Robust Location Determination in Ad-hoc Wireless Networks

by
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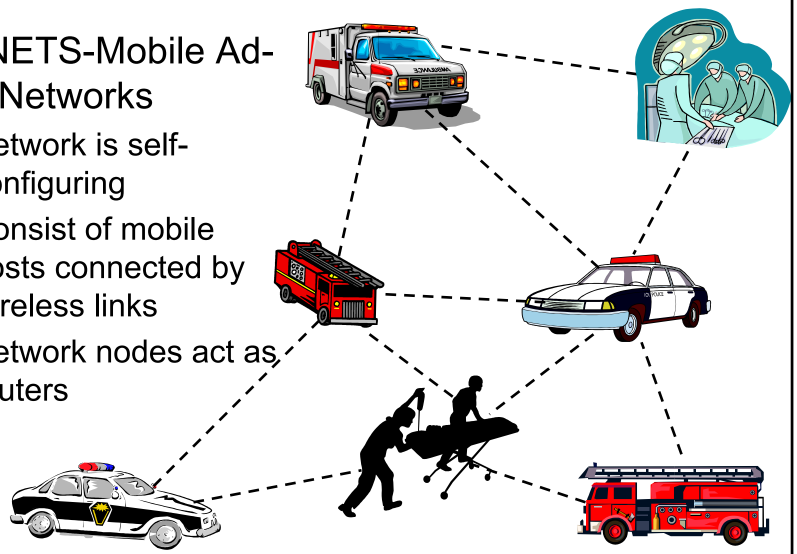
Outline

- **Introduction and Motivation**
- Relevant Background
- Effect of topological characteristics
- Location determination with directional antennas
- Conclusions
- Significance of work

Mobile Ad-hoc Networks

- MANETS-Mobile Ad-hoc Networks
  - Network is self-configuring
  - Consist of mobile hosts connected by wireless links
  - Network nodes act as routers



Sensor Networks

- A kind of large scale wireless ad-hoc network
- Designed to sense environment and collect data
- Collected data sent to *base station* or *cluster-head*
- Sensor node properties
  - Low cost and small in size
  - Battery powered and energy constrained
  - Limited transmission range
  - Limited computational power
  - Can be mobile or static

Need for Location Determination

- Location-aware applications
  - Most sensor network applications require knowledge of location of origin of sensed data
  - Examples:
    - Monitoring weather conditions in a habitat
    - Monitoring migration pattern of an endangered species
    - Military surveillance

Location Determination in Sensor Networks

- Special location determination hardware, e.g. GPS receivers
  - too expensive
  - bulky in nature
  - uses too much energy
- Prevailing approach
  - A small fraction of sensors equipped with location determination hardware (*anchors*)
  - Software protocols used for disseminating location information to other sensors nodes

Sections of Thesis

- Study of the effect of a network's topological characteristics on accuracy of location determination.
- Development of a technique for doing location determination with directional antennas

Outline of Rest of Presentation

- **Relevant Background on Location Determination**
- Effect of topological characteristics
- Location determination with directional antennas
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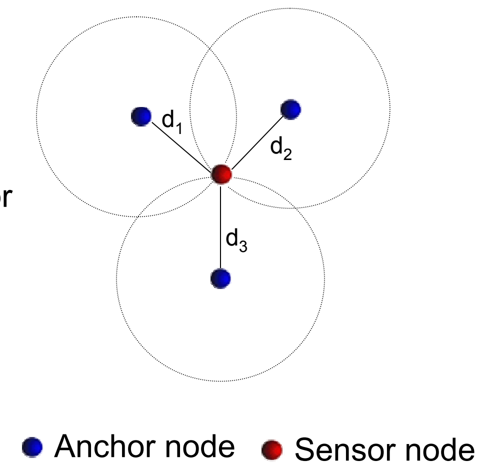
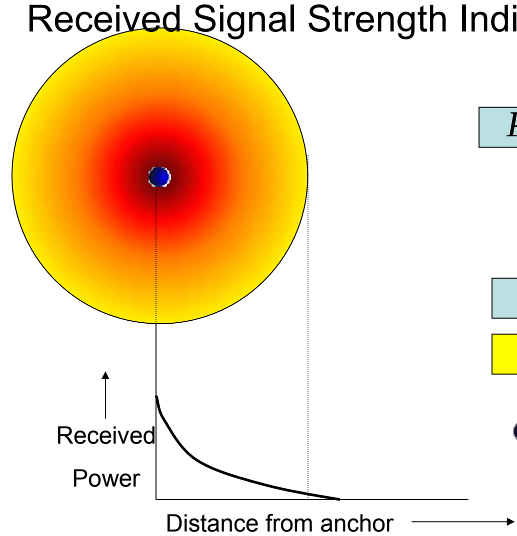
Location Determination Technique

- Triangulation
  - Given locations of three anchor nodes and distances from each of them the location of the sensor node can be calculated

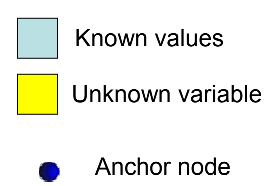


Distance Estimation

Received Signal Strength Indication (RSSI)

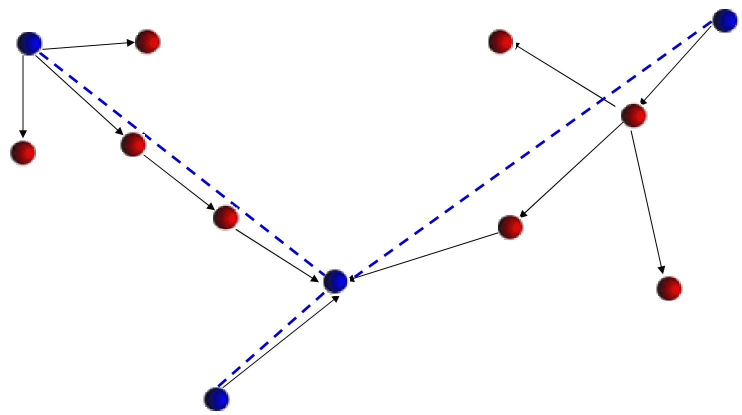


$$P_{received} = \frac{P_{transmitted}}{r^2}$$



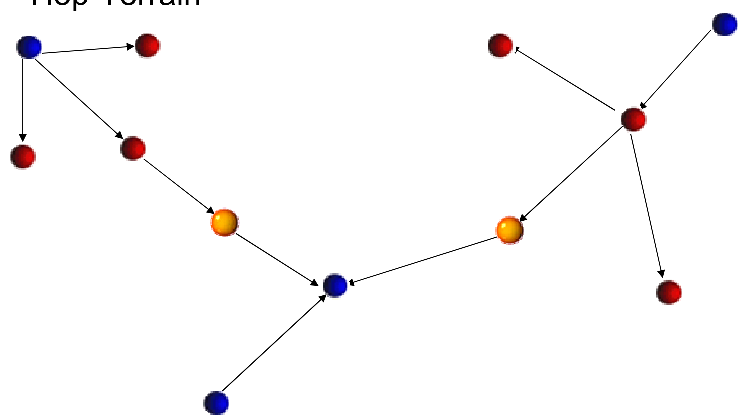
Location Determination Protocol: Hop Terrain & Refinement

- Hop-Terrain Phase
  - Used to get rough estimate of sensor node positions



Location Determination Protocol (contd.)

- Refinement Phase
  - Used to improve location estimates obtained from Hop-Terrain



Location Determination Protocol (contd.)

- Refinement Phase
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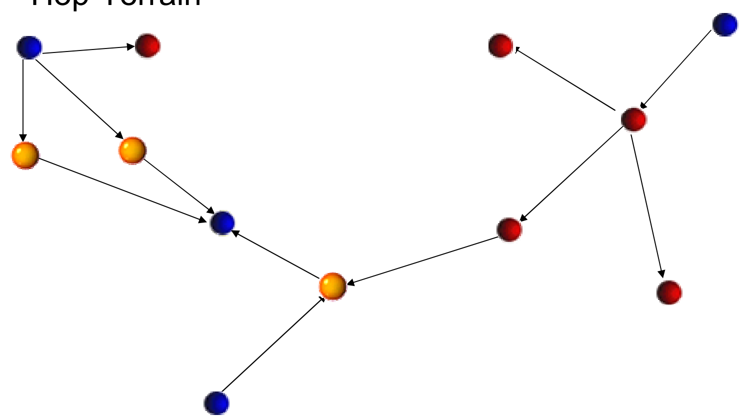

Outline of Presentation

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Over constrained system

$$(x_1 - u_x)^2 + (y_1 - u_y)^2 = r_1^2$$
$$(x_2 - u_x)^2 + (y_2 - u_y)^2 = r_2^2$$
$$(x_3 - u_x)^2 + (y_3 - u_y)^2 = r_3^2$$
$$(x_4 - u_x)^2 + (y_4 - u_y)^2 = r_4^2$$
$$(x_5 - u_x)^2 + (y_5 - u_y)^2 = r_5^2$$
$$(x_6 - u_x)^2 + (y_6 - u_y)^2 = r_6^2$$

$$Ax = b$$
$$x = (A^TA)^{-1}A^Tb$$

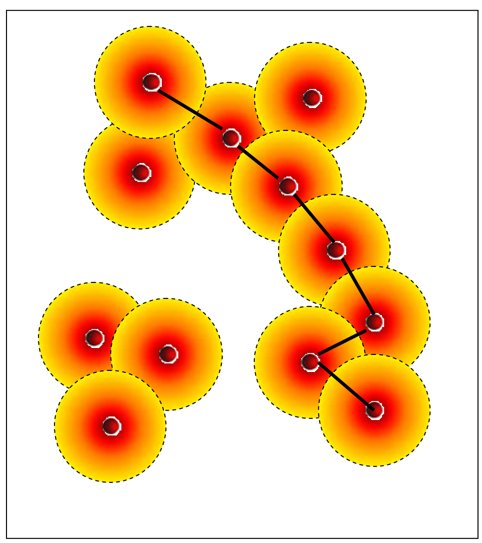
Error Resilient Triangulation

Error in (u_x, u_y) decreases with increasing number of equations

Higher *neighbor connectivity* leads to lower error in location determination

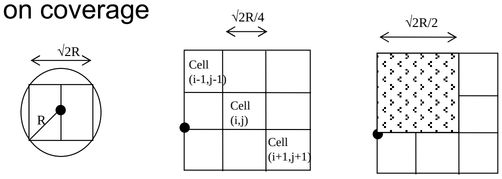
Definition of Topological Parameters

- Coverage
  - Total area covered by sensors
- Connectivity
  - Size of maximum connected component/Total number of nodes
- Diameter
  - Max. number of hops between any two nodes



Coverage Computation: Simplification

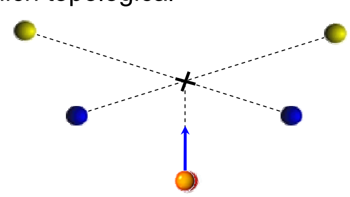
- Circular sensing region approximated by square region
  - simplifies computation
  - gives lower bound on coverage



- A node covers a square region of side √2R
- Sensor field split into cells of side √2R/4
- Claim: If there is a node in any of the 8 adjacent cells to cell(i,j), then cell(i,j) is covered
- Coverage computed as number of covered cells/total number of cells

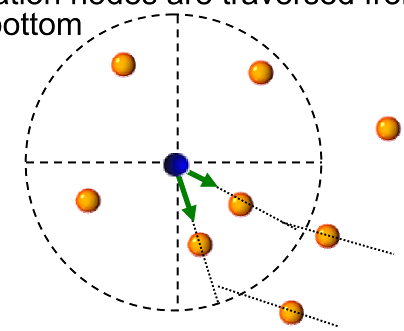
Intelligent Motion

- Mean Shift Clustering (MSC)
  - Algorithm for decreasing diameter
  - Moves node toward centroid of neighbors
    - Neighbors up to *k*-hops away are considered
  - Coverage preserved by evaluation function
    - LEF= w1 * Sum of distances from neighbors up to *k*-hops away – w2 * Distance from centroid
    - Node moved if LEF positive
    - Weights adjusted depending on which topological characteristic requires adjustment



Intelligent Motion (contd.)

- Shift Neighbors Away (SNA)
  - Algorithm for increasing diameter and coverage
  - Pushes neighbors outwards
  - In each iteration nodes are traversed from left to right and top to bottom

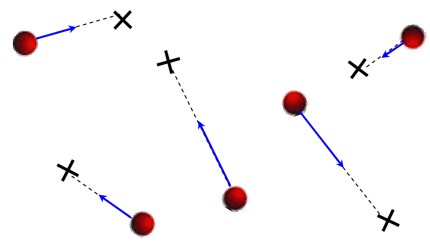


Intelligent Motion (contd.)

- Final Algorithm
  - Choose MSC or SNA depending on what topological conditions need to be fulfilled
  - Evaluation function for motion step
    - *GEF = W1 * Connectivity + W2 * Coverage - W3 * Diameter*
    - Motion rolled back if GEF decreases
    - GEF evaluated before actual motion executed
    - GEF calculation at
      - Cluster head
      - Base station

Random Way Point Model

- Each node picks random destination
- Nodes move to destination with random velocity



Effect of Topology on Location Determination

- Pick random topology
- Kept fraction of anchors fixed
- Apply intelligent motion model with varying topological requirements
- Run Hop-Terrain and Refinement
- Evaluate accuracy of location estimates
- Simulation setup in ns-2

Simulation Results

- Parameters
  - Coverage = 80%
  - Diameter = 6
  - Anchor fraction = 20%

Number of Nodes	Random Motion		Goal-directed Motion		Improvement (%)
	Neigh. Conn.	Error(%)	Neigh. Conn.	Error(%)	
30	5	22	11	12	45.5
40	6	20	14	8.5	57.5
50	7	18	17	7	61.1

- Observations
  - Intelligent motion improves accuracy by about 50%
  - Improvement greater for larger no. of nodes

Simulation Results

- Parameter
  - No. of Nodes = 30
  - Anchor fraction = 20%

Coverage	Diameter	Neigh. Conn.	Error (%)	Improvement (%)
Random Way Point		5	22	NA
55	4	16	7	68.1
62	6	15	8	63.6
70	6	13	9	59.1
80	6	11	12	45.5
80	8	9.5	13	41

- Observations
  - Low diameter gives better location determination accuracy
  - Trade off between coverage and accuracy

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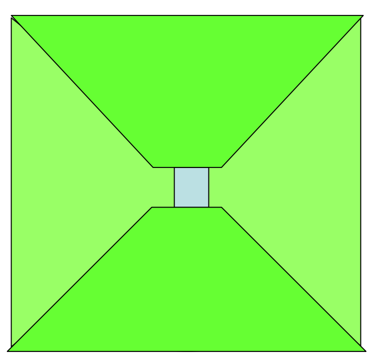
Directional Antennas in Sensor Networks

- Diversity Configuration
  - Multiple antennas on a sensor node
  - Redundancy in coverage area leads to fault tolerance



Range Estimation

- Omni-directional antenna

$$P_{received} = \frac{P_{transmitted}}{r^2}$$

- Directional antenna

$$P_{received} = \frac{P_{transmitted}}{r^2} \cdot G(\theta_t) \cdot H(\theta_r)$$

Known values: $P_{received}$, $P_{transmitted}$

Unknown variable: r^2, θ_t, θ_r

Range Estimation with Directional Antennas

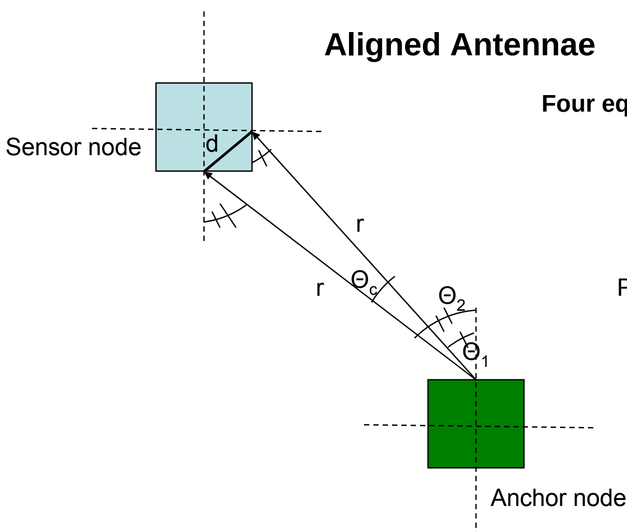
- Solution
  - Use power measurements from multiple antennas on same sensor node

Deployment Scenario

- All nodes have aligned antennas
  - Nodes manually deployed
  - Nodes oriented along some global reference direction
    - e.g. North-South
  - Example
    - Nodes placed by construction workers on a bridge
    - Mobile nodes
      - Location changes but orientation fixed

Solving for location

Aligned Antennae



Four equations in four unknowns

$\Theta_c = d/r$

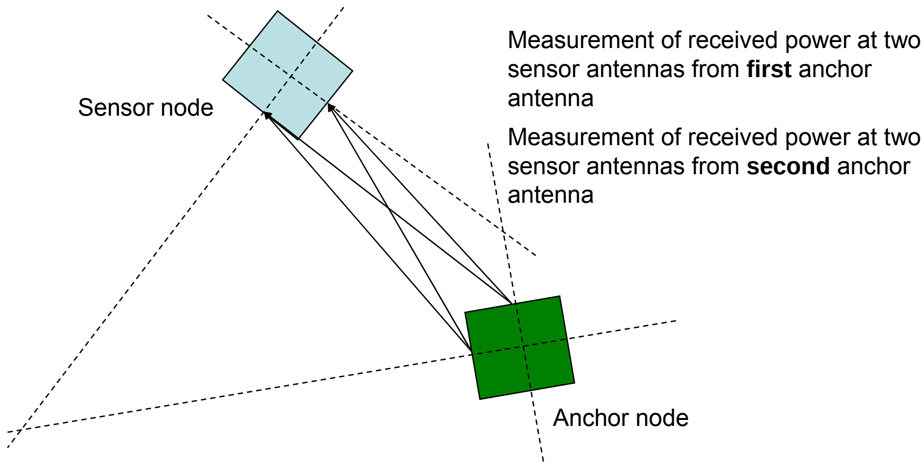
$\Theta_2 - \Theta_1 = \Theta_c$

$P_{r1} = P_{t1}\, G(\Theta_1)\, H(pi/2-\Theta_1)/r^2$

$P_{r2} = P_{t2}\, G(\Theta_2)\, H(\Theta_2)/r^2$

Unaligned antennas

General orientation for randomly deployed nodes



Observations

- Neighboring anchors required for location determination
  - Directional antenna scheme : One
  - Omni-directional antenna scheme : Three
- Messages transmitted for each location estimate
  - Directional antenna (Aligned nodes) : One
  - Directional antenna (general orientation) : Two
  - Omni-directional antenna : Three

Problems

- Small node size of the order of size of carrier wavelength
  - Model used for transmitted power becomes inaccurate
  - Error in power received at multiple antennas on a sensor are correlated
- Inability to simultaneously receive messages at multiple antennas on sensor

Using Multiple Anchors

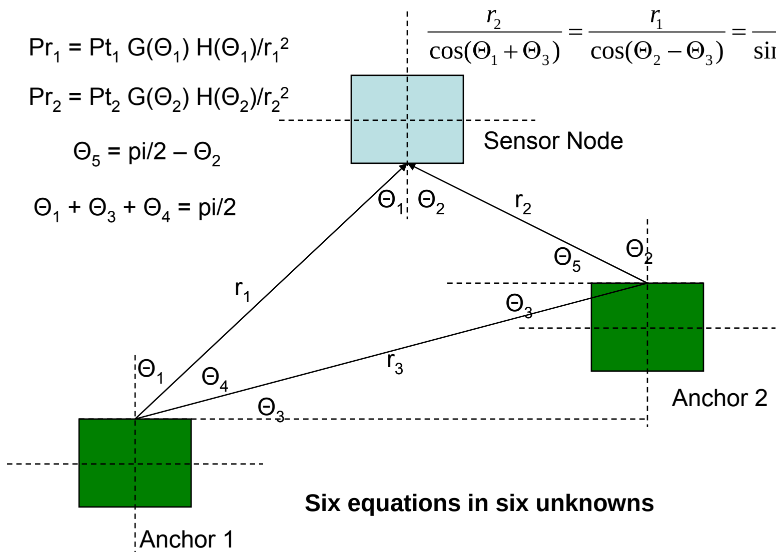
$$\frac{r_2}{\cos(\Theta_1+\Theta_3)} = \frac{r_1}{\cos(\Theta_2-\Theta_3)} = \frac{r_3}{\sin(\Theta_1+\Theta_2)}$$

$Pr_1 = Pt_1\ G(\Theta_1)\ H(\Theta_1)/r_1^2$

$Pr_2 = Pt_2\ G(\Theta_2)\ H(\Theta_2)/r_2^2$

$\Theta_5 = pi/2 - \Theta_2$

$\Theta_1 + \Theta_3 + \Theta_4 = pi/2$



Six equations in six unknowns

Position Estimation Error

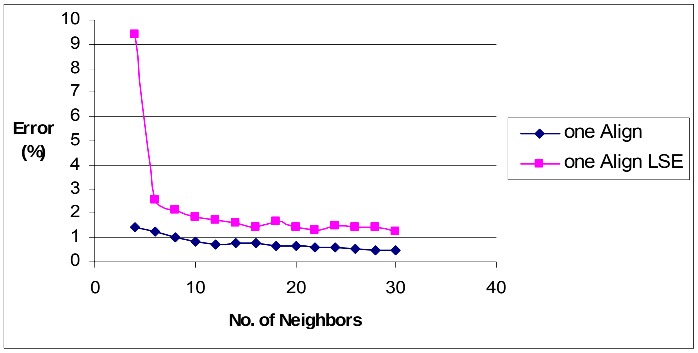
$$P[|u_{xn} - E[u_x]| \geq \epsilon] \leq (0.2/R^3 e^2 (2\ e^2/81 + 4/9))/\ n\epsilon^2$$

- Observations
  - Error depends on cube of inter-node distance
  - More accurate location determination at smaller distances

Simulation Setup

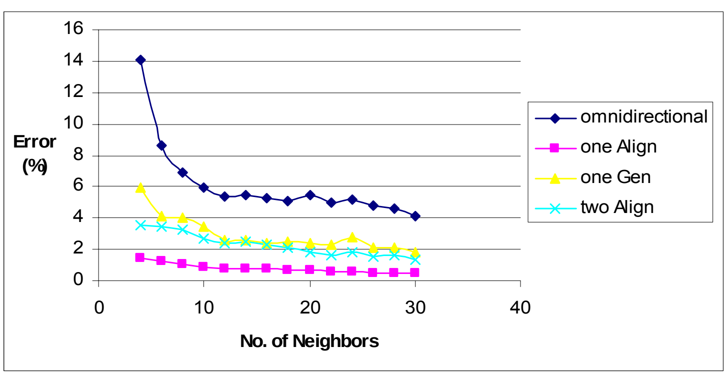
- Randomly place a sensor node on a two-dimensional plane
- Randomly place anchor nodes around the sensor
- Calculate received power at sensor antennas based on antenna model
- Introduce error in received power
  - Normal distribution of errors
- Estimate position of sensor using perturbed power values
- Distance between estimated position and true position of sensor gives location determination error

Simulation Results



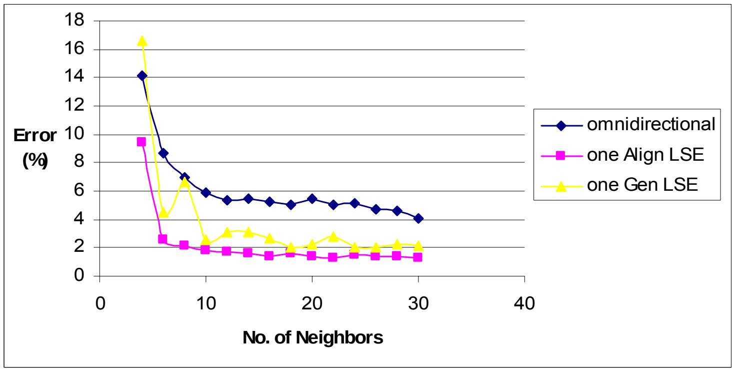
- Observation
  - Averaging is twice as accurate as Error Resilient Triangulation (ERT)
  - ERT discards angle information and gives a non-optimal estimate of position

Simulation Results



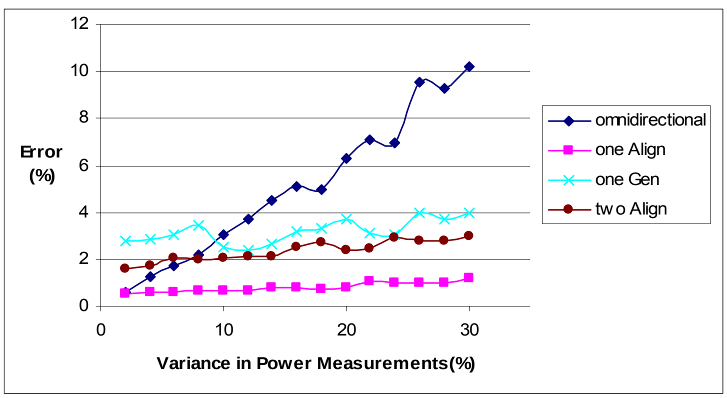
- Observations
  - Directional antenna schemes more accurate than omni-directional antenna schemes
  - Directional antenna schemes do not have a sharp knee point
    - Graceful degradation with low sensor density

Simulation Results



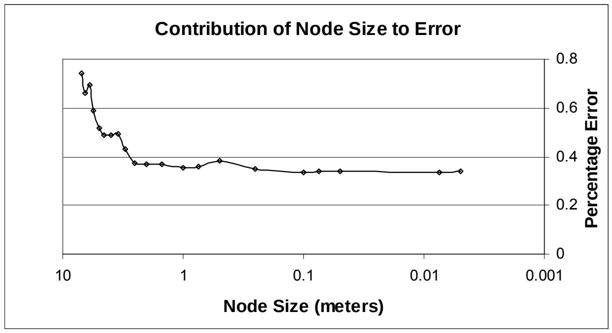
- Observations
  - Range estimates obtained from directional antennas more accurate

Simulation Results



- Observation
  - Location Determination with directional antennas degrades more gracefully with error in power measurements

Simulation Results



- Observation
  - Shielding Effect
    - Large node size makes it difficult measure power at two receiving antenna on sensor node

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- **Conclusions**
- Significance of work

Conclusions

- Effect of topology on accuracy of location determination
  - Improvement in topology can reduce error by up to 50%
  - Can reduce diameter without affecting coverage for greater accuracy

Conclusions

- Location Determination with Directional antennas
  - More accurate range estimates with directional antennas
  - Significant improvement in accuracy of location estimates
  - Requires transmission of less messages leading to energy conservation
  - Requires less neighboring anchors
  - Graceful degradation in performance for low sensor density and high error in power measurements

Significance of Work

- Quantitative estimate of effect of topological characteristics on accuracy of location determination
- Evaluated trade-off between topological requirements of application protocols
- Developed technique for location determination with directional antennas
- Demonstrated
  - Improvement in accuracy
  - Robustness to errors and low sensor density
  - Reduction in power consumption

Future Work

- Extension of two anchor based technique for general node orientation
- Linearize equations for closed form solution
- Experimental evaluation of correlation in error in received power at multiple antennas
  - Sensitivity analysis
- Development of protocol using the proposed scheme with directional antennas
  - Implementation and testing on modified Berkeley motes (part of NSF project)

Thank You