Exploiting Sensing Diversity for Confident Sensing in Wireless Sensor Networks

CSCI 780 Sensors and Ubiquitous Computing

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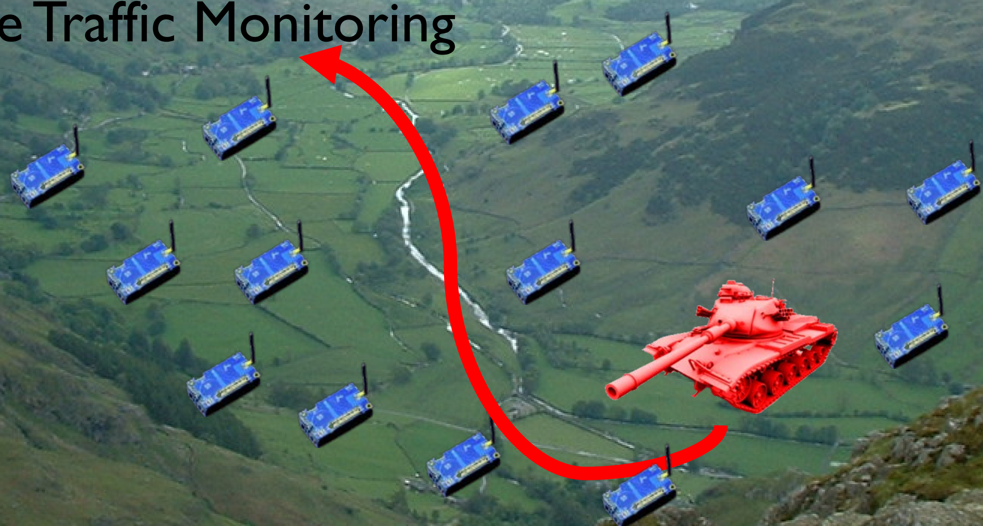
Slides are from Matthew Keally with modifications

Introduction

- Wireless Sensor Networks are increasingly used for performance critical applications
  - Military Surveillance
  - Natural Disasters
  - Vehicle Traffic Monitoring

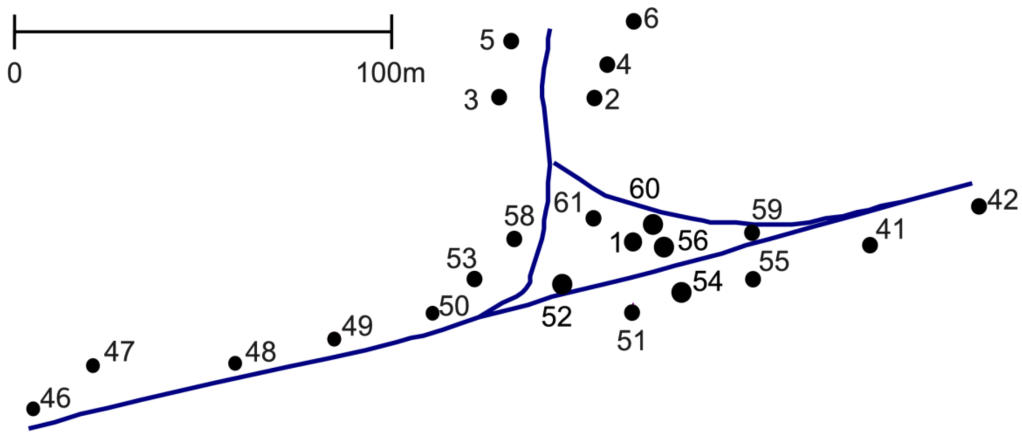


Introduction

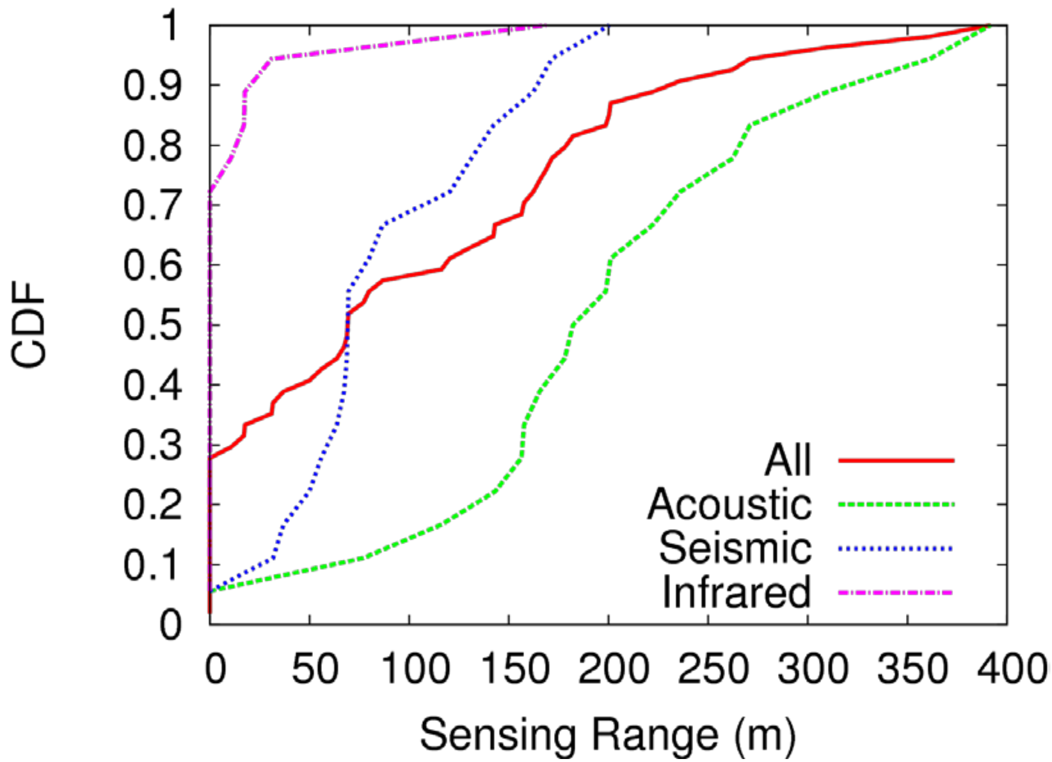
- Performance critical applications need:
  - Accuracy enforcement
  - Long system lifetimes (battery powered)
- We propose **confident** sensing:
  - Meet user accuracy requirements in terms of false positive and false negative rates

Motivation: Vehicle Detection

- 23 nodes with acoustic, seismic, and infrared sensors
- Deployed in a desert in CA, vehicles pass with GPS ground truth
- We choose 100 locations along the road to detect vehicles
  - Evaluate different machine learning methods for detection

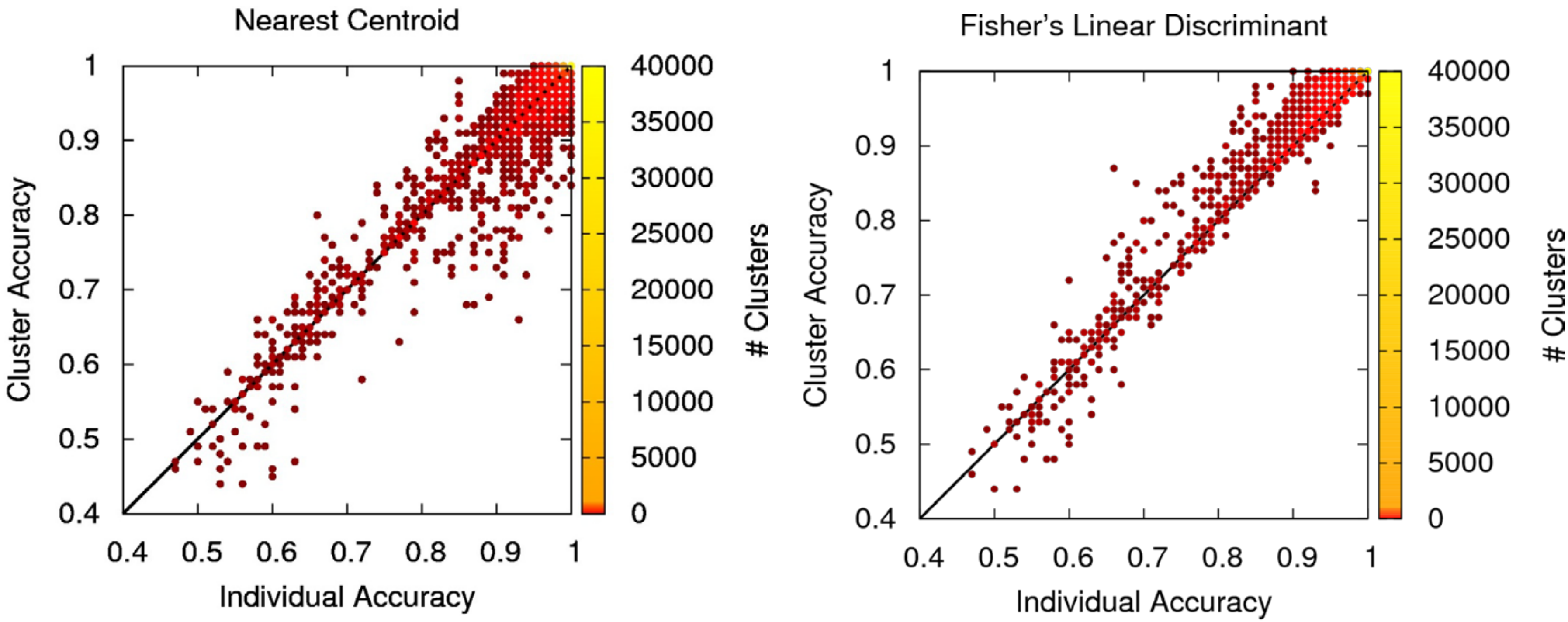


Motivation: Sensing Diversity



- Sensing diversity encompasses the sensing capability differences among:
  - Sensors of the same modality
  - Sensors of different modalities
- **We can use sensing diversity to our advantage**

Motivation: Sensor Collaboration



- When are individual sensors good enough?
- If collaboration is needed, how to choose the right sensors?
- How to collaborate efficiently in a distributed environment?

Contributions

- We explore the fundamental challenges in addressing sensing diversity for confident sensing
  - We identify when and how to collaborate sensors
- We exploit sensing diversity to provide confident sensing coverage
  - Theoretical analysis
  - Practical solution, Wolfpack
- Evaluation with real trace data for vehicle detection
  - Compared with state of the art, we cover 30% more locations using 20% less energy

Outline

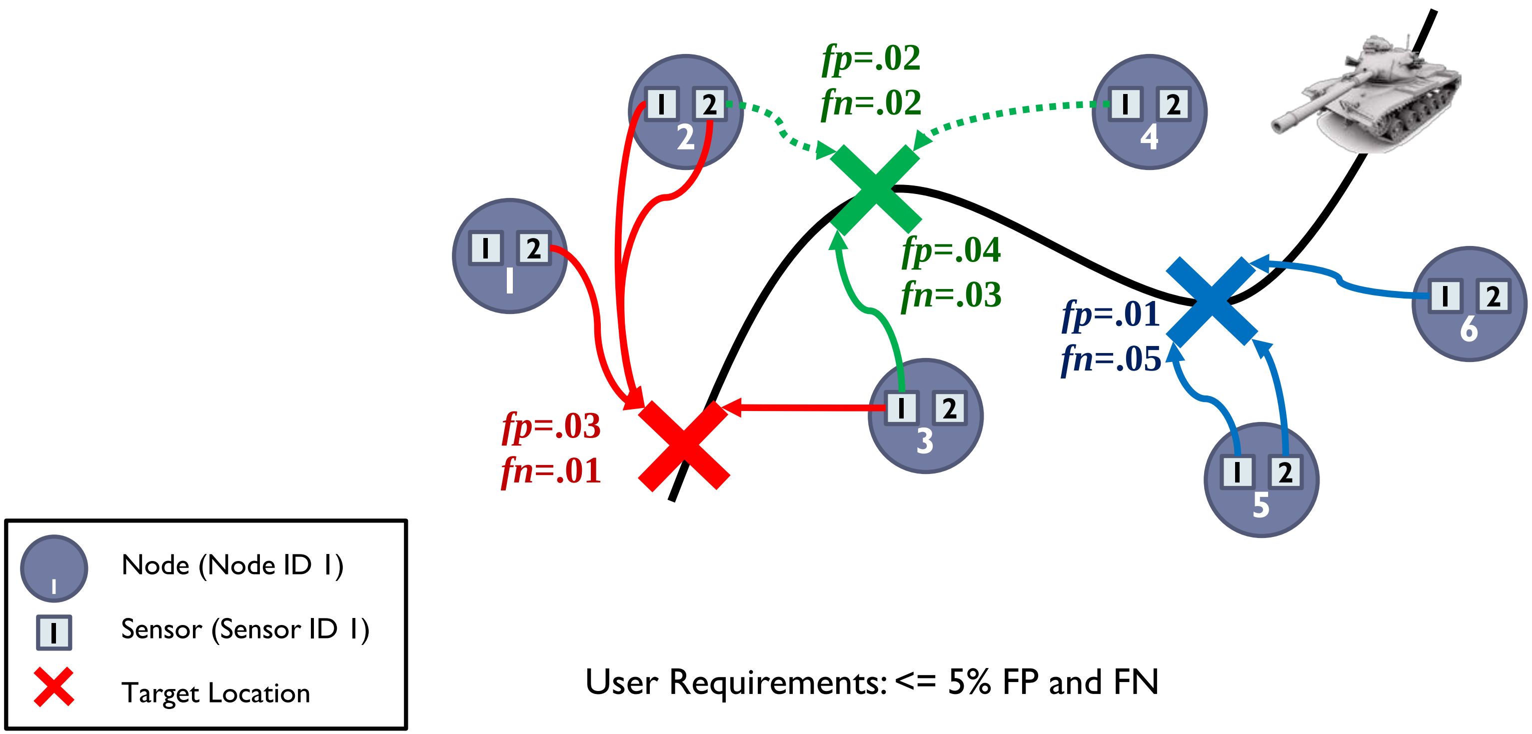
- Introduction and Motivation
- Related Work
- Problem Statement: Confident Coverage
- Wolfpack Framework Design
- Evaluation
- Conclusion

Related Work

- Sensing coverage
  - *k* nodes awake to cover a location of interest
  - Ignore sensing diversity and confidence
  - (Kumar, 2005), (Hsin, 2004)
- Data fusion and modality-specific sensing models
  - Theoretical models do not provide confidence in reality
  - Modality-specific models make collaboration difficult
  - (Yang, 2008), (Volgyesi, 2007)
- Existing machine learning and calibration efforts
  - Recognize sensing diversity but do not provide confidence
  - (Hwang, 2007), (Tan, 2010)

Problem Statement: Confident Coverage

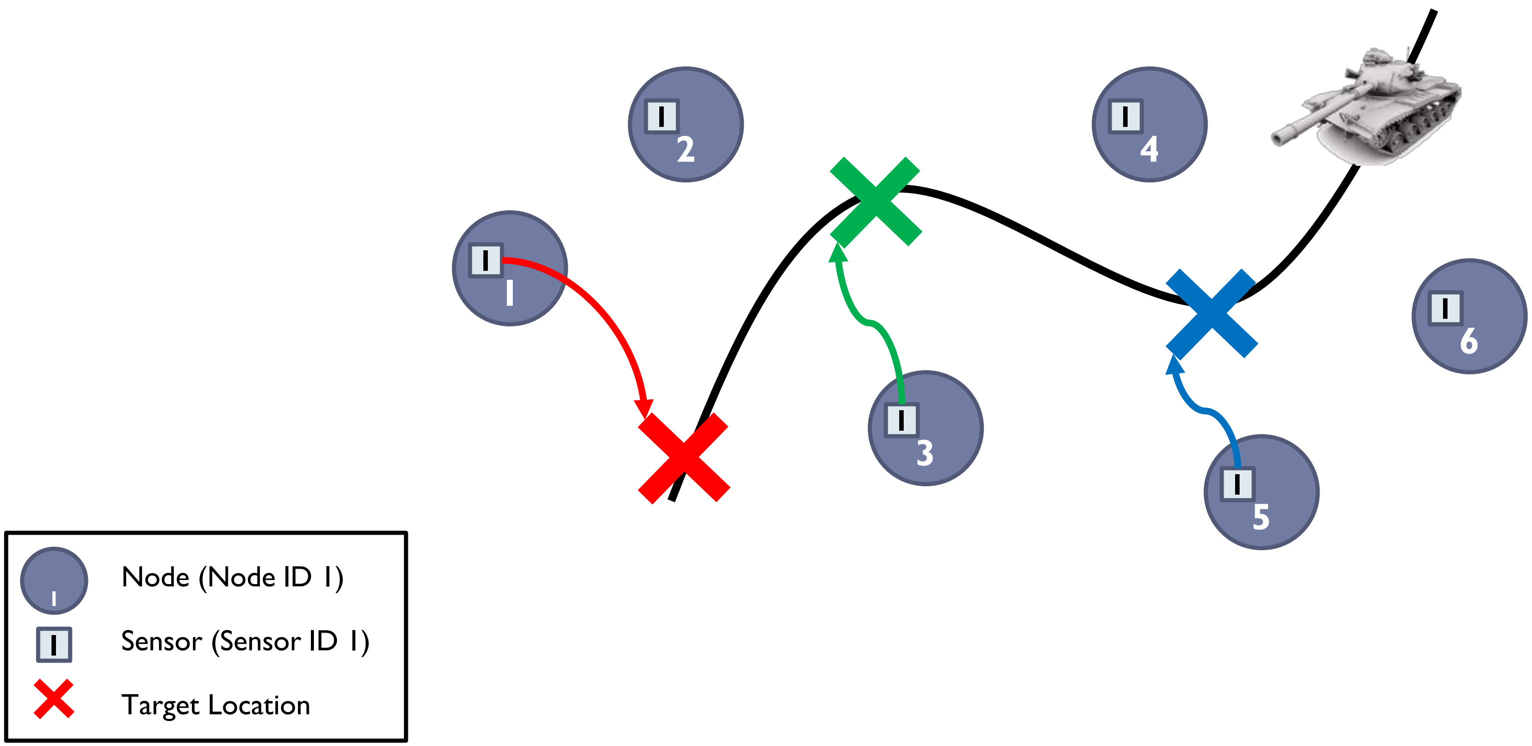
- Find set of clusters that meets user requirements for all locations while residing on the fewest number of nodes



User Requirements: <= 5% FP and FN

Cluster Selection is NP-hard

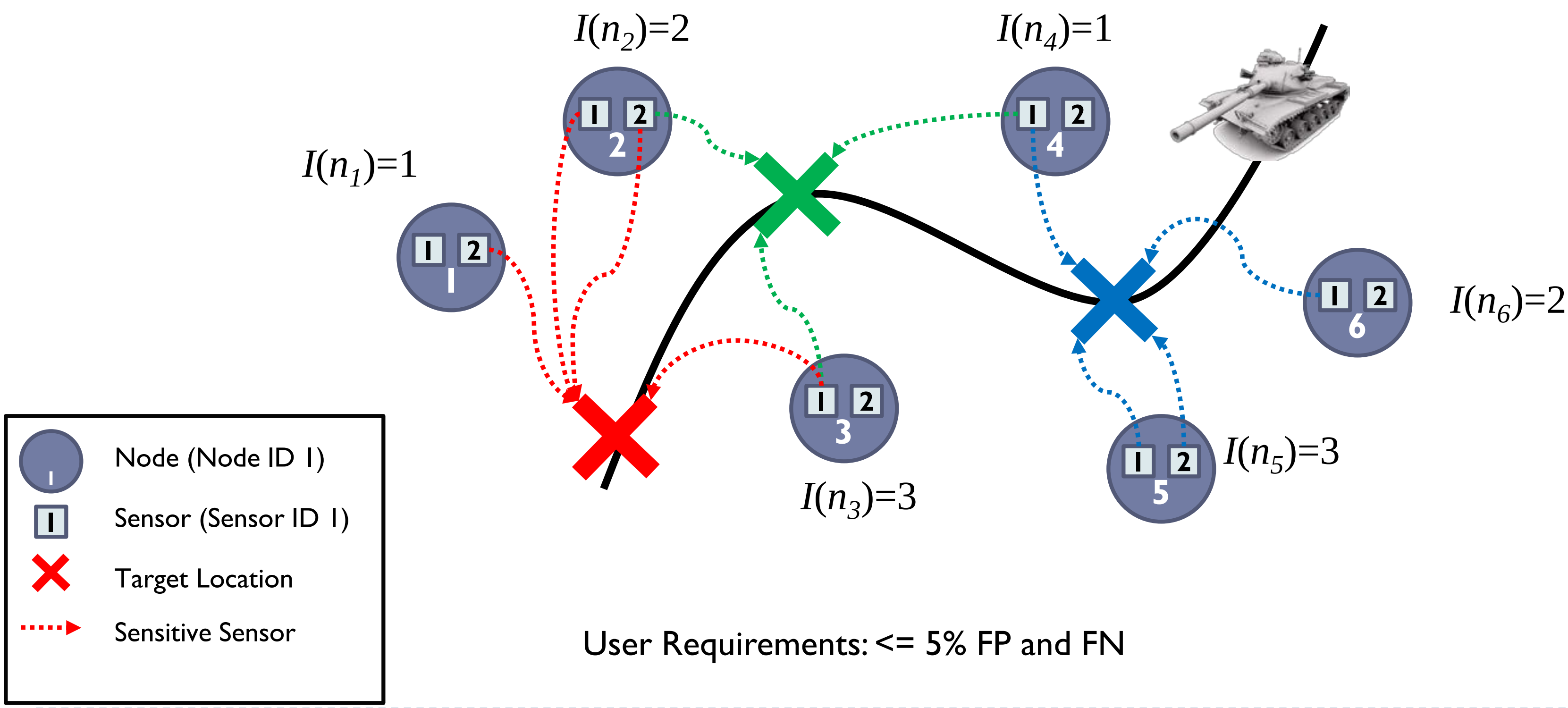
- A special case is equal to the NP-hard Set Cover problem
  - Each node only has one sensor
  - Each cluster only has one sensor
- A greedy solution for cluster selection is appropriate



Wolfpack Design

- ➢ Clustering
- ➢ Runtime and Adaptive Coverage

1. Train detection model for each individual sensor and location
2. Discard detection models with poor accuracy
3. Each node computes its importance
   - Quantified sensing capability for multiple locations using FP/FN rates

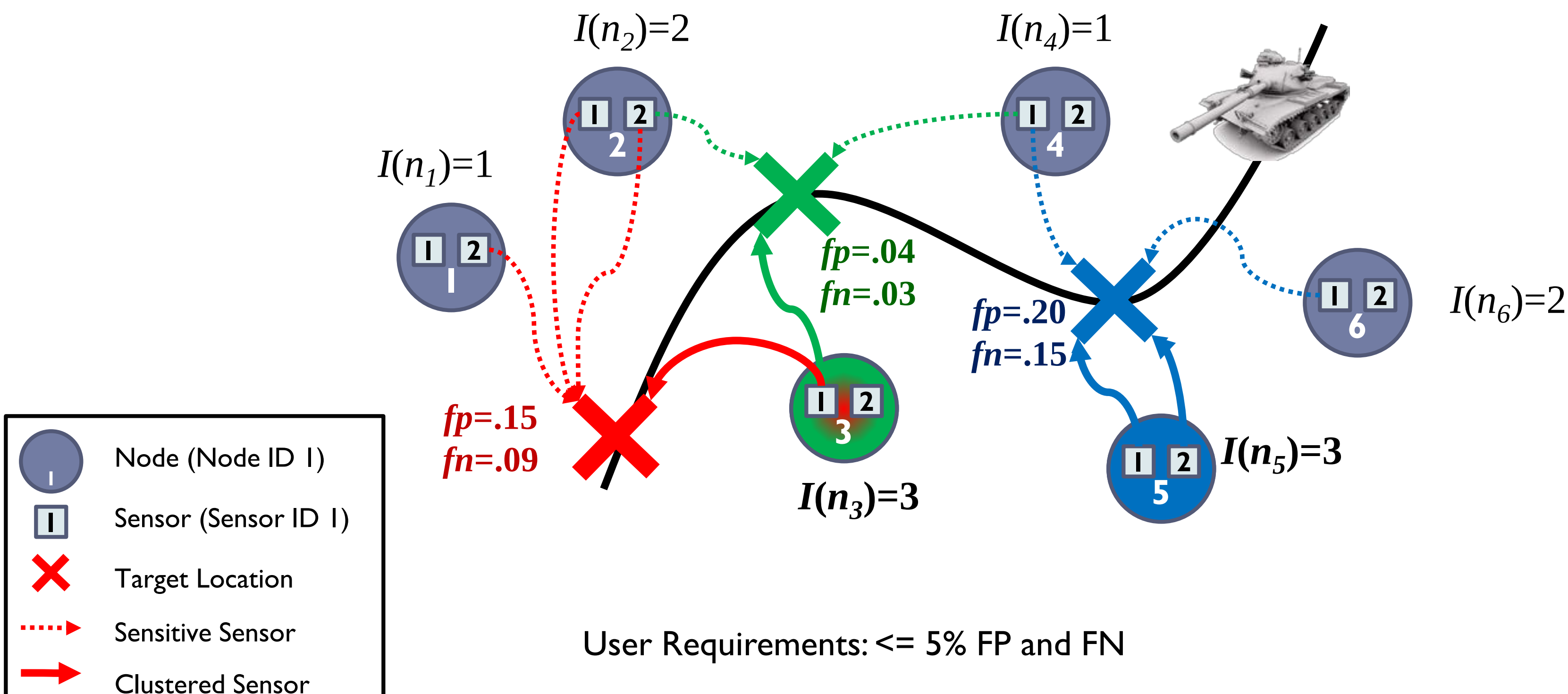


User Requirements: <= 5% FP and FN

Wolfpack Design

- ➢ Clustering
- ➢ Runtime and Adaptive Coverage

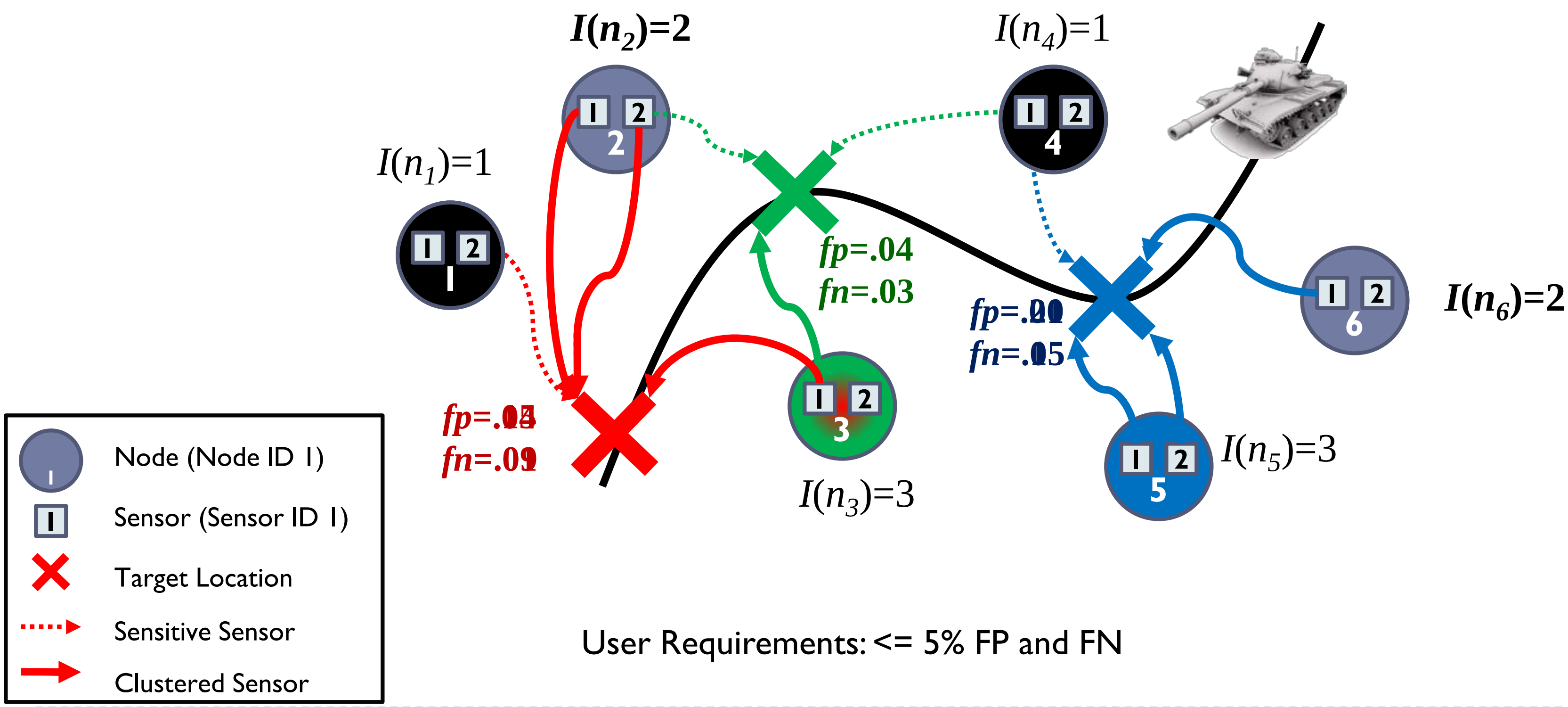
4. Importance-based competition
   - Cluster head declarations
   - Cluster member declarations



Wolfpack Design

- ➢Clustering
- ➢Runtime and Adaptive Coverage

4. Importance-based competition
   - Cluster head declarations
   - Cluster member declarations
5. All unused nodes go to sleep



User Requirements: <= 5% FP and FN

Wolfpack Design

- Clustering
- Runtime and Adaptive Coverage

- During runtime, each cluster member transmits its readings to its cluster head at regular intervals
  - CH makes detection decision for its location using trained model
- Adaptive Coverage: cluster heads evaluate their accuracy (FP/FN) at each interval
  - If user requirements are no longer met, broadcast message to retrain a new cluster; competition restarts

Evaluation Setup

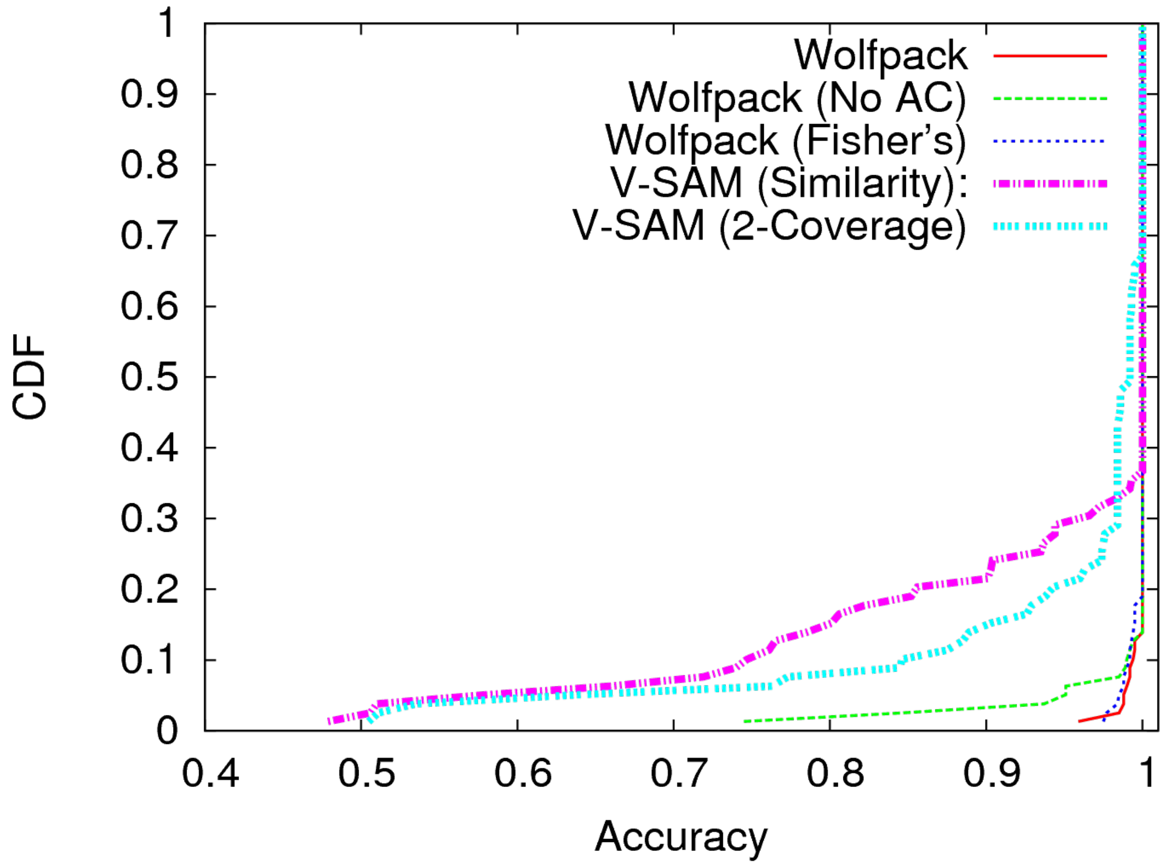
- Wisconsin SensIT vehicle detection trace data
  - 79 detection locations, 23 nodes with acoustic, seismic, and infrared sensors
  - First vehicle pass used for training, remaining 10 used for evaluation
  - Vehicle path and speed varies noticeably with each pass
- Compare with V-SAM (Hwang, 2007)
  - Attempts to keep sensors awake that have dissimilar readings
  - Force *k*-coverage on V-SAM
- User Requirements: 5% FP and FN rates

Meeting User Requirements

	Accuracy %	FP %	FN %	Locations Met %
Wolfpack	**99.8**	**0.0**	**0.4**	**98.7**
Wolfpack, No AC	99.2	**0.0**	1.9	93.7
Wolfpack, Fisher's	**99.8**	**0.0**	0.6	96.2
V-SAM Sim-cov	93.4	**0.0**	15.1	67.1
V-SAM 1-cov	94.2	**0.0**	13.0	68.4
V-SAM 2-cov	94.6	1.6	9.7	74.7
V-SAM 3-cov	94.8	2.2	8.0	57.0

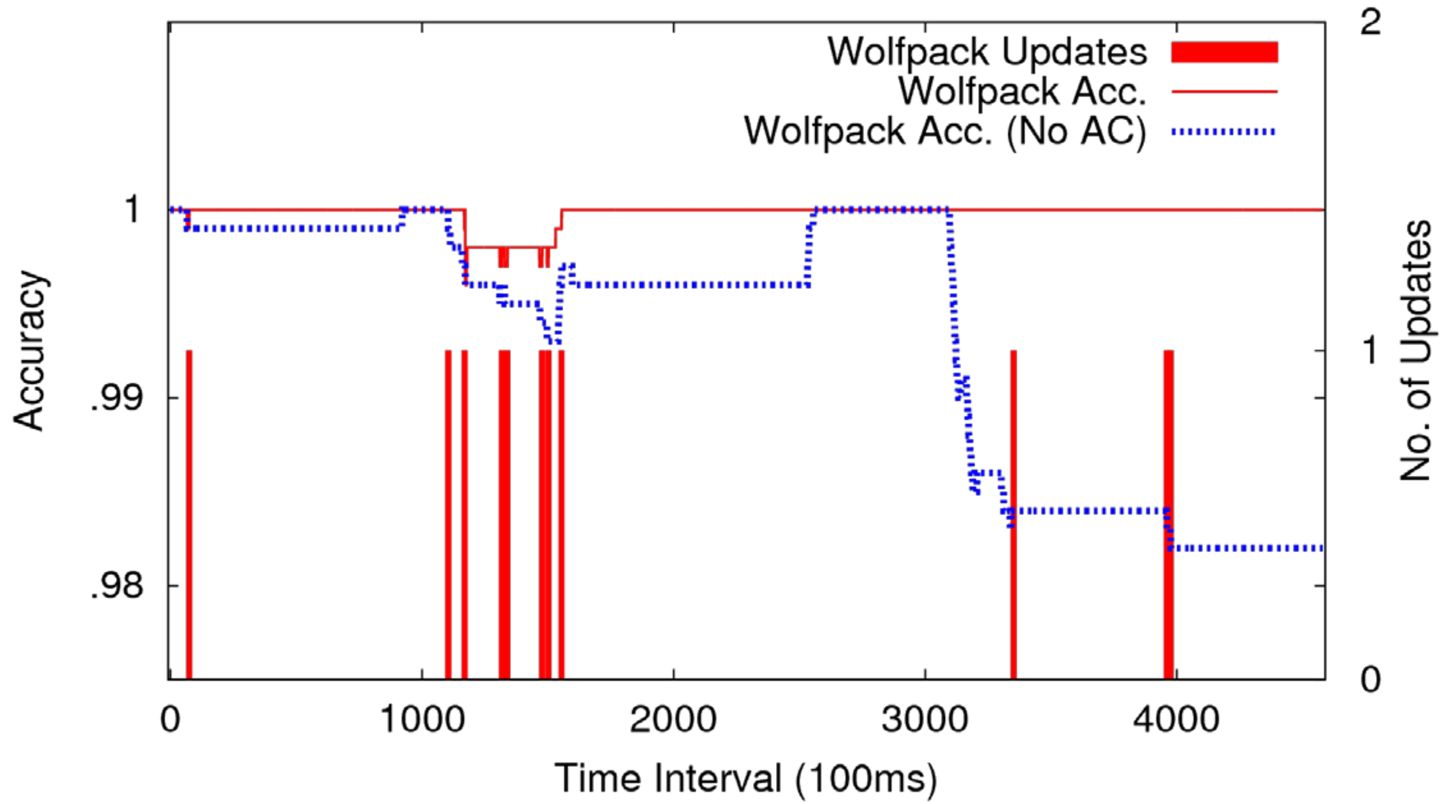
- Wolfpack can choose the nodes with the most capable sensors to achieve confidence
- V-SAM does not learn the sensing capabilities of different sensors, nor does it collaborate carefully

Meeting User Requirements: Accuracy by Location



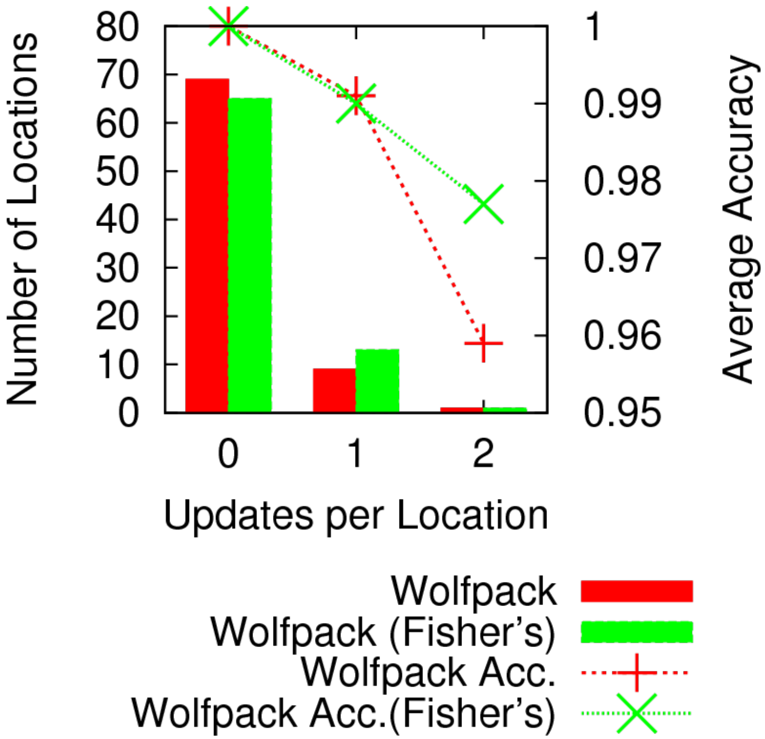
- Wolfpack has perfect accuracy for 85% locations

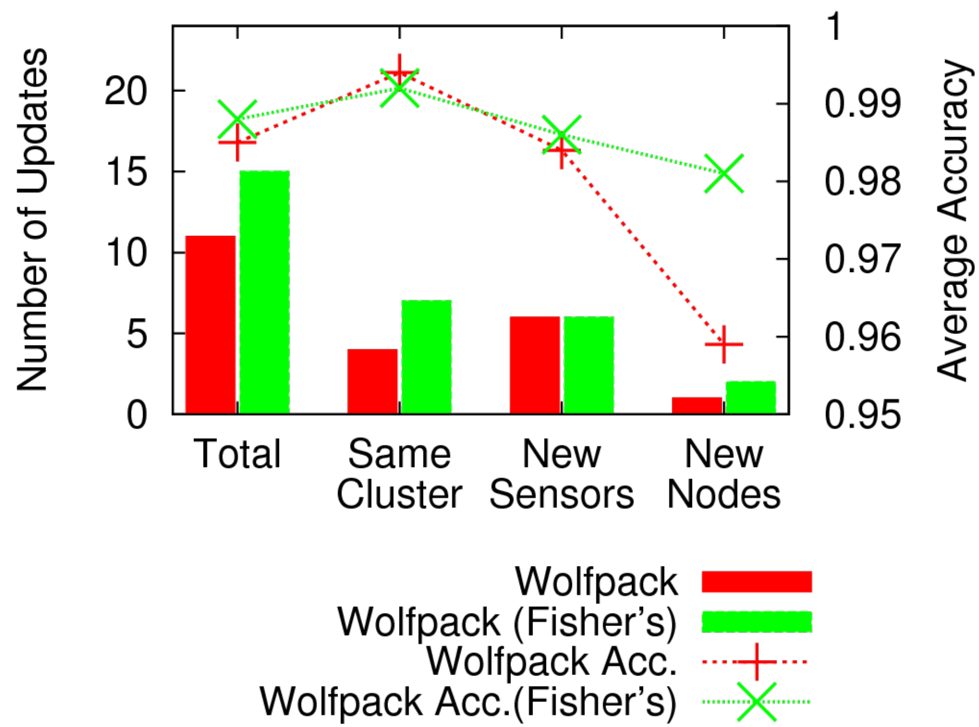
Adaptive Coverage



- Adaptive Coverage allows Wolfpack to tolerate environmental changes while providing confidence

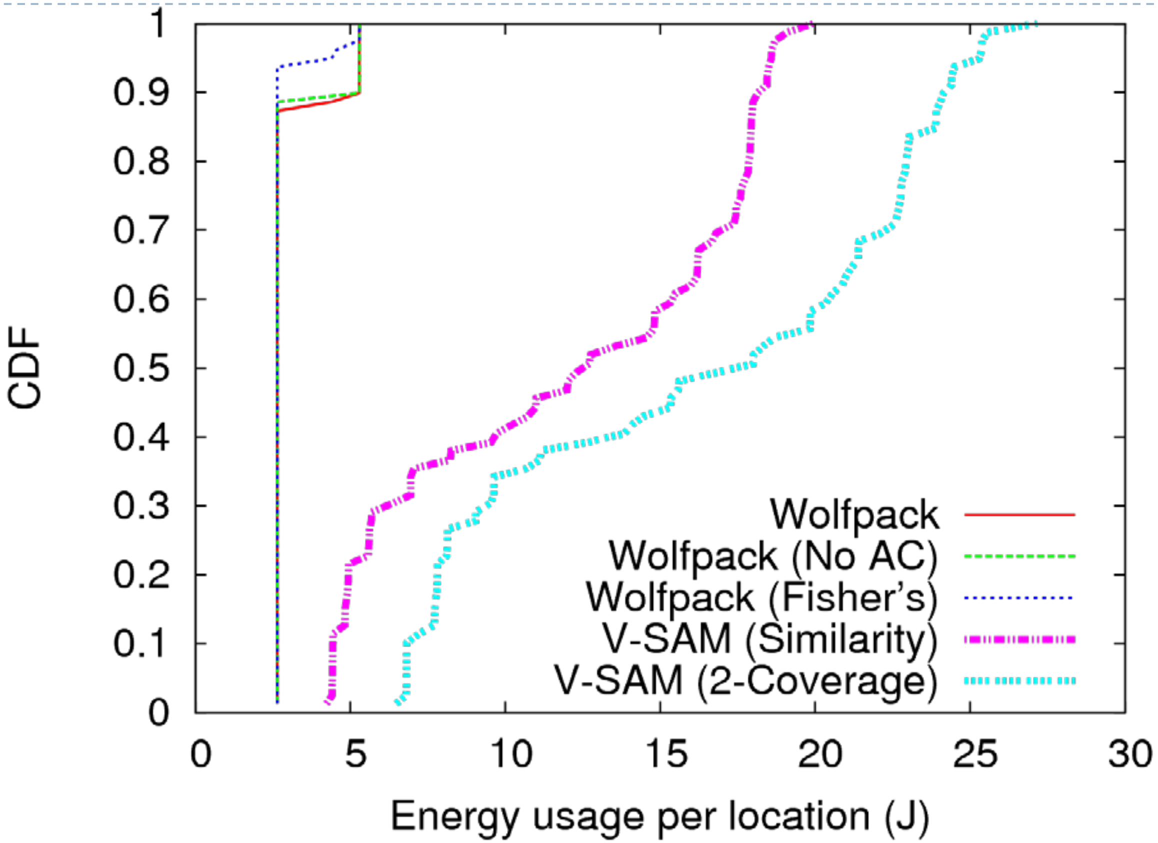
Adaptive Coverage





- Locations with more updates have lower accuracy
- Most updates retrain the same cluster or use the same nodes

Energy Usage Per Location



- 60% of V-SAM locations use more energy than the most expensive Wolfpack locations

Conclusion

- We explore sensing diversity and determine:
  - When sensor collaboration is needed
  - How to perform sensor collaboration
- We exploit sensing diversity for confident sensing coverage
  - Theoretical analysis
  - Practical solution, Wolfpack
- Wolfpack outperforms existing approaches in terms of meeting user requirements and reducing energy usage

Discussion

- How sensitive is Wolfpack to machine learning algorithms?
- What are other possible schemes, rather than differentiated backoff periods, that we can use for the Wolfpack collaboration?
- Any other scenarios rather than ad hoc wireless sensor network deployment?
- Any application scenario you can come up with that needs sensing coverage?