Distributed Active Sensing in the MVE Framework

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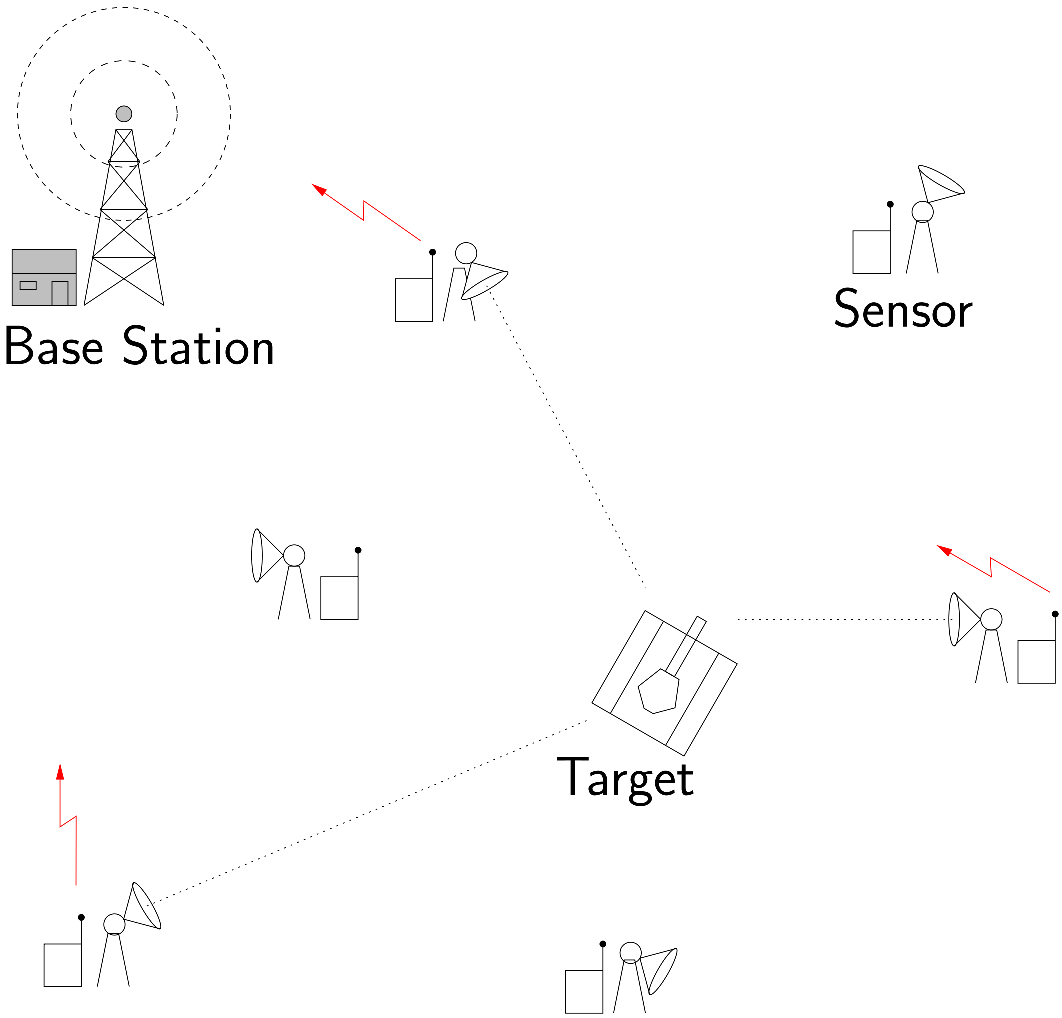
Distributed Active Sensing



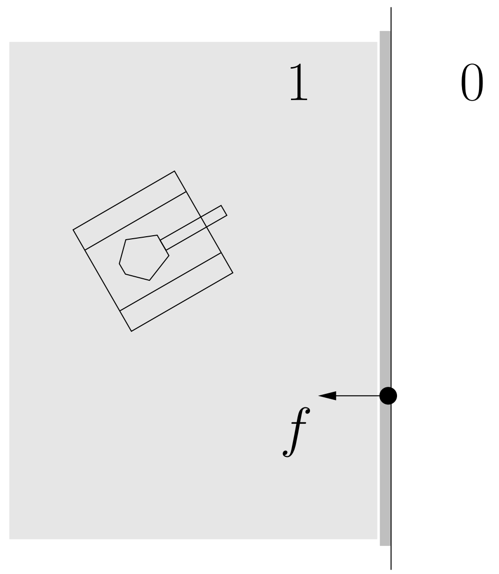
Issues: Sensor selection & coordination
Centralized vs distributed

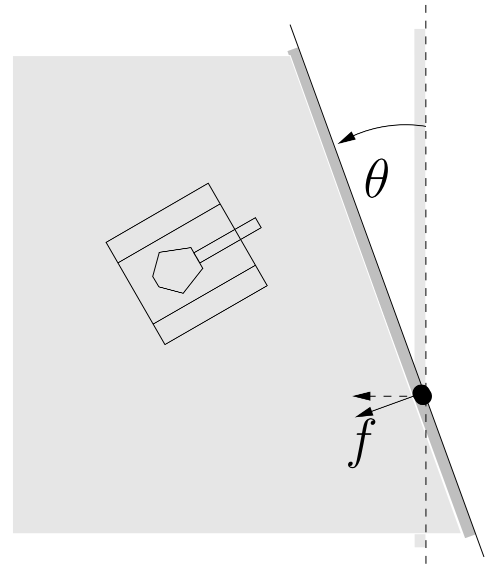
Problem: Central coordination for globally optimal estimation extremely difficult problem

Objective: Present **effective heuristic** distributed coordination of active sensors, in MVE framework

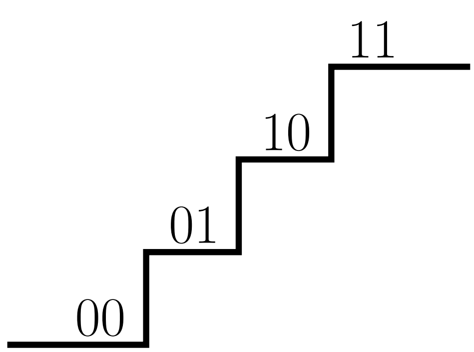
Half-Space Based Sensors

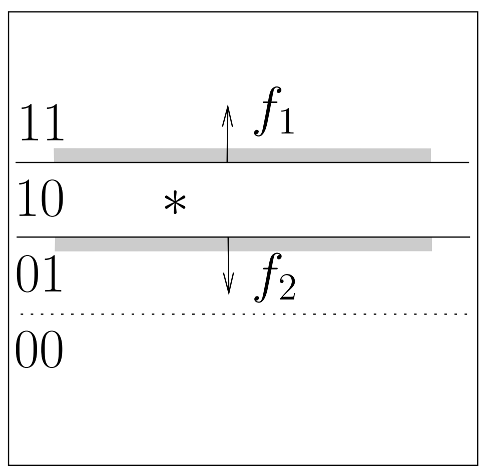
Half-space sensor (1-bit sensor) is "building block" for polyhedral estimation





Quantization yields one or two inequalities:





Active sensing: sensor can adjust key parameters.

Polyhedral Estimation

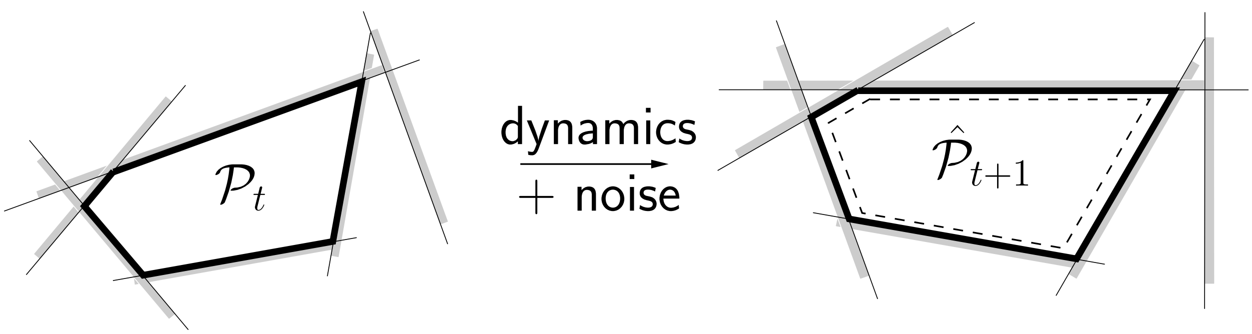
Dynamical system:

$$x(t+1) = Ax(t) + Bw(t), \qquad |w(t)| \leq 1$$

1. Dynamics Update:

– $x(t)$ known to lie in polyhedron $\mathcal{P}_t$

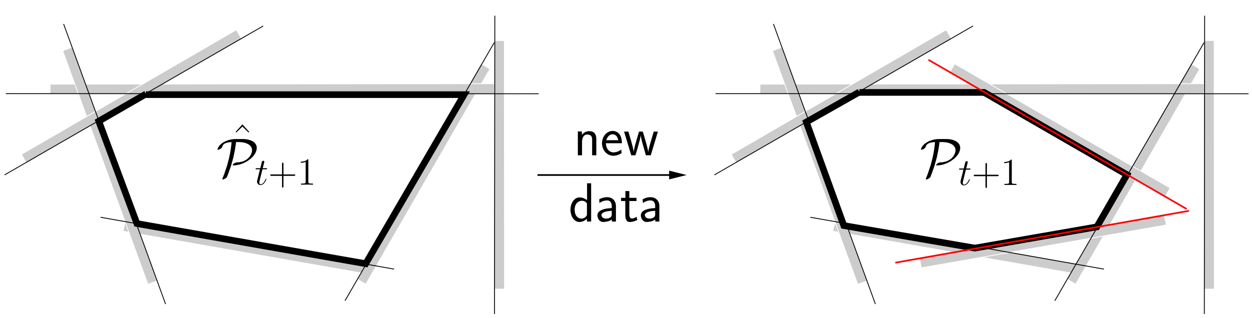
– dynamics predict $x(t+1) \in \hat{\mathcal{P}}_{t+1}$



2. Measurement Update:

– new sensor measurements $\Rightarrow x(t+1) \in \mathcal{S}_{t+1}$

– update polyhedron $\mathcal{P}_{t+1} = \hat{\mathcal{P}}_{t+1} \cap \mathcal{S}_{t+1}$



Polyhedral Approximation and Pruning

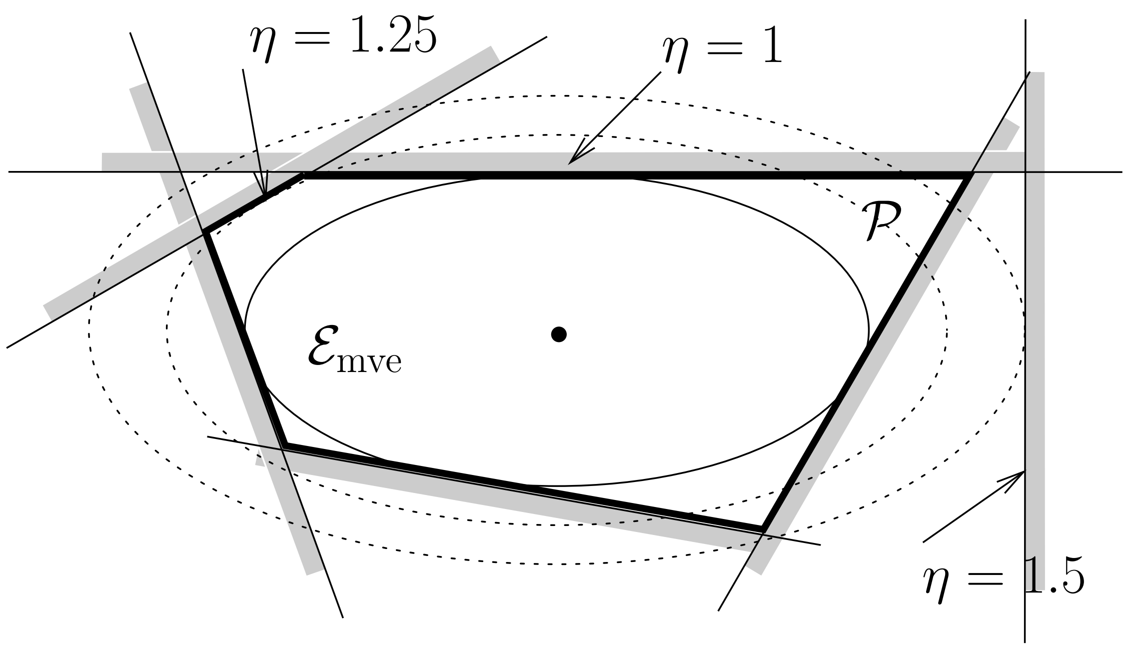
Problem: Polyhedral description grows with each measurement: need to **prune** polyhedron

Proposal: use minimum-volume ellipsoid (MVE)

– computing MVE convex problem, easily solved.

– MVE good quadratic approximation/bounds of $\mathcal{P}$

– MVE gives natural relevance ranking for inequalities



Last talk: Pruning makes polyhedral estimation practical.

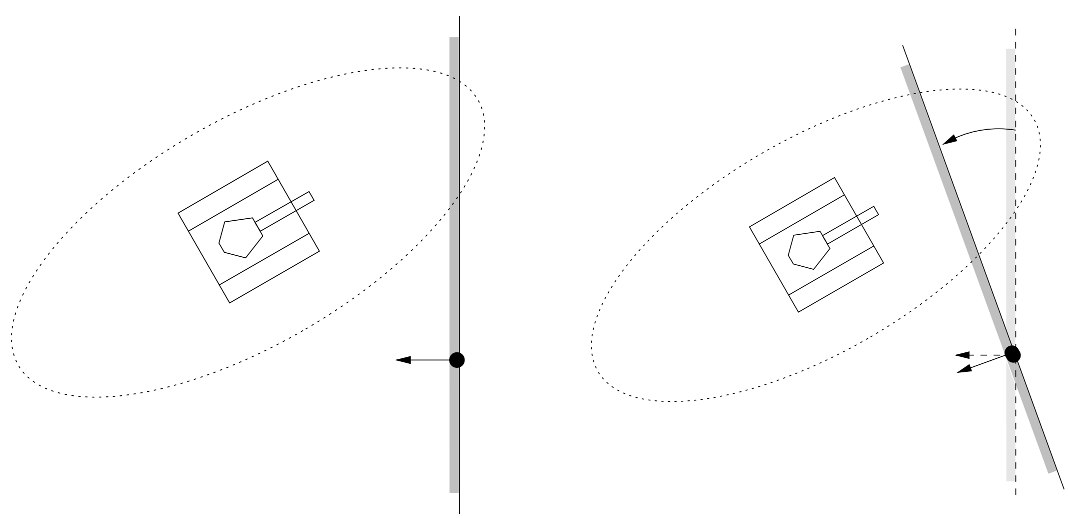
Active Sensing via the MVE

Ignorance measure:

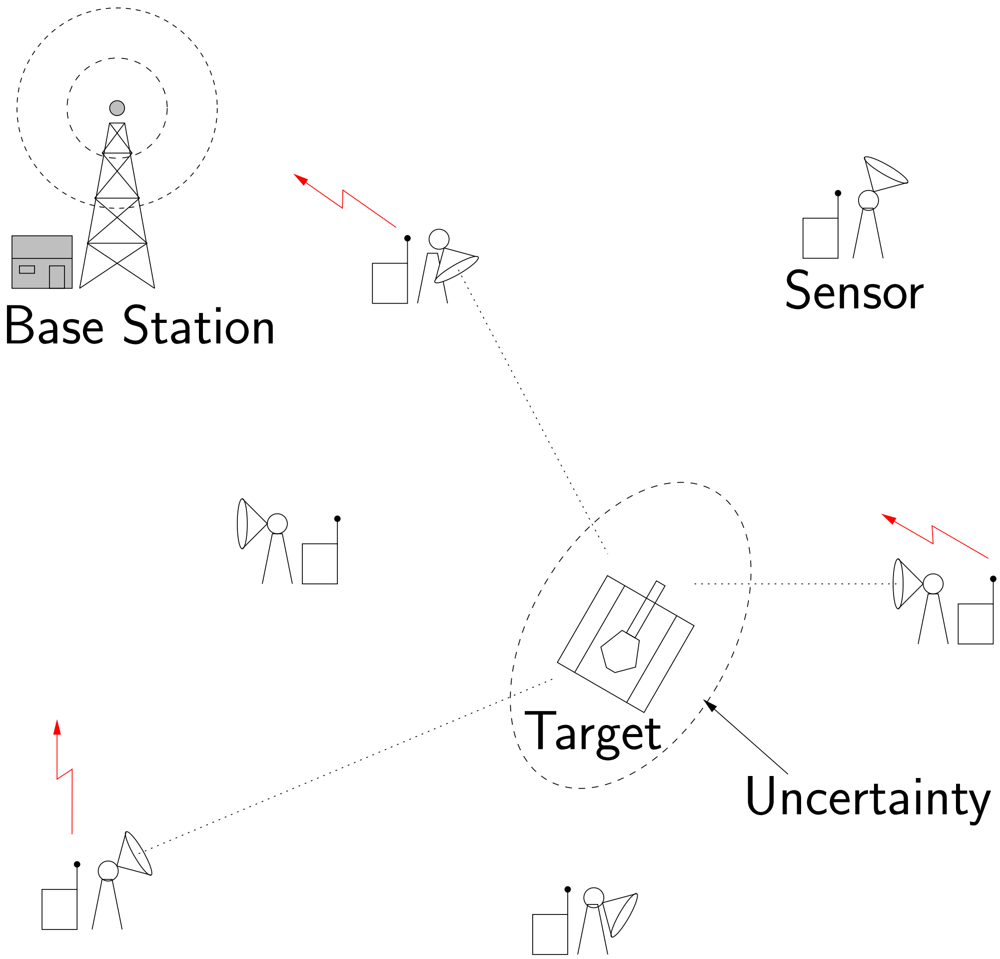
- volume of uncertainty ellipsoid
- cuts with same η, cut off same volume from MVE

Active distributed sensing:

- sensors reconfigure to "cut away" as much as possible of MVE
- sensors only make measurement if they can cut off a substantial part of MVE, *i.e.*, $\eta < \eta_{\max}$



Distributed Active Sensing – Idea

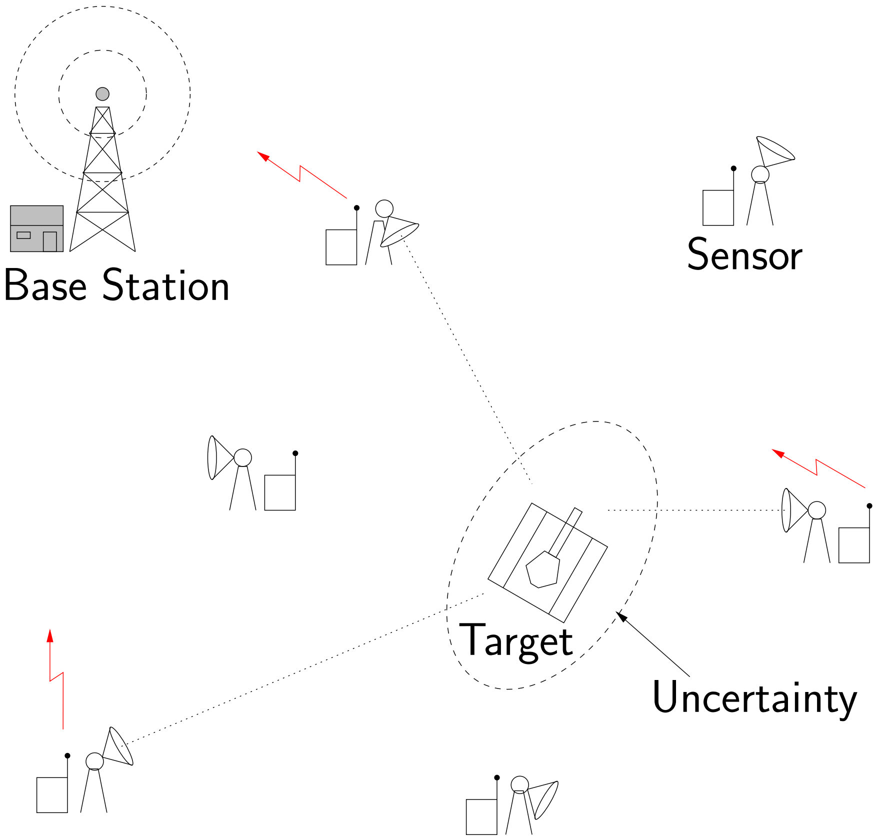


Approach:

- Broadcast uncertainty estimate & threshold
  - MVE ellipsoid (covariance matrix) & $\eta_{\max}$
- Each sensor assess its own "informativeness"
  - reconfigures to maximize own informativeness
  - measures & transmits only when needed

$\Rightarrow$ Greedy (sub-optimal) but **distributed** sensing.

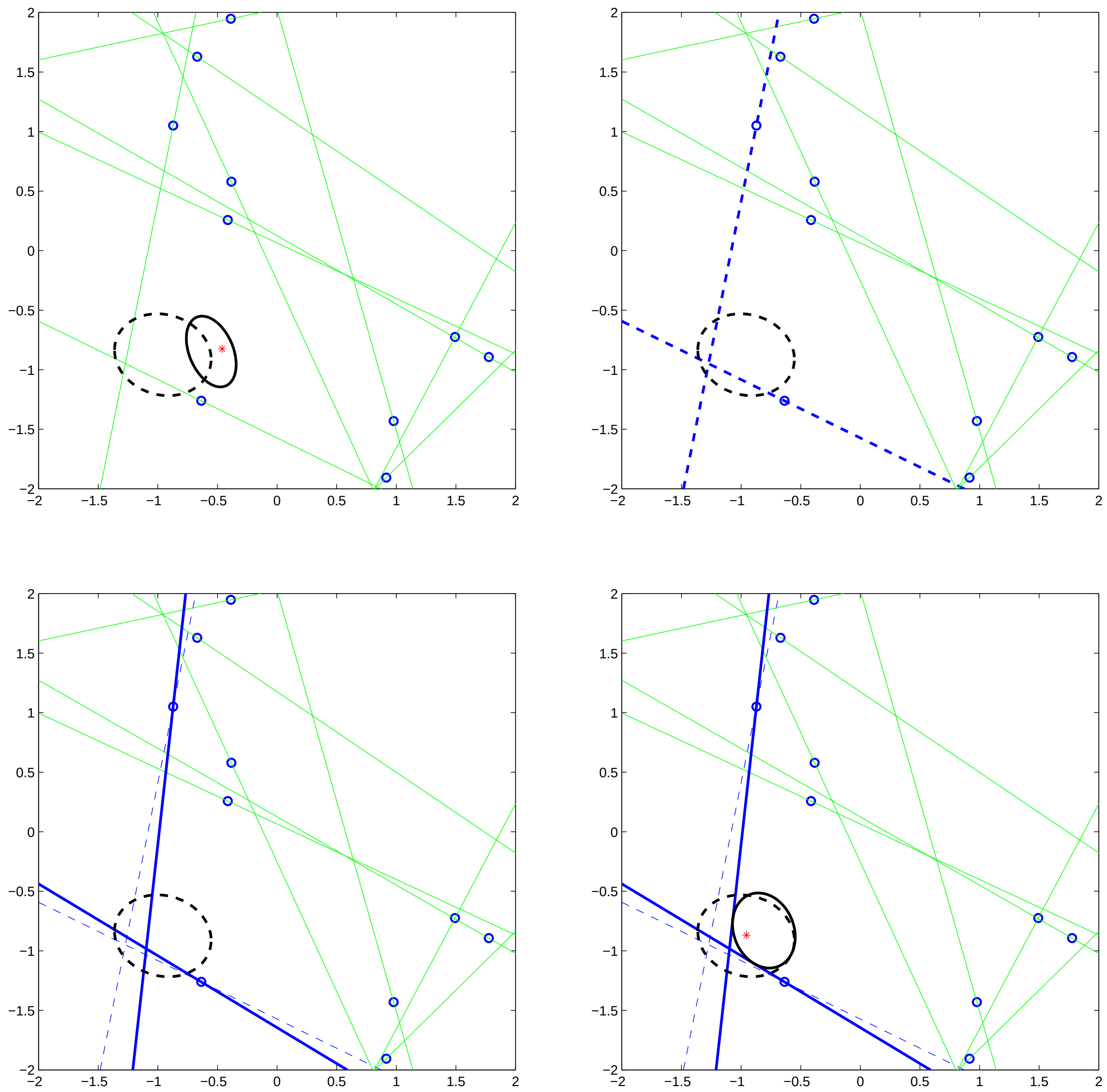
Distributed Active Sensing – Advantages



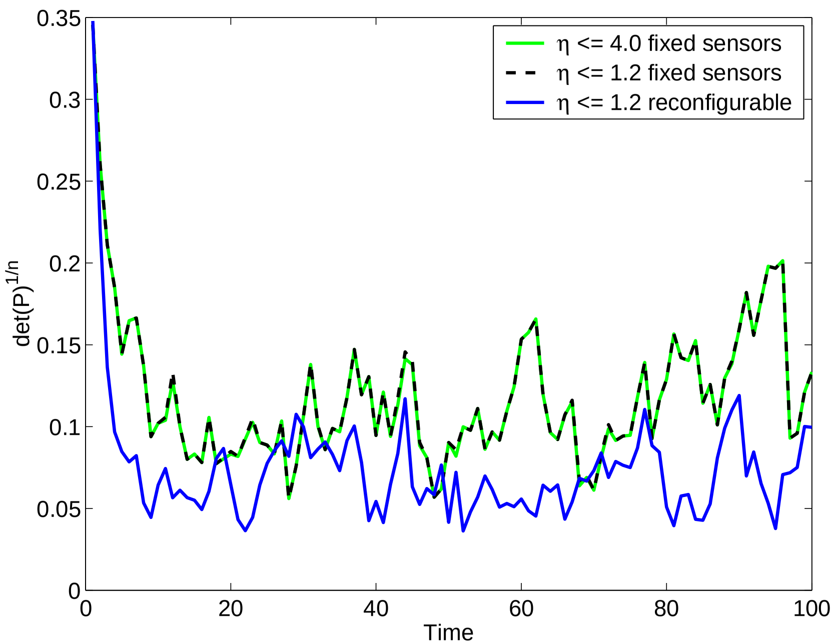
Advantages:

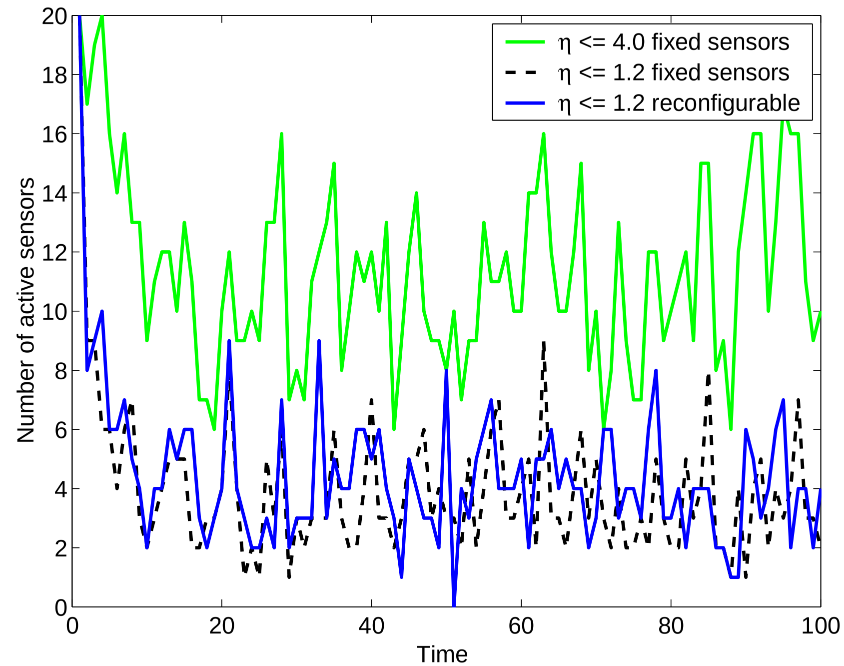
- base station need not know sensor position
  - sensors could be moving, multitasking, hiding, . . .
- avoids making/sending unnecessary measurements
  - saves sensor power, communication bandwidth.
  - avoids detection
- extends easily to multiple targets
  - produces fair sensor allocation

Simulation: Distributed Active Sensing



Example: Fixed versus Self-Configuring Sensors



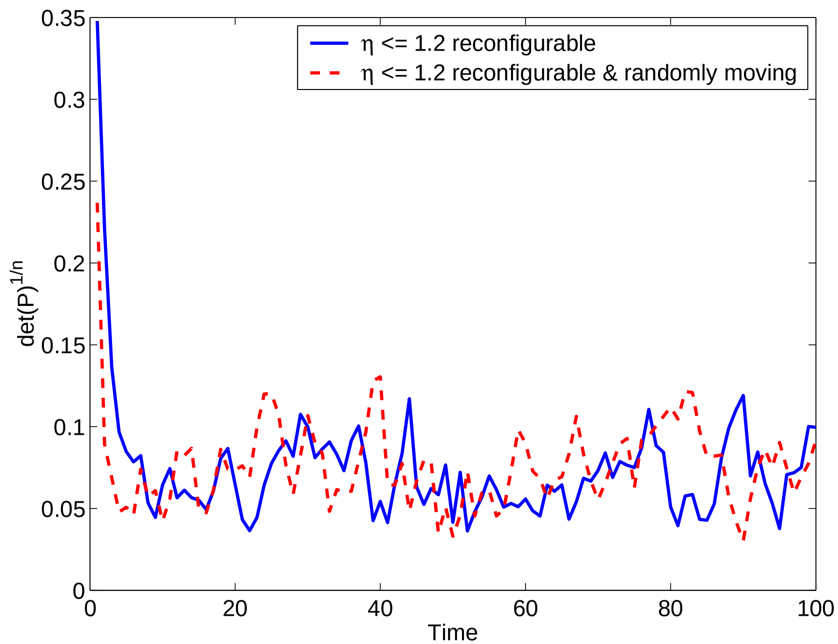


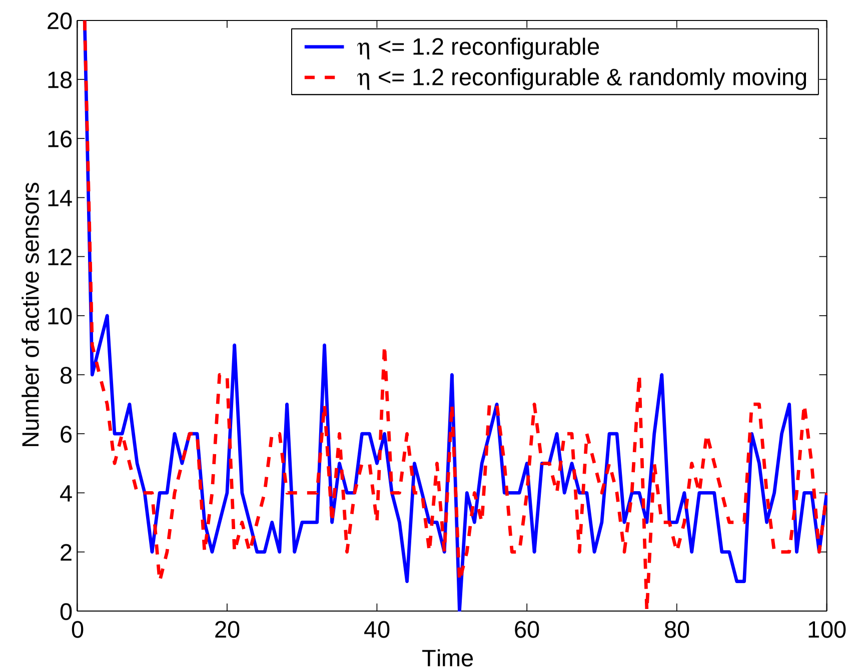
Setup: 20 half-space sensors, random positions; target moving randomly

Result: For same informativeness threshold ($\eta_{\max}$)

Self-configuring sensors give **improved estimation**

Example: Moving Self-Configuring Sensors

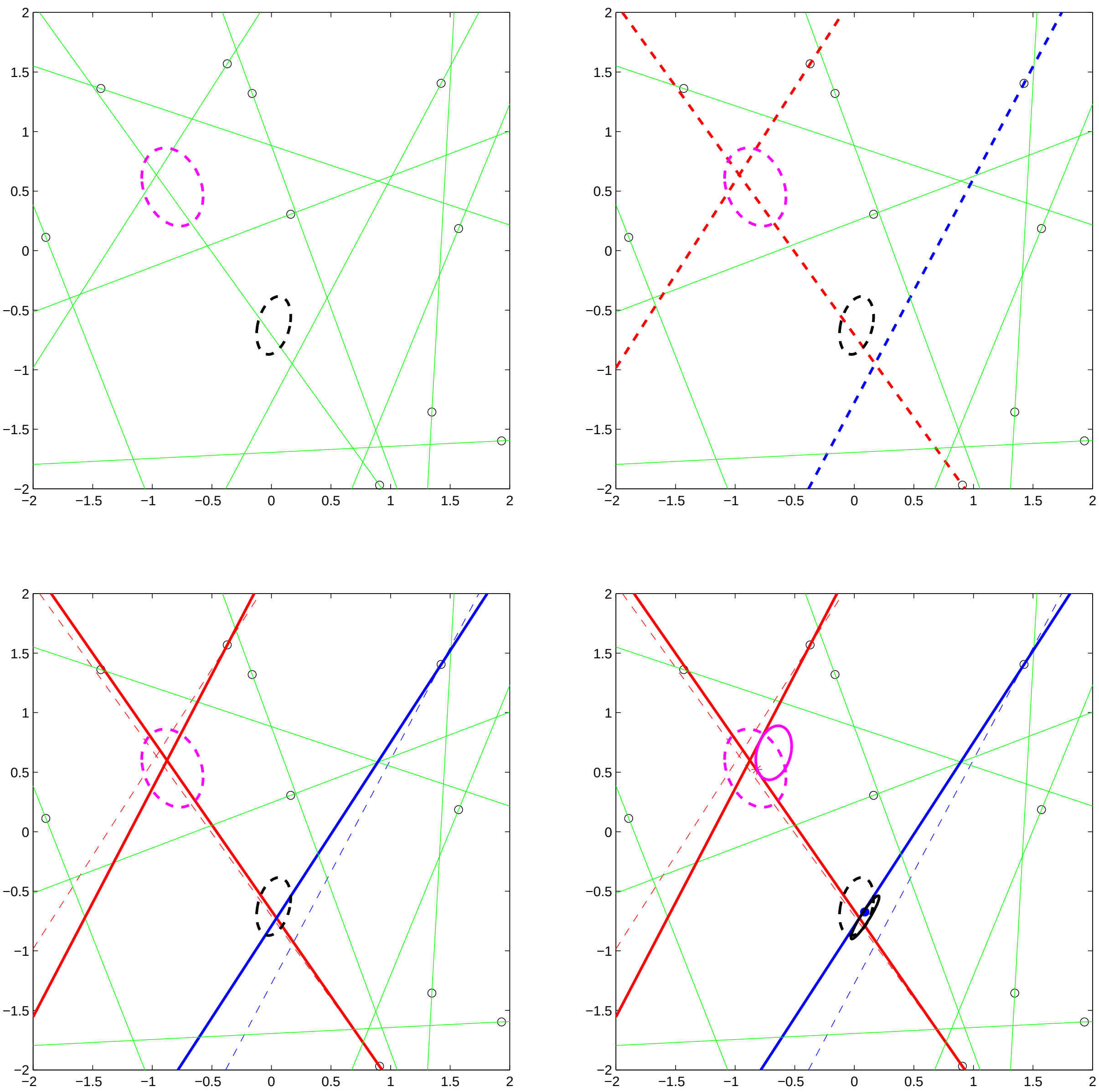




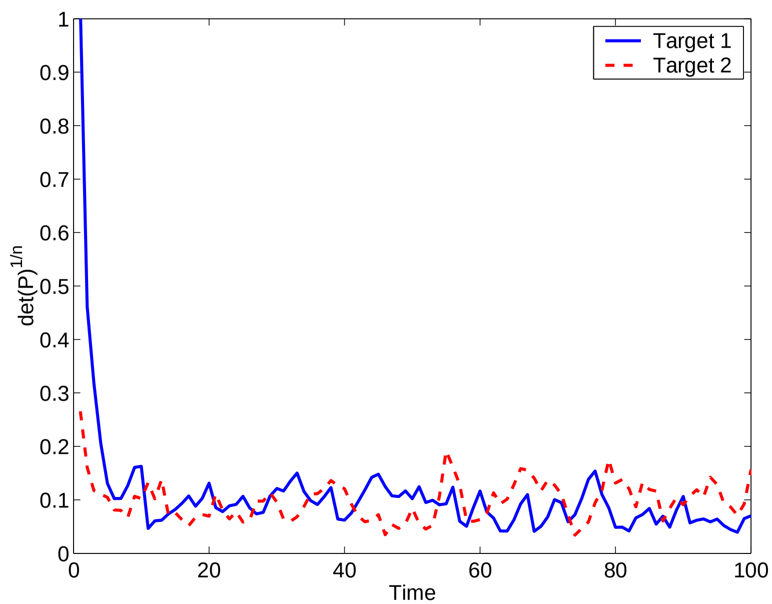
Setup: now sensors move in random walk (*e.g.*, multi-tasking, etc.)

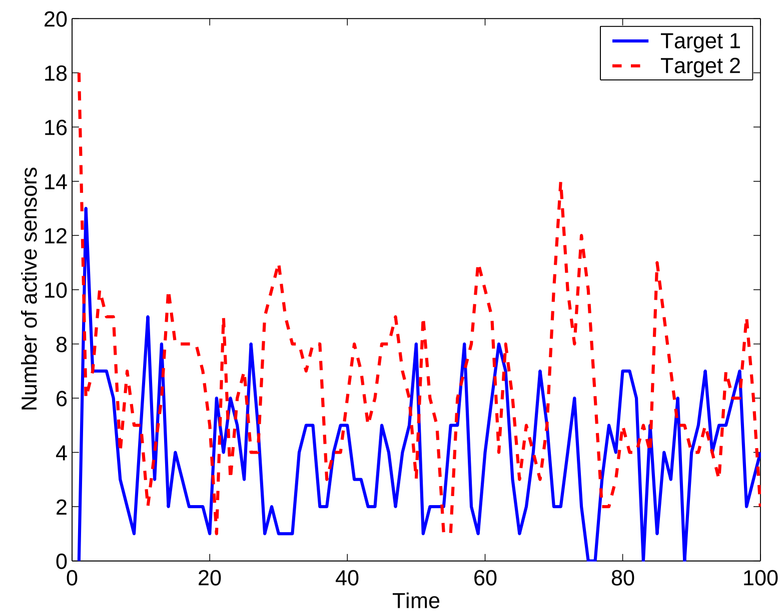
Result: Same performance even with **moving** reconfigurable sensors!

Simulation: Multiple Targets



Example: Multiple Target Tracking





Setup: Two targets: same dynamics; different noise & initial conditions

Result:
- **equal** performance
  - volume of uncertainty ellipsoids is same
- sensors **coordinate**
  - have **fair** allocation of sensors between targets
  - more measurements of target with greater uncertainty

Extensions

Distributed active sensing and estimation

- Distrisbuted sensors exchange information, packages broadcasted in the network, could be blocked, lost, degraded.
- Each sensor runs its own version of the estimation algorithm, based on what it can receive, and makes decision when and how to act.

Fully distributed estimation, no central station required. Each one serves as a central station for what it knows.

Conclusions

Objective: distributed active sensing

globally optimal solution very hard (even centralized)

proposed **effective heuristic** in MVE framework

- broadcast MVE and "informativeness" threshold
- sensors reconfigure to optimize informativeness
- measure/transmit only if useful
- greedy, but appears to work well in practice

many nice features

- **distributed** decision making
- handles moving, multi-tasking, sensors
- avoids making unnecessary measurements
- easily extends to multiple-targets