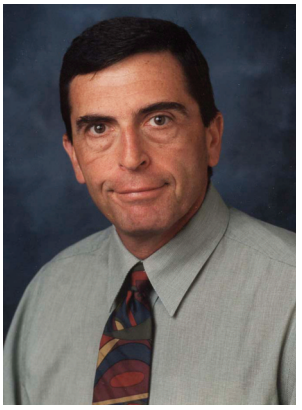
# 2016 ANNUAL RESEARCH DAY

# The Elisha Yegal Bar-Ness Center for Wireless Communications and Signal Processing Research

*Tuesday, March 29, 2016*

# *Welcome to the Center for Wireless Communications and Signal Processing Research (CWCSPR) Research Day 2016!*



*The Elisha Yegal Bar-Ness Center for Wireless Communications and Signal Processing Research (CWCSPR) at NJIT was founded in 1985 by Professor Yeheskel Bar-Ness, who also served as its director until 2014. Since its inception, it has contributed to technological advances in many areas of communications and signal processing. Research activity in the Center has grown over the years and diversified into new research fields. Current main areas of research are wireless networking, information theory, cloud radio access networks, radar and sensor networks.*

*The Center serves as a collaboration hub of faculty, visiting scholars, postdoctoral fellows, graduate and undergraduate students. The Center routinely hosts visiting scholars from overseas. Several students pursue double Ph.D. programs according to agreements between NJIT and other universities.*

*The theme of the Research Day is "Meeting the 5G Challenges." The development of 5G wireless technologies is driven by convergent trends: the expected huge increase in the number of machine-to-machine wireless connections as the Internet of Things is taking shape, the proliferation of cloud-based services, advances in consumer electronics that will require ultra- high definition communication and high-definition multimedia interactions, vehicular connectivity and others. Presentations by faculty affiliated with the Center and other ECE faculty showcase research addressing the challenges posed by the next generation of mobile networks. The presentations cover a broad range of topics such as error control strategies, cloud processing, geolocation, optical filters and others. The keynote address will be provided by Dr. Robert A. Soni, System Architecture and Engineering Leader, Common R&D Mobile Networks Group, Nokia.*

*I wish you a pleasant experience at NJIT.*

*Sincerely,*

*Alexander M. Haimovich*
*Director, CWCSPR*

# CWCSPR Research Day 2016

## Meeting the 5G Challenges

Tuesday, March 29, 2016
NJIT Campus Center Atrium, University Heights, Newark, N.J. 07102

## Program

| | |
|---|---|
| 9:50-10 a.m. | **Welcoming Remarks**<br>Dr. Moshe Kam, Dean, Newark College of Engineering |
| | **Morning Session Faculty Presentations** |
| 10-10:20 a.m. | **Fog-aided Wireless Networks**<br>Osvaldo Simeone |
| 10:20-10:40 a.m. | **Localization of Unknown Signals Over Multipath Channels**<br>Alexander Haimovich |
| 10:40-11 a.m. | **Coding for Leveraging Network Gains in 5G**<br>Joerg Kliewer |
| 11-11:15 a.m. | **Break** |

| | |
|---|---|
| 11:15 a.m.-12:15 p.m. | **Keynote Speaker**<br>**5G–An Evolution or a Revolution–In Cellular Communication?**<br>Robert A. Soni, Ph.D.<br>*Bell Labs Fellow*<br>*System Architecture and Engineering Leader,*<br>*Common R&D Mobile Networks Group, Nokia* |
| 12:15–1 p.m. | **Lunch** |
| | **Afternoon Session Faculty Presentations** |
| 1-1:20 p.m. | **Optical Filters: From the Near IR Wavelength Range to THz Frequencies**<br>Haim Grebel |
| 1:20-1:40 p.m. | **Fast IP Address Lookup Using Helicoidal Properties of Binary Trees and Parallel Prefix Matching**<br>Roberto Rojas-Cessa |
| 1:40-2 p.m. | **Challenges of Borehole Communication in Oil Wells**<br>Ali Abdi |

Co-sponsored by IEEE North Jersey Section, COMSOC, IT and VTS Chapter

# Keynote Speaker

**Robert A. Soni, Ph.D.**
*Bell Labs Fellow*
*System Architecture and Engineering Leader*
*Common R&D Mobile Networks Group, Nokia*

Robert Soni works at Nokia in Murray Hill, New Jersey. He leads the Wireless System Architecture and Engineering team distributed globally in Nokia's R&D facilities. He received the Bell Labs Fellow Honor in 2009 from the Management Committee of Alcatel-Lucent. He has published more than 50 conference papers and journal articles. He has more than 50 patents to his name. He has also taught classes in signal processing, communications theory and information theory at NJIT. He received his Ph.D. in Electrical Engineering from the University of Illinois at Urbana-Champaign in 1998, Master of Electrical Engineering in 1995, and a Bachelor of Electrical Engineering from the University of Cincinnati in 1992.

## 5G–An Evolution or a Revolution–In Cellular Communication?

Today, all major North American operators have announced accelerated plans for the availability of fifth-generation cellular-access technology, aka 5G. The question really has become what exactly do they plan to launch? How does it differ from 4G? Is it even defined yet? Cellular communication has become a pervasive part of our lives, and the extensive reach and coverage of the networks globally—have allowed individuals, businesses, and enterprises to change their communication methods, the speed at which they do things, and finally their lives. 5G brings with it the promise of "this and more" by leveraging additional spectrum in higher frequencies, targeting and bringing even higher rates— that are competitive with fiber access technologies and ultra-low latency—to enable virtual reality, gaming, and even remote surgery as well as improved support for the burgeoning cellular Internet of Things (IOT) solution. There are also significant technology trends underpinning this migration from today's sophisticated cellular technology shift to open-source, open-compute and open API-based solutions to give the opportunity to launch more than voice and broadband services. We will also dig deeper into the underlying technology advances that help enable this including in particular waveform changes and massive MIMO technology. The real question though becomes—that while 5G introduces potentially significant changes—4G LTE continues to advance. We will discuss the parallel effort to evolve 4G—and how it compares with the "revolution" associated with 5G.

# Faculty Research Presentations

## Fog-Aided Wireless Networks

*Osvaldo Simeone*

Fog-aided wireless networks constitute an emerging class of wireless systems that leverages the synergy and complementarity of cloudification and edge processing, two key technologies in the evolution toward 5G systems and beyond. Fog-aided wireless networks can reap the benefits of centralization via cloud processing, in terms of capital and operating-cost reductions, greening and enhanced spectral efficiency, while at the same time being able to cater to low-latency applications, such as the "tactile" Internet, by means of localized intelligence at the network edge. The operation of fog-aided wireless networks poses novel fundamental research problems pertaining to the optimal management of the communication, caching and computing resources at the cloud and at the edge, as well as to the transmission on the fronthaul network connecting cloud and edge. In this talk, an information-theoretical framework is presented with the main aim of guiding engineering choices and distilling design principles.

## Localization of Unknown Signals Over Multipath Channels

*Alexander Haimovich*

Localization of radio-frequency sources over multipath channels is a difficult problem arising in applications such as outdoor or indoor geolocation. Common approaches that combine ad-hoc methods for multipath mitigation with indirect localization relying on intermediary parameters such as time-of-arrivals, time difference of arrivals or received signal strengths, provide limited performance and are unsuitable when the source signals are unknown. This work models the localization of unknown waveforms over unknown multipath channels in a sparse framework, and develops a direct approach in which multiple sources are localized jointly, directly from observations obtained at distributed sensors. Since the signals transmitted from the emitters are unknown, the proposed approach leverages the covariance matrix of the received signals. To achieve this, a second-order cone-based optimization problem is developed to find the signals with a covariance matrix that is the closest in a norm sense to the covariance matrix of the received signals. It is shown that the proposed localization method produces high accuracy location estimates over complex scenes, in which emitters are subject to diverse multipath conditions.

## Coding for Leveraging Network Gains in 5G

*Joerg Kliewer*

During the next couple of years, an exponential increase of data use per capita will be experienced. For example, a prediction from Cisco Systems states that the global per-capita information usage will grow from 15.5GB in 2014 to 37GB in 2019. In order to support this major data increase, further technological advances will be required to increase the bit-carrying capacity of the telecommunications infrastructure. Improvements for error-correcting codes have been mostly limited to the point-to-point case, and maximizing coding gains for the point-to-point channel setup will not be sufficient to satisfy the throughput requirements of emerging communication systems, such as 5G cellular. Moreover, in contrast to improvements in network communication performance, relatively little attention has been paid so far on how data compression can reduce the network traffic. This talk attempts to provide some insight into these problems and outlines practical low-complexity low-latency sparse graph codes, which are able to leverage network gains for distributed error correction and source compression.

## Optical Filters: From the Near IR Wavelength Range to THz Frequencies

*Haim Grebel*

There are several factors contributing to the increased interest in infrared (IR), and far-IR detection. Some applications are military oriented: (1) IR and in particular, far-IR radiation (namely, THz and mm-waves) are readily transmitted through most nonmetallic and relatively dry environments (aka, "see through" systems). (2) Many materials of interest, such as explosives, chemical and biological agents have fingerprints in the IR and THz spectral regions. (3) IR and far-IR radiation poses either no or minimal health risk. In addition, environmental and medical applications make these spectral regions very appealing. These applications aim mainly at absorption or emission of electromagnetic radiation. Recently though, larger communication bandwidths are driving the channel carrier frequencies closer to the THz frequency range. These applications require good filters. This talk will describe new types of optical filters that are applicable to the IR and far-IR wavelength region.

## Fast IP Address Lookup Using Helicoidal Properties of Binary Trees and Parallel Prefix Matching

*Roberto Rojas-Cessa*

In this presentation, we discuss the problem of Internet Protocol (IP) address lookup and the challenges that have persisted for a long time. We focus on schemes based on binary trees, which are known to be lagging in lookup speed as compared to content-addressable memory solutions. We present a recently designed IP lookup scheme, called Helix, that performs parallel prefix matching at the different prefix lengths and uses the helicoidal properties of binary trees to reduce their height. Helix minimizes the amount of memory used to store long and numerous prefixes and achieves IP lookup and route updates in a single memory access. We show the evaluations of the performance of Helix with several IPv4 and IPv6 forwarding tables.

## Challenges of Borehole Communication in Oil Wells

*Ali Abdi*

To extract oil from underground reservoirs, a well needs to be drilled using a long drill string. During the drilling process, real-time transmission of important data such as temperature, pressure, torque, drilling direction, etc., from downhole to the surface, is of high importance. Such data allows the driller to closely monitor the process, change the drilling direction, adjust the penetration rate, etc., to minimize the failure chance of the costly operation and the machines. Since boreholes are typically very deep, several thousand feet or more, wired communication is very expensive and prone to failure. On the other hand, wireless electromagnetic-based and mud-based methods can provide only very low data rates, typically a few bits per second. Acoustic transmission, however, can offer higher data rates. In this talk, some challenges of communication through drill pipes will be discussed, and some channel characteristics will be presented.

# Poster Presentations

## A Study of the Channel for Communication via Drill Strings in Oil Wells

*Ali Alenezi, Ph.D. Student, and Ali Abdi*

Communication thru drill strings using acoustic waves is a promising method for uphole and downhole data transmission. The drill string behaves similarly to a channel with many passbands and stopbands. In this work, different characteristics of the channel are studied. Behavior of the channel in terms of some physical parameters of the system is investigated as well. The goal is to utilize certain channel features for more effective communication.

## Experimental Results on Underwater Communication in Particle Velocity Channels

*Erjian (Eric) Zhang, Ph.D. Student, and Ali Abdi*

The commonly used underwater communication channel is the acoustic pressure channel, which is the scalar component of the acoustic field. Acoustic particle velocity channels, which are vector components of the acoustic field, are used together with the acoustic pressure channel, to increase the transmission rate and also improve the signal-to-noise ratio in proposed work. Experimental results on underwater communication via particle velocity channels are provided. Acoustic vector transducers, devices that can excite or measure the vector and scalar components of the acoustic field, are used in our experiments. Here we show how a compact vector transducer can be used either as a multichannel transmitter or a multichannel receiver for underwater communication. Without loss of generality, we have used frequency shift keying as a simple modulation scheme to demonstrate the feasibility of underwater communication in particle velocity channels via vector transducers. Comparisons are also made with systems that utilize scalar transducers only.

## Green Cloudlet Networks: A Sustainable and Efficient Mobile Cloud Computing Architecture

*Xiang Sun, Ph.D. Student, and Nirwan Ansari*

We propose a Green Cloudlet Network (GCN) architecture to provide seamless Mobile Cloud Computing (MCC) services to User Equipments (UEs) with low latency in which each cloudlet is powered by both green and brown energy. Fully utilizing green energy can significantly reduce the operational cost of cloudlet providers. However, owing to the spatial dynamics of energy demand and green-energy generation, the energy gap among different cloudlets in the network is unbalanced, i.e., some cloudlets' energy demands can be fully provided by green energy but others need to utilize on-grid energy (i.e., brown energy) to satisfy their energy demands. We propose a Green-energy awarE Avatar migRation (GEAR) strategy to minimize the on-grid energy consumption in GCN by redistributing the energy demands via Avatar migration among cloudlets according to cloudlets' green energy generation. Furthermore, GEAR ensures the Service Level Agreement in terms of the maximum Avatar propagation delay by avoiding Avatars hosted in the remote cloudlets. We formulate the GEAR strategy as a mixed-integer linear programming problem, which is NP-hard, and thus apply the Branch and Bound search to find its sub-optimal solution. Simulation results demonstrate that GEAR can save on-grid energy consumption significantly as compared to the Follow me AvataR (FAR) migration strategy, which aims to minimize the propagation delay between an UE and its Avatar.

## Fast Converging Iterative Orthogonal Projections for Maximum Likelihood DOA Estimation of Multiple Sources

*Enlong Hu, Ph.D. Student, and Hongya Ge*

We present an iterative orthogonal projection technique for achieving near maximum likelihood (ML) performance in estimating the directions of arrival of multiple sources. The method transforms a multivariate nonlinear maximization problem into a sequence of nested one-dimensional maximization problems. Its major advantage over the maximum likelihood estimation solution is a lower computational complexity delivered by faster converging iterations.

## Non-Coherent Direction of Arrival Estimation

*Wei Jiang, Ph.D. Student, and Alexander M. Haimovich*

In previous work we proposed a direction of arrival (DOA) estimation method from non-coherent measurements taken by an array of sensors. Here, it is shown that the non-coherent measurements in the form of magnitude squared of array observations measured in the presence of additive white Gaussian noise are distributed according to a non-central chi-square distribution. It is further shown that, under certain conditions, the non-coherent measurements may be approximated by a Gaussian distribution. With this approximation, we develop the Cramer-Rao bound on the non-coherent DOA estimation of a single source as well as an analytical expression of the maximum likelihood estimation of the DOA. Numerical examples are presented to illustrate the performance of the non-coherent DOA estimator. For example, non-coherent DOA estimation outperforms coherent DOA when the standard deviation of the phase errors exceeds 15 degrees and the signal-to-noise ratio exceeds 5 dB.

## Cost Analysis of Compressive Sensing for MIMO STAP Random Arrays

*Haley Kim, Ph.D. Student, and Alexander Haimovich*

This work proposes an augmented variation of conventional space-time adaptive processing (STAP), and explores the application of multi-branch matching pursuit (MBMP) to a multiple-input multiple-output (MIMO) beamformer whose steering vector is created over an array having random, inter-element spacing. By applying compressive sensing, a radar system is able to minimize the undesired effects of an undersampled array while providing adequate clutter suppression and reduced burden on array integration. In this paper, we compare the performance and computational complexity of the MBMP applied to the STAP problem and the STAP beamformer. In addition, we propose two methods to reduce the computational complexity of MBMP, a modification to the MBMP algorithm which we refer to as truncated MBMP, and a grid refinement technique. We evaluate our approach and extend this aspect to help in understanding the necessary computations required for practical target detection.

## Direct Tracking of Multiple Targets in MIMO Radar

*Phuoc Vu, Ph.D. Student, and Alexander M. Haimovich*

We consider the problem of tracking multiple moving targets in multiple-input multiple-output (MIMO) radar systems with widely distributed antennas and non-coherent processing. Two tracking algorithms based on the extended Kalman filter are proposed to estimate locations and velocities of multiple targets. With indirect tracking, the tracker observations model consists of time delay and velocity estimates and nearest-neighbor data association, whereas in the direct approach, tracking is performed directly on the radar observations, and the data association is implicit. A Bayesian Cramer-Rao bound (BCRB) is developed for direct tracking of multiple targets. The performance of the two trackers is analyzed through BCRB analysis and numerical examples. The analysis shows that for multiple targets, direct tracking outperforms indirect tracking at all signal-to-noise ratio values. The advantage of direct tracking is traced to the elimination of intermediate estimated parameters and explicit data association.

## Ultra-Reliable Cloud Mobile Computing With Service Composition and Superposition Coding

*Mohammadreza Azimi, Ph.D. Student, and Osvaldo Simeone*

An emerging requirement for 5G systems is the ability to provide wireless ultra-reliable communication services with close-to-full availability for cloud-based applications. Among such applications, a prominent role is expected to be played by mobile cloud computing (MCC), that is, by the offloading of computationally intensive tasks from mobile devices to the cloud. MCC allows battery-limited devices to run sophisticated applications, such as for gaming or for the "tactile" internet. This paper proposes to apply the framework of reliable service composition to the problem of optimal task offloading in MCC over fading channels, with the aim of providing layered, or composable, services at differentiated reliability levels. Interlayer optimization problems, encompassing offloading decisions and communication resources, are formulated and addressed by means of successive convex approximation methods. The numerical results demonstrate the energy savings that can be obtained by a joint allocation of computing and communication resources, as well as the advantages of layered coding at the physical layer and the impact of channel conditions on the offloading decisions.

## Control-Data Separation in Cloud RAN: The Case of Uplink HARQ

*Shahrouz Khalili, Ph.D. Student, and Osvaldo Simeone*

The performance of uplink HARQ in a Cloud-Radio Access Network (C-RAN) architecture is limited by the two-way latency on the fronthaul links connecting the Remote Radio Heads (RRHs) with the Baseband Unit (BBU) that performs decoding. In order to alleviate this problem, this work considers an alternative architecture based on the separation of control and data planes, in which the control plane is implemented at the edge, namely at the RRHs and at the User Equipments (UEs), while data decoding is still carried out remotely at the BBU as in a conventional C-RAN. More specifically, the RRHs perform local uplink channel estimation and feed back low-rate information to the UEs, which then make low-latency local retransmission decisions. Retransmission control is hence not subject to the fronthaul latency constraints. "Hard" and "soft" local feedback schemes are presented. The analysis, which is based on finite blocklength bounds, allows the optimization of the considered schemes, as well as the investigation of the impact of system parameters such as blocklength and number of feedback bits on the performance of the proposed architecture.

## Joint Uplink/Downlink and Offloading Optimization for Mobile Cloud Computing with Limited Backhaul

*Ali Najdi, Ph.D. Student, and Osvaldo Simeone*

Mobile cloud computing enables the offloading of computationally heavy applications, such as for gaming, object recognition or video processing, from mobile users (MUs) to a cloud server connected to wireless access points. The optimization of the operation of a mobile cloud computing system amounts to the problem of minimizing the energy required for offloading across all MUs under latency constraints at the application layer. In a scenario with multiple MUs transmitting over a shared wireless medium across multiple cells, this problem requires the management of interference for both the uplink, through which MUs offload the data needed for computation in the cloud, and for the downlink, through which the outcome of the cloud computation are fed back to the MUs, as well as the allocation of backhaul resources for communication between wireless edge and cloud and of computing resources at the cloud. In this paper, this problem is formulated for general multi-antenna, or multiple-input multiple-output (MIMO), channels and tackled by means of successive convex approximation methods. The numerical results illustrate the advantages of a joint allocation of computing and communication resources.

# Notes


NJIT
New Jersey Institute
of Technology