MURI - Kickoff Meeting

Adaptive Waveform Design for Full Spectral Dominance*

Project Overview

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Acknowledgments

We are grateful to:

- Dr. Jon Sjogren, program manager.
- Panel members.
- DoD employees.
- The Air Force Office of Scientific Research (AFOSR).

Team Members

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Princeton University
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Purdue University
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University of Melbourne
William Moran*

Raytheon Missile Systems
Harry Schmitt*

* Independently funded

Team Members (Cont.)

We have:

- 11 co-PIs, including 2 independently funded.
- 6 funded universities.
- 1 independently funded university.
- 1 independently funded industry.

Background and Motivation

Conventional sensing and communication systems:

- Use fixed transmitted waveforms.
- Focus on receiver design.
- Operate in open-loop independently of the environment.

Hence, the system performance can be severely limited.

Background and Motivation (Cont.)

Recent advances in technology:

- New sensor information processing.
- New hardware:
  - Low-noise linear amplifiers.
  - Arbitrary waveform generators.
  - Programmable vector modulators.
- Makes feasible real-time waveform selection implemented pulse-to-pulse, subarray-to-subarray.

These motivate interest in adaptive waveform design and dynamic scheduling with potential dramatic improvements in performance.

Background and Motivation (Cont.)



The Chesapeake Beach Radar Facility of NRL (system functionalities include independent transmit and receive elements, rapid polarization, PRI, and waveform agility).

Research Overview

We propose a synergistic and multi-disciplinary research on adaptive waveform diversity design to substantially increase:

- Radar systems resolution, detection and accuracy.
- Communication systems capacity.

Research Overview (Cont.)

Waveform diversities: To obtain the best performance, we will exploit diversities in multiple dimensions, including:

- Time
- Space
- Frequency
- Phase
- Power
- Polarization

Research Overview (Cont.)

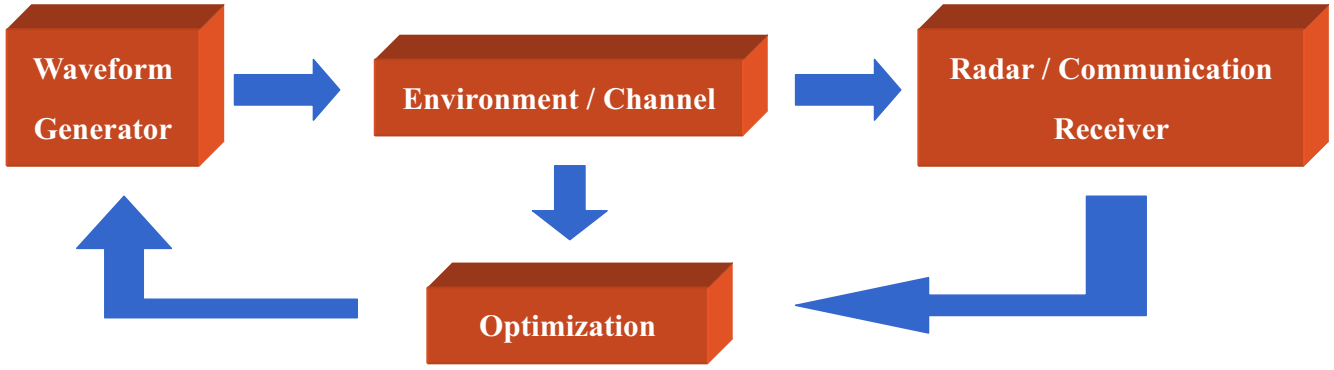
Performance measures: We will define them to fit the system operation modes:

- Detection: probability of detection, given false alarm rate.
- Classification: Kullback-Leibler information number.
- Estimation: Cramér-Rao bounds and ambiguity functions.
- Tracking: predicted mean square tracking error and length of false tracks.
- Communication: bit error rate (BER), frame error rate (FER), and outage capacity.

Research Overview (Cont.)

We propose adaptive design: at each time sample, the system:

- Generates a set of parameterized waveforms.
- Estimates the environment model based on the data.
- Computes the cost function based on the latest information.
- Adaptively selects the optimum waveform for the next transmission.



Research Aspects

- Adaptive waveform diversity design to significantly improve sensing and communication systems performance.
- Practical yet tractable performance metrics.
- Parametric waveforms and libraries.
- Physical and statistical models approximating real problems.
- Statistically and computationally efficient algorithms to estimate the environment.
- Robustness against inaccuracy in the models.

Research Aspects (Cont.)

- Dynamic optimization and scheduling algorithms for a broad range of applications and environments.
- Ensure the best ideas for waveform design in sensing are practical in communications, and vice versa.

Research Tasks

The research plan is divided into four major tasks:

- Task 1: Developing waveform design methods that exploit both existing and new forms of diversities.
- Task 2: Modeling the environment and channel to extract attributes needed for optimal waveform selection.
- Task 3: Optimizing waveform scheduling applying cost functions adapted to the channel and/or environment.
- Task 4: Testing the new waveform designs in complex realistic environments using an anechoic chamber and radar tower test-bed facilities.

Task Assignments

		Antonia	Arye	Bill	Danilo	Darryl	Harry	John	Mark	Mike	Navin	Robert
Task 1	Temporal diversity			X				X	X	X		X
	Spatial diversity			X				X	X	X		X
	Polarimetric signals		X							X		
	Time-varying signals	X				X						
	UWB signals		X		X							
	OFDM		X									X
	CDMA			X								X
	Waveform libraries			X								X
Task 2	MIMO radar models		X									
	Time-varying channel	X				X						
	Dispersive channel	X				X						
	Polarimetric channel		X									
	Parametric propagation		X		X							
	Stochastic clutter		X									
	Kernel perspective			X								
	Communication	X							X	X		
	Model selection	X	X			X			X			
Task 3	Cost functions	X	X	X		X			X	X		X
	Adapt. design & scheduling	X		X		X			X		X	X
	Distr. sensor management		X									
Task 4	Distributed platforms		X						X			
	Countermeasures		X									
	Polarimetric radar		X									
	Detection procedures		X									
	STAP		X									
	Hot clutter		X									
	Robust design		X									
	Tests in anechoic room				X							
	Tests in radar tower						X					

Expected Impact

We will produce:

- Fundamental advances in optimal waveform design and scheduling.
- Accurate estimation methods of channels and environments with performance analysis.
- Significant performance improvements in:
  - Radar detection, tracking and resolution.
  - Communication systems capacity.
  - Interference avoidance and mitigation.
  - Integrated multitask systems.

Deliverables

- Parameterized waveform families and libraries.
- Scheduling algorithms exploiting information gathered from the operating scenario.
- Estimation algorithms of channels and environments.
- Software packages for multidimensional waveform design.
- Validations of advanced waveform design techniques using real-world scenarios.

Deliverables (Cont.)

- Disseminating scientific results through:
  - Journal papers.
  - Workshops, conferences and symposia.
  - Website.
  - Book on adaptive waveform design.
- Educating undergraduate and 15 graduate students, also 3 post-doctoral associates.
- Developing a graduate level course on Waveform Diversity in Sensor Processing.

Milestones

1	2	3	4	5	6	7
5 Mos	12 Mos	12 Mos	7 Mos	5 Mos	12 Mos	7 Mos
Task 1: Unified Approach to Waveform Design						
Temporal and Spatial Diversity						
OFDM & CDMA Waveforms						
Polarimetric Signals						
Time-Varying Signals and Processing						
		Waveform Libraries				
				UWB Signals		
Task 2: Environment and Channel Modeling						
MIMO, Time Dispersive, Polarimetric and Layered Media						
		Models in Communications				
		Kernel Perspective				
		Model Selection				
Task 3: Optimization						
		Cost Functions: CRB, AF, etc.				
		Adaptative Waveform Design and Scheduling				
					Multitask Systems	
					Distrib. Sensor	
						Extensions
Task 4: Applications and Validations						
		Detection Procedures				
		Polarimetric Radar				
			Robust Design			
			Countermeasures, Hot Clutter, STAP			
			Waveform Experiments and Real Data (Anechoic Chamber and Radar Tower)			
						Extensions

Collaborations

Our program will promote interactions between team members who are

- mathematicians,
- engineers, and
- applied scientists.

Integrating

- education,
- research,
- experiments with defense labs, and
- industry.

Collaborations (Cont.)

- Within the team:
  - Sharing ideas at workshops and meetings.
  - Writing joint papers.
  - Joint visits of investigators, students and postdocs.
  - Testing algorithms in UIC anechoic chamber and Raytheon radar test-bed facilities.

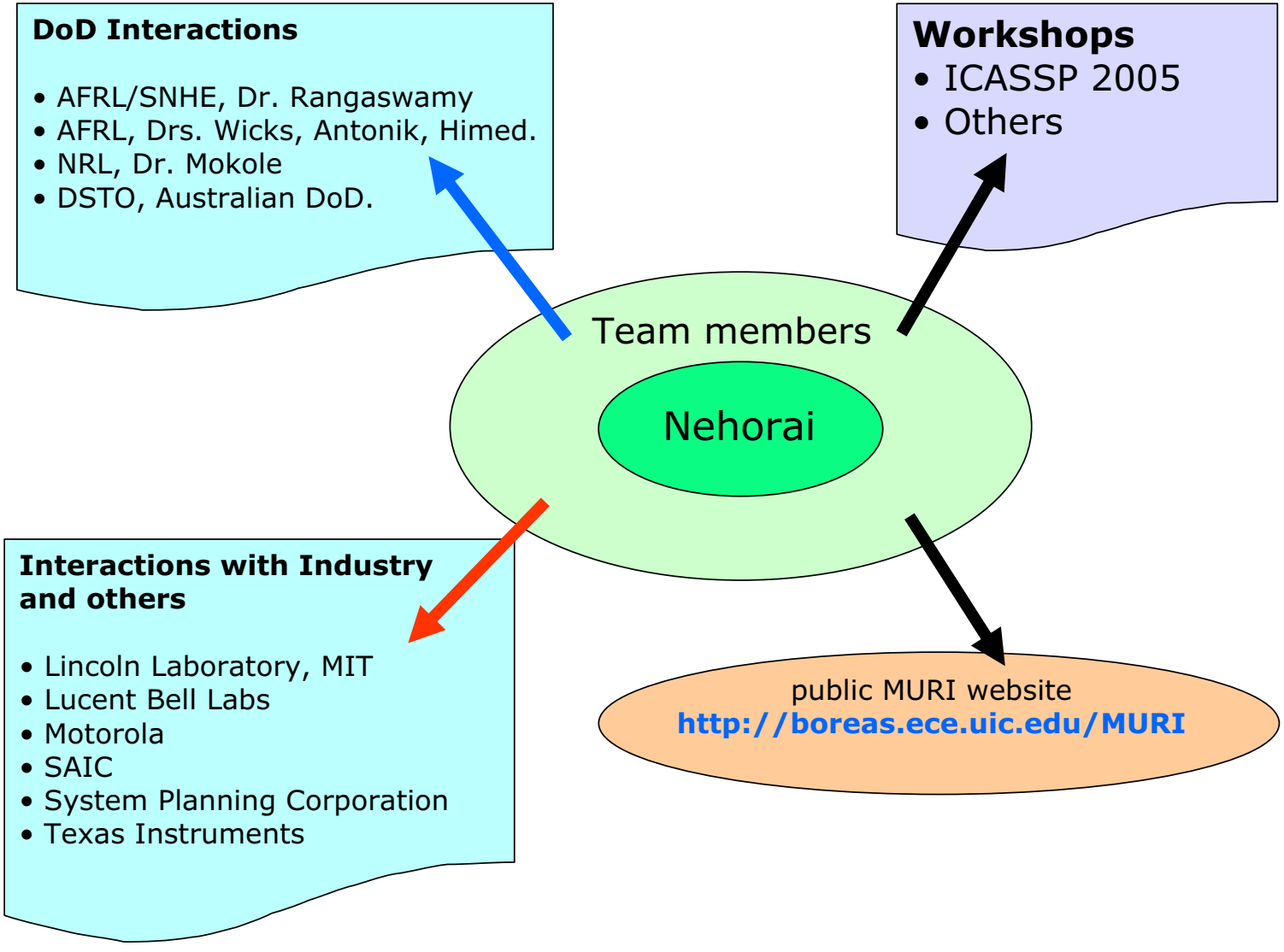
Interactions and Outreach

- Exchanging results and applications to real data with defense labs, for instance:
  - AFRL/SNHE, Hanscom, Dr. M. Rangaswamy.
  - AFRL, Rome, Sensors Directorate, Dr. M. Wicks, Dr. P. Antonik, and Dr. B. Himed.
  - NRL, Radar Division, Dr. E. Mokole.
  - ARL, Dr. A. Swami.
  - DSTO, Australian DoD, Dr. S. Howard.

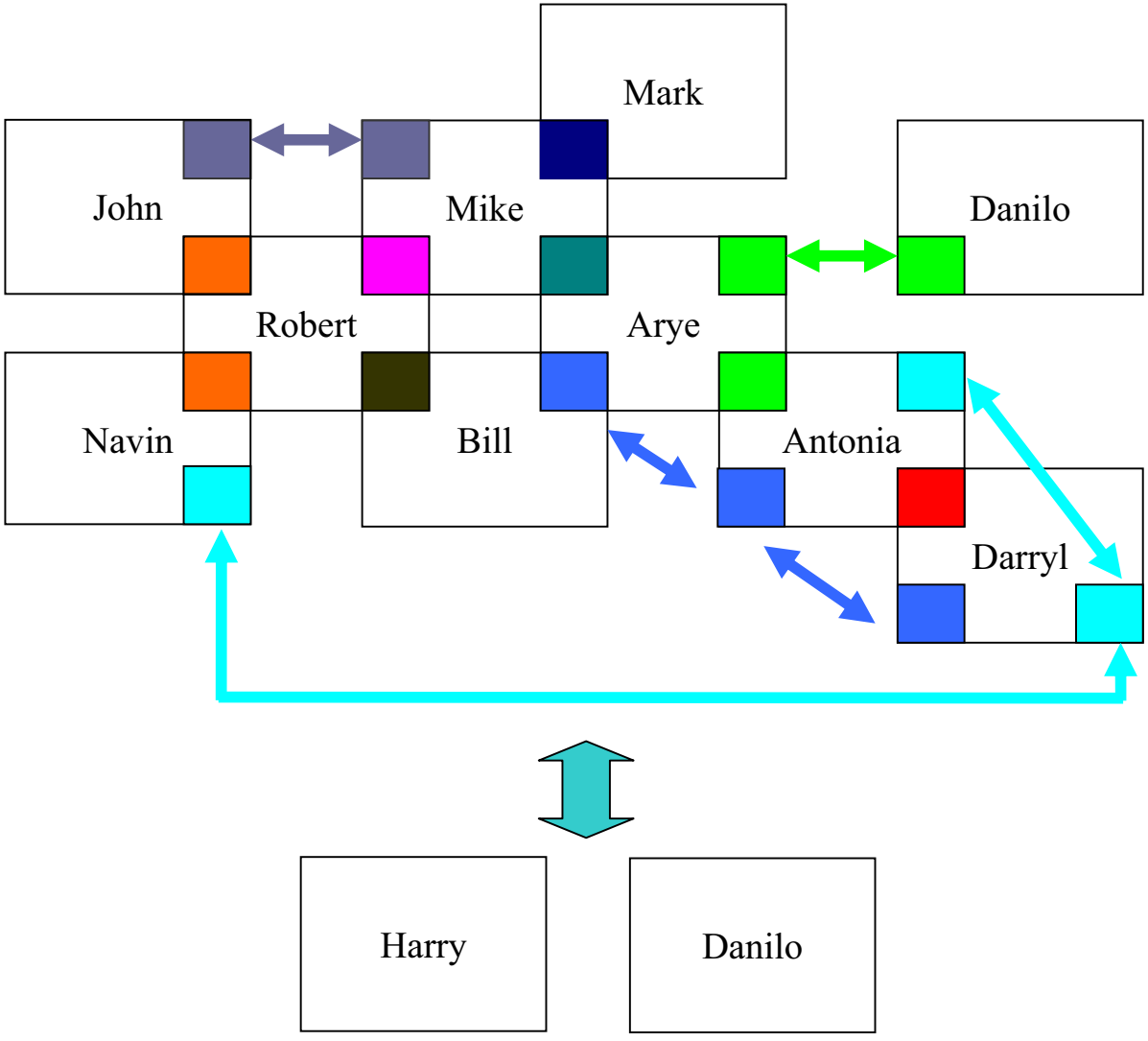
Interactions and Outreach (Cont.)

- Sharing ideas with industry and others in open workshops, for example:
  - Lincoln Laboratory, MIT.
  - Lucent Bell Labs.
  - Motorola.
  - SAIC.
  - System Planning Corporation.
  - Texas Instruments.

Interactions and Outreach (Cont.)



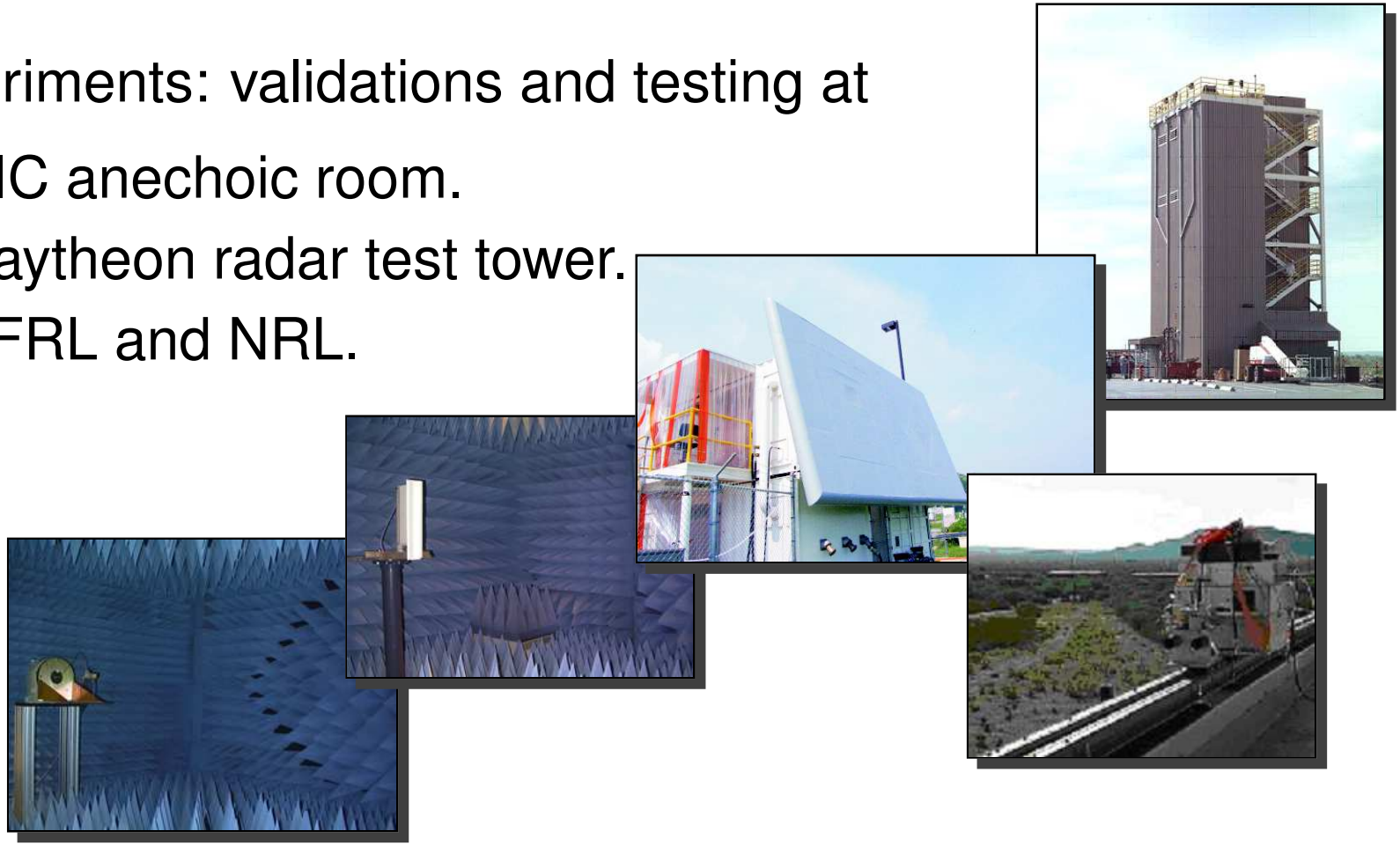
Collaborations Chart



LEGEND	
	Uni-modular Coded Radar
	Waveform Diversities
	Sub-aperture Array Waveform
	Polarized and OFDM Signals
	Quantum Computing
	Waveform Libraries
	Cost Functions
	Scheduling
	Environment Modeling
	GNC Waveform Selection
	Radar Test-bed and Chamber

Facilities

- Computations: institutions are well equipped with facilities for complex calculations.
- Experiments: validations and testing at
  - UIC anechoic room.
  - Raytheon radar test tower.
  - AFRL and NRL.



Future Meetings

- Annual reviews.
- Mid-year meetings.
- Mutual visits.
- Special sessions at conferences.
- Workshops.
- Visits to DoD labs.