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- Design & Development Forum

Three Dimensional Localization in Wireless Sensor Networks using the Adapted Multi-Lateration Technique Considering Range Measurement Errors

G. Selda Kuruoglu*, Melike Erol*, Sema Oktug*

*CNRL: Computer Networks Research Laboratory
Department of Computer Engineering,
Istanbul Technical University, Turkey

Outline

1. Motivations
2. Localization Techniques & Problems
3. Proposed Method
4. Simulation Results
5. Conclusions

WSNs

- Medium is space, water -> wireless com.
- Several nodes (may rise up to thousands !!) :
  - Small
  - Sensing Capabilities for environment monitoring etc.
  - Low power !..
  - Low bit rate
  - Low cost (dispensable)
  - Autonomous
- Applications:

  Target Tracking, Military and Security Issues, Environmental Montoring, Health, Home, Space Exploration, Chemical Processing, Disaster Relief, etc...

➡ 3D Localization is essential in most of them!..

Localization Problem:

- Nodes are usually spread out in environment *(deployment phase)*

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- Why location information is needed ??

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- Why location information is needed ?? ***data tagging***

- Location info. can also be used in *position-aware routing algorithms*

Some ‘Localization’ Terms:

- **Physical Position:** numeric coordinate system
- **Symbolic Location:** Relative or application related info
- **Anchor ≡ beacon ≡ landmark:** know their own position
- **Localized vs Centralized Computation**
  - Computations are done by? the nodes or a common center
- **Accuracy, Precision**
- **Range-free :** proximity based
- **Range-based: precise distant measurements**
- **Single/**Multi **Hop**
- **Iterative**

Range- Based Localization Schemes:

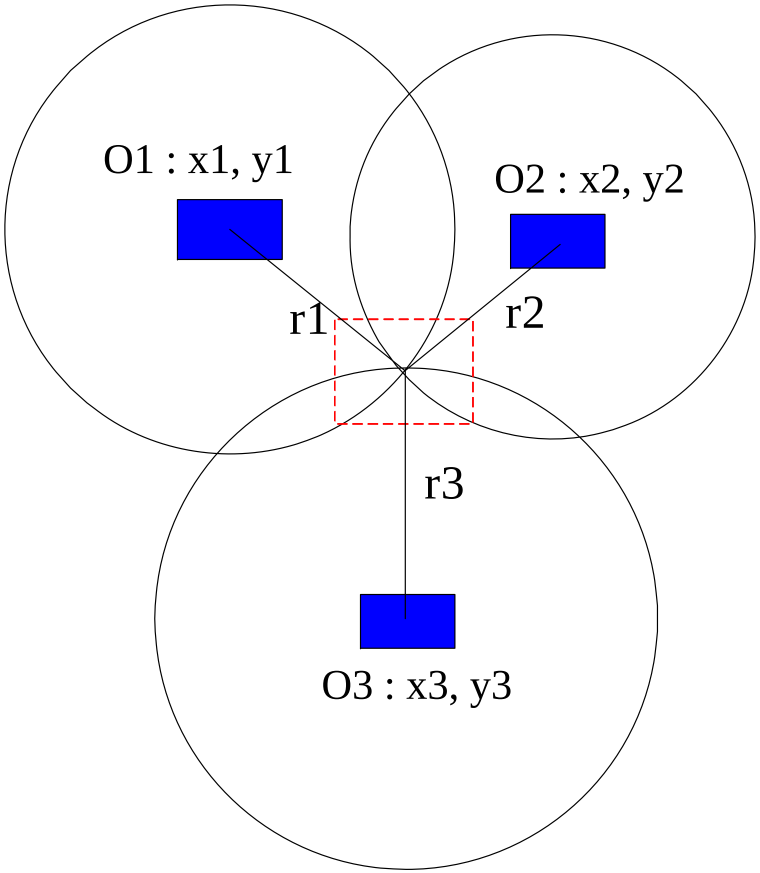
- Uses distance measurements retrieved by:
  - ❖ RSSI : Received Signal Strength Indicator
  - ❖ ToA : Time of Arrival
  - ❖ TDoA : Time Difference of Arrival
  - ❖ AoA : Angle of Arrival
  - ❖ Dv Hop : Approximation…

What about measurement errors ??

- Multi-Lateration*
- Bounding-Box
- APIT (Approximate point in triangle)
- Arithmetic (Blusu et al, GPS free localization)

How to Calculate Location?? (Range-Based)

- **Lateration, Multi – Lateration (2D demonstration)**
  - Measure distances from 3 anchors
  - Possible location points form a circle
  - the intersection of those 3 circles: real loc.
  - Used for performance comparisons of AML



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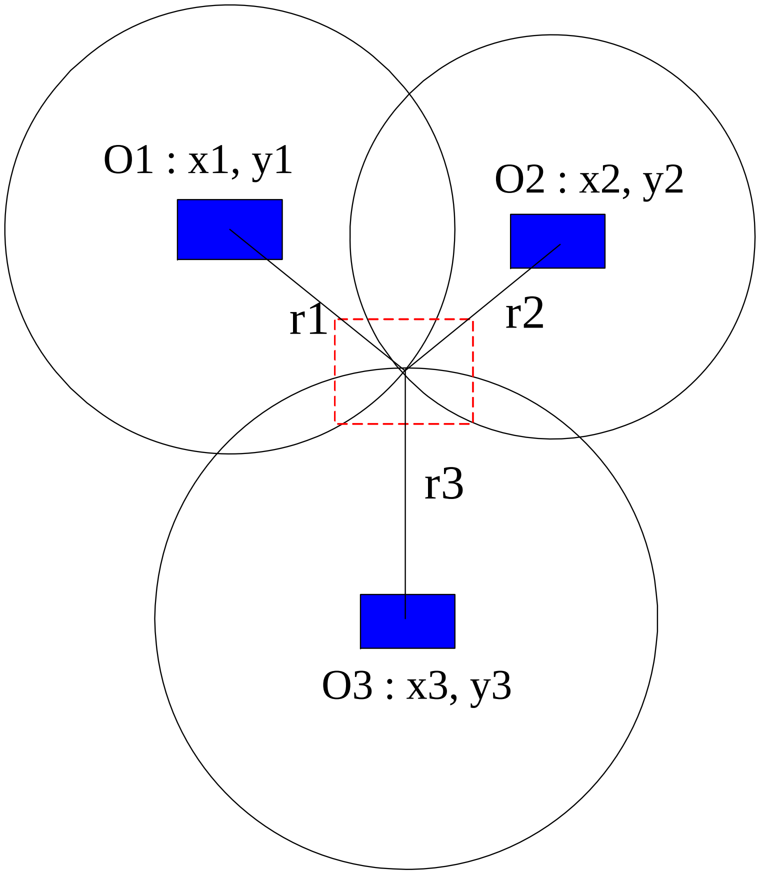

Problem :

which one if the the intersection will not result in a single point → **multilateration** (more distance measurements)

Multi-Lateration with Distance Measurement Errors:

Sphere Equations:

$$(x_1 - x_U)^2 + (y_1 - y_U)^2 + (z_1 - z_U)^2 = r_1^2 \qquad \text{I}$$

$$(x_2 - x_U)^2 + (y_2 - y_U)^2 + (z_2 - z_U)^2 = r_2^2 \qquad \text{II}$$

$$(x_3 - x_U)^2 + (y_3 - y_U)^2 + (z_3 - z_U)^2 = r_3^2 \qquad \text{III}$$

$$(x_4 - x_U)^2 + (y_4 - y_U)^2 + (z_4 - z_U)^2 = r_4^2 \qquad \text{IV}$$

I-IV: $(x_1 - x_U)^2 - (x_4 - x_U)^2 + (y_1 - y_U)^2 - (y_4 - y_U)^2 + (z_1 - z_U)^2 - (z_4 - z_U)^2 = r_1^2 - r_4^2$

...

$$2(x_4 - x_1)x_U + 2(y_4 - y_1)y_U + 2(z_4 - z_1)z_U = (r_1^2 - r_4^2) - (x_1^2 - x_4^2) - (y_1^2 - y_4^2) - (z_1^2 - z_4^2)$$

II-IV: $(x_2 - x_U)^2 - (x_4 - x_U)^2 + (y_2 - y_U)^2 - (y_4 - y_U)^2 + (z_2 - z_U)^2 - (z_4 - z_U)^2 = r_2^2 - r_4^2$

...

$$2(x_4 - x_2)x_U + 2(y_4 - y_2)y_U + 2(z_4 - z_2)y_U = (r_2^2 - r_4^2) - (x_2^2 - x_4^2) - (y_2^2 - y_4^2) - (z_2^2 - z_4^2)$$

III-IV:

$(x_3 - x_U)^2 - (x_4 - x_U)^2 + (y_3 - y_U)^2 - (y_4 - y_U)^2 + (z_3 - z_U)^2 - (z_4 - z_U)^2 = r_3^2 - r_4^2$

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Generalize for more anchors,
Rewrite as a linear matrix equation: ➡

Generalized Form:

$$2\underbrace{\begin{pmatrix} x_n - x_1 & y_n - y_1 & z_n - z_1 \\ \dots & \dots & \dots \\ x_n - x_{n-1} & y_n - y_{n-1} & z_n - z_{n-1} \end{pmatrix}}_{A}\underbrace{\begin{pmatrix} x_U \\ y_U \\ z_U \end{pmatrix}}_{x} - \underbrace{\begin{pmatrix} (r_1^2 - r_n^2) - (x_1^2 - x_n^2) - (y_1^2 - y_n^2) - (z_1^2 - z_n^2) \\ \dots \\ (r_{n-1}^2 - r_n^2) - (x_{n-1}^2 - x_n^2) - (y_{n-1}^2 - y_n^2) - (z_{n-1}^2 - z_n^2) \end{pmatrix}}_{b}$$

$$= \underbrace{\begin{pmatrix} 0 \\ \dots \\ 0 \end{pmatrix}}_{\text{error vector}}$$

$$\left(\|Ax-b\|_2\right)^2 = (Ax-b)^T(Ax-b)$$

$$= x^T A^T Ax - 2x^T A^T b + b^T b$$

$$2A^T Ax - 2A^T b = 0 \Leftrightarrow \boxed{A^T Ax = A^T b}$$

Minimize the total error -> minimize norm 2 of error_vec

known as LSE problem.

3D-AML: Three Dimensional Adapted Multilateration

- Aim: reduce the computational cost, increase accuracy
- uses beacon spheres as well (range-based)

Method Overview:

1. First step: Arbitrarily pick three intersecting spheres

   Gives two/one intersection points

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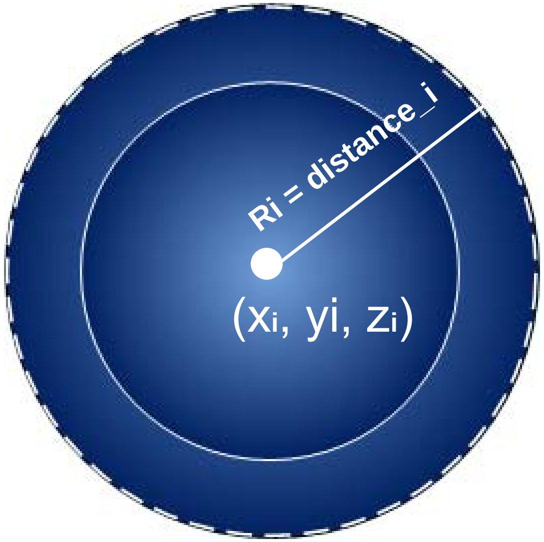
3. Move towards next (forth) sphere
4. Try to refine position estimation with leaving beacons

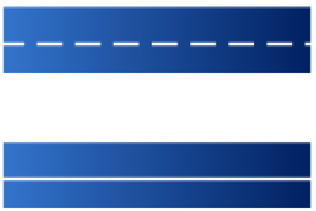
AML is implemented in three steps: *intersection and elimination*, *first estimation* and *refinement*.

"Intersection & Elimination" Phase



- Start with intersecting 3 spheres.
- Why not two? This gives circle equation, latter gives two intersection points

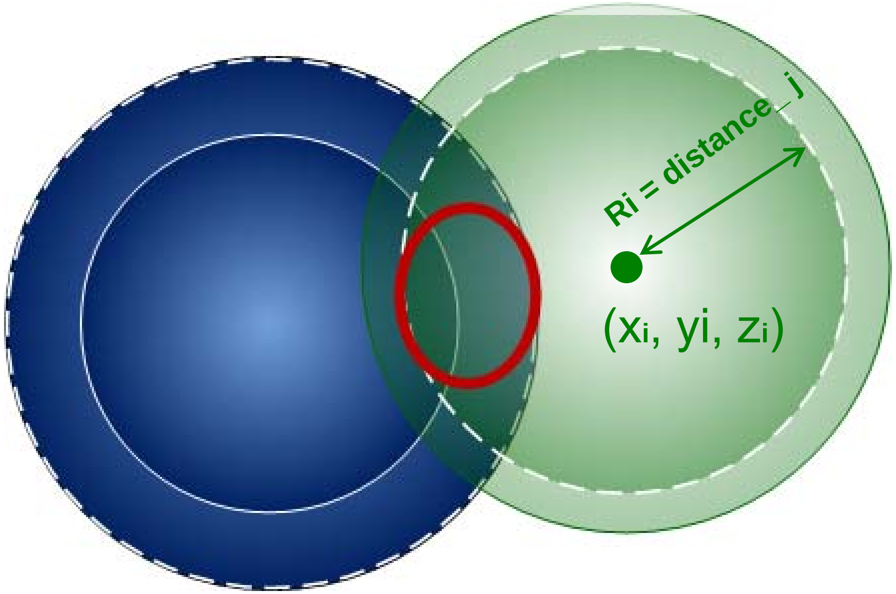
Anchor i (at (x_i,y_i,z_i)):



REAL Dist.s

MEASURED Dist.s

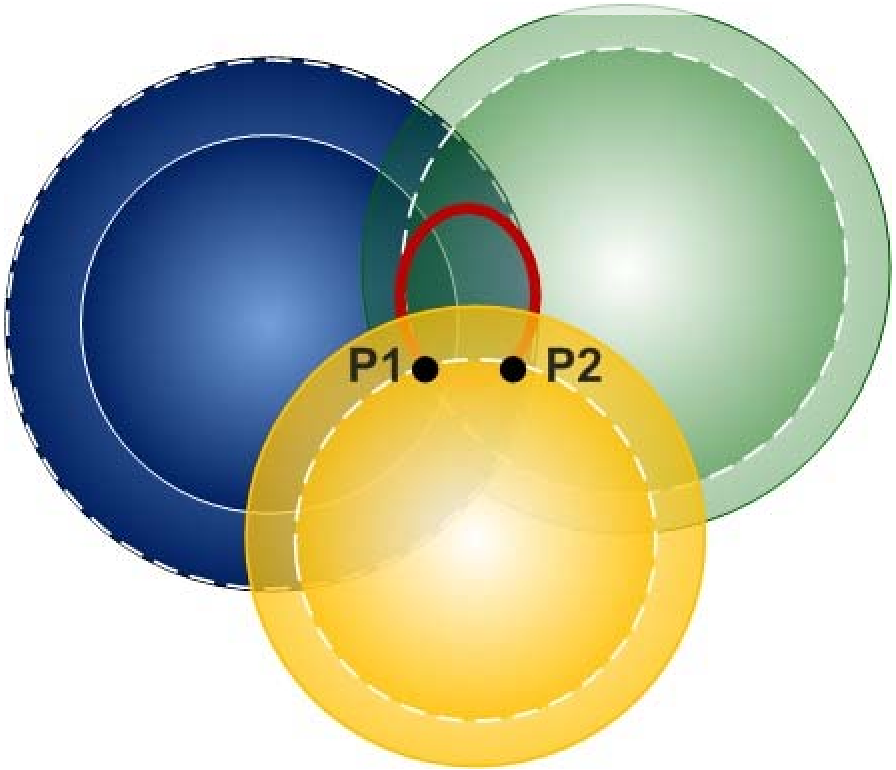
"Intersection & Elimination" Phase



Anchor j (at (xj,yj,zj))

Intersection of two sphere surfaces randomly chosen from the anchor set : circle in red

“Intersection & Elimination” Phase

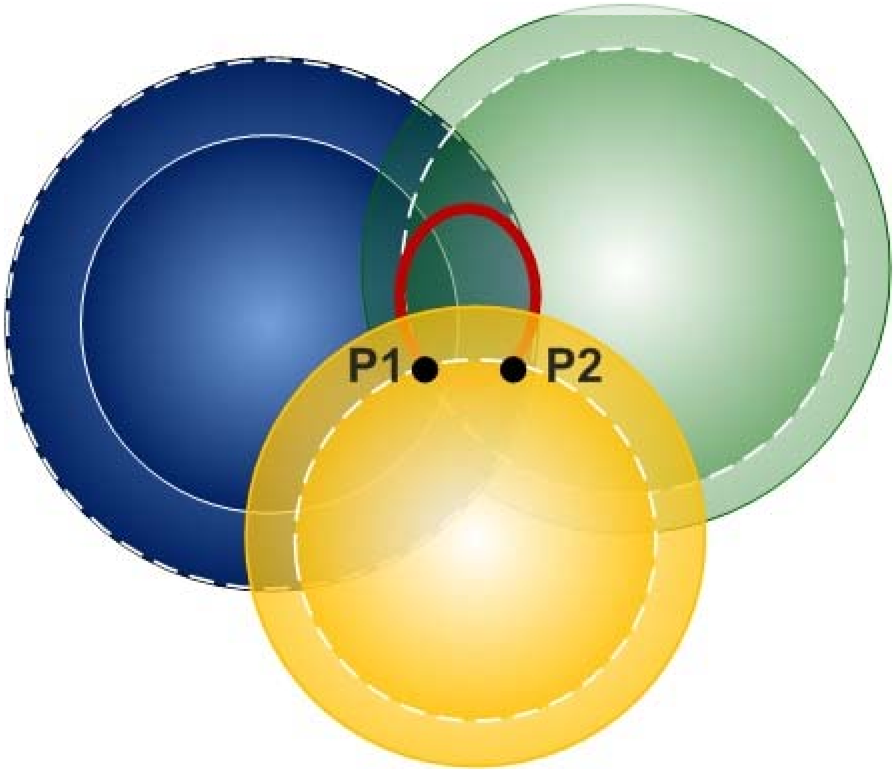


Intersection of three sphere surfaces : P1 & P2

(Intersection phase is over…)

Anchor k (at (xk,yk,zk))

“Intersection & **Elimination**” Phase

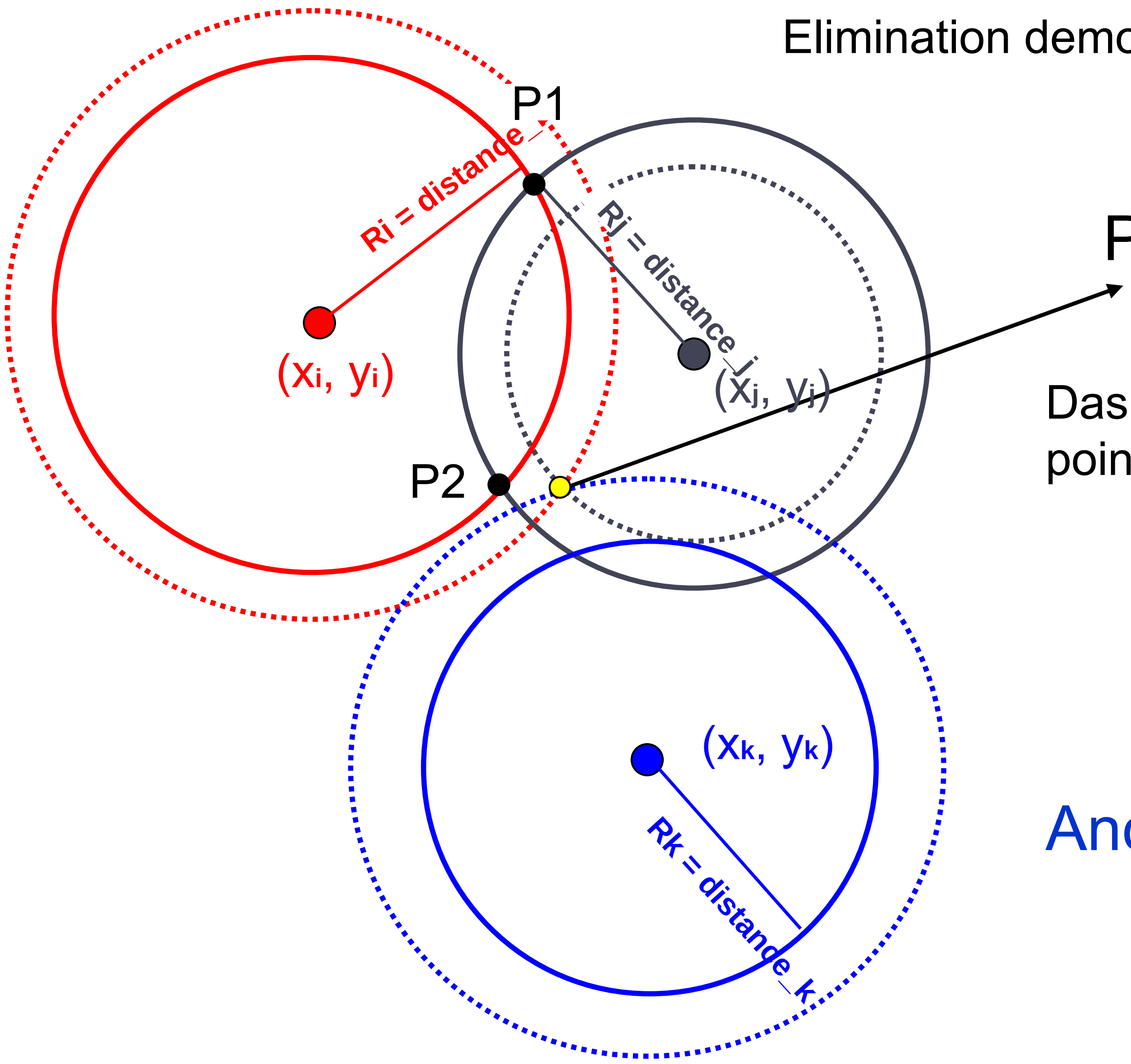


at elimination phase we have to choose between
P1 & P2:

Principle: Choose nearest one to the next anchor

"Intersection & Elimination" Phase

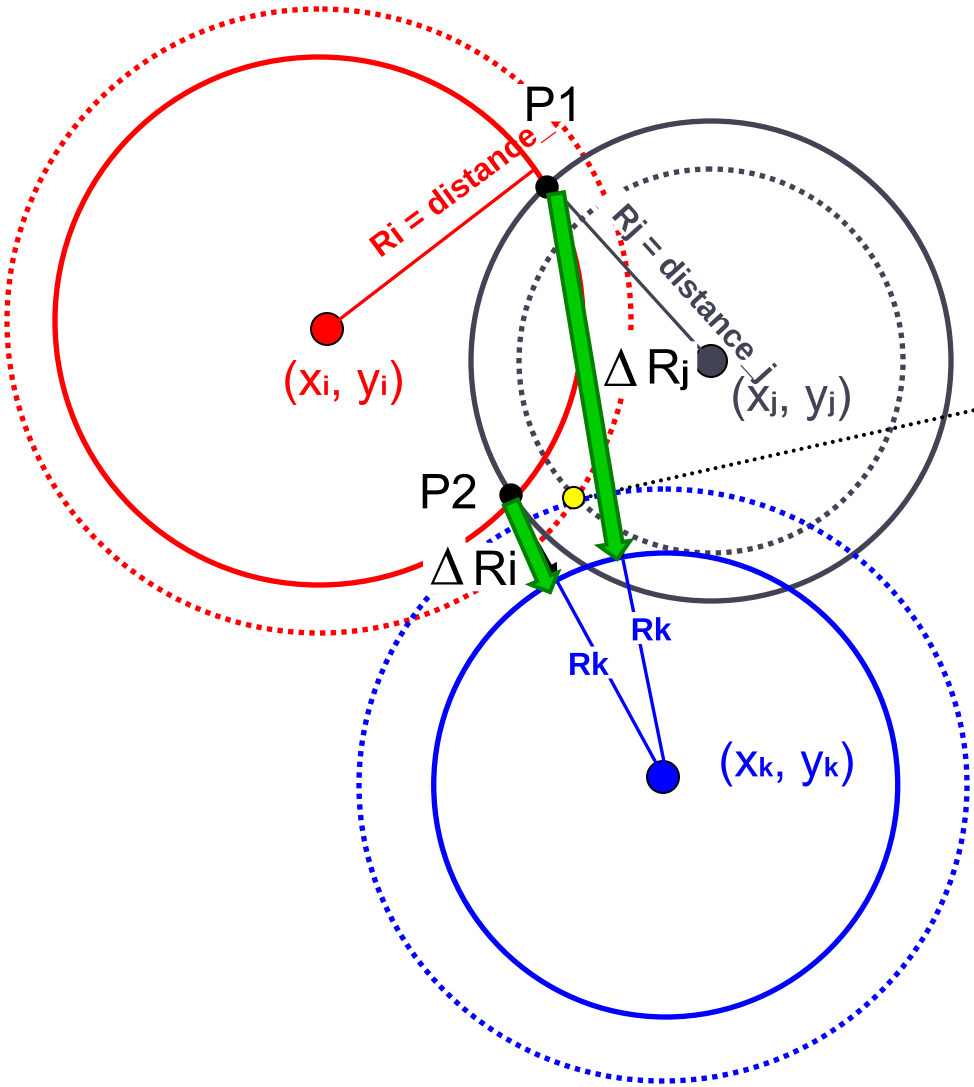
Elimination demonstration in 2D:



Dashed lines intersect at one point as ideal !...

Anchor k

"Intersection & **Elimination**" Phase



(ΔR values are defined with same principle as in 2D: distance to next anchor sphere as:)

$$\Delta R = \sqrt{(x_p - x_s)^2 + (y_p - y_s)^2 + (z_p - z_s)^2} - r_k^{\,2}$$

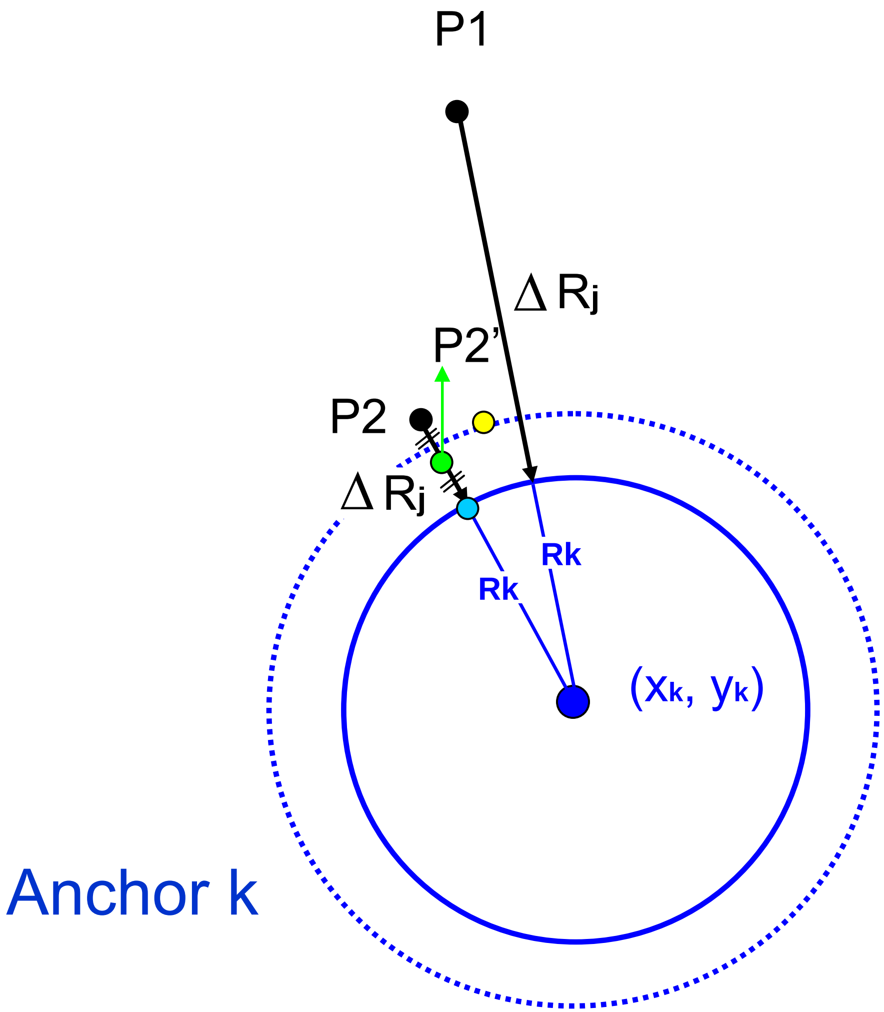
Ps : Real Pos.

Δ Ri < Δ Rj

Select P2

Anchor k

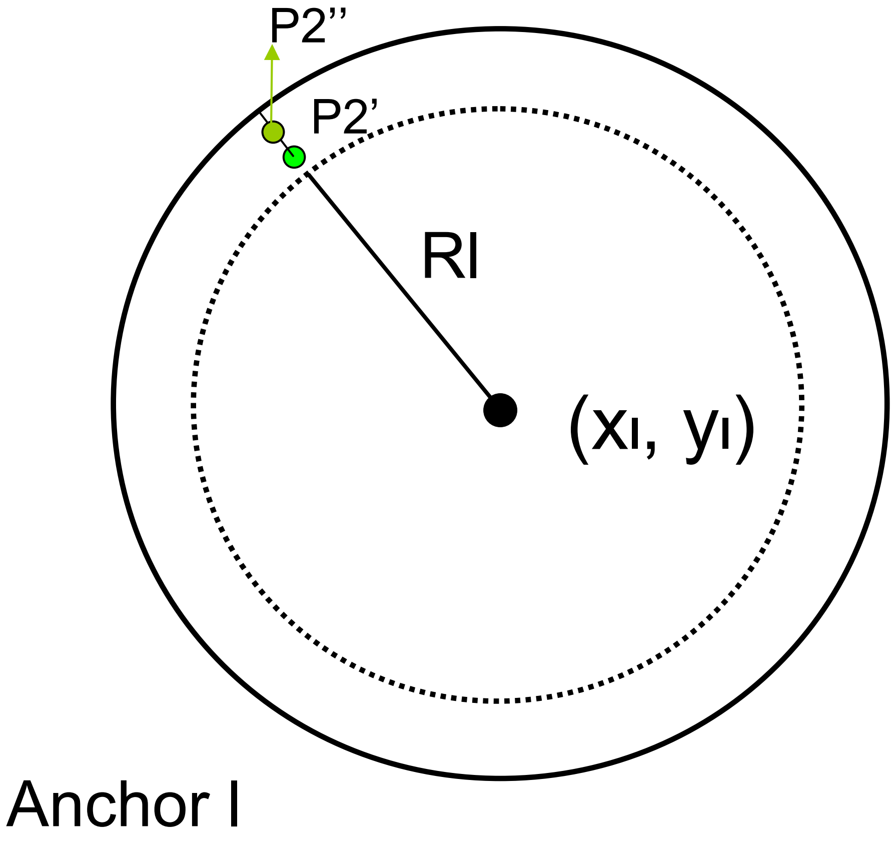
"First Estimation" Phase



- P2 is selected.
- " Move p. to the middle of the line connecting p. and the nearest point to p. (light blue p.) on the third circle " *(sphere surface in 3D)*

MOVE P2 to P2'

"Refinement" Phase/s



- Use leaving beacons.
- Same principle
- I.e. Use 4th beacon: Move P2' to P2''

Notes:

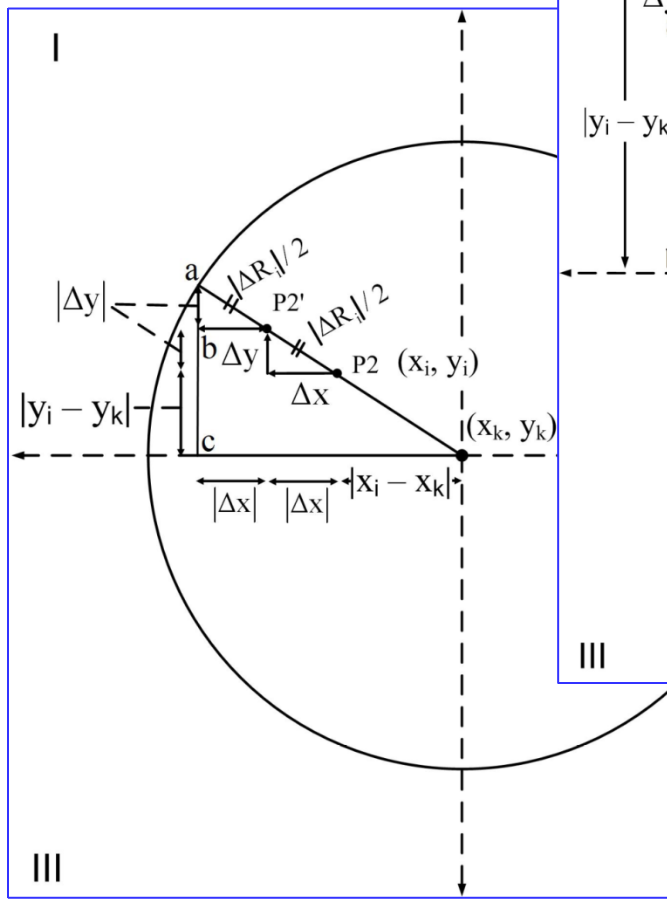
- P2' is inside beacon circle
- Δ Rl is negative

Movement Formulations:

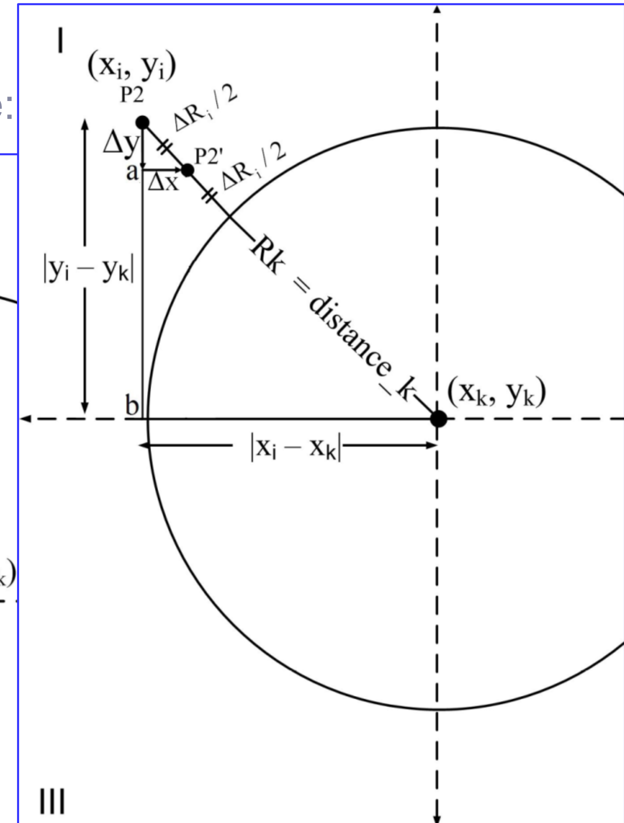
- Movement formulations differ when point is inside/outside beacon circle/sphere

- Besides, sign of the displacement differs in
4 quarters in 2D,
8 quarters in 3D
defined from the center of the considered circle/sphere

P2, so P2' are inside k^{th} circle:



P2, so P2' are outside k^{th} circle:



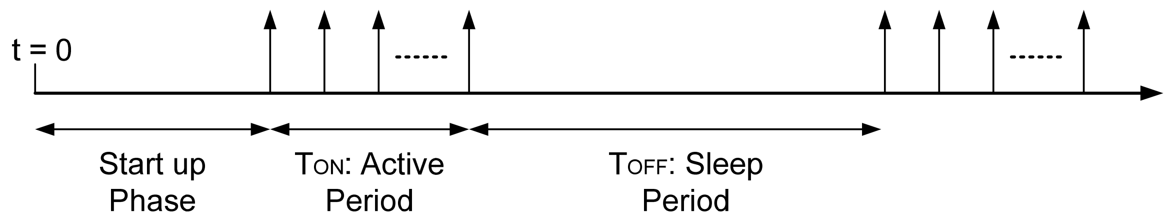
Movement Formulations:

Point is inside the sphere:	Point is outside the sphere:
$RR = \frac{\frac{\lvert \Delta R_i \rvert}{2}}{\Delta R_i + R_k}$ $\frac{\lvert \Delta_x \rvert}{\lvert x_k - x_i \rvert} = RR \Rightarrow \lvert \Delta_x \rvert = RR * \lvert x_k - x_i \rvert$ $\frac{\lvert \Delta_y \rvert}{\lvert y_k - y_i \rvert} = RR \Rightarrow \lvert \Delta_y \rvert = RR * \lvert y_k - y_i \rvert$ $\frac{\lvert \Delta_z \rvert}{\lvert z_k - z_i \rvert} = RR \Rightarrow \lvert \Delta_z \rvert = RR * \lvert z_k - z_i \rvert$	$RR = \frac{\frac{\lvert \Delta R_i \rvert}{2}}{R_k}$ $\frac{\lvert \Delta_x \rvert}{2 * \lvert \Delta_x \rvert + \lvert x_k - x_i \rvert} = RR \Rightarrow \lvert \Delta_x \rvert = \frac{RR * \lvert x_k - x_i \rvert}{1 - (2 * RR)}$ $\frac{\lvert \Delta_y \rvert}{2 * \lvert \Delta_y \rvert + \lvert y_k - y_i \rvert} = RR \Rightarrow \lvert \Delta_y \rvert = \frac{RR * \lvert y_k - y_i \rvert}{1 - (2 * RR)}$ $\frac{\lvert \Delta_z \rvert}{2 * \lvert \Delta_z \rvert + \lvert z_k - z_i \rvert} = RR \Rightarrow \lvert \Delta_z \rvert = \frac{RR * \lvert z_k - z_i \rvert}{1 - (2 * RR)}$
$\Delta_x, \Delta_y, \Delta_z$'s sign: identical to the sign of $!(x/y/z_k - x/y/z_i)$	$\Delta_x, \Delta_y, \Delta_z$'s sign: identical to the sign of $(x/y/z_k - x/y/z_i)$

Simulator Design

- C++, Discrete Event Simulator

  3 Event Types: *sleep, wake up, try localization*



- Iterative Loc.
- Beacon usage limitation to 5 in AML-5
- Error_percentage in error model: 20%,30%,40%

(Gaussian error modelling with zero mean and variance=realDistance * errorMaxPercentage)

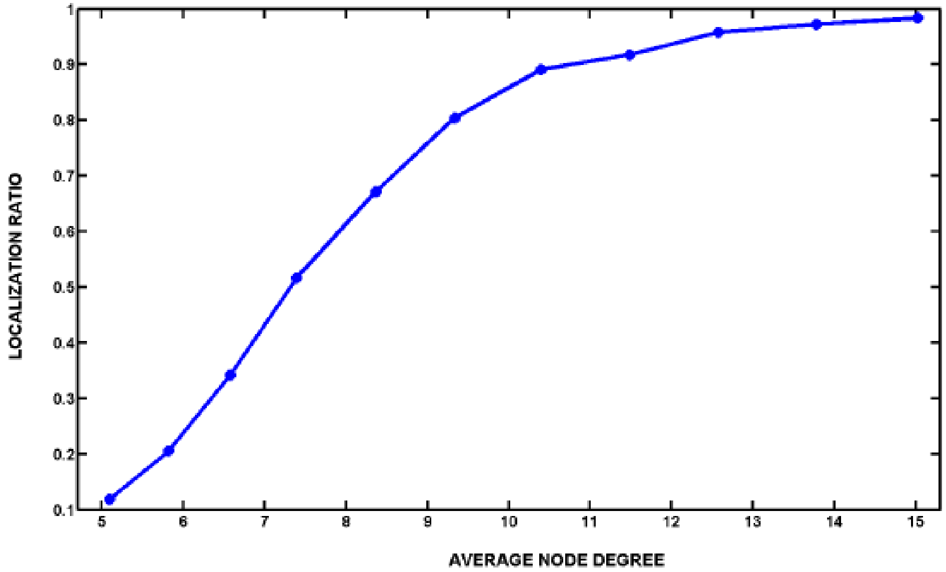
- Each point represents 10 sims at same environmental cond. with different rng seeds

Environment:

- 200 sensor nodes in a terrain of 100*m* * 100m * 100m (uniform randomly deployed)
- Initial beacon percentage is %20
- RR varied from 20m to 30m with 1m (affects node degree!)
- 2 schemes in 3 environments were compared:
  - Schemes:
    - Multilateration (all and 5 beacons used)
    - AML (all and 5 beacons used)
  - Environments:
    - error percentages: 20, 30 and 40%

Localization ratio:

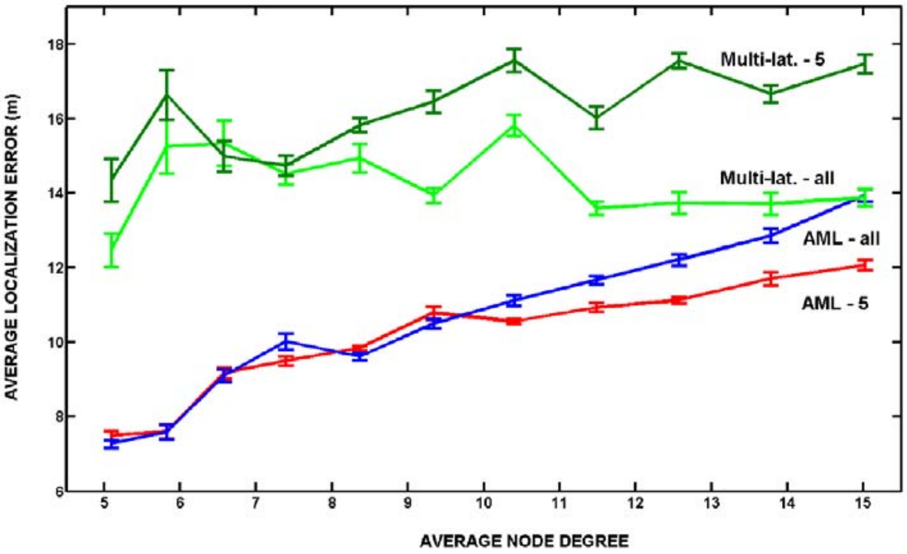
ratio of localized nodes over initial non-beacon nodes



As node degree increases, prob. of anchor neighbor rises

Localization error: Mean of location estimation errors

errorPercentage: 20%



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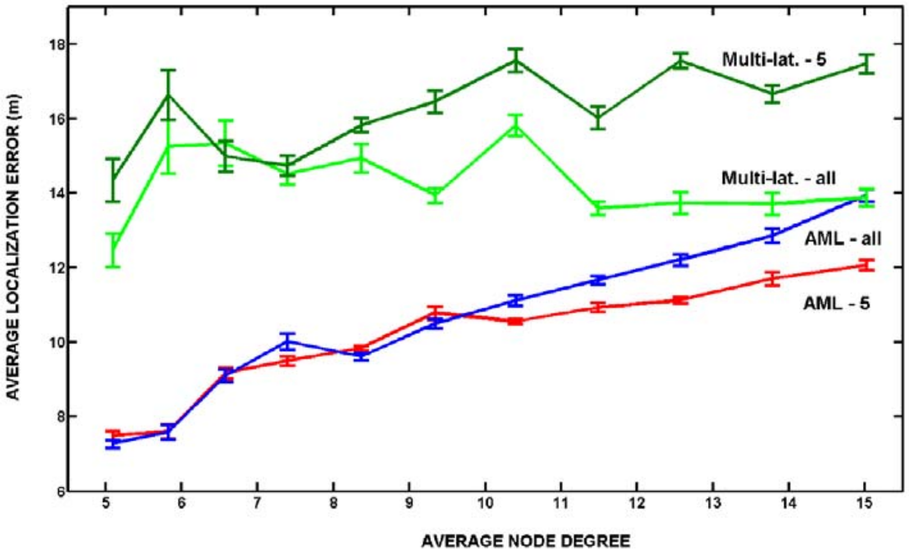
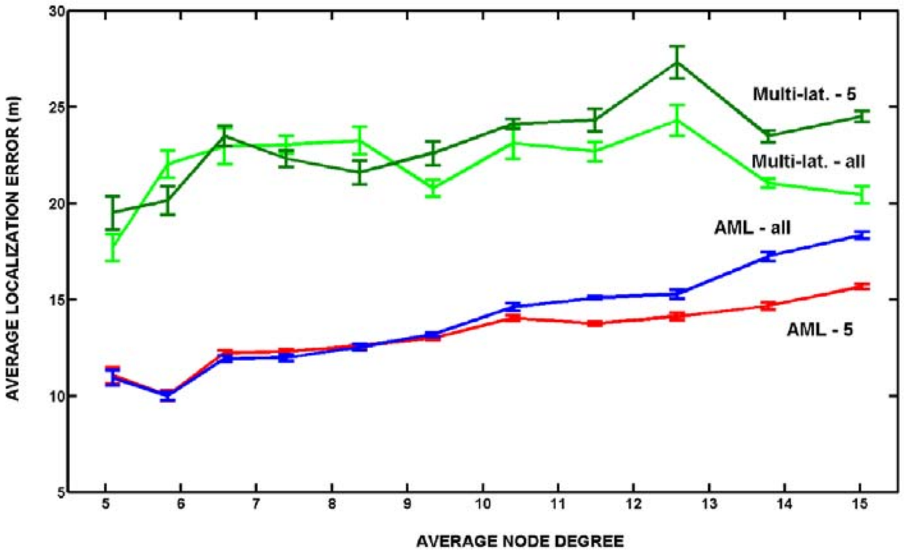


errorPercentage: 30%



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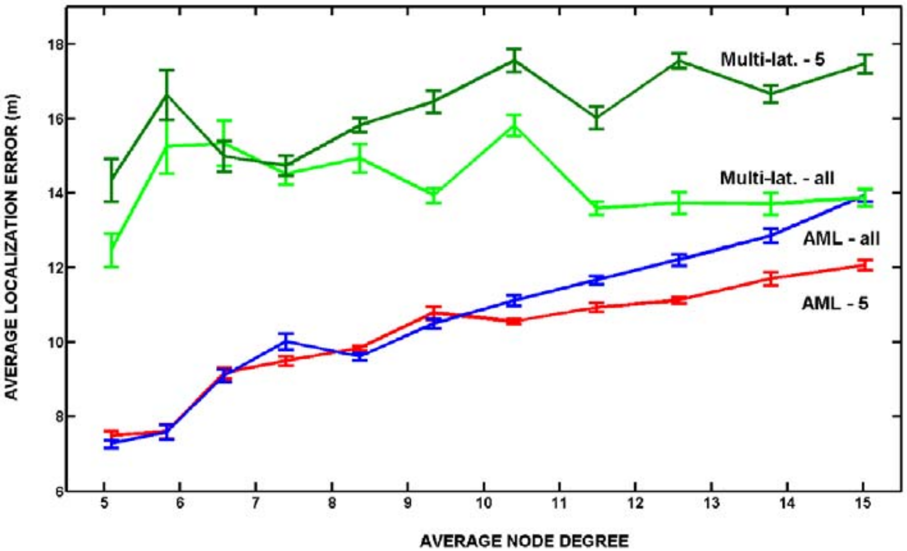

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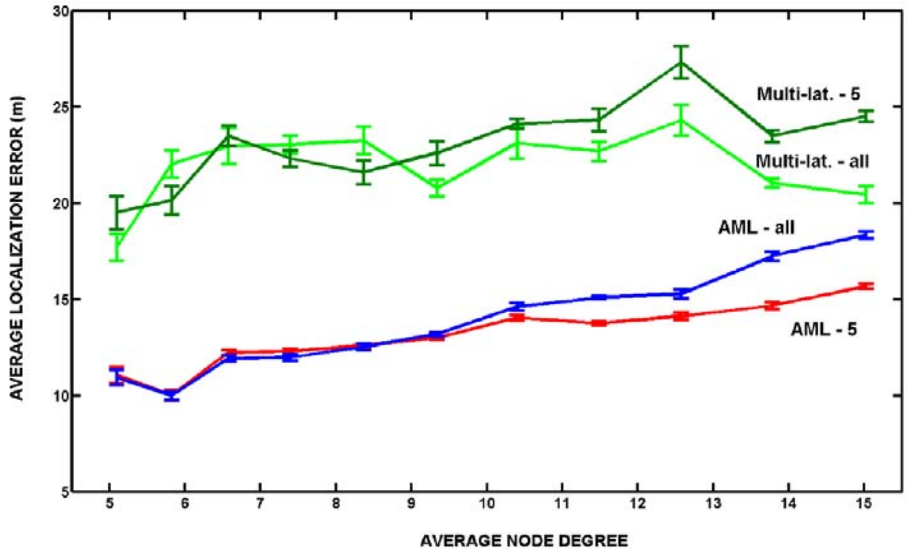
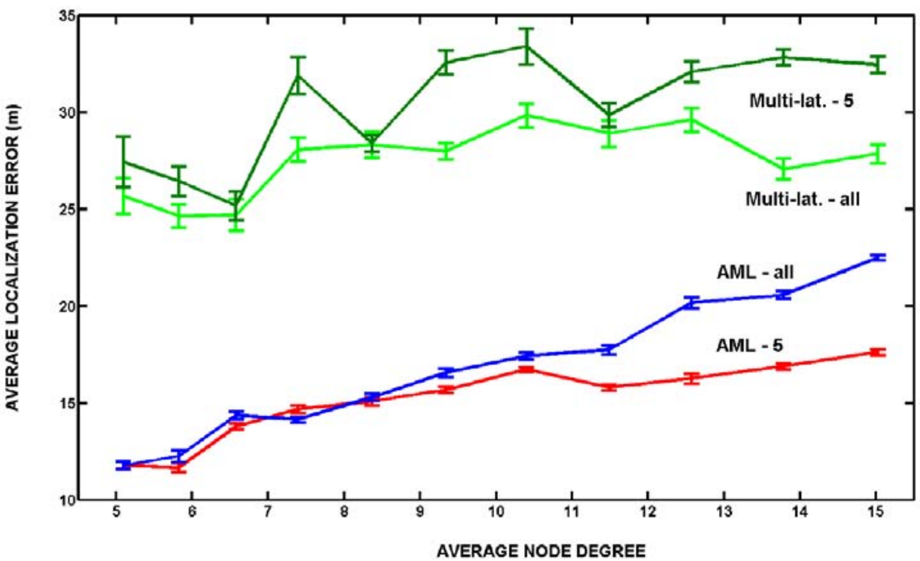


errorPercentage: 40%



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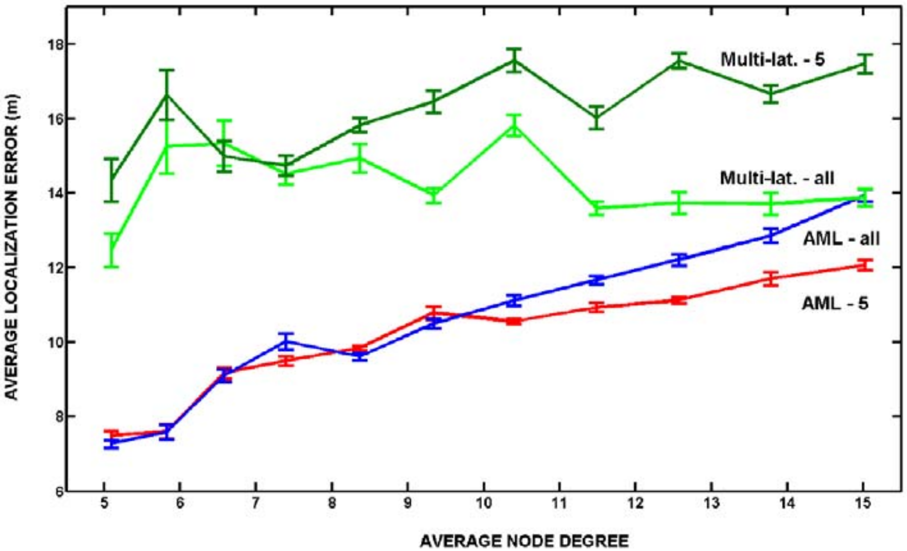

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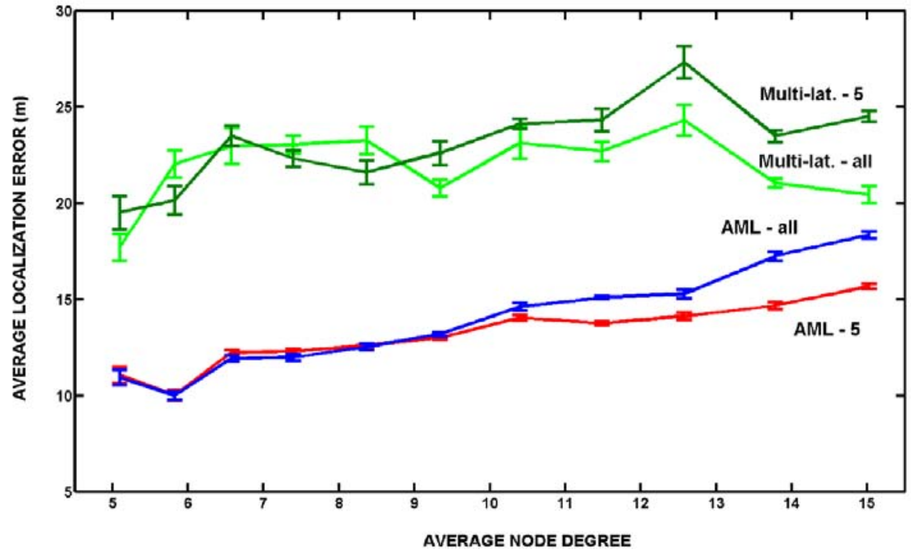
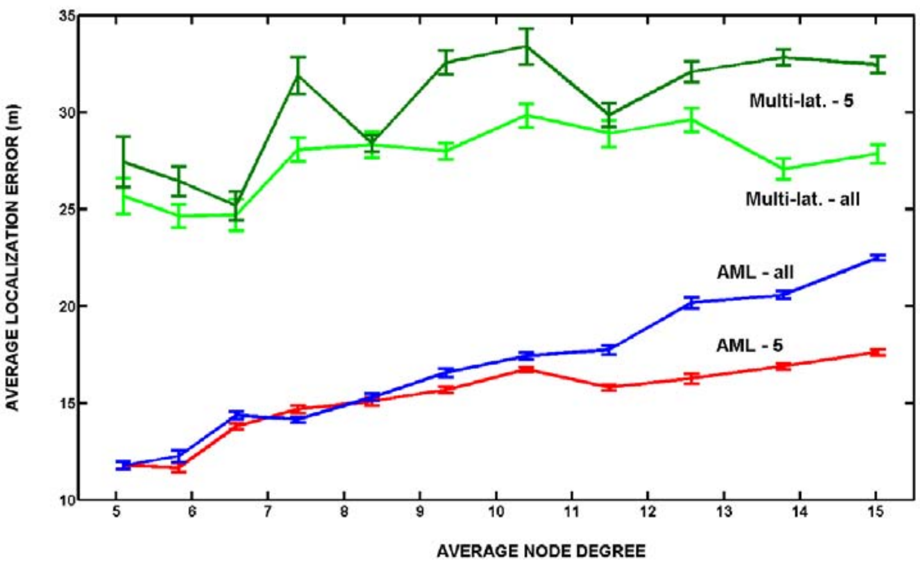


errorPercentage: 40%



- Anchor usage: favor for multilateration but not for AML at higher node degrees
- *errorPercentage* increases loc errors in all schemes..

- sensor technology ⬆ => more capable nodes => Wide Usage Area
- "Localization" : key concept for interpreting the gathered data
- 3D version of a new approach named AML is developed and tested for loc. problem

AML:

- has lower computatinal cost
- More robust (avg loc error)
- Disadvantage comes from heuristics (1st step)
- Can be used when GPS is not available but have some distance measurements

Any Questions ?

THANKS …

Contact info for the authors:

G. Selda KURUOĞLU, kuruoglug@itu.edu.tr

Melike EROL, melike.erol@itu.edu.tr

Sema Oktug, oktug@itu.edu.tr