A Decentralized Location System for Sensor Networks Using Cooperative Calibration and Heuristics

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Sensor Network Applications

- Physical security
  - Detecting intruders
- Medical
  - Patients in a hospital
- Habitat monitoring
  - Wildlife, plants
- Environmental
  - Tracking forest fires, pollution
- Smart buildings
- Surveillance

Sensor Localization is important in most applications

Introduction

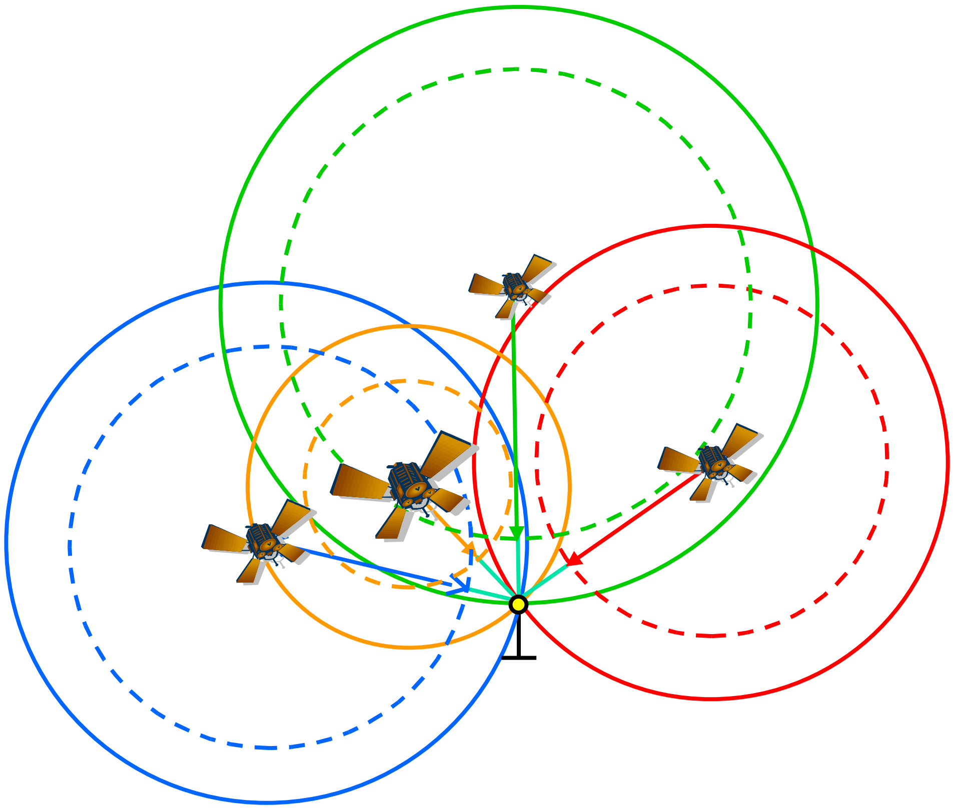
- Problem
  - Given a set of nodes with unknown position coordinates, and a mechanism by which a node can estimate its distance to a few nearby (neighbor) nodes, determine the position coordinates of every node via local node-to-node communication.
  - There are few nodes that know their exact position and range measurements are inaccurate
- Challenge #1 reduce RM errors
  - Heuristics
- Challenge #2 sparse anchor node problem
  - All nodes as potential landmarks

Determining Location

- Landmark nodes positions
- Range measurements
- Position calculation methods
  - Triangulation
  - Trilateration
  - Multilateration
  - Min-max

Location Methods: Time of arrival (TOA)

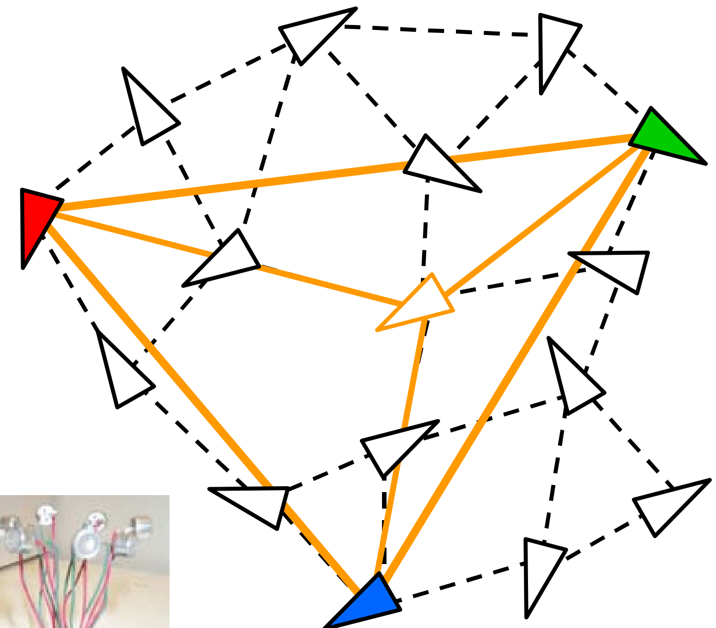
- Example: GPS
  - Uses a satellite constellation of satellites with atomic clocks
  - Satellites broadcast precise time
  - Estimate distance to satellite using signal TOA
  - Trilateration

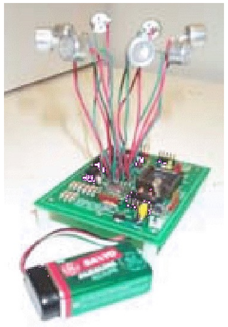


Wellenhoff, et al, 1997

Location Methods: Angle of arrival (AOA)

- Idea: Use antenna array to measure direction of neighbors
  - Special landmarks have compass + GPS, broadcast location and bearing
  - Flood beacons, update bearing along the way
  - Once bearing of three landmarks is known, calculate position



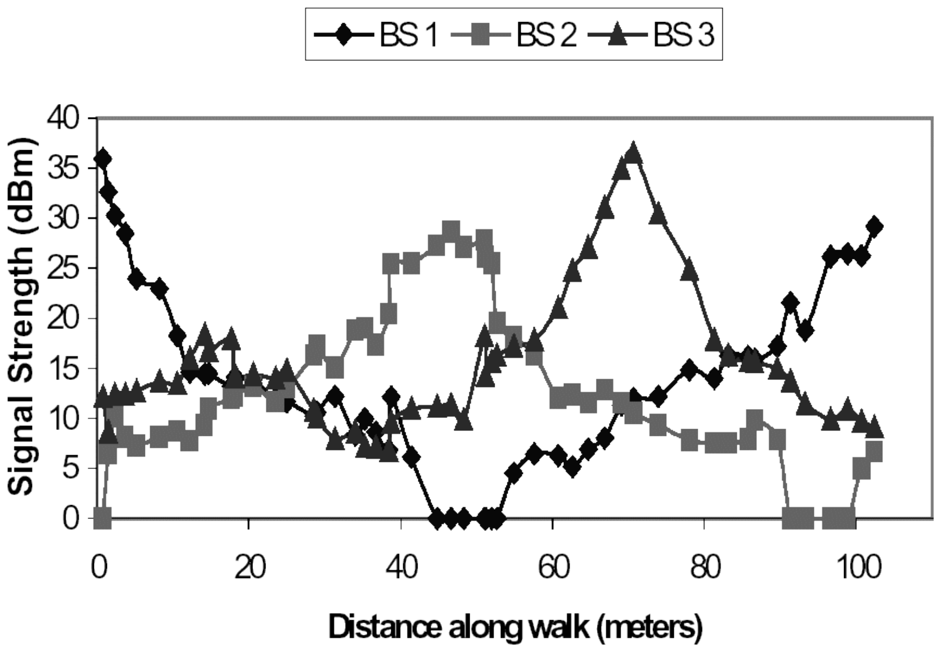


"Medusa" mote

Niculescu and Nath, 2003

Location Methods: RSSI

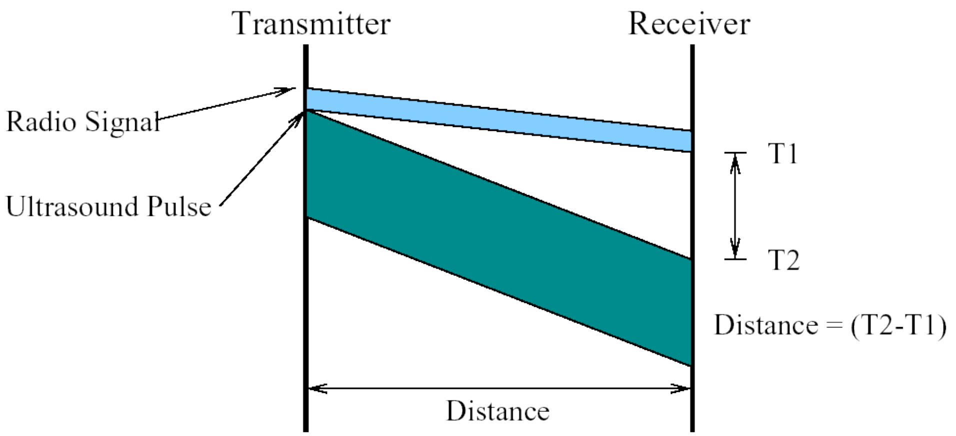
- Received Signal Strength Indication
- No additional hardware required
- Problem: Irregular signal propagation characteristics (fading, interference, multi-path etc.)



Bahl and Padmadabhan

Location Methods: Time difference of arrival (TDOA)

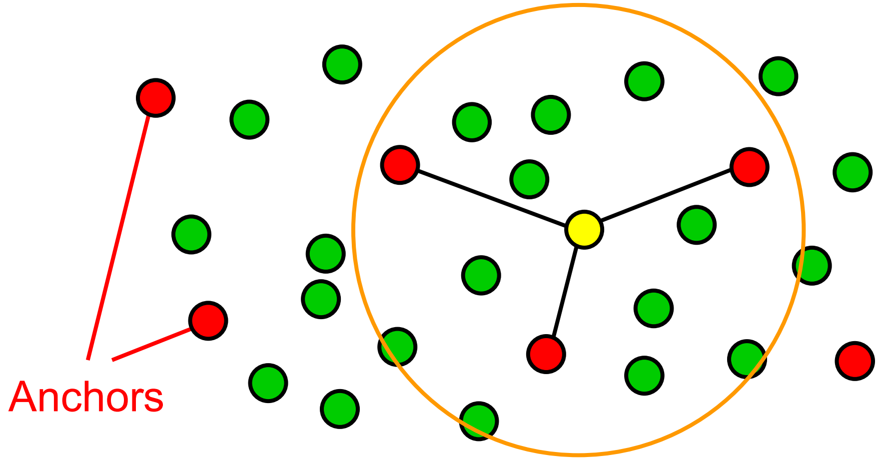
- RSS is not reliable enough to do ranging
- Idea: Use time difference between arrival of RF and ultrasound signals
- Some beacon nodes have GPS receivers
- Multilateration

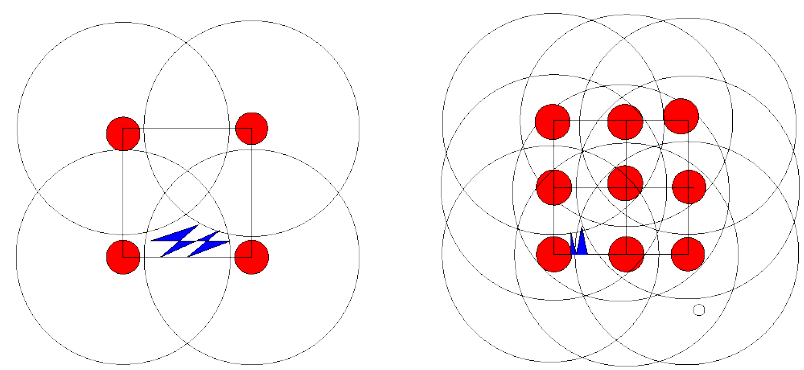


Savvides et al, 2001

Location Methods: Centroid

- Do not use any ranging at all, simply deploy enough beacons
- Anchors periodically broadcast their location
- Localization:
  - Listen for beacons
  - Average locations of all anchors in range
- Good anchor placement is crucial!

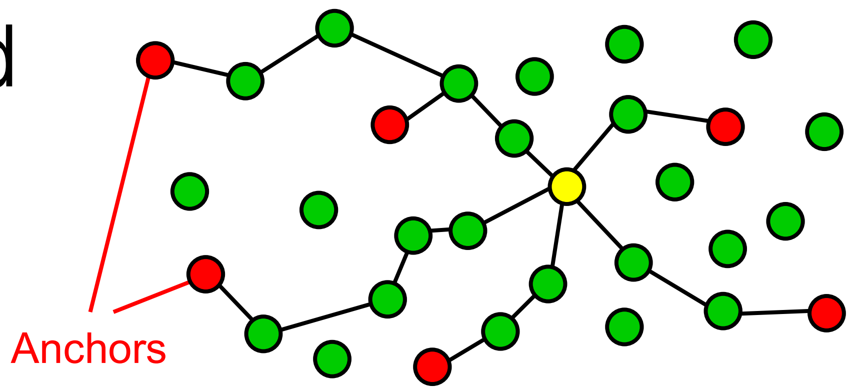


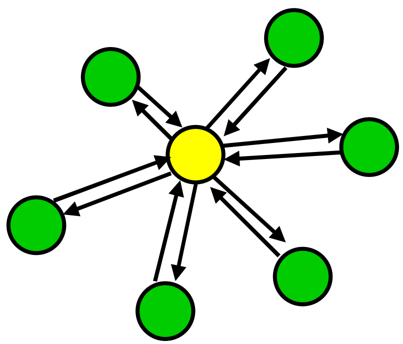


Bulusu et al, 2001

Location Methods: Two-phase refinement

- Get a rough estimate first and then improve it gradually
- Hop-TERRAIN:
  - Anchors flood beacons through the network
  - Each node uses the hop count to do triangulation
  - Refinement steps:
    - Broadcast estimate to immediate neighbors
    - New position := centroid
    - Repeat until stable



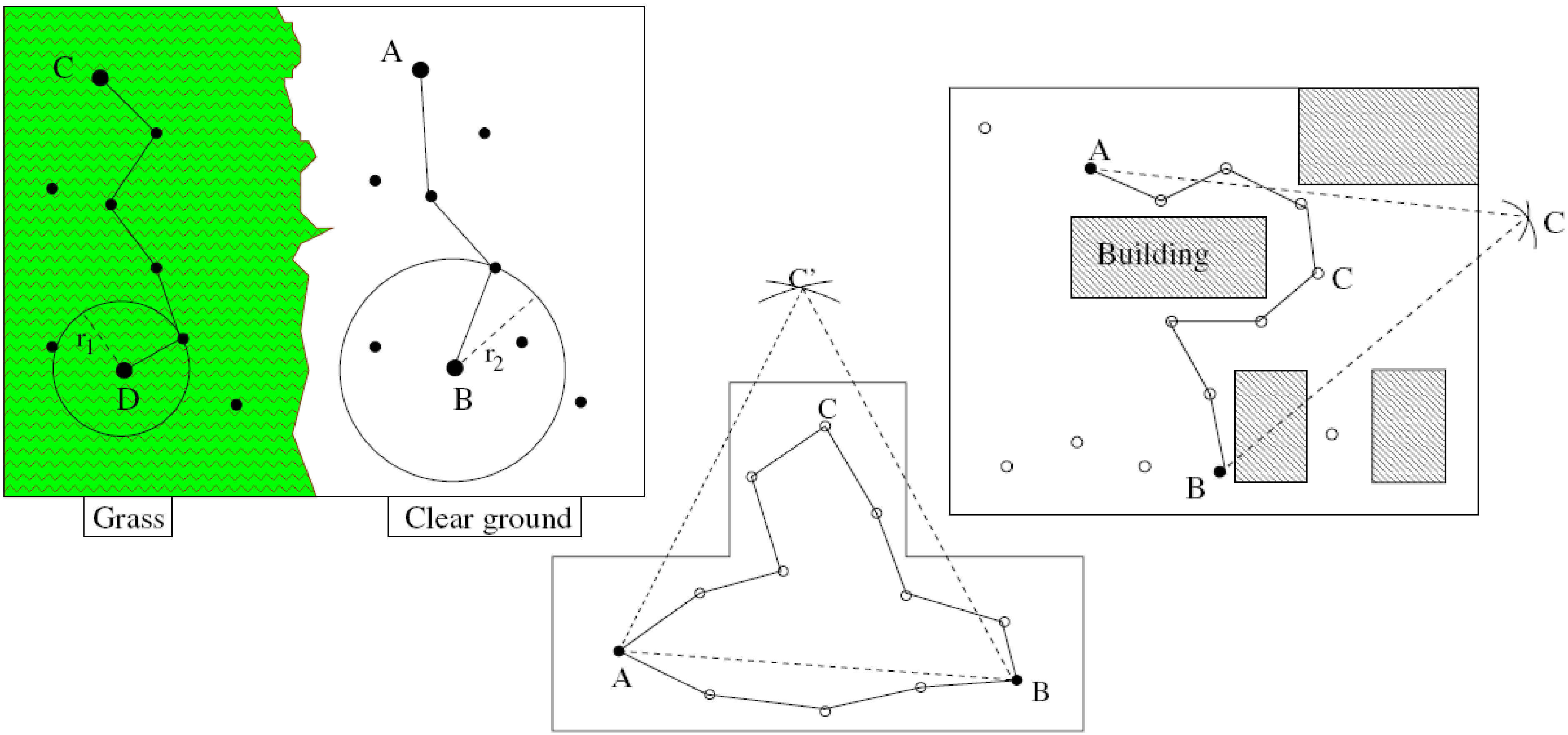


Savarese et al, 2002

HECOPS

- Heuristic Environmental Consideration Over Positioning System
- Objectives:
  - Self-configurability
  - Robustness
  - High accuracy
- Main idea:
  - Use fewer but more reliable landmarks
  - Detect deviation and calibrate neighbors

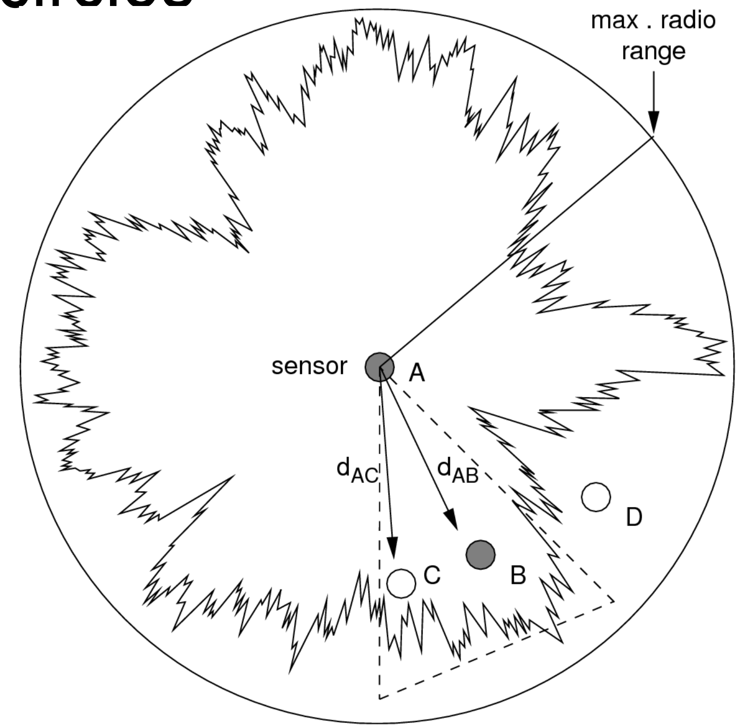
Problem:
complex terrain and anisotropic topology

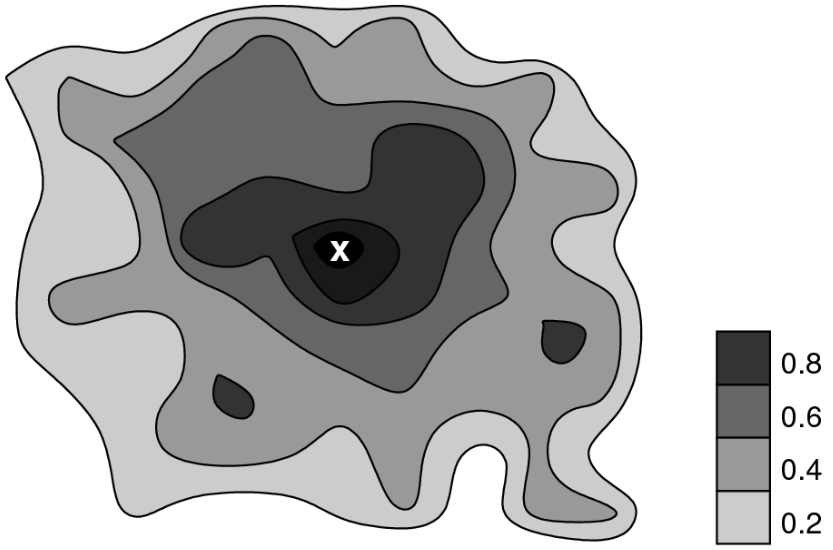


Ganesan, 2002

Inspiration

- Although irregular, RSSI levels can be seen as concentric circles



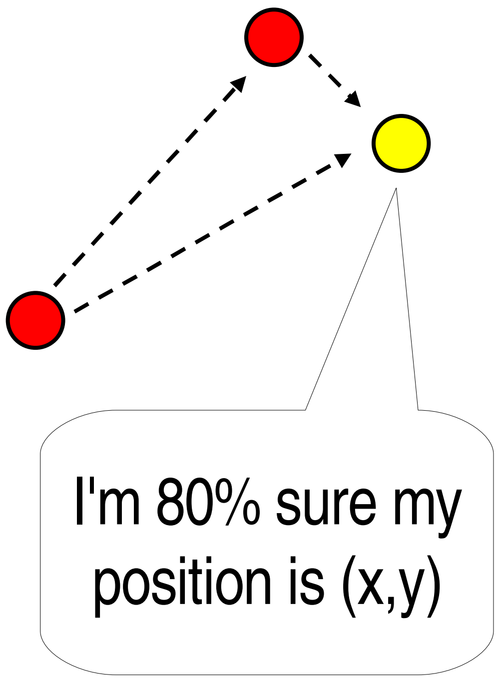


Contour or propability of packet reception from a central node at two different transmit power settings.

Ganesan, 2002

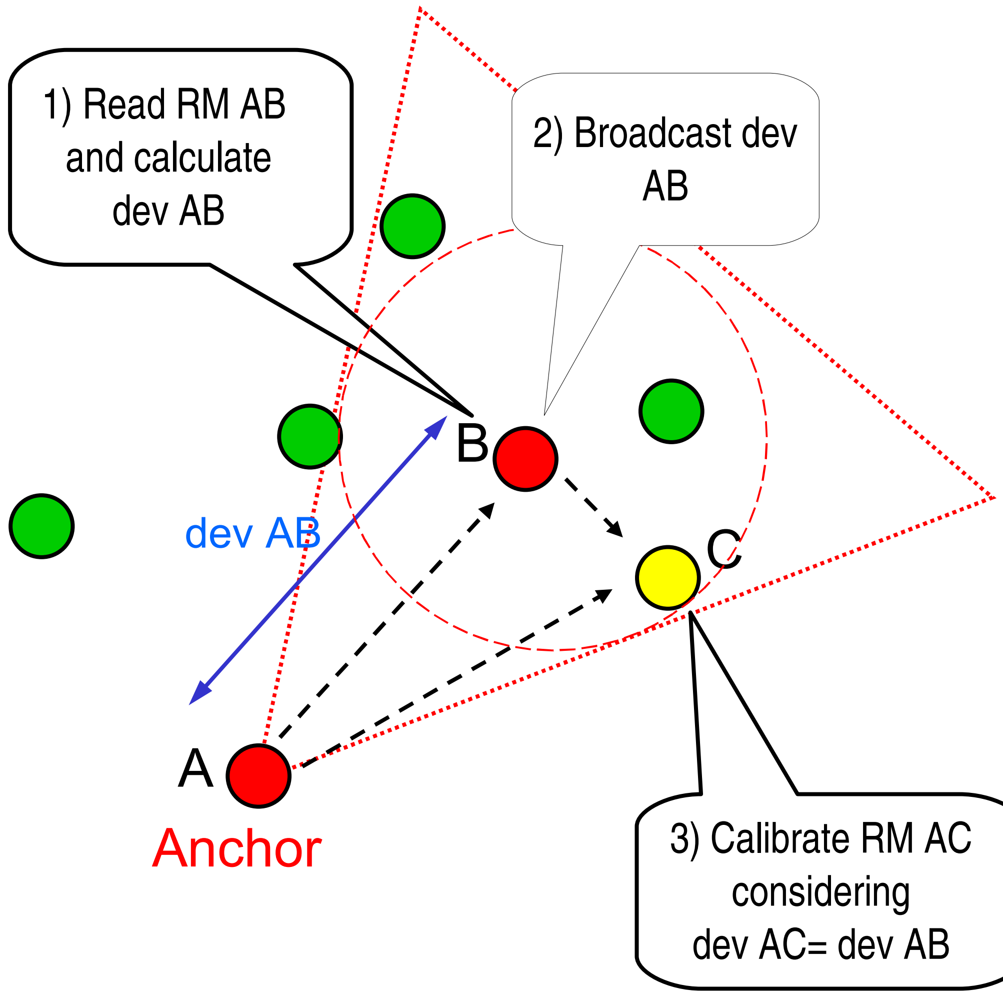
HECOPS: Basic principles

- Calibrate Range Measurements with deviations of nearby landmark nodes
- Estimate positions based on Range Measurements deviations and landmark positions
- Assert a “confidence value” for estimated position based on the confidence of the landmarks
- Exchange positions and confidence values between nodes



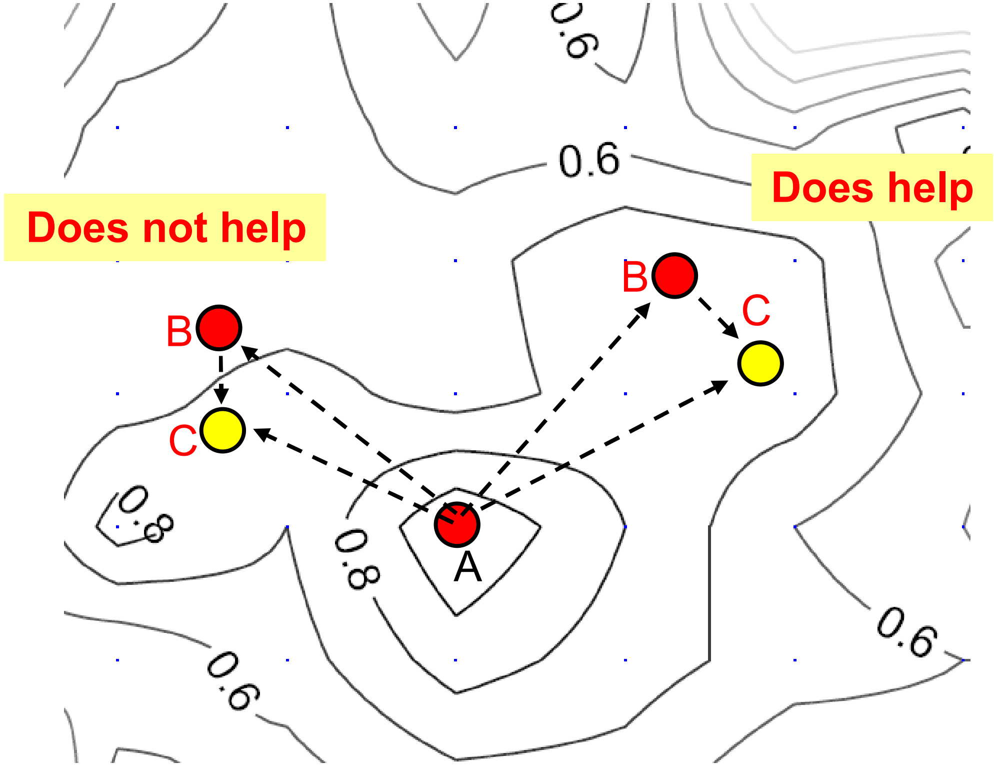
Tri Function

- Detect deviation and calibrate neighbors



Tri Function

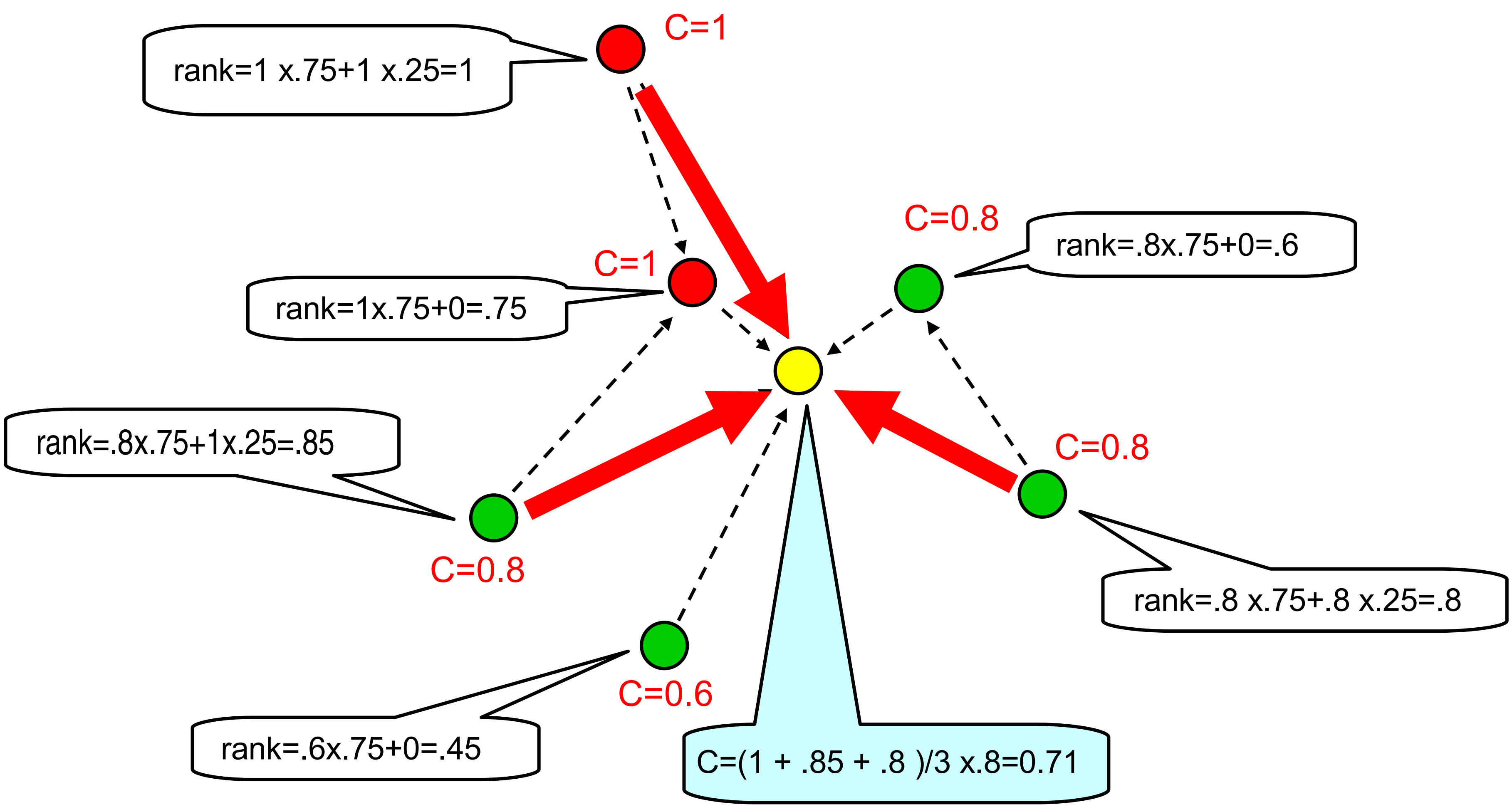
- Tri function helps only if B,C are on the same RM level
- Conclusion: B,C must be as close as possible



Confidence system

- A node estimating its position ranks landmarks through: $rank_n = C_n * 0.75 + C_{trin} * 0.25$
- Confidence of anchor nodes is 1
- Confidence of estimating nodes is the average of its landmarks' ranks multiplied by 0.8.
- C_{trin} is the confidence of the node used to calculate the deviation with n.

Confidence system



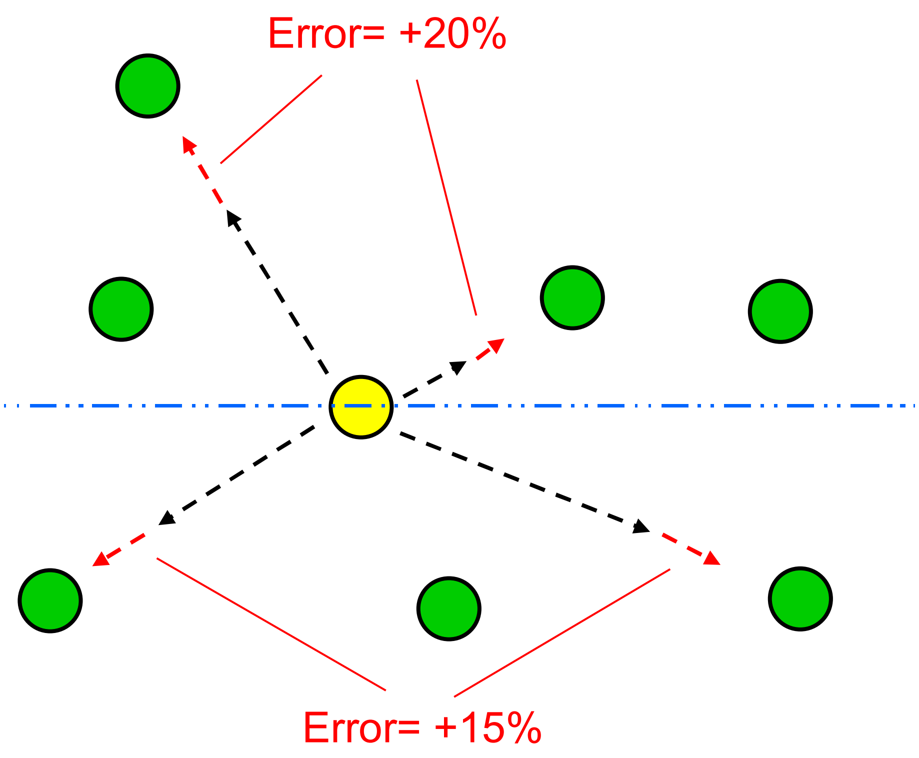
$$C_n = 0.8 * [(C_1 * 0.75 + tri_1 * 0.25) + (C_2 * 0.75 + tri_2 * 0.25) + (C_3 * 0.75 + tri_3 * 0.25)] / 3$$

Table information exchanging

- Anchors broadcast their coordinates and their deviation to other anchors.
- Estimating nodes broadcast their calculated position and its confidence.
- As every node is a potential landmark, even it's not an anchor, estimating nodes broadcast deviation information too.

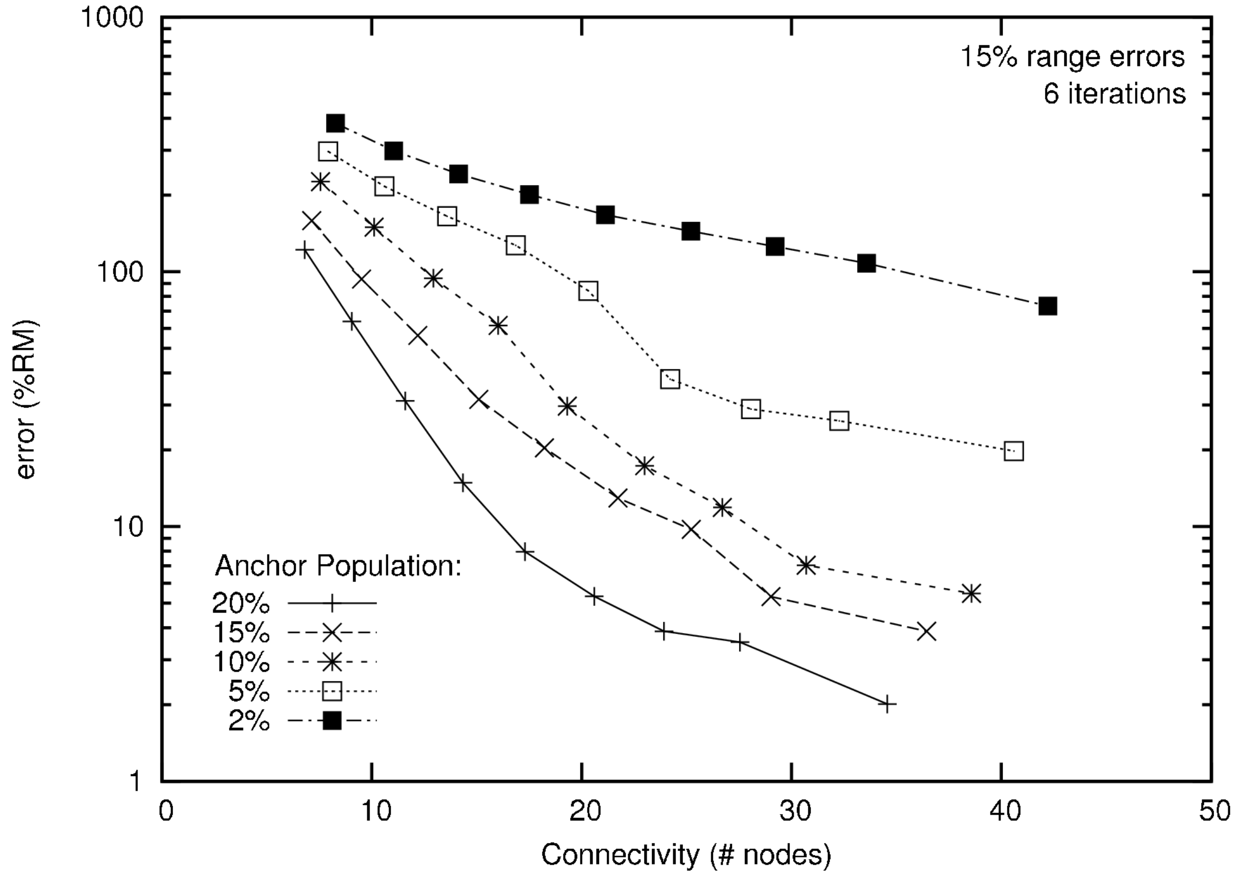
Simulation environment

- 100 nodes random distributed in 700x700
- # Anchor selected and random distributed
- Average results of 20 scenarios
- # conectivity (nodes) set by max range
- RM random error added to each node (limit to a max value)
- Irregular antenna represented by 2 hemisphere, bottom 30% less error the top part



Simulation results

- Average position error for different anchor populations after HECOPS



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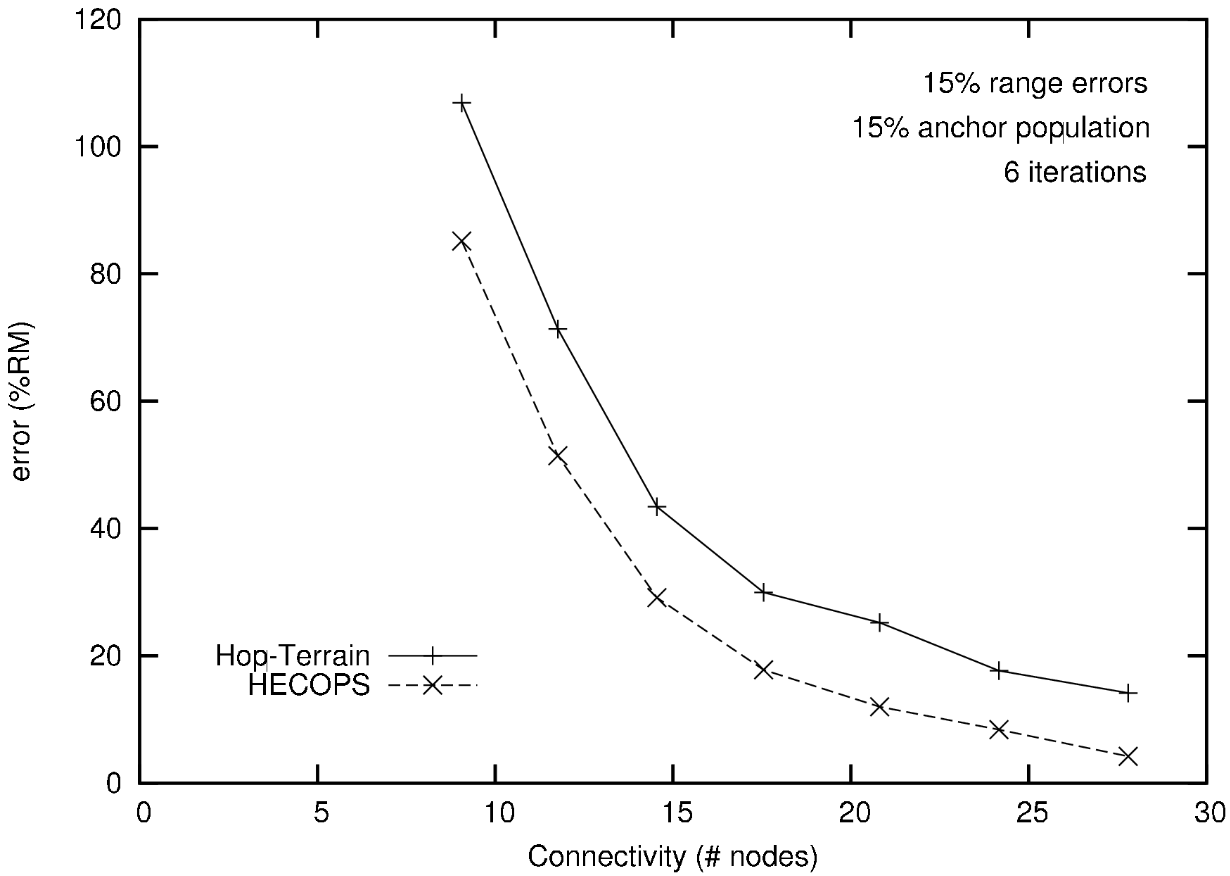
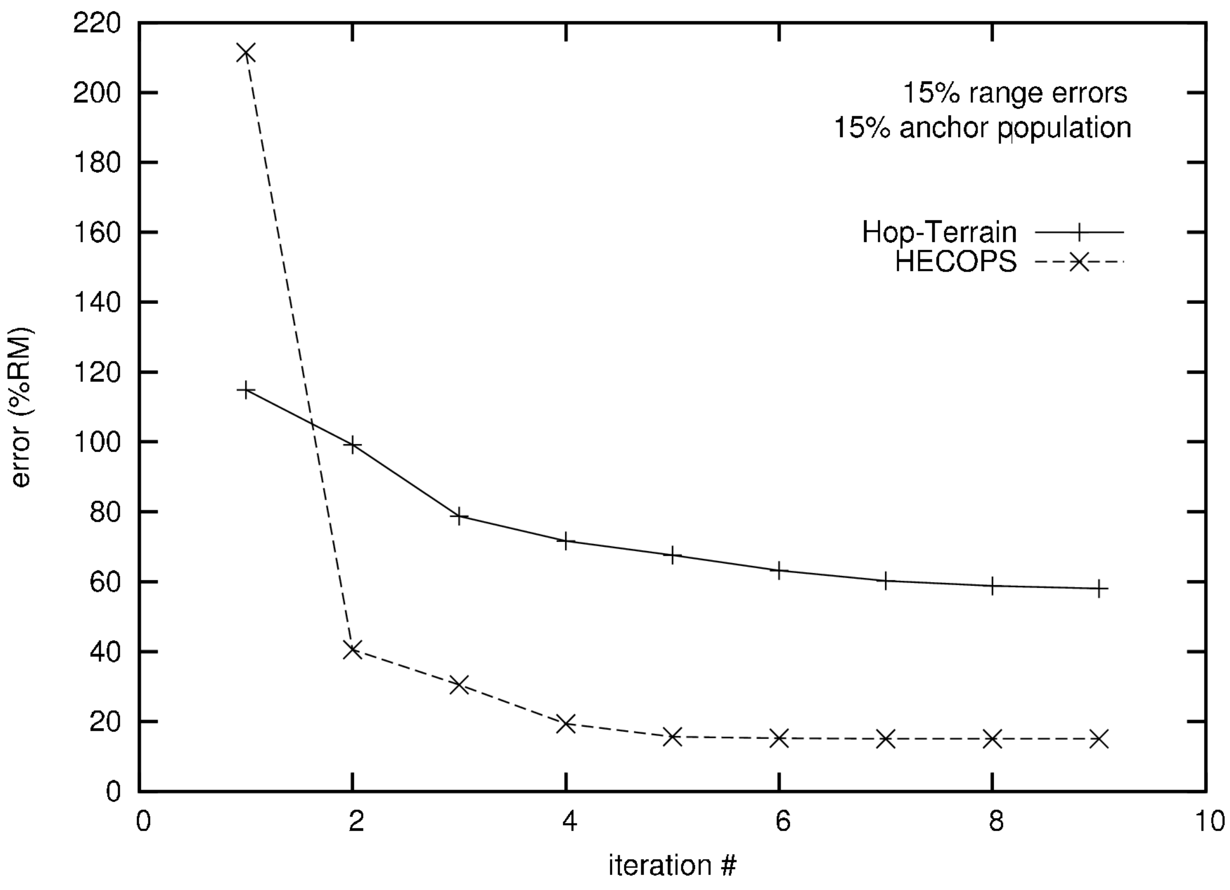
Simulation results

- Average position errors: HECOPS and HOP-Terrain



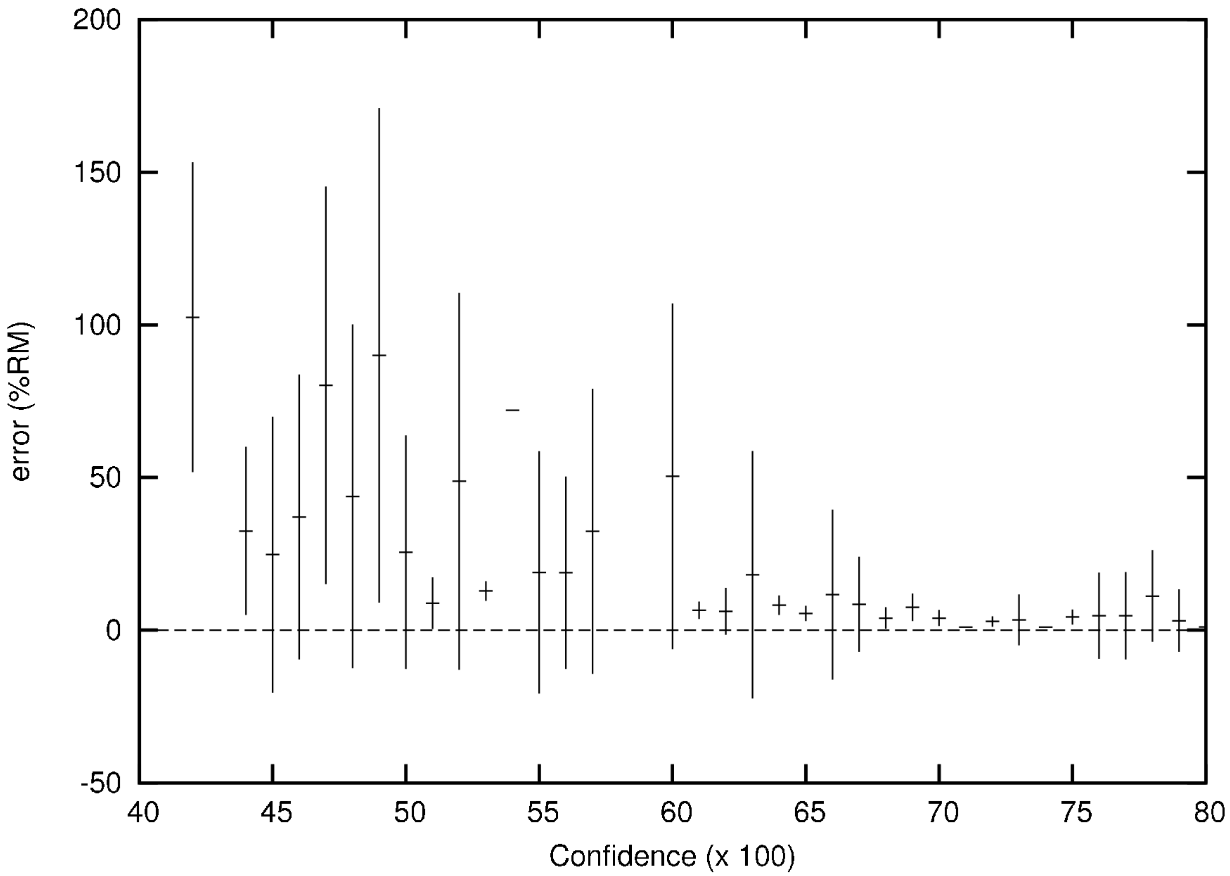
Simulation results

- Results along iterations: HECOPS and HOP-Terrain



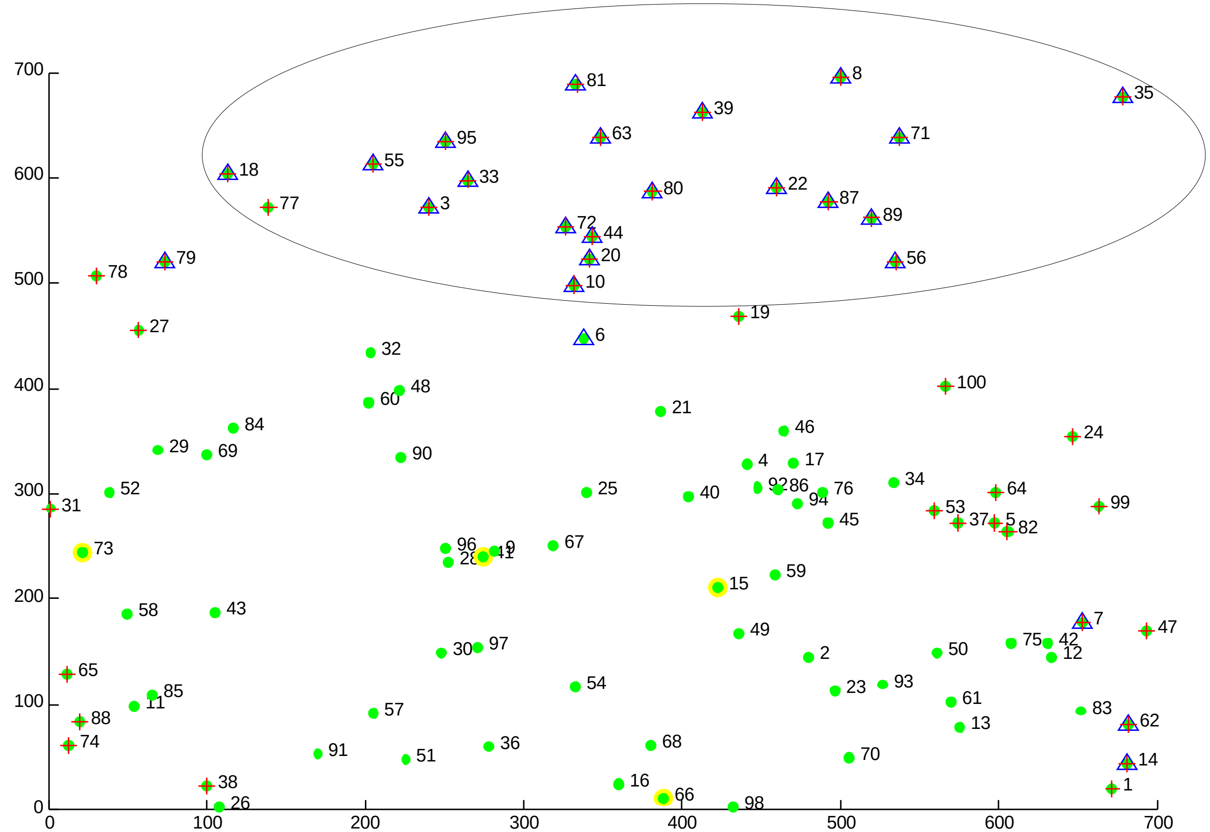
Simulation results

- Relation between confidence and positioning error



Simulation results

- Geographic position error
  (5% anchors, connectivity = 12, 5% range errors)



High error level due to distance from anchors

Conclusions

- Contribution 1: Localization algorithm (HECOPS)
  - No expensive hardware required
  - Outperforms existing Hop-Terrain
  - Low communication overhead
  - Limited error propagation
- Contribution 2: Heuristic approach
  - Innovates with tri function and confidence system
  - Establish a confidence level for each node
  - Best landmark selection