Localization for Anisotropic Sensor Networks

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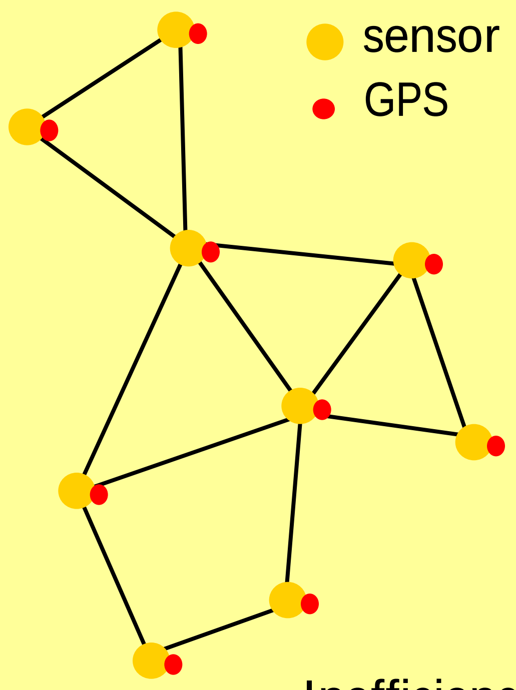
Hyuk Lim and **Jennifer C. Hou**
University of Illinois at Urbana Champaign

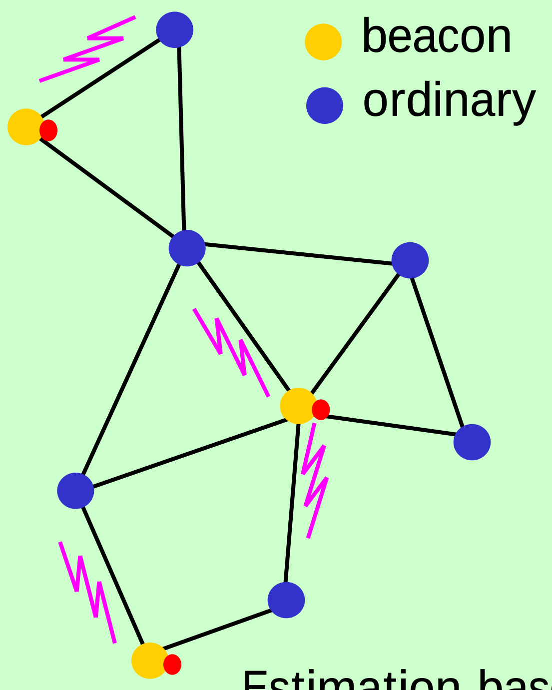
Localization

- Determining **geographical locations** of sensor node in sensor networks.



Inefficiency
- cost, size, power consumption

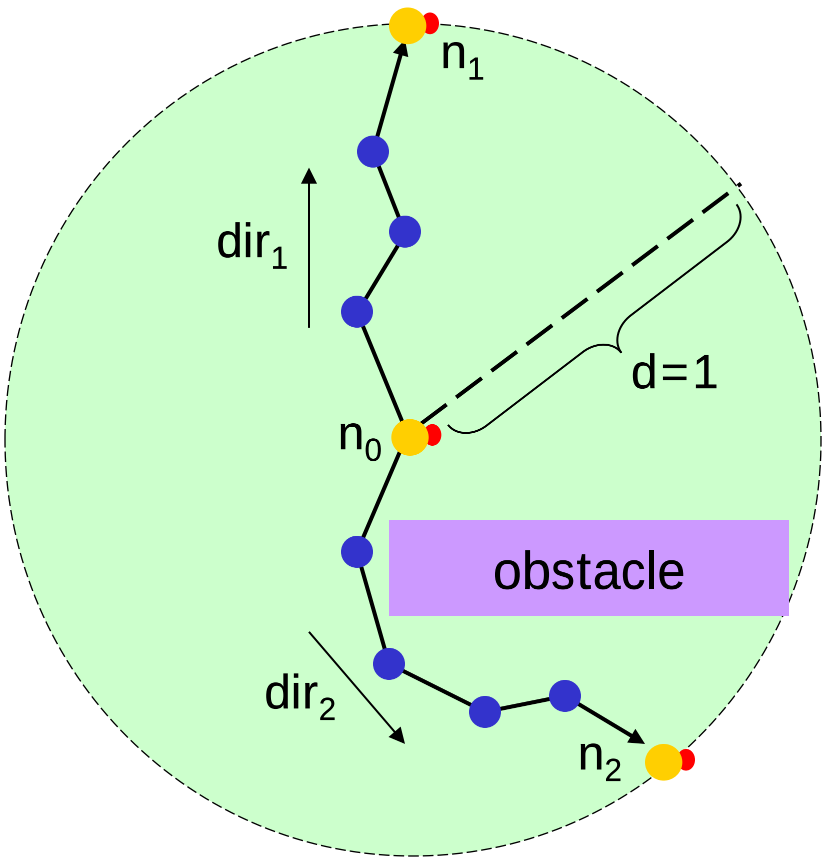
vs



Estimation based on Measurements
- hop-counts, radio signals

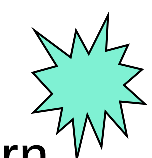
Anisotropy

- Definition: “Having properties that **differ** according to the **direction** of measurement.”

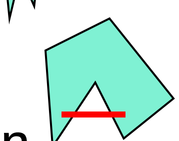


Ratio of distance / hops
is anisotropic.

	distance	hops	ratio
dir_1	1	4	1/4
dir_2	1	5	1/5



- Irregular radio pattern
- Non-convex region
- Non-uniform distribution of beacon nodes



This paper …

- Goal: To achieve **accurate** and **robust** estimation of geographical node locations in **anisotropic** sensor networks.
- Procedures:
  - Discovering anisotropic properties from measurements between beacon nodes.
  - Constructing a **proximity-distance map (PDM)** retaining as much topological information as possible in all directions of the measurements.
  - Estimating distances from a node without a GPS to beacon nodes and computing the location by triangulation.

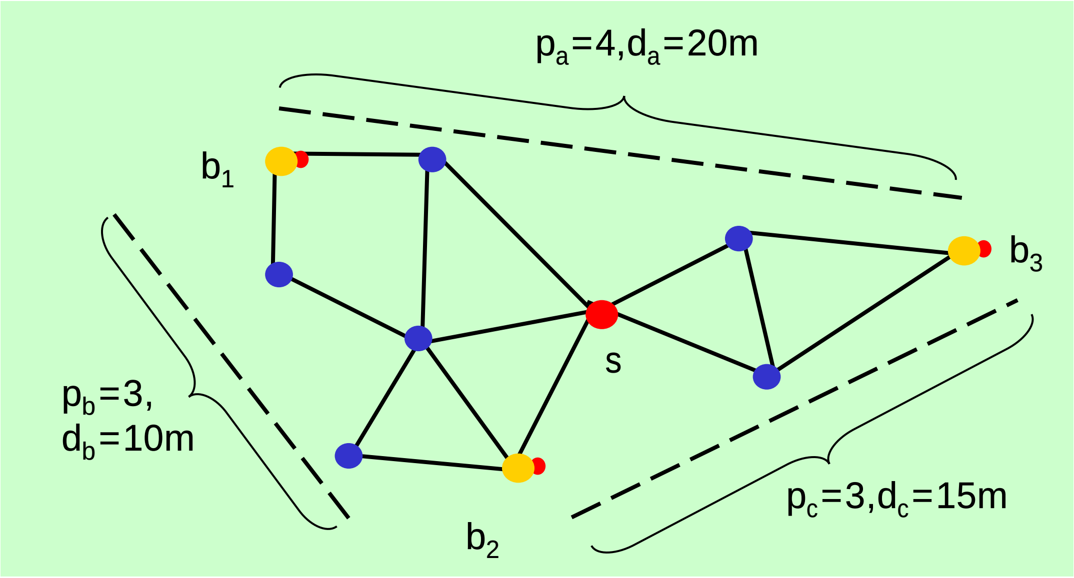
Related Work

- Centroid localization - Bulusu et al., IEEE Pers. Commun. 2000
- **Adhoc positioning system (APS)** - Niculescu et al., Globecom 2000
  - DV-hop, DV-distance, and Euclidean propagation method.
  - In DV-hop, each beacon node computes the distance per hop by averaging the measurements from all the directions of beacon nodes
  - $c_i = \frac{\sum_j \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_j h_j}, i \neq j$ $\qquad d_{ik} = c_i \times h_{ik}$
- Amorphous localization - Nagpal et al., ISPN 2003
- APIT - He. et al., Mobicom 2003
- **Multidimensional Scaling (MDS) based algorithm**
  - Ji et al. INFOCOM 2004
  - Shang et al. Mobihoc 2003, INFOCOM 2004

Hundreds of papers in this topic …

Proximity and Distance

- Proximity: quantitative measure that reflects the geographic distance.
- Example: proximity = number of hops



For b_1,

proximity $\vec{p}_1 = [0,3,4]^T$

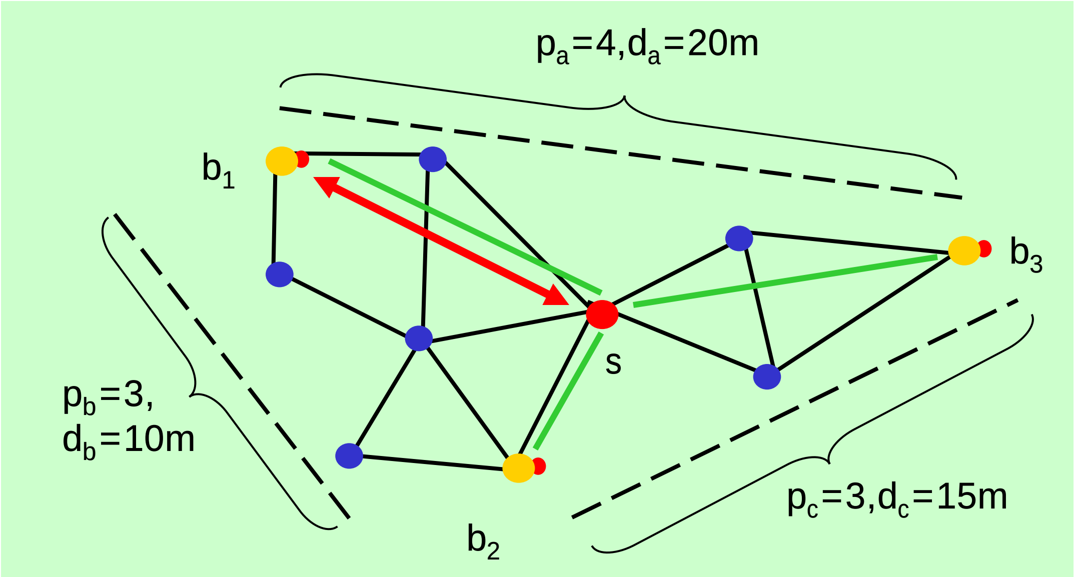
distance $\vec{d}_1 = [0,10,20]^T$

For s,

proximity $\vec{p}_s = [2,1,2]^T$

distance $\vec{d}_s = ?$

Localization for Anisotropic Networks



DV-hop	Proposed method
Average ratio over all the directions	Generalized proximity-distance function

average distance per one hop for b_1

$$c_1 = \frac{10+20}{3+4} = 4.28$$

distance between b_1 and s

$$d_{b_1 s} = 4.28 \times p_{b_1 s} = 8.56$$

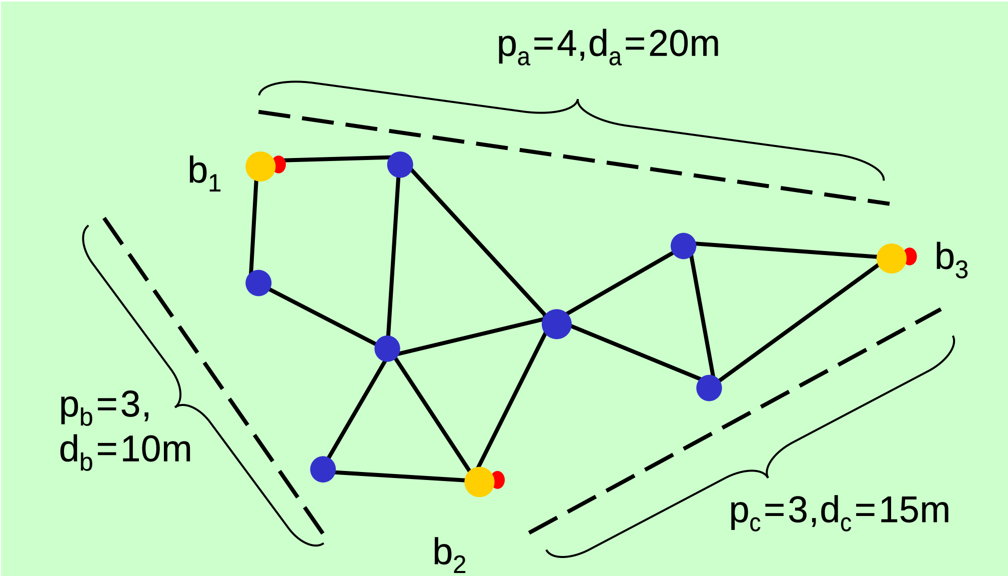
$$d_{b_1 s} = t_{b_1 b_1} p_{b_1 s} + t_{b_1 b_2} p_{b_2 s} + t_{b_1 b_3} p_{b_3 s}$$

Proximity distance map

$$T = \begin{bmatrix} t_{b_1 b_1} & \cdots & t_{b_1 b_M} \\ \vdots & \ddots & \vdots \end{bmatrix} 7$$

Proximity-Distance Map

- Construct proximity-distance map (PDM) from measurements <u>between beacon nodes</u>
- Least square solution: $T = DP^T(PP^T)^{-1}$
  - P and D are proximity and distance matrices.



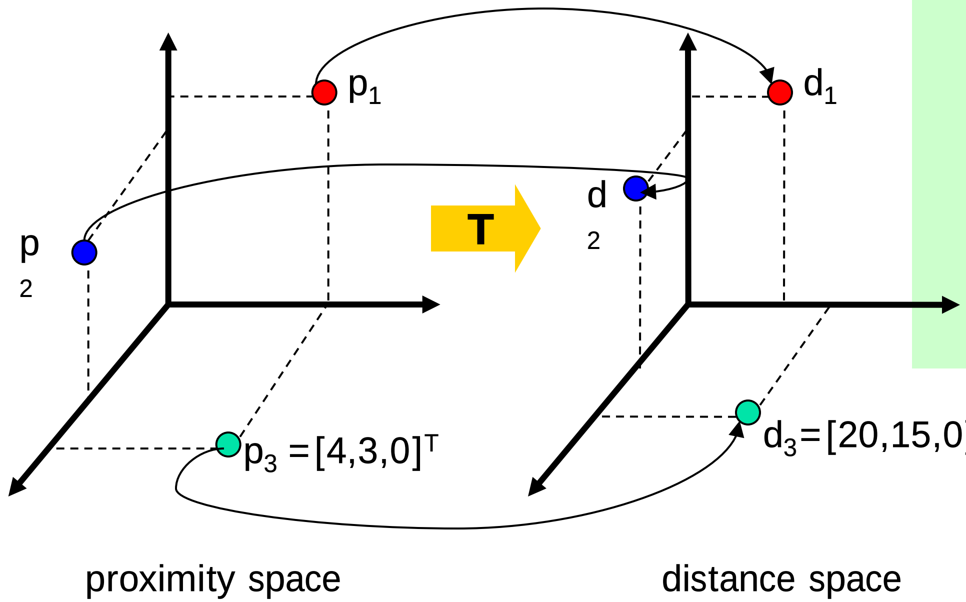
$$\left[\begin{bmatrix}0\\10\\20\end{bmatrix}\begin{bmatrix}10\\0\\15\end{bmatrix}\begin{bmatrix}20\\15\\0\end{bmatrix}\right] = T \bullet \left[\begin{bmatrix}0\\3\\4\end{bmatrix}\begin{bmatrix}3\\0\\3\end{bmatrix}\begin{bmatrix}4\\3\\0\end{bmatrix}\right]$$

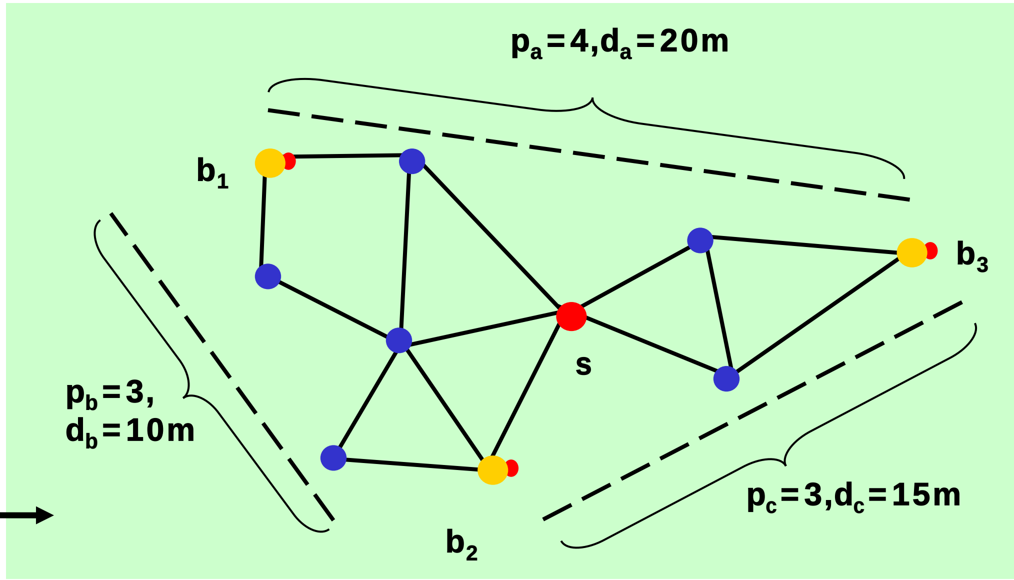
$$T = \begin{bmatrix}4.16 & 1.11 & -0.83\\0.62 & 4.16 & -0.62\\0.00 & 0.00 & 5.00\end{bmatrix}$$

Distance to i^{th} beacon node
= $T_{ij} \times$ Proximity to j^{th} beacon node

Distance Estimation for Sensors

PDM: Transformation matrix from a proximity embedding space to a distance embedding space.





for node s, $\vec{d}_s = \begin{bmatrix} 7.77 \\ 4.16 \\ 10.0 \end{bmatrix} = T \bullet \begin{bmatrix} 2 \\ 1 \\ 2 \end{bmatrix}$

Robust Computation of PDM

- Matrix inversion incurred by $T = DP^T(PP^T)^{-1}$
  - Singular value decomposition (SVD)

$$P = U \bullet \begin{bmatrix} \Sigma & 0 \\ 0 & 0 \end{bmatrix} \bullet V^T \qquad U = [u_1, \cdots, u_M] \quad V = [v_1, \cdots, v_M] \qquad \Sigma = \mathrm{diag}(\sigma_1, \cdots, \sigma_W)$$

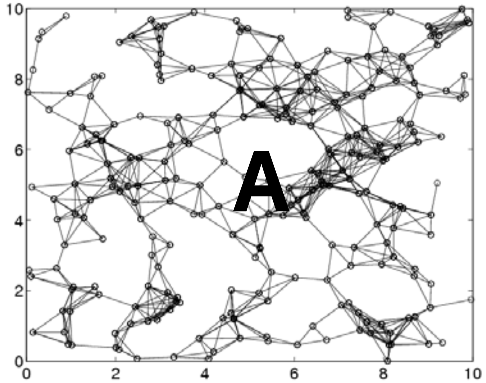
$$P^T(PP^T)^{-1} = V \bullet \begin{bmatrix} \Sigma^{-1} & 0 \\ 0 & 0 \end{bmatrix} \bullet U^T = \sum_{i=1}^{W} \frac{1}{\sigma_i} v_i u_i^T \qquad \Sigma^{-1} = \mathrm{diag}(\sigma_1^{-1}, \cdots, \sigma_W^{-1})$$

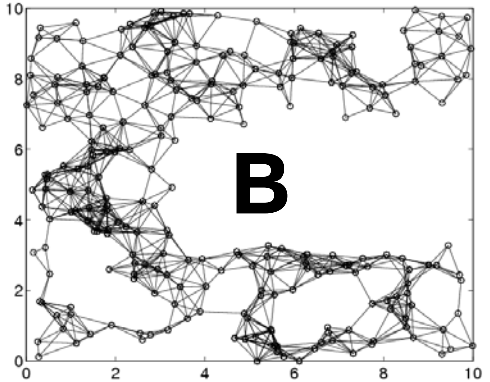
- Truncated pseudo-inversion technique
  - Discarding components corresponding to small (near-zero) singular values by truncating terms at an earlier index $\gamma < w$.
  - $T = D \bullet \sum_{i=1}^{\gamma} \frac{1}{\sigma_i} v_i u_i^T$
  - Cumulative percentage method for selecting γ ($\tau^* = 0.98$).

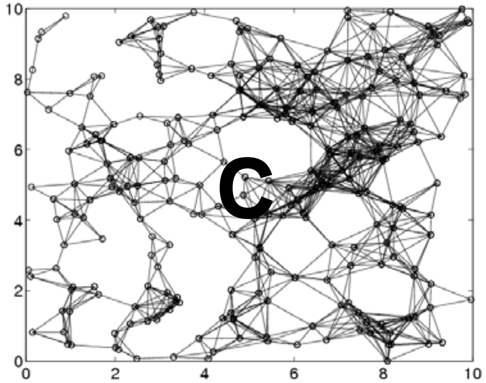
$$\tau(\gamma) = \frac{\sum_{i=1}^{\gamma} \sigma_i}{\sum_{i=1}^{W} \sigma_i} \geq \tau^*$$

Simulation Results

- Network setup
  - Radio range = u and 1.3 u, Area = 10 x 10 u
  - # of nodes = 250, # of beacon nodes = 4 ~ 30.
- Algorithms: APS, MDS-based algorithm, PDM
  - MDS-based algorithm
    - Use SVD but take <u>2-3 components</u> for obtaining 2-3 dimensional representation (locations).
    - Complexity ~ $O(N^3)$, N = <u>total number of sensor nodes</u>.
- Topologies



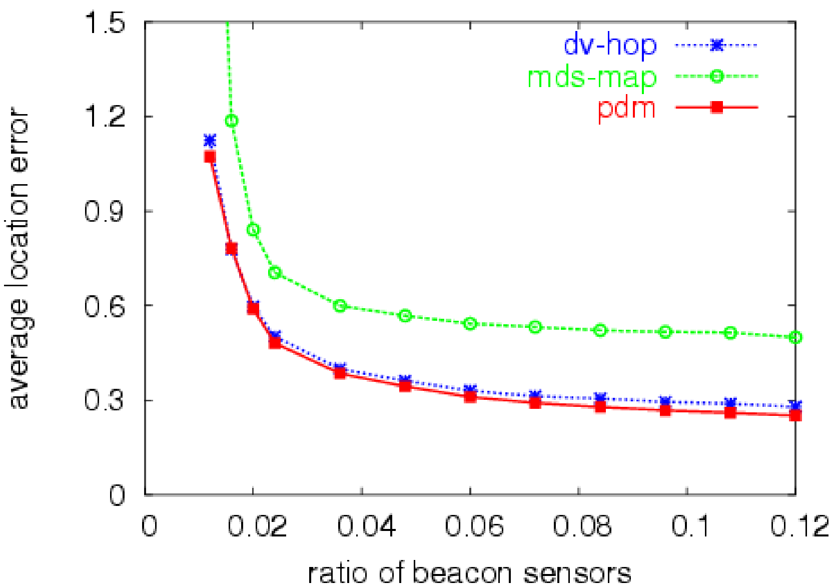




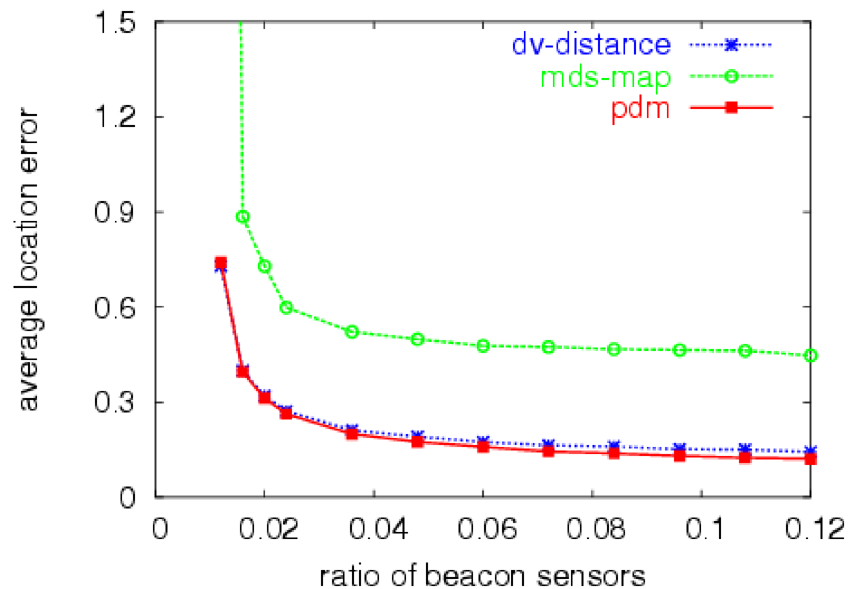
Performance in Isotropic Networks

Topology A
Uniform distribution of beacon and sensor nodes
High connectivity (r=1.3u)

Hop-count



Estimated distance

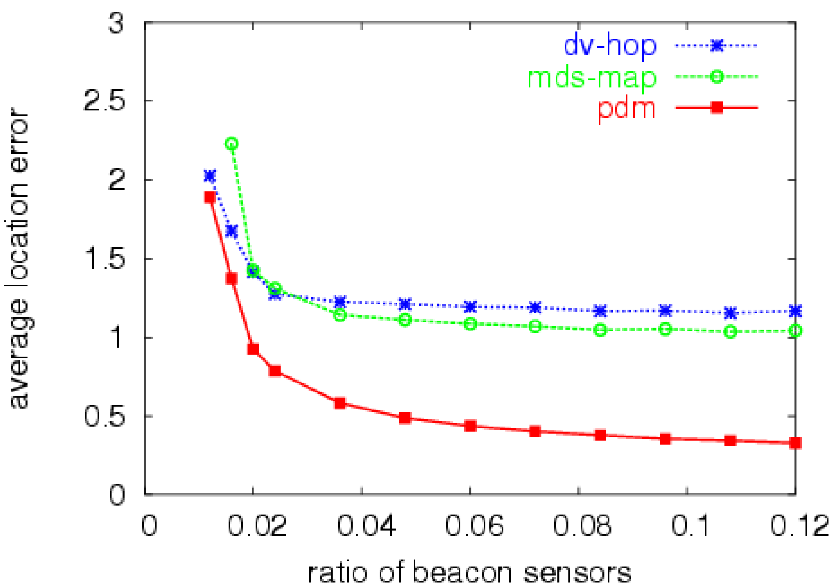


DV-hop (DV-distance) and PDM achieve the same performance in isotropic network using the same amount of measurement data.

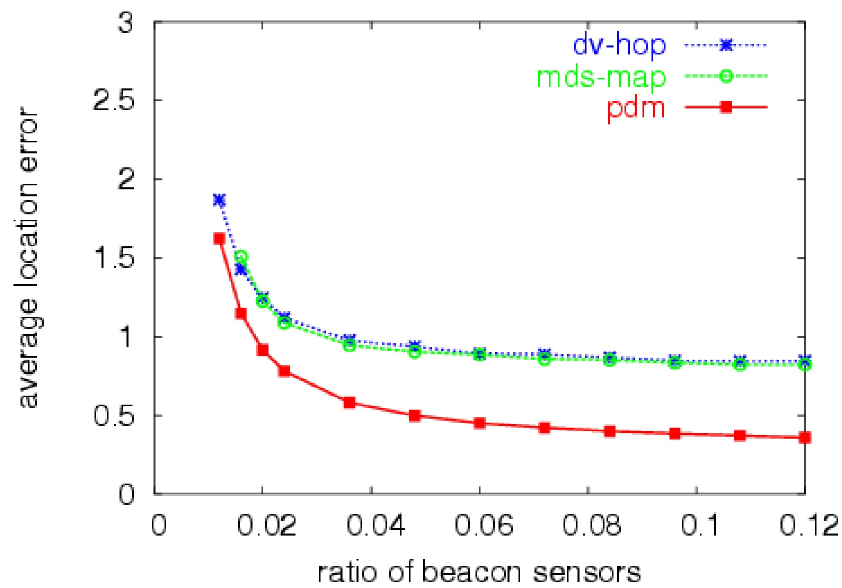
Performance in Anisotropic Networks

Topologies B and C
Uniform distribution of beacon
Proximity = Hop-count

Topology B



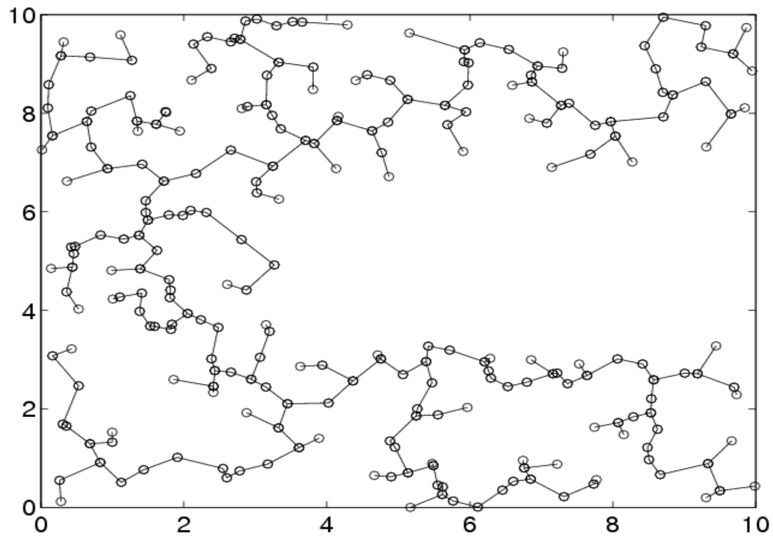
Topology C

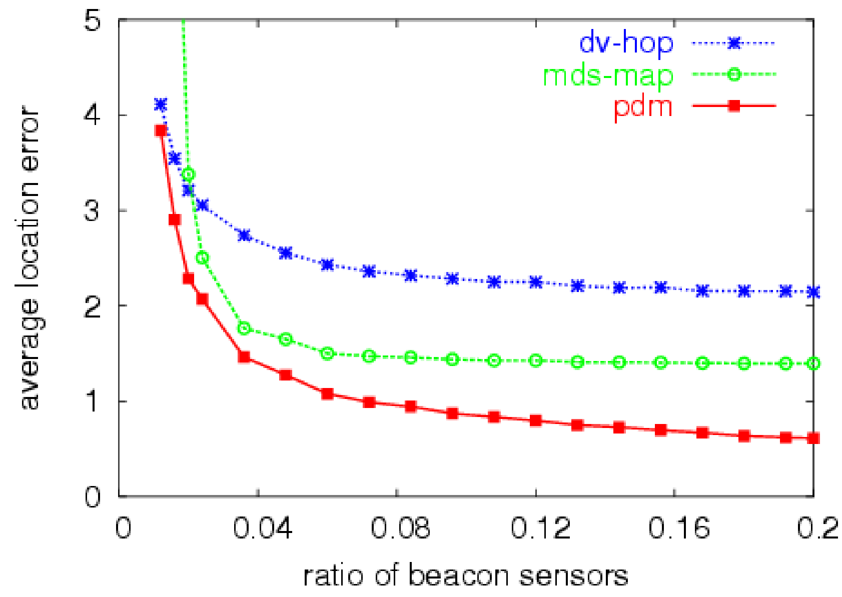


PDM achieves much better performance
in anisotropic sensor networks

Performance under Topology Control

Under Topology Control (Minimum Spanning Tree)
Low connectivity
Each node has a different radio range



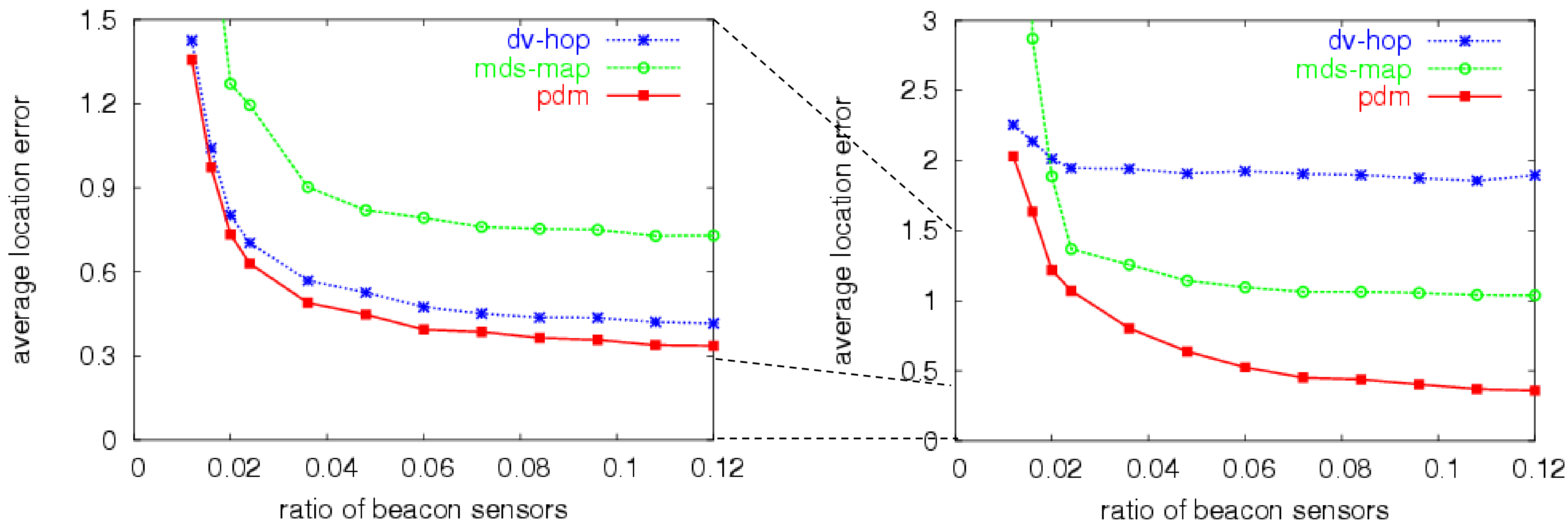


Under topology control, more beacon nodes are needed for accurate estimation. Still PDM achieves the best performance.

Non-uniform Distribution of Beacons

Topologies A and B
Non-Uniform distribution of beacon

Topology A Topology B



PDM achieves almost the same performance even when beacon nodes are not uniformly distributed.

Summary

- PDM achieves accurate and robust estimation of locations in both isotropic and anisotropic sensor networks.

- In various scenarios, the achieved location errors in anisotropic sensor network were below 0.4 radio range as long as a ratio of beacon nodes exceeds a certain threshold.