Statistical Signal and Array Processing

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Objectives

- Apply statistical signal processing techniques to important new systems
- Advance the theory in the areas of:
  - Array processing
  - Bayesian estimation
  - Nonlinear tracking/filtering
- Write / edit books

Activities

- Applications
  - Novel Satellite Communications (Argon ST / DARPA)
  - Space-time Adaptive Processing (STAP)
    for Navy E2C (Lockheed Orincon / ONR)
  - Aeroacoustic Sensor Networks (Army Research Office)
- Theory
  - Recursive Bayesian bounds (DARPA SPO)
  - Tracking using sparse arrays (DARPA SPO)
  - Multistatic radar (DARPA SPO)
- Books
  - Optimum Array Processing, Part IV of
    Detection, Estimation & Modulation Theory
    H. L. Van Trees, 2002
  - Bayesian Bounds, H. L. Van Trees and K. Bell,
    IEEE Press, 2006

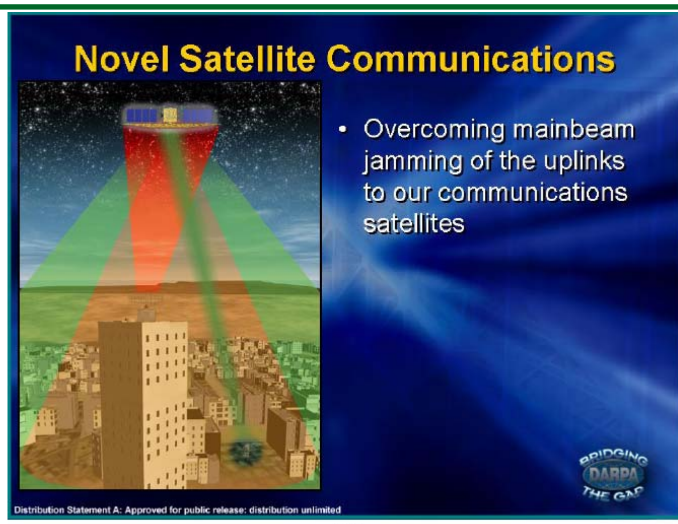
Novel Satellite Communications

" In the past, we successfully showed we can overcome the jamming of our satellite navigation systems. Can we also protect the uplinks of our satellite communications systems? The Novel Satellite Communications program (NSC) is using new phenomenologies to overcome this vulnerability, ensuring that our troops will always have robust satellite communications available.

Last year, we performed field testing that confirmed the properties of the antijam phenomenologies we are exploiting. This year, three teams are developing the algorithms and techniques that exploit these phenomena to provide a robust antijam capability for our communications satellites."

Michael Zatman, DARPA Tech 2005, August 9-11, 2005

DARPATech 2005 August 9—11, 2005



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Overview

- Full Beam Set Algorithm
  - Provides a set of beampatterns that collectively “cover” an Area of Interest (AOI) on the earth’s surface while suppressing up to N_T jammers in the AOI
  - Each beam may allow j_{max} jammers not to be nulled
  - Beams may be scanned to detect new users and jammers

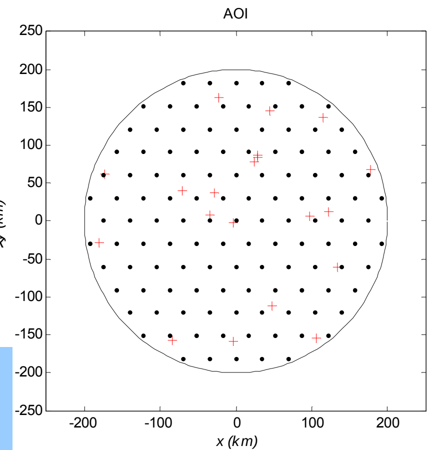
- Beam Subspaces
  - For a known user (or set of users), beam subspaces are collection of beams that span the user and un-nulled jammer subspaces
  - Subspace processing provides reduced rank data for subsequent processing

Full Beam Set Generation

- Define Grid Points on AOI
  - e.g. hexagonal grid with 121 points
- For each Grid Point
  - Find maximum SINR beam with j_{max} un-nulled jammers
  - MVDR with parametric interference covariance matrix, pointing to Grid

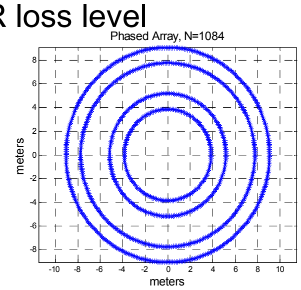
Start by excluding j_{max} closest jammers

Adjust jammer selection iteratively to improve SINR

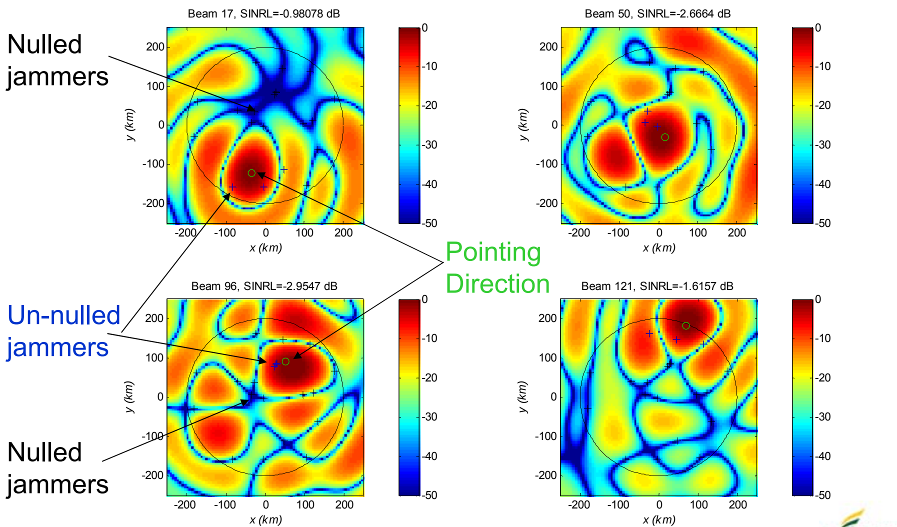


Scenario

- 1084-element cantor ring array configuration
- N_T = 20 randomly distributed jammers
- j_{max} = 3 un-nulled jammers per beam
- Beam set quality given as percent coverage of AOI at -3 dB SINR loss level



Typical Beams (j_{max} = 3)

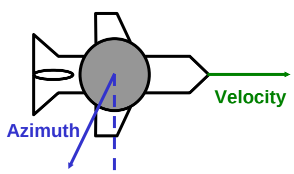


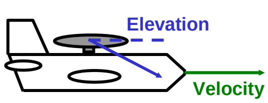
STAP for E2C

- Program
  - Replace rotating linear array with circular phased array
  - Develop STAP algorithm
- Our role
  - Full rank algorithms have too many DOF to be computationally feasible (e.g. 360) in real time
  - Develop clever reduced-rank algorithms that have acceptable performance

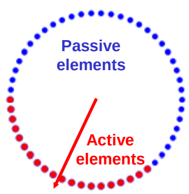
CSTAP Scenario Modeled

Geometry

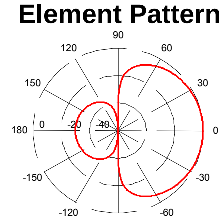




Antenna Array



Element Pattern



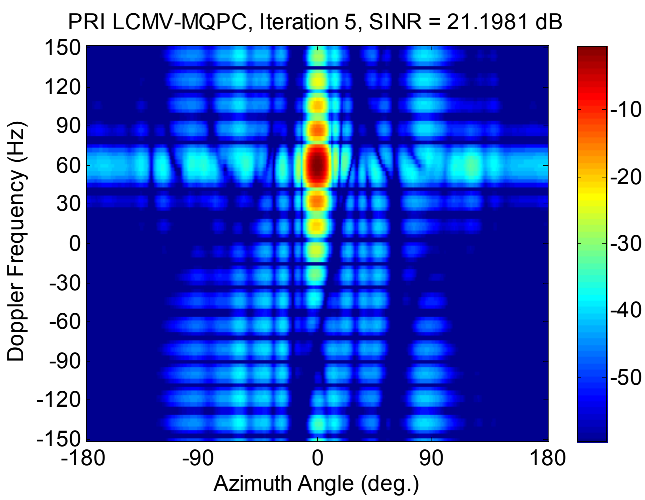
Radar Parameters

Frequency	435 MHz
Bandwidth	3.75 MHz
Samp. Freq.	3.75 MHz
PRF	300 Hz
# Pulses	18

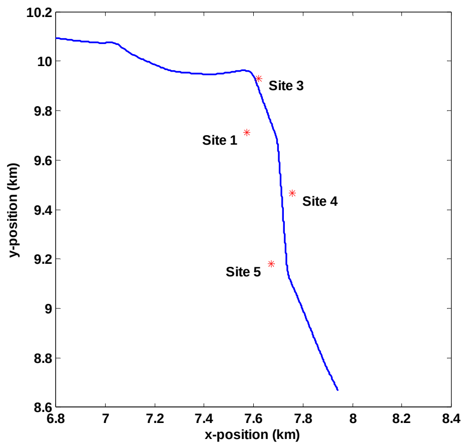
Candidate techniques

- PRI LCMV – MQPC
- Adaptive Subspace
  - EIgenspace
  - Conjugate gradient / MSWF

PRI LCMV-MQPC



Battlefield Aeroacoustic Sensor Network

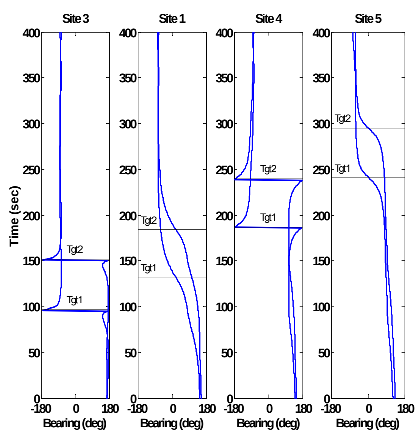


- Targets move along track between arrays
- Arrays collect broadband aero-acoustic data
- Bearing and power levels seen at arrays change rapidly as vehicle passes

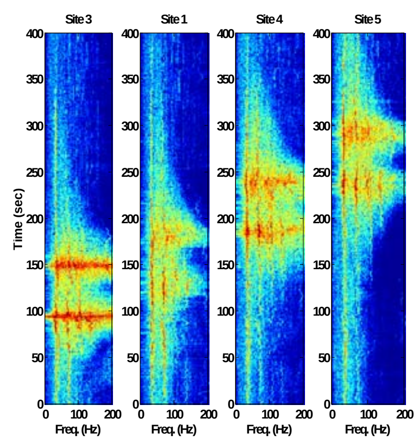
Sponsored by Army Research Lab

Target Data as Seen at Arrays

Bearing

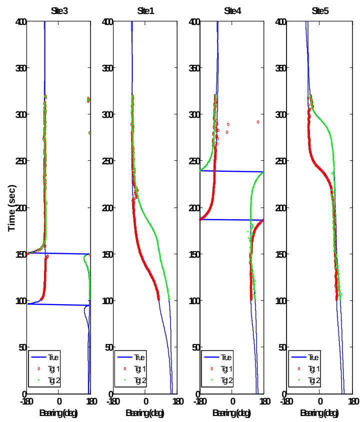


Spectrogram

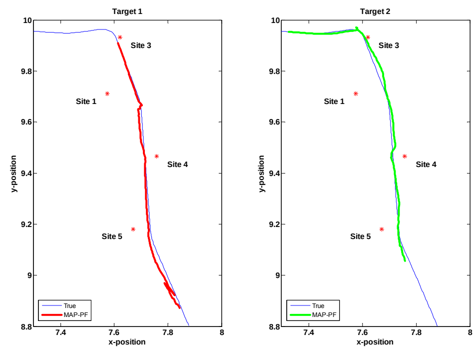


MAP-PF Position Tracking Results

Guided Signal Processing



Tracking



Theory

- Recursive Bayesian bounds (DARPA SPO)
- Tracking using sparse arrays (DARPA SPO)
- Multistatic radar (DARPA SPO)

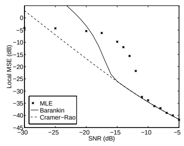
Recursive Bayesian Bounds

- Observe a nonlinear function of a vector parameter $\underline{\theta}$ on the presence of noise
- Observe a nonlinear function of a discrete-time random process $\underline{x}(k)$ in the presence of noise
- In general, an analytic expression for the performance of the estimator cannot be found
- Lower bounds on performance are the primary approach

Parameter Estimation Bounds (Covariance Inequality)

Deterministic	Bayesian	Recursive Bayesian
Cramér-Rao [Fisher 22, Dugue 37, Cramér 46, Rao 45]	BCRB [Van Trees 68]	RBCRB [Tichavsky et al 98]
Bhattacharyya [Bhat. 48]	B Bhat. (BB) [Van Trees 66, 68]	RB Bhat. [Reece & Nicholson 05 (T)]
Barankin [Barankin 4-9] [McAulay & Hofstetter 71]	Bobrovsky – Zakai (BZB) [Bobrovsky et al 76, 87] [Reuven & Messer 97]	RBZB [Reece & Nicholson 05 (T)]
Mixed [Abel 93] [McAulay & Hofstetter 71]	Mixed Bayesian [Renaux et al 06]	Recursive mixed [Bell & Van Trees 06]
	Weiss – Weinstein (WW) [Weiss & Weinstein 85, 88]	Recursive WW [Rapoport & Oshman 04 (T)] [Reece & Nicholson 05 (T)] [Bell & Van Trees 06 (T/A)]

An SAT – type analogy



BOUNDS are to ESTIMATION THEORY

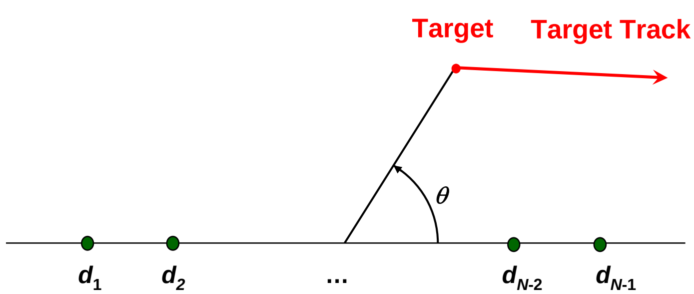
as

REBOUNDS are to BASKETBALL

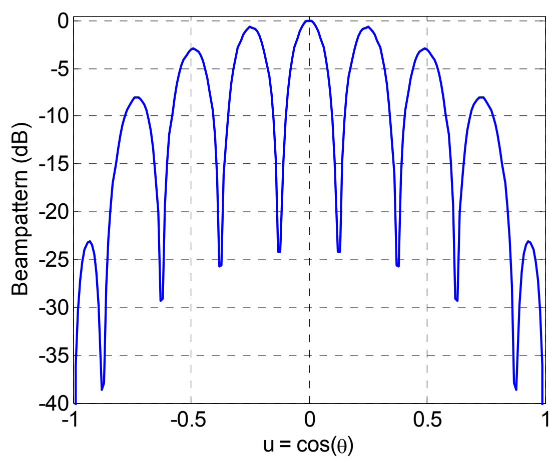
- IN BOTH CASES -

GEORGE MASON IS IN THE FINAL FOUR!

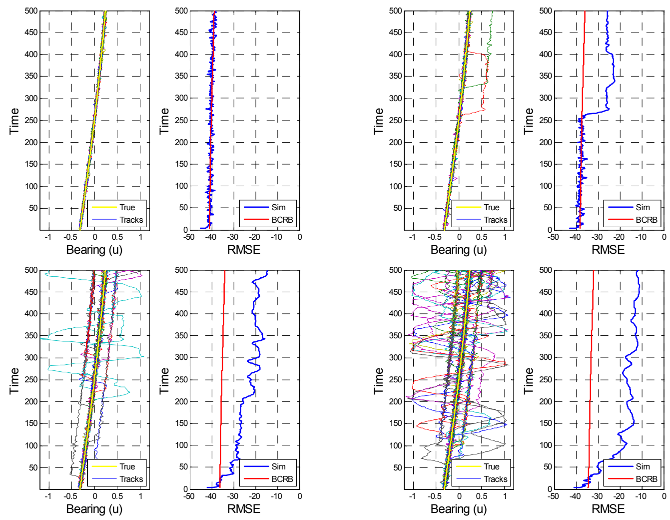
Tracking using sparse arrays



Tracking using sparse arrays



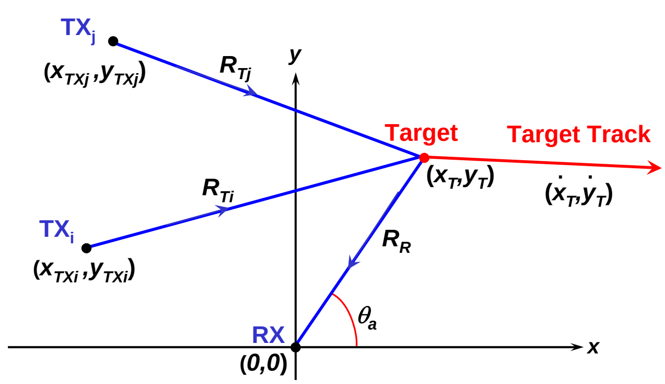
Tracking using sparse arrays



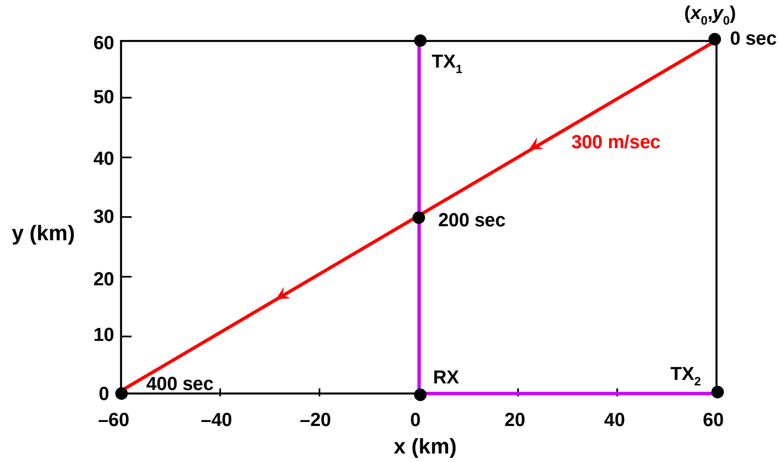
Issues

- Bound performance of trackers
- Utilize sidelobe / grating lobe structure to improve performance

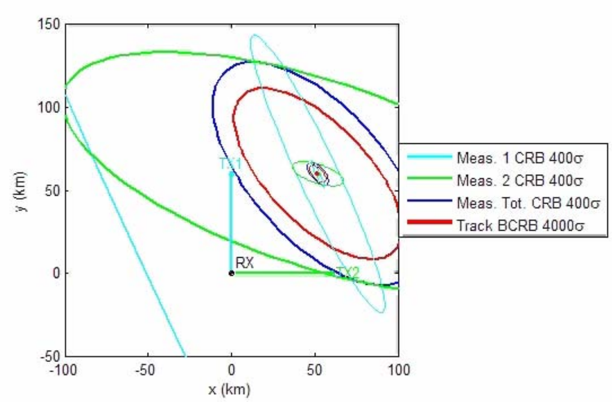
Multistatic Radar Geometry



Two Transmitter Example



Multistatic Radar BCRB



Books

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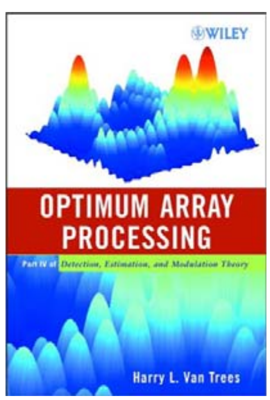
Optimum Array Processing



- Published in 2002
- Widely-used in graduate schools & industry
- In 4^{th} printing
- Chinese edition in print

Bayesian Bounds

- An IEEE Press Reprint Book published in conjunction with Wiley
- Contains 80 selected papers which include most of the important results in the area
- Contains about 50 pages of new text to provide context and integration of the material

Summary

- An active research and educational program that combines theory and practical application