Locating Sensors in the Wild: Pursuit of Ranging Quality

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Contents

Introduction & Motivation

- Sensors' data are useless without accurate location information
- GPS fails in handling localization for certain applications
- Target Application: GreenOrbs
  - A large-scale forest based sensor network system.
- Use other localization approaches
  - Range-based (expensive hardware & sensitive to environmental conditions)
  - Range-free (affected by node density & non-uniform deployment of nodes)

Proposed Solution

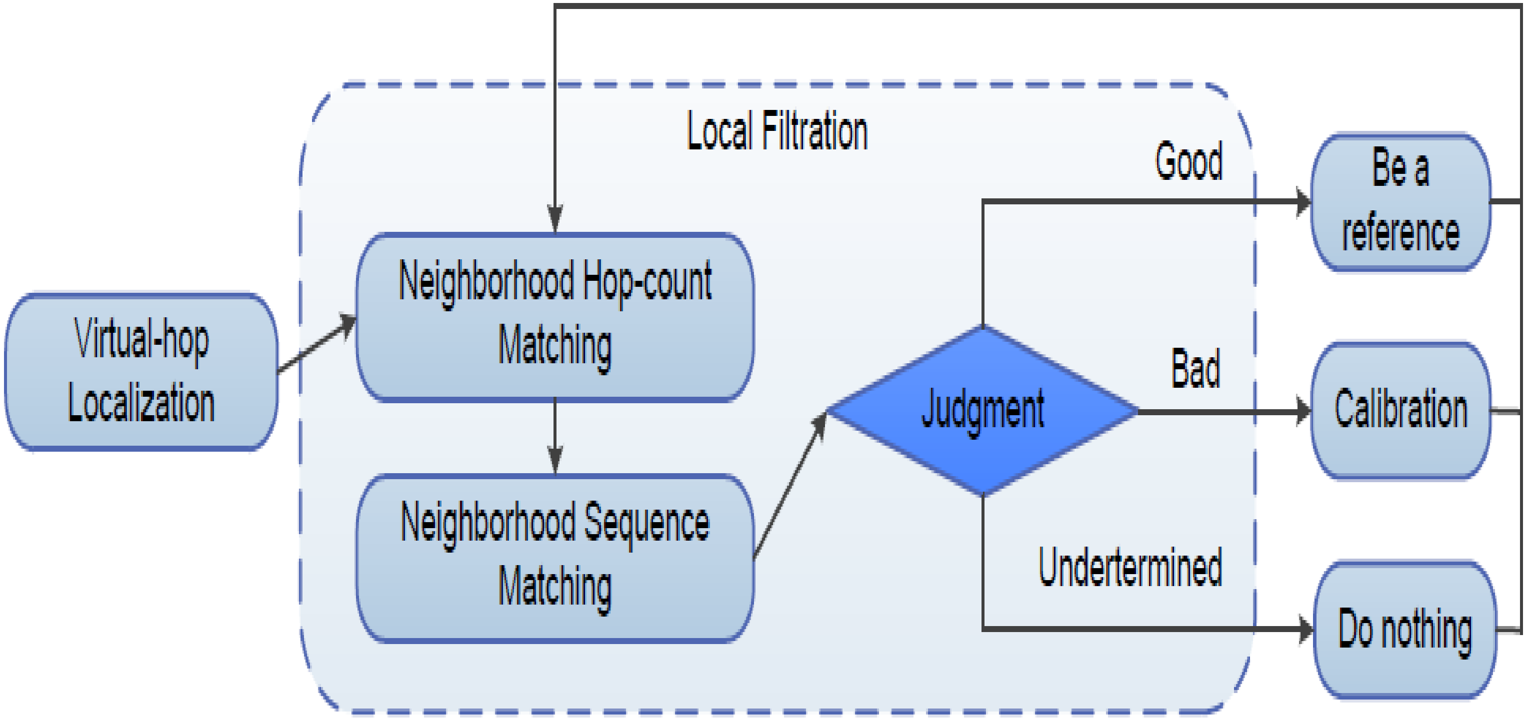
- Combined and Differentiated Localization (CDL)
  - Combines the advantages of both localization approaches
  - Range-free
    - Virtual-hop localization for non-uniform deployment
    - More accurate initial location estimation
  - Range-based
    - Two filtration schemes for better ranging quality
    - Calibrating bad nodes for managing ranging errors

CDL Block Diagram

CDL

Overview

- Three phases

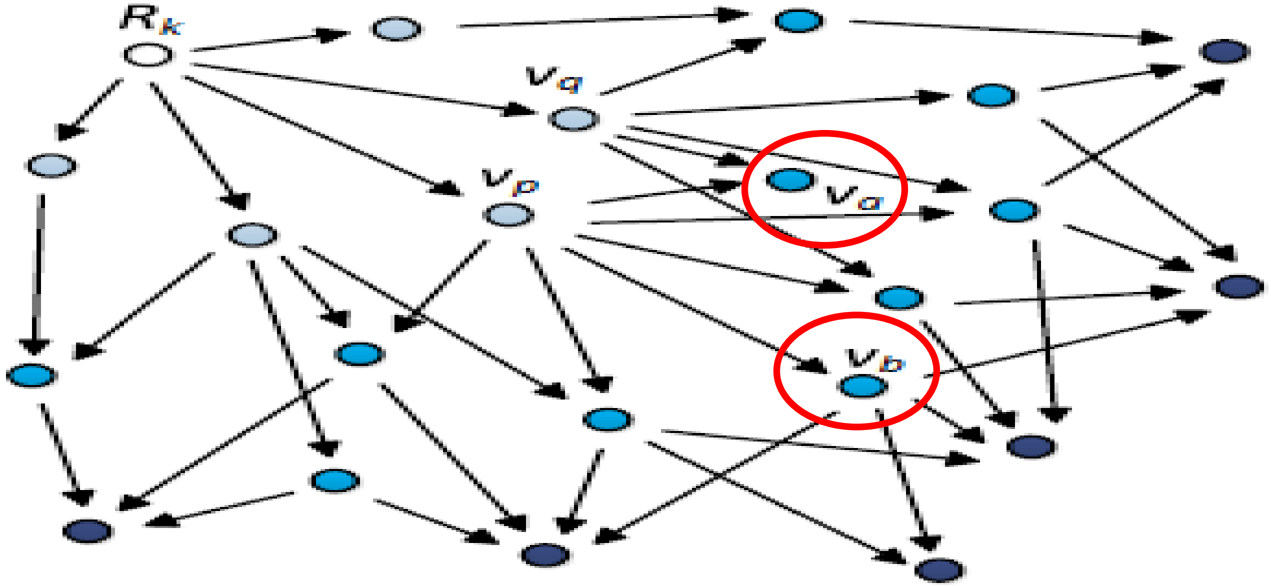


CDL

Virtual-Hop Localization

- Nodes having similar hop-count from the landmark
  - Closer nodes tend to have more previous-hop neighbors
  - They also have less next-hop neighbors

- Each node maintains virtual-hop count, beside the real hop-count



CDL

Virtual-Hop Localization

- Virtual hop-count is calculated hop by hop, and consists of two parts
  - Average virtual hop-count of prev. neighbors
  - The last virtual hop-count

$$VH_{jk} = \frac{1}{|P_j|}\sum_{i=1}^{|P_j|} VH_{ik} + LH_{jk}$$

$$LH_{jk} = \begin{cases} \dfrac{|N_j|}{|N_j| + \zeta_j - 1}, |N_j| > 0 \\ \dfrac{|P_j|}{|P_j| + \varphi_j - 1}, |N_j| = 0 \end{cases}$$

where: VH_{jk} is virtual-hop count from Landmark R_k to node v_j

P_j is the set of previous-hop neighbors

N_j is the set of next-hope neighbors

CDL

Virtual-Hop Localization

- Per-virtual-hop distance is calculated for Landmark R_k ($\tilde{d}_k$)

$$\tilde{d}_k = \frac{\sum \rho_{tk}}{\sum VH_{tk}} \; where\, R_t\, is\, a\, landmark, t \neq k$$

where ρ_{tk} is the Euclidean distance between landmarks R_t & R_k

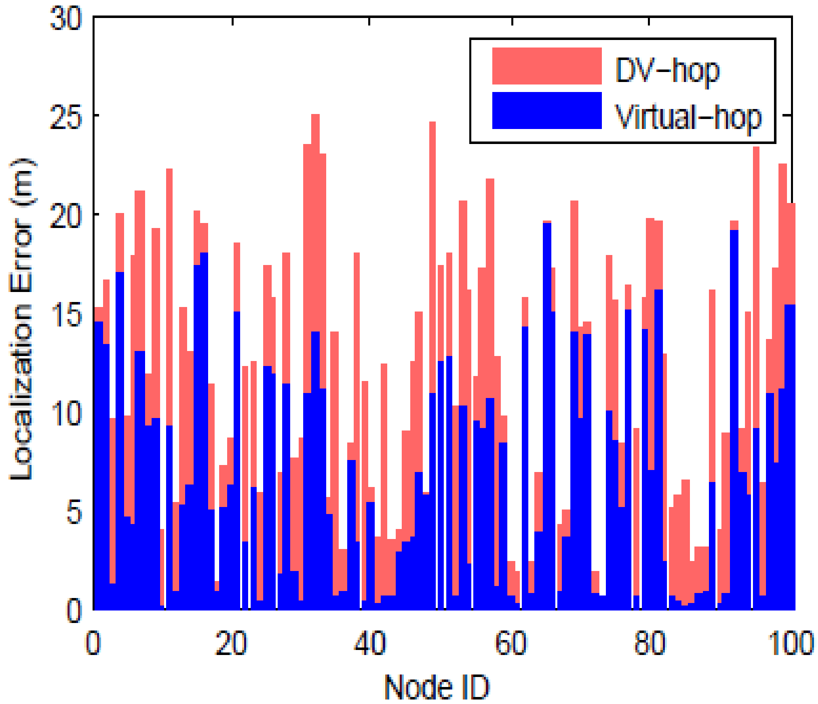
- Nodes compute their distances to the landmarks

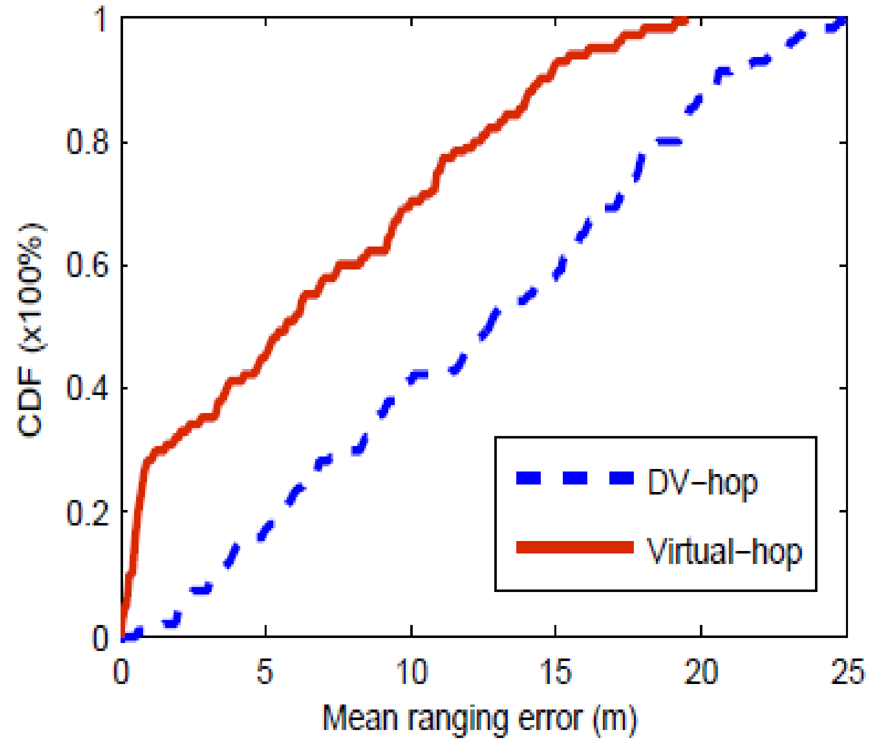
$$\rho_{jk} = \tilde{d}_k \cdot VH_{jk}$$

- Finally, nodes use trilateration to calculate their coordinates

CDL

Virtual-Hop Localization - Results





- Localization errors are reduced by 10% ~ 99%, as compared to DV-hop
- Big ranging errors (>5m) can be identified and further improved later

CDL

Local Filtration - Neighborhood Hop-Count Matching

- Uses hop-count as a rough distance estimation
- Node v_i estimates the distance (d'_{ij}) to its neighbor v_j using the estimated coordinates
- v_i estimates the hop-count (h'_{ij}) to its 2-hop neighbors using d'_{ij} and $\widetilde{d_k}$
- Comparing the actual hop-count (h_{ij}) and estimated h'_{ij} to all 2-hop neighbors, we can distinguish bad nodes

$$h'_{ij} = \lceil d'_{ij} / \tilde{d}_k \rceil \quad \Rightarrow \quad H_{ij} = \begin{cases} 0 & (h_{ij} \neq h'_{ij}) \\ 1 & (h_{ij} = h'_{ij}) \end{cases}$$

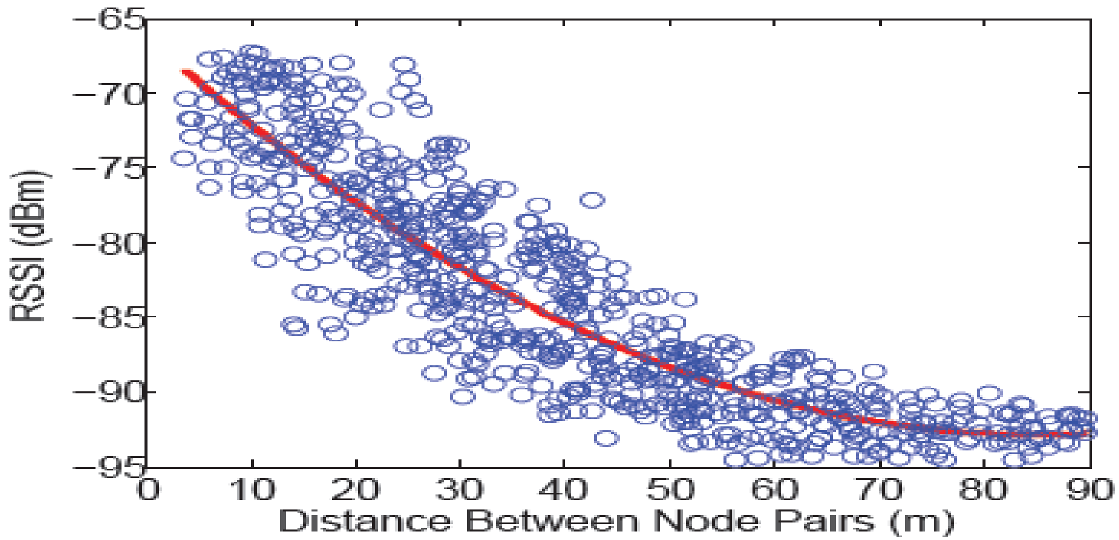
$$r_i = \frac{1}{n} \sum_{j=1}^{n} H_{ij} \quad \Rightarrow \quad \bar{r}_i = \frac{1}{n+1} \left(\sum_{j=1}^{n} r_j + r_i \right)$$

Filter-NH sequence

CDL

Local Filtration - Neighborhood Sequence Matching

- Depends on the monotonic decrease of RSSI with increasing distance



- Each node (v_a) generates two sequences for its neighbors
  - RSSI sequence S_a (Descending order; furthest last)
  - Distance sequence S'_a (Ascending order; closest first)

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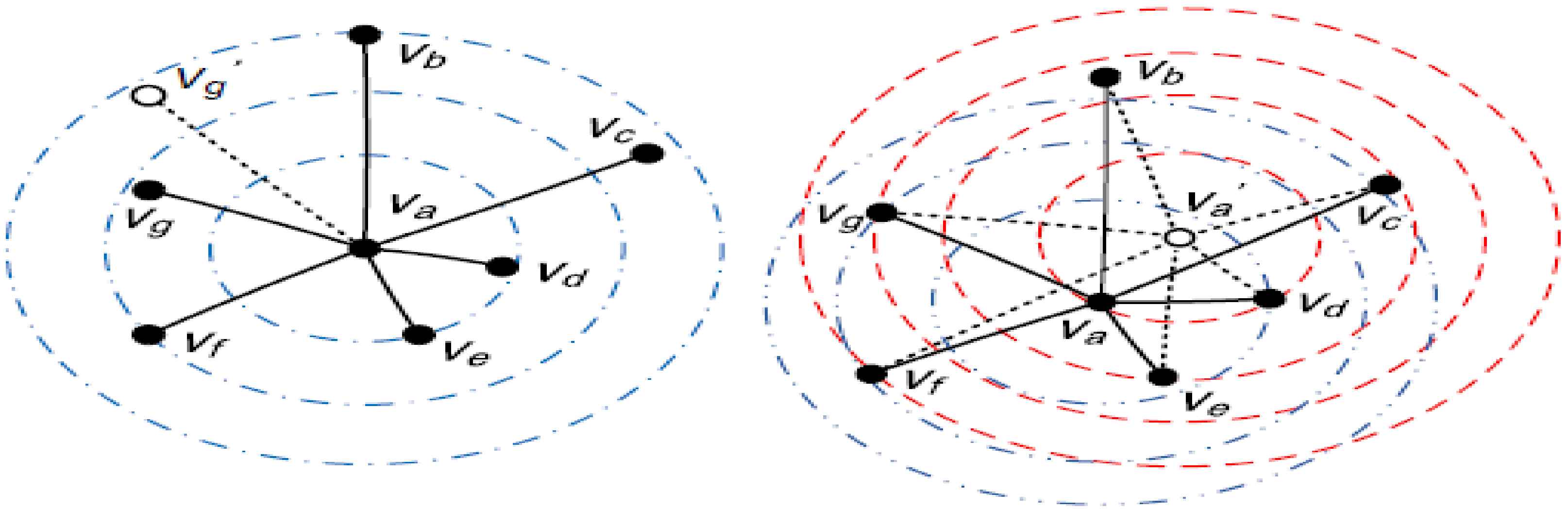
Local Filtration - Neighborhood Sequence



N_a	B	C	D	E	F	G
S_a	6	5	1	2	4	3
S_a'	6	4	1	2	3	5

N_a	B	C	D	E	F	G
S_a	6	5	1	2	4	3
S_a'	4	2	1	3	6	5

- Comparing the two sequences Sa and S'_a
  - Using cosine distance and matching degree for comparison

$$\mathbf{M_i = \delta_i \,.\, CosDist_i}$$

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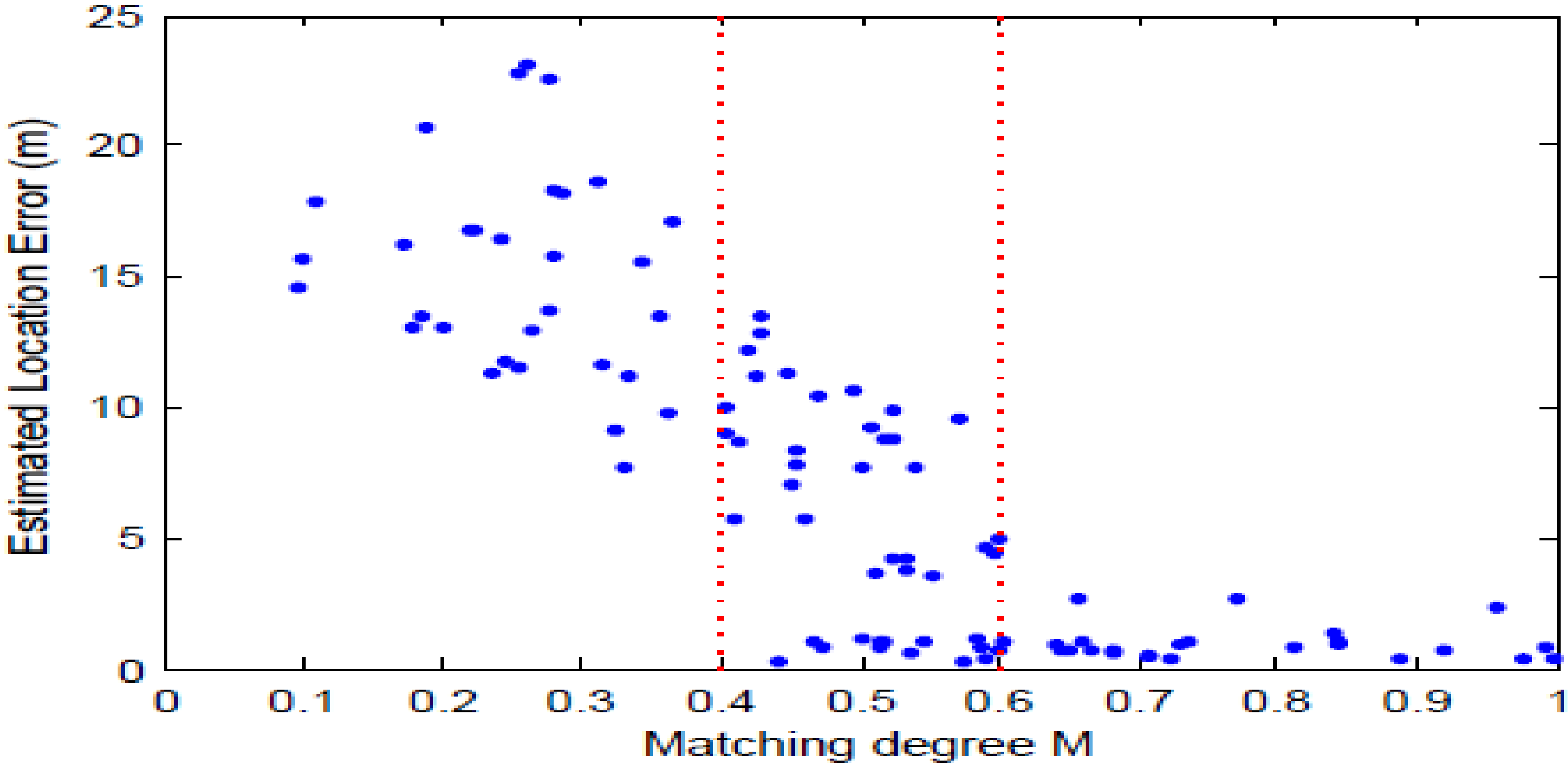
Local Filtration - Results



- $M_i > 0.6$: Location errors < 4m => Good nodes
- $M_i < 0.4$: Location errors > 5m => Bad nodes
- $0.4 < M_i < 0.6$: 0.1m < Location errors < 12m =>Undetermined nodes

CDL

Ranging-Quality Aware Calibration (RQAC)

- Use only good nodes output from filtration phase as references

$$G_i = \begin{cases} 0 & M_i < \tau_l \\ 0.5 & \tau_l < M_i < \tau_u \\ 1 & M_i > \tau_u \end{cases}$$

- Give high weight to good node v_j
  - Based on RSSI measurements

$$\omega'_{jk} = \begin{cases} 1 & |l_{ij} - d_{ij}| < \theta \\ 0 & otherwise \end{cases} \Rightarrow \tilde{\omega}_j = \sum_{k=1}^{|\Re_j|} \omega'_{jk} \cdot \lfloor G_k \rfloor$$

More equations

CDL

Ranging-Quality Aware Calibration (RQAC)

- Normalizing to get the weight of the good node v_j
- Weights are then used to maximize good nodes' contribution

$$\omega_j = \frac{\tilde{\omega}_j}{\sum_{k=1}^{|\Re_j|} \tilde{\omega}_k} \Rightarrow g(i,j) = \begin{cases} \omega_j (l_{ij} - d_{ij})^2 & |l_{ij} - d_{ij}| < \varepsilon \\ \ln(|l_{ij} - d_{ij}| - \varepsilon + 1) & |l_{ij} - d_{ij}| \geq \varepsilon \end{cases}$$

- Estimate bad node v_i through minimizing f* in the neighborhood of good neighbors v_j

$$f^* = \sum_j g(i,j)$$

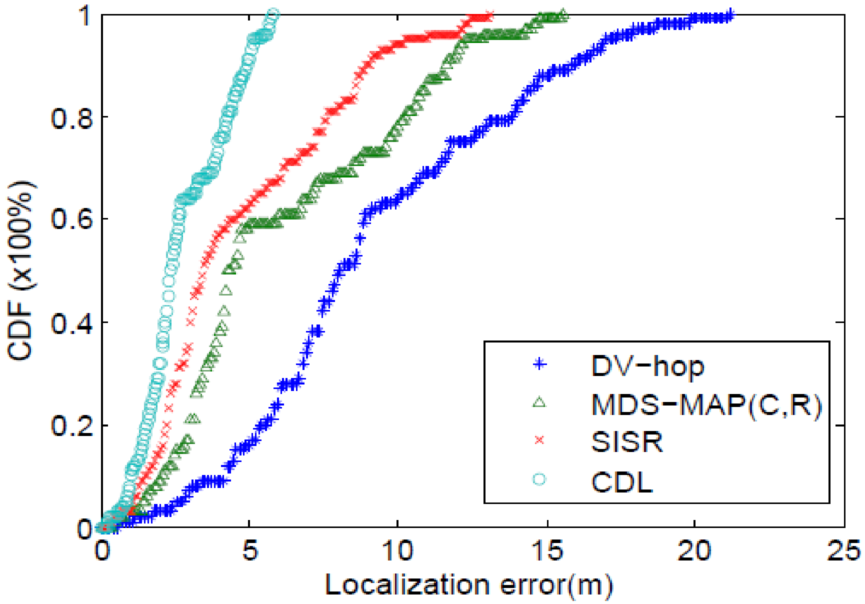
Evaluation

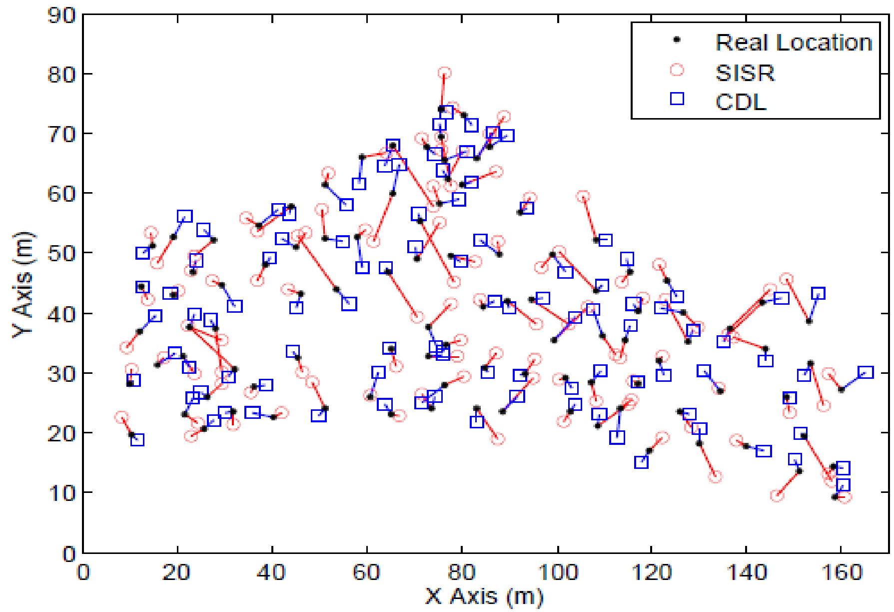
Experiments

- Experiments run for 4 localization schemes (DV-hop, MDS-MAP, SISR & CDL)
  - MDS-MAP: Range-free, Centralized localization algorithm
  - SISR: Iterative outlier rejection for better ranging quality
- 100 GreenOrbs nodes positioned in a rectangular region
- 4 landmark nodes near the borders

Evaluation

Experiments



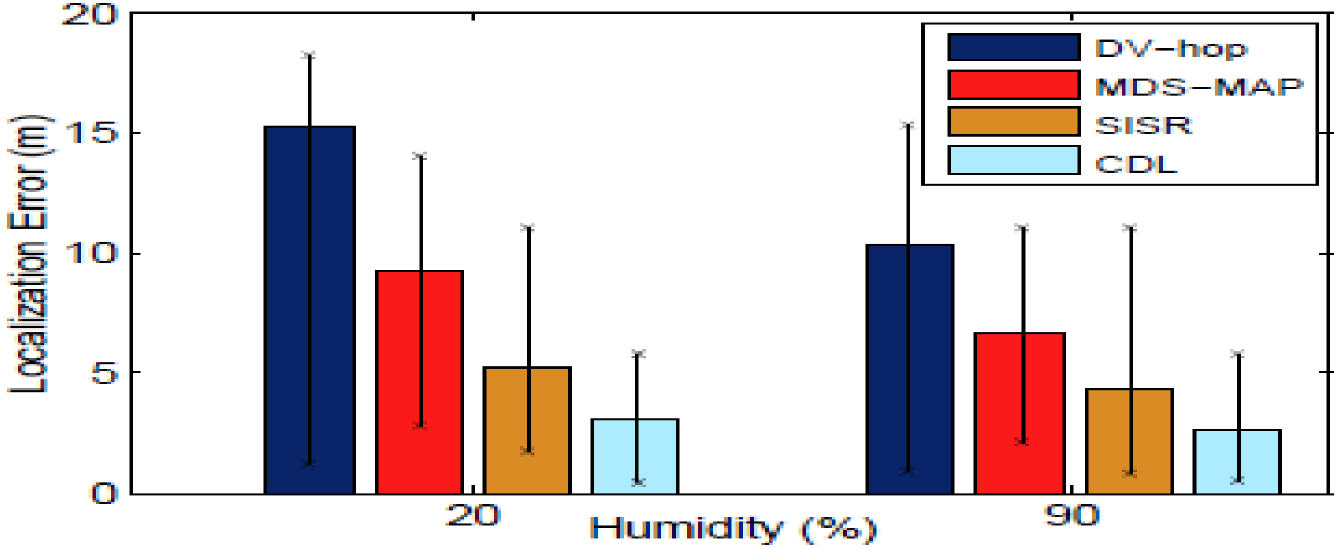


- CDL results
  - 100% of nodes have errors < 7m (70% at most in SISR)
  - 65% of nodes have errors < 3m (35% at most in SISR)
  - Average localization error is 2.9m (4.6m in SISR)

Evaluation

Experiments

- Different humidity percentages
- All 4 approaches have better results with higher humidity (RSSI)
- CDL outperforms all approaches in both cases

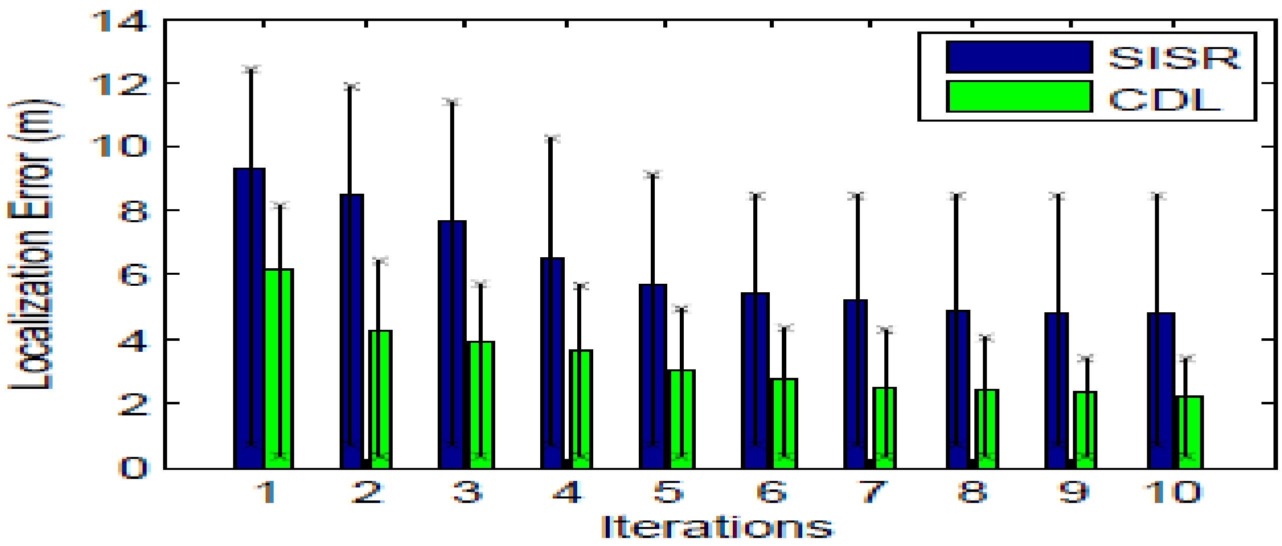


Convergence

Evaluation

Experiments

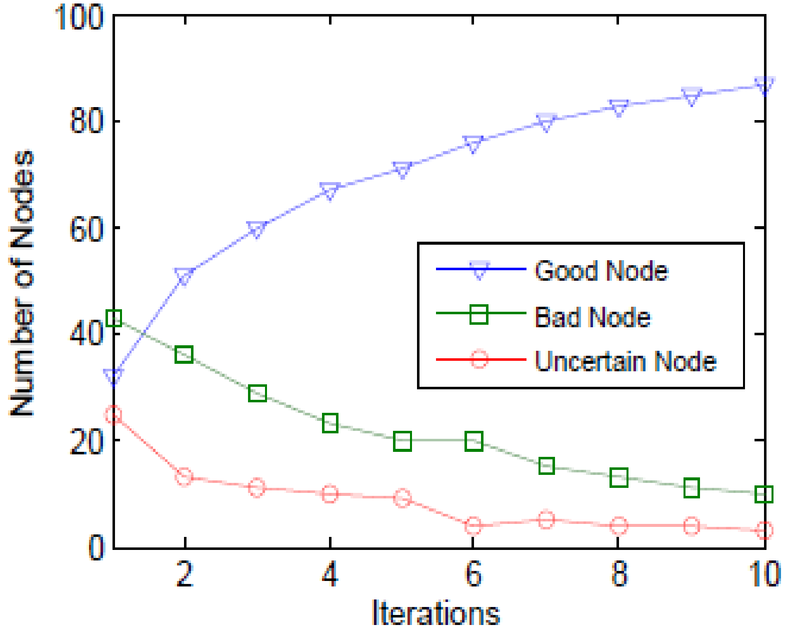
- CDL and SISR converges after 6~8 rounds of iterations
  - CDL outperforms SISR in all iterations
    - Virtual-hop gives better initial locations
    - Filtration and calibration maximizes good nodes contribution

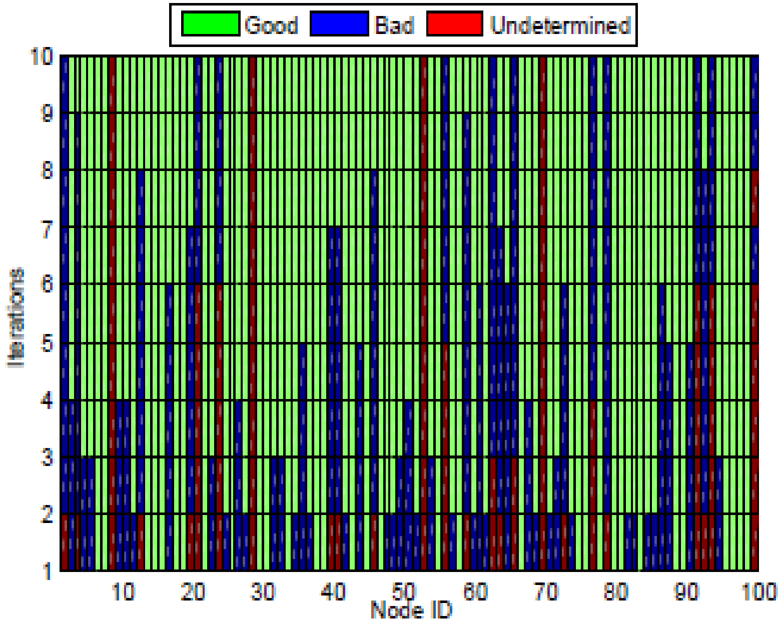


Evaluation

Experiments

- CDL can distinguish almost all nodes (good or bad) after 10 iterations
  - 31% nodes initially identified good
  - 44% nodes initially identified bad, then calibrated to be good
  - 25% nodes are initially undetermined, then calibrated bad, then good nodes





Conclusion

- WSN deployed in complex environments need more accurate localization schemes
- CDL copes well with the number of interfering factors faced by localizing WSN nodes in the wild (GreenOrbs)
  - Environmental dynamics
  - Obstacles
  - Signal irregularities (RSSI)
- CDL outperforms existing schemes
  - High Accuracy
  - High Efficiency
  - Consistent performance

Q & A

- Thanks for Listening

- Questions ?!