Achieving Range-free Localization Beyond Connectivity

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Localization problem

- *<erno> hm. I've lost a machine.. literally _lost_. it responds to ping, it works completely, I just can't figure out where in my apartment it is.*

  Random IRC quote

Outline

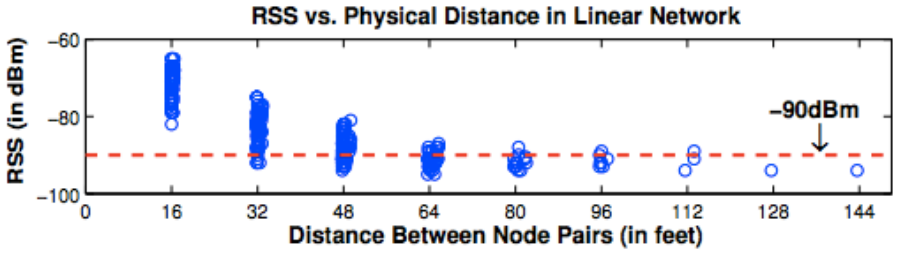
- Localization
- Signature distance
- Regulated signature distance
- Experimental results
- Conclusion

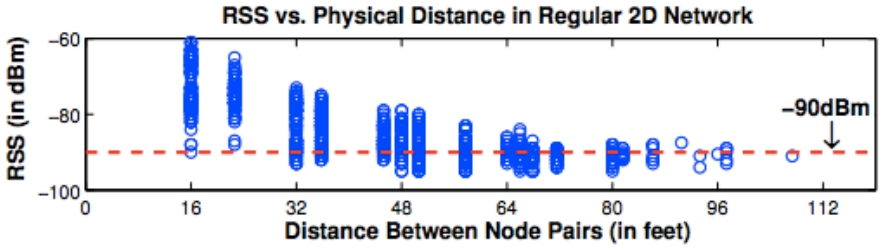
Localization

- Range determined by
  - Time of Arrival (ToA), Angle of Arrival (AoA), Phase of Arrival (PoA)
    - Can be accurate
    - Expensive hardware
    - Not suitable for large scale systems
  - Received signal strength (RSS)
    - Extremely inaccurate
    - Careful calibration needed
    - Cheap
- Range-free localization
  - MDS-MAP, DV-Hop, RPA, etc
- Localization by connectivity
- One hop virtual distance
- High node density required
- More information available but is not used
  - RSSI, neighborhood ordering

Preliminary work

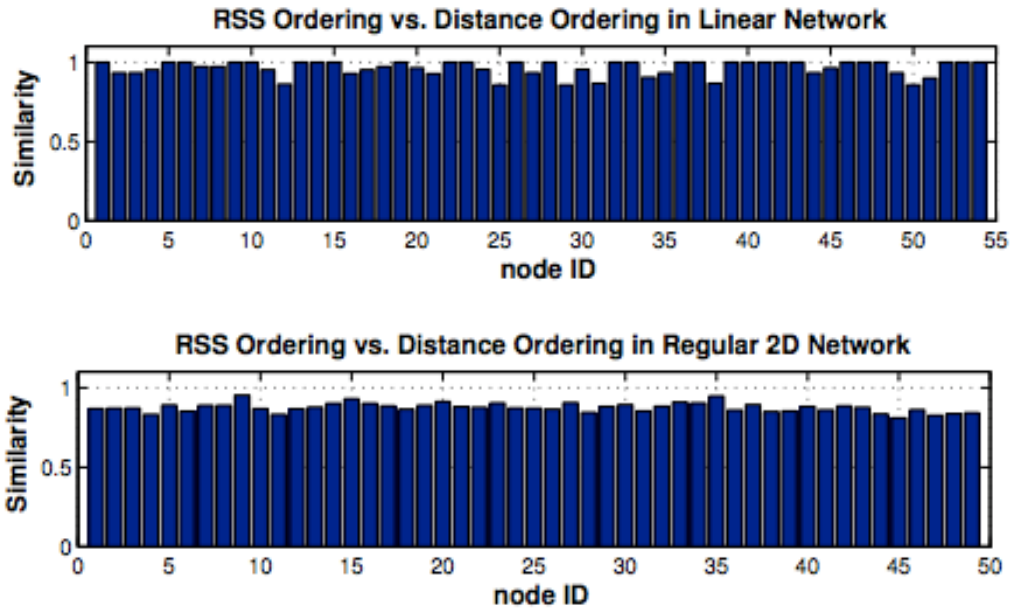
- RSSI extremely inaccurate
- Not usable for accurate range between nodes





Preliminary work

- Create node neighbor list
  - Order based on RSSI
- Compare to physical distance
  - Accordant node pairs
- Similarity good
  - Linear networks
  - 2D networks

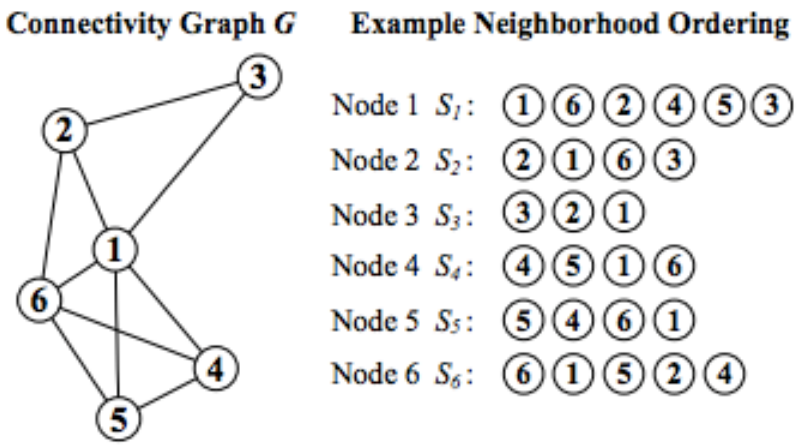


Relative distance

- Algorithm for determining
  - Relative distance between nodes
- Three steps:
  - Determine neighborhood ordering
  - Calculate signature distance
  - Correct signature distance

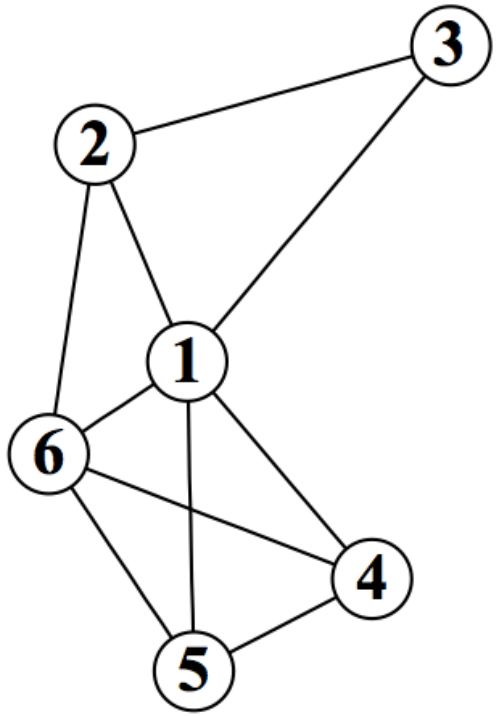
Neighborhood ordering

- Sort 1-hop neighbors
  - Based on RSSI
  - Start with yourself
- Big assumption:
  - Ordering is presumed correct
- Count inconsistencies
  - Flips



Explicit flip

Connectivity Graph G



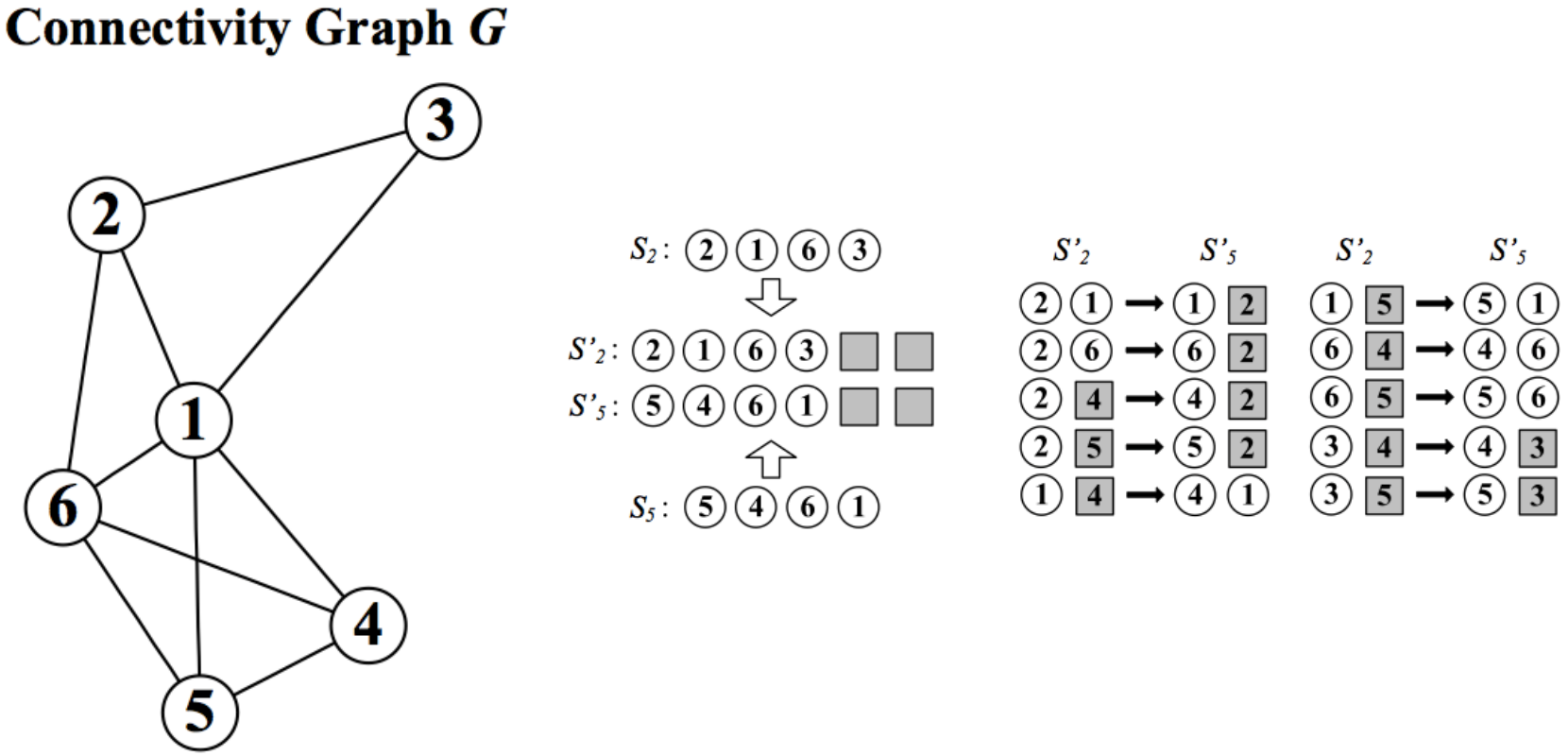
S_2: (2) (1) (6) (3)

S_5: (5) (4) (6) (1)

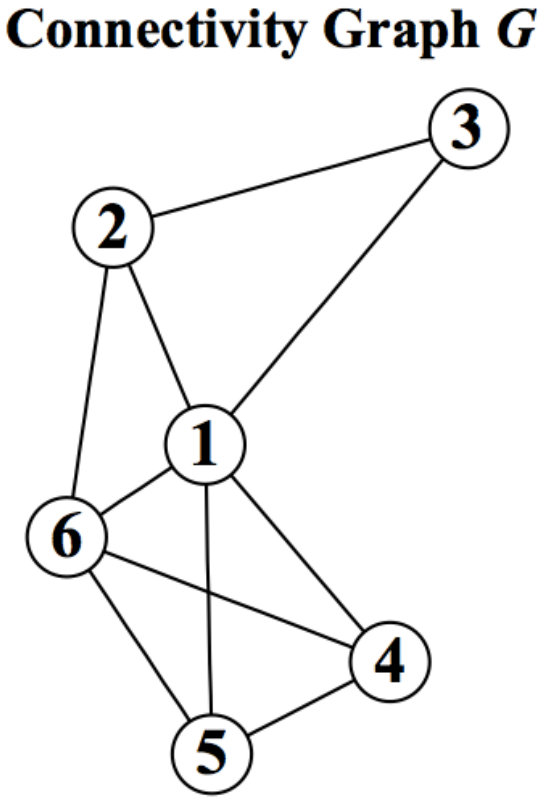
S_2 S_5

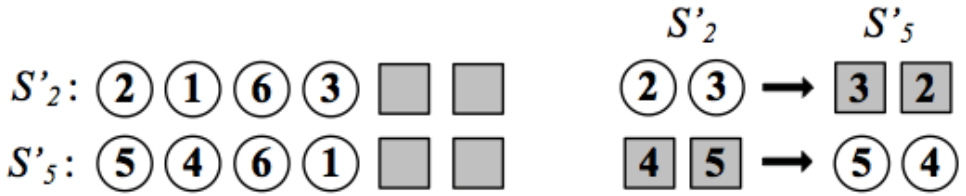
(1) (6) → (6) (1)

Implicit flip



Possible flip

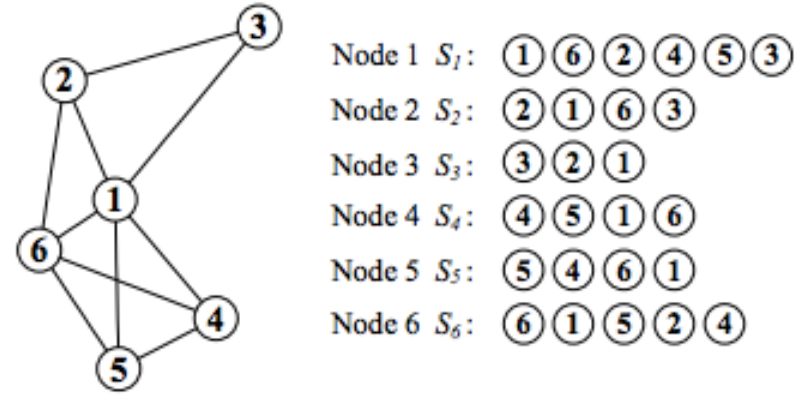




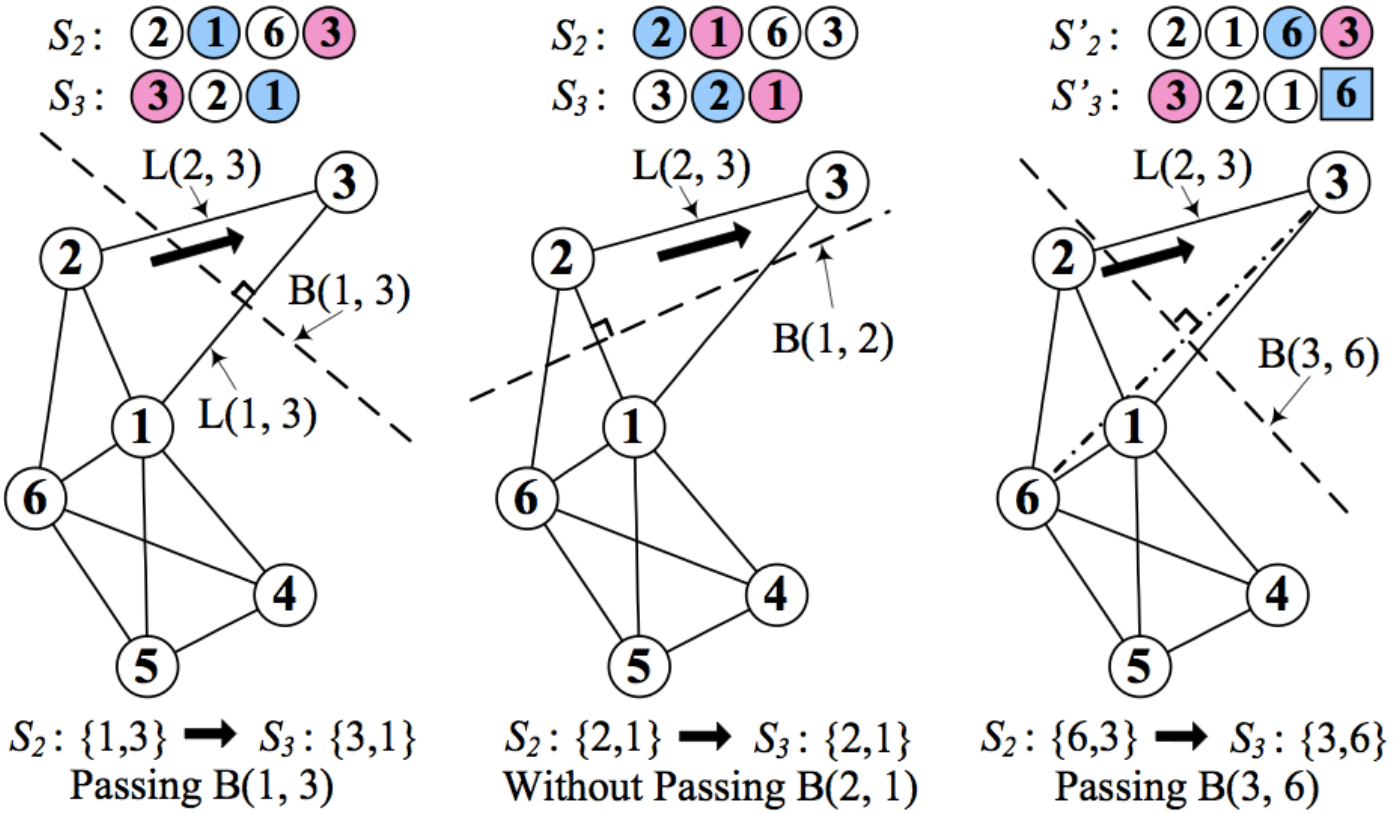
Signature distance

- Based on node-pair flips
  - Explicit
  - Implicit
  - Possible

$$SD(S_i, S_j) = F_e(S_i, S_j) + F_i(S_i, S_j) + \frac{F_p(S_i, S_j)}{2}$$

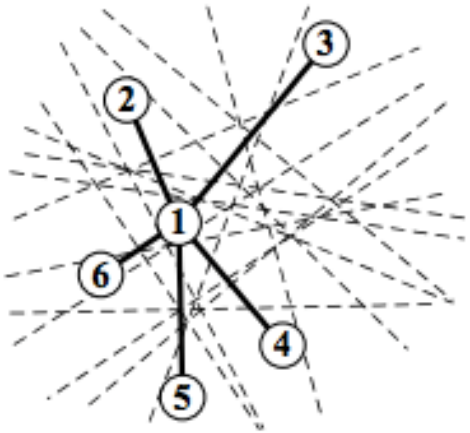


Insight in signature distance



Physical distance

- Observations:
  - Node pair flip indicates passing of bisector line
  - SD(S_i , S_j) = bisector line crossing
  - Under uniform bisector density SD is proportional to physical distance



(a)

Line Segments	Bisectors Passing	SD
1 — 6	3	3
1 — 2	4	4.5
1 — 4	6	6.5
1 — 5	8	8.5
1 — 3	8	8.5

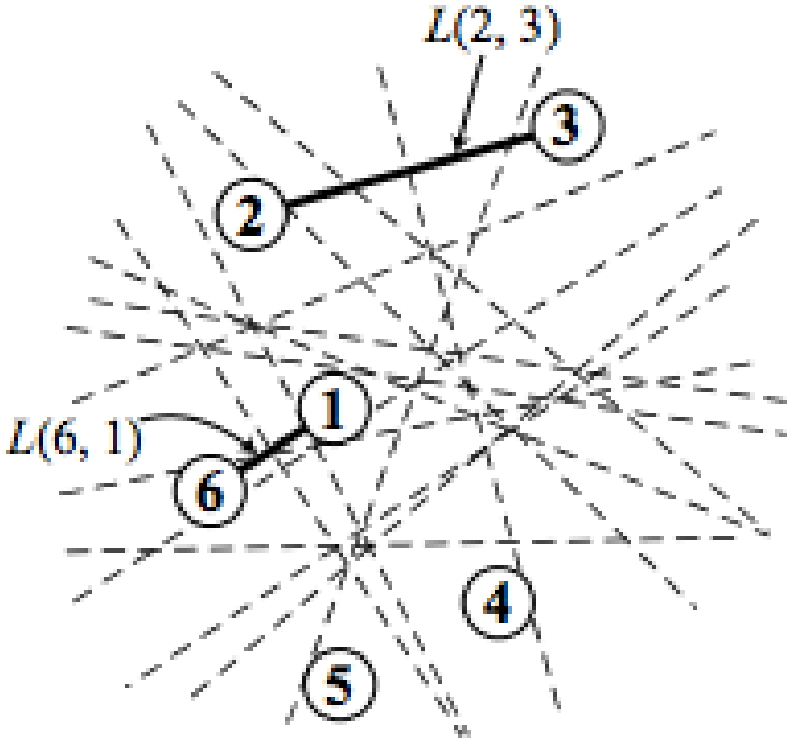
(b)

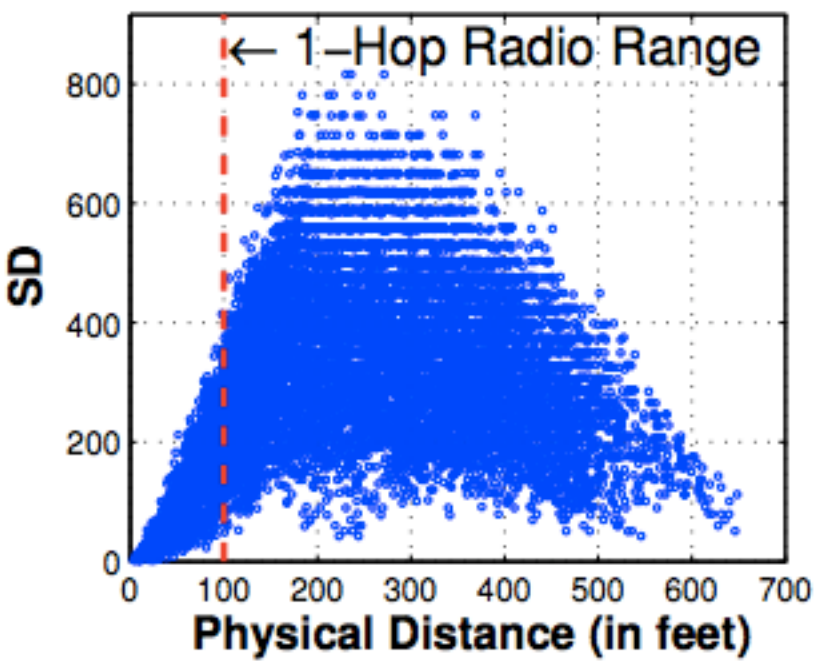
Regulated signature distance

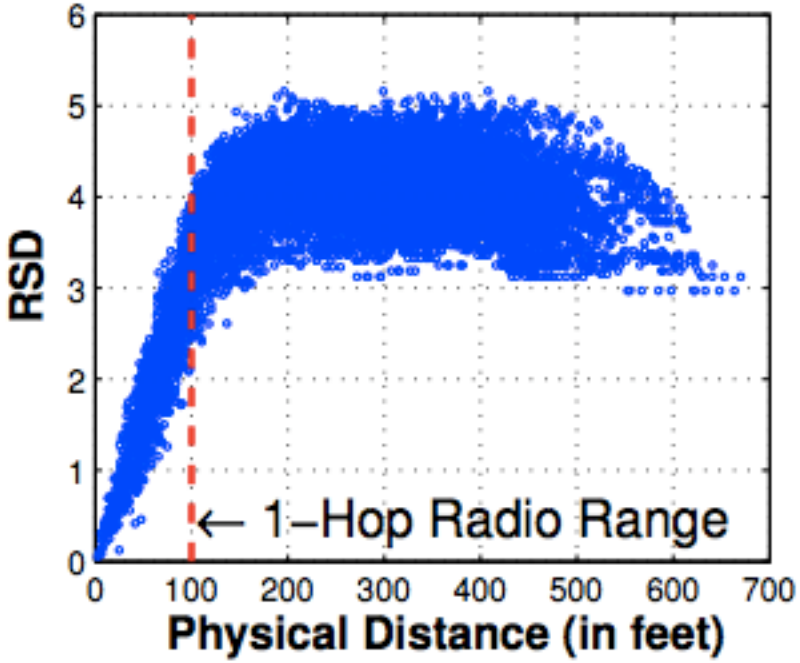
- Unbalanced bisector line density
- Refine SD
  - Calculate total number of local bisector lines
  - Normalize SD

$$RSD(u_i u_j) = SD(S_i S_j) * \frac{\sqrt{K}}{K * (K-1)/2}$$

$$K = |S_i \cup S_j|$$







SD vs RSD

Within 1-hop range RSD achieves good ranging compared to SD. For larger distances SD is not correlated to physical distance.

Experimental results

RSD support layer

- Supports existing schemes
  - MDS-MAP
    - Uses distance matrix A
      - Normally holds 1 or 0 indicating connection
      - Instead use RSD
  - DV-Hop

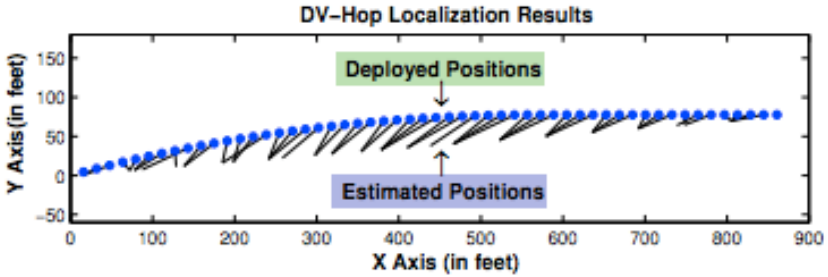
$$RSD_{unit}Size = \frac{\sum_{i \neq j} Distance(v_i v_j)}{\sum_{i \neq j} RSD(v_i v_j)}$$

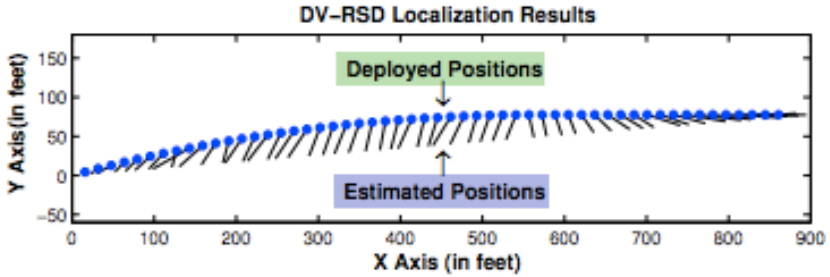
  - RPA
    - Embed in Hop-TERRAIN step

Experiment

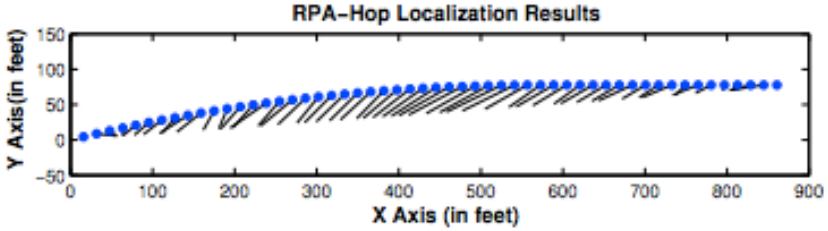
- Linear network
  - 848 feet network
    - Node distance of 16 feet
  - 15 hops
  - 54 MICAz nodes
  - 0dBM sending power at C26
- Grid network
  - 100 by 100 feet
    - 7 by 7 sensors
  - 3 hop network
  - 49 MICAz nodes
  - 0dBM sending power at C26

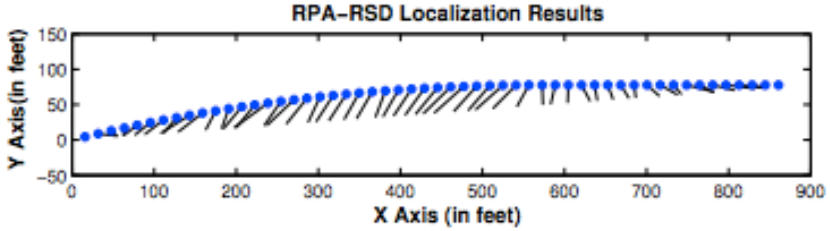
Linear network



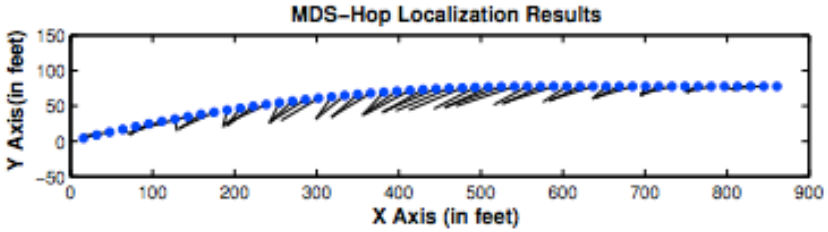


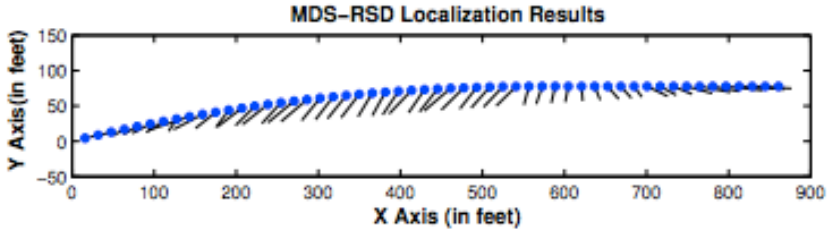
(a) DV-Hop vs. DV-RSD





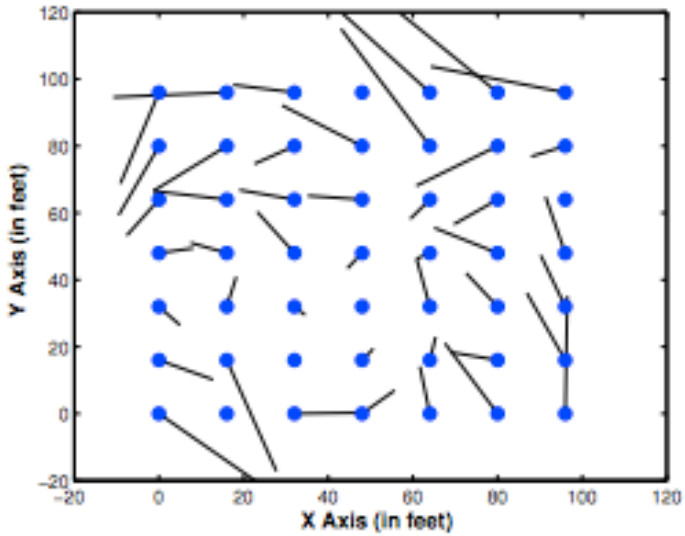
(b) RPA-Hop vs. RPA-RSD



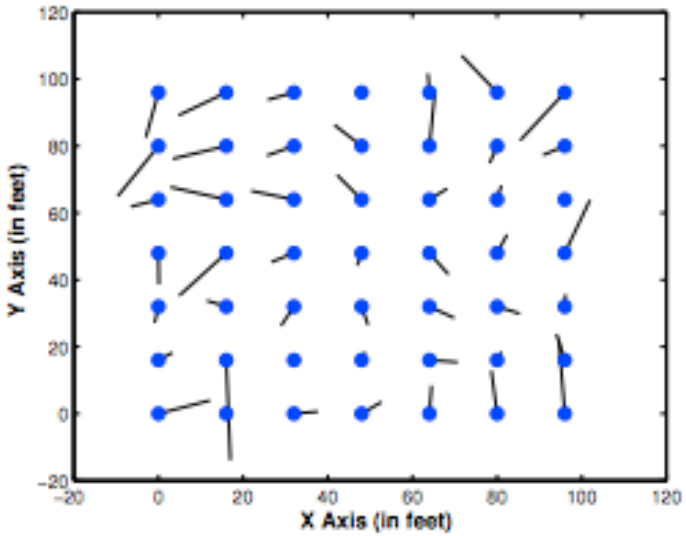


(c) MDS-Hop vs. MDS-RSD

Grid network



(a) Localization by MDS-Hop



(b) Localization by MDS-RSD

Conclusion

- What RSD is not:
  - A complete mechanism
- But:
  - Increase accuracy of existing schemes
  - Sub hop accuracy
  - Efficient
    - Signature exchange
    - No flooding
- Computational complexity

$$O(nK^2 * \log(K))$$

- Localized or centralized