THE ELISHA YEGAL BAR-NESS CENTER FOR WIRELESS INFORMATION PROCESSING (CWiP)

ACTIVITY REPORT

2017 TO PRESENT

NJIT

New Jersey Institute of Technology

ABOUT THE CENTER

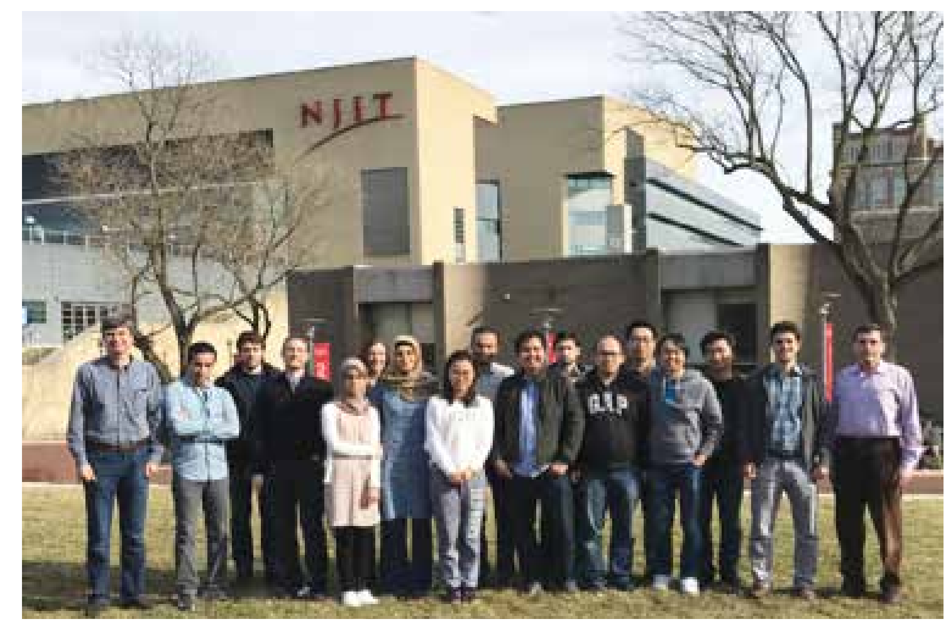
The Elisha Yegal Bar-Ness Center for Wireless Information Processing (CWiP) engages in a broad range of research areas ranging from wireless communications, radar, sensor networks, cloud radio, information theory and signal processing. A unifying theme of the Center's research is that of 5G wireless mobile networks.

There are five faculty members associated with the Center and over 20 graduate students, most of them pursuing their Doctor of Philosophy degree.

The Center routinely hosts visiting researchers, post-docs and students from overseas. Several students pursue double Ph.D. programs according to agreements between NJIT and other universities.

The Center seeks new collaborations with the wireless communications industry.

For more information, please contact Alexander Haimovich, Center Director, 973-596-3534 or alexander.m.haimovich@njit.edu.



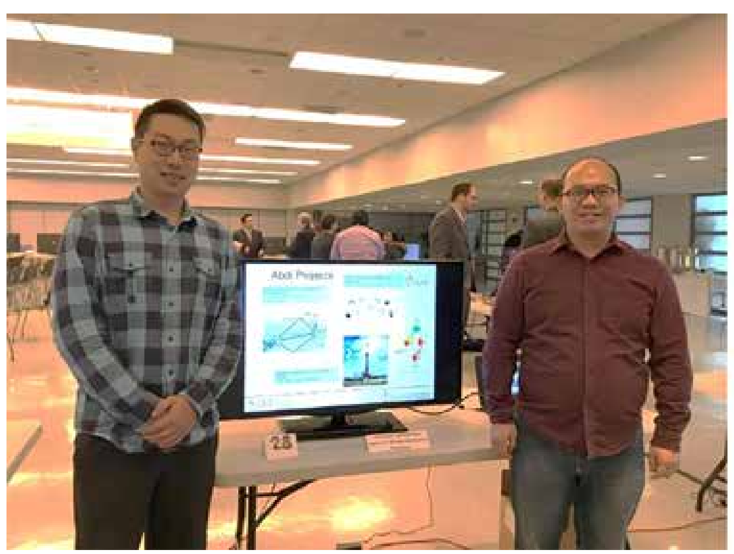
VISION OF THE CENTER

Primary Goal:

Serve as a focal point in the Department of Electrical and Computer Engineering for research on wireless, communications and signal processing.

Activities carried out by participants:

- Initiate and pursue research in the fields of wireless, communications and signal processing.
- Search, collectively as well as individually, for possible sources of financial research support for themselves and their affiliates (graduate students or visiting faculty).
- Establish contacts in the electronics industry in the Newark-metropolitan area and New Jersey as a whole, learn about their needs and suggest methods of collaboration.
- Assume responsibility for teaching graduate courses in the fields of communications and signal processing, propose and plan new courses, and monitor graduate courses taught by adjunct faculty.
- Undertake initiatives to recruit highly qualified graduate students, research associates and visiting faculty members, and support the efforts of the department chairman to recruit new faculty.
- Suggest, design, prepare and deliver short courses as part of New Jersey Institute of Technology's continuing education program.
- Organize seminars on topics of interest to Center members, the Department of Electrical and Computer Engineering and local industry.



Center Ph.D. Students and Visiting Scholars:

First	Last	Adviser
Ali	Alenezi	Abdi
Erjian (Eric)	Zhang	Abdi
Mustafa	Ozen	Abdi
Enlong	Hu	Ge
Annan	Dong	Haimovich
Phuoc	Vu	Haimovich
Wei	Jiang	Haimovich
Kyle	Wensell	Haimovich
Chen	Yi	Kliewer
Sarah	Obead	Kliewer
Salman	Habib	Kliewer
Malihe	Aliasgari	Kliewer
Yashar	Naderzadeh	Kliewer
Alireza	Bagheri	Simeone
Seyyed Mohammadreza	Azimi	Simeone

Center Master's and Undergraduate students working on projects:

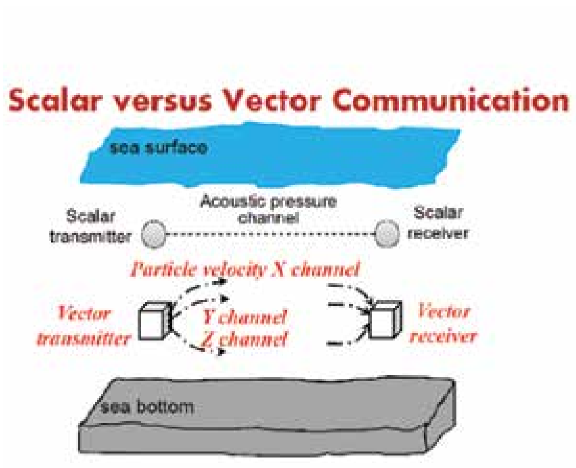
First	Last	Adviser
Santosh	Pishey Ramesh	Abdi
Xiaoyu	Chen	Abdi

Center Faculty and Staff:

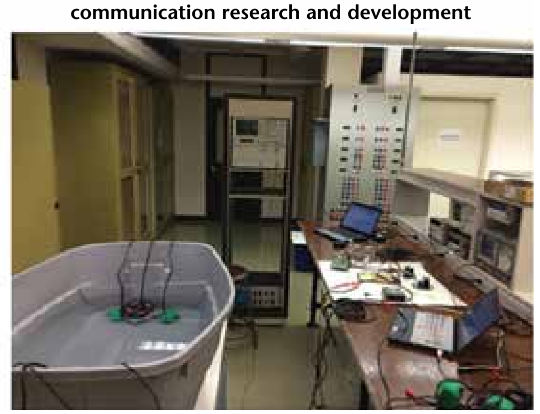
First	Last	Adviser
Ali	Abdi	Faculty
Yeheskel	Bar-Ness	Faculty Emeritus
Hongya	Ge	Faculty
Alexander	Haimovich	Faculty
Joerg	Kliewer	Faculty
Osvaldo	Simeone	Faculty
Kathy	Bosco	Staff
Changshi	Zhou	Staff

VECTOR ACOUSTIC COMMUNICATION TECHNOLOGY FOR HIGH SPEED UNDERWATER MODEMS

Faculty: Ali Abdi
Ph.D. Student: Erjian (Eric) Zhang
Sponsor: NSF



advanced Communication and Signal Processing (aCASP) Lab setup at NJIT for underwater communication research and development

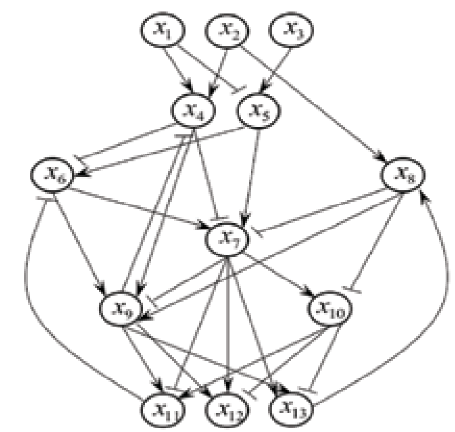


Over 75% of the earth's surface is covered with water that overlays many resources upon which our lives depend. High speed wireless underwater data communication between underwater sensors, deepwater moored instruments, autonomous underwater vehicles and surface vessels is of crucial importance in many applications of national interest. However, the achievable data rates by the conventional technologies are much smaller than what is needed for effective communication and management. To have high speed communication links in underwater environments, the transformative concept of communication via the vector components of the acoustic field was proposed and developed by A. Abdi in a prior NSF supported project.

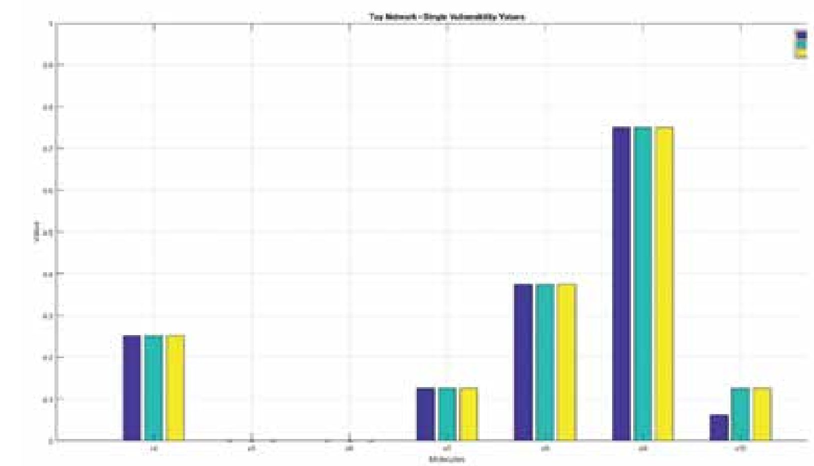
In this new project, a prototype modem is going to be developed, based on the vector field concept. The key difference between the new modem and other existing modems is that it uses vector transducers, which are compact multichannel devices, to transmit several data streams via multiple particle velocity vector channels. This is while other modems use scalar transducers, which can modulate the data only on the scalar acoustic pressure.

FAULT DIAGNOSIS AND THERAPEUTIC TARGET DISCOVERY IN HUMAN SIGNAL TRANSDUCTION NETWORKS

Faculty: Ali Abdi
Ph.D. Student: Mustafa Ozen



A Toy Molecular Network



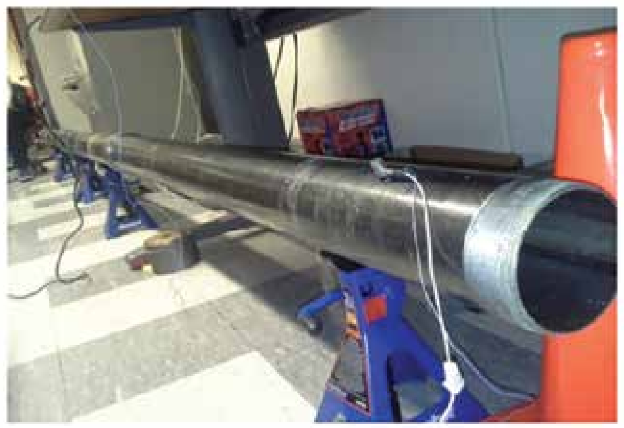
Single Fault Vulnerability Analysis Results

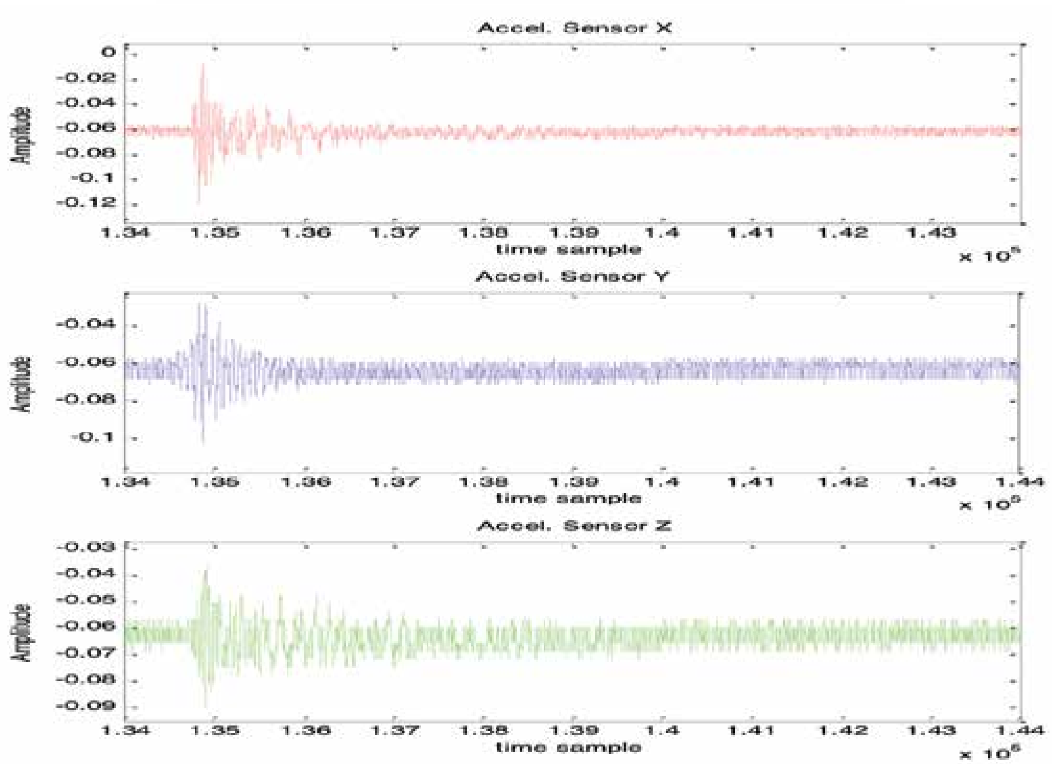
Failure analysis of signal transduction networks is an important topic in systems and molecular biology and has many applications in target discovery and drug development. In this work, some advanced methods for fault diagnosis in signaling networks are developed. The goal is to understand how, and to what extent, the dysfunction of molecules in a network contributes to the failure of the entire network. Network dysfunction is defined as failure to produce the expected outputs in response to the input signals. Vulnerability level of a molecule is defined as the probability of the network failure, when the molecule is dysfunctional. In this study, a method to calculate the vulnerability level of single molecules for different combinations of input signals is developed. Furthermore, a more complex yet biologically meaningful method for calculating the multi-fault vulnerability levels is suggested, in which two or more molecules are simultaneously dysfunctional. Additionally, a method is developed for fault diagnosis of networks based on a ternary logic model, which considers three activity levels for a molecule, instead of the previously published binary logic model. Moreover, proper methods for network training using experimental data are developed.

BOREHOLE COMMUNICATION VIA STEEL PIPES IN OIL WELLS

Faculty: Ali Abdi
Ph.D. Student: Ali Alenezi
Sponsor: National Science Foundation

Advanced Communication and Signal Processing (aCASP) Lab testbed at NJIT for communication vi steel pipes

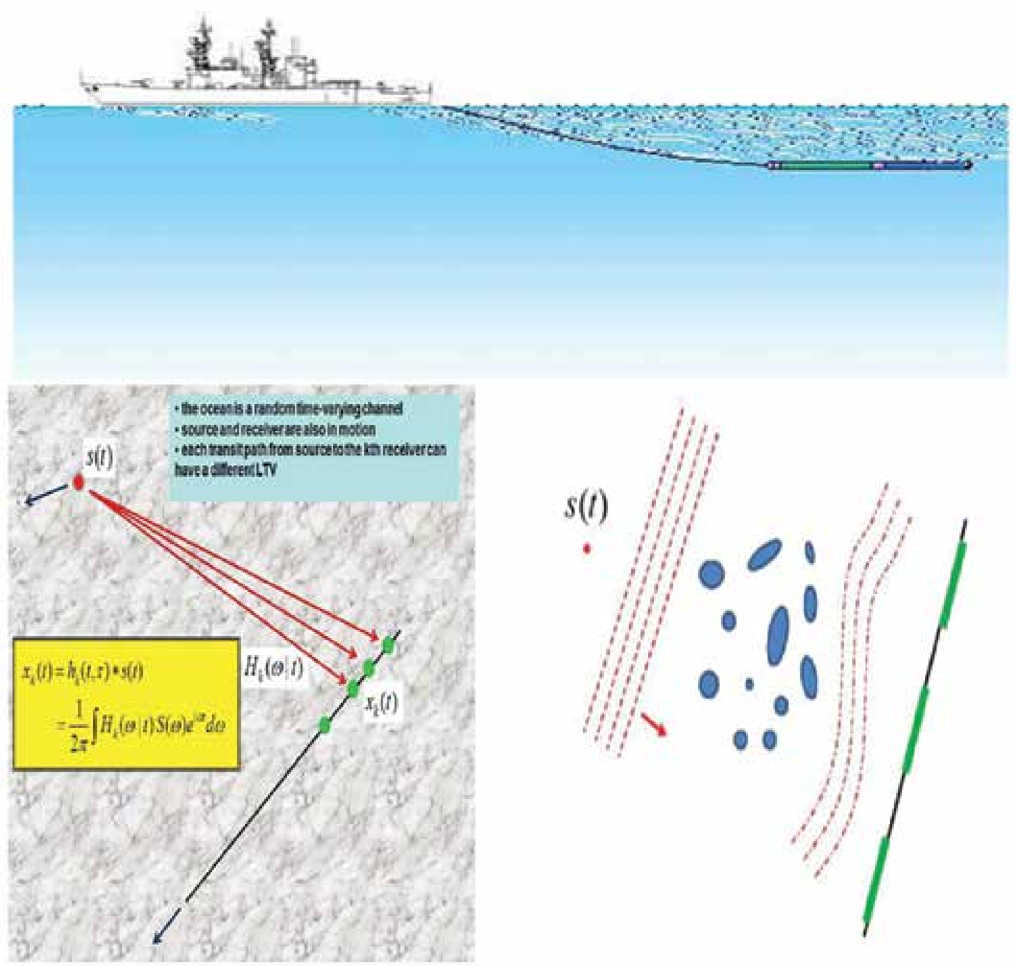




Since boreholes in oil wells are typically very deep, several thousand feet or more, wired communication is very expensive and prone to failure. On the other hand, wireless electromagnetic-based and mud-based methods can provide only very low data rates, typically a few bits per second. Acoustic transmission, however, offers higher data rates. In this research, new high rate and reliable communication schemes are going to be developed, by utilizing the physics of sound propagation in steel pipes, and through the proposed strain and x-y-z acceleration channels.

PASSIVE RANGING USING DISTRIBUTED ARRAYS IN UNDERWATER ACOUSTIC ENVIRONMENTS SUBJECT TO SPATIAL COHERENCE LOSS

Faculty: Hongya Ge
Collaborator: Ivars P. Kirsteins (NUWC, Newport, RI)
Sponsors: U.S. Office of Naval Research (ONR), NAVSEA and NUWC



Passive ranging in challenging underwater environments is an important problem in many naval applications, ranging from national defense to disaster recovery and environmental monitoring. Large aperture and/or moving aperture array systems have been designed and redesigned to enable the performance gain in passive methods to source detection, localization and tracking.

Through data-driven adaptive signal processing, our research explores statistical as well as tempo-spatial-spectral features of acoustic data collected by towed array systems comprised of multiple distributed volumetric array modules. The large amounts of space-time data are collected during different sea trials under the sponsorship of ONR, NAVSEA and NUWC. The goal is to design real-time solutions to passively localize (detection and estimation), classify and track distant emission sources undersea. Due to the turbulent nature and random media effects of underwater acoustic channels, an emission source's spherical or plane wavefronts are partially distorted when arriving at the receiving arrays of large/moving aperture. The relative motion between the source of interest and receiving arrays makes data and the associated parameters highly time varying (a typical high-dimension and sample poor scenario). All these will result in performance degradation to the wavefront curvature ranging systems equipped with very long aperture. We developed maximum likelihood multi-stage and multi-rank wavefront curvature passive ranging solutions to the problem of localizing and tracking distant sources of interest.

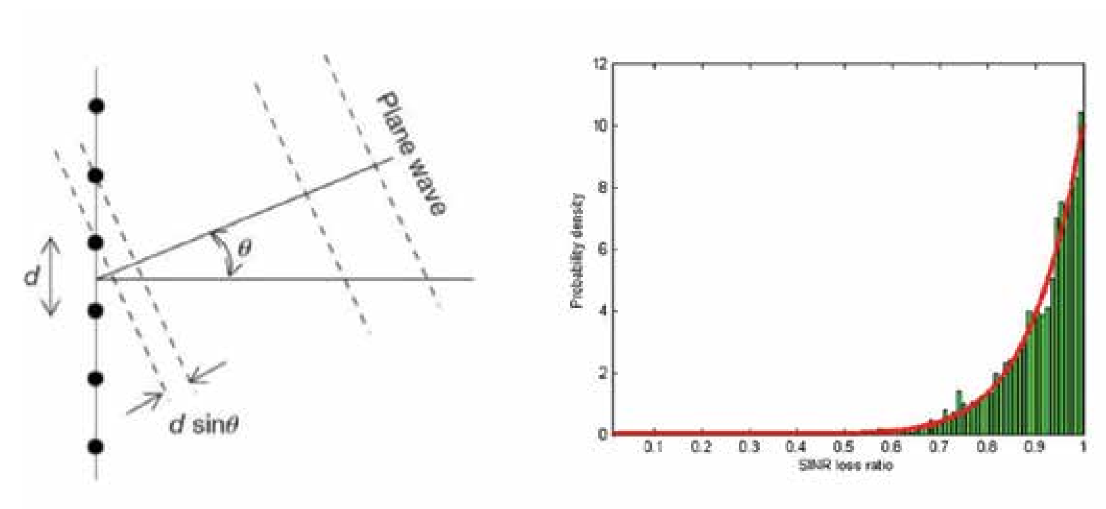
LUCKY RANGING: A NEW SIGNAL PROCESSING PARADIGM FOR PASSIVE RANGING IN UNDERWATER ACOUSTIC ENVIRONMENTS SUBJECT TO INTERNAL WAVES AND TURBULENCE

Faculty: Hongya Ge
Collaborator: Ivars P. Kirsteins (NUWC, Newport, RI)
Sponsors: NAVSEA and NUWC

The detection and localization of signals using large arrays is challenging in low coherence underwater environments. Poor spatial coherence is a consequence of signal wave front distortions caused by time-dependent three-dimensional spatial fluctuations in the sound speed from internal waves, fronts and random medium effects such as turbulence. In this project, we had proposed a new paradigm for array processing in poor coherence environments, motivated by real data observations, which exploited lucky moments or favorable scintillations when the signal wave front momentarily had little or no distortion. In addition to the ONR's passive array datasets, we also examined the HLA and VLA data from the 2006 Shallow Water Experiment provided by the Woods Hole Oceanographic Institute to better understand and characterize the occurrence of lucky moments or favorable scintillations in actual data and how they can be utilized in array processing. Because of uncertainties in the HLA element positions, we developed a new empirical canonical correlation-based technique for the analysis utilizing lucky moments to blindly estimate the array manifold.

PERFORMANCE ANALYSIS ON THE SINR LOSS OF THE DOMINANT MODE REJECTION BEAMFORMER

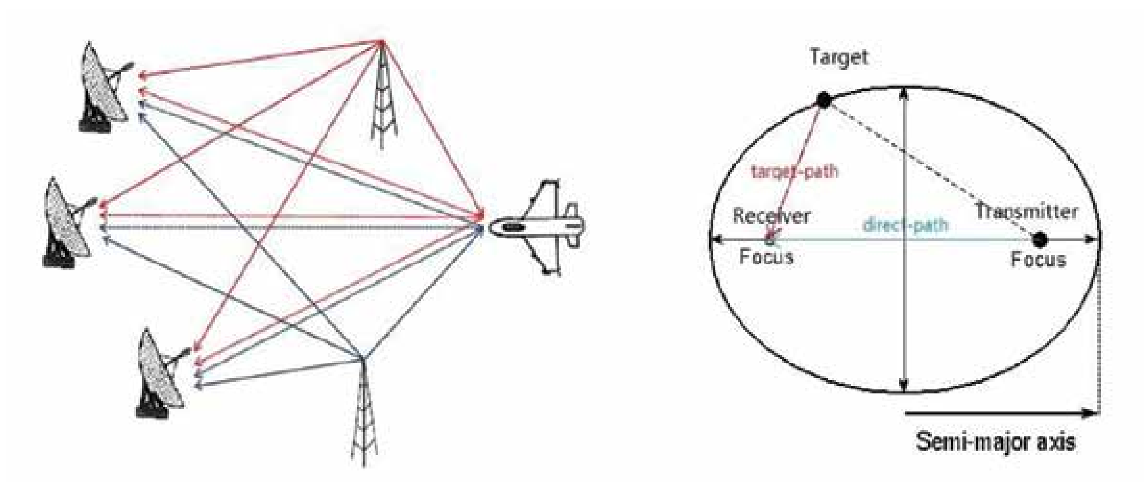
Faculty: Hongya Ge
Graduate Student: Enlong Hu



The key performance measure, the probability density distribution of the SINR loss of the Dominant Mode Rejection Beamformer, is derived through projection approximation along with the multivariate statistical analysis.

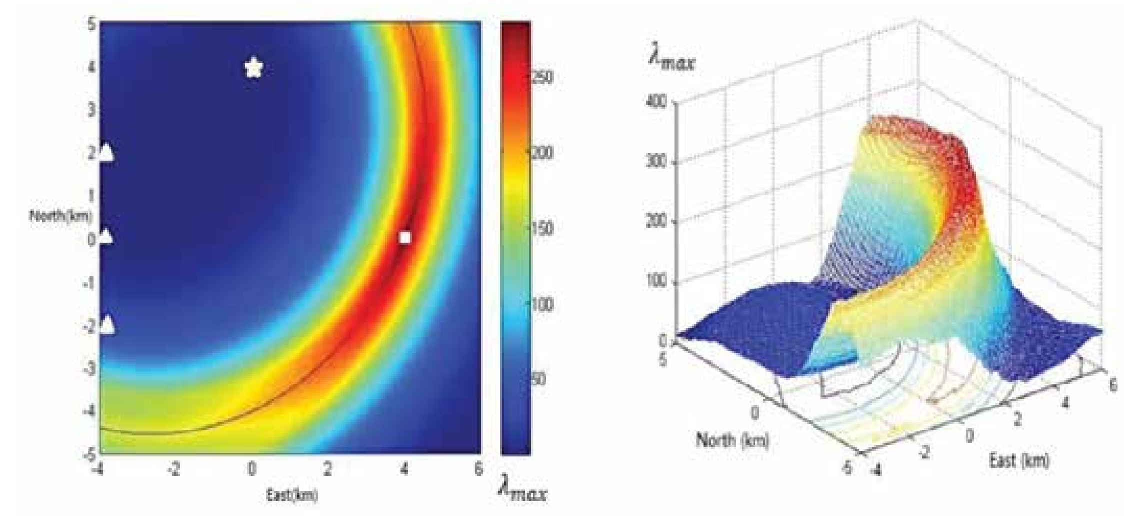
PASSIVE MIMO-RADAR FOR TARGET DETECTION

Faculty: Hongya Ge
Graduate Student: Enlong Hu

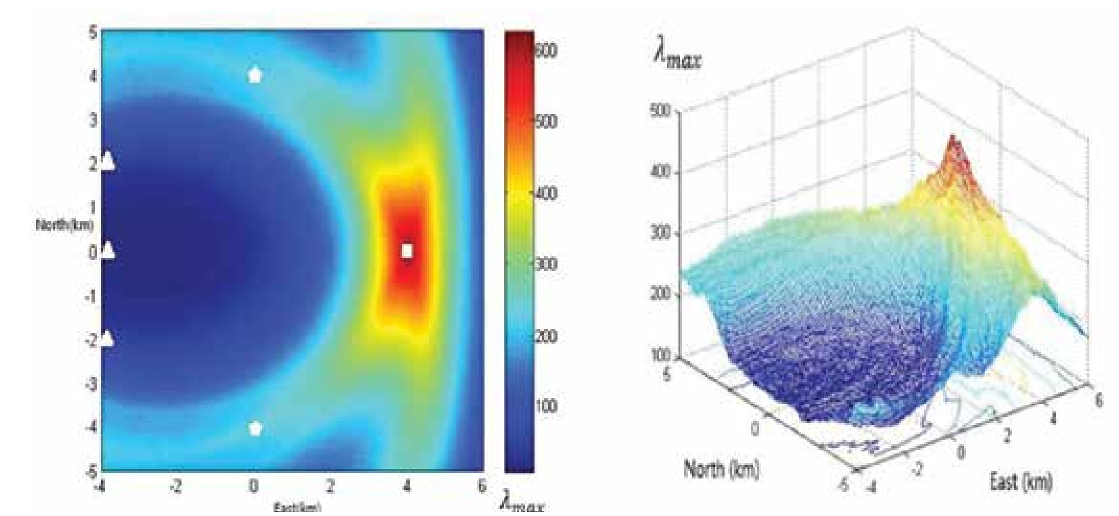


In the passive MIMO-Radar system, the RF transmission from existing radio towers along with the reflected RF signals from a target is utilized by low-cost radar antennas. Such primary and secondary multi- channel data can be used to build low-cost MIMO radars for surveillance applications. We studied the performance gain in detection using multiple RF towers as well as reference channel data.

Results obtained by using the transmission from a single RF tower and the target reflection

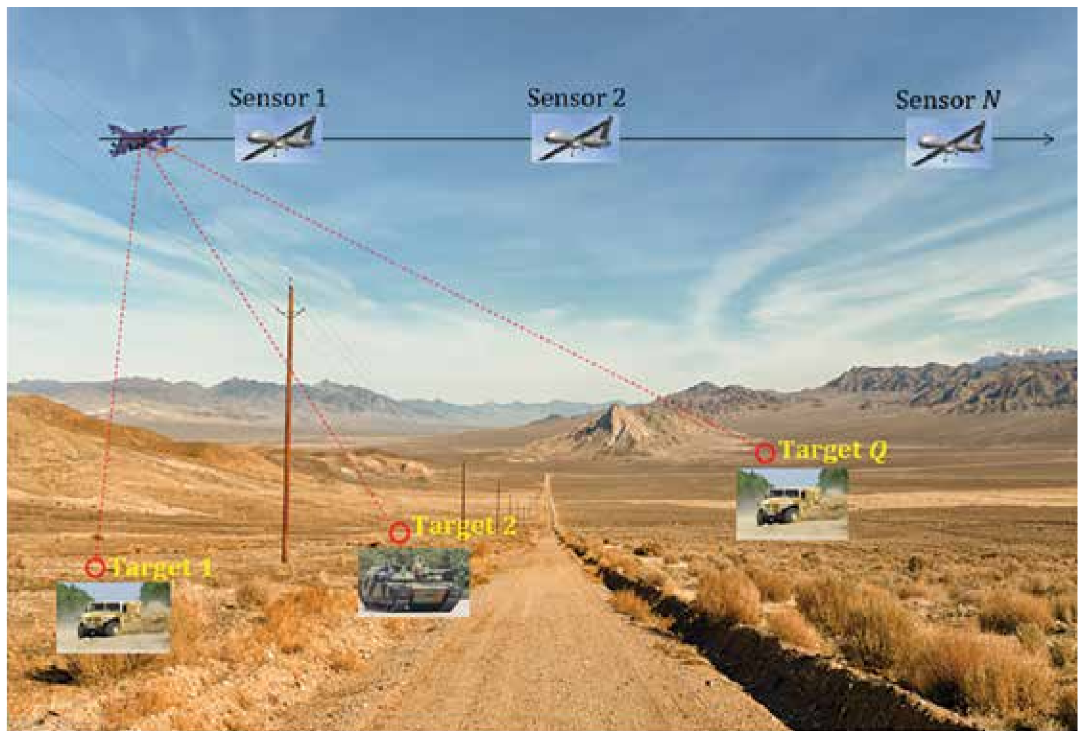


Results obtained by the using transmissions from two RF towers and the target reflection



DISTRIBUTED RADAR GROUND MOVING TARGET INDICATOR

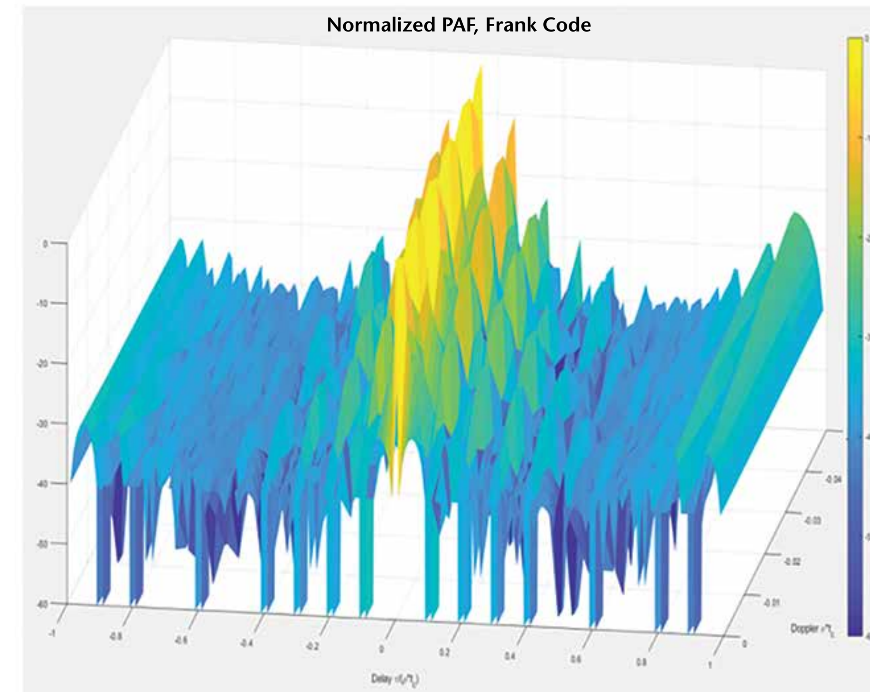
Faculty: Alexander Haimovich
Graduate Student: Phuoc Vu
Sponsor: Air Force Research Lab/Matrix Research



Ground moving target indicator (GMTI) detects and localizes moving targets in the presence of ground clutter and other interference sources. Space-time adaptive processing (STAP) implemented with antenna arrays has been a classical approach to clutter cancellation in airborne radar. The proliferation of relatively inexpensive autonomous sensing vehicles, such as unmanned airborne systems, raises the question of whether it is possible to carry out GMTI by distributed airborne platforms. A major obstacle to implementing distributed GMTI is the synchronization of autonomous moving sensors. For range processing, GMTI processing relies on synchronized sampling of the signals received at the array, while STAP processing requires time, frequency and phase synchronization for beamforming and interference cancellation. Distributed sensors have independent oscillators, which are naturally not synchronized and are each subject to different stochastic phase drift. Each sensor has its own local oscillator, unlike a traditional array in which all sensors are connected to the same local oscillator. Even when tuned to the same frequency, phase errors between the sensors will develop over time, due to phase instabilities. These phase errors affect a distributed STAP system. This project evaluates the effect of phase noise on STAP with distributed antenna arrays, in which spatial processing is performed (together with Doppler processing) over a coherent processing interval.

NOISE WAVEFORMS FOR NEXT GENERATION FUZE RADAR

Faculty: Alexander Haimovich
Graduate Student: Kyle Wensell
Staff: Changshi Zhou
Sponsor: U.S. Army

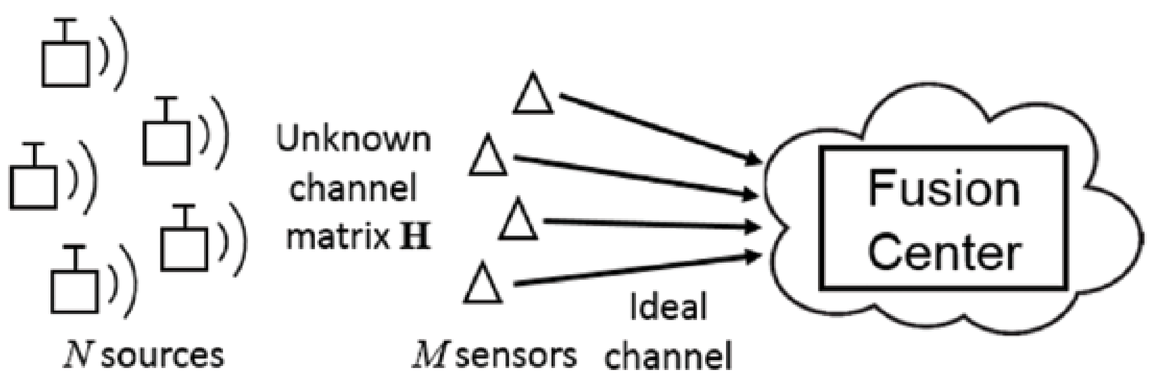


Next generation electronic counter measures (ECM) are expected to pose great challenges to current fuze radar systems that rely on Frequency-Modulated, Continuous-Wave (FMCW) technology. Such ECM systems will likely be able to exploit the low instantaneous bandwidth and distinct spectral features of FMCW waveforms to degrade radar performance. It is therefore necessary for future next generation fuze radar to develop advanced waveforms that overcome these deficiencies.

In order to address these deficiencies, our research designs the next generation noise radar waveforms that enable range and Doppler processing, support high range resolution, and feature increased ECM resistance in terms of lower probability of intercept and robustness to intentional and unintentional interference. Also we study the computational complexity of the new waveforms and develop low complexity algorithms in view of the severe space and power limitations in the fuze radar environment. As a proof of concept, the newly designed waveforms and processing algorithms are implemented and validated in our software defined radio (SDR) prototype platform.

BLIND SPARSE ESTIMATION FOR SPORADIC SOURCES OVER UNKNOWN FADING CHANNELS

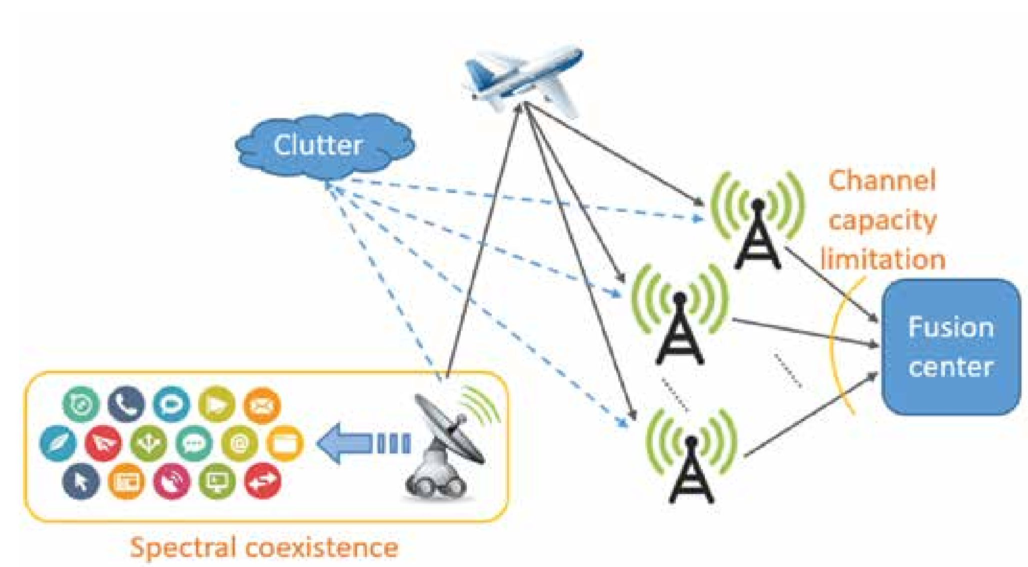
Faculty: Alexander Haimovich
Graduate Student: Annan Dong
Collaborators: Jason Dabin (U.S. Navy)
Sponsors: U.S. Navy/Booz Allen Hamilton



Blind source separation (BSS) is the separation of unknown mixed signals without information about the signals or the mixing process. In this project, we are interested in sparse BSS, where the sources are sparse in the sense that: (1) only a subset is active at any time; and (2) for each source, the cumulative activity of each source is a relatively small fraction of the observation time. The mixtures, viewed as a superposition of sources, are in general less sparse compared to the original sources. Dictionary Learning (DL) is an iterative approach between estimating the dictionary and the sparse source signals during which the dictionary is learned from the observations. We propose an improved DL-based source separation algorithm that exploits knowledge about the time variability of the signals. Moreover, we propose a further improvement to the DL-based source separation scheme when we have prior information about the source patterns. Numerical results shows our algorithms have the advantage in separation accuracy and robustness compared to regular DL algorithms.

JOINT OPTIMIZATION OF WAVEFORM AND QUANTIZATION IN A SPECTRALLY DENSE ENVIRONMENT

Faculty: Alexander Haimovich
Graduate Student: Wei Jiang



As communication systems are allowed to operate in some RF spectra that heretofore were reserved solely for radar use, it is necessary to redesign radar waveforms to prevent interference with the communication functions.   In this project, the transmitted waveform is also optimized with respect to a target detection metric computed at the fusion center. The waveform optimization accounts for capacity-limited links to the fusion center and for known statistics of the interference and clutter environment experienced by the radar sensors. To tackle the proposed optimization problem, we propose an algorithm based on a block coordinate descent method coupled with majorization-minimization and semidefinite programming. Numerical results demonstrate our joint optimization scheme outperforms the conventional separate optimization of the radar waveform and the statistic of the quantization noise.

MEASURING DIRECTIONAL AND CAUSAL INFORMATION FLOW IN EEG FOR ASSESSING PERCEIVED AUDIO QUALITY

Faculty: Joerg Kliewer
Graduate Student: Ketan Mehta
Sponsor: National Science Foundation

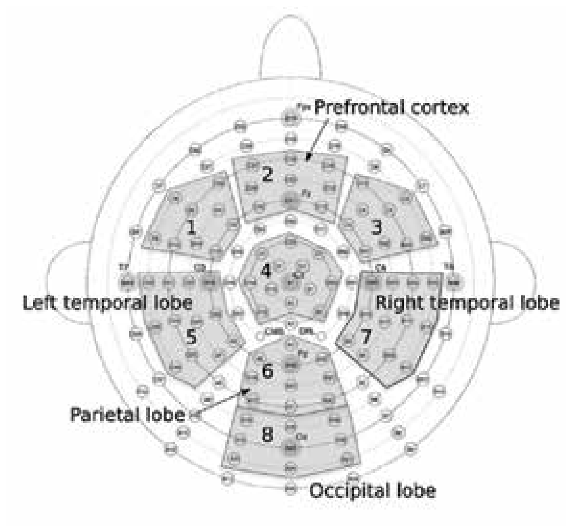


Fig. 1: The 128 electrodes are grouped into eight ROIs to effectively cover the different cortical regions (lobes) of the brain.

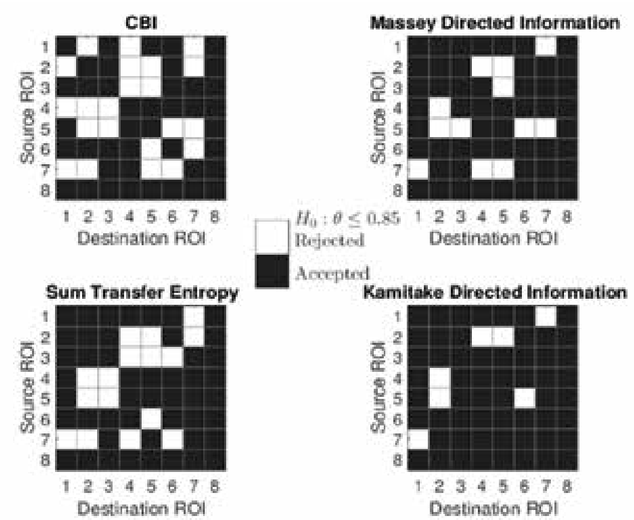


Fig. 2: Inferred connectivity change matrix in response to the change in the perceived audio quality. The white squares indicate significant connections which show the largest change in their information transfer rates in response to changing audio quality.

The superposition of electrical activity patterns in the brain can be non-invasively recorded via electroencephalography (EEG) by placing sensors on the scalp. In the conducted study [1, 2], EEG activity of human subjects is recorded as they listen to audio sequences whose quality varies with time. Functional connectivity refers to the statistical dependencies between neural data recorded from spatially distinct regions in the brain. The aim of the study is to then use EEG measurements to infer changes in cortical functional connectivity in response to audio stimulus.

A novel information theoretic framework is proposed in [1, 2] to measure the causal information flow between EEG sensors which are appropriately grouped into different regions of interest (ROI) over the cortex as shown in Fig. 1. In particular, a new causal bidirectional information (CBI) measure is defined as an improvement over standard directed information measures for the purposes of identifying connectivity between ROIs in a generalized cortical network setting. CBI can be intuitively interpreted as a causal bidirectional modification of directed information, and inherently calculates the divergence of the observed data from a multiple access channel with feedback. Further, the analytical relationship between the different causal measures is determined in [1] and subsequently used to compare how well they are able to distinguish between the perceived audio quality.

The connectivity results demonstrate that a change in information flow between different brain regions typically occurs as the subjects listen to different audio qualities, with an overall increase in the information transfer when the subjects listen to degraded quality as opposed to high quality audio. Also, as shown in Fig. 2, the results indicate that the proposed measure CBI performs significantly better in being able to discriminate between the perceived audio quality, compared to using standard directed information measures.

[1] K. Mehta and J. Kliewer, “Directional and causal information flow in EEG for assessing perceived audio quality,” Accepted Feb. 2018, IEEE Journal of Transactions on Molecular, Biological and Multi-Scale Communications.

[2] K. Mehta and J. Kliewer, “A new EEG-based causal information measure for identifying brain connectivity in response to perceived audio quality,” Proc. IEEE International Conference on Communication, Paris, France, May 2017.

ERROR CORRECTION FOR ASYNCHRONOUS COMMUNICATION

Faculty: Joerg Kliewer
Graduate Student: Chen Yi
Sponsor: National Science Foundation
Collaborator: Wei Tang (New Mexico State University)

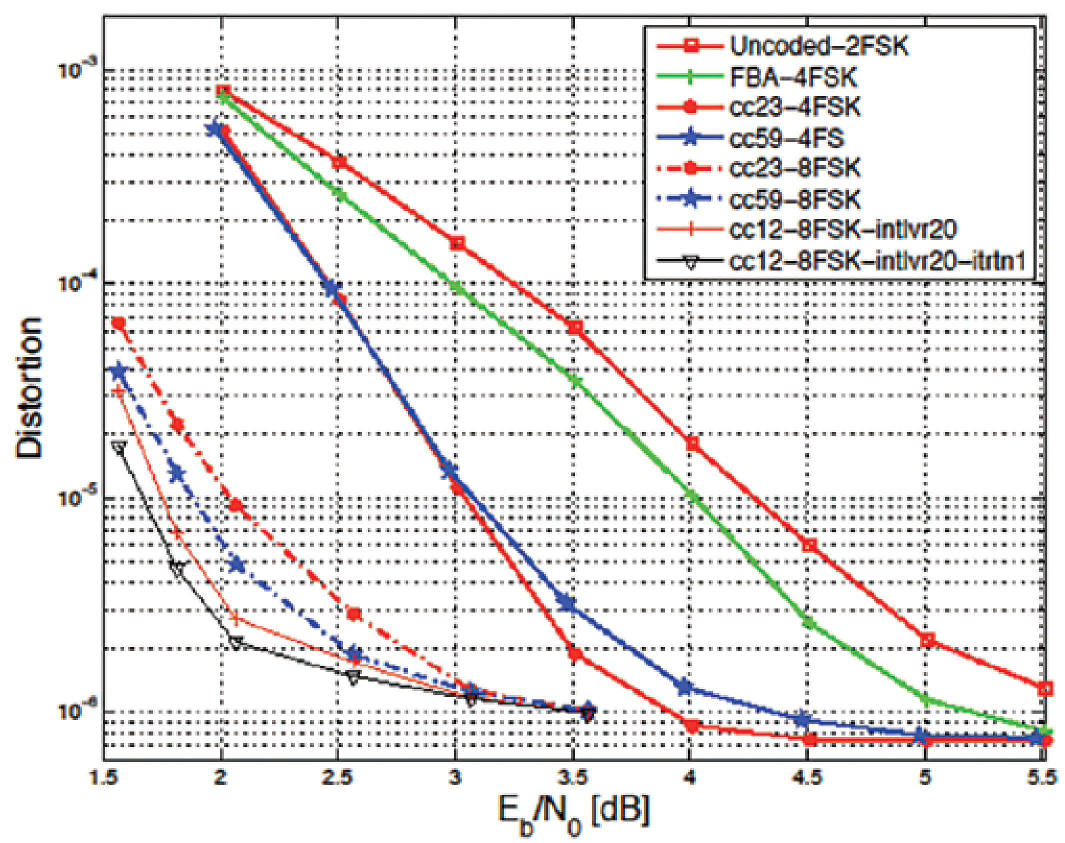


Figure: End-to-end distortion versus channel SNR for several coded asynchronous communication systems.

In recent years, integrated wireless sensors have emerged in a wide range of applications including health care, surveillance, smart buildings, disaster mitigation and environment monitoring, and therefore have significantly benefited society due to alleviating certain monitoring tasks associated with these applications. However, new applications as implantable biopotential sensors or submersible sensors for measuring mechanical stress require further miniaturization of existing state-of-the-art sensor hardware while having a significantly increased transmission data rate due to the need to perform multichannel processing, i.e., to aggregate the data of multiple single sensors on the same chip over a single communication link. Thus, these approaches require the design of very low-power sensor hardware architectures including novel low complexity modulation and coding schemes which can support reliable and secure transmission over these high speed data links.

The goal of this project is to find and study novel designs and strategies that are tailored to this emerging class of low-power integrated wireless sensor nodes. We analyze a systematic solution for integrated wireless sensors by devising asynchronous delta modulation on the sensor interface in combination with asynchronous ultra-wideband transmission on the wireless radio interface in order to significantly decrease the power consumption of the sensor hardware. In particular, we propose a forward error correction scheme for asynchronous sensor communication, where a continuous-time sparse waveform signal is asynchronously sampled and communicated over a noisy channel via Q-ary frequency-shift keying [1,2]. The presented concatenated code employs outer systematic convolutional codes and inner embedded marker codes, which effectively preserve the timing information along with a protection against symbol insertions and deletions [3]. We show that by iteratively decoding marker and convolutional codes along with interleaving a short block of parity bits a significant reduction in terms of the expected end-to-end distortion between original and reconstructed signals can be obtained compared to non-iterative processing [3] (see figure).

[1] Q. Hu, C. Yi, J. Kliewer, and W. Tang, "Asynchronous communication for wireless sensors using ultra wideband impulse radio," in *Proc. IEEE 58th International Midwest Symposium on Circuits and Systems*, Fort Collins, CO, Aug. 2015, pp. 1–4.

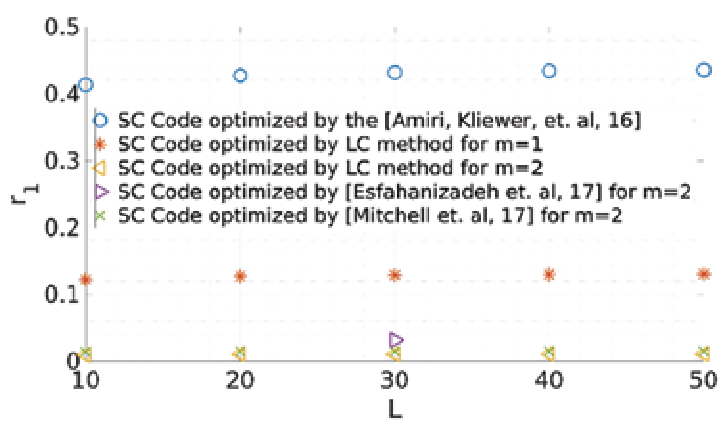
[2] C. Yi and J. Kliewer, "Error correction for asynchronous communication," in *Proc. 9th International Symposium on Turbo Codes and Iterative Information Processing (ISTC)*, Brest, France, September, 2016, pp. 310–314.

[3] C. Yi and J. Kliewer, "On error correction for asynchronous communication based on iterative processing.," in *Proc. 50th Asilomar Conference on Signals, Systems and Computers*, 2016, pp. 240–244.

OPTIMIZATION OF PRACTICAL SPATIALLY COUPLED LDPC CODES

Faculty: Joerg Kliewer
Graduate Student: Salman Habib
Sponsor: National Science Foundation
Collaborators: Christine Kelley (University of Nebraska Lincoln), David Mitchell (New Mexico State University)

Figure:
Experimental results



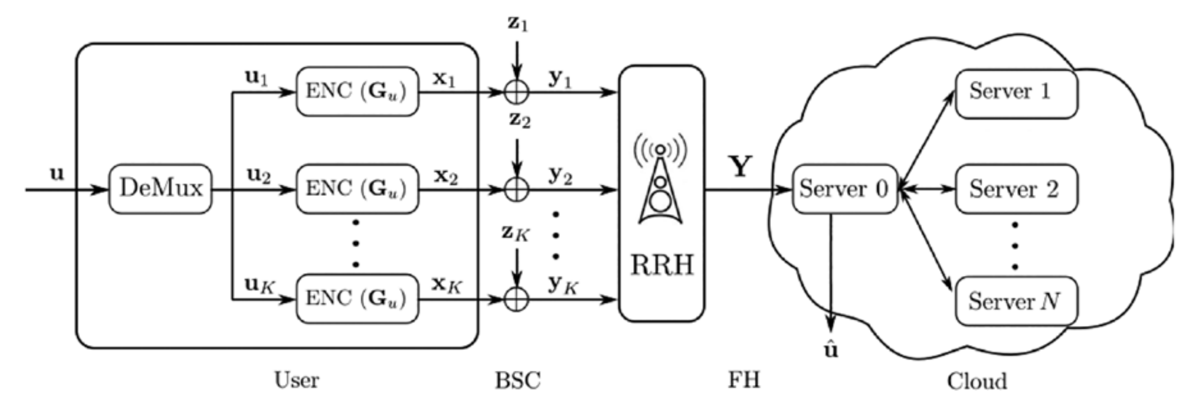
Low density parity check (LDPC) codes are linear codes used for correcting errors in data transmitted over noisy communication channels. These codes are constructed using a low complexity encoder, and the decoding can be done reliably using low-complexity message passing algorithm. Even though LDPC codes have excellent decoding performance close to the Shannon limit, they exhibit a so-called error floor beyond a certain signal to noise ratio. This does not pose a great problem for applications that operate at moderate bit error rate such as in wireless communications. However, the error floor degrades the performance of these codes in applications that requires very low bit error rates such as in non-volatile memory (flash) storage. The message-passing technique used for decoding these codes takes place on a bipartite graph known as the Tanner graph. The error floor is caused due to the presence of some critical sub-structures in the Tanner graph of LDPC codes known as absorbing sets. Spatially coupled (SC) LDPC codes are constructed from LDPC codes in order to minimize the presence of absorbing sets in the Tanner graph. In particular, SC codes have a much smaller number of absorbing sets and therefore a much better performance in the error floor region.

In this research, we consider an efficient SC-LDPC construction scheme based on algebraic lifting, which is optimized in order to minimize the number of critical absorbing sets. For this purpose, we propose a so-called line counting optimization scheme with only linear complexity in the blocklength of the code. Algebraic lifting combined with line-counting based optimization enables us to design SC-LDPC codes with a minimal number of harmful absorbing sets. Fig. 1 displays the performance of our designed SC-LDPC codes where r_1 indicates a parameter related to the number of critical absorbing sets, and L is a parameter related to the blocklength of the code. It can be seen that the proposed optimization approach (results represented by the yellow curve) outperforms existing constructions from the literature.

[1] A. Beemer, S. Habib, C. Kelley, J. Kliewer, "A generalized algebraic approach to optimizing SC-LDPC codes", *Proc. 55th Annual Allerton Conference on Communication, Control and Computing*, 2017

CODED COMPUTATION AGAINST STRAGGLING DECODERS FOR NETWORK FUNCTION VIRTUALIZATION

Faculty: Joerg Kliewer
Graduate Student: Malihe Aliasgari
Sponsor: National Science Foundation
Collaborator: Osvaldo Simeone (King's College London / NJIT)



The uplink of a cloud radio access network (C-RAN) architecture is studied in which decoding at the cloud takes place via network function virtualization (NFV) on commercial off-the-shelf (COTS) servers. In order to mitigate the impact of straggling decoders in the cloud computing platform, a novel coding strategy is proposed, whereby the cloud re-encodes the received frames via a linear code before distributing them to the decoding processors. Transmission of a single frame is considered first, and upper bounds on the resulting frame unavailability probability (FUP) as a function of the decoding latency are derived by assuming a binary symmetric channel for uplink communications. The bounds leverage large deviation results for correlated variables and depend on the properties of both the uplink linear channel code adopted at the user and the NFV linear code applied at the cloud. Then, the analysis is extended to account for random frame arrival times. In this case, the trade-off between average decoding latency and the frame error rate (FER) is studied for two different queuing policies, whereby the servers carry out perframe decoding or continuous decoding, respectively. Numerical examples demonstrate that the bounds are useful tools for code design, and that coding is instrumental in obtaining a desirable compromise between decoding latency and reliability.

[1] M. Aliasgari, J. Kliewer, and O. Simeone, "Coded computation against processing delays for virtualized cloud-based channel decoding", Submitted to *IEEE Transaction of Communication*, 2018.

[2] M. Aliasgari, J. Kliewer, and O. Simeone, "Coded computation against straggling decoders for network function virtualization", submitted to *IEEE International Symposium on Information Theory 2018.*

[3] M. Aliasgari, J. Kliewer, and O. Simeone, "Coded computation for distributed channel decoding", *2017 North-American School of Information Theory*, June 6-9, 2017, Atlanta, GA.

COORDINATION IN NETWORKED MULTI-AGENT SYSTEMS

Faculty: Joerg Kliewer
Graduate Student: Sarah Obead
Postdoctoral Researcher: Badri Vellambi
Sponsor: National Science Foundation

Figure 1: Point-to-point strong coordination over a discrete memoryless channel

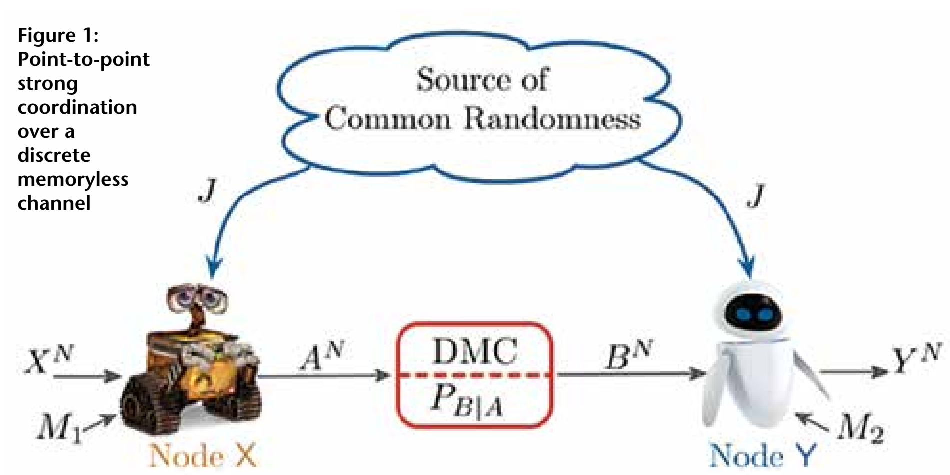
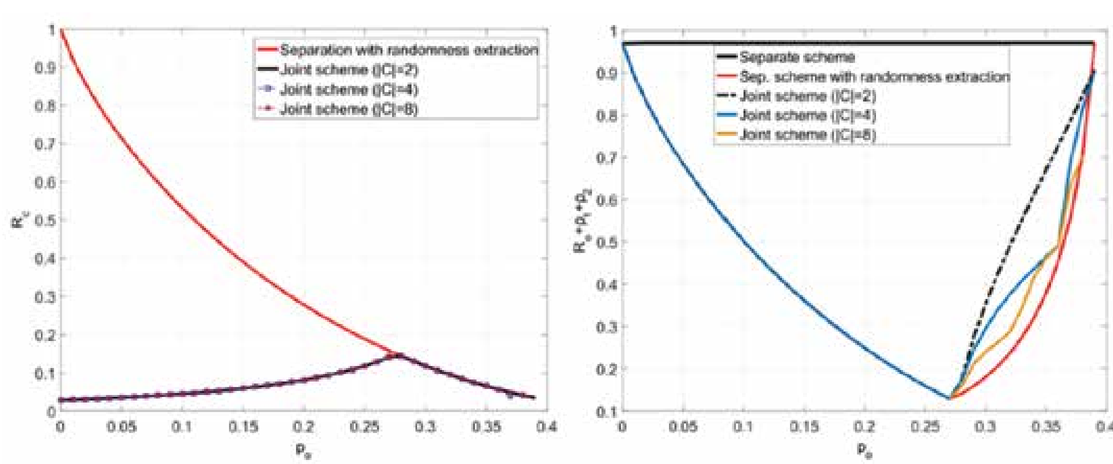


Figure 2: Numerical results for target P_(Y|X)=" BSC(0.4)"



(a) Communication rate vs. BSC crossover probability p_o

(b) Randomness sum rate vs. BSC crossover probability p_o

In decentralized networked systems, the system is operated by multiple agents and the agents can interact using communication channels. A fundamental problem in decentralized networked systems is to coordinate activities of different agents with the goal of reaching a state of agreement. Coordination in multi-agent systems can be seen as an instance of a distributed open-loop stochastic control problem.

This problem arises in numerous applications in several domains including autonomous robots systems for unmanned search and rescue or exploration of unknown territory, smart traffic control and automated surveillance applications, and distributed computing such as distributed games and grid computing.

One of the major challenges in multi-agent systems is to design an appropriate coordination scheme that enable the agents to efficiently exchange information and correlate their actions to achieve a desired overall behavior. To this end, we investigate the problem of strong coordination over point-to-point noisy communication channels as a building block of a more complex networked setting. We focus on the problem of strong coordination of the actions of two agents X and Y that communicate over a discrete memoryless communication channel (DMC) such that the actions follow a prescribed joint probability distribution (see Figure 1). We have proposed two novel random coding schemes and a polar coding scheme for this noisy strong coordination problem, and have derived inner bounds for the respective strong coordination capacity region based on the random coding schemes. The first scheme is a joint coordination-channel coding scheme that implicitly utilizes the randomness provided by the communication channel to reduce the amount of local randomness required to generate the sequence of actions at agent Y [1]. The second scheme is a joint coordination-channel polar coding scheme for strong coordination [2]. We show that polar codes are able to achieve the established inner bound to the strong noisy coordination capacity region and thus provide a constructive alternative to a random coding proof. Our polar coding scheme also offers a constructive solution to a channel simulation problem where a DMC and shared randomness are together employed to simulate another DMC. The third scheme is a random coding scheme that exploits separate coordination and channel coding where local randomness extracted from the channel after channel decoding stage [1].

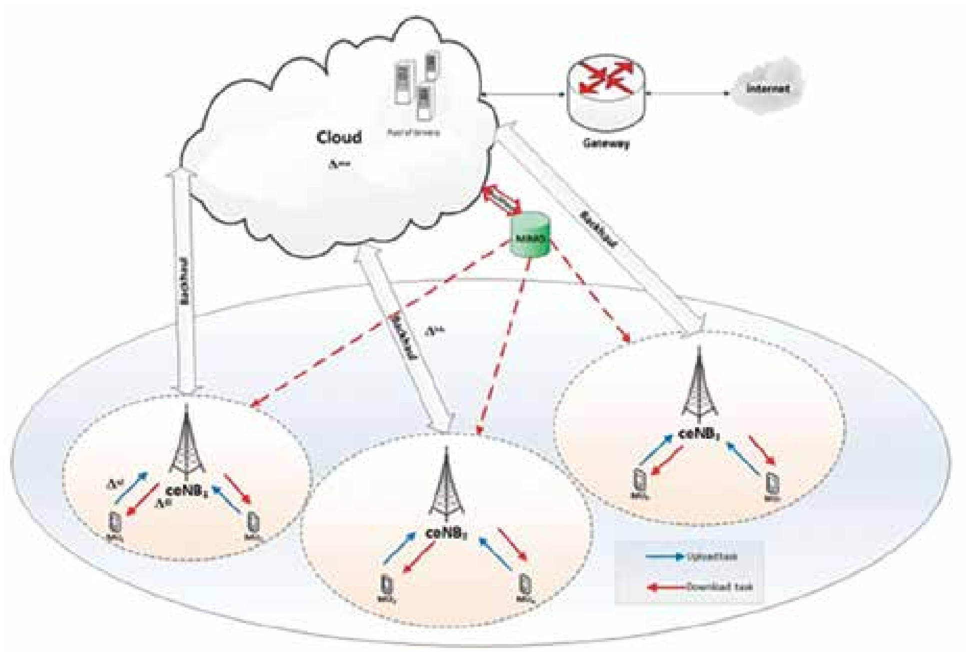
Finally, by leveraging the random coding inner bounds for this problem, we examine whether joint coordination and channel coding provides a benefit over separate coding in terms of achievable rates. Accordingly, for binary symmetric communication channels (BSC) and binary symmetric actions, we make the interesting observation that the joint scheme is able to provide a lower communication rate (see Figure 2(a)) compared to the separate scheme under the same amount of total randomness injected into both systems (see Figure 2(b)). This observation establishes that the proposed joint scheme strictly outperforms the separate scheme.

[1] S. A. Obead, B. N. Vellambi and J. Kliewer, "Strong coordination over noisy channels: Is separation sufficient?," in *IEEE International Symposium on Information Theory (ISIT)*, Aachen, Germany, June 2017, pp. 2840–2844.

[2] S. A. Obead, J. Kliewer and B. N. Vellambi, "Joint coordination-channel coding for strong coordination over noisy channels based on polar codes," in Proc. *55th Annual Allerton Conference on Communication, Control, and Computing*, Monticello, IL, USA, October 2017, pp. 580–587.

MOBILE FOG COMPUTING

Faculty: Osvaldo Simeone
Graduate Student: Ali Najdi
Collaborator: Gesualdo Scutari (Purdue University)
Sponsor: US NSF

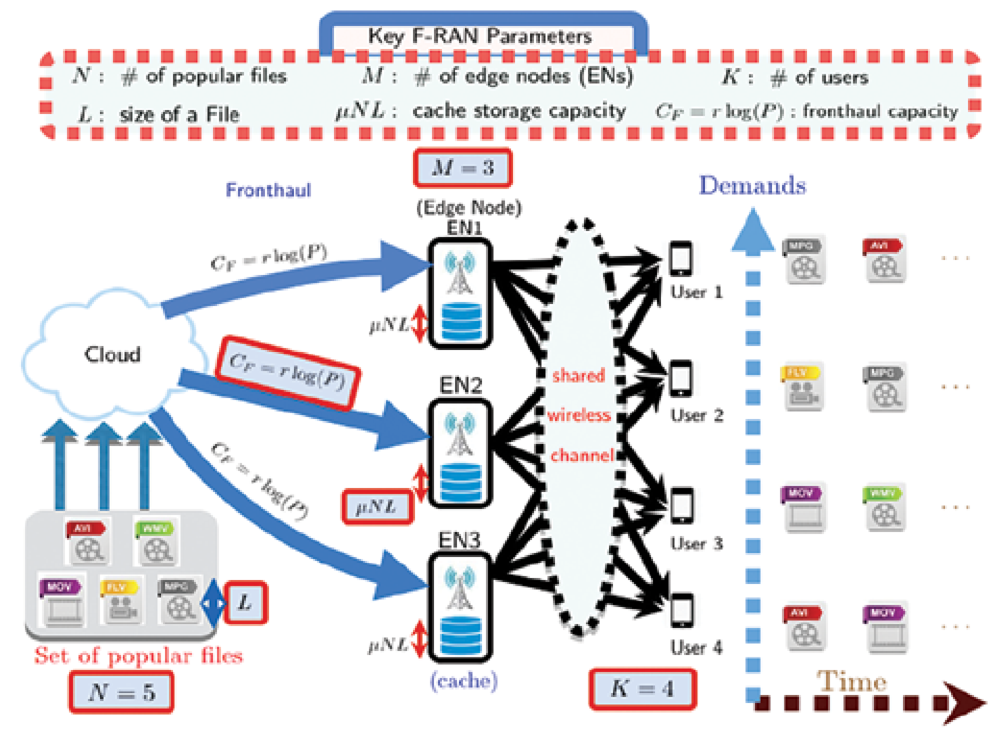


While the number of computation-intensive applications that users expect to run on mobile devices–including video processing, object recognition, gaming, automatic translation and medical monitoring–continues to grow, the devices' computing capabilities are ultimately limited by the battery lifetime. Barring breakthroughs in battery technology, the only potential solution to this challenge appears to be mobile cloud computing; that is, the offloading of computation-intensive tasks to a cloud service provider, such as for speech recognition with Google Voice Search and Apple Siri. However, accessing the cloud through a wireless network entails the energy and latency required for uplink and downlink transmissions, as well as the delay caused by routing on the backhaul network, hence potentially offsetting the gains of mobile cloud computing.

This research project proposes to tackle the above problem by introducing the fog mobile computing architecture, in which the small-cell base stations of a cellular system are endowed with computing capabilities to offer proximate wireless access and computing. The key objective of the project is to develop effective, low-complexity, scalable and flexible offloading strategies based on the inter-layer optimization of computation and communication resources, with the aim of ensuring Quality of Experience (QoE) constraints in terms of minimal mobile energy expenditure and latency.

FOG RADIO ACCESS NETWORKS: CLOUD AND CACHE-AIDED WIRELESS SYSTEMS

Faculty: Osvaldo Simeone
Graduate Student: Mohammadreza Azimi
Collaborator: Ravi Tandon (University of Arizona)



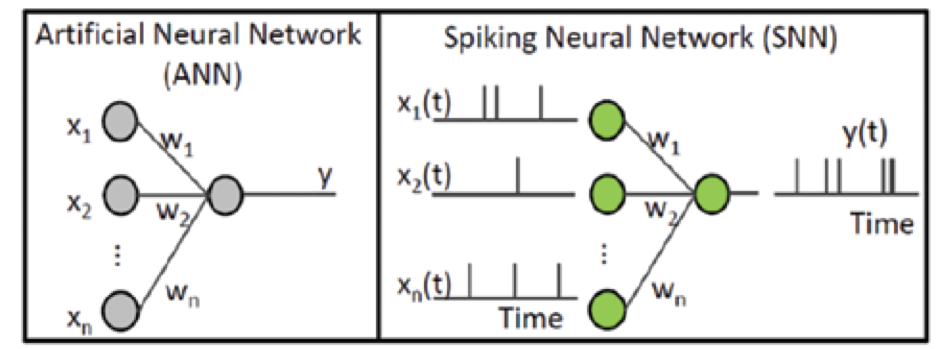
Virtualization and edge processing are among the most promising and transformative trends in the evolution of wireless network architectures. Virtualization of radio access, also known as Cloud Radio Access Network (C-RAN), prescribes the centralization of baseband and higher-layer processing, with the aim of boosting spectral and cost efficiency in interference-limited dense wireless deployments. In contrast, edge processing leverages local content reuse by means of edge caching, with the goal of catering to hot-spot or proximate traffic of popular multimedia content. In order to accommodate the broad range of use cases that are envisioned to be within the scope of 5G systems and beyond, a hybrid architecture, referred to as Fog-RAN (F-RAN), that harnesses the benefits of, and the synergies between, both technologies, has been recently advocated and is the subject of this project. In an F-RAN, edge nodes may be endowed with caching capabilities, so as to serve local data requests of popular content with low latency, while at the same time being controllable from a central cloud processor, in order to serve arbitrary data requests with stronger interference management properties and less stringent delay constraints.

continued

The optimal operation of an F-RAN architecture poses a complex design problem that is characterized by the interaction between the policies used for caching, for transmission over the fronthaul links connecting cloud and edge nodes, and for wireless delivery. The policies operate at heterogeneous time scales and under different conditions in terms of channel state information and knowledge of users' requests. In order to tackle this complex design problem and obtain insights into the main trade-offs between performance and resources, namely caching and fronthaul capacities, a novel information-theoretic model for F-RAN is introduced along with a fundamental performance metric that quantifies the worst-case delivery latency needed to support the users' requests. The delivery latency encompasses the delays associated with the transfer of information on the fronthaul network and on the wireless segment. Novel information-theoretic achievability and converse arguments will be developed to obtain tight characterizations of the tradeoff between latency, on the one hand, and fronthaul and edge caching capacities, on the other hand. Through this information-theoretic analysis, fundamental insights into optimal design choices will be revealed. The theory will be complemented by means of system-level simulations that will be carried out in collaboration with industrial and academic partners.

SNNNOW: PROBABILISTIC LEARNING FOR DEEP SPIKING NEURAL NETWORKS: FOUNDATIONS AND HARDWARE CO-OPTIMIZATION

Faculty: Osvaldo Simeone
Graduate Student: Alireza Bagheri
Collaborator: Bipin Rajendran (NJIT)



Deep neural networks (DNN) have become the de-facto standard tool to carry out complex learning tasks. DNNs belong to the second generation of artificial neural networks (ANNs), which rely on neurons that implement memory-less non-linear transformations of the synaptic inputs. Motivated by the biological analogy with the behavior of neurons in the brain, the third generation of neural networks, also referred to as Spiking Neural Networks (SNNs), was introduced in the nineties. In SNNs, synaptic input and neuronal output signals are spike trains. This proposal argues that the time for the use of SNNs as machine learning tools has come, and sets forth a systematic approach for the design and implementation of SNNs as learning and inference machines.

SNNs have a number of unique advantages as compared to ANNs: (i) They are event-based systems with natural sparsity properties, which have the potential to make deep learning machines feasible for energy-limited devices; (ii) They are uniquely capable to natively process data that comes in the form of time-encoded processes, for example, from bio-inspired sensors. The main goal of this project is the establishment of a theoretical framework to enable the design of flexible spike-domain learning algorithms that are tailored to the solution of supervised and unsupervised cognitive tasks, as well as their co-optimization on nanoscale hardware architectures. To this end, this project puts forth a principled probabilistic framework based on the graphical formalism of Directed Information Graphs.

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NEWS

Three Doctoral Students Present Research at Annual NJIT Center Showcase
NJIT's Elisha Yegal Bar-Ness Center for Wireless Communications and Signal Processing Research recently showcased the research of three doctoral students. The students' work was featured in presentations and posters displayed for the showcase. The annual event gives doctoral students and their advisers from the Center a chance to exchange current information about ongoing work.

New Jersey Institute of Technology

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