other scenarios, when SUtx knows only the channel between SUtx and SUrx, and, when SUtx knows all fading channels.

Track A – Communications Systems

Session: TP8b2 – Communication System Design and Resource Allocation 3:30 PM–5:35 PM

Chair: ***Matthias Grosglauser,*** *EPFL, Switzerland*

TP8b2-1

Underwater Acoustic Communications using Quasi-Orthogonal Chirps

Song-Wen Huang, George Sklivanitis, Dimitris A. Pados, Stella N. Batalama, State University of New York at Buffalo, United States

We study the correlation of linear chirp waveforms under various bandwidth and signal duration constraints and propose a quasi-orthogonal chirp waveform design technique for underwater acoustic communications. Specifically, we consider binary information symbols that are carried over optimized binary linear chirp waveforms and transmitted over an underwater acoustic multipath channel.We present a coherent receiver design and derive a closed-form expression for the cross-correlation coefficient of binary linear chirp waveforms. Then, we evaluate the bit-error-rate (BER) performance for the proposed quasi-orthogonal chirp waveforms through simulations as well as experiments that utilize in-house built software-defined underwater acoustic modems.

TP8b2-2

Pulse Design for Spectrally Efficient Transmissions Assuming Maximum Likelihood Detection

Baptiste Cavarec, Mats Bengtsson, Royal Institute of Technology, Sweden

In this paper, we analyse different spectrally efficient waveforming modulations under the framework of Gabor analysis. We derive a channel adaptive pulse design paradigm for such modulations under Maximum Likelihood (ML) detection at the receiver. The proposed pulse design is tested on a simulation scenario with high self-interference and compared with existing pulses at different spectral densities.

TP8b2-3

Path-Based Channel Estimation for Acoustic OFDM Systems: Real Data Analysis

Amir Tadayon, Milica Stojanovic, Northeastern University, United States

We address detection of acoustic OFDM signals using a channel estimation method based on a physical model of multipath propagation rather than an equivalent sample-spaced model. The path identification (PI) algorithm focuses on explicit estimation of delays and complex amplitudes of the channel paths. We apply this algorithm, along with the conventional least squares (LS) and orthogonal matching pursuit (OMP) to a set of signals recorded over a mobile acoustic channel. We demonstrate excellent performance of the PI algorithm and show that its complexity is considerably lower than that of the OMP algorithm. The PI algorithm consistently outperforms the conventional LS and compares favorably with the OMP algorithm in terms of the mean-squared data detection error observed for a varying number of OFDM carriers and receiver array configurations.

TP8b2-4

On the Performance of Polar Codes for 5G eMBB Control Channel

Seyyed Ali Hashemi, Carlo Condo, Furkan Ercan, Warren Gross, McGill University, Canada

Polar codes are a class of error-correcting codes which can provably achieve the capacity of a binary memoryless symmetric channel with low-complexity encoding and decoding algorithms. They have been selected for use in the next generation of wireless communications, as a coding scheme for the enhanced mobile broadband (eMBB) control channel, which requires codes of short lengths and low rates. Successive-cancellation (SC), SC list (SCL), and their modifications, are some of the most studied polar code decoding algorithms. In this paper, we study polar codes of short lengths and different code rates. We show that for a fixed target frame error rate (FER), there is an optimal code rate with which SC and SCL decoders can achieve the target FER with minimum Eb/N0. In addition, we study the effect of CRC on the error-correction performance of SCL decoders and show that there is an optimal CRC length with which the decoder achieves its best results. We further analyze the speed of polar code decoding by considering state-of-the-art fast SC and SCL decoders available in literature, thus providing a survey of the decoder design space for eMBB, considering error-correction performance, achievable throughput, flexibility and estimated complexity.

TP8b2-5

Multiple Transmitter Localization using Clustering by Likelihood of Transmitter Proximity

Marjan Saadati, Jill Nelson, George Mason University, United States

We propose a measurement clustering method for estimating the locations of multiple radio transmitters based only on received signal strength and a performance analysis approach drawn from a hypothesis testing framework. Measurements are collected at a set of arbitrary locations in the area of interest. Measurements are retained (or discarded) for transmitter localization based on the probability that a transmitter lies within a given neighborhood of the measurement location. Retained measurements are clustered using k-means or a similar approach, and individual transmitter localization is performed in each cluster. The proposed approach makes no assumptions that the measurements are clustered around transmitters; measurement locations may be at a similar distance from several transmitters, complicating the estimation process. The effect of the choice of neighborhood size and measurement threshold is analyzed using a hypothesis testing framework in which the probability of detection, probability of false alarm, and receiver operating characteristic are derived. Simulation results show that, over a wide range of shadowing noise variance, the proposed clustering-based localization achieves performance gains over algorithms that estimate transmitter locations jointly.

TP8b2-6

Kolkata Paise Restaurant Game for Resource Allocation in the Internet of Things

Taehyeun Park, Walid Saad, Virginia Tech, United States

In this paper, a distributed approach is proposed for enabling Internet of Things (IoT) devices with incomplete information and multiple objectives to effectively utilize limited communication resources. The problem is formulated using a novel Kolkata paise restaurant game, and a learning algorithm is developed to enable the IoT devices to optimize their transmission. The effectiveness of the proposed scheme in increasing the successful transmissions as function of the amount of available information is analyzed. Preliminary results show that the proposed approach can significantly increase successful transmissions in dense IoT environments, compared to a baseline with no learning.

TP8b2-7

Implementation Approaches for 512-tap 60 GSa/s Chromatic Dispersion FIR Filters

Anton Kovalev, Oscar Gustafsson, Mario Garrido, Linköping University, Sweden

In optical communication the non-ideal properties of the fibers leads to pulse widening from chromatic dispersion. On way to compensate for this is through digital signal processing. In this work two architectures for compensation are compared. Both are designed for 60 GSa/s and 512 taps. It is shown that the high-speed requirements introduce constraints on possible architectural choices. Furthermore, the complexity estimates are not good predictors for the energy consumption.

TP8b2-8

Brain-Aware Wireless Networks: Learning and Resource Management

Ali Taleb Zadeh Kasgari, Walid Saad, Virginia Tech, United States; Merouane Debbah, CentraleSupelec, Universite Paris-Saclay, France

Human centric applications such as virtual reality and immersive gaming will be central to future wireless networks.One common feature of such services is their dependence on the human user's behavior and state. To successfully deploy such applications over wireless and cellular systems, the network must be cognizant of the human in the loop. In this paper, a novel approach based on Lyapunov optimization and dynamic learning is proposed for allocating radio resources for human and machine type devices while considering the brain processing power of human users. Preliminary results show that a brain-aware approach can significantly improve network reliability.

Track A – Communications Systems

Session: TP8b3 – Coding Theory and Sequences 3:30 PM–5:35 PM

Chair: ***Nicolò Michelusi,*** *Purdue University*

TP8b3-1

Zero-Forcing Precoding Using Generalized Inverses for G.fast DSL Systems

Andreas Barthelme, Michael Joham, Technische Universität München, Germany; Rainer Strobel, Intel, Germany; Wolfgang Utschick, Technische Universität München, Germany

Previous work on precoding for G.fast systems focused on linear and non-linear precoding techniques to maximize the overall throughput. It has been shown that the existing algorithms almost achieve the sum capacity. However, the rate region does no longer feature a rectangular shape as for VDSL systems, that motivates the utilization of operating points suboptimal w.r.t. sum rate to meet the individual users demands. In these points, the gap between existing zero-forcing techniques and the corresponding weighted sum capacity is significantly larger. Therefore, we propose to improve the linear zero-forcing precoding by employing generalized inverses and reevaluate the performance of linear weighted minimum mean square error (WMMSE) precoding.

TP8b3-2

Coding Scheme for Reliable In-Memory Hamming Distance Computation

Zehui Chen, Clayton Schoeny, Lara Dolecek, University of California, Los Angeles, United States; Yuval Cassuto, Technion - Israel Institute of Technology, Israel

Computation-in-memory is a technique that has shown great potential in reducing the burden of massive data processing. Allowing for ultra-fast Hamming distance computations to be performed in-memory will drastically speed up many modern machine-learning algorithms. However, these in-memory calculations have not been studied in the presence of errors due to process variabilities. In this paper, we develop coding schemes to reliably compute, in-memory, the Hamming distances of pairs of vectors in the presence of write-time errors. Using an inversion coding technique, we establish error-detection guarantees as a function of the number of errors and the non-ideality of the resistive array memory in which the data is stored. To correct errors in the vector similarity comparison, we propose codes that achieve error correction and useful techniques for bit level data access and error localization. We demonstrate the effectiveness of our coding scheme on a simple example using the k-nearest neighbors algorithm.

TP8b3-3

Polar Coding for the Large Hadron Collider: Challenges in Code Concatenation

Alexios Balatsoukas-Stimming, Tomasz Podzorny, Jan Uythoven, European Organization for Nuclear Research (CERN), Switzerland

We study a channel coding scheme for possible use in the beam interlock system of the Large Hadron Collider at CERN. This coding scheme uses a polar code concatenated with a long repetition code in order to protect the most critical bit within the codeword, while still providing good error protection for the remaining information bits. We explain why the most straightforward way to decode this concatenated coding scheme is ineffective and, using our observations, we propose an improved scheme that has an SNR gain of approximately 2 dB for an N = 128 polar code and a k_rep = 11 repetition code.

TP8b3-4

A Block-Based Tomlinson-Harashima Precoder for Wireless Uplink

Ismail Mohamed, Vaughan Clarkson, University of Queensland, Australia

Peak-to-amplitude power ratio (PAPR) has long been a key research topic in telecommunications, especially in orthogonal frequency division multiplexing (OFDM) based communications systems. Tomlinson-Harashima precoding (THP) is a classical technique that demonstrates most of the desired qualities, except that it is unsuited to block-based transmission. In this paper, we propose a modification that naturally adapts THP to block-based transmission, thus applicable to “bursty” transmission in wireless systems. We demonstrate that it arises out of a so-called lattice-based multi-carrier modulation (LBMCM) [1], [2]. Simulations show dramatic reduction in storage of channel-related coefficients without significantly affecting the operational BER.

TP8b3-5

Joint Constellation and Code Design for the Gaussian Multiple Access Channel

Yu-Chung Liang, Stefano Rini, National Chiao Tung University, Taiwan; Joerg Kliewer, New Jersey Institute of Technology, United States

This paper considers the joint design of both transmit constellation and LDPC codes for the two-user, symbolsynchronous, binary-input Gaussian multiple access channel. We consider the problem of attaining the symmetric capacity without the use of time-sharing or rate-splitting by joint decoding of the noisy sum of two LDPC codewords. To this end, a decoding algorithm is considered which extends the classic belief propagation algorithm to allow for the simultaneous decoding of two codewords. We exploit a Gaussian approximation of the message distribution to investigate the convergence of the decoding process and also introduce a linear programming technique for joint code design. For this decoding algorithm and proposed code optimization procedure, different constellation choices are obtained which perform well in different SNR regimes.

TP8b3-6

Pseudorandom Tableau Sequences

Prashanth Busireddygari, Subhash Kak, Oklahoma State University, United States

This paper proposes a new class of random sequences called binary primes tableau (PT) sequences that have potential applications in cryptography and communications. The PT sequence of rank p is obtained from numbers arranged in a tableau with p columns where primes are marked off until each column has at least one prime and where the column entries are added modulo 2. We also examine the dual to the PT sequences obtained by adding the rows of the tableau. It is shown that PT sequences have excellent autocorrelation properties.

TP8b3-7

Effect of Inter-User Delay and Channel Phase Response on MC-CDMA using WBE Codes with Application to Lower VHF

Fikadu Dagefu, Army Research Laboratory, United States; Predrag Spasojevic, Oak Ridge Associated Universities / Rutgers University, United States; Gunjan Verma, Brian Sadler, Army Research Laboratory, United States

Reliable, ad hoc communications among multiple users is a crucial objective in complex tactical scenarios. A major challenge is that synchronization mechanisms (such as GPS) are intermittent, and fixed centralized coordinators (e.g., base stations) are infeasible. Classical approaches to multi-user communications relying on tight time and frequency synchronization and/or power control are impractical in such scenarios. In this paper, we study the effect of coarse time synchrony and phase response variation on a class of code division multiple access (CDMA) strategies known as multi-carrier (MC) CDMA. We study this sensitivity when binary codes achieving the Welch bound in a potentially user-overloaded system are used. The optimal codes are selected to minimize the L_1, L_2 and the L_{∞} bounds. We investigate the potential advantages of coupling our code designs with the favorable channel characteristics of flat (amplitude and phase) response channels. Of particular interest is the near-

ground lower VHF band, which has improved penetration and reduced multipath relative to microwave, in particular in non-line of sight environments, such as through-buildings. We aim at taking advantage of the low phase variation in such channels. We study the reduction in the necessary inter-user time synchrony required of bands having a lower phase variation.

TP8b3-8
Unique Paraunitary-Based Complementary QAM Sequences
Predrag Spasojevic, Rutgers University, United States; Srdjan Budishin, RT-RK, Yugoslavia

A Boolean generator for a broad set of standard pairs of complex valued complementary sequences of length 2^K is proposed. Binary, M-PSK and QAM sequences can be generated. The Boolean generator is derived from our earlier paraunitary algorithm that is based on matrix multiplications. Both algorithms are based on unitary matrices. In contrast to previous Boolean QAM algorithms, proposed by Li and Liu et al., which have an additive form, our algorithm has a multiplicative form. Any element of the sequence can be efficiently generated by indexing entries of unitary matrices using a binary counter. Generalized Case I, II and III sequences given by Li are identical to those generated by our Boolean generator with one QAM unitary matrix (1Qum). The generalized Cases IV and V given by Liu et al. correspond to a special case of our generator with two QAM unitary matrices (2Qum). The ratio of the total number of proposed sequences to earlier generalized Case I-V sequences grows with the constellation size and the length of the sequence. As an example, for 1024-QAM and length 1024, our algorithm generates 340% additional sequences.

Track A – Communications Systems

Session: TP8b4 – Detection Methods and mmWave Systems 3:30 PM–5:35 PM
Chair: ***Lee Swindlehurst,*** *University of California, Irvine*

TP8b4-1
Detection of Almost-Cyclostationarity: An Approach Based on a Multiple Hypothesis Test
Stefanie Horstmann, Universität Paderborn, Germany; David Ramírez, Universidad Carlos III de Madrid, Spain; Peter J. Schreier, Universität Paderborn, Germany

This work presents a technique to detect whether a signal is almost-cyclostationary (ACS). Commonly, ACS (and also CS) detectors require a priori knowledge of the cycle period, which in the ACS case is generally not an integer. To tackle the case of unknown cycle period, we propose an approach that combines a resampling technique, which handles the fractional part of the cycle period and allows the use of a generalized likelihood ratio test (GLRT), with a multiple hypothesis test, which handles the integer part of the cycle period. We are able to control the probability of false alarm by using the known distribution of an individual GLRT statistic, results from order statistics, and the Holm multiple test procedure. Simulation results show that the proposed technique outperforms state-of-the-art competitors.

TP8b4-2
Sparse Estimation for Wideband mmWave Channel with Hybrid Antenna Architecture
Ganesh Venkatraman, Alok Sethi, Antti Tölli, Aarno Pärssinen, Markku Juntti, University of Oulu, Center for Wireless Communications, Finland

We propose a sparse channel estimation for millimeter-wave (mmWave) communication using hybrid analog-digital architecture with multiple radio frequency (RF) chains driving a dedicated phased subarray. Due to the high path loss, pilots are beamformed and swept to scan the environment in angular domain, since the mmWave channel can be represented as a linear combination of angle-of-arrivals (AoAs) and angle-of- departures (AoDs). Unlike the existing narrowband channel estimation schemes, we consider a wideband orthogonal frequency division multiplexing (OFDM) model wherein delay profile is also accessible in addition to the angular information of the mmWave channel. Due to the huge computational complexity involved in the wideband sparse channel estimation, we model the problem as an alternating directions method of multipliers (ADMM) based reweighted-l2 norm minimization to obtain a sparse solution in both angular and delay domain. Even though the channel is sparse in the delay domain, the sparsity is not prominently visible because of power leakage caused by non-sample-spaced multipath time delays. Thus, to obtain a sparse solution in this scenario, we extend the proposed technique by incorporating group sparsity in the delay domain. Numerical simulations will be presented in the full paper to illustrate the efficacy of the proposed techniques.

TP8b4-3
Multi-scale Spectrum Sensing in Mm-Wave Cognitive Networks
Nicolo Michelusi, Purdue University, United States; Matthew Nokleby, Wayne State University, United States; Urbashi Mitra, University of Southern California, United States; Robert Calderbank, Duke University, United States

In this paper, a multi-scale approach to spectrum sensing and information exchange in mm-wave cognitive cellular networks is proposed. In order to overcome the huge energy cost of acquiring full network state information on the occupancy of each cell over the network, secondary users (SUs) acquire local state estimates, which are aggregated up the hierarchy to produce multi-scale estimates of spectrum occupancy. The proposed design accounts for local estimation errors and the irregular interference patterns arising due to sensitivity to block- ages, high attenuation, and high directionality at mm-wave. A greedy algorithm based on agglomerative clustering is proposed to design an interference-based tree (IBT), matched to interference pattern. The proposed aggregation algorithm over IBT is shown to be much more cost efficient than acquiring full network state information from the neighboring cells, requiring up to 1/5th of the energy cost.

TP8b4-4
CA-CFAR Detection Based on AWG Interference Model in a Low-Complexity WCP-OFDM Receiver
Steven Mercier, Stéphanie Bidon, Damien Roque, Univ. Toulouse, France

In this paper, we study the self-interference component induced by targets at the output of a previously described low-complexity WCP-OFDM radar receiver. Particularly, we advocate that the former can be modeled as an additive white Gaussian noise independent from internal noise. To that end, we propose an expression for the signal-to-interference-plus-noise ratio and verify by simulation that the expected performance of the well-known CA-CFAR detector are recovered and thus predictable.

TP8b4-5
Synchronization Signal Design and Hierarchical Detection for the D2D Sidelink
Konstantinos Manolakis, Wen Xu, Huawei Technologies, Germany; Giuseppe Caire, Technische Universität Berlin, Germany

Device-to-device (D2D) communication is considered as a key component for existing and future cellular networks. At the same time, safety and emergency applications must be served by so-called ultra-reliable low-latency communication (URLLC). In D2D, fast and reliable synchronization and user identification are required for link establishment and dynamic topology estimation. In this work, a method is proposed for generating advanced sequences, which can provide more information than only user identity (ID), as done by Long Term Evolution (LTE) sequences. This can include information about the synchronization source followed by the transmitting user, e.g. base station or Global Navigation Satellite System (GNSS), the number of hops over which the user obtains its time reference, or even for supporting a larger number of user IDs. Such information allows for prioritizing and accordingly weighting a potentially large number of received beacons, based on the source reliability and accuracy with the goal of a faster and more precise synchronization. On the receiver side, advanced detection algorithms dealing with channel high time-variance is considered. Evaluation results show the benefits of using such sequences, which at the same time allow for backwards-compatible synchronization.

TP8b4-6
60 GHz Blockage Study using Phased Arrays
Christopher Slezak, Aditya Dhananjay, Sundeep Rangan, New York University, United States

The millimeter wave (mmWave) frequencies offer the potential for enormous capacity wireless links. However, a key requirement for designing robust communication systems in these frequencies is the need to understand the channel dynamics over both time and space: mmWave signals are extremely vulnerable to blocking and the channel can thus rapidly appear and disappear with small movement of obstacles and reflectors. In rich scattering environments, different paths may experience different blocking trajectories and understanding these multi-path blocking dynamics is essential for developing and assessing beamforming and beam-tracking algorithms. This paper presents the design and experimental results of a novel measurement system which uses phased arrays to perform mmWave dynamic channel measurements. Specifically, human blockage and its effects across multiple paths are investigated with only several microseconds between successive measurements. From these measurements we develop a modeling technique which uses low-rank tensor factorization to separate the available paths so that their joint statistics can be understood.

TP8b4-7

Two-Stage LASSO ADMM Signal Detection Algorithm For Large Scale MIMO

Anis Elgabli, Purdue University, United States; Ali Elghariani, University of Tripoli, Libyan Arab Jamahiriya; Abubakr Al-Abbasi, Mark Bell, Purdue University, United States

This paper explores the benefit of using machine learning and Big data optimization algorithms, such as least absolute shrinkage and selection operator (LASSO) in approximating maximum likelihood (ML) detection of Large Scale MIMO systems. First, large scale MIMO detection problem is formulated as a LASSO convex optimization problem. Then, Alternating Direction Method of Multipliers (ADMM) is considered in solving this problem. The choice of ADMM is motivated by its ability to solve convex optimization problems by breaking them into smaller sub-problems, each of which are then easier to handle. Further improvement is implemented using two stages of LASSO and ADMM combination with interference cancellation from the first stage. The proposed algorithm is investigated at various modulation techniques with a different number of antennas. It is also compared with widely used algorithms in this field. Simulation results demonstrate the efficacy of the proposed algorithm for both uncoded and coded cases.

TP8b4-8

Radio Signal Identification using Deep Scattering Networks

Hao Chen, Seung-Jun Kim, University Maryland, Baltimore County, United States

Identifying individual RF emitters from their mixture measurements is an important problem in radio scene analysis with both civilian and military applications. This work aims at achieving this in the feature space using only a single receiver. A key aspect is to obtain a set of features that are invariant to signal variations such as temporal/frequency translations, as well as various RF channel impairments, while not losing discriminative patterns that appear in multiple scales/resolutions. In this work, deep scattering spectrum is adopted as the baseline features, and spatial transformer networks are employed to cope with RF-specific signal impairments. Then supervised dictionary learning in the feature space is used to identify the component RF signals. Preliminary feature extraction and classification results show the potential of the proposed approach.

Track A – Communications Systems

Session: WA1a – Theory of Wireless Systems

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

WA1a-1 8:15 AM

On Deep Learning-Based Communication Over the Air

Sebastian Dörner, Sebastian Cammerer, University of Stuttgart, Germany; Jakob Hoydis, Nokia Bell Labs, France; Stephan ten Brink, University of Stuttgart, Germany

End-to-end learning of communications systems is a fascinating novel concept that has so far been only validated by computer simulations for block-based transmissions. It allows learning of transmitter and receiver implementations—without any prior knowledge—that are optimized for an arbitrary differentiable end-to-end performance metric, e.g., block error rate (BLER). We demonstrate in this paper that it is possible to build and train such a system using off-the-shelf softwaredefined radios (SDRs) and open-source deep learning software libraries. We extend the existing ideas towards continuous data transmission, unrestricted of a short block length. A comparison of the BLER performance of the “learned” system against that of various practical baselines shows competitive performance. We identify several practical challenges of training such a system over-the-air, in particular the missing channel gradient, and propose a learning procedure that circumvents this issue.

WA1a-2 8:40 AM

Energy Optimization for Hybrid-ARQ and AMC

Bentao Zhang, Pamela Cosman, Larry Milstein, University of California, San Diego, United States

We consider the energy optimization of a cross-layer design which combines hybrid automatic repeat request (HARQ) and adaptive modulation and coding. We consider two cases: variable alphabet size with constant transmit power and variable alphabet size with variable transmit power. We optimize the alphabet size selection algorithm and/or the transmit power for each transmission round to minimize energy consumption, subject to an overall packet error probability constraint. Numerical results show that the variable alphabet size and variable power case significantly reduces energy consumption compared to conventional HARQ schemes. For example, at a packet error probability of $6\times10-2$, energy consumption of the proposed scheme is reduced by 36% compared to a comparison scheme.

WA1a-3 9:05 AM

Age Minimization in Energy Harvesting Communications: Energy-Controlled Delays

Ahmed Arafa, Sennur Ulukus, University of Maryland, College Park, United States

We consider an energy harvesting source that is collecting measurements from a physical phenomenon and sending updates to a destination within a communication session time. Updates incur transmission delays that are function of the energy used in their transmission; the higher the transmission energy used per update, the faster it reaches the destination. The goal is to transmit updates in a timely manner, namely, such that the total age of information is minimized by the end of the communication session, subject to energy causality constraints. We consider two settings. In the first setting, the source controls the number of measurement updates, their transmission times, and the amounts of energy used in their transmission (which govern their delays, i.e., service times, incurred). In the second setting, measurement updates externally arrive over time, and therefore the number of updates becomes fixed, at the expense of adding data causality constraints to the problem. We characterize age-minimal policies in the two settings, and discuss the relationship of the age of information metric to other metrics used in the energy harvesting literature, such as throughput, delay, and transmission completion time.

WA1a-4 9:30 AM

Correlated Interference with Interferer Memory

Eric Ruzomberka, David J. Love, Purdue University, United States

We examine worst-case interference introduced by cooperative relay and repeater nodes in a wireless network, which we model as a zero-sum mutual information game between a user and interferer. We assume that the interferer has memory of the user's past transmissions but lacks information about the current input. The user and interferer compete non-cooperatively with average power constraints over an AWGN channel with memory. We investigate the behavior of the two players and show whether optimal strategies for the user and interferer exist simultaneously. Channel capacity follows from the optimal strategies.

Track A – Communications Systems

Session: WA1b – Theory of Structured Waveforms

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

WA1b-1 10:15 AM

HiHTP: A Custom-Tailored Hierarchical Sparse Detector for Massive MTC

Gerhard Wunder, Ingo Roth, Rick Fritschek, Jens Eisert, FU Berlin, Germany

Recently, the Hierarchical Hard Thresholding Pursuit (HiHTP) algorithm was introduced to optimally exploit the hierarchical sparsity structure in joint user activity and channel detection problems, occurring e.g. in 5G massive Massive Machine-type Communications (mMTC) scenarios. In this paper, we take a closer look at the performance of HiHTP for user activity detection under noise and relate its performance to the classical block correlation detector with orthogonal signatures. More specifically, we derive a lower bound for the diversity order of HiHTP and provide explicit and easy to handle formulas for numerical evaluations and (5G) system designs. Furthermore, we surprisingly find that in specific parameter settings non-orthogonal pilots, i.e. pilots of which shifted versions actually interfere with each other, outperform the block correlation detector, which is optimal in the non-sparse situation. Finally, we evaluate our findings with numerical examples.

WA1b-2 10:40 AM

Lossless Natural Sampling for PWM Generation

Noyan Sevuktekin, Andrew Singer, University of Illinois at Urbana-Champaign, United States

Sufficient conditions for different reference signals to ensure lossless natural sampling of a finite energy, band-limited signal are derived in the contexts of pulse-width modulation (PWM). Range and period conditions for saw-tooth signals, which are commonly used in PWM generation, are shown to ensure lossless natural sampling in the Landau sense. These results are extended to any absolutely continuous reference signal that span its dynamic range monotonically on a pulse interval under certain derivative conditions. Finally, a first order sinusoidal reference signal is shown to ensure lossless natural sampling for the purpose of reducing PWM generator complexity.

WA1b-3 11:05 AM

Dimension Spreading for Coherent Opportunistic Communications

Jordi Borras, Josep Font-Segura, Jaume Riba Sagarra, Gregori Vazquez, Technical University of Catalonia, Spain

The waveform optimization problem for opportunistic communications is addressed, based on sensing the second-order statistics of the existing transmissions. We propose a minimum-norm waveform optimization that exhibits robustness to the worst-case subspace mismatch, minimizes the spectral overlapping with the existing transmissions, is rotationally invariant, and has

maximally white spectrum. This paper also deals with a different kind of signal dimension-based spreading. In addition, the effects of the residual interference caused to the existing transmissions are studied. Numerical results are provided to assess the performance of the proposed solution in the frequency domain for the asymptotic case. The level of induced interference is compared to traditional null space techniques.

Track B – MIMO Communications and Signal Processing

Session: WA2a – MIMO Channel Estimation

Chair: ***Lee Swindlehurst,*** *University of California, Irvine*

WA2a-1 — 8:15 AM

The Impact of Impedance Matching on Channel Estimation in Compact MIMO Receivers

Wuyuan Li, Brian Hughes, North Carolina State University, United States

Accurate channel estimates are essential to realize the high capacity of MIMO communication channels. In compact receivers, prior work has shown that mutual coupling among antennas can significantly degrade the performance of channel estimation algorithms. However, this work did not consider the impact of coupling on observation noise, or the possible benefits of antenna impedance matching, which can profoundly alter the characteristics of observation noise. In this paper, we revisit the channel estimation problem for compact MIMO receivers. We consider a MIMO front-end that consists of coupled antennas, impedance matching and amplifiers, and includes physical models of antenna and amplifier noise. Using this model, we derive the error covariance of MMSE channel estimation and explore how it varies with front-end impedance and noise characteristics. We show the MMSE error covariance is always minimized by one kind of impedance matching, called minimum-noise-factor matching. We present numerical results that compare the estimation error achievable with optimal matching to conventional antenna self-matching. These results suggest that, when conventional self-matching is used, estimation error is highly sensitive to amplifier noise in the presence of strong coupling. However, optimal matching completely eliminates this sensitivity and significantly outperforms self-matching when amplifier noise is not negligible.

WA2a-2 — 8:40 AM

Affine Precoding-based Superimposed Training for Semi-Blind Channel Estimation in OSTBC MIMO-OFDM Systems

Himanshu B. Mishra, Indian Institute of Technology Kanpur, India; Naveen K. D. Venkategowda, Korea University, Republic of Korea; Aditya K. Jagannatham, Indian Institute of Technology Kanpur, India

This paper develops a framework for semi-blind channel estimation in MIMO-OFDM systems that use orthogonal space-time block codes (OSTBCs). The proposed technique is based on a whitening unitary (WU) decomposition together with superimposed training (ST). The ST incorporates an orthogonal affine precoder to avoid interference between the pilot and data symbols during both channel estimation and data detection. The complex constrained Cramer-Rao bound (CC-CRB) is derived to characterize the mean squared error (MSE) of the proposed semi-blind channel estimation scheme. Simulation results using practical IMT-2000 channel models demonstrate the improved performance of the proposed semi-blind scheme in comparison to both non-semiblind ST and conventional training techniques.

WA2a-3 — 9:05 AM

Joint Channel-Estimation/Decoding with Frequency-Selective Channels and Low-Precision ADCs

Peng Sun, Philip Schniter, The Ohio State University, United States; Robert Heath, University of Texas, United States; Zhongyong Wang, Zhengzhou University, China

We propose an approach for joint channel-estimation/equalization/decoding of data transmitted over frequency- selective channels and received through few (e.g., 1–4) bit analog-to-digital converters (ADCs). Our approach uses the recently proposed parameteric bilinear generalized approximate message passing (PBiGAMP) algorithm in a turbo configuration with soft-input soft-output decoding, and is capable of exploiting channel sparsity and multiple antennas. Furthermore, it leverages FFTs for fast operation.

WA2a-4 9:30 AM

Sparse channel estimation using bad measurement matrices for FDD massive MIMO systems

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

Massive MIMO systems operating in FDD mode may use sparse channel estimation to reduce the overheads in downlink channel estimation. Unfortunately, current commercial activities in massive MIMO are focusing on the use of beam training with relatively pointy, non-random beams. This leads to a sparse measurement matrix that diverges from what is considered to be good. In this paper, we focus on how to modify the sparse recovery approaches to operate with beam training methodologies with non-ideal measurement matrices. We propose an approach for dimensionality reduction that leads to better performance at low SNRs for frequency selective massive MIMO-OFDM systems.

Track H – Speech, Image and Video Processing

Session: WA2b – Speech Processing

Chair: ***Issa Panahi,*** *University of Texas at Dallas*

WA2b-1 10:15 AM

Real-World Evaluation of Multichannel Audio Enhancement Systems Using Acoustic Beacons

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

State-of-the-art multichannel audio enhancement systems rely on precise estimates of acoustic impulse responses, but these are difficult to estimate from source data alone in noisy and reverberant environments. We propose a measurement system using acoustic beacons attached to the sources of interest. Each beacon produces an inaudible pilot signal that is used to estimate the acoustic impulse responses between the sources and microphones. Using the estimated impulse responses, we can evaluate the achievable performance of multichannel audio enhancement systems in challenging real-world environments.

WA2b-2 10:40 AM

Robust Real-time Sound Pressure Level Stabilizer for Multi-Channel Hearing Aids Compression for Dynamically Changing Acoustic Environment

Yiya Hao, Ram Charan Chandra Shekar, Gautam Shreedhar Bhat, Issa M.S. Panahi, University of Texas at Dallas, United States

Multi-channel compression is one among the most popular techniques of hearing aids of mapping the wide dynamic range of speech signals into the reduced dynamic range of hearing impaired listeners effectively. Most of the Multi-Channel Compressors are particularly designed to manage certain loudness pattern, but it’s quite difficult to efficiently capture the dynamically changing acoustics in Real-Time. The proposed method circumvents this problem by providing a contraption to estimate the fluctuating sound pressure level (SPL) and converting it into the desired SPL suitable for Multi-channel compression. This objective of stabilizing the SPL is achieved by incorporating a rapid voice activated detection (VAD), a root mean square (RMS) estimator, a moving average (MA) rectifier and a SPL regulator. Proposed SPL Stabilizer provides the hearing aids compressor with a comparatively constant SPL level input in Real-Time, and there by improves the quality and intelligibility of compression output signal.

WA2b-3 11:05 AM

Speech Enhancement Using Extreme Learning Machines

Babafemi Odelowo, David Anderson, Georgia Institute of Technology, United States

The enhancement of speech degraded with the non-stationary noise types that typify real-world conditions has remained a challenging problem for several decades. However, recent use of data driven methods for this task has brought great performance improvements. In this paper, we develop a speech enhancement framework based on the extreme learning machine. Experimental results show that the proposed framework is effective in suppressing additive noise. Furthermore, it is always superior to a leading minimum mean square error (MMSE) algorithm in matched noise, and exceeds the said algorithm’s performance in mismatched noise at all but the highest signal-to-noise ratio (SNR) tested.

Track C – Networks

Session: WA3a – Wireless Networks

Chair: ***Tim Davidson,*** *McMaster University, Canada*

WA3a-1 8:15 AM

Analysis of Dense Cellular Networks with Stretched Exponential Path Loss

Ahmad AlAmmouri, Jeffrey Andrews, Francois Baccelli, University of Texas at Austin, United States

Distance-based attenuation is a critical aspect of wireless communications. As opposed to the ubiquitous power-law path loss model, this paper proposes a stretched exponential path loss model that is suitable for short-range communication. In this model, the signal power attenuates over a distance r as (exp(-α r^(β))) , where (α,β) are tunable parameters. We integrate this path loss model into a downlink cellular network with base stations modeled by a Poisson point process, and derive expressions for the coverage probability and area spectral efficiency. Although the most general result for coverage probability has a double integral, several special cases are given where the coverage probability has a compact or even closed form. We show that coverage probability collapses to zero for high base station densities. We next prove that the area spectral efficiency is non-decreasing with the base station density and converges to a constant for high densities.

WA3a-2 8:40 AM

On the Sum Capacity of Many-to-one and One-to-many Gaussian Interference Channels.

Abhiram Gnanasambandam, Ragini Chaluvadi, Srikrishna Bhashyam, IIT Madras, India

We obtain new sum capacity results for the Gaussian many-to-one and one-to-many interference channels in channel parameter regimes where the sum capacity was known only up to a constant gap. Simple Han-Kobayashi (HK) schemes, i.e., HK schemes with Gaussian signaling, no time-sharing, and no common-private power splitting, achieve sum capacity under the channel conditions for which the new results are obtained. To obtain sum capacity results, we show that genie-aided upper bounds match the achievable sum rate of simple HK schemes under certain channel conditions.

WA3a-3 9:05 AM

Energy-optimal Computational Offloading for Simplified Multiple Access Schemes

Mahsa Salmani, Timothy Davidson, McMaster University, Canada

Computation offloading is a promising approach to reducing the energy consumption or application execution time in mobile devices. In this paper, we consider a system in which two users offload their latency-constrained applications to a single access point. The system has a three time slot structure in which the users transmit simultaneously or separately, and we determine quasi-closed-form expressions for the transmission powers, the rates and the duration of each time slot to minimize the energy consumption of such a system when the simplified multiple access schemes time-division multiple access (TDMA), sequential decoding (without time sharing) and independent decoding are employed in the first time slot. The results enable us to examine how the shape of the achievable rate region of the chosen multiple access scheme influences the performance of that scheme under different conditions.

WA3a-4 9:30 AM

Echo State Transfer Learning for Data Correlation Aware Resource Allocation in Wireless Virtual Reality

Mingzhe Chen, Beijing University of Posts and Telecommunications, France; Walid Saad, Virginia Tech, United States; Changchuan Yin, Beijing University of Posts and Telecommunications, China; Me´rouane Debbah, Huawei France R & D, France

In this paper, the problem of data correlation aware resource management is studied for a network of wireless virtual reality (VR) users communicating over cloud-based small cell networks (SCNs). In this model, the small base stations (SBSs) with limited computation resource act as VR control centers that collect the tracking information from users over uplink and send them to the users over downlink. In such a setting, users may send or request the correlated data. This potential data correlation can be factored into the resource allocation problem in order to reduce the traffic load in both uplink and downlink. This resource allocation problem is formulated as a noncooperative game that allows jointly optimizing the computation and spectrum resources, while being cognizant of the data correlation. To solve this game, a transfer learning algorithm based on the echo state networks (ESNs) is proposed. Unlike conventional learning algorithms that need to be executed each time the environment changes, the proposed algorithm can transfer information on the learned utility, so as to adapt to environmental dynamics such as changes in data correlation. Simulation results show that the proposed algorithm achieves up to 18.2% gain in terms of delay compared to the Q-learning.

Track C – Networks

Session: WA3b – Signal Processing over Graphs and Networks

Chair: ***Antonio G. Marques,*** *King Juan Carlos University, Spain*

WA3b-1 10:15 AM

Time Estimation for Heat Diffusion on Graphs

Oguzhan Teke, P. P. Vaidyanathan, California Institute of Technology, United States

This paper studies the estimation of the starting time of a diffusion process from its noisy measurements when there is a single point source located on a known vertex of a graph with unknown starting time. The diffusion process is assumed to be governed by the heat equation. In particular, the Cramer-Rao lower bound (CRLB) for the problem is derived. It is shown that the problem has a larger CRLB for graphs with higher connectivity. Closed form expression of the bound is derived for some graphs. The ML estimator is numerically verified to be unbiased, and achieve the CRLB for some graphs.

WA3b-2 10:40 AM

Partial Embedding Distance for Networks

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

This paper presents methods to compare networks where relationships between pairs of nodes in a given network are defined. We define such network distance by searching for the optimal method to embed one network into another network, and prove that such distance is a valid metric in the space of networks modulo permutation isomorphisms. The network distance defined can be approximated via multi-dimensional scaling, however, the lack of structure in networks results in poor approximations. To alleviate such problem, we consider methods to define the interiors of networks. We show that comparing interiors induced from a pair of networks yields the same result as the actual network distance between the original networks. Practical implications are explored by showing the ability to discriminate networks generated by different models. This paper is eligible for the student paper award.

WA3b-3 11:05 AM

A Graph Diffusion LMS Strategy for Adaptive Graph Signal Processing

Roula Nassif, Cédric Richard, Université Nice Sophia Antipolis, France; Jie Chen, Northwestern Polytechnical University, China; Ali H. Sayed, University of California, United States

The massive deployment of distributed acquisition and signal processing systems, as well as the ubiquity of connected devices, is currently contributing to the development of graph signal processing. Nevertheless, this discipline still suffers from the lack of several theories and methods widely developed in signal processing. In particular, current research activities focus mainly on the processing of static graph signals (with respect to time) despite the natural anchoring in dynamic application contexts. We note, in fact, the lack of works on (on-line) identification of systems operating on streaming graph signals, and on adaptive algorithms to adapt to changes in their statistical properties over time. The objective of this paper is to introduce new tools for adaptive graph signal processing. In the first part, we propose an adaptive filtering method for streaming graph signals based on the LMS. Since this algorithm is centralized, we show how to distribute it across the graph nodes using diffusion adaptation. In the second part, we analyze the performance of the diffusion graph-LMS in both the mean and mean-square sense, as well as its stability.

Track H – Speech, Image and Video Processing

Session: WA4a – Computational Imaging

Chair: ***James Fowler,*** *Mississippi State University*

WA4a-1 8:15 AM

Physics-Driven Deep Training of Dictionary-Based Algorithms for MR Image Reconstruction

Saiprasad Ravishankar, Il Yong Chun, Jeffrey A. Fessler, University of Michigan, United States

Techniques involving learned dictionaries outperform conventional approaches involving analytical sparsifying models for MR image reconstruction. Inspired by iterative dictionary learning-based methods, we propose a novel efficient image reconstruction framework involving multiple iterations (layers). Each layer involves applying a transformation to image patches, thresholding, and then reconstructing the patches in a dictionary, followed by an update of the image using observed k-space data. We train the transforms, thresholds, and dictionaries within the multi-layer algorithm to minimize reconstruction errors. Our experiments demonstrate that for highly undersampled k-space data, such trained reconstruction algorithms provide high quality results.

WA4a-2 **8:40 AM**

Iterative Image Reconstruction for Neutron Laminography

Singanallur Venkatakrishnan, Ercan Cakmak, Hassina Billheux, Philip Bingham, Richard Archibald, Oak Ridge National Laboratory, United States

Neutron laminography, a variant of conventional tomography, where the sample is tilted and rotated in a manner that can image objects with unique shapes is important for emerging applications such as additive manufacturing. However, the data inversion can be challenging due to the non-traditional acquisition geometry combined with the imperfections in the detector system. In this paper, we present iterative reconstruction approaches for neutron laminography that formulate the reconstruction as optimizing a high dimensional cost function. We will compare different iterative reconstruction approaches and demonstrate how they can improve the quality of the reconstruction compared to the traditional back-projection type algorithm.

WA4a-3 **9:05 AM**

Computational Imaging with LORAKS: Reconstructing Linearly Predictable Signals using Low-Rank Matrix Regularization

Justin Haldar, University of Southern California, United States

Although many modern computational imaging approaches rely on sparse or low-rank modeling assumptions, it is worth remembering that many classical approaches relied on some form of linear predictability assumptions. Several years ago, we introduced the LORAKS framework, which views classical linear prediction models through the modern lens of low-rank matrix completion. LORAKS is based on the observation that linearly predictable data can be embedded into high-dimensional structured low-rank matrices. This enables a powerful and flexible new approach for imposing a range of important image reconstruction constraints. In this work, we review LORAKS and describe our recent progress in this area.

WA4a-4 **9:30 AM**

Physics Based Modeling for the Development of Soft Segmentation and Reconstruction Algorithms

Amirkoshyar Ziabari, Purdue University, United States; Jeffrey Rickman, Lehigh University, United States; Charles Bouman, Purdue University, United States; Jeff Simmons, Air Force Research Laboratory, United States

One of the most common regularizations in Computational Imaging is the Markov Random Field, derived from the Ising and Potts models of the early 20th Century. Since then, quantitative models of atomic interactions have been developed in solid-state physics as well as “coarse graining” approaches that give accurate energy predictions at the micron scale. Phase Field modeling uses both these advancements, and employs a continuous “field variable” for describing different classes of material. We propose a new regularization approach, using Phase Field as a prior, that incorporates physics-based parameter estimates for joint “soft segmentation” and for reconstruction algorithms that avoid discontinuities between region labels.

Track D – Signal Processing and Adaptive Systems

Session: WA4b – Deep Learning and Applications

Chair: ***Karl Ni,*** *In-Q-Tel*

WA4b-1 **10:15 AM**

Interleaver Design for Deep Neural Networks

Sourya Dey, Peter A. Beerel, Keith M. Chugg, University of Southern California, United States

We propose a class of interleavers for a novel deep neural network (DNN) architecture that uses algorithmically pre-determined, structured sparsity to significantly lower memory and computational requirements, and speed up training. The interleavers guarantee clash-free memory accesses to eliminate idle operational cycles, trade-off spread and dispersion to improve network performance, and are designed to be implemented in hardware with minimal space complexity. We present a design algorithm with mathematical proofs for these properties. We also explore interleaver variations and analyze the behavior of neural networks as a function of interleaver metrics.

WA4b-2 **10:40 AM**

On Noise Reduction for Handwritten Writer Identification

Karl Ni, Patrick Callier, Bradley Hatch, In-Q-Tel, United States

Academic work in identifying writers of handwritten documents has previously focused on clean benchmark datasets:plain white documents with uniform writing instruments. Solutions on this type of data have achieved hit-in-top-10 accuracy rates reaching upwards of 98%. Unfortunately, transfer-ring competitive techniques to handwritten documents with noise is nontrivial,

where performance drops by two-thirds.Noise in the context of handwritten documents can manifest itself in many ways, from irrelevant structured additions, e.g.,graph paper, to unstructured partial occlusion, e.g. coffee stains and stamps. Additional issues that confound algorithmic writer identification solutions include the use of different writing implement, age, and writing state of mind. The proposed work explores training denoising neural networks to aid in identifying authors of handwritten documents. Our algorithms are trained on existing clean datasets artificially augmented with noise, and we evaluate them on a commissioned dataset, which features a diverse but balanced set of writers, writing implements, and writing substrates (incorporating various types of noise). Using the proposed denoising algorithm, we exceed the state of the art in writer identification of noisy handwritten documents by a significant margin.

WA4b-3 11:05 AM

Association of Emitter and Emission Using Deep Learning

Trevor Landeen, Jake Gunther, Todd Moon, Utah State University, United States; David Ohm, Robert North, KickView, United States

This paper addresses the fusion of heterogeneous multi-sensor data to answer the question: Which object emitted which signal? Object detection in images provides hypothesized emitter locations. Signal processing on multiple received RF signlas provides time difference of arrivals. Deep neural networks (DNNs) are trained to learn the probability of association. The paper discusses the structure, training, refinement and performance of DNNs for the association problem.

Track E – Array Signal Processing

Session: WA5a – Information Limits and Signals Representations

Chair: ***Massimo Franceschetti,*** *University of California, San Diego*

WA5a-1 8:15 AM

I-MMSE Relationships under Random Linear Mixing

Galen Reeves, Duke University, United States

Models using random linear mixing have been used to study compressed sensing, matrix factorization, and multi-layer generalized linear networks. This talk discusses fundamental relationships between the mutual information and minimum mean square error (MMSE) in these models. These relationships can be used to characterize fundamental phase transitions. Connections with free probability theory are discussed.

WA5a-2 8:40 AM

Non-Smooth Convex Optimization and Structured Signal Recovery

Ehsan Abbasi, Babak Hassibi, California Institute of Technology, United States

In the past couple of decades, non-smooth convex optimization has emerged as a powerful tool for the recovery of structured signals (sparse, low rank, etc.) from possibly) noisy measurements in a variety applications in statistics, signal processing, machine learning, etc. While the algorithms (basis pursuit, LASSO, etc.) are fairly well established, rigorous frameworks for the exact analysis of the performance of such methods are only just emerging. We develop and describe a fairly general theory for how to determine the performance (minimum number of measurements, mean-square-error, etc.) of such methods for various measurement ensembles (Gaussian, Haar, etc.). The theory includes all earlier results as special cases. It builds on a 1962 lemma of Slepian (on comparing Gaussian processes), as well as on a non-trivial generalization due to Gordon in 1988, and introduces concepts from convex geometry (such as Gaussian widths) in a very natural way.

WA5a-3 9:05 AM

Completely Blind Sensing for Robust Recovery of Multi-Band Signals

Taehyung Lim, Massimo Franceschetti, University of California, San Diego, United States

We consider the problem of robust recovery of multi-band signals from measurements, without any spectral information beside the measure of the whole support set in the frequency domain. Usually partially blind sensing is performed, assuming to have some partial spectral information available a priori. We provide an answer for the completely blind sensing problem, deriving the minimum number of measurements to guarantee robust reconstruction. Our results show that a factor of two in the measurement rate is the price pay for blindness, compared to reconstruction with full spectral knowledge. The minimum number of measurements is also related to the fractal (Minkowski-Bouligand) dimension of a discrete approximating set, defined in terms of the Kolmogorov ϵ-entropy. A comparison with analogous results in compressed sensing is illustrated, where the relevant dimensionality notion in a stochastic setting is the information (R\'{e}nyi) dimension, defined in terms of the Shannon entropy.

WA5a-4 **9:30 AM**

Off the grid Sparse Recovery in Bilinear Inverse Problems: Fundamental Limits and Algorithms

Yanjun Li, Yoram Bresler, University of Illinois at Urbana-Champaign, United States

Bilinear inverse problems (BLIPs) arise in many applications. Two classical examples of such problems are blind deconvolution, and blind gain and phase calibration (BGPC). Blind deconvolution arises in blind image deblurring, blind channel equalization, speech dereverberation, and seismic data analysis. BGPC in of interest in blind albedo estimation in inverse rendering, in sensor array processing with miscalibrated arrays, in multichannel blind deconvolution, and in synthetic aperture radar autofocus.
In certain cases, low dimensionality or sparsity constraints alleviate the ill-posedness of BLIPs. Recently, optimal sample complexity results and recovery algorithms have been derived for blind deconvolution and for BGPC, assuming signal sparsity. The results are applicable to discrete-index signals, or to continuous index signals with non-zero components lying on a grid. However, in many important applications, the signals are continuous index signals, where the sparse components may be located off the grid. While there are quite a few results for off the grid sparse recovery for compressed sensing in linear inverse problems, there are few results for the bilinear counterpart, and the ones available are not optimal in sample complexity. In this paper we examine this scenario for BLIPs, studying fundamental conditions on sample complexity and efficient recovery algorithms.

Track E – Array Signal Processing

Session: WA5b – Array Signal Processing Algorithms

Chair: ***Piya Pal,*** *University of California, San Diego*

WA5b-1 **10:15 AM**

MUSIC and Ramanujan: MUSIC-like Algorithms for Integer Periods Using Nested-Periodic-Subspaces

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

Can the MUSIC algorithm be used for period estimation? Prior works in this direction were based on modifying the search over the conventional complex-exponentials based pseudospectrum to look for harmonically spaced peaks. For applications where the period of the discrete signal can be well approximated by integers, this paper proposes much simpler integer valued basis functions. It is shown that this new re-formulation of MUSIC not only makes the pseudo-spectrum computation much simpler, but also offers significantly higher accuracy than the conventional techniques, especially for mixtures of periodic signals.

WA5b-2 **10:40 AM**

Underwater Acoustic Source Localization using Unimodal-constrained Matrix Factorization

Junting Chen, Urbashi Mitra, University of Southern California, United States

This paper studies simultaneous multiple source localization based on a modest number of energy measurements in different locations, while no specific knowledge of the source signature is assumed, nor does it exploit a particular energy decay model, except for a general unimodal structure. The localization problem is modeled as a matrix factorization problem to recover the column-wise unimodal structure that corresponds to the signatures of the sources. Two practical challenges are addressed. First, a fast approximate unimodal projection algorithm is developed, which is demonstrated to have only marginal perfor- mance loss. Second, convergence enhancement of the factorization algorithm is studied and a method based on optimizing the coordinate system for the sample matrix is developed. Numerical results demonstrate good localization performance in spite of the original factorization problem being non-convex.

WA5b-3 **11:05 AM**

Leveraging Massive MIMO Spatial Degrees of Freedom to Reduce Random Access Delay

Fatima Ahsan, Ashutosh Sabharwal, Rice University, United States

Random access is a crucial building block for nearly all wireless networks, and impacts both the overall spectral efficiency and latency in communication. In this paper, we show that the spatial degrees of freedom, e.g.\ available in massive MIMO systems, can potentially be leveraged to reduce random access latency. Using one-ring propagation model, we show that random access collision probability depends on the aperture of the array and the ``cone" of angle-of-arrivals. Practically, large arrays in outdoor environments can significantly reduce collision probability and thereby result in higher efficiency of random access.

Session: WA6a – Signal Processing for Hearing Aids

Chair: ***Harinath Garudadri,*** *University of California, San Diego*

WA6a-1 8:15 AM

A Robust Adaptive Binaural Beamformer for Hearing Aids

Jinjun Xiao, Tom Luo, Ivo Merks, Tao Zhang, Starkey Hearing Technologies, United States

In a hearing aid application, the performance of an adaptive binaural beamformer is sensitive to errors in the acoustic transfer function or noise estimation. The estimation errors can be caused by factors including the user's head movement, non-stationarity of the environment, or imperfect array calibration. With these inaccurate estimates, the beamformer not only provides less noise reduction, but also causes undesirable target speech distortions. Thus robust beamforming algorithms are needed to improve the beamformer's performance in such conditions. In particular, to minimize the speech distortions caused by imperfect look direction estimation, a robust binaural beamforming algorithm was presented at WASPAA (Liao et al., 2015). This paper aims to evaluate the proposed binaural beamforming algorithm by comparing its performance with the Minimum Variance Distortionless Response (MVDR) beamformer in various noisy environments. The benefit of the proposed algorithm is demonstrated through both objective and subjective evaluations. Specifically, multiple-microphone recordings on a pair of binaural hearing aids on a mannequin are used. Objective perception scores are calculated and compared. A subjective evaluation of speech intelligibility using normal-hearing listeners is conducted. Both the objective and subjective evaluation results confirm the robustness of the proposed algorithm.

WA6a-2 8:40 AM

Noise Suppression and Speech Enhancement for Hearing Aid Applications using Smartphones

Issa M.S. Panahi, Chandan K. A. Reddy, Linda Thibodeau, University of Texas at Dallas, United States

In our research, smartphone is used as a powerful platform to implement complex signal processing algorithms for improving hearing aid applications. As part of the hearing aid signal processing pipeline is speech enhancement (SE) algorithm aimed at suppressing the noise and enhancing the speech. Measures used in evaluating the performance of a SE algorithm include; (a) the quality of processed signal representing the attenuation level of noise and the type and amount of residual noise, and (b) the intelligibility or perception of enhanced speech signal representing the speech distortion level and the effect of interfering residual noise. Achieving high quality and high perception of speech simultaneously presents challenging problem in developing a SE algorithm for varying types of noise and signal to noise ratios (SNRs). A solution could be developing and using different SE algorithms based on the type and intensity of noise. In this paper, we present a review of some SE algorithms developed for operating under different noise types and SNRs. These algorithms are aimed to improve the quality and perception of speech for hearing aid users through their real-time implementations on smartphones. Performance of these algorithms are presented and compared using various objective and subjective tests.

WA6a-3 9:05 AM

Improving Auditory Externalization for Hearing-Aid Remote Microphones

James Kates, Kathryn Arehart, University of Colorado, Boulder, United States

Combining a remote wireless microphone (RM) with hearing aids often improves speech intelligibility for hearing-impaired listeners. However, the head-related acoustic cues that contribute to sound externalization are bypassed when a direct signal link is used. The result is an apparent sound source located within the head of the listener rather than at the talker position. This presentation describes using a structural binaural model combined with simulated room reverberation to produce an externalized RM sound source. The simulated room reverberation uses a two-dimensional virtual image model. The binaural model simulates sound propagation around the head, the reflections generated by the pinna, the directional filtering provided by the pinna protrusion from the head, and the ear-canal resonance. Externalization judgments were obtained for normal-hearing (NH) and hearing-impaired (HI) subjects listening through headphones. The stimuli were sentences processed through the binaural model plus reverberation in comparison with no processing, the listener's own anechoic head-related impulse response (HRIR), and the listener's HRIR including room reverberation. The results show that externalization for both NH and HI listeners using the structured binaural model is comparable to that obtained when using the listeners' own HRIR.

WA6a-4 9:30 AM

A Realtime, Open Speech Platform for Research in Hearing Loss Compensation

Harinath Garudadri, University of California, San Diego, United States; Arthur Boothroyd, San Diego State University, United States; Chinghua Lee, Swaroop Gadiyaram, Justyn Bell, Dhiman Sengupta, Sean Hamilton, Krishna Chaitanya Vastare, Rajesh Gupta, Bhaskar Rao, University of California, San Diego, United States

We are developing a realtime, wearable, open speech platform (OSP) that can be configured at compile and run times by audiologists and hearing aid (HA) researchers to investigate advanced HA algorithms in field studies. The goals of this contribution are to present the current system and propose areas for enhancements and extensions. We identify (i) basic and (ii) advanced features in commercial HAs and describe current signal processing libraries and reference designs to build a functional HA. We present performance of this system and compare with commercial HAs using "Specification of Hearing Aid Characteristics," the ANSI 3.22 standard. We then describe the wireless protocol stack for remote control of the HA parameters and uploading media and HA status for offline research. The proposed architecture enables advanced research to compensate for hearing loss by offloading processing from ear-level-assemblies, thereby eliminating the bottlenecks of CPU and communication between left and right HAs.

Track F – Biomedical Signal and Image Processing

Session: WA6b – Neural Signal Processing

Chair: ***Behnaam Aazhang,*** *Rice University*

WA6b-1 10:15 AM

Data-Driven Estimation of Mutual Information using Frequency Domain and its Application to Epilepsy

Rakesh Malladi, LinkedIn and Rice University, United States; Don Johnson, Rice University, United States; Giridhar Kalamangalam, Nitin Tandon, University of Texas Health Science Center, United States; Behnaam Aazhang, Rice University, United States

We consider the problem of estimating mutual information between dependent data, an important problem in many science and engineering applications. We propose a data-driven estimator of mutual information in this paper. The main novelty of our solution lies in transforming the data to frequency domain to make the problem tractable. We define a novel metric–mutual information in frequency (MI-in-frequency)–to detect and quantify the dependence between two random processes across frequency using Cramer's spectral representation. Our solution calculates mutual information as a function of frequency to estimate the mutual information between the dependent data over time and validate its performance on linear and nonlinear models. We then use our MI-in-frequency metric to infer the cross-frequency coupling during epileptic seizures, by analyzing electrocorticographic recordings from a total of eleven seizures in four medial temporal lobe epilepsy patients.

WA6b-2 10:40 AM

An Autoregressive Approach to Inference in Populations of Correlated Stochastic Neurons

Alireza Sheikhattar, University of Maryland, College Park, United States; Siamak Sorooshyari, Ellipsis Health, United States; Behtash Babadi, University of Maryland, College Park, United States

In this paper, we study the correlated neuronal activity caused by afferent inputs from distinct and common population of pre-synaptic neurons. We present a method based on the integration of the expectation-maximization algorithm, Kalman filtering and backward smoothing in order to estimate the parameters associated with pre-synaptic activity and the latent common inputs from post-synaptic measurements. We provide simulation results that validate the performance of the proposed methodology in terms of parameter estimation and tracking the dynamics of the common pre-synaptic inputs.

WA6b-3 11:05 AM

Multiplicative Updates for Optimization Problems with Dynamics

Abbas Kazemipour, Behtash Babadi, Min Wu, University of Maryland, United States; Kaspar Podgorski, Shaul Druckmann, Janelia Research Campus, United States

We consider the problem of optimizing general convex objective functions with nonnegativity constraints. Using the Karush-Kuhn-Tucker (KKT) conditions for the nonnegativity constraints we will derive fast multiplicative update rules for several problems of interest in signal processing, including nonnegative deconvolution, point-process smoothing, ML estimation for Poisson Observations, nonnegative least squares and nonnegative matrix factorization (NMF). Our algorithm can also account for temporal and spatial structure and regularization . We will analyze the performance of our algorithm on simultaneously recorded neuronal calcium imaging and electrophysiology data.

Session: WA7a – Hardware Design for Machine Learning

Co-Chairs: ***David Brooks,*** *Harvard University* ***and Paul Whatmough,*** *Harvard University*

WA7a-1 8:15 AM

Minimizing Area and Power of Deep Learning Hardware Design Using Binarization and Structured Compression

Shihui Yin, Deepak Kadetotad, Gaurav Srivastava, Minkyu Kim, Ming Tu, Chaitali Chakrabarti, Visar Berisha, Jae-sun Seo, Arizona State University, United States

Deep learning algorithms have shown tremendous success in many recognition tasks, but typically includes a deep network structure and excessive number of parameters, which makes it challenging to implement them on power-/area-constrained embedded platforms. To reduce the network size, a number of works investigated compression by introducing element-wise or row-/column-/block-wise sparsity via pruning and different types of regularization. In addition, reducing precision of activations and weights has been a common practice, but recent works have been able to reduce the activations and weights down to a single bit. However, the combining various sparsity structures with binarized or very-low-precision (2-3 bit) neural networks have been yet explored comprehensively. In this work, we present design techniques exploring and designing the minimum-area/-power deep neural network hardware with minimal degradation in accuracy. During training, both binarization and structured sparsity are applied as constraints to find the smallest memory footprint for a given deep learning algorithm. Experimental results on image classification hardware design in 40nm CMOS are reported for MNIST and CIFAR-10 datasets, and the area, performance, and power consumption will be discussed.

WA7a-2 8:40 AM

Sub-uJ Deep Neural Networks for Embedded Applications

Paul Whatmough, Sae Kyu Lee, Gu-Yeon Wei, David Brooks, Harvard University, United States

Sensor-rich IoT and Mobile devices interpret the world around them through classification of noisy data. Deep neural networks (DNNs) are a mature machine learning model, well suited to such general purpose classifications tasks. However, DNNs require a large compute load and memory footprint. Achieving sufficient energy efficiency for DNN inference tasks necessitates specialized hardware and efficient circuits. We present an efficient SIMD microarchitecture for DNN acceleration, which demonstrates a number of architectural and circuit techniques including support for small datatypes, sparse data, and fault tolerance. Silicon measurements for the accelerator show energy efficiency of less than a micro-joule per invocation.

WA7a-3 9:05 AM

How to Estimate the Energy Consumption of Deep Neural Networks

Tien-Ju Yang, Yu-Hsin Chen, Massachusetts Institute of Technology, United States; Joel Emer, Massachusetts Institute of Technology/Nvidia, United States; Vivienne Sze, Massachusetts Institute of Technology, United States

Abstract: Deep Neural Networks (DNN) have enabled state-of-the-art accuracy on many challenging artificial intelligence tasks. While most of the computation currently resides on the cloud, it is desirable to embed DNN processing locally near the sensor due to privacy, security, and latency concerns or limitations in communication bandwidth. Accordingly, there has been increasing interest in the research community to design energy-efficient DNN models. However, estimating energy consumption from the DNN model is much more difficult than other metrics such as storage cost (model size) and throughput (number of operations). This is due to the fact that a significant portion of the energy is consumed by data movement, which is difficult to extract directly from the DNN model. This work proposes an energy-modeling methodology that can estimate the energy consumption of a DNN model based on its architecture, sparsity, and bitwidth. This methodology can be used to evaluate the various network architectures and energy-efficient techniques that are currently being proposed in the field. We believe that this methodology will play a critical role in bridging the gap between algorithm and hardware design and provide useful insights for the development energy-efficient DNN models.

WA7a-4 9:30 AM

Hardware-Algorithm-Application Co-Design for Efficient Embedded Deep Inference

Bert Moons, Marian Verhelst, KU Leuven, Belgium

Deep Neural Networks (DNN) are state-of-the-art classification algorithms, achieving super-human performance in Computer Vision. Yet, advanced neural nets are too expensive in terms of energy consumption for always-on embedded applications, due to their high computational complexity and bandwidth requirements. However, the exceptional capabilities of DNN's can be brought within the power envelope and energy budget of battery-constrained embedded systems by co-designing and co-optimizing the embedded hardware platform, together with the DNN-algorithm and higher-level application. In this work we

illustrate this principle for a hierarchical face-recognition pipeline without sliding windows, enabled only by DNN's, offering an order of magnitude of energy-savings compared to classical approaches. This application employs custom designed DNN's, trained for inference at limited computational precision, allowing them to be mapped efficiently on our dedicated hardware platforms. The energy-savings introduced by this cross-optimization enables always-on DNN-based recognition in wearable and future IoT devices.

Track H – Speech, Image and Video Processing

Session: WA7b – Video Processing

Co-Chairs: ***Ioannis Schizas,*** *University of Texas at Arlington* ***and Guohua Ren,*** *University of Texas at Arlington*

WA7b-1 — 10:15 AM

Multi-Object Detection and Tracking via Kernel Covariance Factorization in Thermal Video

Guohua Ren, Ioannis Schizas, University of Texas at Arlington, United States

This paper addresses the problem of joint object detection and tracking in thermal videos. Object detection is formulated as a sparse factorization task of a properly defined kernel covariance matrix. The support of these estimated factors is used to determine the indices of the pixels that form each object. A coordinate descent approach is utilized to determine the sparse factors, and extract the object pixels. For each object, the centroid pixel is subsequently tracked via Kalman filtering. A novel interplay between the sparse kernel covariance factorization scheme along with Kalman filtering is proposed to enable joint object detection and tracking, while a divide and conquer strategy is put forth to reduce computational complexity in tracking. Numerical tests demonstrate the improved tracking performance over existing alternatives.

WA7b-2 — 10:40 AM

Interactive Image and Video Classification using Compressively Sensed Images

Jaclynn Stubbs, Marios Pattichis, Gabriel Birch, University of New Mexico, United States

The paper investigates the use of compressively sensed images in interactive image classification. To speed-up the classification process, we consider the use of a reduced complexity, feed-forward neural network with a reduced number of sensed image features. Then, to dramatically reduce training time, we consider the use of transfer learning from a system pre-trained with regular images to images reconstructed from compressively sensed images. The interactive image and video classification systems have been used for real-time demonstrations that have been effectively utilized in outreach activities for attracting middle-school students to STEM.

WA7b-3 — 11:05 AM

Motion-Aware Video Quality Assessment

Marina Georgia Arvanitidou, Thomas Sikora, Technische Universität Berlin, Germany

This work focuses on considering motion towards improving video quality assessment algorithms. The improvement refers to improving computational video quality assessment algorithms in order to be in closer agreement with the subjective evaluation of video quality. We propose a motion saliency model that exploits motion features on spatial level and also an approach for consideration of global motion in the temporal dimension, leading to further improvements in the accuracy of video quality assessment. We perform evaluation by integrating them in existing objective quality models and also by comparing them to existing related state-of-the-art methods.

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

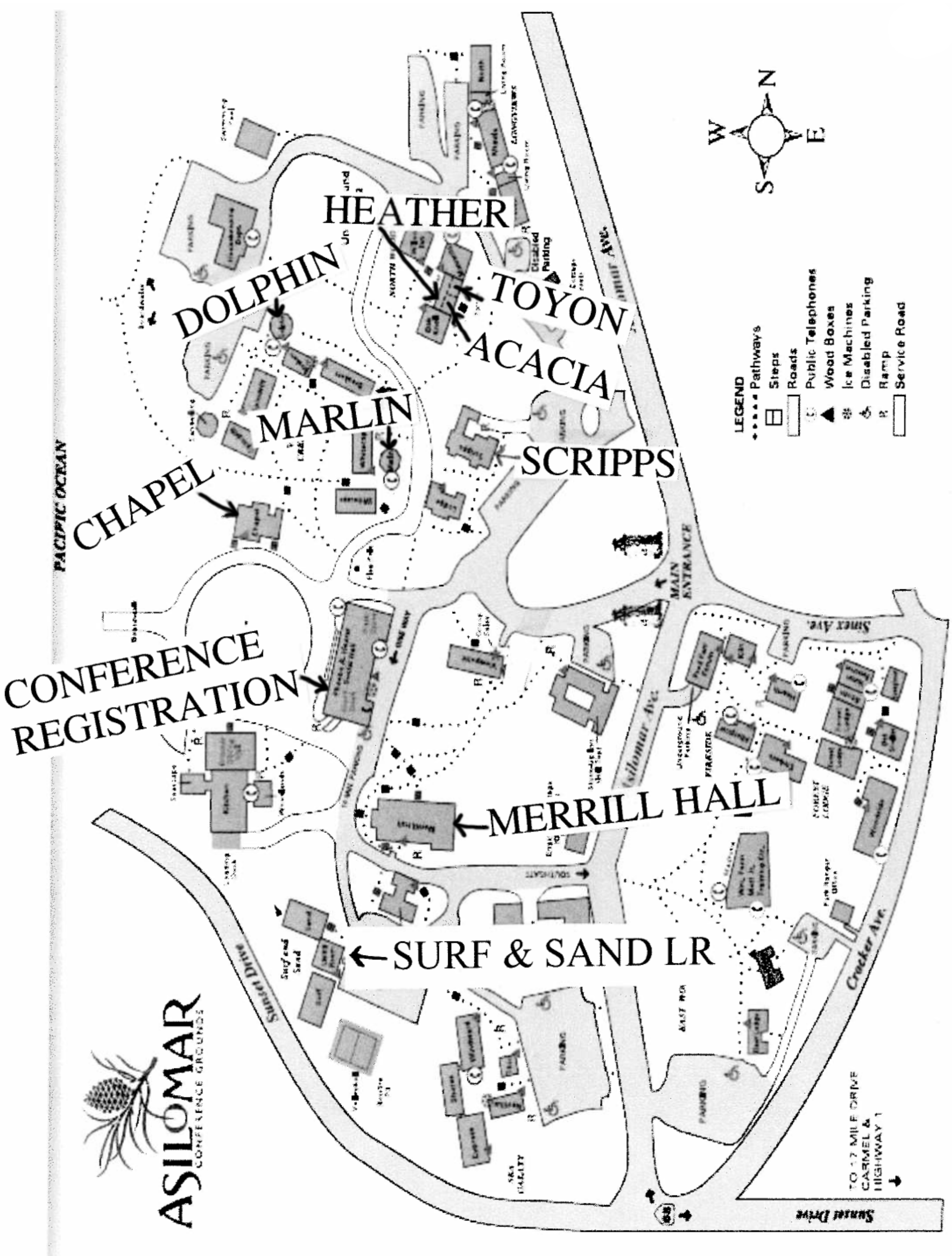
AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

AUTHOR LIST

NAME SESSION NAME SESSION



HEATHER
DOLPHIN
TOYON
ACACIA
MARLIN
SCRIPPS
CHAPEL
CONFERENCE
REGISTRATION
MERRILL HALL
SURF & SAND LR
PACIFIC OCEAN
MAIN ENTRANCE
Asilomar Ave.
Sinex Ave.
Crocker Ave.
Sunset Drive
ASILOMAR
CONFERENCE GROUNDS
N
S
E
W
LEGEND
Pathways
Steps
Roads
Public Telephones
Wood Boxes
Ice Machines
Disabled Parking
Ramp
Service Road
TO 17 MILE DRIVE
CARMEL &
HIGHWAY 1