Robust Decentralized Signal Processing and Distributed Control of Autonomous Sensor Networks

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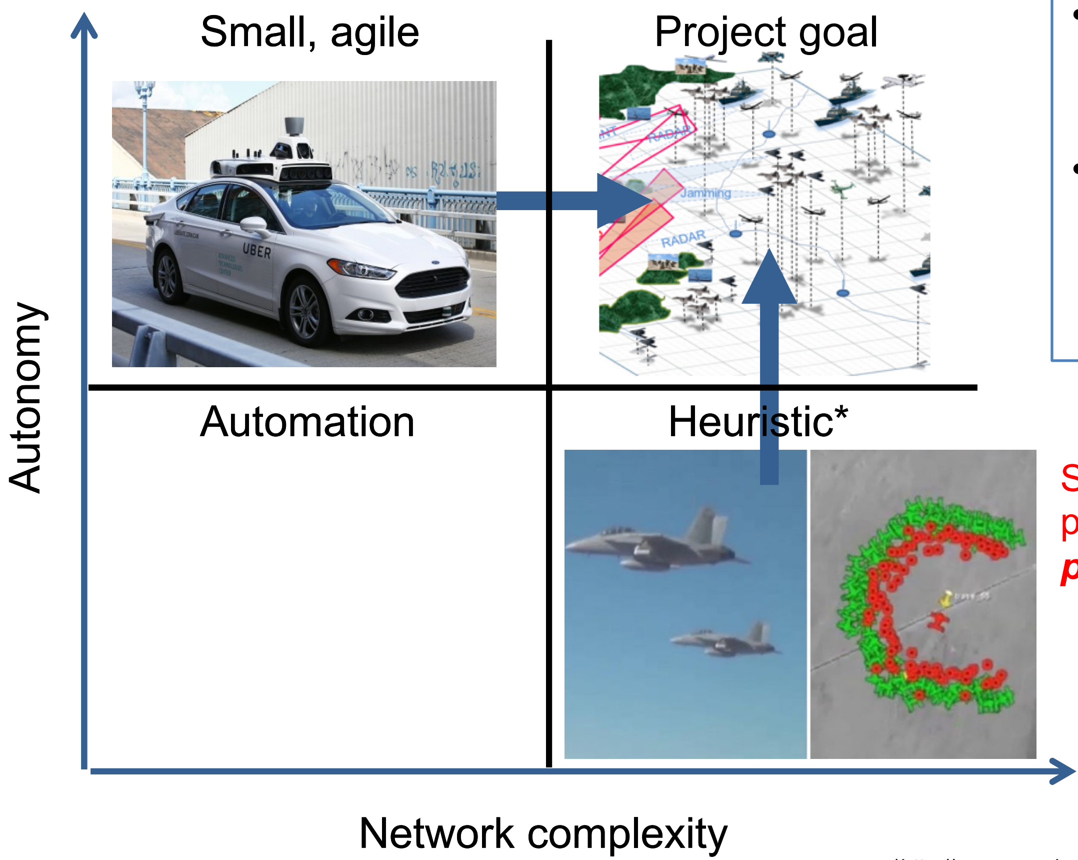
There are no current solutions for large networks with a high degree of autonomy

Optimal methods with approximate real time solutions *for* ***large network sizes***



Challenges:

- Insufficient bandwidth to share all sensor data with other agents
- Complexity of network optimization grows exponentially with the number of agents

Simple node processing/behaviors producing network intelligence with ***provable performance bounds***

*http://www.popularmechanics.com/military/aviation/a24675/pentagon-autonomous-swarming-drones/

Goal is scalable, real time network adaptation and signal processing which has provable performance bounds.

Project Objectives

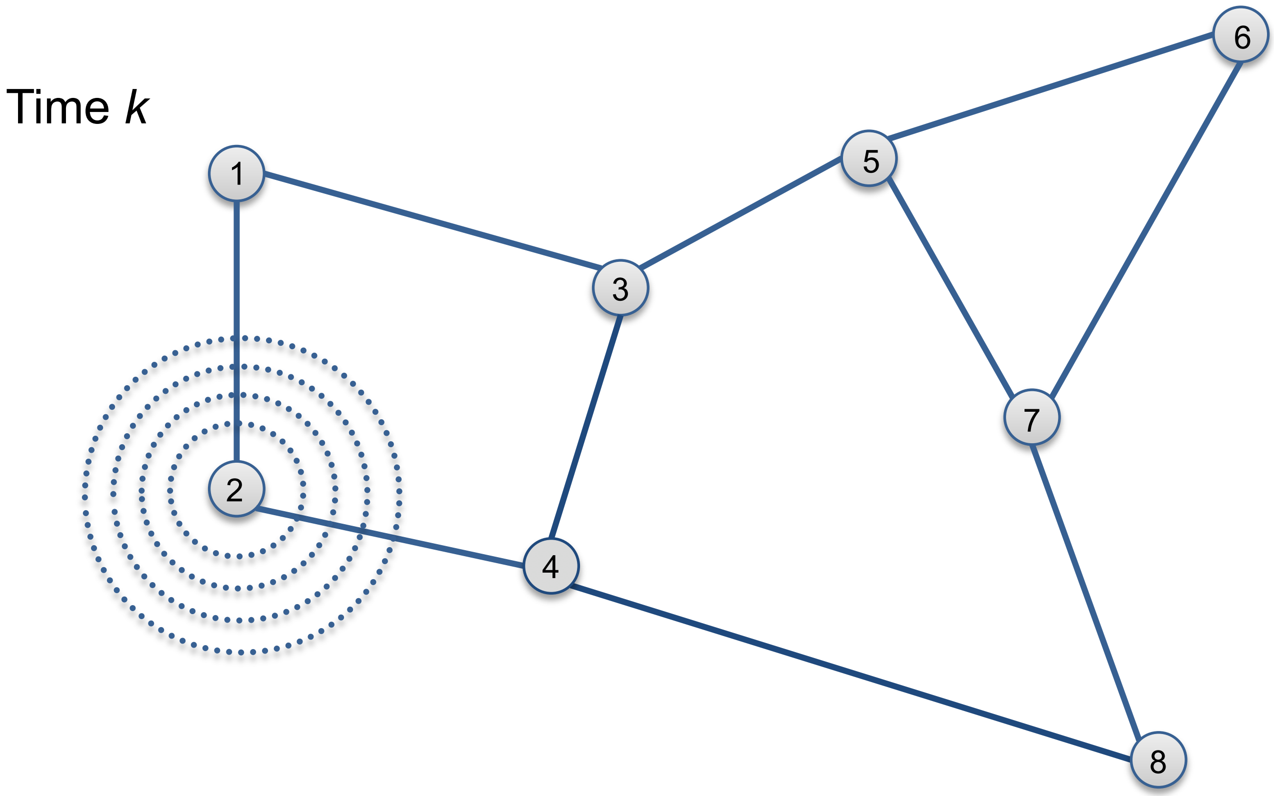
- The project objectives are algorithms for “swarm” decisions which are
  - ***Decentralized*** - no central fusion, C2 node
  - ***Scalable*** - solvable for large networks, provable performance bounds
  - ***Robust*** - graceful degradation of network performance in the presence of jamming, nodes being destroyed or compromised, can operate without *a priori* information

Distributed Sensing: How should the data collected over the entire network be shared/combined at individual nodes to reach good global decisions?

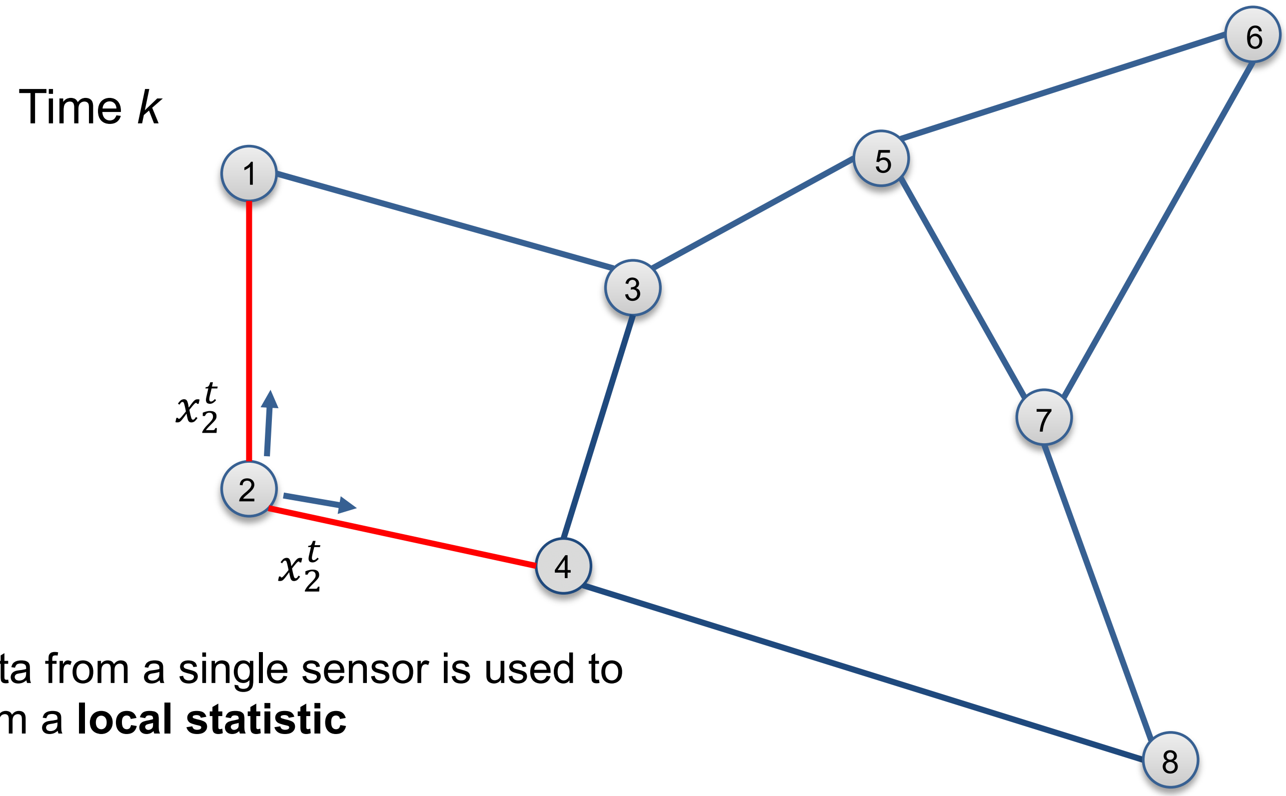
Network Adaptation: Given all previous data and actions, how should the network adjust itself (position, sensing decisions, communication strategies) for future time steps to perform better?

Project Objectives: General decentralized mathematical frameworks for robust sensing and network decisions for detection/estimation problems

Sensors take measurements and form a local statistic



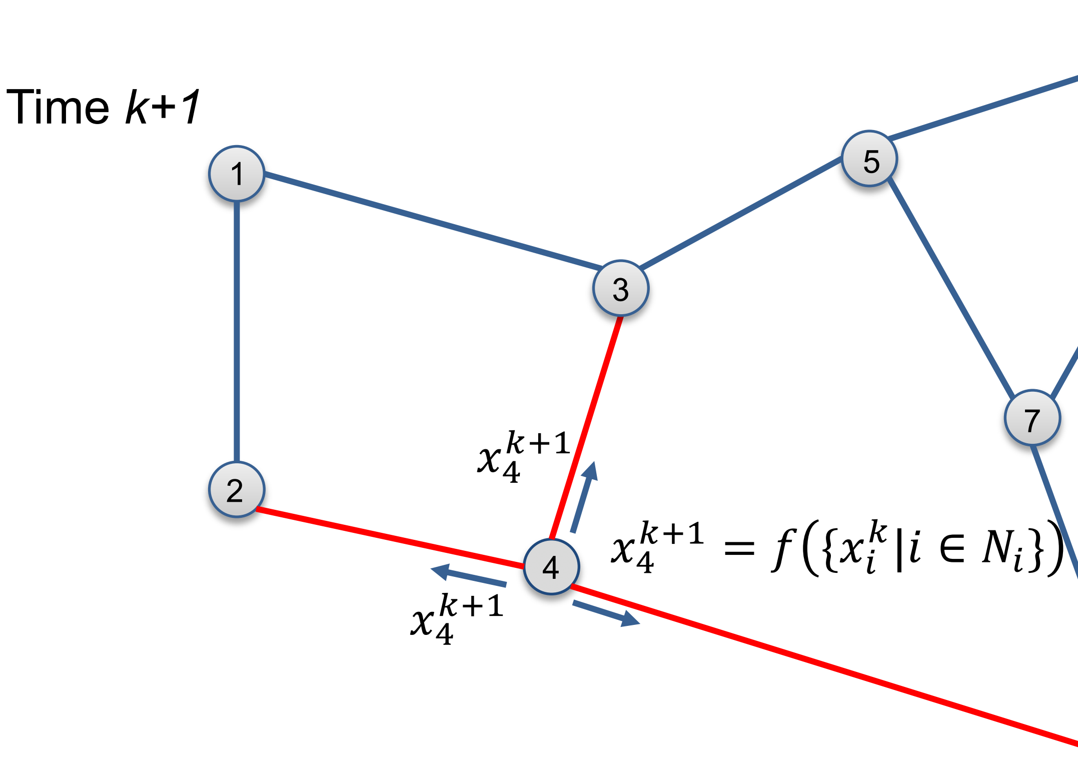
Sensors take measurements and form a local statistic



Data from a single sensor is used to form a **local statistic**

B. Kailkhura, P. Ray, D. Rajan, A. Yen, P. Barnes, R. Goldhahn, *Byzantine-resilient collaborative autonomous detection*, 2017 IEEE Conference on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2017.

Sensors share a function of the local messages from connected nodes

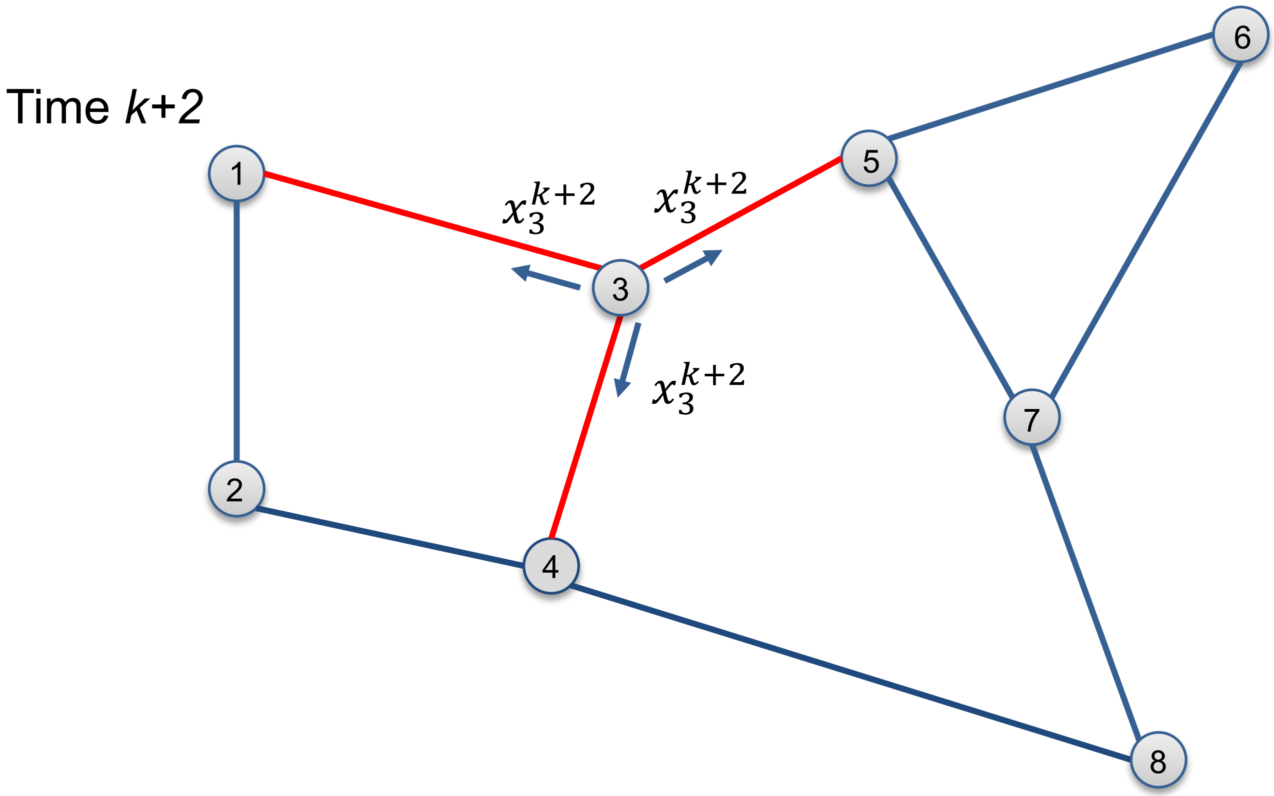


A **fusion rule** defines how data from neighboring nodes is used

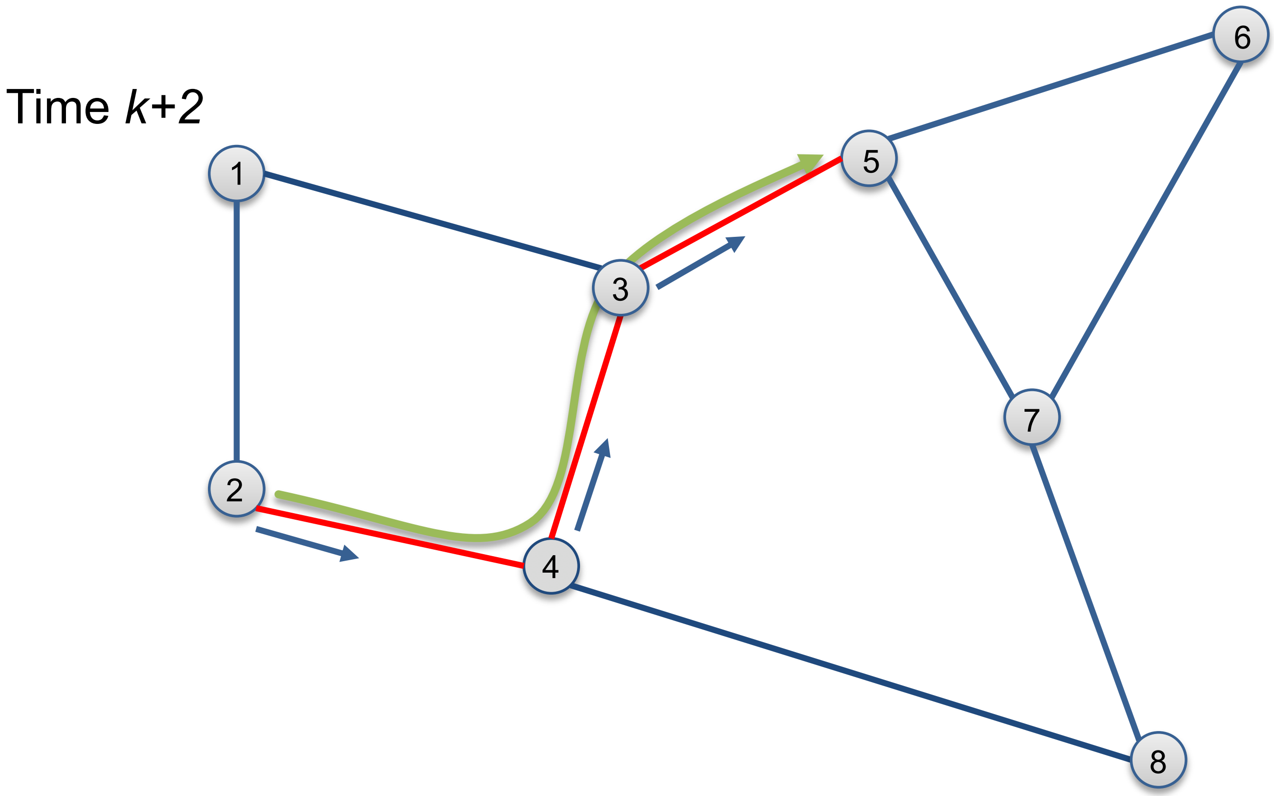
B. Kailkhura, P. Ray, D. Rajan, A. Yen, P. Barnes, R. Goldhahn, *Byzantine-resilient collaborative autonomous detection*, 2017 IEEE Conference on Computational Advances in Multi-Sensor Adaptive Processing (CAMSAP), 2017.

Q. Li, B. Kailkhura, R. Goldhahn, P. Ray, P. Varshney, *Robust Decentralized Learning Using ADMM with Unreliable Agents*, 2018 Conference on Neural Information Processing Systems (NIPS), Submitted.

Information propagates with latency based on network size and connectivity

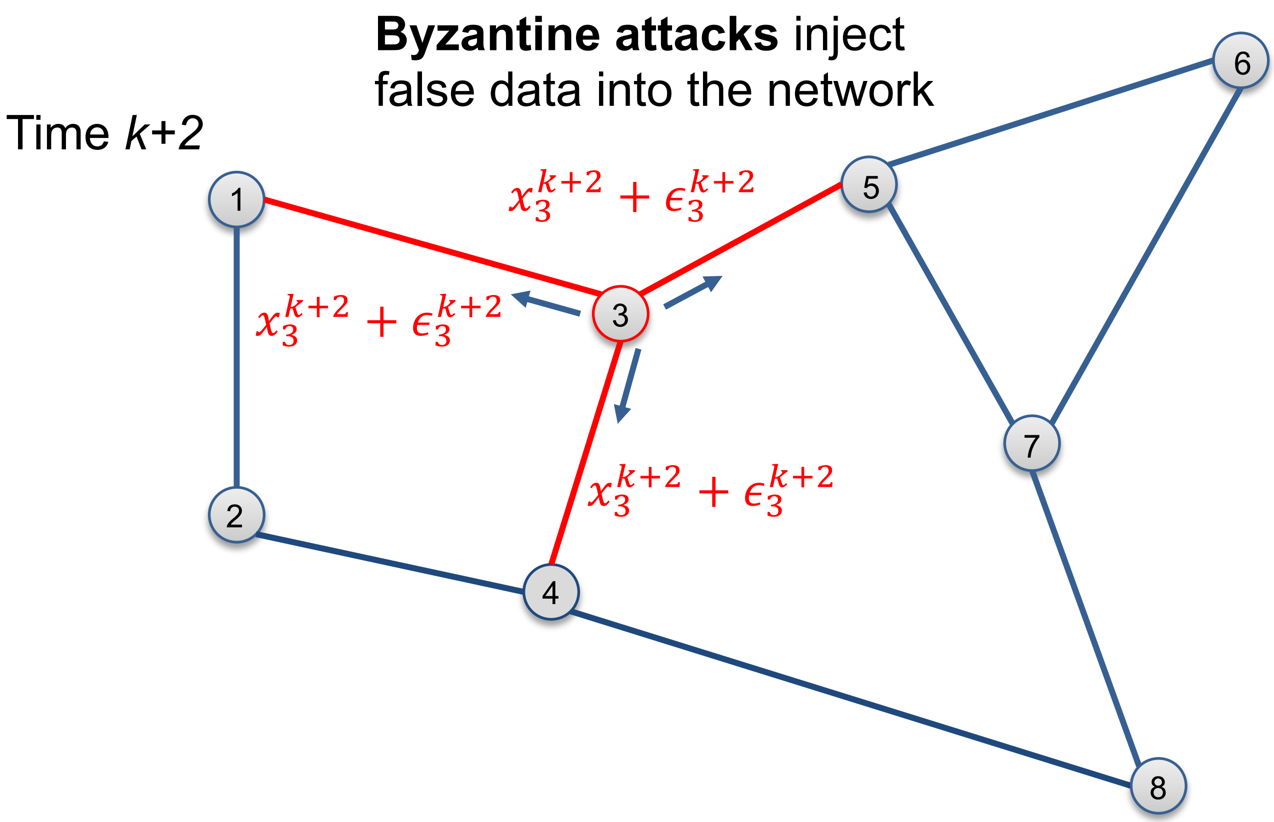


Decentralized algorithms trade latency for reduced communications overhead



Convergence is reached when $x_1^K = x_2^K = \ldots = x_N^K$

Data falsification attacks modify the value of a the variable shared by a compromised node



Q. Li, B. Kailkhura, R. Goldhahn, P. Ray, P. Varshney, *Robust Decentralized Learning Using ADMM with Unreliable Agents*, 2018 Conference on Neural Information Processing Systems (NIPS), Submitted.

Robust ADMM Convergence Bounds

- Convergence proved with noisy data in terms of network connectivity and noise level (convex, Lipschitz continuous fcns)
- Bounds value of ADMM algorithm to be within a neighborhood of true value
  - B, C are functions of the network topology/connectivity
  - e is "noise" in the ADMM update variable (e.g. channel noise, decoding error, Byzantine attack, quantization error)

Distance from true value

Linear convergence, based on network structure and initial distance from the optimal value

Depends on network structure magnitude of "noise"

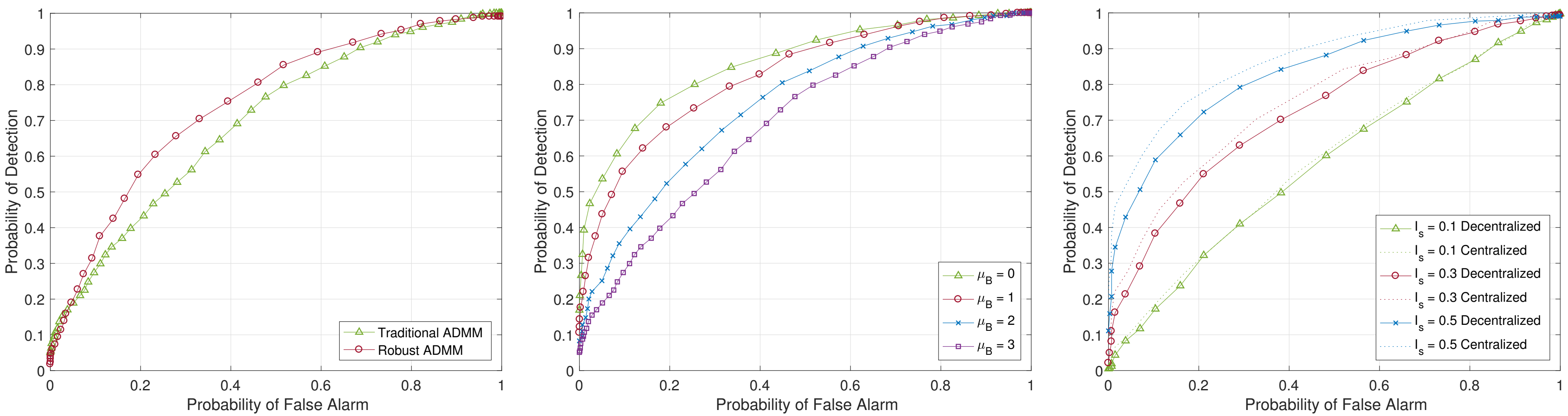
$$\|z^{k+1} - z^*\|_2^2 \leq B^k \|y^0 - y^*\|_2^2 + B^{k+1} \sum_{s=1}^{k+1} B^{-s} C \|\epsilon^s\|_2^2$$

Q. Li, B. Kailkhura, R. Goldhahn, P. Ray, P. Varshney, *Robust Decentralized Learning Using ADMM with Unreliable Agents*, 2018 Conference on Neural Information Processing Systems (NIPS), Submitted.

Large scale simulations of collaborative autonomous detection using ns-3

- Robust collaborative autonomous detection algorithms tested on large (1K node) networks under realistic communications conditions using a LLNL-modified version of ns-3

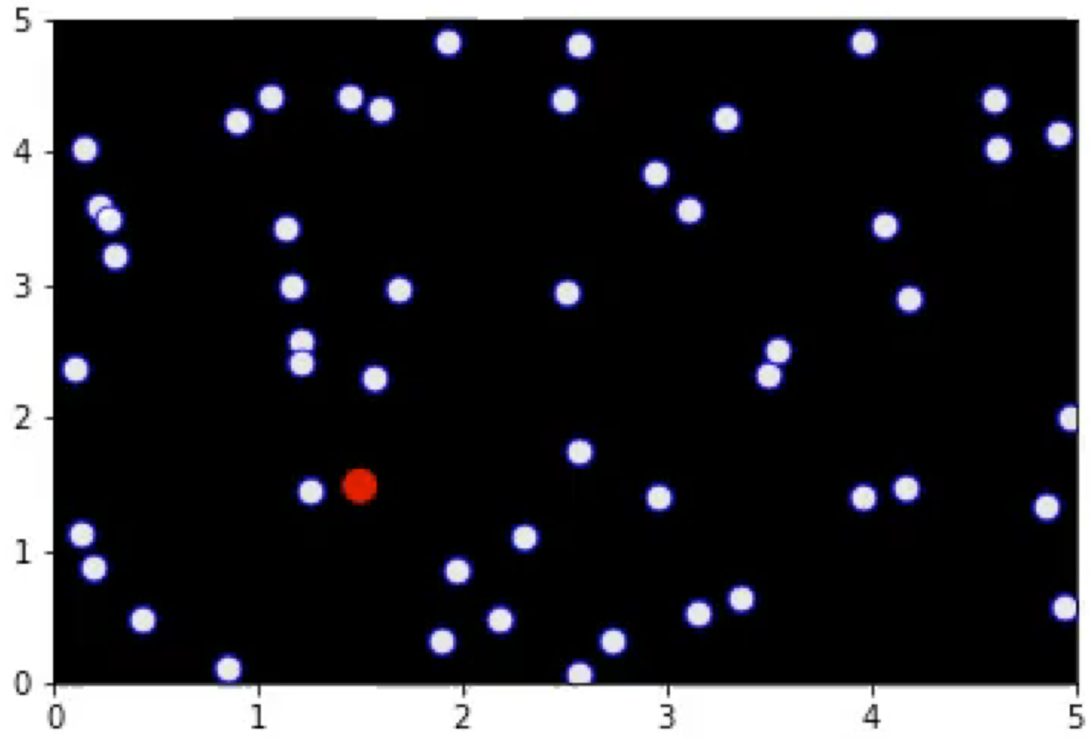
- Impact on detection performance quantified for Byzantines presence (left), attack strength (middle), and robust fusion rule without Byzantines (right)



A. Yen, P. Barnes , B. Kailkhura, P. Ray, D. Rajan, K. Schmidt, R. Goldhahn, *Large-scale parallel simulations of distributed detection algorithms for collaborative autonomous sensor networks*, SPIE Disruptive Technologies in Information Science, May 2018.

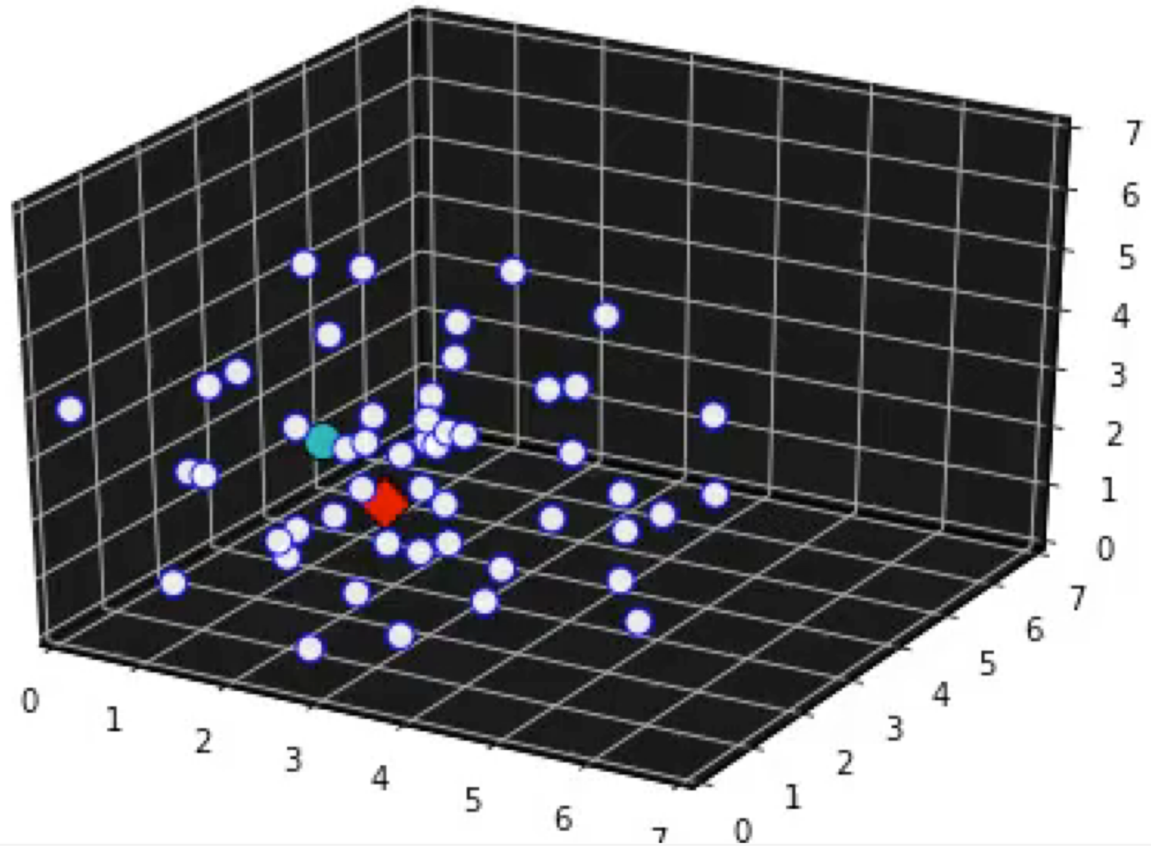
Autonomous Formation (Sense + Control)

- Sense the target (in red) and create a global formation only using local interactions



Autonomous Multi-Target Tracking (Sense + Assign)

- Assign agents to track multiple targets using local interactions



Application: Plume Modelling and Estimation

- Network of mobile sensors to:
  - Detect a chemical release
  - Estimate source location, strength
- Reposition network to maximally reduce uncertainty in source location and concentration estimates
- Gaussian plume model:
  - A source at height *h*, *s*table height *H, w*ind direction *x*
  - Horizontal and vertical concentrations independent Gaussians

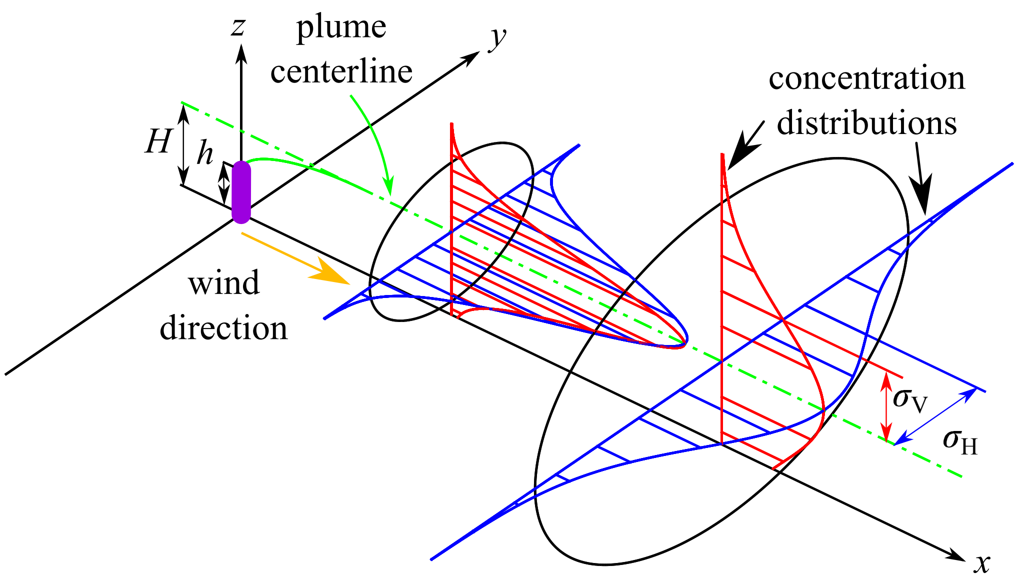
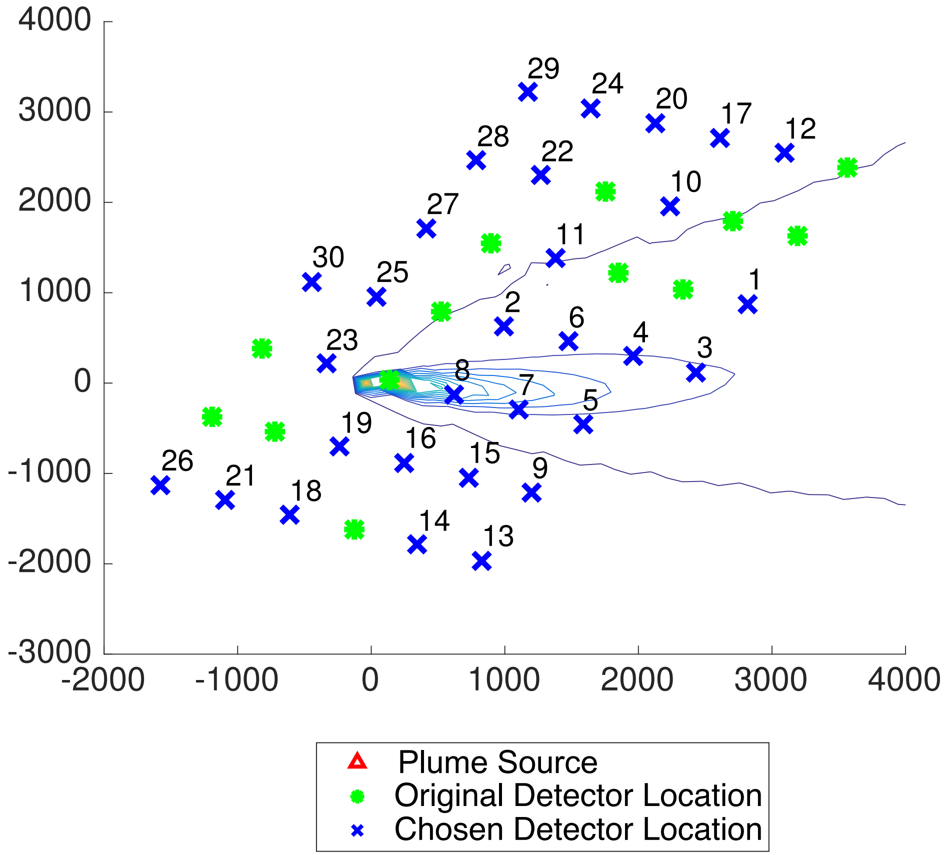
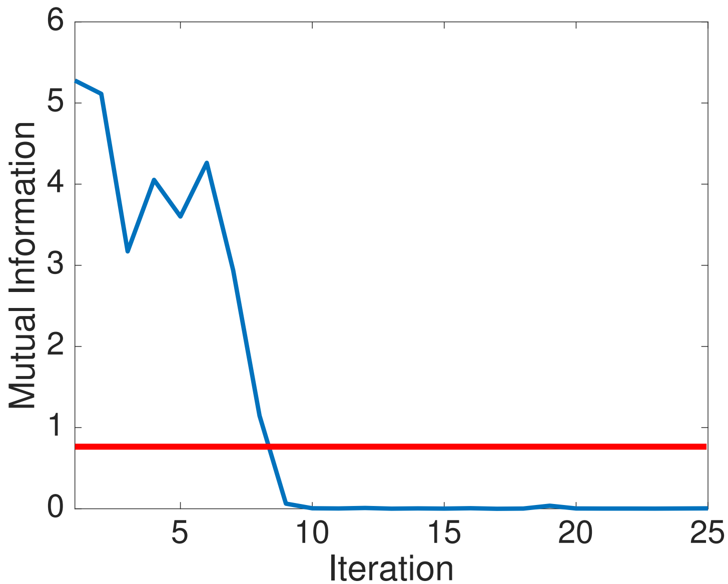


Image from C.L. Dean, *Efficient MCMC for Remote Sensing of Emission Sources*, PhD Thesis, 2015.

Chemical Plume with Mobile Sensors: Results

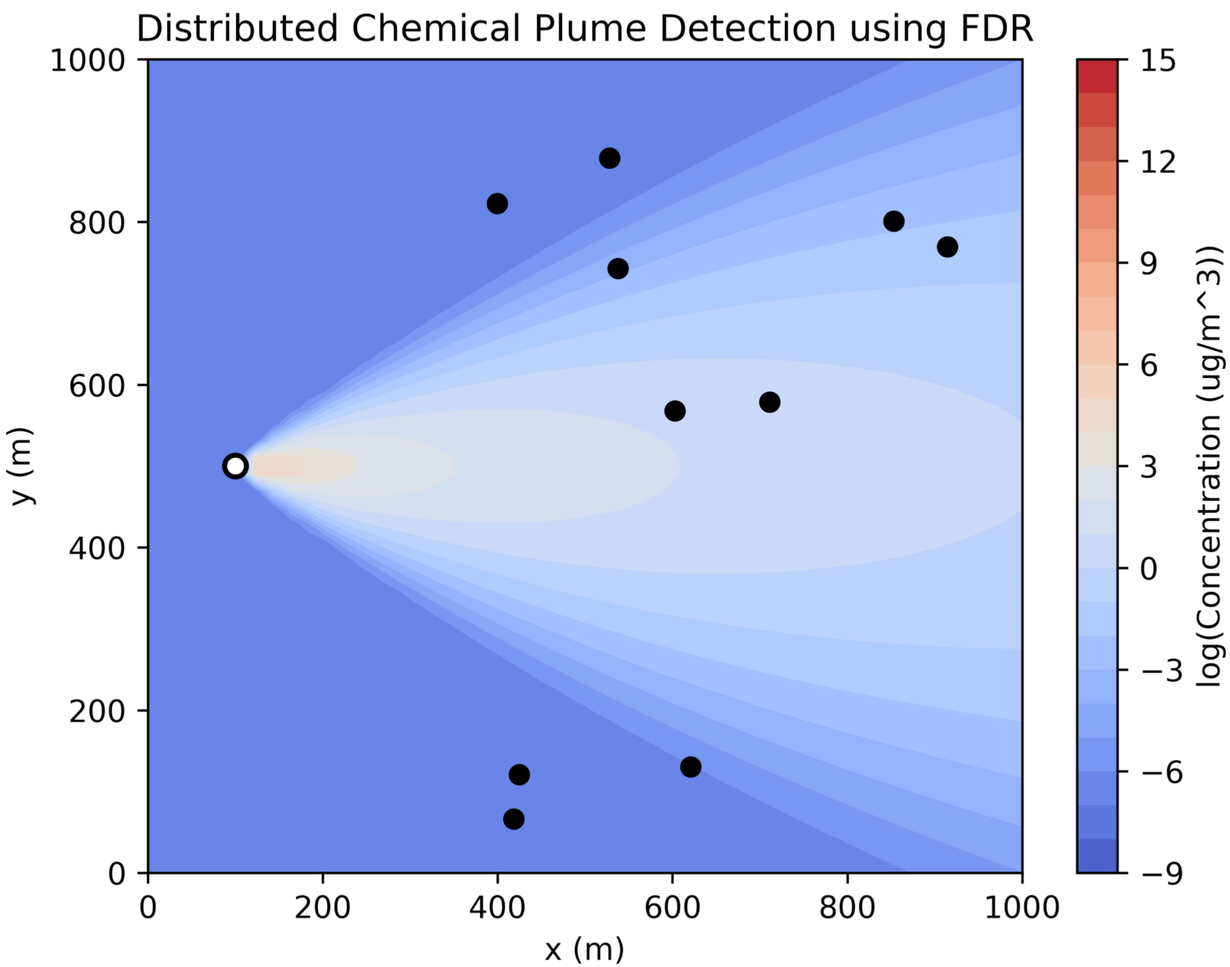




Can stop sensing when future measurements are not worth the cost of collection.

K. Schmidt, R. C. Smith, J. Hite, J. Mattingly, Y. Azmy, D. Rajan, R. Goldhahn, “Optimal Positioning of Mobile Sensors Using Mutual Information,” Journal of Statistical Analysis and Data Mining, 2018, Submitted.

Cooperative autonomous detection and estimation of chemical plume source parameters



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