ITIS 6010/8010: Localization in Sensor Networks

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Applications

Position awareness will help many applications:

- Wildlife Tracking
- Weather Monitoring
- Location-based Authentication
- Interested event tracking
- Smart vehicle systems

Three Techniques for Determining Location

- Triangulation

  Location determined by using triangle geometry.

- Scene Analysis

  Observed features used to infer location.

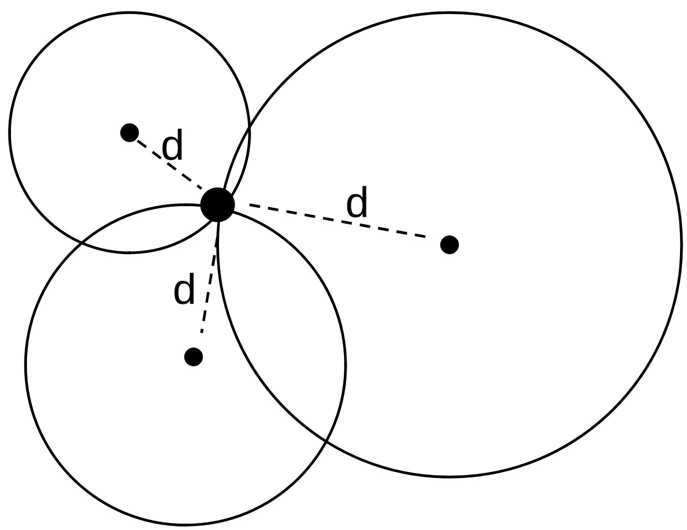
- Proximity

  Detection of change near known location.

Triangulation: Lateration

Lateration is the calculation of position information based on distance measurements.

- 1D position requires two distance measurements.
- 2D position requires three distance measurements.
- 3D position requires four distance measurements.



Triangulation: Lateration

Measuring Distance

- Direct measurement, eg: tape measure.
  Difficult to automate.

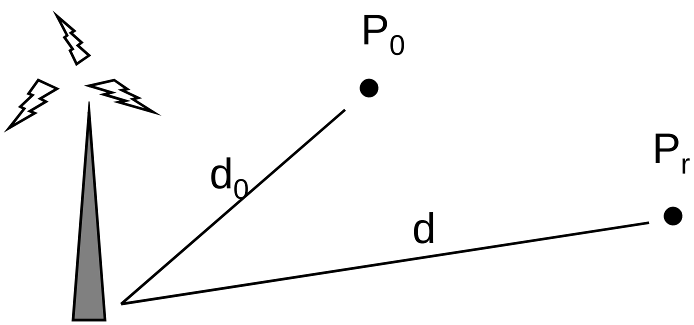
- Time of flight measurement.
  Sound = 344 m/sec. Radio = 3 * 10^9 m/sec.

  Challenges: multipath interference, clock synchronization. GPS atomic clocks synchronized to 10^{-13} seconds.

- Measuring Distance
  - Time difference of signals
    - Same source, multiple signals sent simultaneously, and we measure the difference to reach a target
    - E.g.: send radio and ultrasound at the same time

Triangulation: Attenuation

Decrease in signal intensity as distance from transmitter increases.



$P_r = P_0 (d / d_0)^{-n}$

n = Path-loss exponent (2, 4).

P_0 = Power at reference distance d_0.

Pr = Power at distance d.

Triangulation: Attenuation

Challenges:

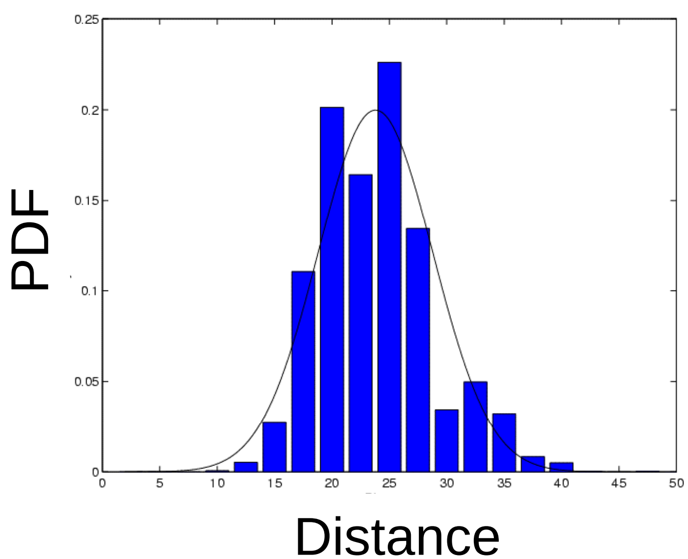
Signal propagation issues, especially indoors: shadowing, scattering, multipath propagation. The error rate can easily reach 20% to 40%.

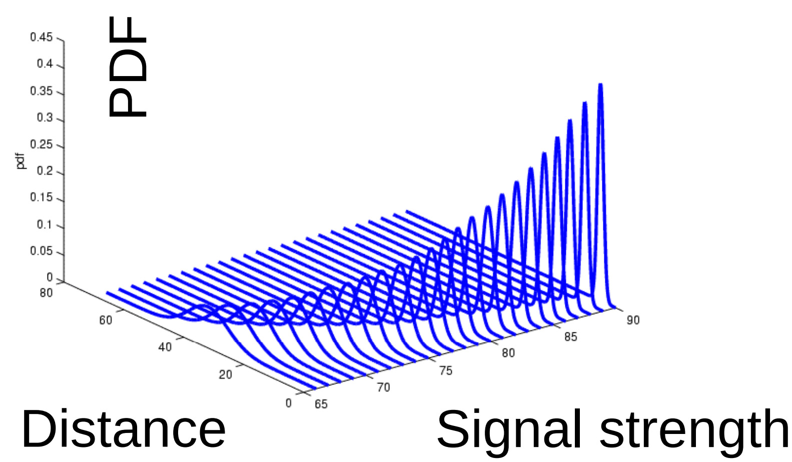
Estimating distances – RSSI

- Received Signal Strength Indicator
  - Send out signals at a known strength level, use received signal strength and path loss coefficient to estimate distance

$$P_{\text{recv}} = c\frac{P_{\text{tx}}}{d^{\alpha}} \Leftrightarrow d = \sqrt[\alpha]{\frac{cP_{\text{tx}}}{P_{\text{recv}}}}$$

  - Problem: Highly error-prone process – Shown: PDF for a fixed RSSI

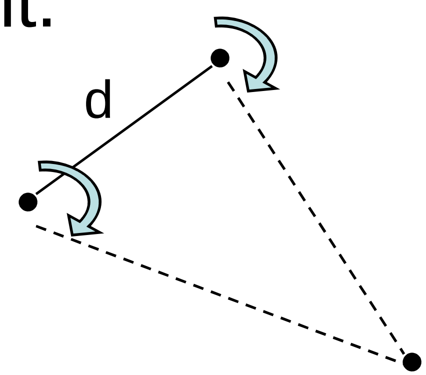




Triangulation: Angulation

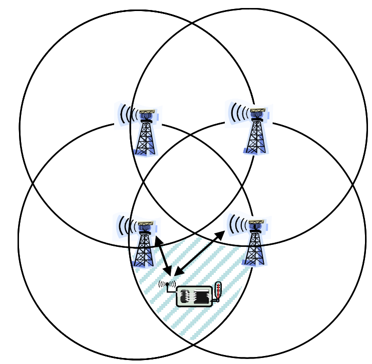
Angulation: using angles to determine distance with directional, or phased-array antennas.

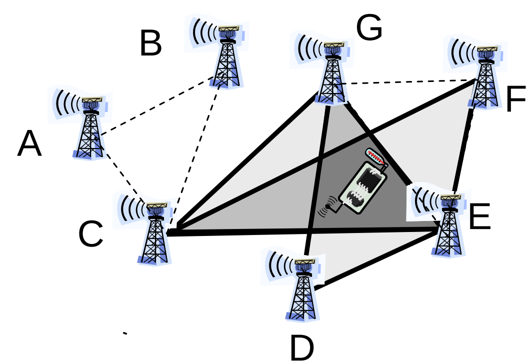
- 2D position requires two angle + one distance measurement.
- 3D position requires two angle + one length + one azimuth measurement.



Some range-free, single-hop localization techniques

- **Overlapping connectivity**: Position is estimated in the center of the area from which signals are heard/not heard
- **Approximate point in triangle**
  - – Determine triangles of anchor nodes where node is inside, overlap them
  - – Check whether inside a given triangle – move node or simulate movement by asking neighbors
  - – Only approximately correct





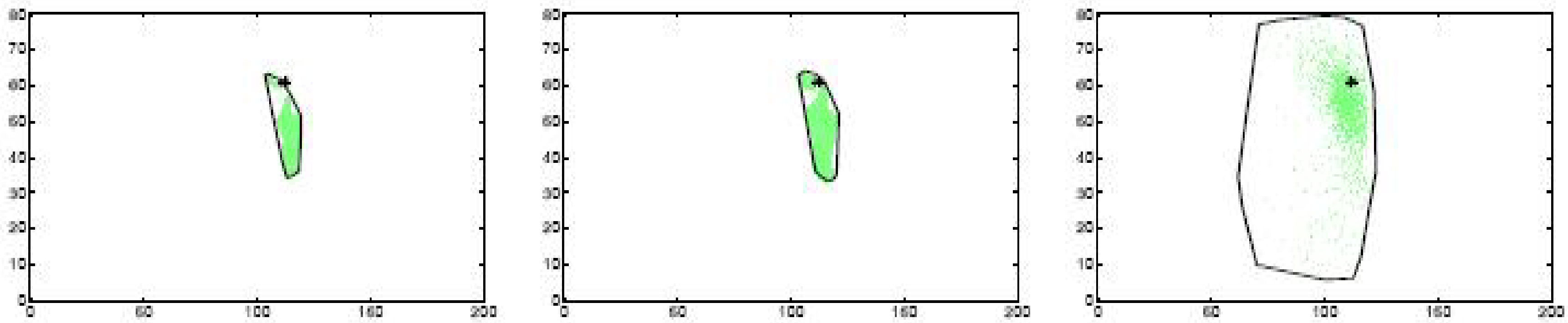
Location Properties

- Physical vs Symbolic: accurate position or “in the kitchen”
- Accuracy or granularity eg: within 1 meter.
- Precision or repeatability eg: within 1 meter 75% of the time.

Location System Properties

- Scale - locate how many objects over what area?
- Localized, sensor-based computation: better privacy, but higher computational, power, cost requirements.
- Infrastructure-based computation: shift the computation and power costs to the wired infrastructure. Allows smaller and cheaper sensors.
- Cost

- Several problems to be considered
  - Who sends out signal: the node or the anchors? (privacy)
  - Signal strength map in a building

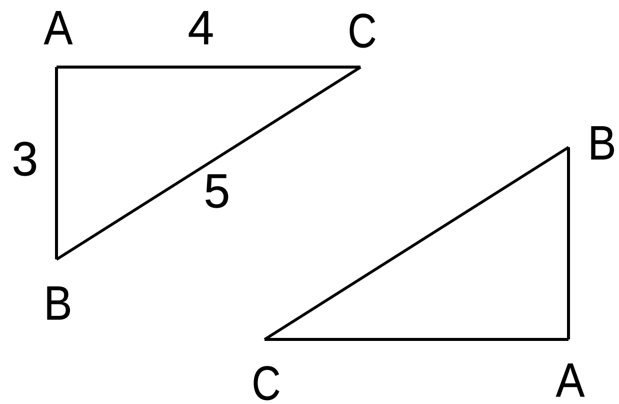


Approaches to Localization

- MDS based approaches
  - Can be used based on measured distances or simply connectivity
  - Can be used with centralized method or distributed approach
  - Robust to some level of noises (errors)
  - The overhead is roughly O(n^3)

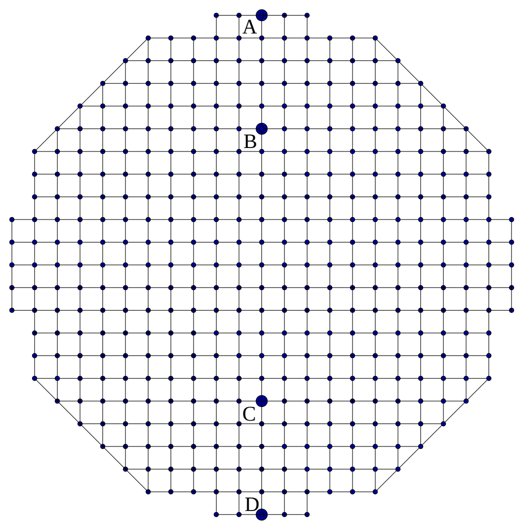
- Network reconstruction using multi-dimensional scaling (MDS)
  - input: distance matrix between sensors
  - output: layout of sensors in a three-dimensional space

$$\begin{array}{c|c} & \begin{array}{ccc} A & B & C \end{array} \\ \begin{array}{c} A \\ B \\ C \end{array} & \begin{pmatrix} 0, & 3, & 4 \\ 3, & 0, & 5 \\ 4, & 5, & 0 \end{pmatrix} \end{array} \xrightarrow{\text{MDS}}$$

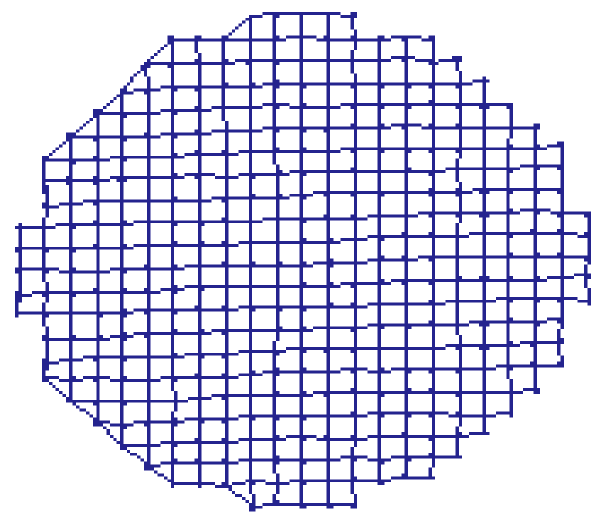


Network reconstruction using MDS

- Video

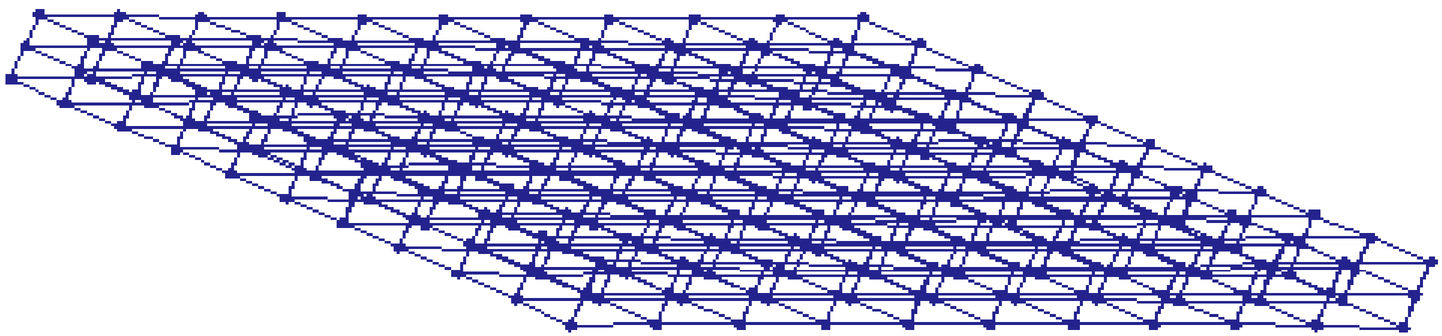


(a) Original network

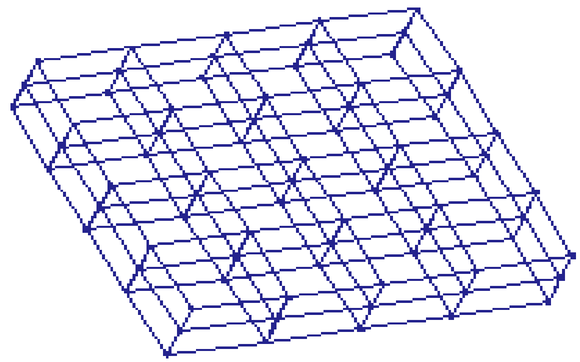


(b) MDS result

Reconstruction of 3D network



(a) Original sensor layout: a 11x11x3 grid



(b) localized reconstruction result

Building blocks

- Distance estimation between sensors
  - Signal propagation time
  - Received signal strength
- Generation of distance matrix

$$\begin{bmatrix} 0 & d_{1-2} & & & d_{1-n} \\ d_{2-1} & 0 & & \cdots & d_{2-n} \\ & & 0 & & \\ & \cdots & & \cdots & \cdots \\ d_{n-1} & d_{n-2} & & \cdots & 0 \end{bmatrix} \xrightarrow{\text{Dijkstra}} \begin{bmatrix} 0 & d_{1-2} & d_{1-3} & \cdots & d_{1-n} \\ d_{2-1} & 0 & d_{2-3} & \cdots & d_{2-n} \\ d_{3-1} & d_{3-2} & 0 & \cdots & d_{3-n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ d_{n-1} & d_{n-2} & d_{n-3} & \cdots & 0 \end{bmatrix}$$

- After reconstructing the network topology
  - Using a few anchor nodes to determine the absolute positions of the sensors

Localization from Mere Connectivity

Algorithm

-Only Connectivity information is available

1. Compute all-pairs shortest paths (hop count) to roughly estimate the distance between all pairs of nodes. The shortest path distances are used to construct the distance matrix for MDS.

2. Apply classical MDS to the distance matrix, retaining the largest 2 (or 3) largest eigenvalues and eigenvectors to construct a 2-D (or 3-D) relative map.

3. Given sufficient anchor nodes (3 or more for 2-D, 4 or more for 3-D), transform the relative map to an absolute map based on the absolute positions of anchors.

Algorithm

-The distances with limited accuracy between neighbor nodes are known

1. Compute all-pairs shortest paths (estimated distances) to roughly estimate the distance between all pairs of nodes. The shortest path distances are used to construct the distance matrix for MDS.

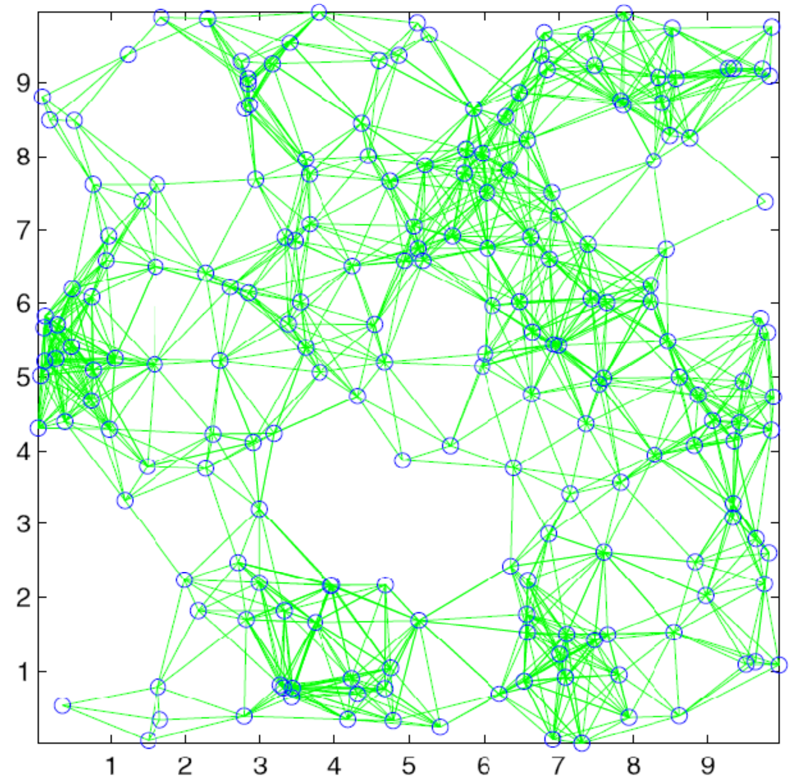
2. Apply classical MDS to the distance matrix, retaining the largest 2 (or 3) largest eigenvalues and eigenvectors to construct a 2-D (or 3-D) relative map.

3. Given sufficient anchor nodes (3 or more for 2-D, 4 or more for 3-D), transform the relative map to an absolute map based on the absolute positions of anchors.

Experimental Results

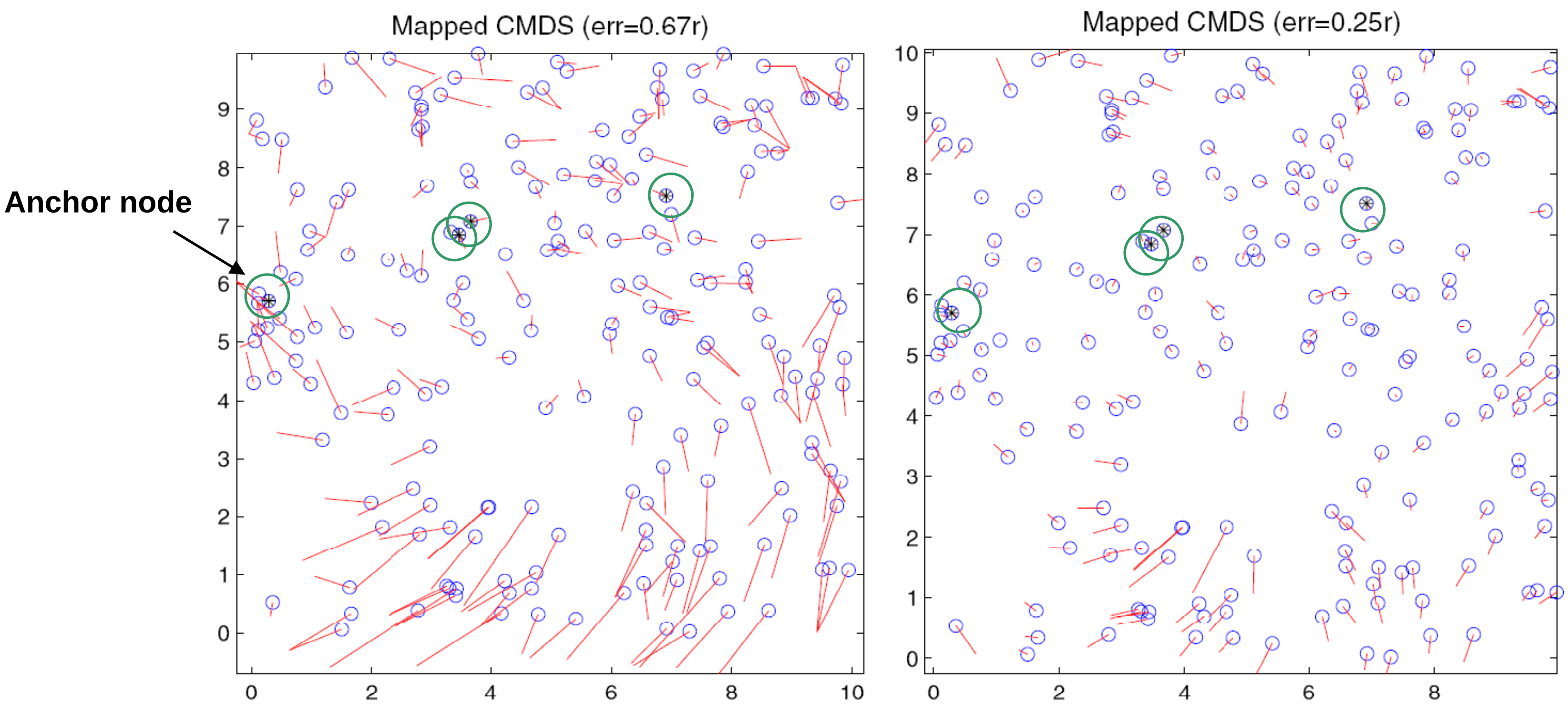
- Scenario 1:
  - 200 nodes randomly placed in a $10r \times 10r$ square area, where R is radio range.

200 nodes, R=1.5r



Experimental Results
(Random Placement)

- Random uniform placement using
  - connectivity only (left) or the *distance measures* between neighboring nodes with 5% errors (right).
  - The same four random anchors are used and the position estimation errors are 0.67r and 0.25r, respectively.

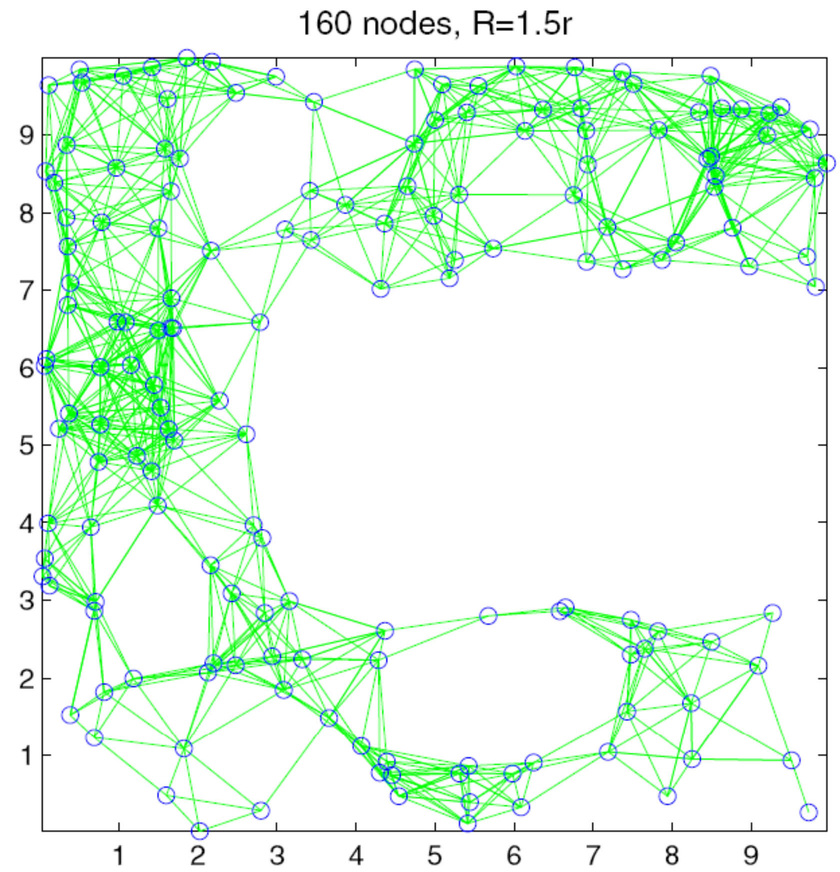


Connectivity only

Distance measure

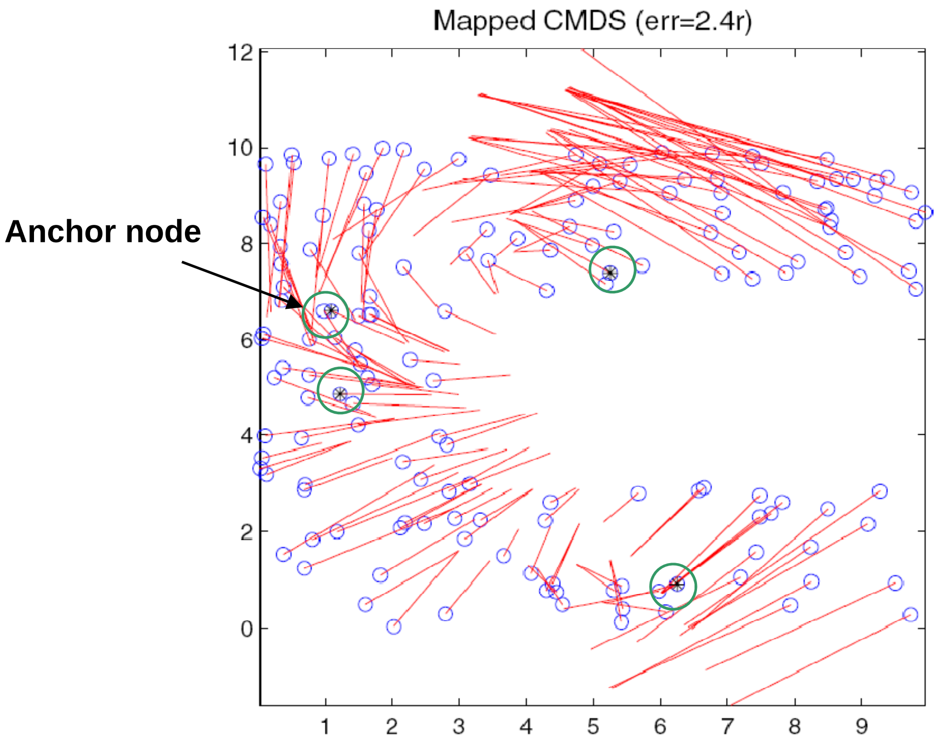
Experimental Results
(Random C-Shaped Placement)

- Scenario 2
  - 160 nodes are randomly placed in an area of C shape within a $10r \times 10r$ square

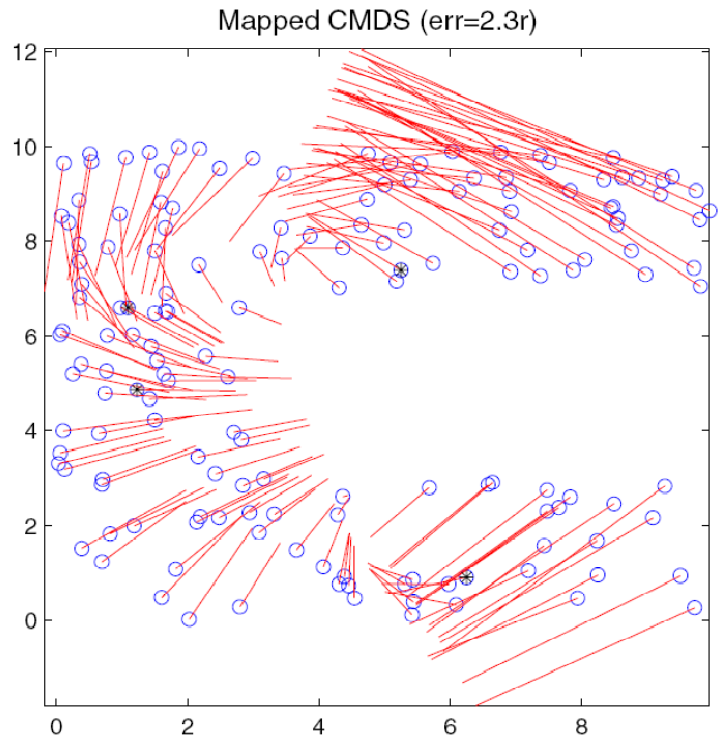


Experimental Results
(Random C-Shaped Placement)

- connectivity only (left) or the *distance measures* between neighboring nodes with 5% errors (right).
- The same four random anchors are used and the position estimation errors are 2.4r and 2.3r, respectively.



Connectivity only



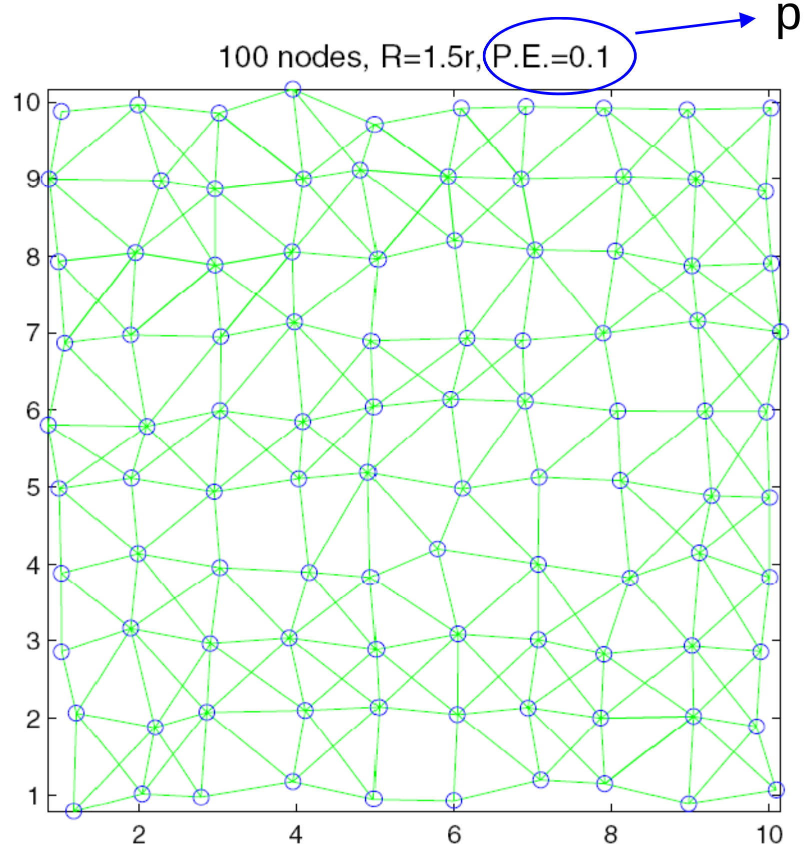
Distance measure

- Why in the C shape case the error is so large even when the distance estimations among neighbors are available
  - The Dijkstra method cannot distinguish a straight line from a curve line if there is no “direct neighbor restriction”

Experimental Results
(Grid Placement)

- Scenario 3:
  - grid placement – 100 nodes are placed on a grid with10%r placement errors.

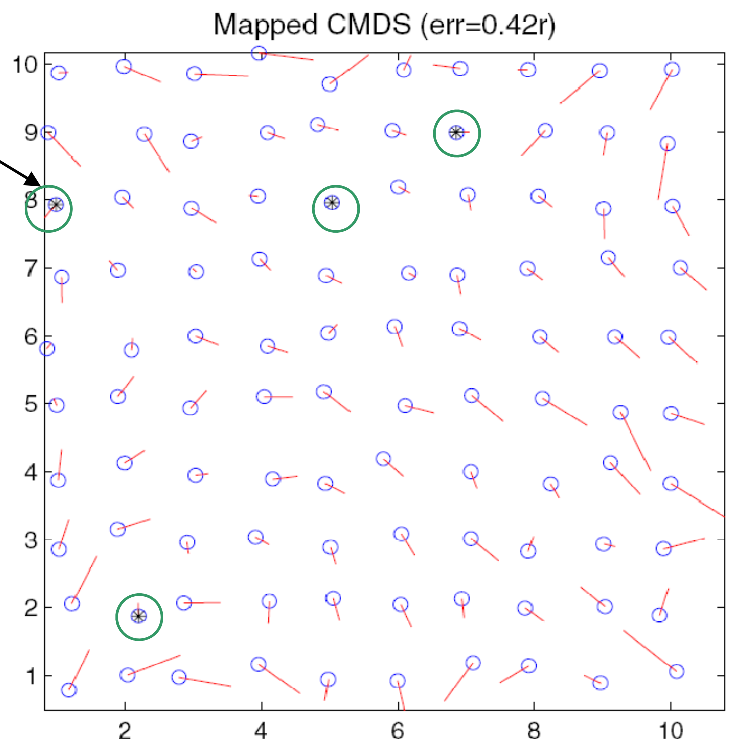
placement error



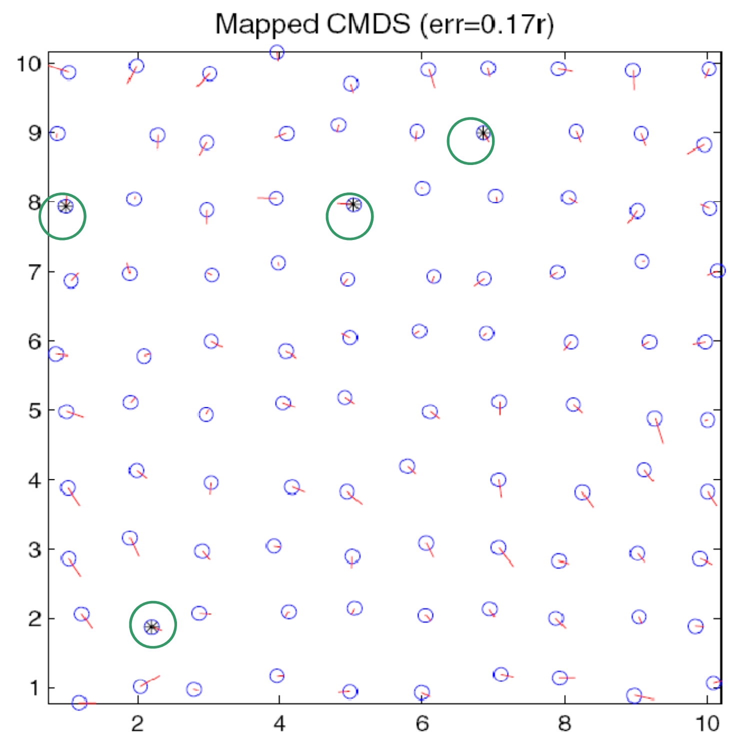
Experimental Results
(Grid Placement)

– connectivity only (left) or the *distance measures* between neighboring nodes with 5% errors (right).
– The same four random anchors are used and the position estimation errors are 0.42r and 0.17r, respectively.

Anchor node



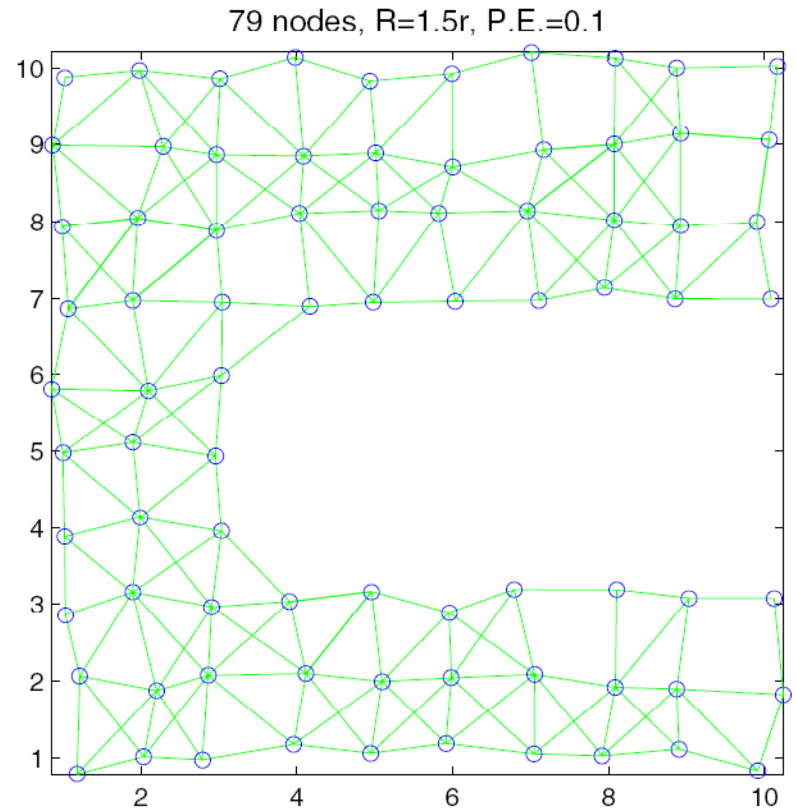
Connectivity only



Distance measure

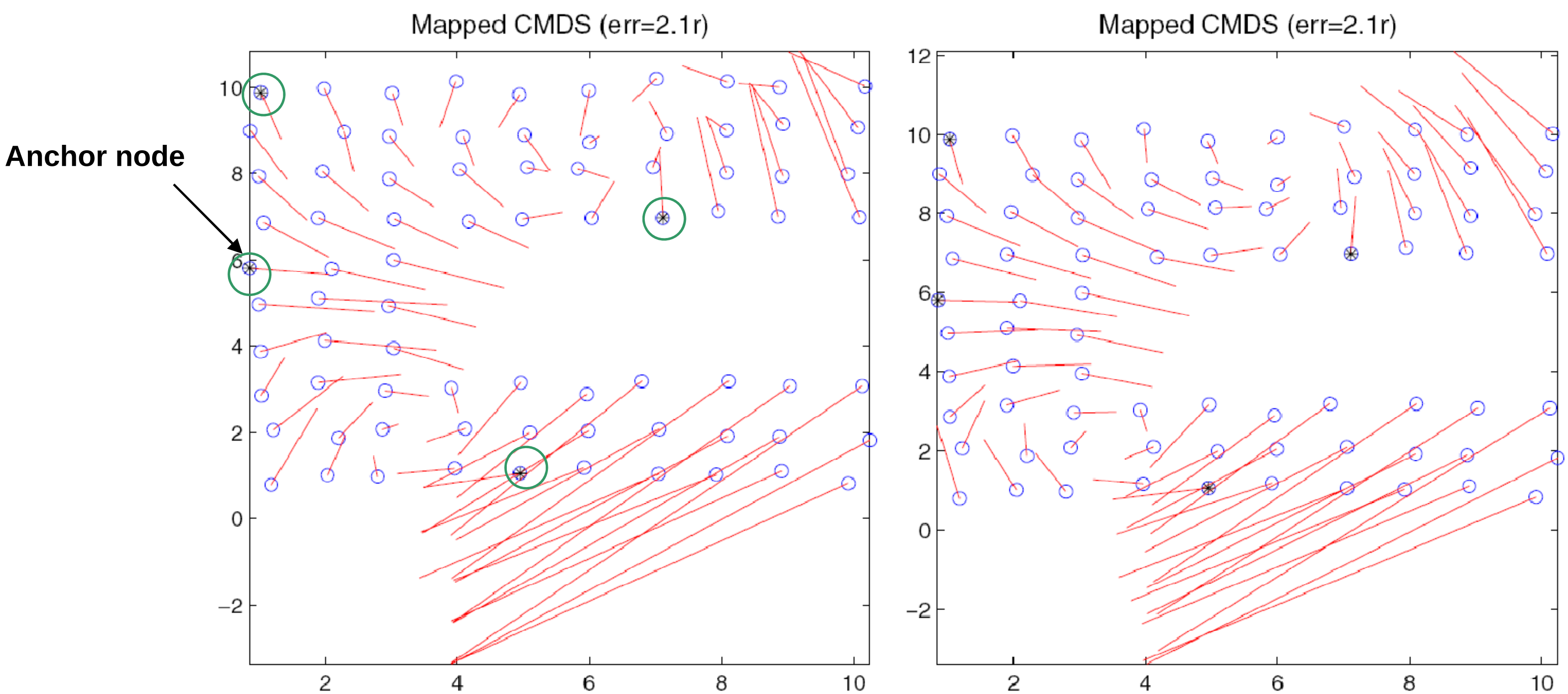
Experimental Results
(Grid C-Shaped Placement)

- Scenario 4
  - 79 nodes are placed on a C shape grid with 10%*r* placement errors.

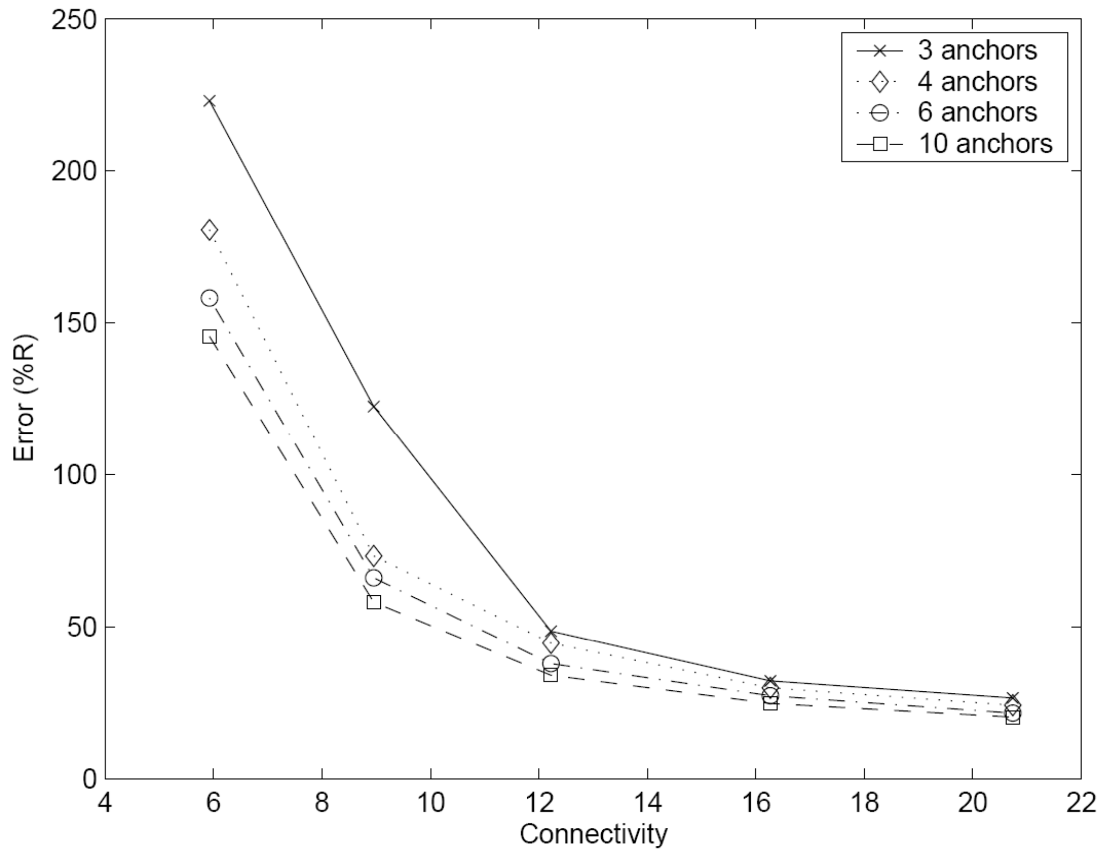


Experimental Results
(Grid C-Shaped Placement)

- connectivity only (left) or the *distance measures* between neighboring nodes with 5% errors (right).
- The same four random anchors are used and the position estimation errors are 2.1 for both cases.

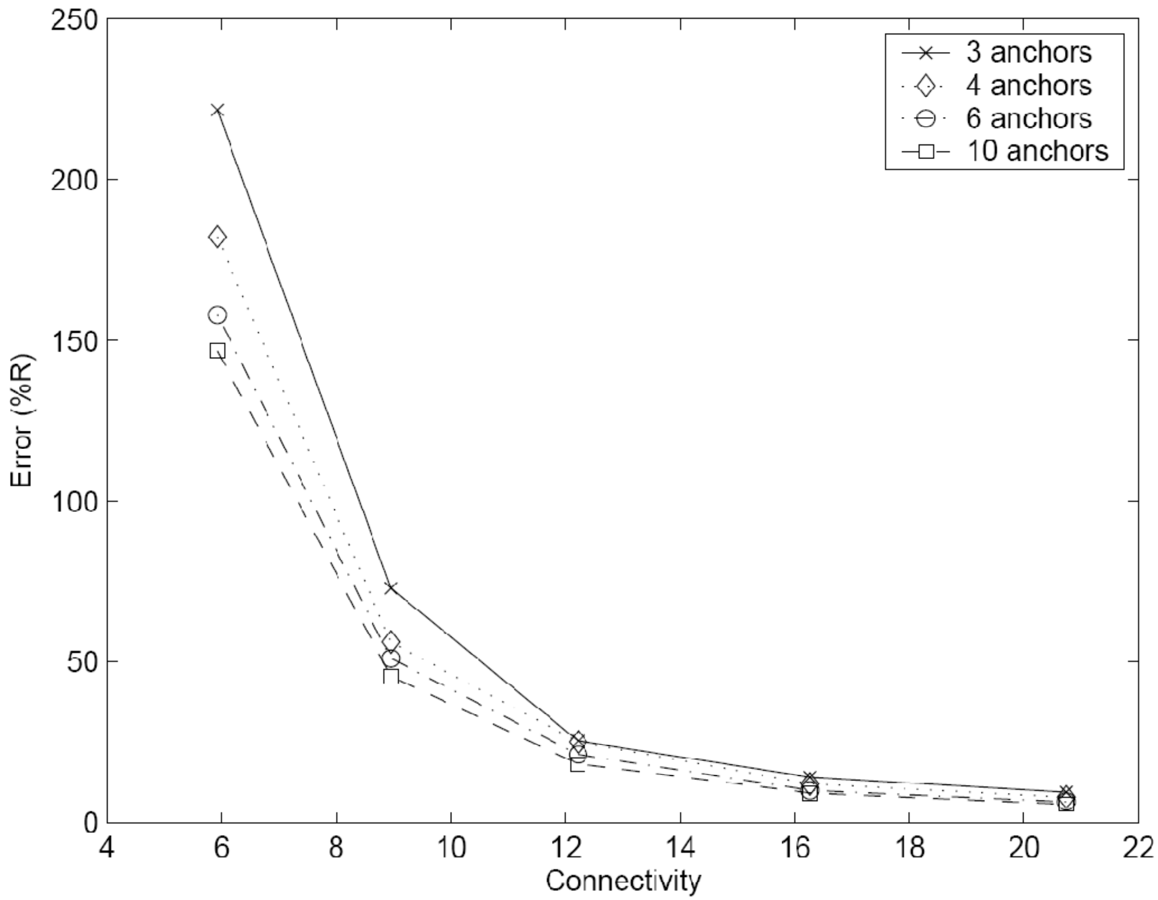


Average Position Error V.S Connectivity



Using proximity information only

Average Position Error V.S Connectivity



Using distances between neighbors (5% range error)

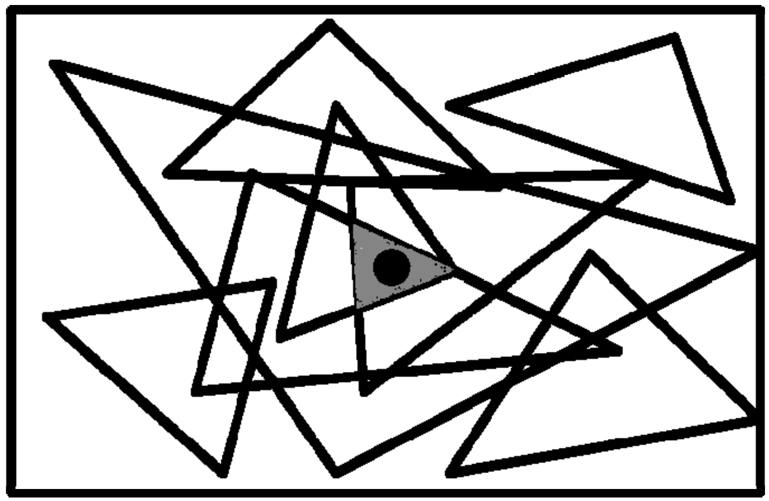
Conclusion

- This paper proposed a new method called, MDS-MAP
- MDS-MAP builds a relative map of the nodes without anchor nodes. With three or more anchor nodes, the relative map can be transformed into absolute coordinates.

Range-free Localization Schemes for Large Scale Sensor Networks

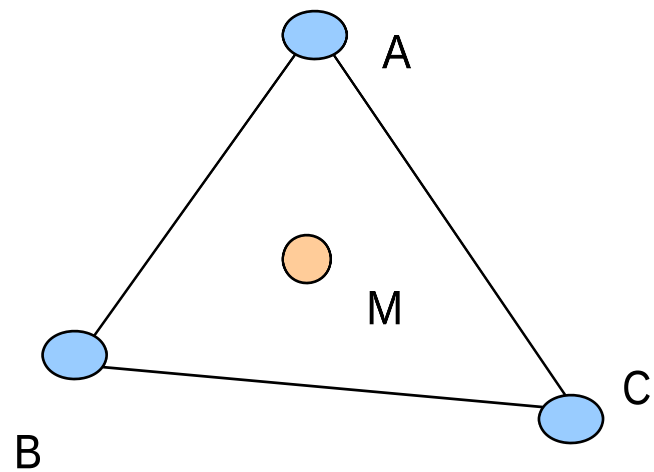
Basic APIT scheme

- Anchors are location aware sensors in the sensor network.
- APIT employs area-based approach to isolate triangular regions between beaconing nodes.
- Once the area is known the COG calculation is performed for the location.



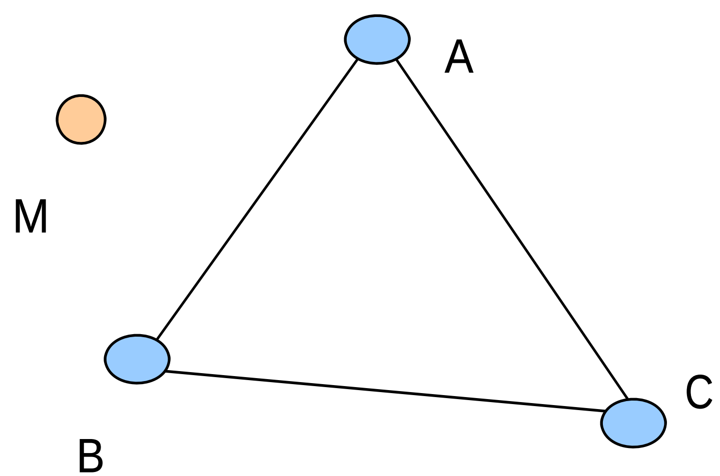
Perfect PIT Test

- Proposition 1: If M is inside triangle ABC, when M is shifted in any direction, the new position must be nearer to (further from) at least one anchor A, B or C



Continued…

- Proposition 2: If M is outside of triangle ABC, when M is shifted, there must exist a direction in which the position of M is further from or closer to all three anchors A, B and C.

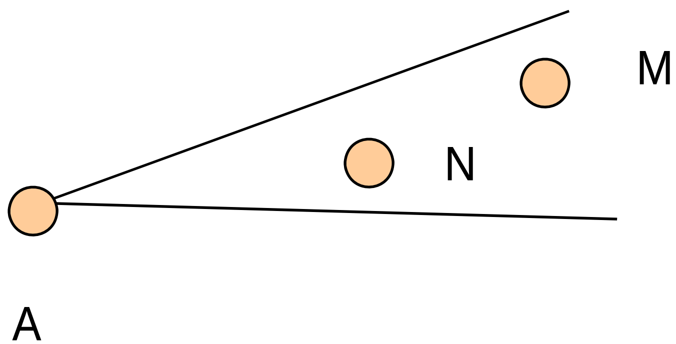


Perfect PIT Test

- If there exists a direction such that a point adjacent to M is further/ closer to points A, B, and C simultaneously, then M is outside of ABC. Otherwise, M is inside ABC.
- Perfect PIT test is infeasible in practice.
  - Nodes cannot really move
  - How to test all directions??

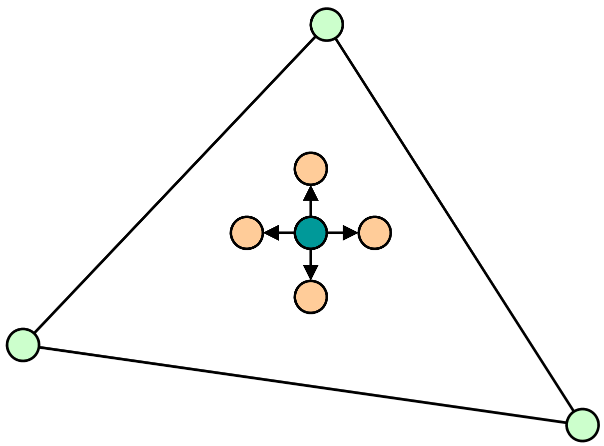
Departure Test.

- Experiments show that, the receive signal strength is decreasing in an environment without obstacles.
- Therefore further away a node is from the anchor, weaker the received signal strength.

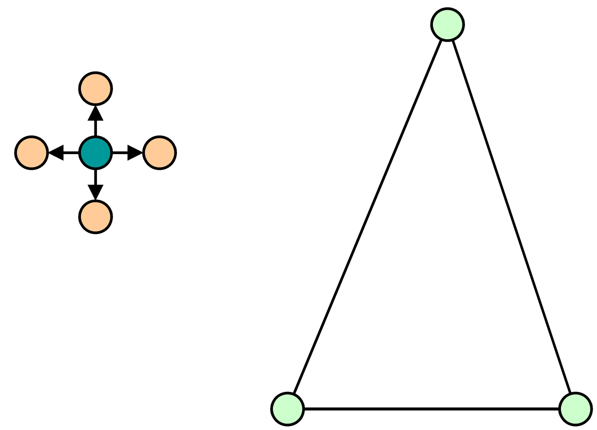


Appropriate PIT Test.

- Use neighbor information to emulate the movements of the nodes in the perfect PIT test.
- *If no neighbor of M is further from/ closer to all three anchors A, B and C simultaneously, M assumes that it is inside triangle ABC. Otherwise, M assumes it resides outside this triangle.*

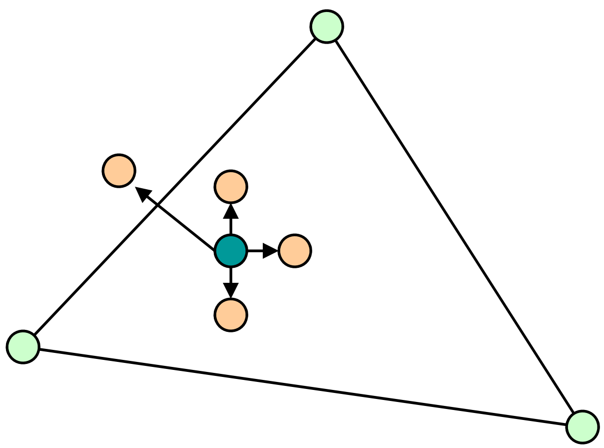


Inside Case

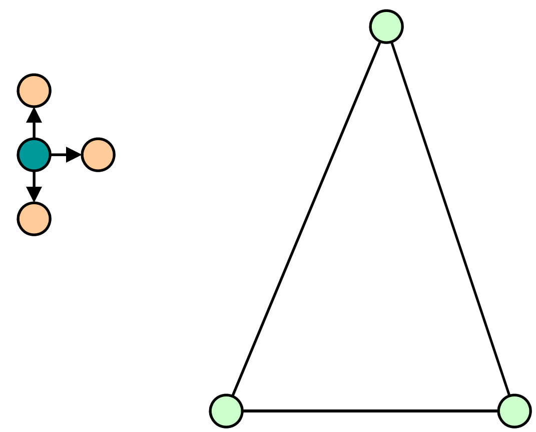


Outside Case

Error Scenarios for APIT test.

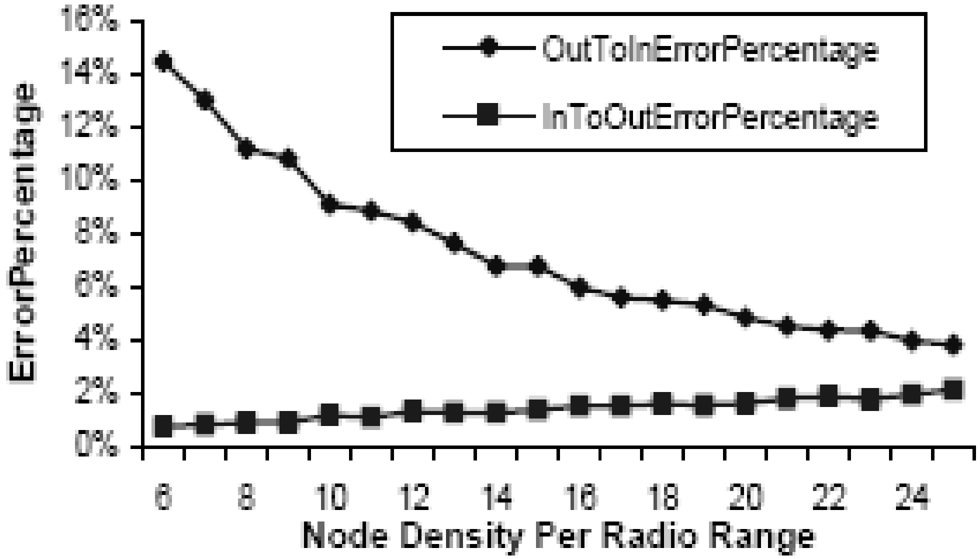


In to out error



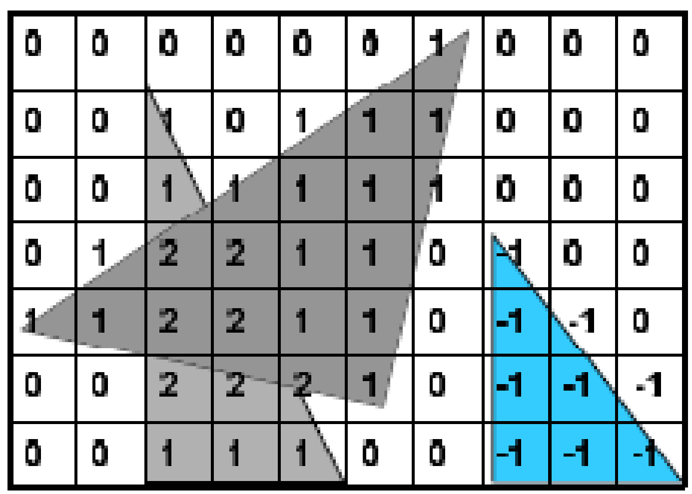
Out to in error

- However, from experimental results we find that the error percentage is small as the density increases.



APIT aggregation

- Represent the maximum area in which a node will likely reside using a grid SCAN algorithm.
  - For **inside** decision the grid regions are incremented.
  - For **outside** decision the grid regions are decremented.



Range Free Schemes.

- Centroid Localization.
  - Receive beacon from anchor nodes.

$$(X_{est}, Y_{est}) = \left(\frac{X_1 + \cdots + X_N}{N}, \frac{Y_1 + \cdots + Y_N}{N} \right)$$

  - It is simple and easy to implement.

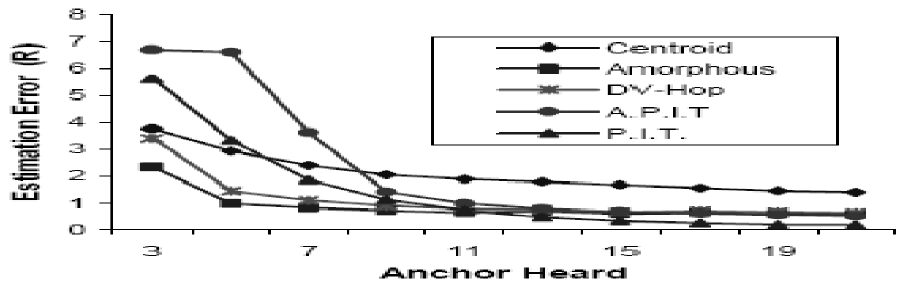
Continued…

- DV-Hop localization.
  - Maintain a running hop count from beacon nodes.
  - Find the average hop length
  - Use tri-lateration to localize the unknowns.
- Amorphous localization.
  - Algorithm is similar to DV-Hop algorithm except that different approach is used to estimate the average distance of a single hop.

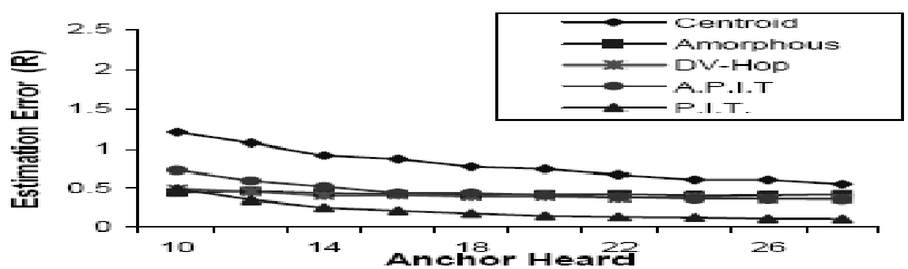
Simulations Settings.

- Radio Model
  - The radio model used in the simulations have a upper bound and lower bound.
  - Beyond the upper bound nodes are out of communication range and within the lower bound nodes are guaranteed to be within communication range.
  - If in b/w there could be symmetric / uni-directional / no communication

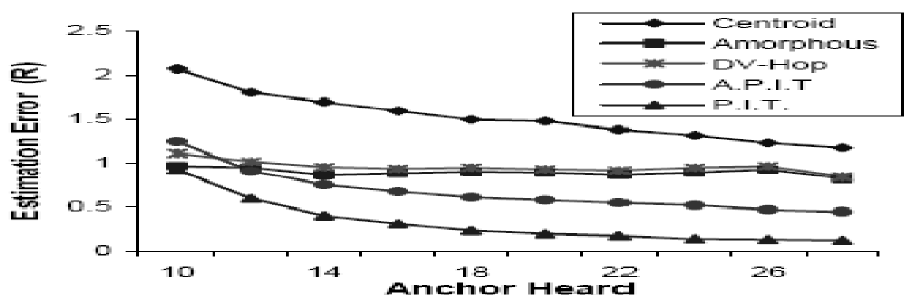
Location error vs AH



A. AH=3~21, DOI=0, ANR = 10, ND = 8, Random

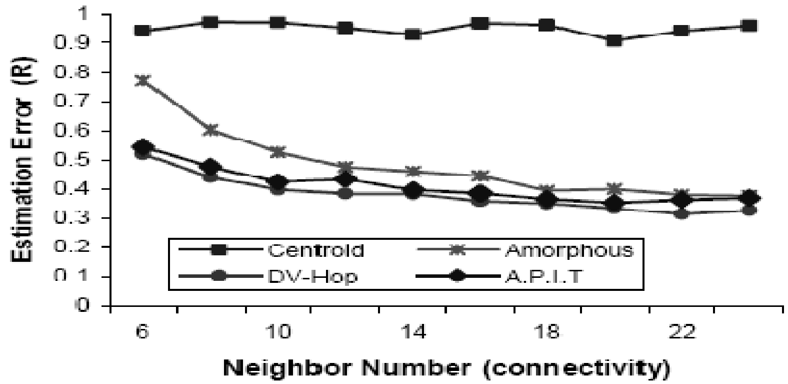


B. AH=10~28, DOI=0, ANR = 10, ND = 8, Uniform

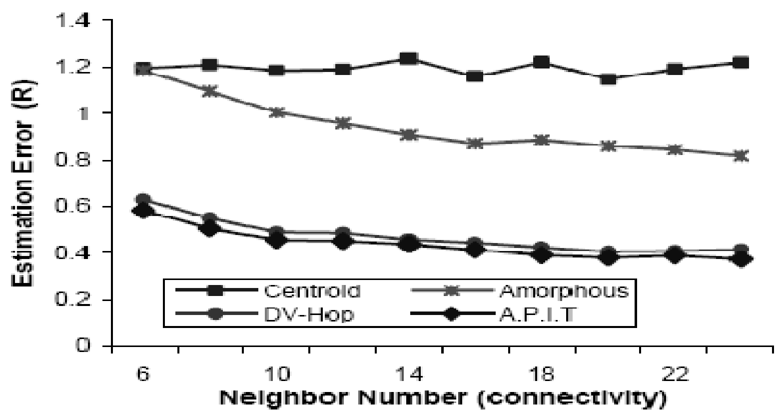


C. AH=10~28, DOI=0, ANR = 10, ND = 8, Random

Location error vs ND

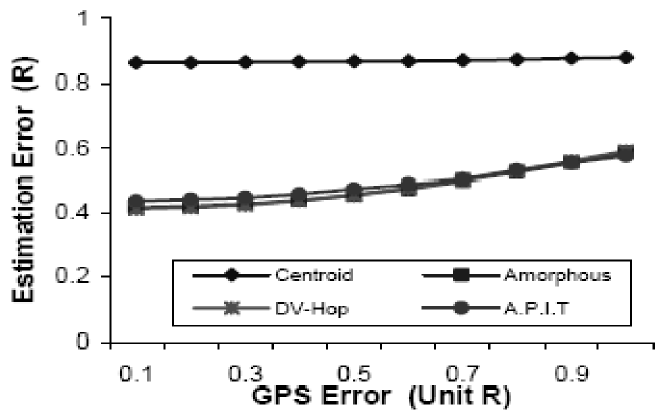


A. DOI=0.1, ANR = 10, AH=16, Uniform

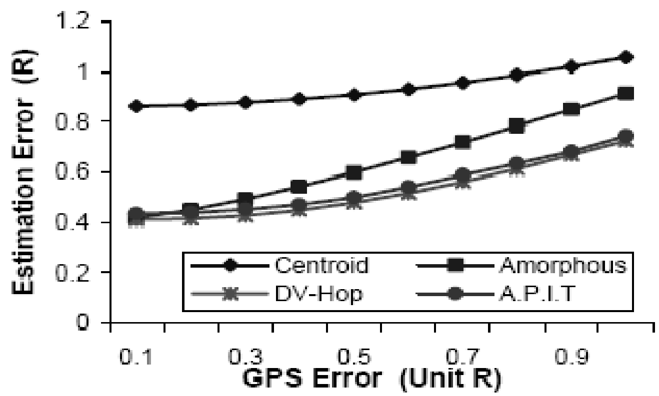


B.DOI=0.2, ANR = 10, AH=16, Uniform

Location error vs. GPS

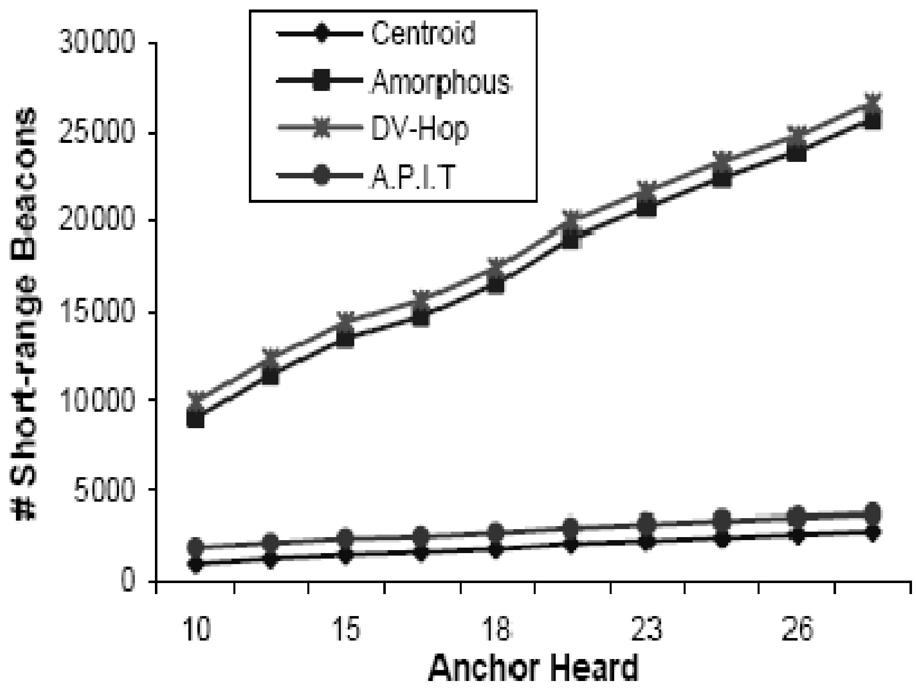


A.ANR = 10, ND = 8, AH=16, Uniform, Random Error



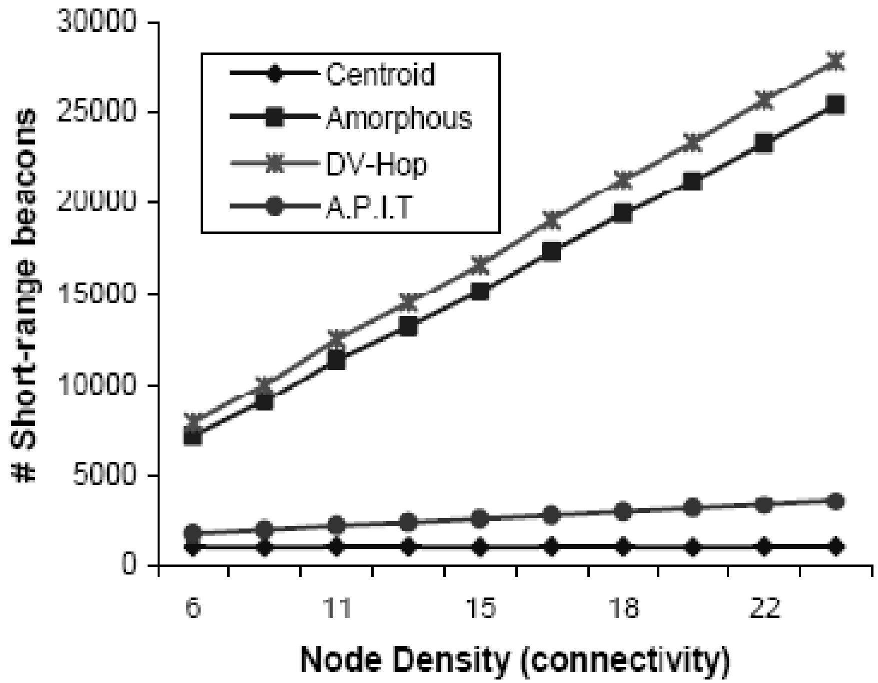
B. ANR = 10, ND = 8, AH=16, Uniform, Bias Error

Comm^n overhead vs. AH



ANR=10, ND = 8, DOI = 0.1, Uniform

Comm^{n} overhead vs ND



ANR=10, AH = 16, DOI = 0.1, Uniform

Evaluation summary

	Centroid	DVHop	Amorp.	APIT
Accuracy	Fair	Good	Good	Good
NodeDensity	>0	>8	>8	>6
AnchorHeard	>10	>8	>8	>10
ANR	>0	>0	>0	>3
DOI	Good	Good	Fair	Good
GPSError	Good	Good	Fair	Good
Overhead	Smallest	Largest	Large	Small

Table 1 Performance and requirements summary

Conclusion

- Range-free localization schemes are cost effective.
- Performs well in irregular radio patterns and random node deployment.
- APIT performs well even in smaller node-densities.