TARANTULAS

The All TeRrain Advanced NeTwork of Ubiquitous MobiLe Asynchronous Systems

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ICT in Natural Disasters

- Breakdown in communications → quick deployment of ad hoc communications infrastructure
- Search and rescue → minimize further loss of human lives
- Coordination of rescue efforts
- Realtime acquisition (sensing) of data from disaster areas

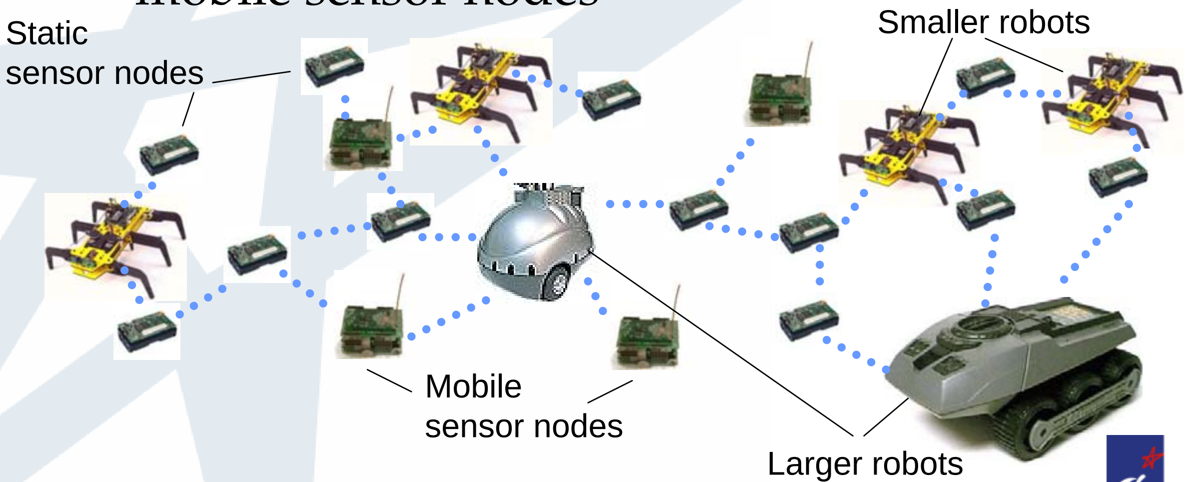
Technology Overview

- Sensor network – self-configurable network of quasi-static sensor nodes with sensing and wireless communication abilities
- Applications in crisis management, disaster recovery and rescue operations, surveillance, environmental monitoring, inventory control, etc.
- In a mobile sensor network:
  - Nodes within the network have movement capabilities
  - User has some control over the node movement

Technology Overview

Mobile Sensor Network Scenario

- Network consisting of nodes with different capabilities – robots, static sensor nodes, mobile sensor nodes



Picture sources: www.robotcafe.com

Relevance to Disaster Management Cycle

Alert

- Realtime monitoring (& forecasting)
- Early warning
- Secure & dependable telecommunications
- Scenario identification

Response

- Dispatching of resources
- Emergency telecommunications
- Situational awareness
- Command control coordination
- Information dissemination
- Early damange assessment

Source: Peter Martin, "Information & Communication Technologies for Tsunami Early Warning and Alert Capacities"

Objective

- System of networked wireless sensors and actuators carried on mobile robots that are able to operate in all kinds of terrain
- Network architecture and protocols that integrate an infrastructure-less location estimation system to support the command, control and communication needs of the network of mobile autonomous systems working together in collaboration

Mobile Ad Hoc and Sensor Networks

Localization

Collaborative Robotics

Mobile Sensor/Actuator Systems

- A Sensor/Actuator (S/A) or set of S/A's carried on a mobile robot that communicates with other mobile sensors using wireless communication.
- A sensor may also be carried on a mobile robot and deployed at a location for a period of time before it is retrieved or moved to another location.

System Requirements

- Have different functionalities, e.g. an audio sensor (microphone), video sensor (video camera), temperature sensor, or a combination of sensors;
- May also have other capabilities, e.g. grappling device, a cutting laser, a welding torch, or even a hypodermic syringe to administer medication to the injured before rescuers reach them.
- Functionally heterogeneous, each unit aware of its locality, communicate and interact with one another, and collectively operate as one integrated sensor system.

Challenges

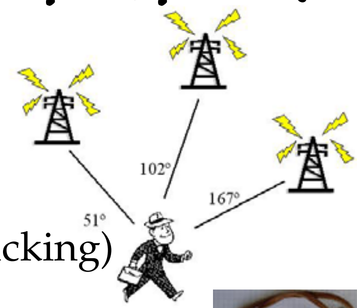
- Distributed functionalities, such as ad hoc routing across a network of ubiquitous devices, with stringent power constraints

  → lightweight ad hoc and sensor network protocols
- Formulating innovative cooperative location estimation of mobile sensors in the harsh multipath environment → infrastructure-less architectures for location estimation
- Heterogeneous mobile robots cooperating and functioning as larger robotic unit

Mobility Enhanced Connectivity in Ad Hoc Networks

- Enhance the connectivity of the ad hoc networks
  – Repair the broken links
  – Shorten the long and indirect links
- Improve localization by combining techniques in robotics and wireless networking to:
  – achieve better accuracy, better energy efficiency, and lower cost
  – be more generic; applicable to both indoor and outdoor environment, to both mobile nodes (robots) and static nodes (wireless sensors)

Why the fuss with Localization?



Location information needed for:

- Sensors – to relay spatial-relevant info (e.g. temp in a room)
- Robots – to perform tasks (e.g. target tracking)

Localization in:

- Communications & Networking
  - RSSI, TOA, TDOA, AoA, hop counts, etc.
  - E.g. Active Badge System, I²R WASP System

- Robotics
  - Laser range sensor, IR sensor, odometry, etc.
  - Data processing techniques e.g. Kalman Filter, Particle Filter

Mobile Sensor Network – aims to combine both fields

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Localization Issues

- Sensor nodes have limited computation and communication capabilities
- Complex and accurate techniques are not viable, e.g. RSSI, TOA, TDOA, AoA, etc.
- Simple methods like Hop-count based localization are usually sufficient for most sensing applications

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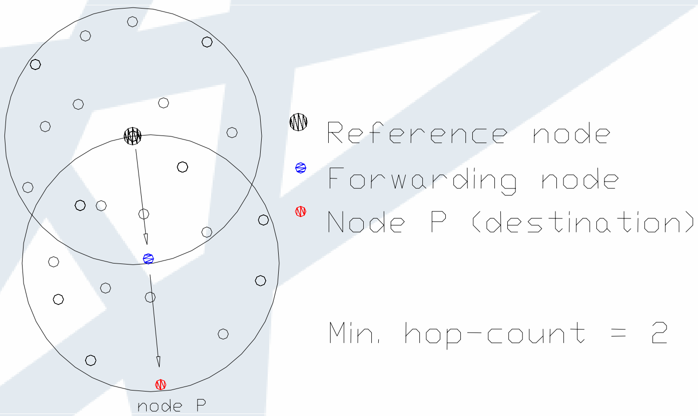
Hop count based

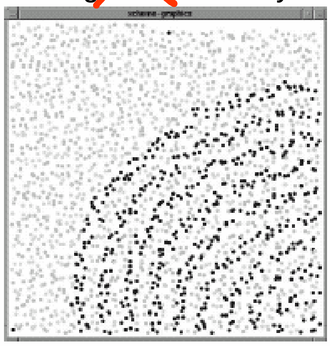
Distance = hop-count *

1. Method of deployment and terrain contour. E.g. Air-dropped sensors accumulate at the bottom of slope → higher density at the bottom than the peak.
2. Environmental phenomenon. E.g. moved away by heavy current, strong wind, animal, enemies, etc
3. Network dynamism. E.g. malfunction, inactive, energy depleted

Assumptions

a. uniform node distribution
b. High node density

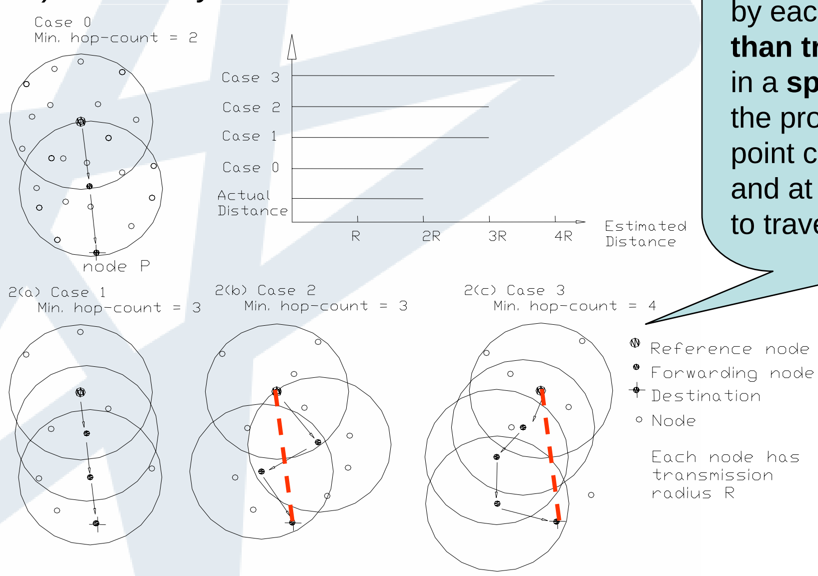




Hop count based Localization

Distance overestimation

a) case 1: distance traversed < average transmission radius
b) case 2: end-to-end path is not straight
c) case 3: hybrid of case 1 and 2



Effective distance covered by each hop is usually **less than transmission radius** in a **sparse network** since the probability of finding a point close to the boundary and at the direction we wish to travel diminishes.

Research Areas (1)

Developed **density-aware hop-count based localization scheme** (DHL)

- Nodes acquire hop counts to known reference nodes
- Hop counts → Distances to perform tri-lateration
- Simple, distributed ⇒ suitable for sensor network

Improved performance in **sparse** and **non-uniform** network conditions through:

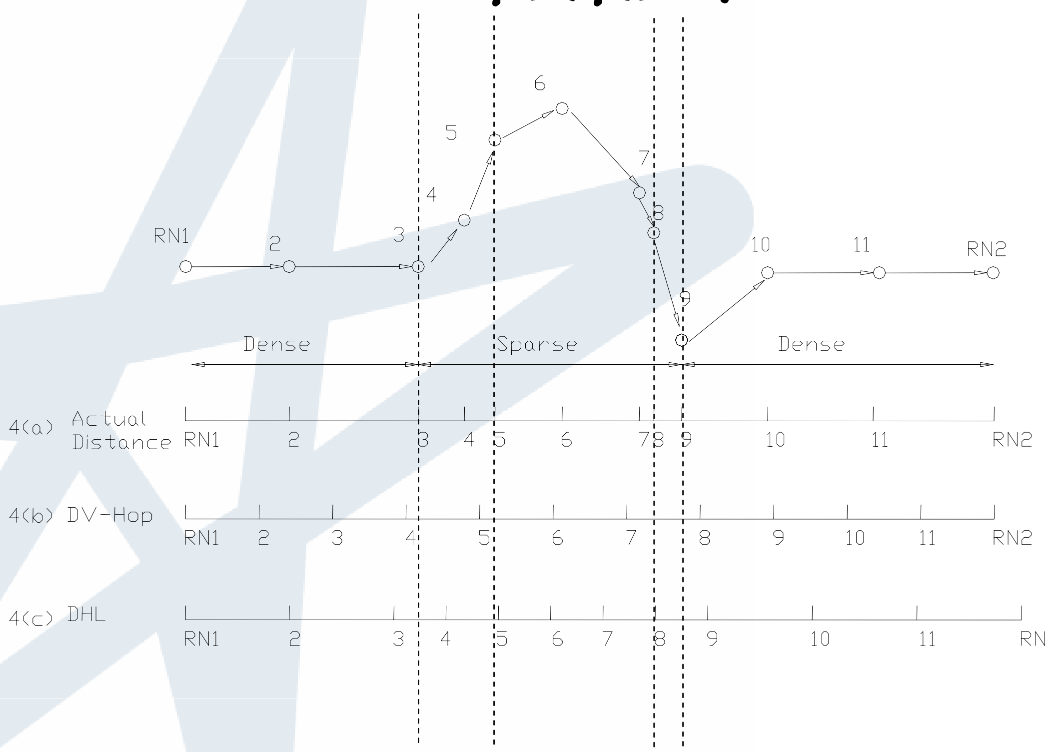
- Local density awareness
- Path length awareness and prioritization
- Mobility of selected nodes

Publications:

Wong, SY, JG Lim, SV Rao and Winston KG Seah, 'Hop-Count Localization with Density and Path Length Awareness in Non-Uniform Wireless Sensor Networks', IEEE WCNC 2005, New Orleans, LA, USA, Mar 13-17, 2005.

Wong, SY, JG Lim, SV Rao and Winston KG Seah, 'Multihop Localization with Density and Path Length Awareness in Non-Uniform Wireless Sensor Networks', IEEE VTC2005-Spring, May 30 - Jun 1, 2005, Stockholm, Sweden.

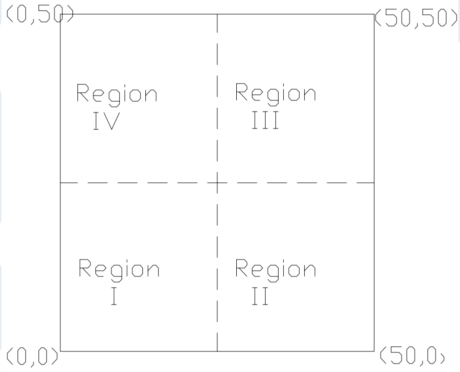
Density Aware Hop-count Localization

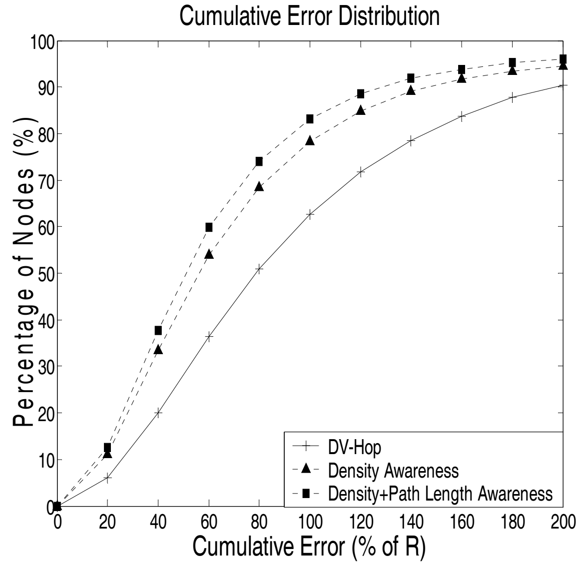


Localization (DHL)

Simulation Topology

- 50x50m, 5m transmission range, 500nodes
- Region I to Region IV, DRI:DRII:DRIII:DRIV = 3:1:3:1.
- RNs are placed such that they are close to the network boundary and surrounded by randomly placed nodes in all directions.





63% of nodes using DV-Hop managed to estimate their locations within one transmission range from their actual locations.

With density-awareness alone → % of nodes increases to 73%.

DHL with path-length awareness → % of nodes able to achieve the same results rises to 83%.

Research Areas (2)

Intelligent Mobility Enhanced Connectivity and Localization

Enable mobile robots to cooperatively move to the node-sparse area to increase the node density

→ improve the precision of the hop count based localization.

Main Research Issues

- Where to move to: static nodes with less neighbors
- Who to move: robot(s) nearest to target static nodes
- How to move: artificial potential field based control

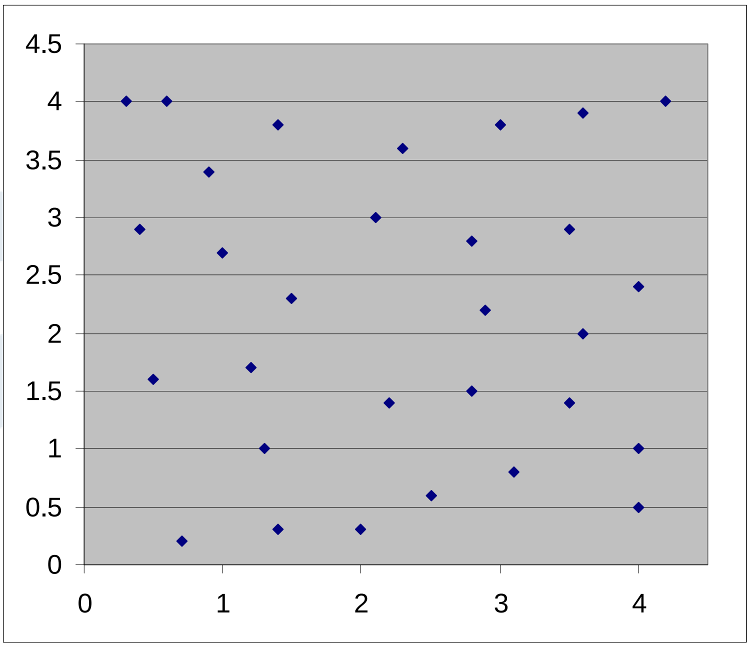
Publications:

Seet, Terrence, Z Liu, Marcelo H Ang Jr, Winston K G Seah, 'Multi-Robot Mobility Enhanced Hop-Count Based Localization in Ad Hoc Networks', submitted to *Journal of Robotics and Autonomous Systems.*

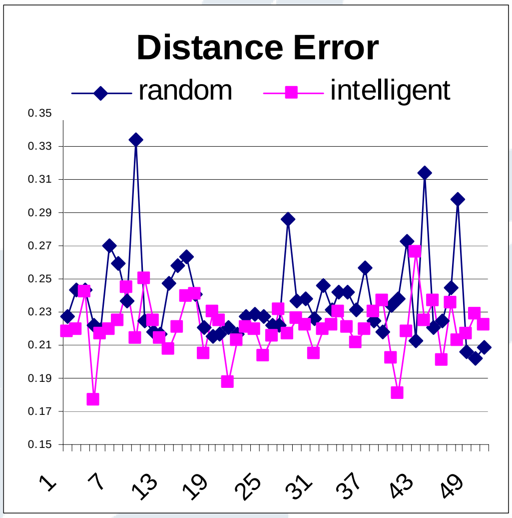
Intelligent Mobility Enhanced Connectivity and Localization

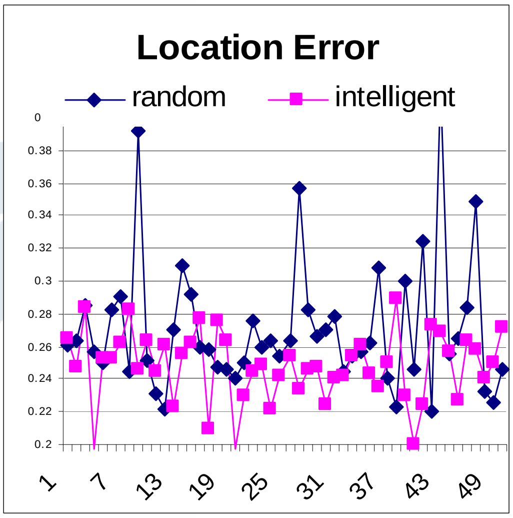
Simulation Setup

- Environment: 4.5m x 4.5m square
- 4 reference nodes at 4 corners.
- 30 static nodes (distributed as shown in the figure on right)
- 10 mobile robots
- The network is fully connected.



Intelligent Mobility Enhanced Connectivity and Localization





- The intelligent mobility model outperforms the random mobility mode, both in terms of distance error and location error.
- The intelligent mobility model is also found to produce more consistent, repeatable results as compared to random mobility.

Research Areas (3)

Analytical characterization of connectivity of mobile ad hoc networks

- Node mobility causes the separation between any pair of nodes to fluctuate
- Atmospheric condition and obstacles can cause the transmission range of the nodes to fluctuate

Derived the connectivity probability that

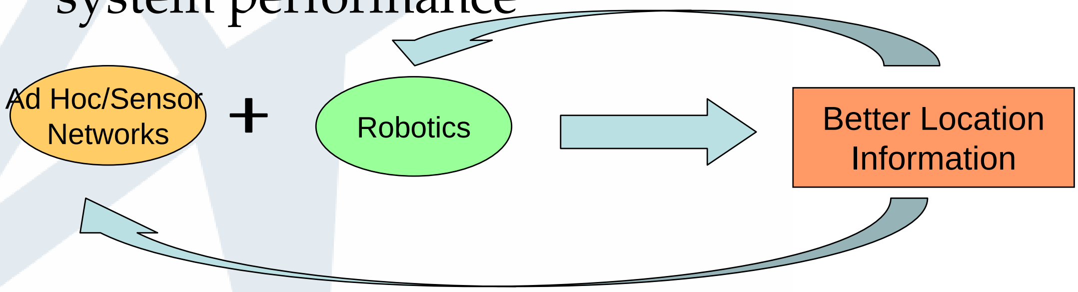
- Represents the fraction of time that a node is connected to at least one other node
- Can be used to study the effect of mobility and fading on the connectivity as the transmission range or number of nodes in the network varies
- Addresses mobility while most work assumes a static network

Publications:

Mar CH and Winston KG Seah, 'An analysis of connectivity in a MANET of autonomous cooperative mobile agents under the Rayleigh fading channel', IEEE VTC2005-Spring, May 30 - Jun 1, 2005, Stockholm, Sweden.

Innovative Impact

- Merging of 2 exciting fields of research (sensor networks and robotics) to solve a common challenge – improved connectivity and localization
- Leverages on the strengths of respective fields
- Location information reapplied into the network and mobile nodes (robots) to improve system performance



Conclusion

- Location is a critical information in mobile ad hoc and sensor networks
- We have developed schemes that combine the strengths of localization in networking and robotics
- Location information acquired can in turn be used to improve networking schemes and robot tasks
- Project has completed a significant portion of the research and moving to integration and prototyping while further research continues

Simulation demo

*Major difficulty faced in simulation: lack of an integrated robotics and network protocols simulator.