Location Estimation in Ad-Hoc Networks with Directional Antennas

Nipoon Malhotra, Mark Krasniewski, Chin-Lung Yang, Saurabh Bagchi, William Chappell
School of Electrical and Computer Engineering
Purdue University

http://shay.ecn.purdue.edu/~dcsl

Outline

- **Introduction and Motivation**
- Directional Antennas
- Experiments and Results
  - Experimental set up
  - Results for different configurations
  - Simulation results
- Conclusions

Sensor Node Localization: Problem Motivation

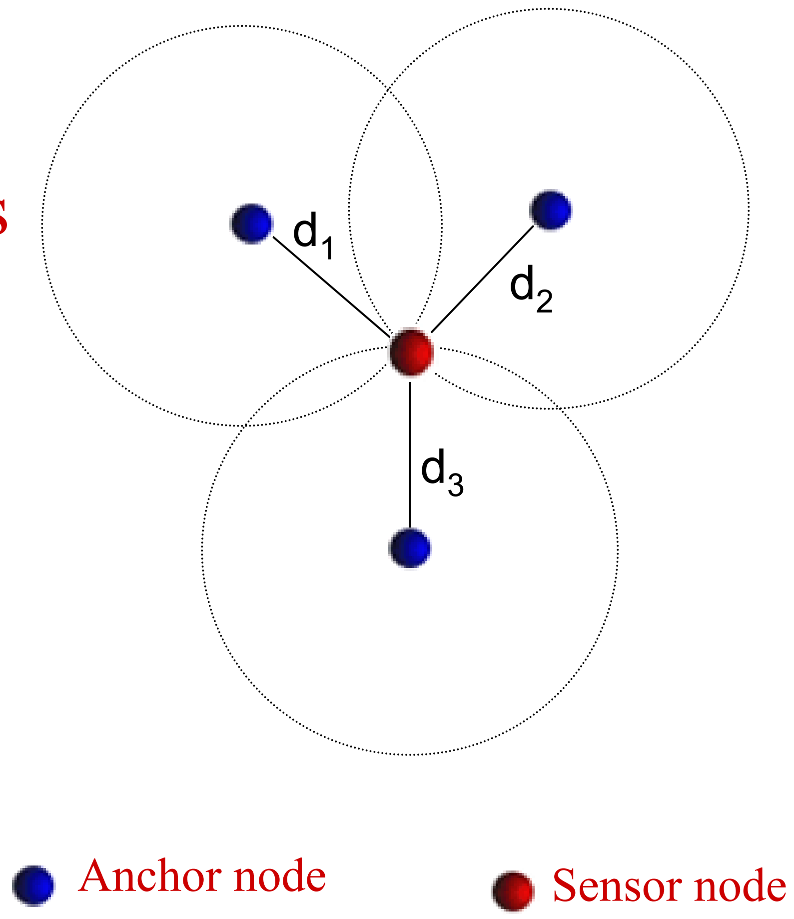
- Many applications need to use location information – sensed data needs context to be meaningful
- Location information can improve quality of application
  - Routing
  - Dissemination
- Mobile networks need updated location information
  - Need localization protocol to be efficient

Localization Techniques – Local Information

- Node localization without network cooperation via some means such as GPS
  - Wide range of hardware accuracy (error from tens of meters to centimeters)
  - Size and weight of additional hardware
  - Cost of additional hardware – $10-$10,000+
  - Battery life of additional hardware – *tens of hours*
  - Different antennas for reception of GPS signals
- A network of these devices violates conventional wisdom that sensor networks should be low-cost components

Localization Techniques – Network-based

- A few nodes know their locations
  - Iteratively localize network
- Lateration – in *k* dimensions use *k+1* neighbors
  - 2D: Triangulation
- Angulation
- Connectivity measurements



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Directional Antennas and their Benefits

- Spatial and angular diversity
  - Multiple antennas on a node to cover entire area
  - Leads to robustness
  - Multiple antennas to receive messages
- Increased transmission range compared to omni-directional antennas
- Patch antennas can be fabricated for sensor nodes
  - Low cost
  - Same form factor as sensor nodes
  - Not completely directed

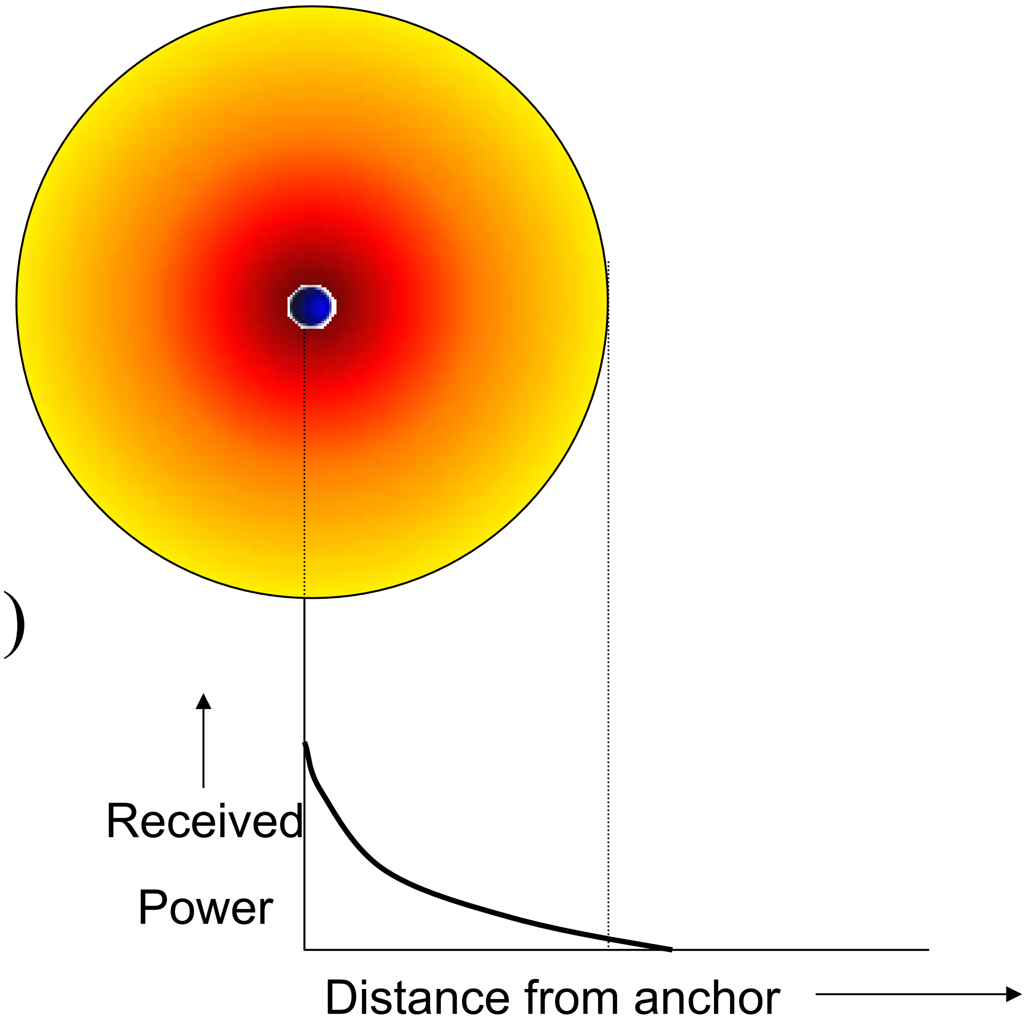
Characteristics of Reception Pattern

- Omni-directional antenna power received

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

- Directional antenna power received

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

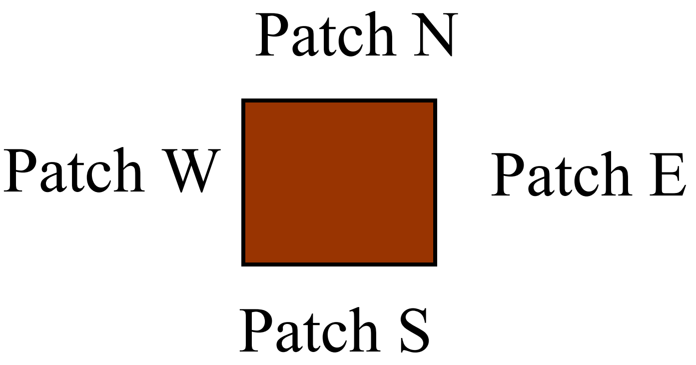


Design Approach

- Use directional antennas to make signal strength measurements
- Delineate which antenna is receiving and at what signal strength – independent power measurement
- Control transmission from different directional antennas on sending node
- Solving for a relative distance and angle for a node from a known source
- Two types of nodes
  - Anchor node – known location in the network
  - Target node – unknown location in the network

Deployment Scenarios

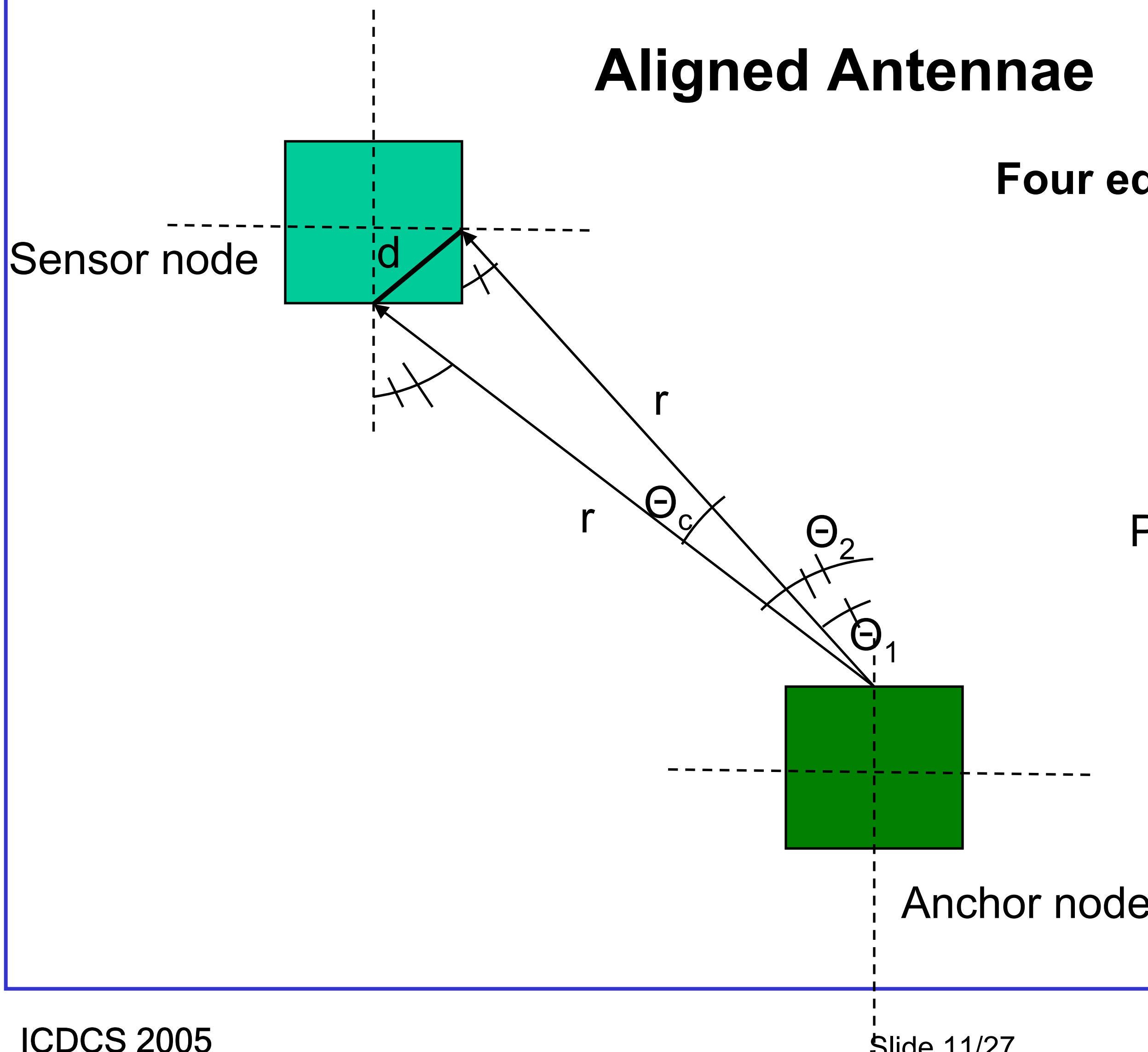
- Nodes seek 2D localization and are equipped with four directional antennas
- Aligned antennas
  - Assume that the target node knows its relative alignment to the anchor node
  - Knowledge of alignment simplifies calculations
  - Realistic assumption given many deployments
  - Digital compass is an inexpensive means of obtaining this information
- Unaligned antennas
  - Purely ad hoc placement of nodes
  - More difficult localization scenario



- Multiple anchor nodes
  - 2 or more nodes with location information
  - Anchors are farther than a half-wavelength apart – limits error correlation

Solving for location

Aligned Antennae



Four equations in four unknowns

$$\Theta_c = d/r$$

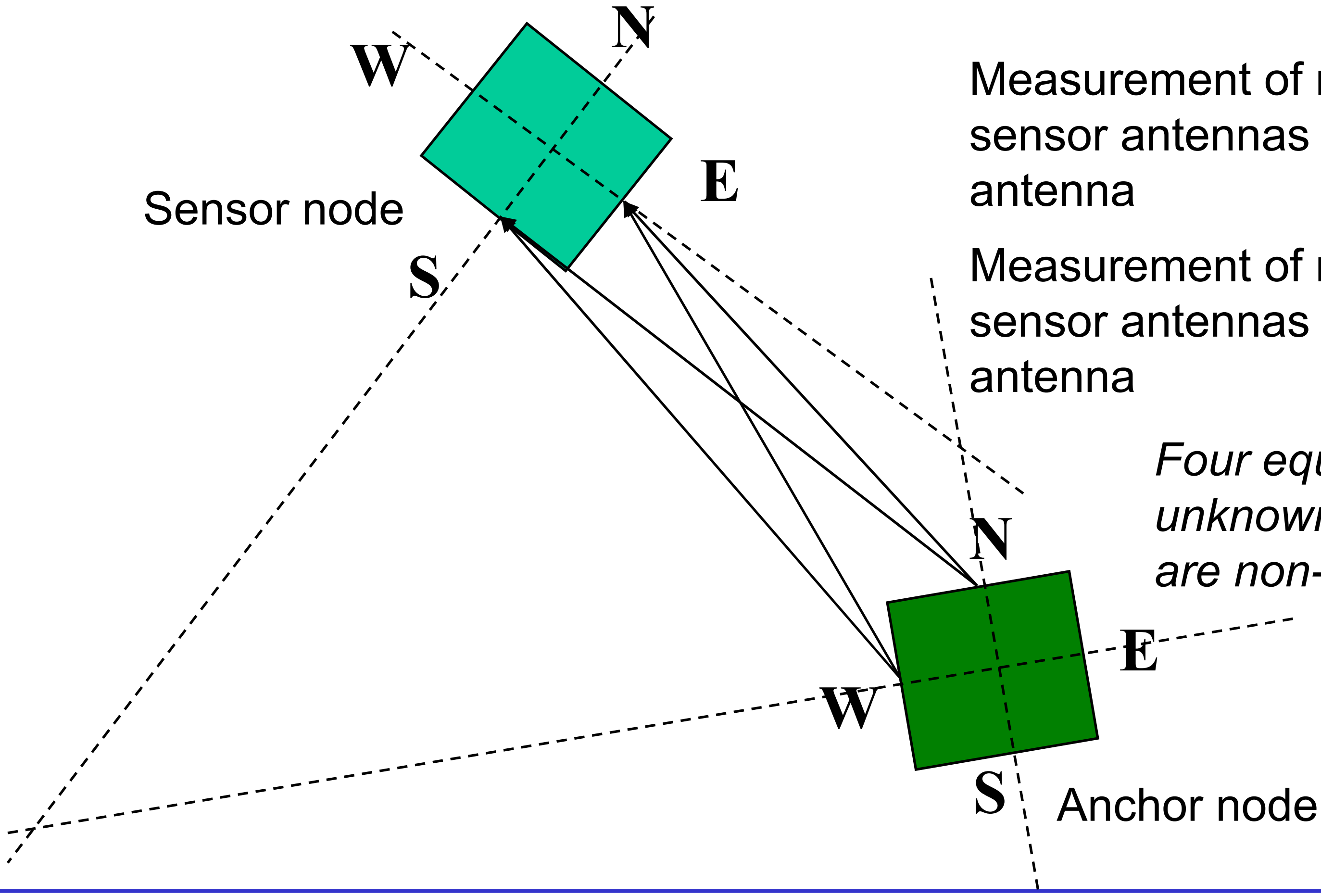
$$\Theta_2 - \Theta_1 = \Theta_c$$

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

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

Unaligned antennas

General orientation for randomly deployed nodes



Measurement of received power at two sensor antennas from **first** anchor antenna

Measurement of received power at two sensor antennas from **second** anchor antenna

Four equations in four unknowns – all four equations are non-linear

Using Multiple Anchors

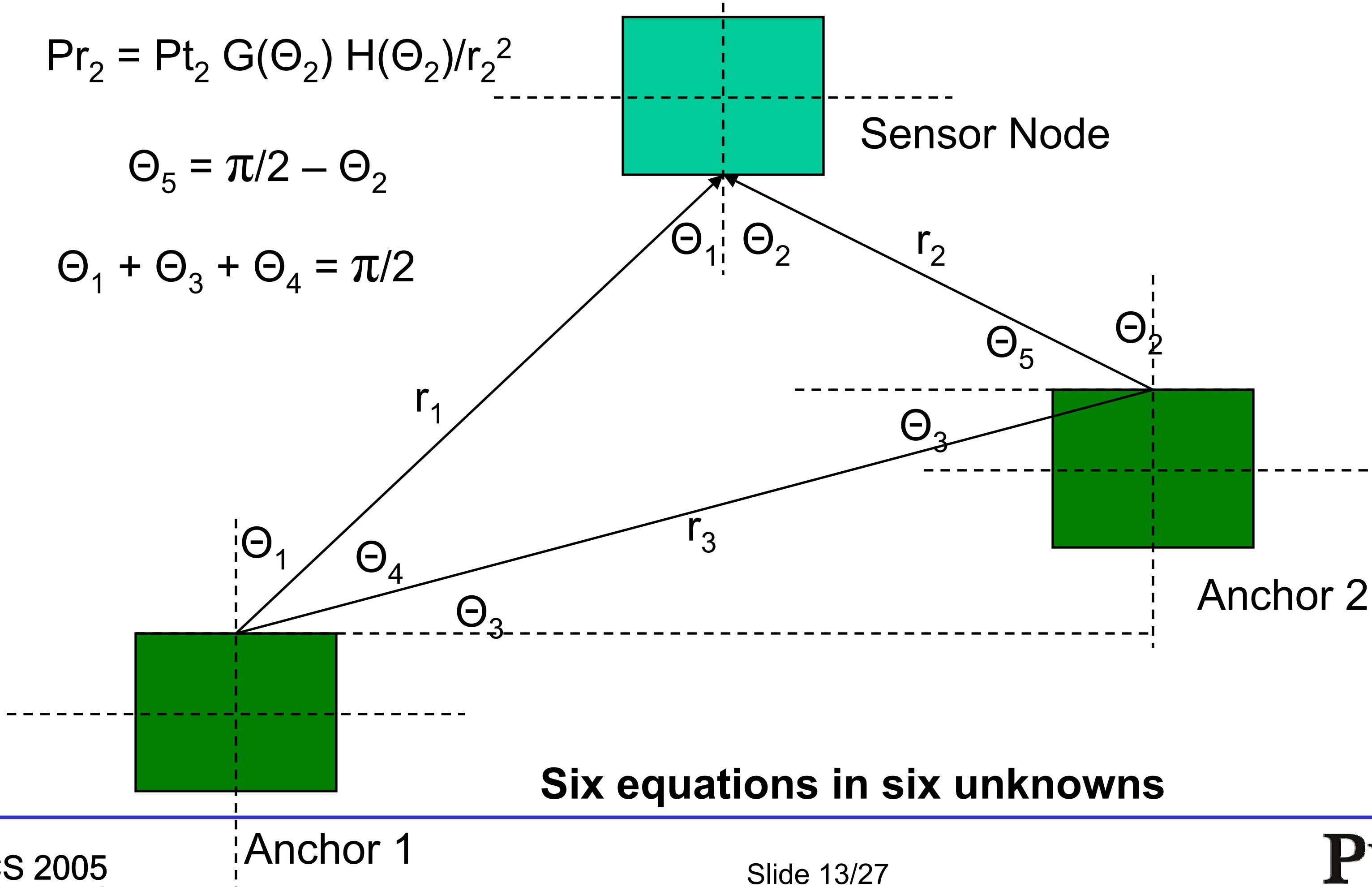
$$\frac{r_2}{\cos(\Theta_1 + \Theta_3)} = \frac{r_1}{\cos(\Theta_2 - \Theta_3)} = \frac{r_3}{\sin(\Theta_1 + \Theta_2)}$$

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

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

$\Theta_5 = \pi/2 - \Theta_2$

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



Six equations in six unknowns

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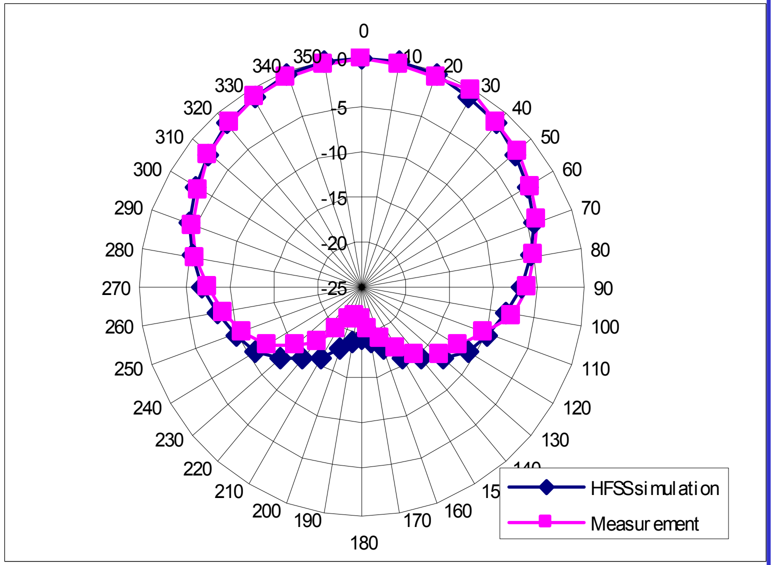
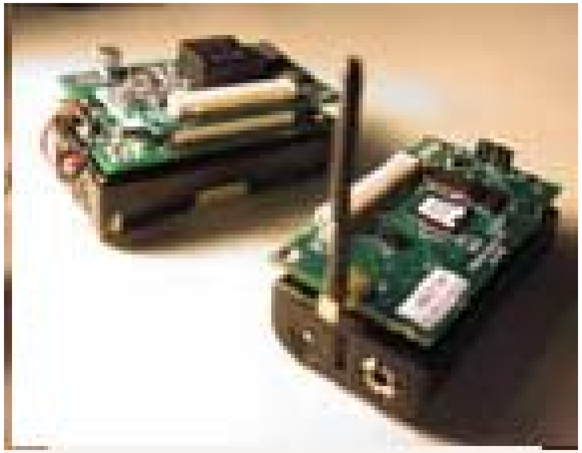
Experimental Set up

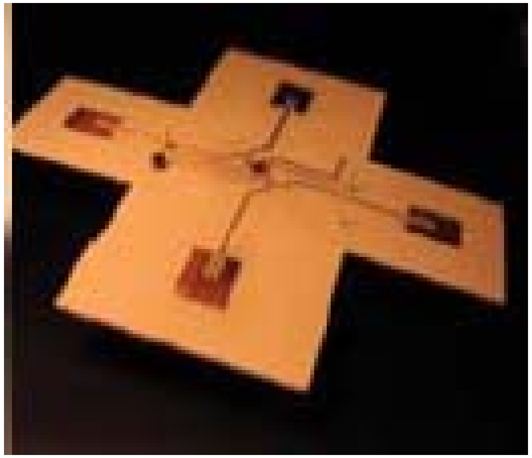
- Mica 2 Berkeley Motes running TinyOS with standard whip antennas from the motes and quarter wavelength omni-directional antenna
- Configure each mote with four directional patch antennas fabricated of duroid substrate – Rogers R03010
- Determine radiation pattern of directional antennas through measurements in an anechoic chamber
- Wrote software to rotate between each antenna via a switch
- Empirically determined the exponent for distance attenuation – $R^{1.89}$
- Ran experiments in parking lot of Civil engineering building

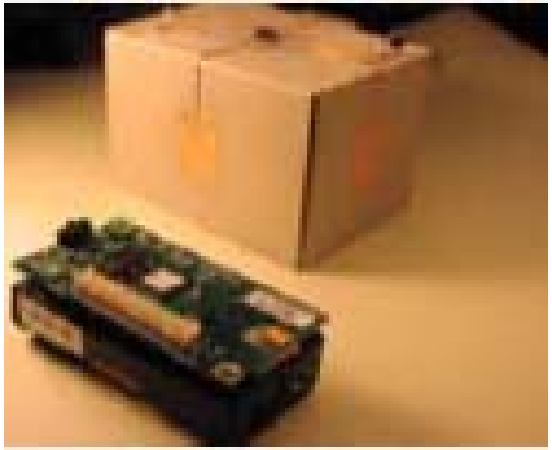


Experimental Hardware

- Standard whip antennas with mica2 motes
- Patch antennas connected into one package







Experiments Conducted

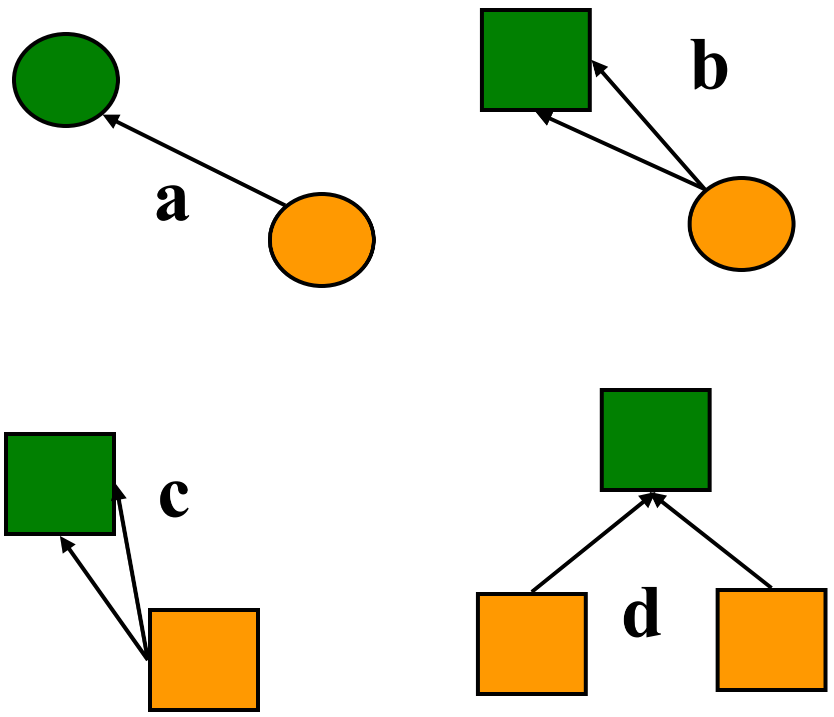
- Ran each experiment with points taken at measured 15° intervals from 0° to 90°
- Each experiment took 50 samples 3 different times for each position
- Experiments run:

  a) Dipole (omni-directional) target, dipole anchor

  a) Patch target, dipole anchor

  b) Patch target, patch anchor

  c) Patch target, two patch anchors



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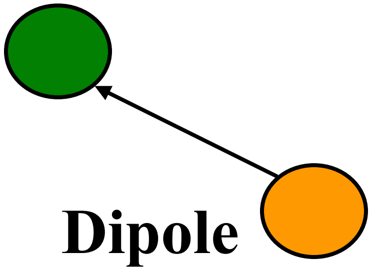
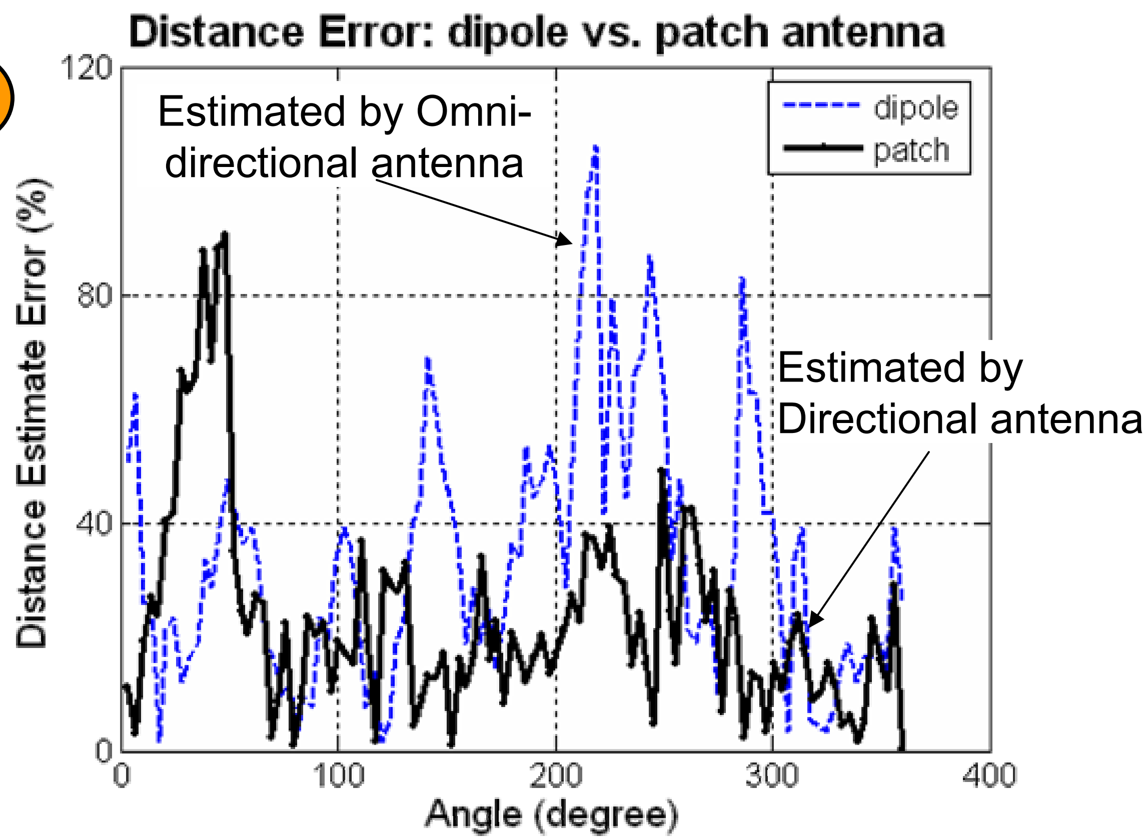
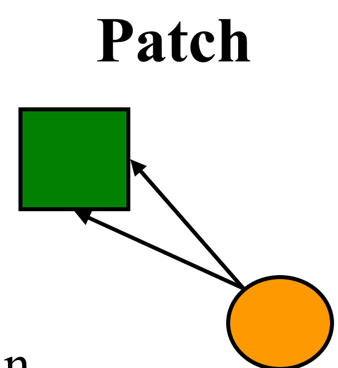
Distance Estimation Error

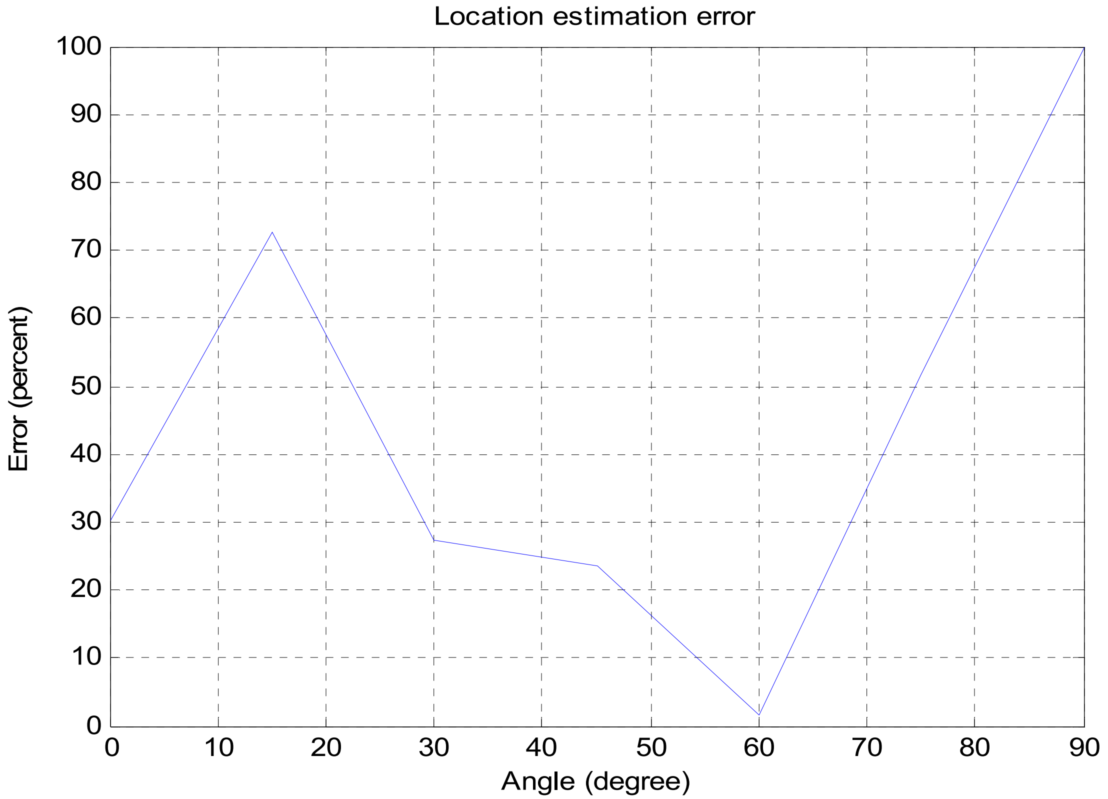


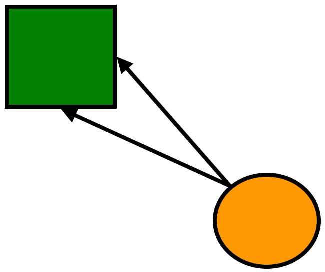




- Distance estimation error for dipole and patch targets
- Dipole target (34% average error) performs worse than patch (23%)

Results – Dipole anchor, Patch target

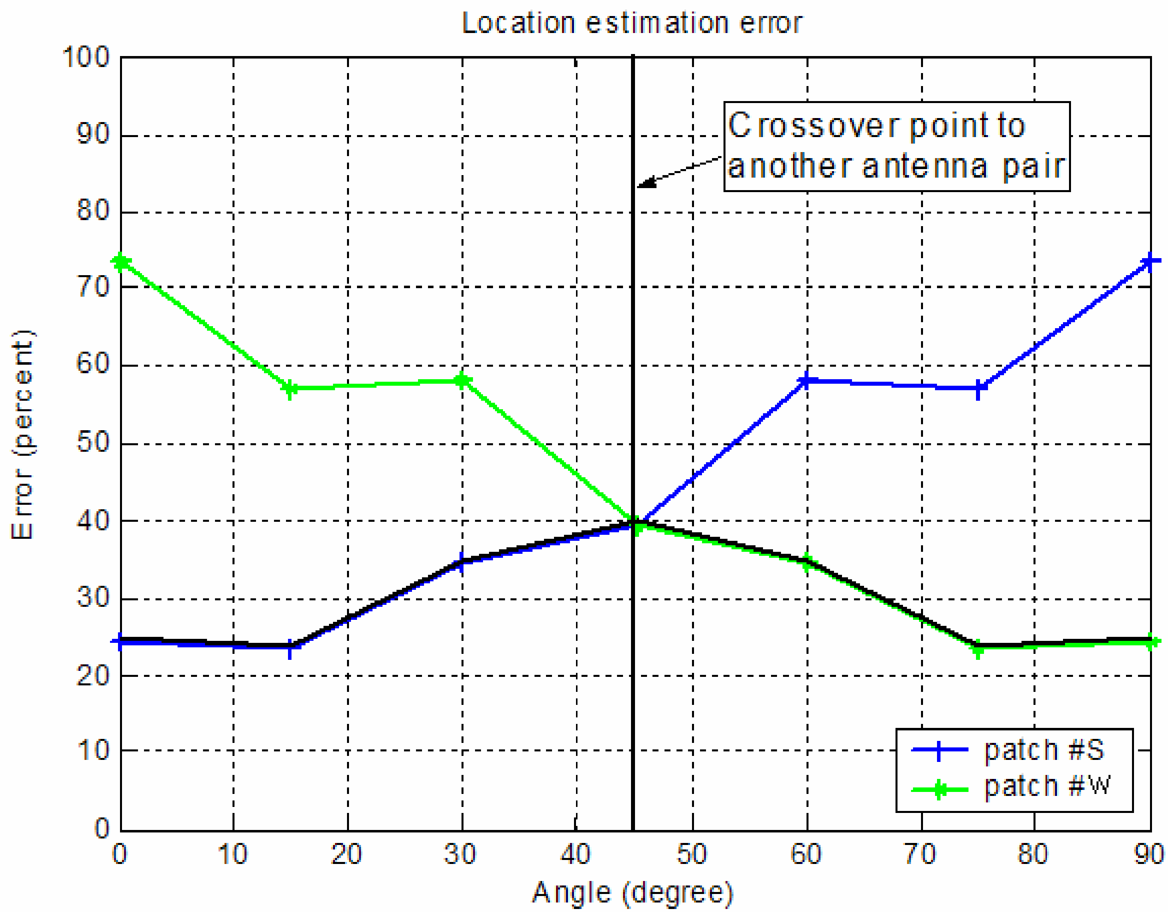




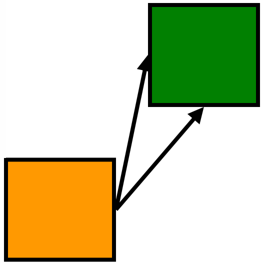
•A single node with patch antenna can find the location

•43.15% error in location estimate

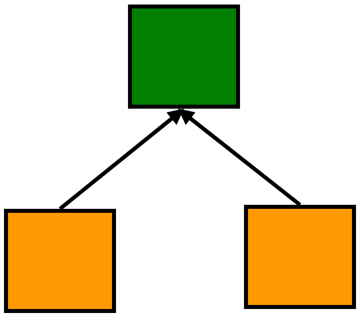
Results – One Patch Anchor

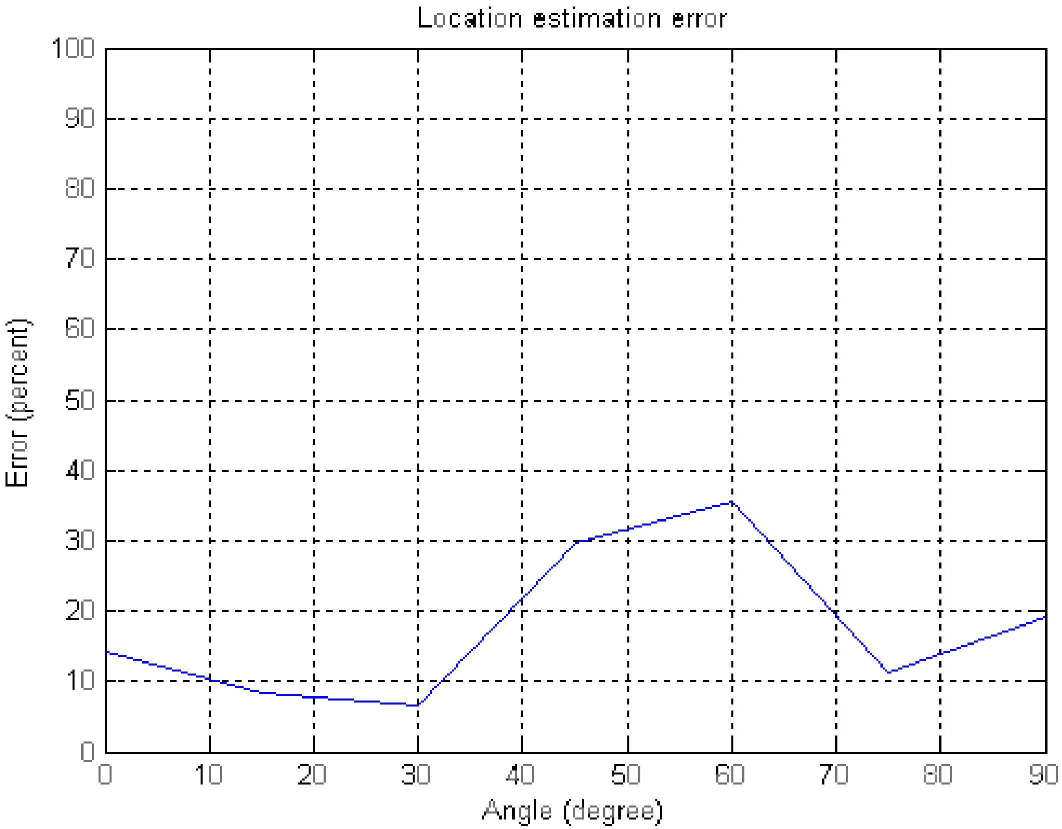


•Demonstrates that as target rotates the estimate is improved by switching antennas : 29.18 % error



Results – Two Patch Anchors





- Two anchors with aligned patch antennas – 17.8% error
- Demonstrates that more anchors give superior localization

Results using Three Anchor Nodes

- Omni-directional antennas:

  27.5% error in location estimation

- Single patch target, single patch anchor

  20% error in location estimation

- Single patch target, two patch anchors

  11.6% error in location estimation

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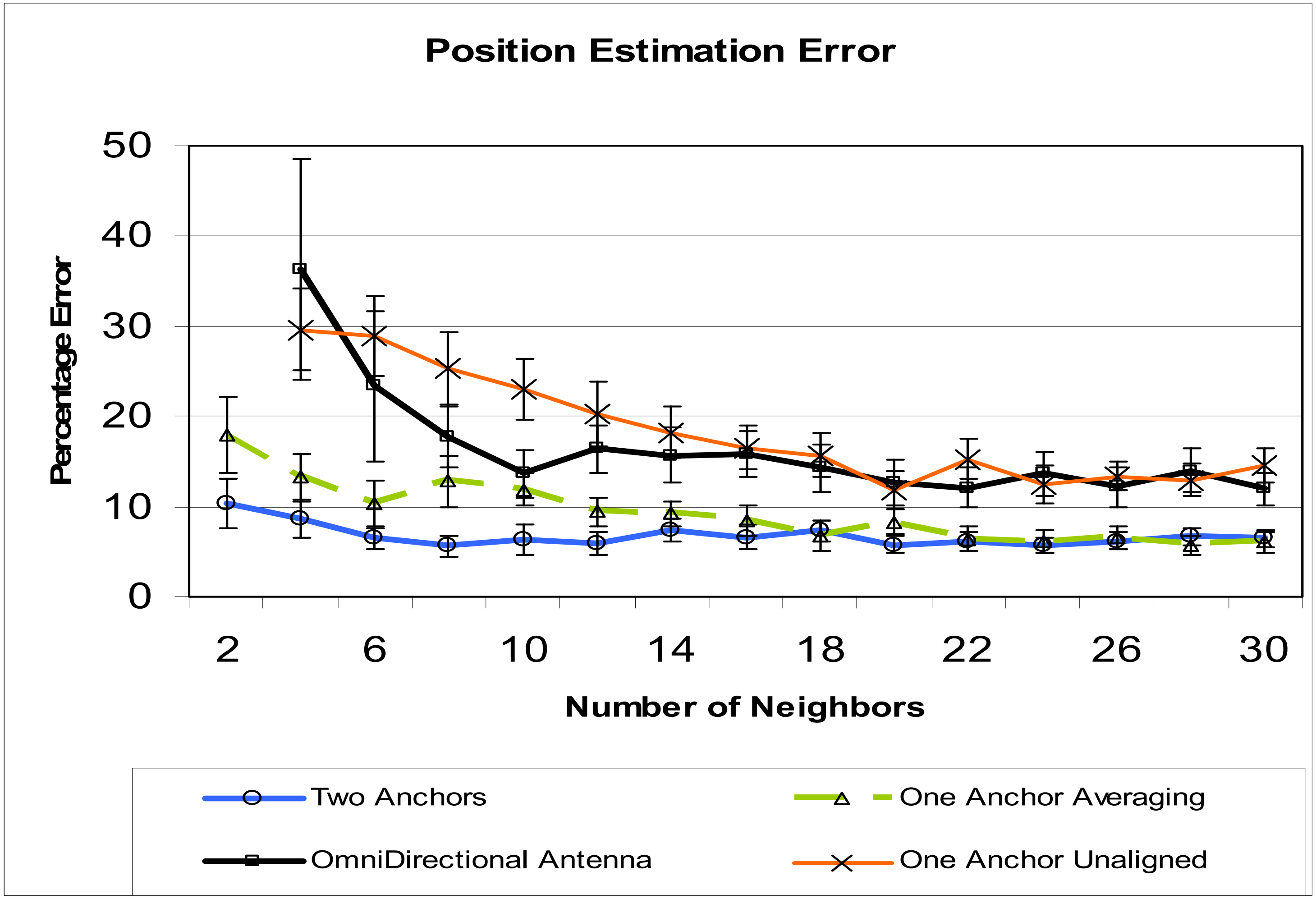
Matlab Simulation Results



- More neighbors create better estimates
- Alignment greatly improves estimates

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Conclusions - Localization

- Directional antennas can improve localization with as little as one anchor node
- Multiple anchor nodes improves performance
- Omni-directional antennas prove less accurate than directional antennas in both distance estimation and location estimation
- Future work
  - Multiple unaligned anchors in hardware
  - Propagation of location information throughout an experimental testbed
  - Combine with location-aware protocol and examine behavior