

# Mobile Sensor-Actuator Networks for Natural Disaster Warning and Recovery

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# Project Overview

- The **A**ll-**teR**rain **A**dvanced **NeT**work of **U**biquitous **moBiLe** **A**synchronous **S**ystems
- System of networked wireless sensors and actuators carried on mobile robots that are able to operate in all kinds of terrain

# Project Phases & Objectives

- Phase I – improved connectivity for range-free localization  
[ending June 30, 2006]
- Phase II – intelligent mobility to assure connectivity for realtime multimedia applications like video surveillance and tracking  
[preliminary studies in-progress]

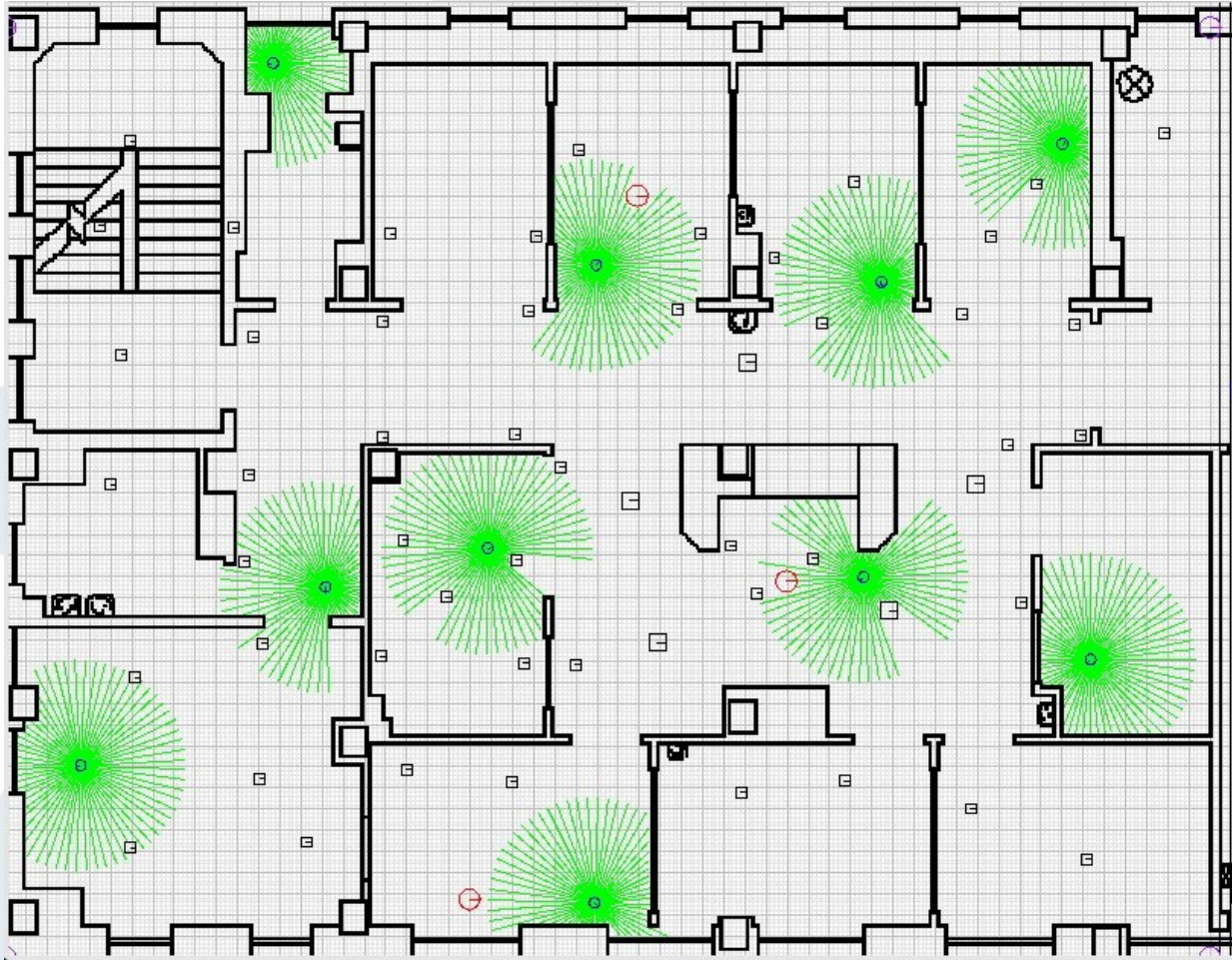
# Objectives

- Use controlled mobility (robots) to improve connectivity and localization of sensor networks
- Mobile sensors (robots) concurrently accomplish high level tasks, e.g. sensing, searching for targets, deploying new sensors to repair network coverage, etc.
- Develop the algorithms and techniques that can be easily adapted and applied on commercially available hardware and readily deployed in realistic scenarios.

# Related Work

- DARPA's SDR program – coordinated behaviours and effective user interfaces to realize large groups of small robots working together to accomplish a collective task
- Centibots – framework for very large teams of costly robots that are able to perceive, explore, plan and collaborate in unknown environments
- Multi-robot systems – sensor nodes and aerial/ground robots networked together have been proposed for tasks such as large scale environmental monitoring or for command and control in emergency situations [Corke, et al., ISER2004]

# Reference Architecture



- Hybrid mobile/static network – number of mobile sensors with significantly larger number of static nodes
- Static sensor network – randomly deployed infrastructure
- Mobile sensors enhance the connectivity and performance of typical sensor networks which is unlikely to be ideally distributed

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# Focus

## Localization

- Location information is critical to sensor networks but not easily obtainable, especially in indoor environments
- Range free methods hop-count based schemes are suitable for sensor networks
- Irregular deployment leads to low accuracy

# Approach

- Static sensors are randomly deployed in the indoor environment, e.g. through windows and other openings
- Beacons with accurate location information are located at the four corners outside the perimeter of the area to be searched/sensed
- Initial localization and sensing can be done
- Multiple mobile sensors (robots) enter to explore the area, and perform multiple concurrent tasks.

# Approach (2)

Key tasks include:

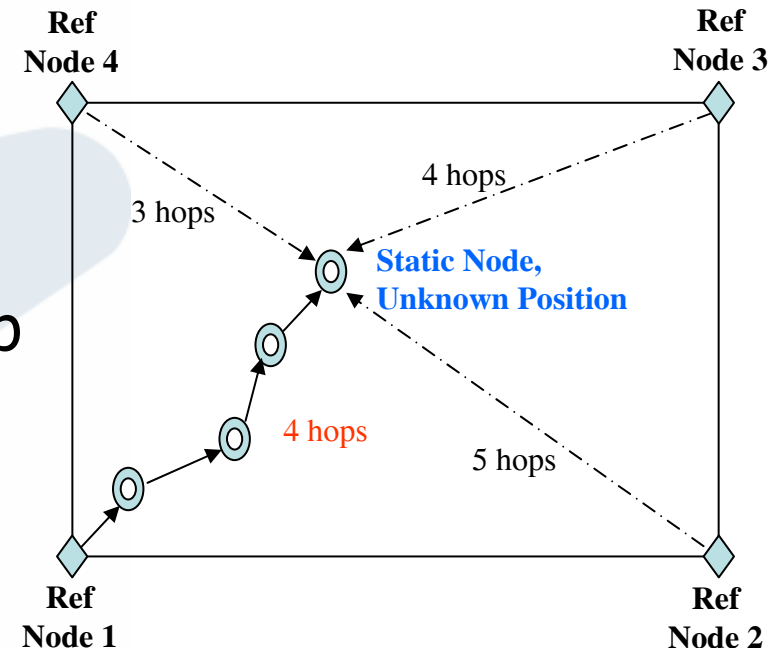
1. search for targets (victims) and communicate their locations back to the control centre via multihop routing;
2. identify critical areas where sensor network communications and coverage is poor (which also results in poor localization) and deploy new sensor nodes to bridge communication gaps, enhance localization, and improve coverage;
3. mark areas that have been searched and communicate the status to other mobile sensors so that the same space will not be repeatedly searched by different mobile sensors.

# Methodology

- Density-aware Hop-count Localization
  - Requires network to be fully connected
  - Designed for non-uniformly distributed sensor networks
- Identifying critical communication gaps
  - Simple method based on hopcounts
- Cooperative search algorithms
  - Potential field, swarm and intelligent

# Density-aware Hop-count Localization

- Estimates the distance from a known reference node/location based on the number of hops from that location
- Average distance covered per hop is estimated based on node density
- Designed for non-uniformly distributed networks



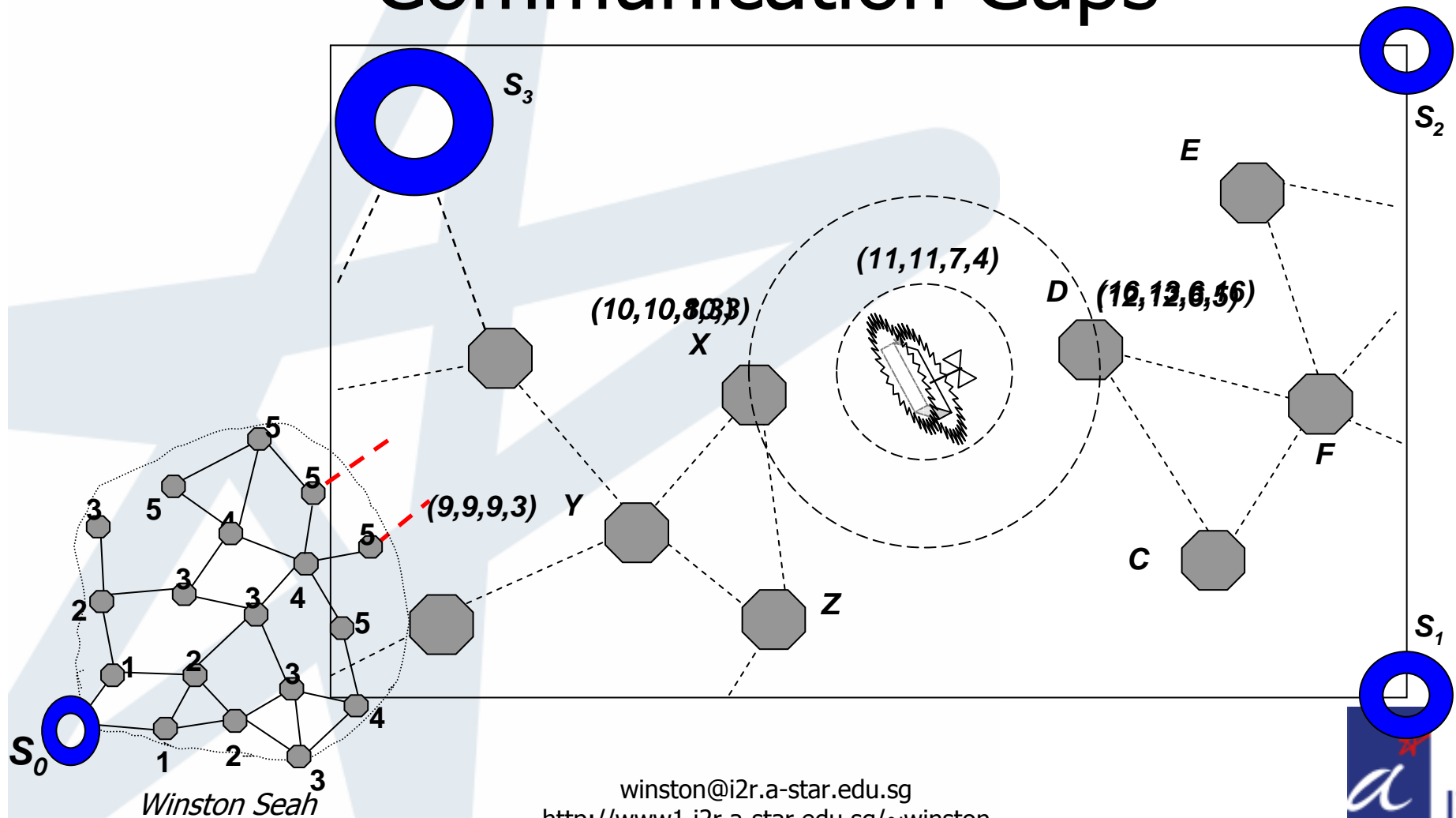
## Publications:

1. Wong, S.Y., JG Lim, SV Rao and Winston KG Seah, 'Multihop Localization with Density and Path Length Awareness in Non-Uniform Wireless Sensor Networks', Proc. of IEEE VTC2005-Spring, May 30 - Jun 1, 2005, Stockholm, Sweden.
2. Tay, Jeffrey HS, Vijay R Chandrasekhar and Winston KG Seah, 'Selective Iterative Multilateration for Hop Count-Based Localization in Wireless Sensor Networks', Proc. of MDM2006 Workshop on Mobile Location-Aware Sensor Networks (MLASN'06), May 9-13, 2006, Nara, Japan.
3. Tay, Jeffrey HS, Vijay R Chandrasekhar and Winston KG Seah, 'Range-free Localization Using Dynamic Hop Size Computation in Wireless Sensor Networks', accepted by the 4th IEEE Conference on Industrial Informatics (INDIN'06), 16-18 August 2006, Singapore.

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# Identifying Critical Communication Gaps



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# Cooperative Search Algorithms

## (1) Potential Field based

- assume neighbor nodes (both mobile and static) and obstacles as repulsive force sources and let the mobile nodes move under these forces

$$F_{sum} = T_{Random} - \sum_i R_i - \sum_j O_j$$

- $T_{Random}$  – random attractive force to make robot move when it has nothing in its vicinity

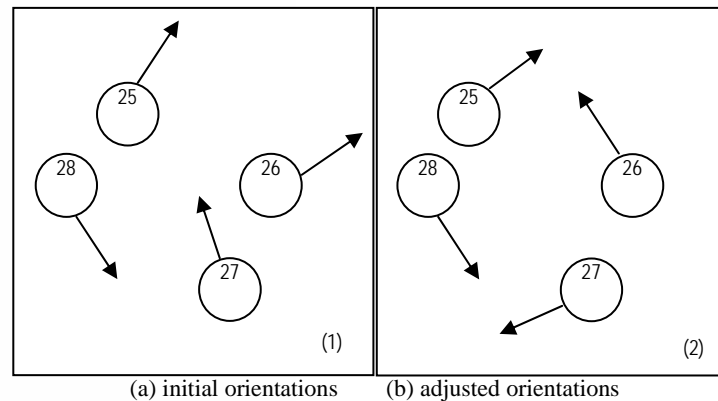
# Cooperative Search Algorithms

## (2) Swarm-like with collaboration

Input (  $i$ : sensor\_id )

1. Set initial values:  $R_{neighbor} = \infty$ ,
2. Repeatedly listen for a period of time  
     if something is heard from neighbor  $j$   
         if ( $j > i$ ) and ( $j < R_{neighbor}$ )  
             let  $R_{neighbor} = j$ ,  $H_{neighbor} = H_j$
3. if  $R_{neighbor} \neq \infty$ ,  
     change heading to  $H_i = H_{neighbor} + 90$  degree
4. goto 1

Node 26 sets new direction w.r.t. Node 25  
 Node 27 sets new direction w.r.t. Node 26  
 Node 28 sets new direction w.r.t. Node 28



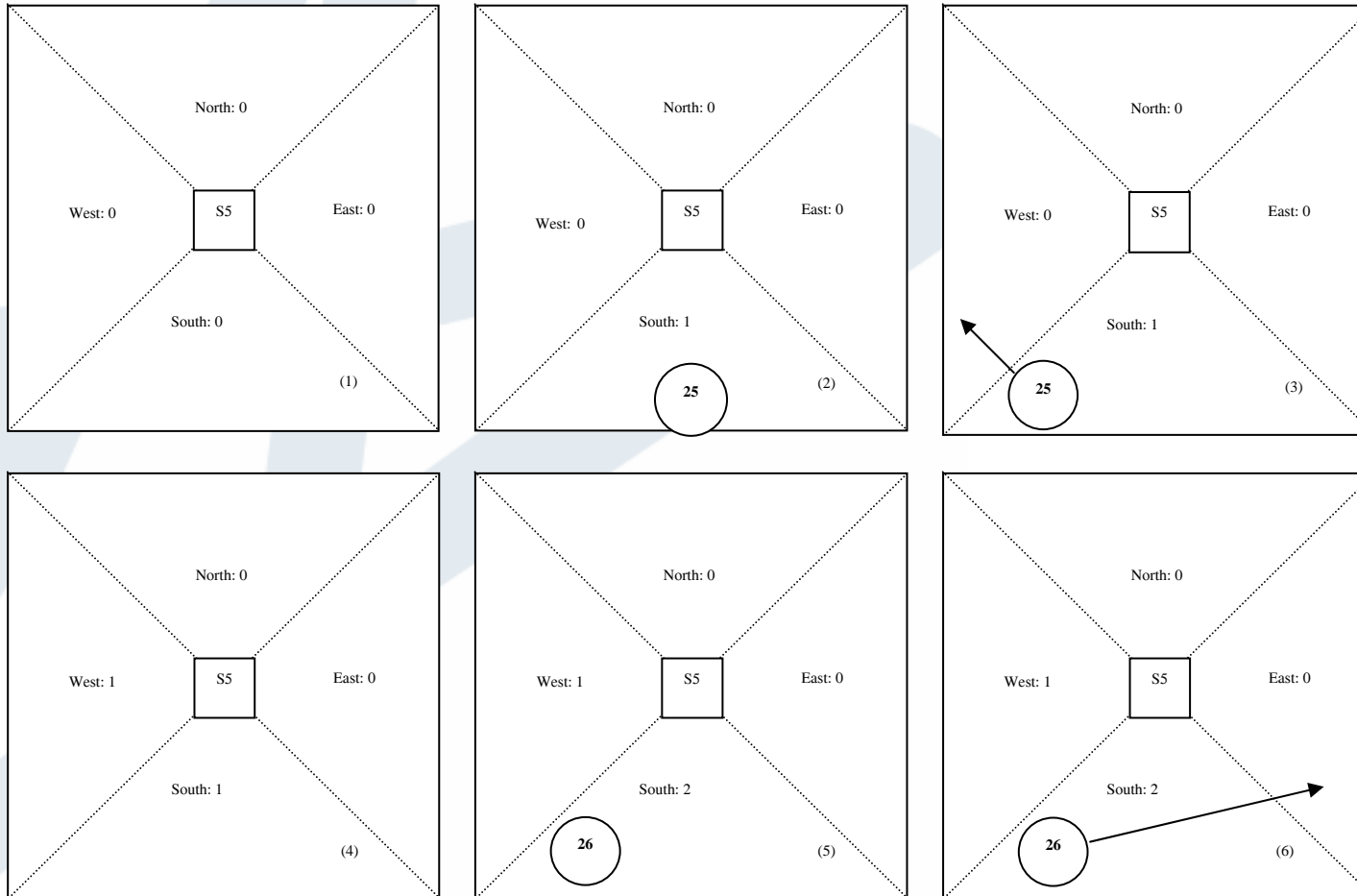
# Cooperative Search Algorithms

## (3) Intelligent with collaboration

- Mobile robots should avoid searching areas that have already been searched
- Inter mobile-static sensor collaboration to avoid re-searching of covered regions and encourage searching of uncovered regions
- Assign static sensors as landmarks, which record the visit history of their neighborhood, and share this information with mobile sensors moving into the vicinity to help them decide the search regions

# Cooperative Search Algorithms

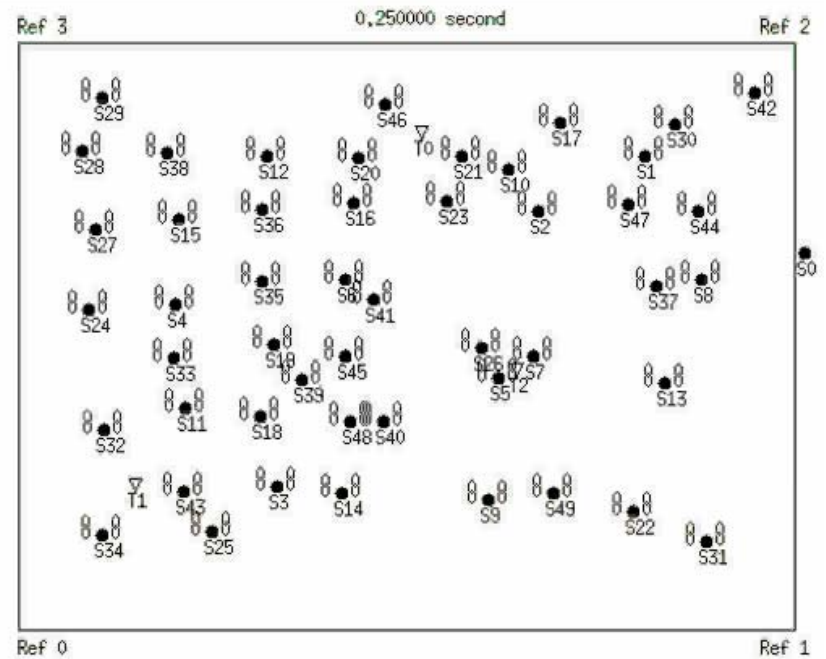
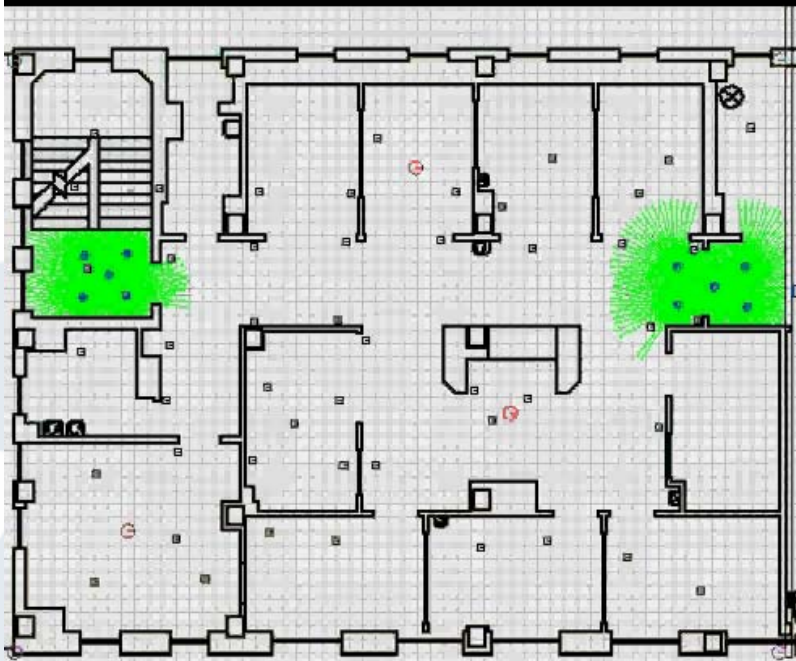
## (3) Intelligent with collaboration



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## Environment: 57x44m 10 Robots, 50 Static Nodes, 3 Targets, 4 Reference Nodes



**Green: Robot**  
**Red: Target**  
**Black Square: Static Node**

**Square: Robot**  
**Circle: Static Node**  
**Triangular: Target**

# Experimentation

Show video...

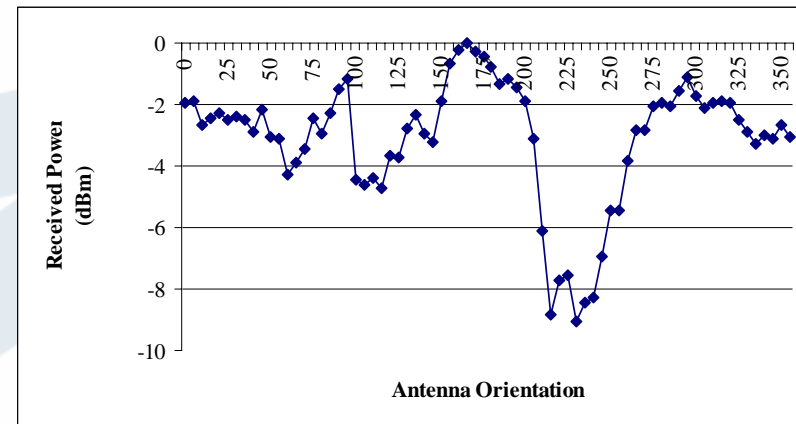
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# Addressing Practical Issues

## Irregular Radio Propagation Pattern

- Far from circular
  - Environment with minimum multipath propagation
- Simple circular radio pattern is hardly realistic
  - Orientation of antenna
  - Battery strength
  - Multipath fading
- Long link or gray area problem is obvious
  - Transmission range exceeds more than 2 times occasionally
  - More obvious in a smaller room



Radio Propagation Pattern of MICAz Mote measured in an Anechoic Chamber

Tan, EBS, JG Lim, Winston KG Seah and SV Rao, 'On the Practical Issues in Hop Count Localization of Sensors in a Multihop Network', Proceedings of the 63rd IEEE Vehicular Technology Conference (VTC2006-Spring), 8-10 May, 2006, Melbourne, Victoria, Australia.

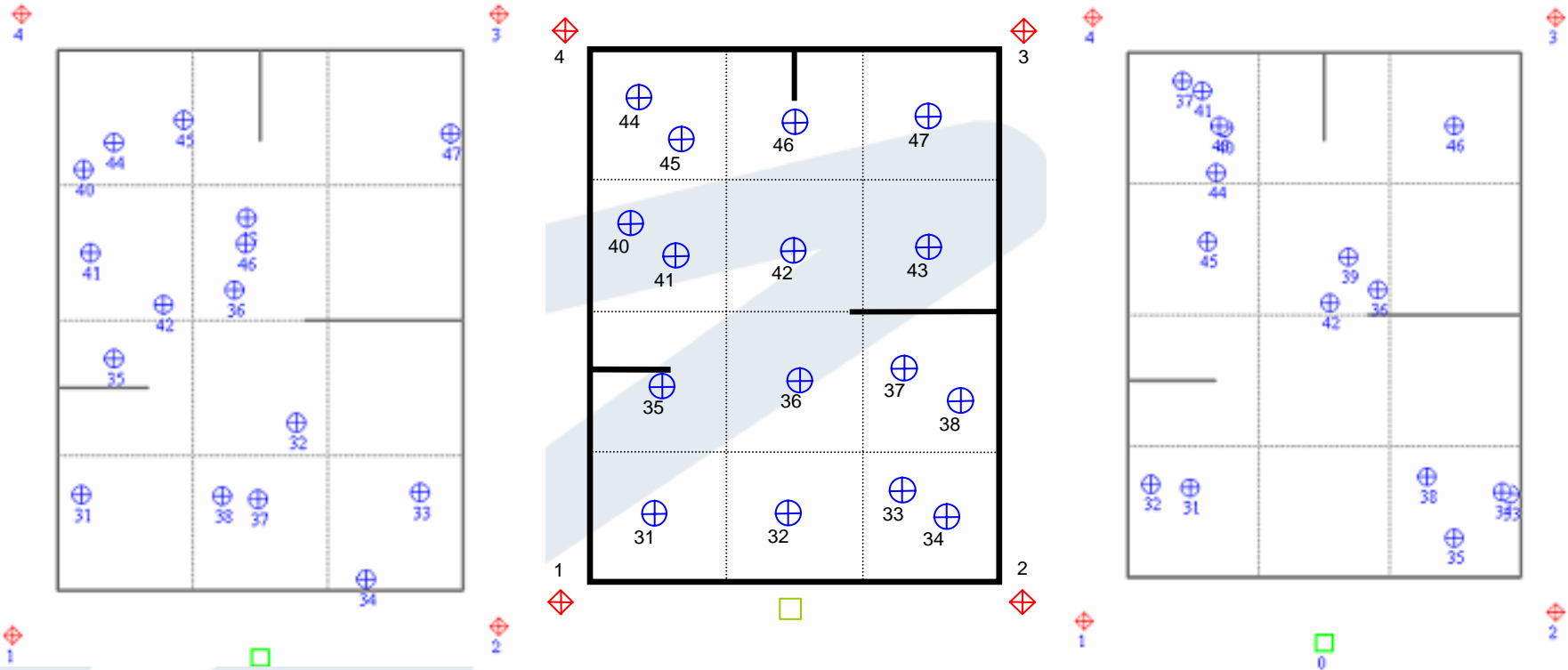
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# Proposed Modifications

1. Specify higher RSSI threshold
  - Filter off unreliable links which are below a certain RSSI level
  - Challenge: threshold changes with environment
2. Sliding Sampling Window
  - Prevent gray area or long link problem
  - Size of Sliding Sample Window varies with node density → 40
  - Accept values received more than a number of times → 4
  - Hop count value adapts and converges to the network environment
  - Hop count based localization can now work in mobile environment
3. Variable Broadcast Rate
  - Possibility of having escalating hop count phenomenon with Sliding Sample Window → favor lower hop count broadcasting
    - nodes with lower hop count broadcast at faster rate

# Localization Estimation Results



**Modified Hop Count Based Localization**

**Actual Node Locations**

**Hop Count Based Localization**

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# Results of Hop-count Localization Enhancements

- In the 16 static nodes implementation
  - Typical hop count based localization scheme experienced 35 hops error in total
  - Modified hop count based localization scheme experienced 20 hops error in total
- Modified hop count based localization can be used in mobile network environment

# Conclusions

- Heterogeneous system of mobile and static wireless sensors
- Collaboration among the sensors to maximize network connectivity to improve localization that in turn improves the sensing capabilities of the mobile sensors
- Proposed three search algorithms without mapping that are distributed in nature and therefore control is simple and scalable
- Proposed enhancements to localization schemes to address practical deployment issues
- Future work include collaborative mobility to support desired quality of service for multimedia services like video streaming, realtime tracking, etc.

# Related publications

- ✓ Winston KG Seah, Z Liu, JG Lim, SV Rao and Marcelo H Ang, Jr., 'Mobility-enhanced Wireless Sensor-Actuator Networks', Proceedings of the IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC2006), June 5-7, 2006, Taichung, Taiwan.
- ✓ Winston KG Seah, HX Tan, Z Liu and Marcelo H. Ang Jr., 'Multiple-UUV Approach to Enhance Network Connectivity in Underwater Ad Hoc Sensor Networks', Proceedings of the MTS/IEEE OCEANS2005 Conference, Sep 19-23, 2005, Washington D.C., USA.
- ✓ Liu, Z, Marcelo H. Ang Jr., and Winston KG Seah, 'Reinforcement Learning of Cooperative Behaviors for Multi-Robot Tracking of Multiple Moving Targets', Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS2005) , Aug 2-6, 2005, Edmonton, Alberta, Canada.
- ✓ Mar CH and Winston KG Seah, 'An analysis of connectivity in a MANET of autonomous cooperative mobile agents under the Rayleigh fading channel', Proceedings of the IEEE 61st Semiannual Vehicular Technology Conference (VTC2005-Spring), May 30 - Jun 1, 2005, Stockholm, Sweden.
- ✓ Wong, S Y, J G Lim, S.V. Rao and Winston KG Seah, 'Density-aware hop-count localization (DHL) in wireless sensor networks with variable density', Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC 2005), New Orleans, LA, USA, Mar 13-17, 2005.



# Thank you

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