A Distributed Range-Free Localization Scheme for Wireless Sensor Networks

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Outline

- Introduction
  - Related Work and Motivation
- Distributed Range-Free Localization Scheme
- Simulation Result
- Conclusion

Introduction

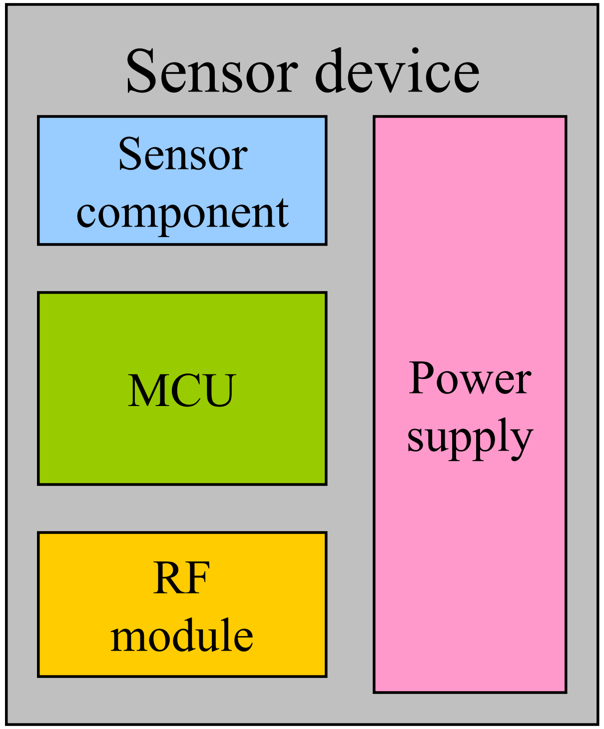
- WSN: A new generation of massive-scale sensor networks suitable for a wide range of applications is brought forth by
  - Advances in MEMS (micro-electromechanical system technology)
  - Embedded microprocessors and RF module

Introduction of Mote

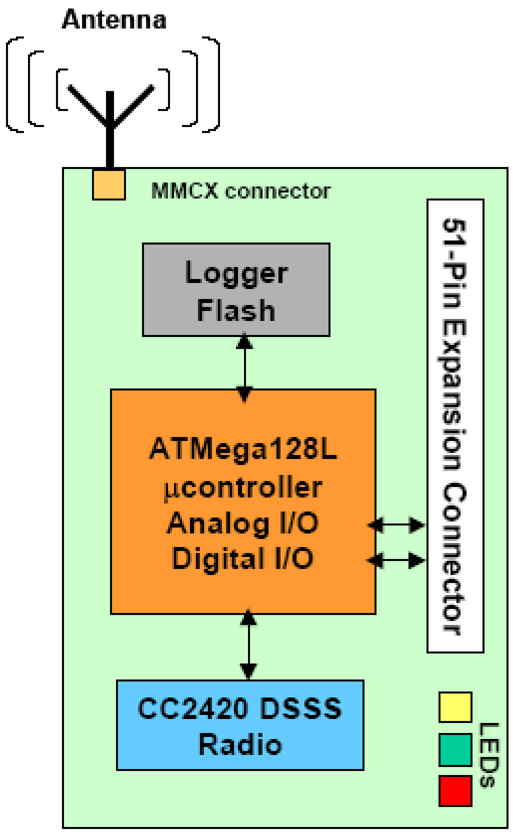
- Mote modules were developed by U.C. Berkeley and Crossbow Technology Inc.
- Power, size, and cost constrained
  - Slow clock cycles of microcontroller
  - Small memory
  - Small number of HW controllers
- TinyOS

Sensor Devices

- Main components:
  - Micro-processor (MCU)
  - Micro-sensor
  - Micro-radio (RF module)
  - Limited power supply



MICAz (Zigbee)



Features of MICAz (Zigbee)

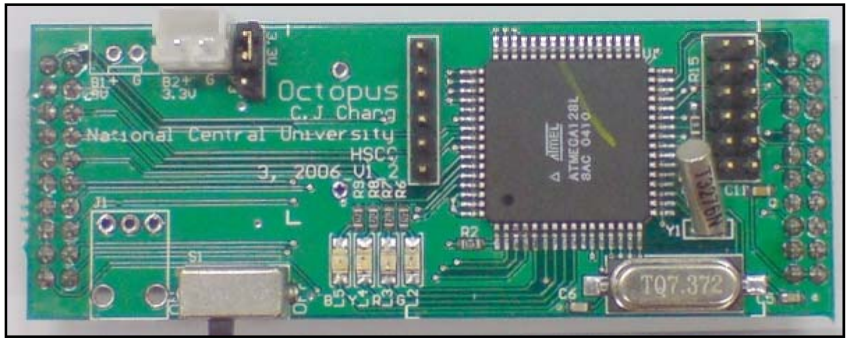
- Atmel ATmega128L 8-bit micro-controller
- 128KB Program Flash Memory
- 4 KB SRAM
- IEEE 802.15.4 radio offers both high speed (250 kbps) and hardware security (AES-128)
- 2400MHz to 2483.5 MHz band radio transceiver

Introduction of Tmote Sky

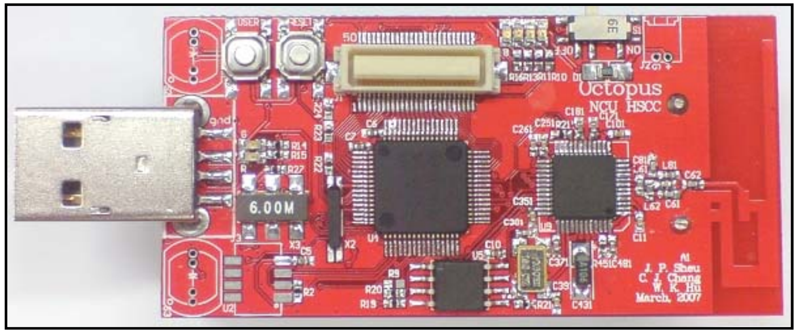
- Hardware features of sensor nodes
  - CC2420 - IEEE 802.15.4 wireless transceiver
  - 16-bit MSP430 microcontroller core @8MHz
  - 40KB in-system programmable flash,10KB RAM, ADC 12-Bit 8 Channels
  - Expandable flash memory – up to 1 Mbytes
  - A connector with 50 expansion I/O pins

Self-Designed Sensor Nodes

- Octopus I
  - Compatible with **MICAz**
- Octopus II
  - Compatible with **Tmote Sky**



Octopus I

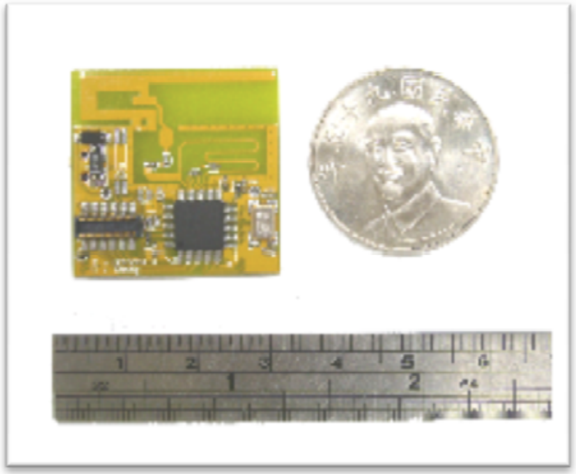


Octopus II

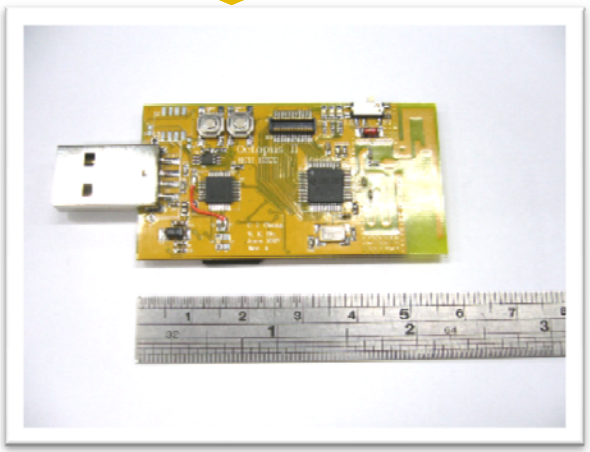
Self-Designed Sensor Nodes

- Simple Node: 8051 + CC2431

Without USB



With USB



WSNs Applications

- Environment monitoring
  - Forest monitoring
  - Climate monitoring
  - Noxious gas detection
- Habitat monitoring
  - Animal migrate route
- Structural monitoring
  - Buildings and Ships
- Healthy monitoring
- Military applications

Localization

- For several sensor network applications, including target tracking and habitat monitoring knowing the exact location where information was collected is critical
- The value of the information collected can be enhanced if the location of the sensors where readings were made is also available

Localization (cont.)

- How To Get Position?
  - Just assume that, don’t have any reason or,
  - The placement of all nodes are regular topology or,
  - All nodes equipped with GPS or,
  - Inferring positional information from some constraints or condition

GPS

- GPS build nodes localize themselves within a few meter's accuracy by listening to signals emitted by a number of satellites
- GPS's cons
  - Expensive
  - Difficult to incorporate into every sensor node
  - Power consumption

Localization Schemes

- Range-Based Localization Schemes
  - Received Signal Strength Indicator (RSSI)
  - Time of Arrival (TOA)
  - Time Difference of Arrival (TDOA)
  - Particularly useful in conjunction with Directionality-Based Localization Scheme
    - Ex: Angle of Arrival (AOA)

Localization Schemes (cont.)

- Range-Free Localization Schemes
  - Don't need additional devices
  - Centralized Schemes
    - A centralized server computes the global solution.
    - Heavy traffic load
  - Distributed Schemes
    - Individual node computes its own location
    - Lower communication cost

Centroid

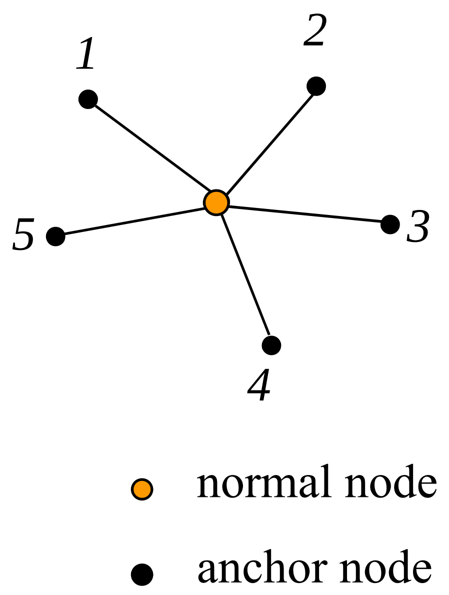
- Receive beacons from neighboring anchors

$$(X_{est}, Y_{est}) = \left(\frac{X_1 + \cdots + X_k}{k}, \frac{Y_1 + \cdots + Y_k}{k}\right)$$

(X_{est}, Y_{est}) – Estimative Location of the normal node

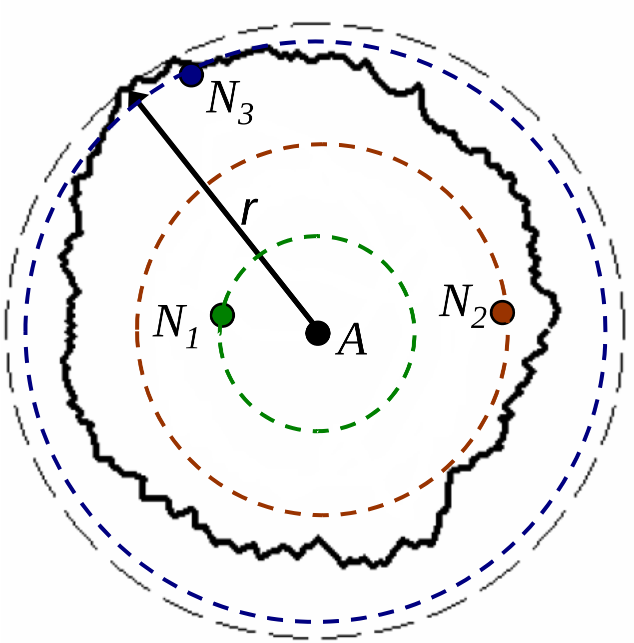
$(X_1, Y_1) \sim (X_k, Y_k)$ – Locations of anchors

- It is simple and easy to implement.



Convex Position Estimation (CPE)

- Connectivity constraint
  - A circle that bounds the maximal range *r* can be used to represent the physical communication range.
  - There are connectivity constraints between anchor *A* and normal nodes N_1, N_2, N_3.

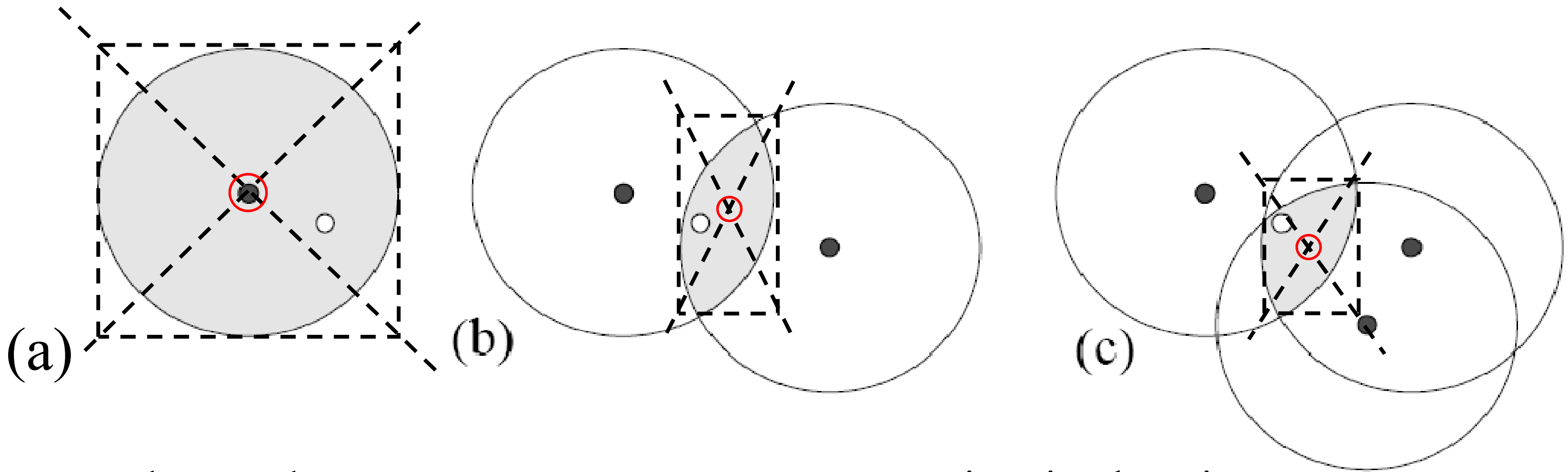


anchor *A*

normal node N_1, N_2, N_3

CPE (cont.)

- Multiple connectivity constraints
  - Feasible location of the normal node resides in the overlapping area
  - Using the minimum estimative rectangle (ER) to cover the overlapping area



● anchor node ○ normal node ○ estimative location

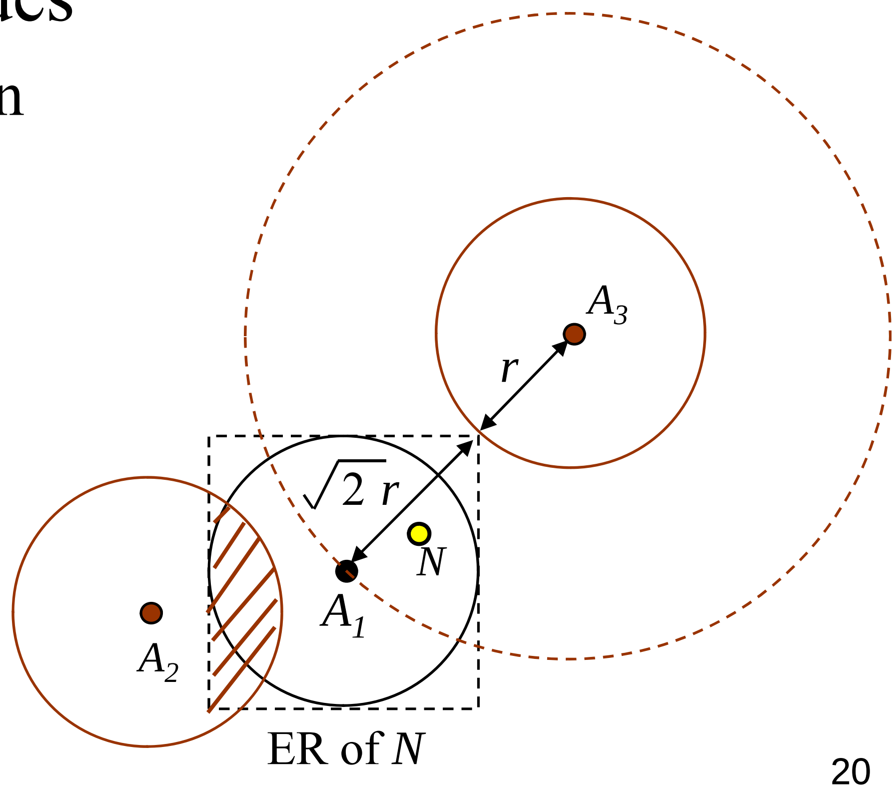
Distributed Location Estimating (DLE)

- Impact of the farther anchor node
  - Reduce the size of ER
- Collect farther anchor nodes
  - Enlarges the communication range of anchors to 2.414*r*

Normal node *N*

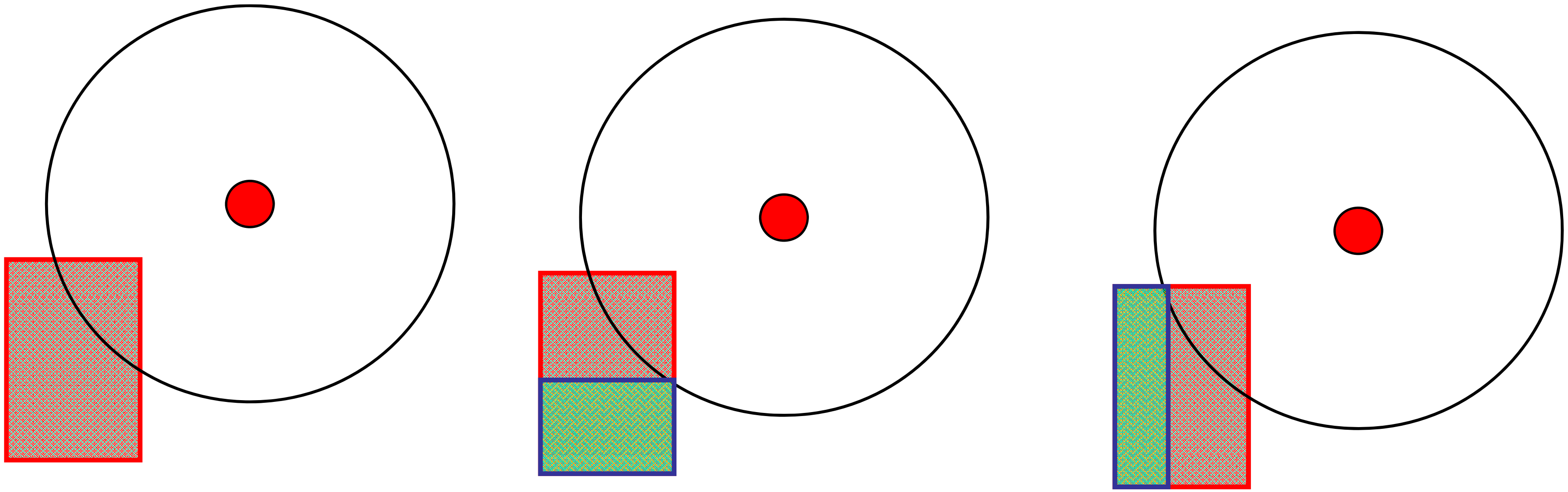
Near anchor A_1

Farther anchors A_2 *and* A_3



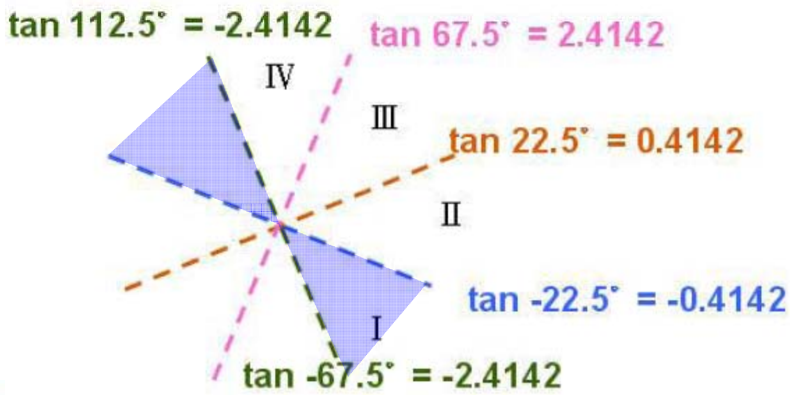
Reduce the ER

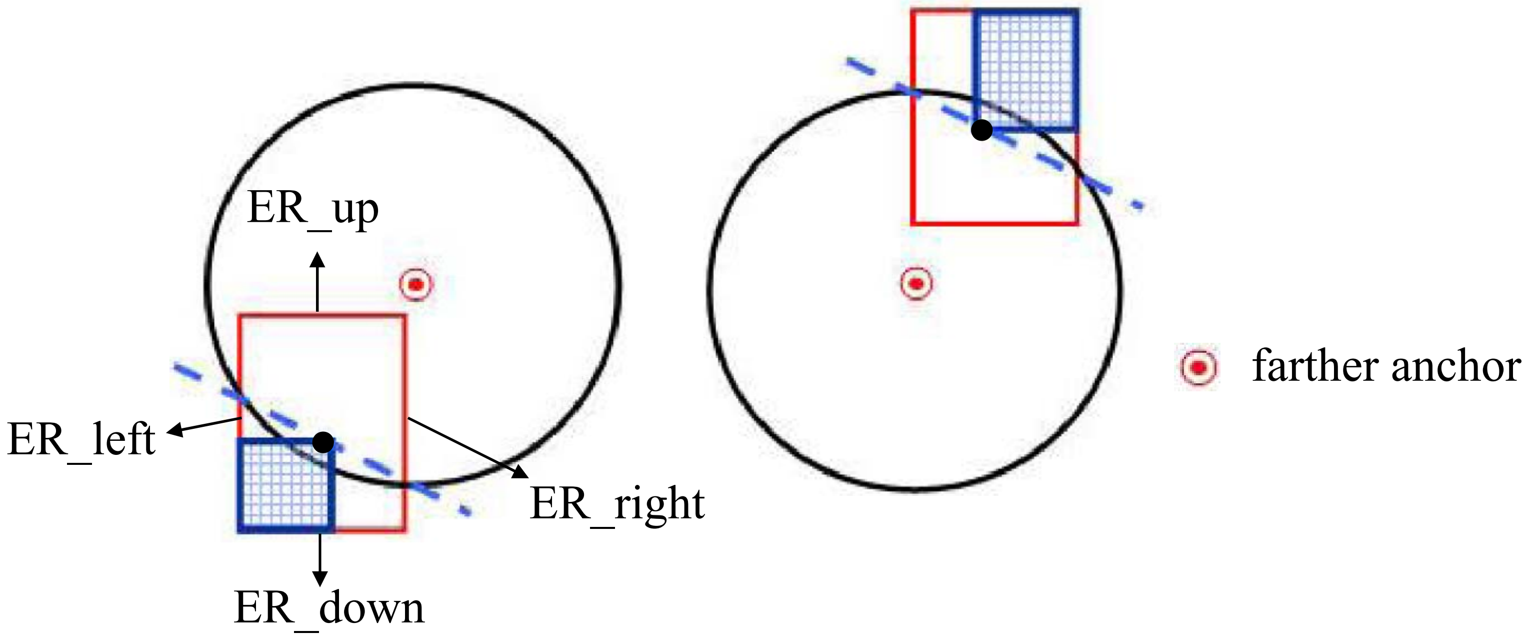
- According to the intersection point of circle and the borders of estimative rectangle (ER)



Reduce the ER (cont.)

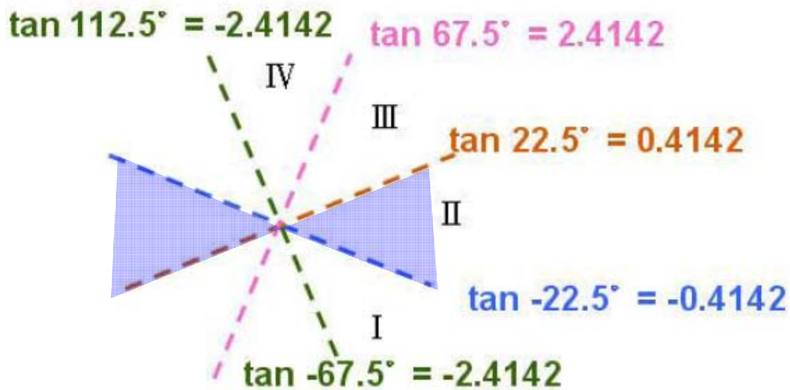
- Rule 1
  - Change ER_up, ER_right
  - Change ER_down, ER_left

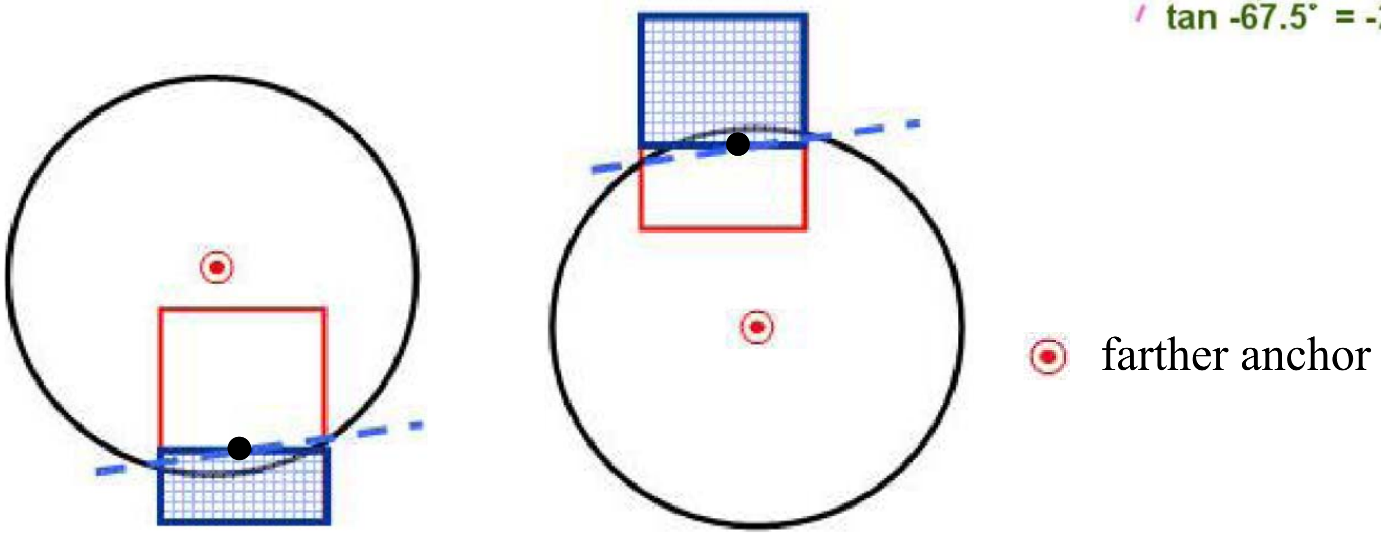




Reduce the ER (cont.)

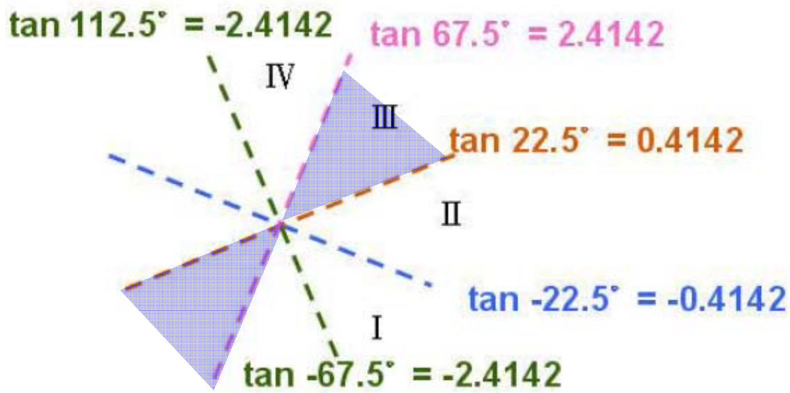
- Rule 2
  - Change ER_up
  - Change ER_down

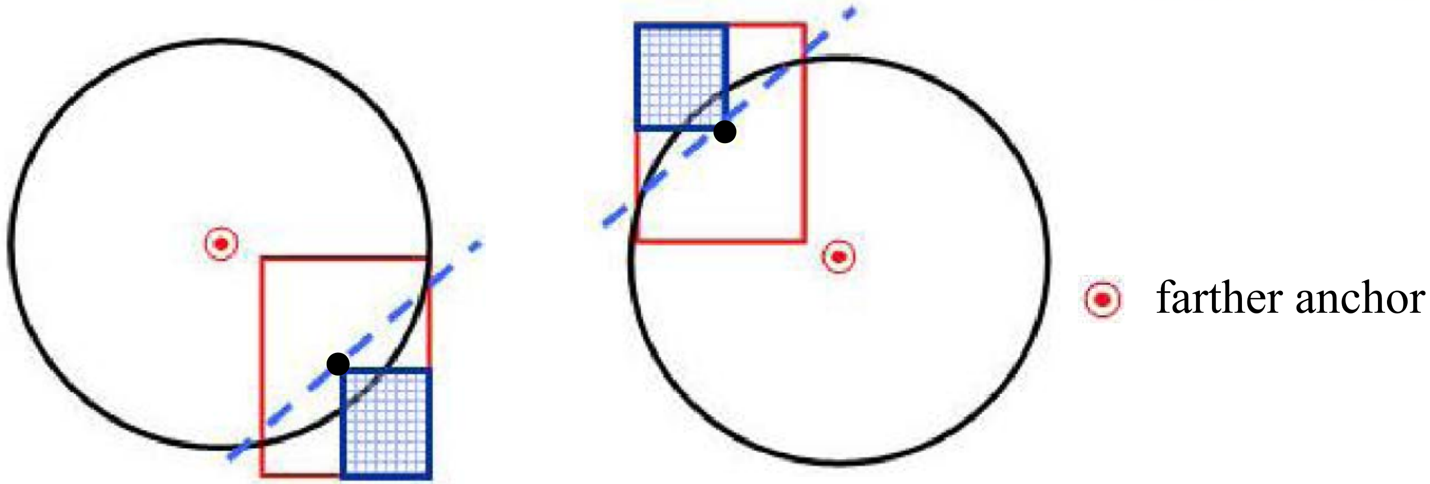




Reduce the ER (cont.)

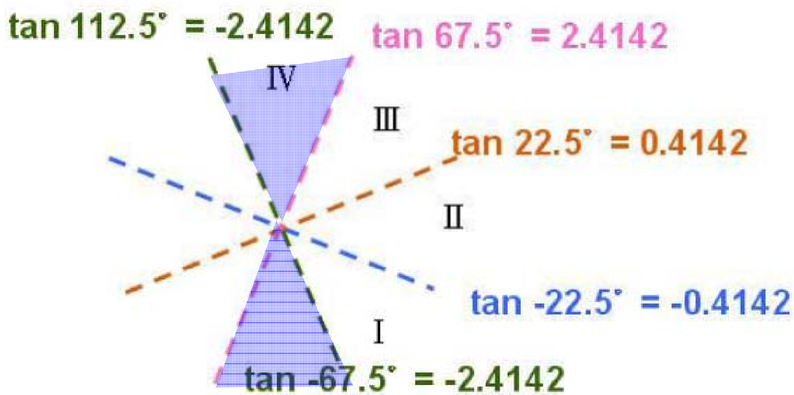
- Rule 3
  - Change ER_up, ER_left
  - Change ER_down, ER_right

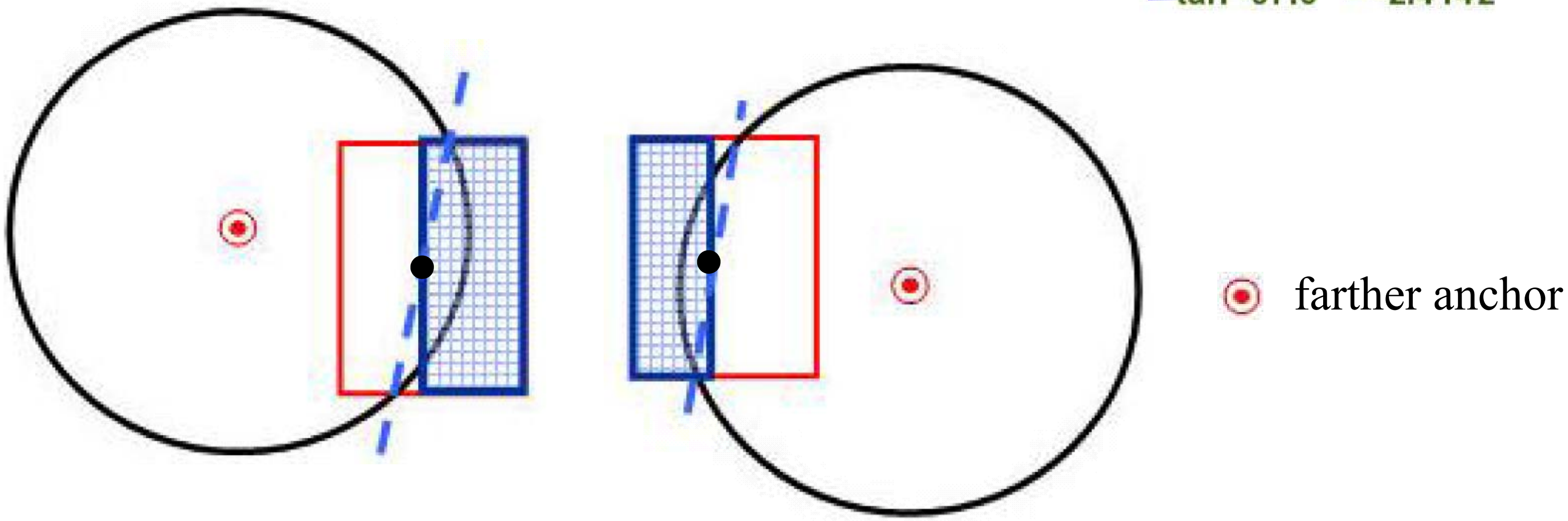




Reduce the ER (cont.)

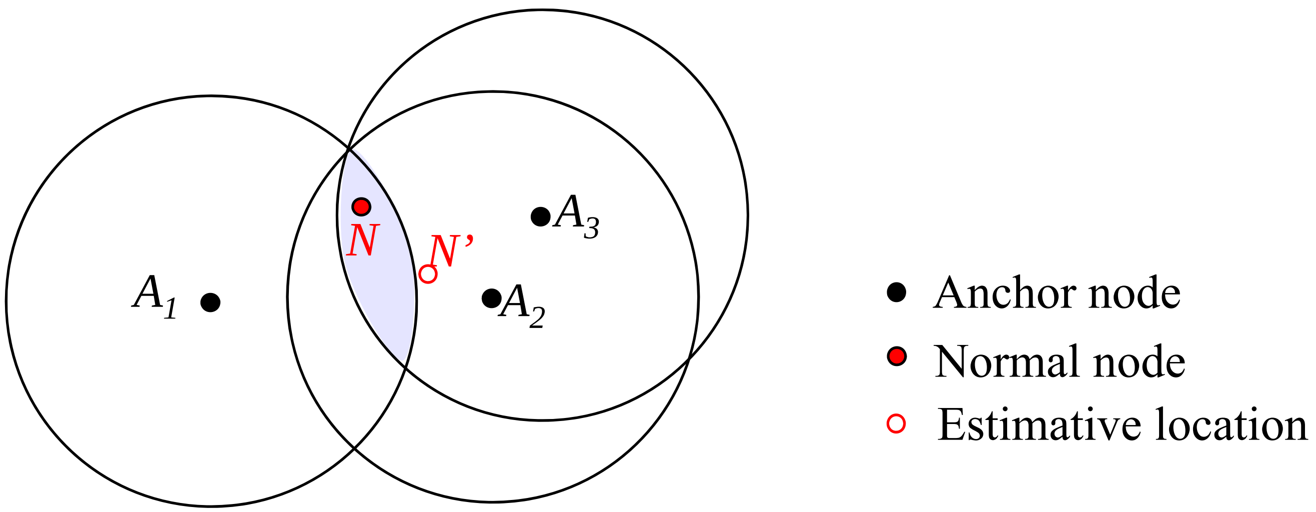
- Rule 4
  - Change ER_right
  - Change ER_left





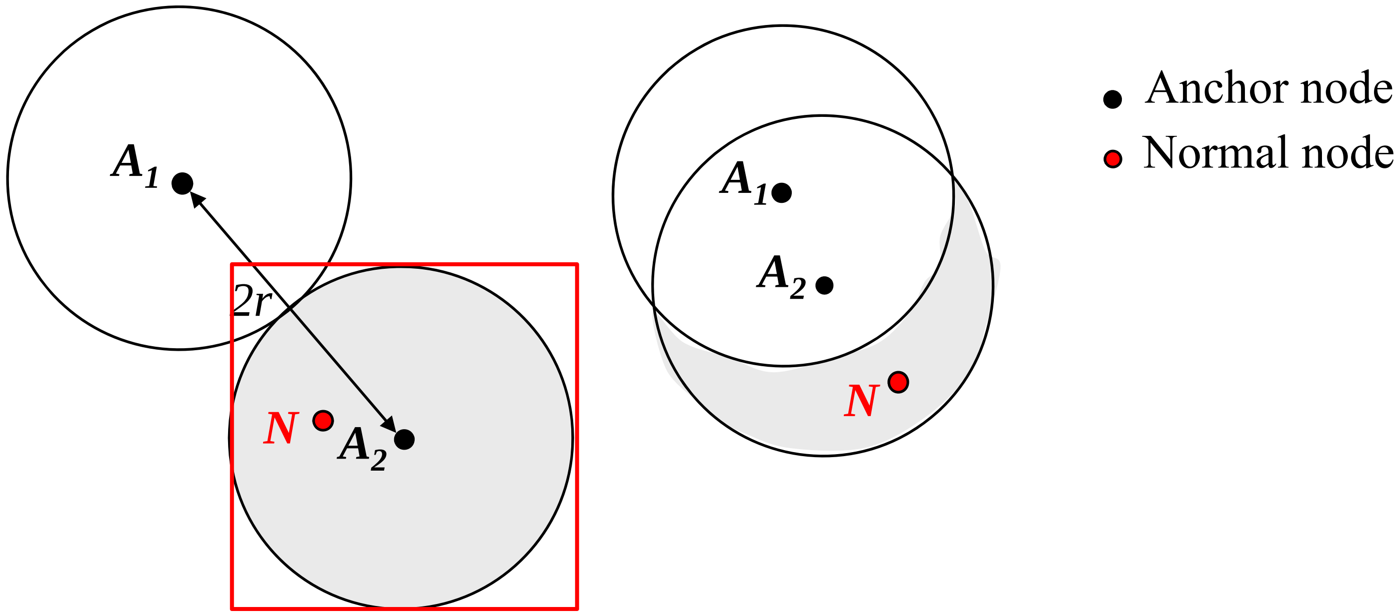
Motivation

- Inaccuracy of the Centroid Scheme
  - The density of anchors is low
  - The distribution of anchors is irregular



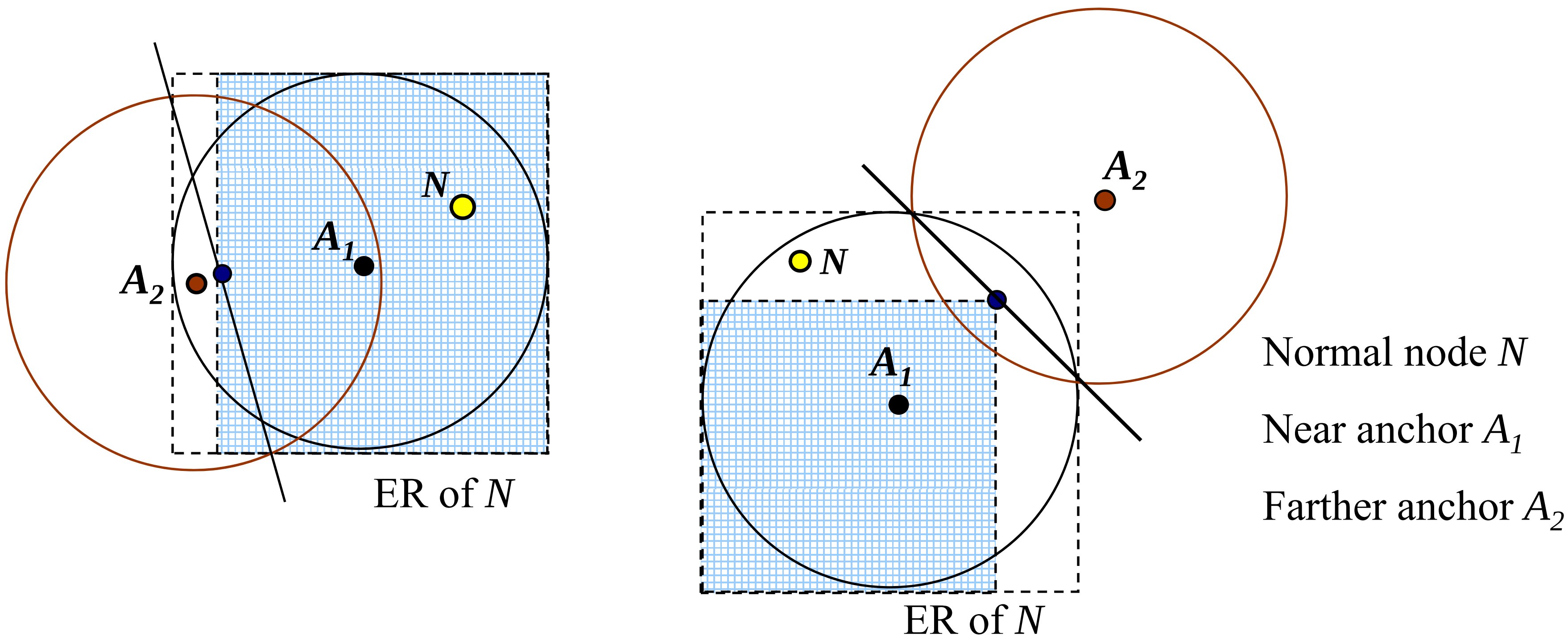
Motivation (cont.)

- DLE
  - Raising communication range to 2.414r consumes too much energy



Motivation (cont.)

- DLE
  - Keep too much area of the ER
  - Discard too much area of the ER

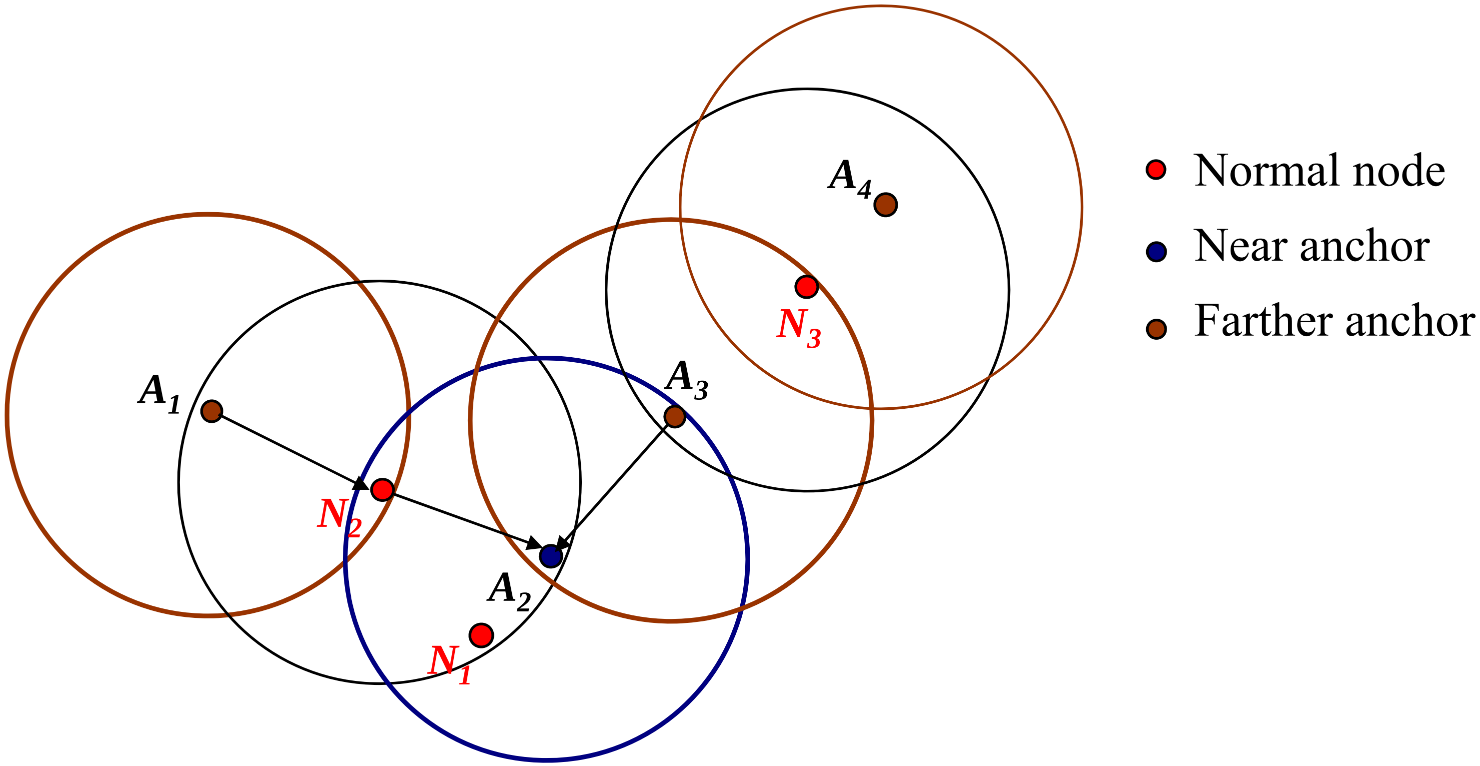


Distributed Range-Free Localization Scheme (DRLS)

- There are three phases in the DRLS algorithm.
  - Phase 1 – Beacon exchange
  - Phase 2 – Using improved grid-scan algorithm to get initial estimative location
  - Phase 3 – Refinement

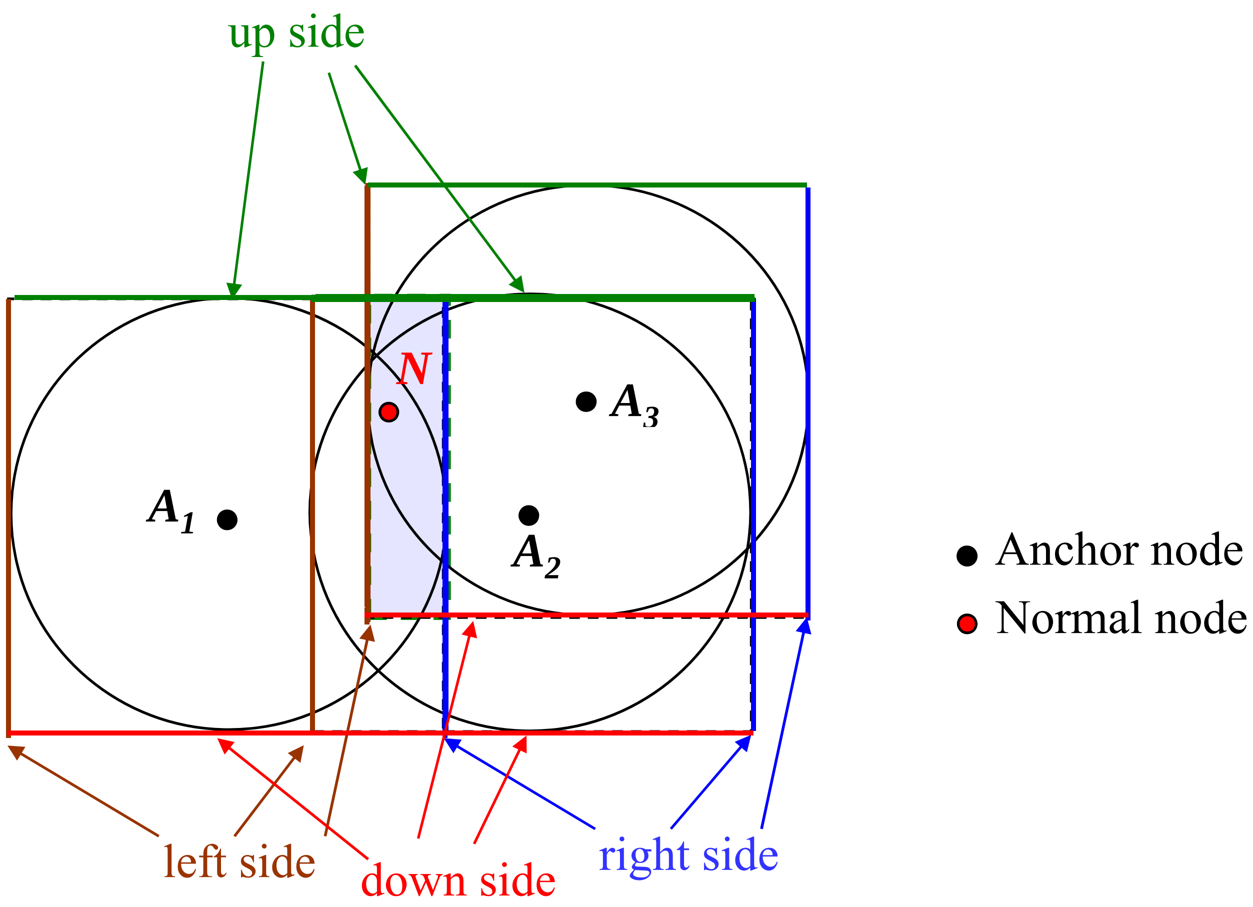
Beacon Exchange

- Beacon exchange via two-hop flooding



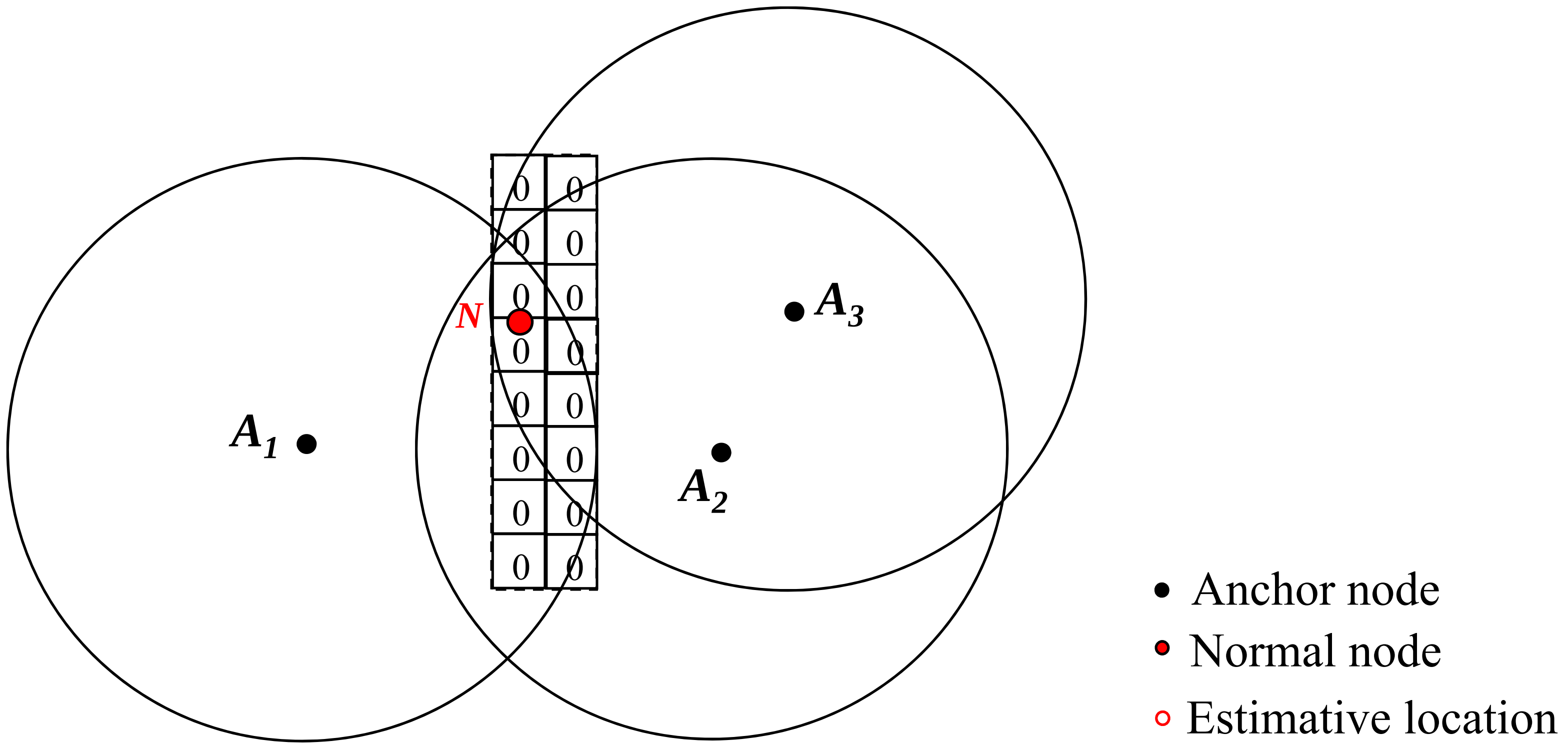
Improved Grid-Scan Algorithm

- Calculate the overlapping rectangle



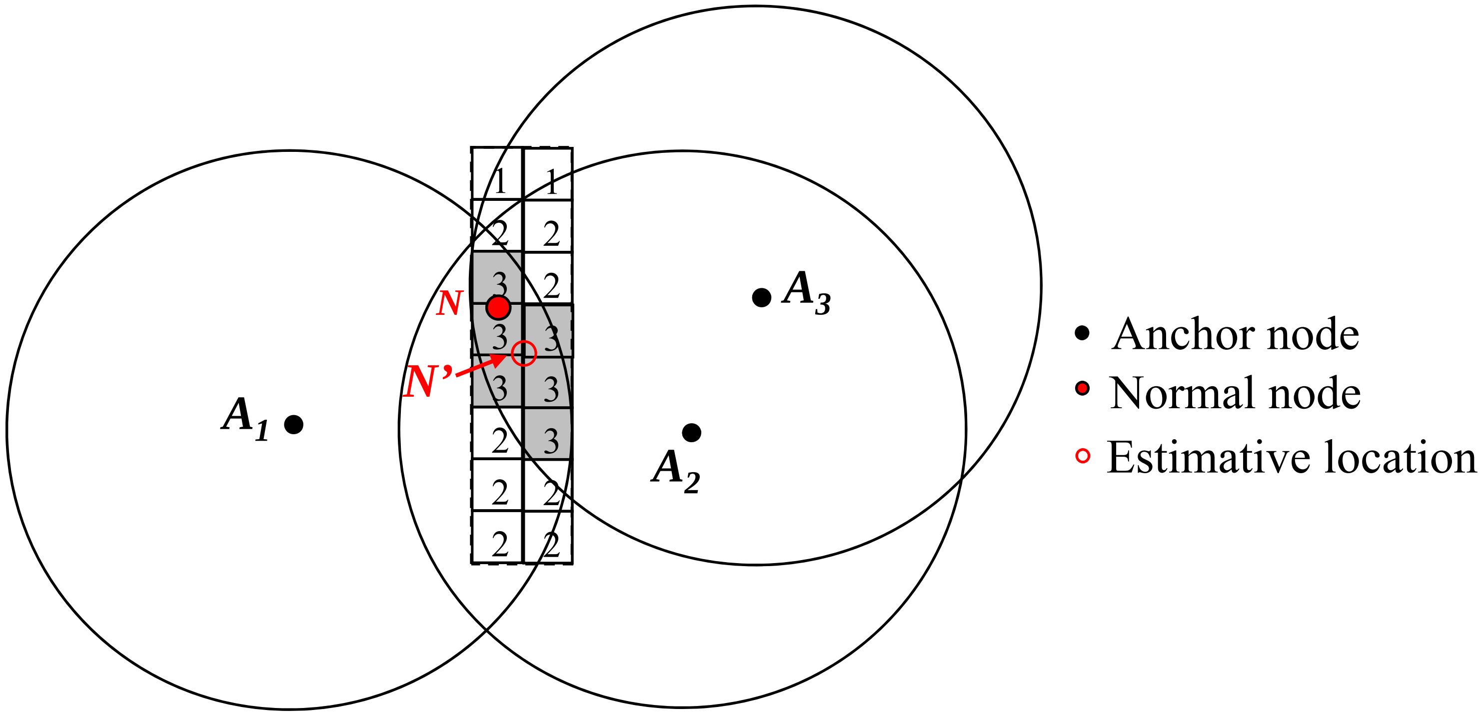
Improved Grid-Scan Algorithm

- Divide the ER into small grids
  - The initial value of the grid is 0



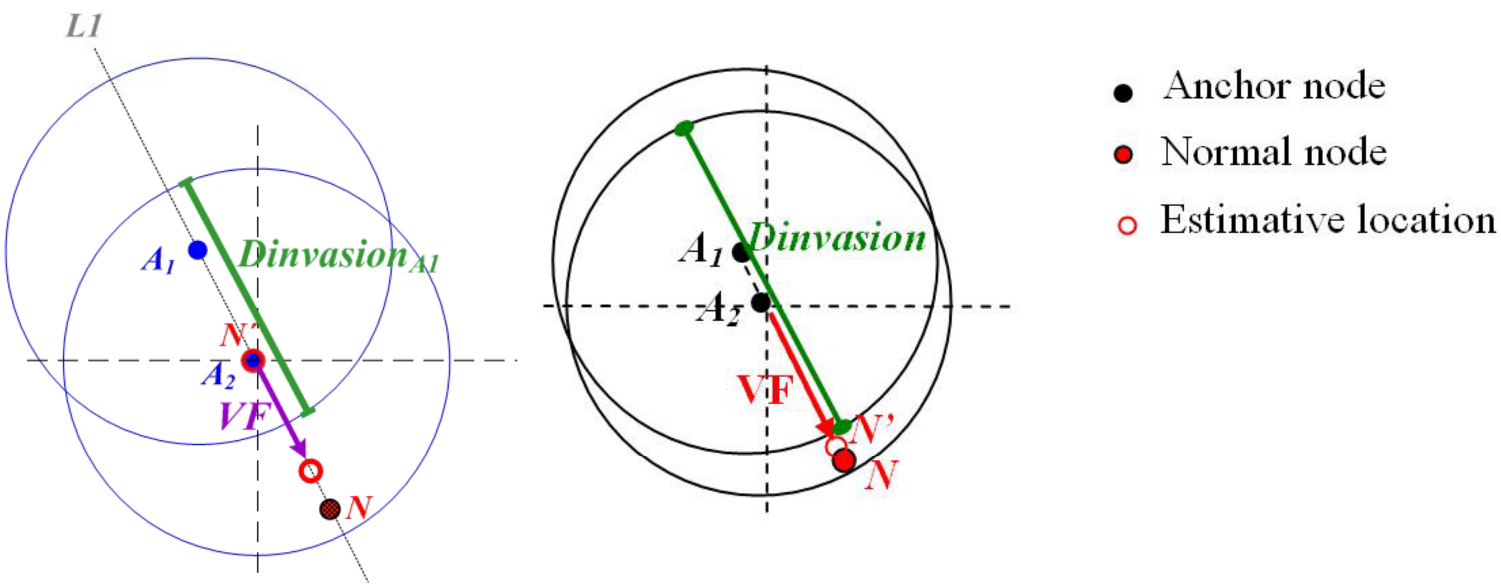
Improved Grid-Scan Algorithm

- Initial estimative location
  - Apply centroid formula to grids with the maximum grid value



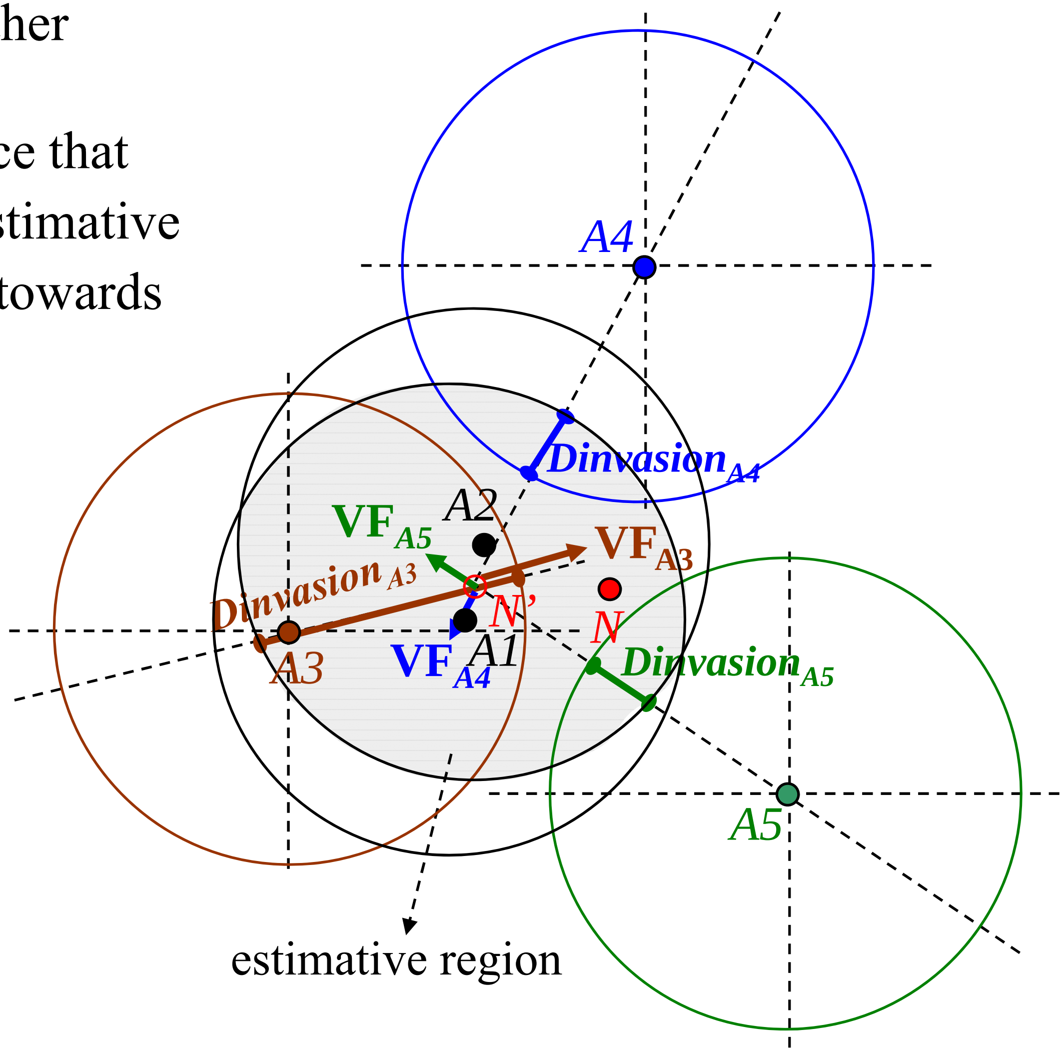
Refinement

- Repulsive virtual force (VF)
  - Induced by farther anchor nodes
- *Dinvasion* : the maximum distance that the farther anchor invades the estimative region along the direction from the farther anchor towards the initial estimative location



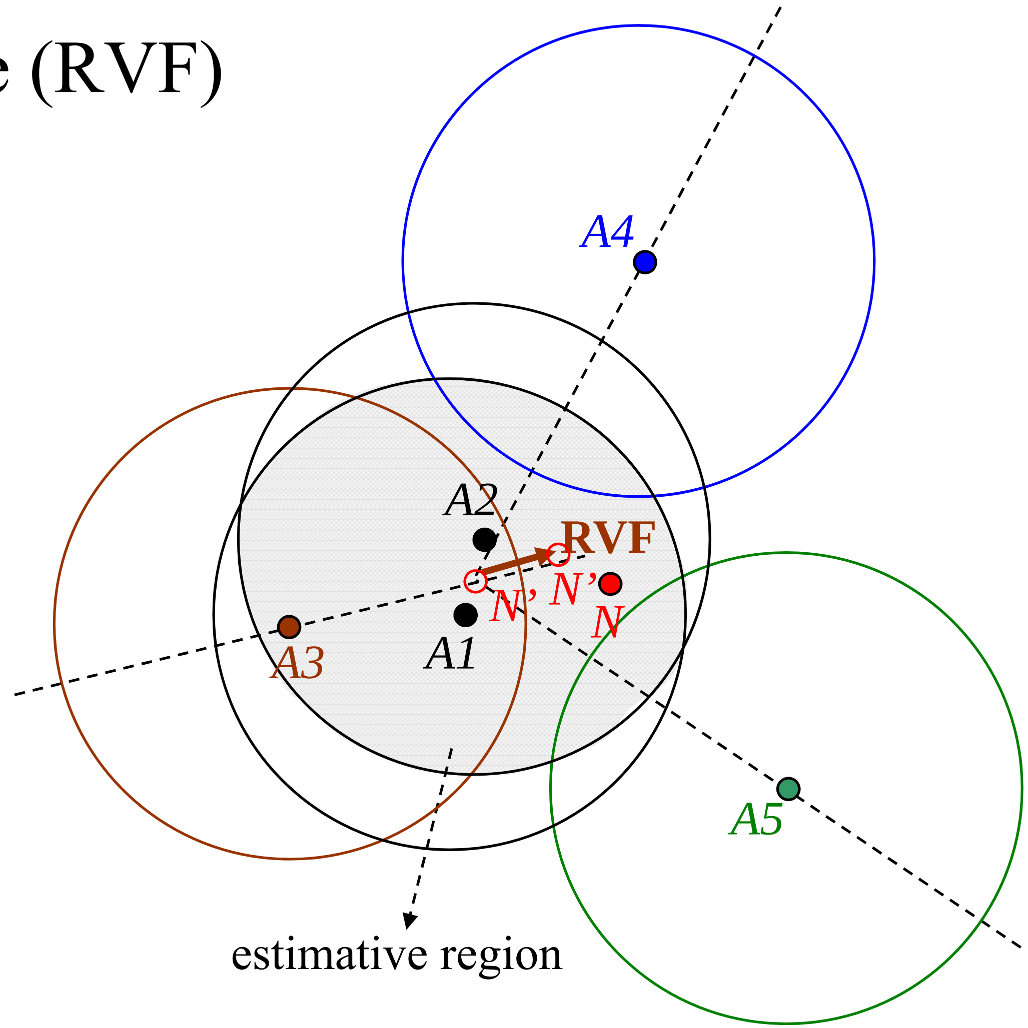
Refinement (cont.)

- VF_i : virtual force induced by farther anchor *i*
- $Dinvasion_i$: the maximum distance that the farther anchor *i* invades the estimative region along the direction from *i* towards the initial estimative location
- $V_{i,j}$: the unit vector in the direction from the farther anchor *i* towards the initial estimative location *j*
- $VF_i = V_{i,j} \cdot Dinvasion_i$



Refinement (cont.)

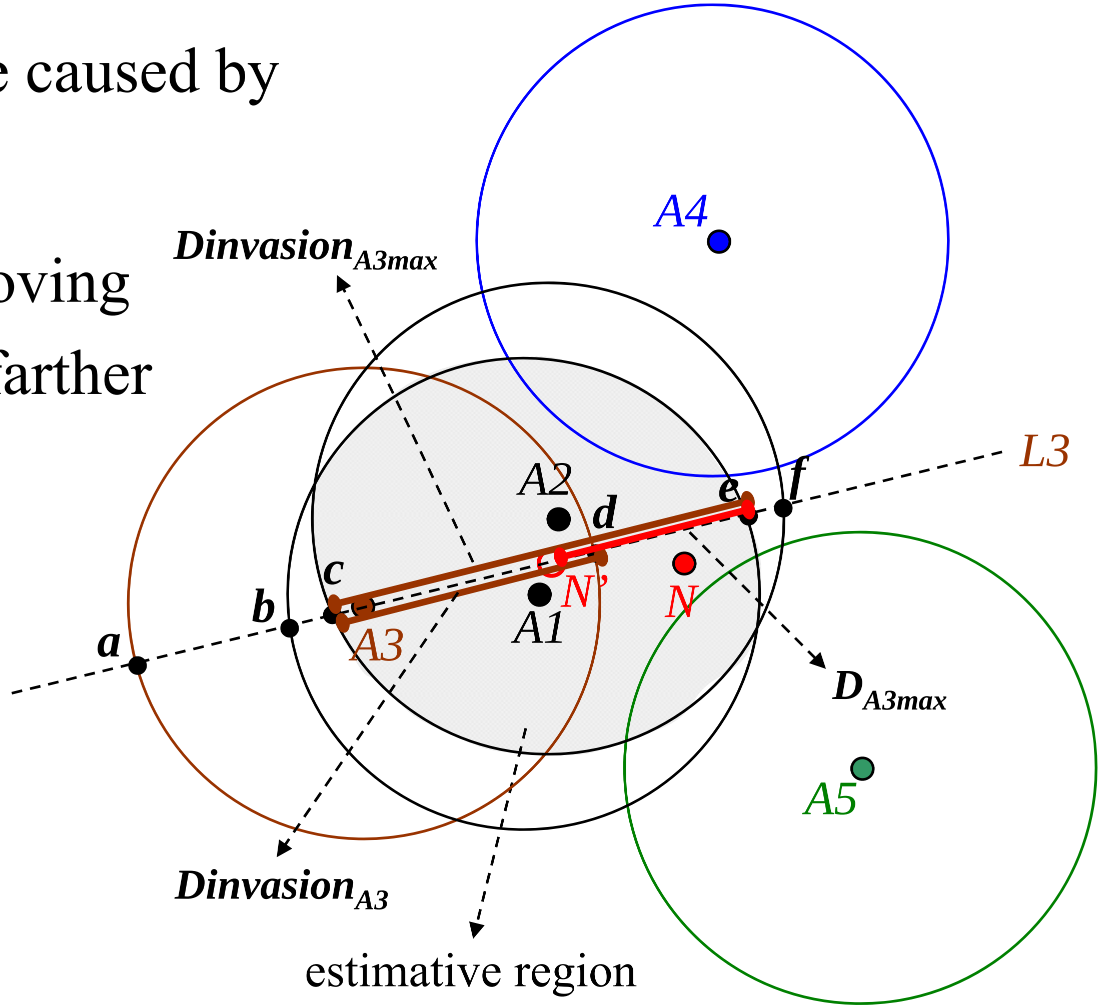
- Resultant Virtual Force (RVF)
- RVF = ΣVF_i



Refinement (cont.)

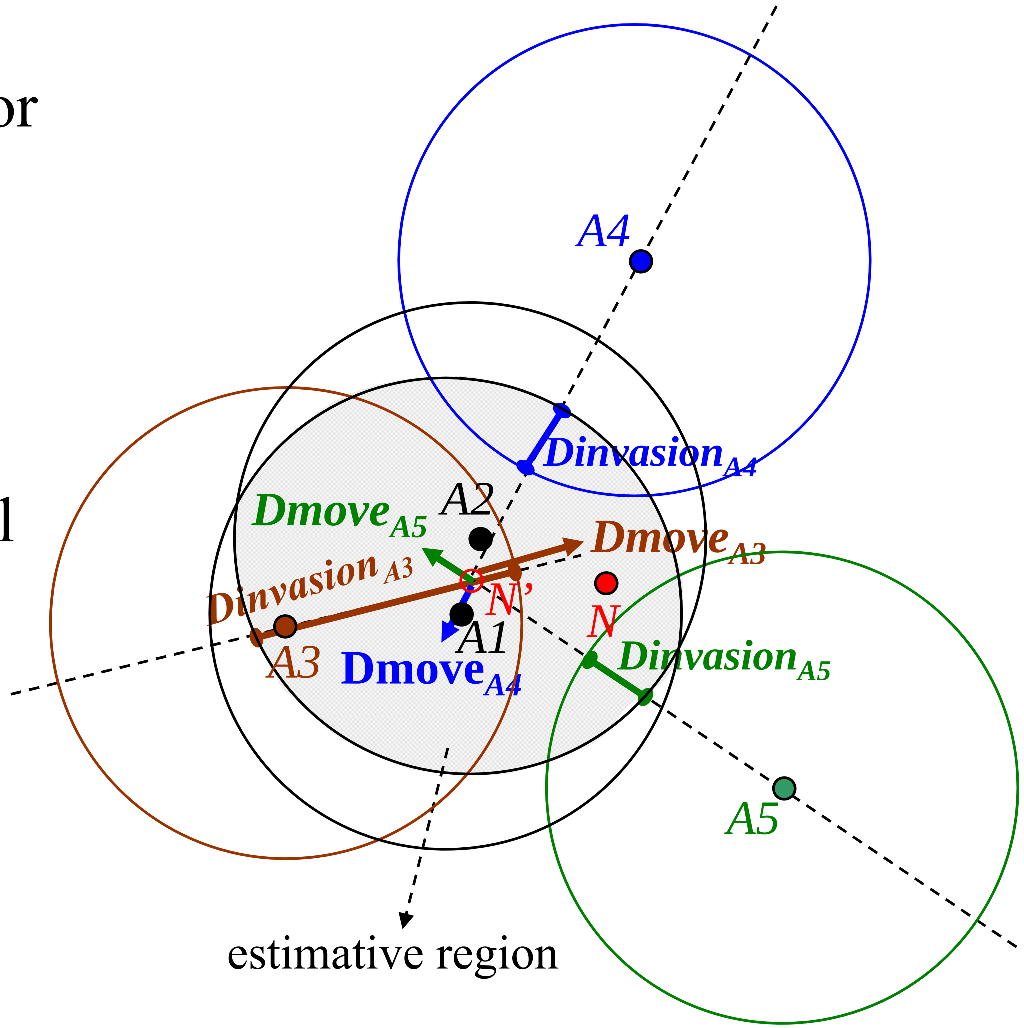
- D_i : the moving distance caused by the farther anchor *i*
- D_{imax} : the maximum moving distance caused by the farther anchor *i*

$$\frac{D_i}{D_{imax}} = \frac{Dinvasion_i}{Dinvasion_{imax}}$$



Refinement (cont.)

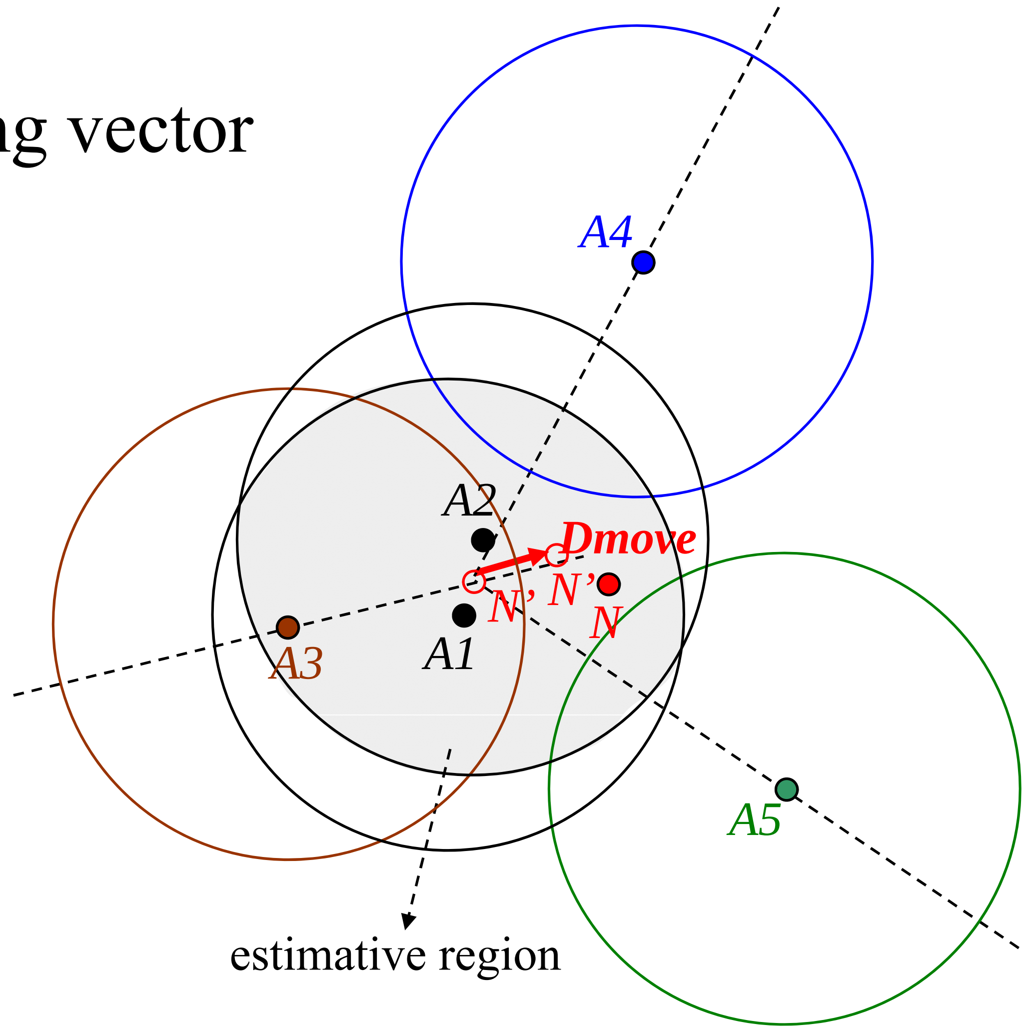
- $Dmove_i$: the moving vector caused by the farther anchor *i*
- $V_{i,j}$: the unit vector in the direction from the farther anchor *i* towards the initial estimative location *j*
- $Dmove_i = V_{i,j} \cdot D_i$



Refinement (cont.)

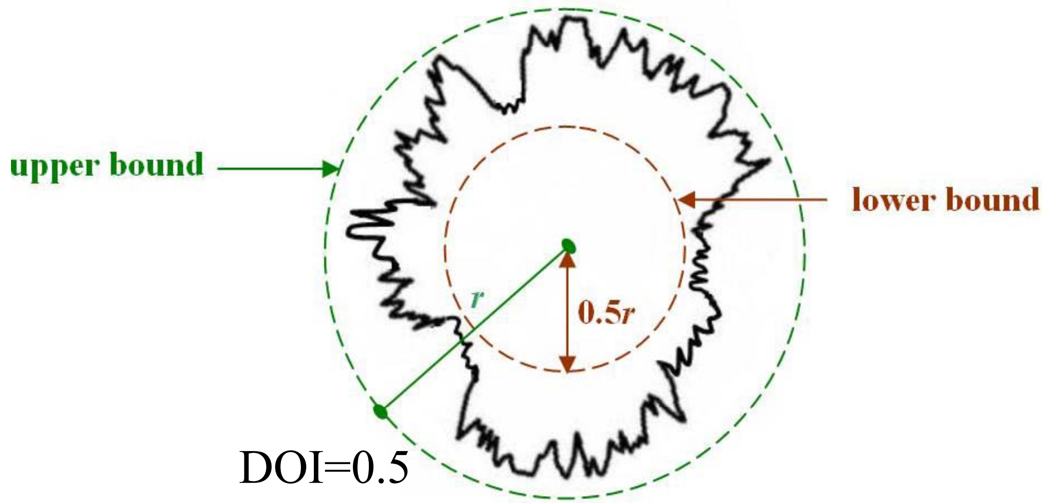
- *Dmove*: the final moving vector

  $Dmove = \Sigma\, Dmove_i$



Simulation Result

- NS-2 simulator
- Random deployment
- Communication range: *r*
- Network size: 10*r* x 10*r*
- Number of nodes : 200
- Grid size: 0.1*r*
- Number of anchors : 10 - 95
- Degree of irregularity (DOI)
  - Ranging from 0 – 0.9
  - Upper bound - *r*
  - Lower bound - (1 – DOI) *r*



Simulation Result (cont.)

- Mean error
- Message overhead

$$mean\_error = \frac{1}{n-m}\sum_{r=m+1}^{n}\sqrt{(x_{esti}^{k} - x_{real}^{k})^2 + (y_{esti}^{k} - y_{real}^{k})^2}$$

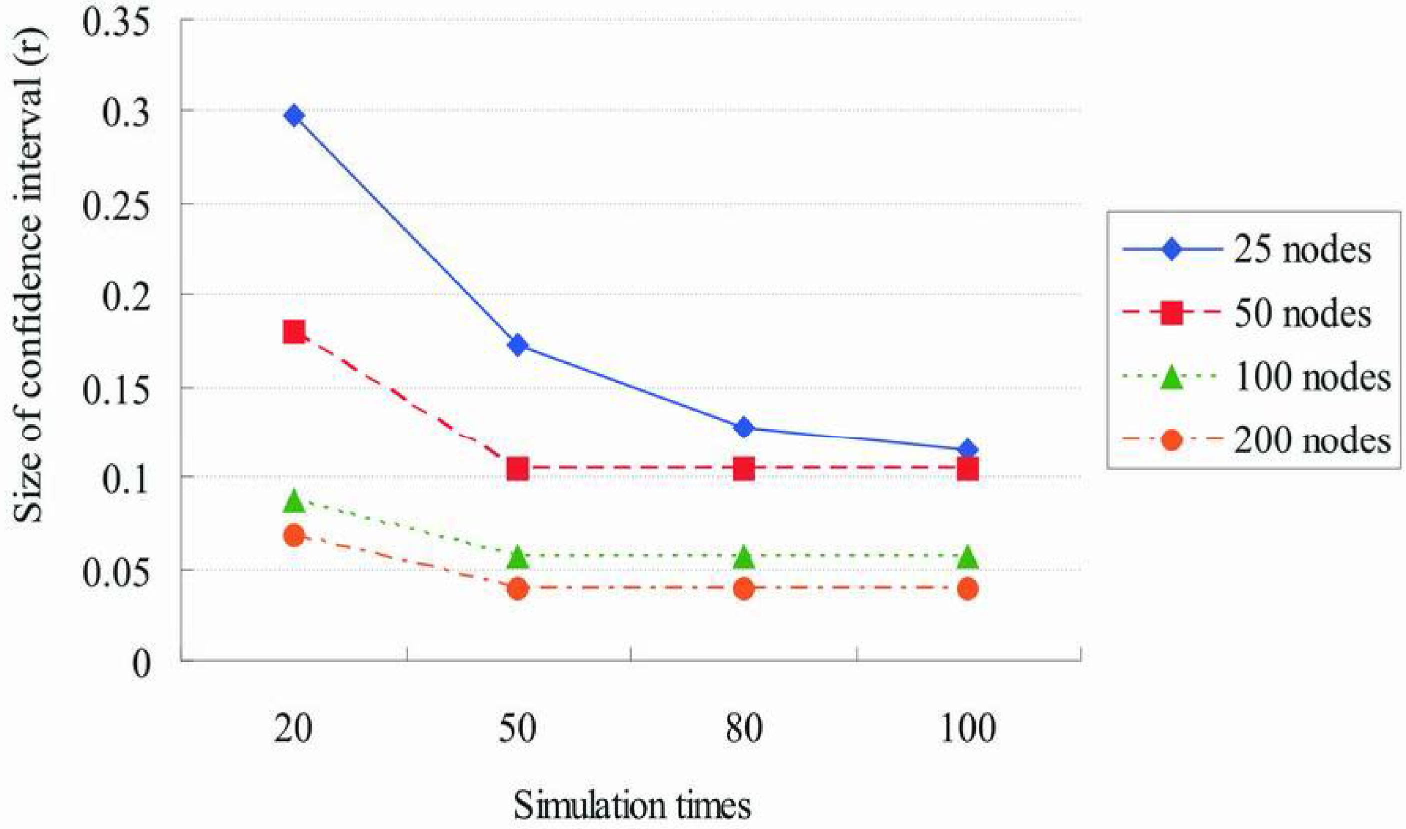
n: the number of total sensor nodes
m: the number of anchors

(x^k_{real}, y^k_{real}): the actual coordinate of the normal node with sensor ID *k*

(x^k_{esti}, y^k_{esti}): the estimative coordinate of the normal node with sensor ID *k*

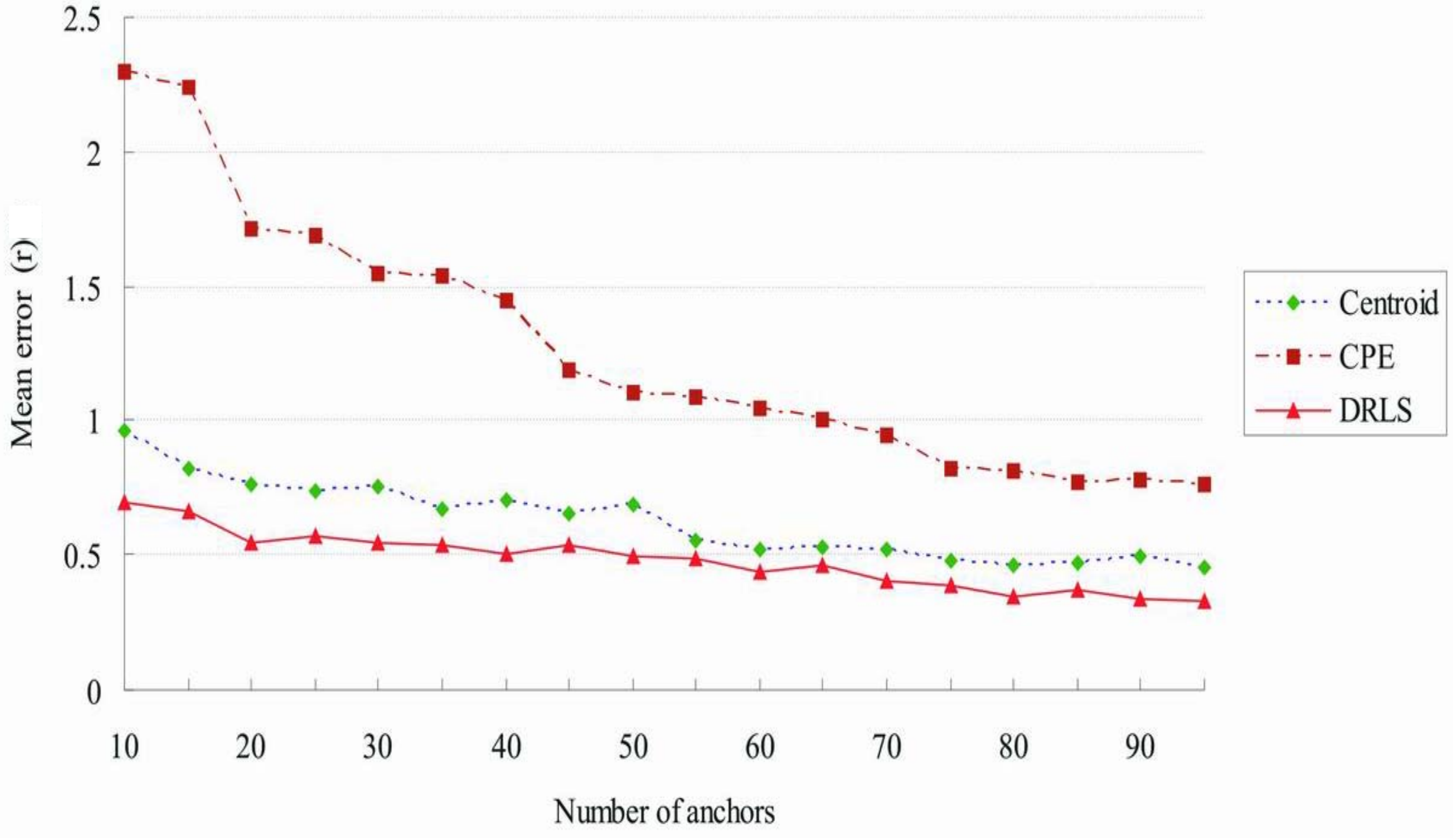
Simulation times vs. the size of confidence interval

(Anchor ratio=40%, DOI=0.7)

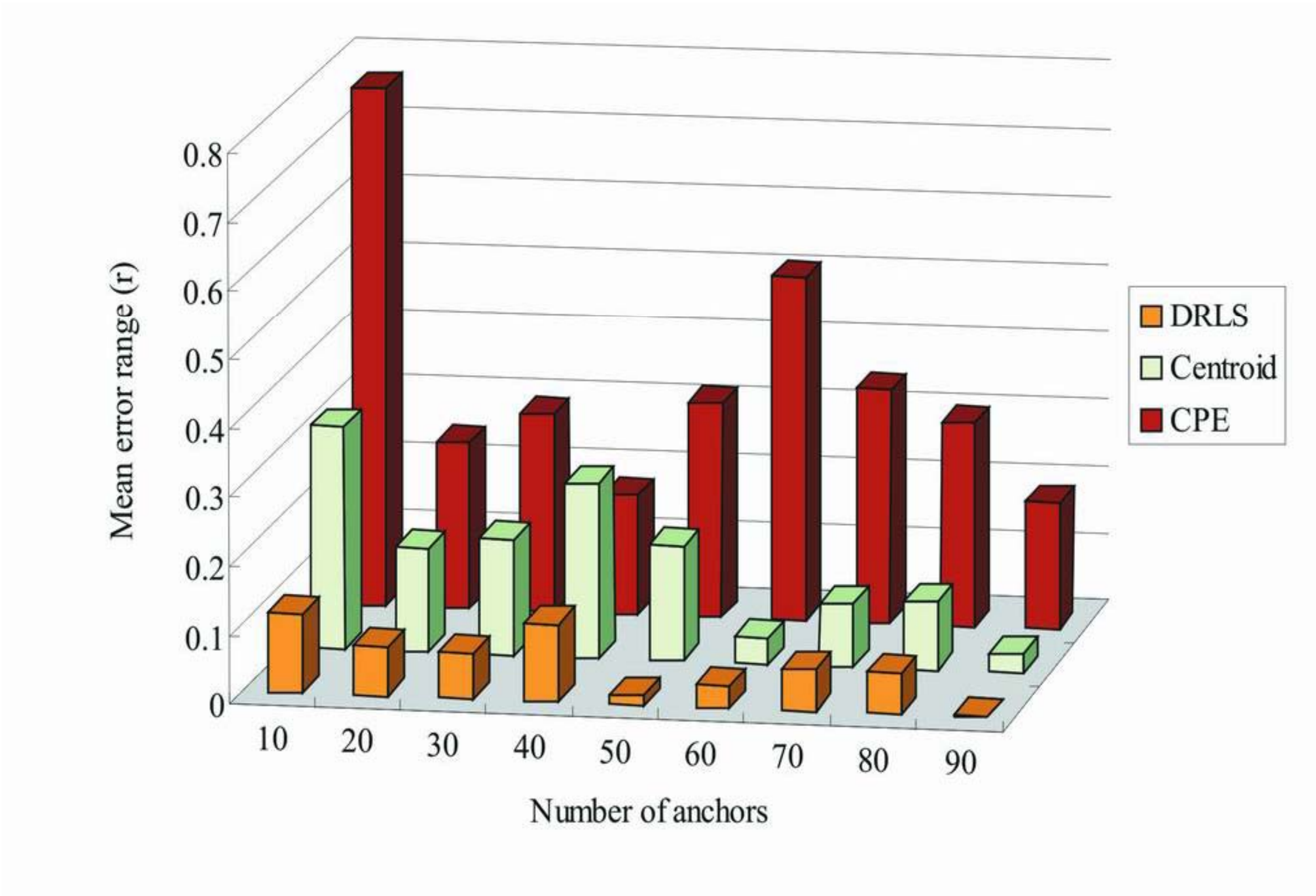


Anchor ratio vs. mean error

(number of sensor nodes=200)

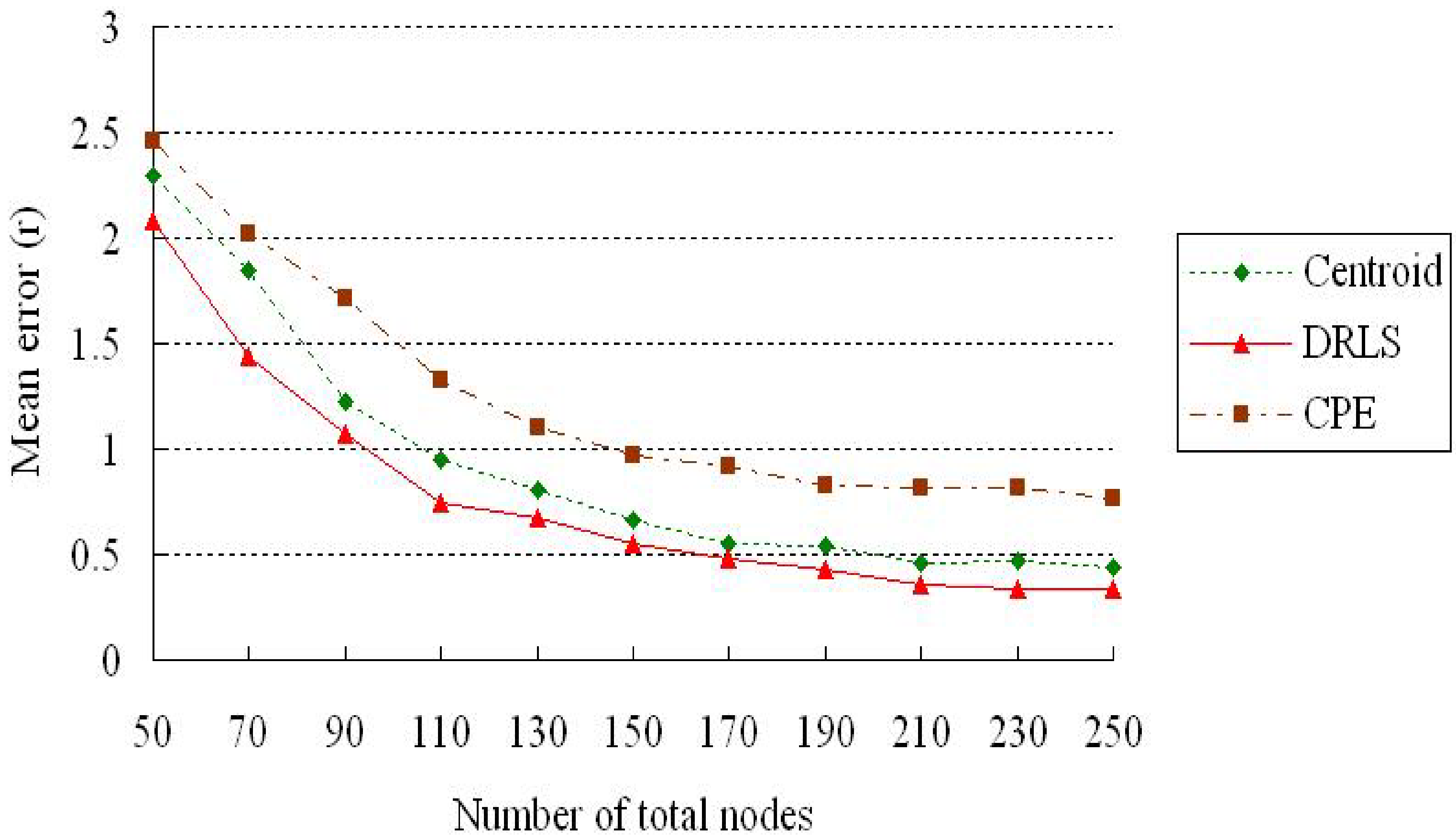


Anchor ratio vs. mean error range



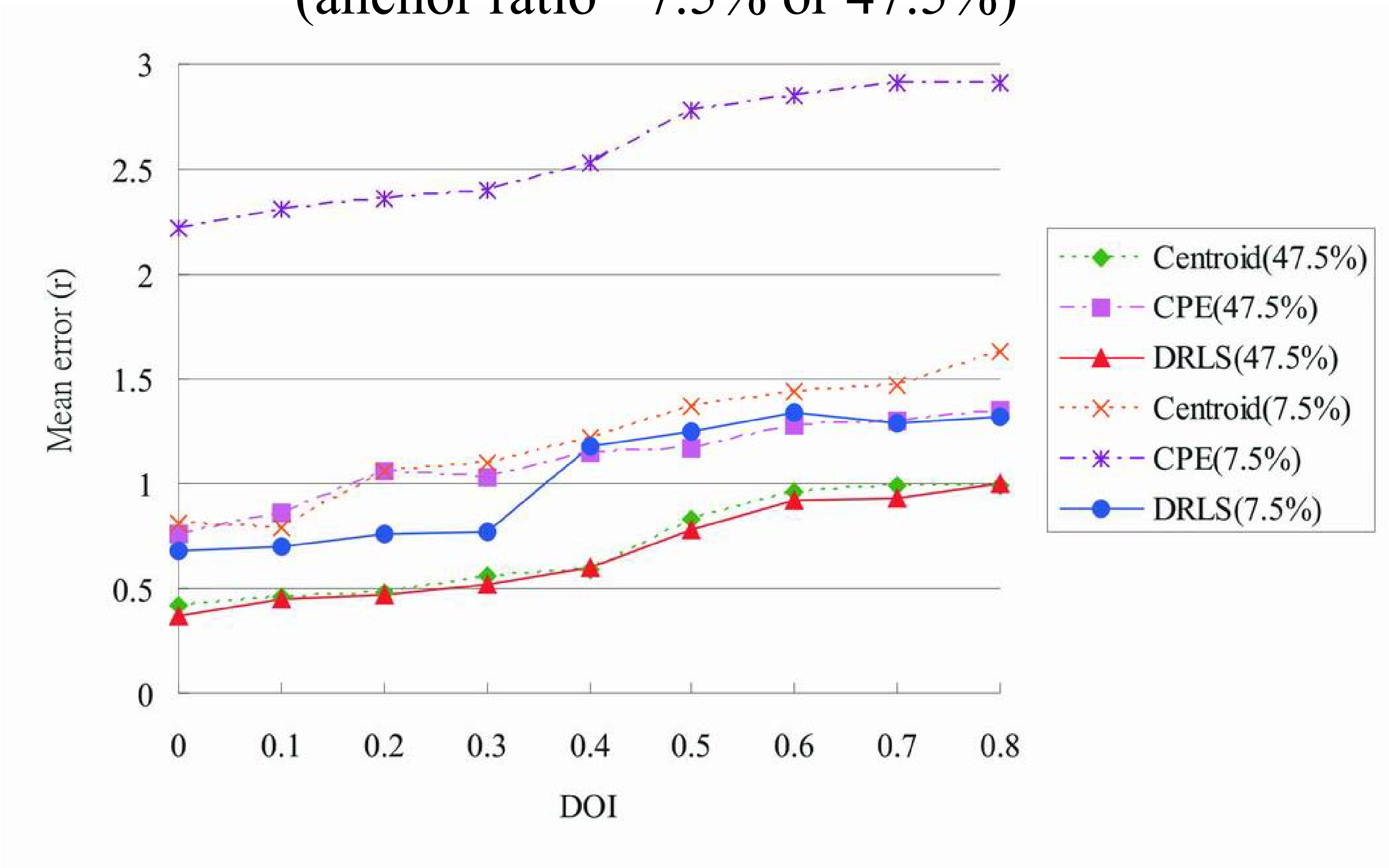
Density of nodes vs. mean error

(Ratio of anchors=40%)

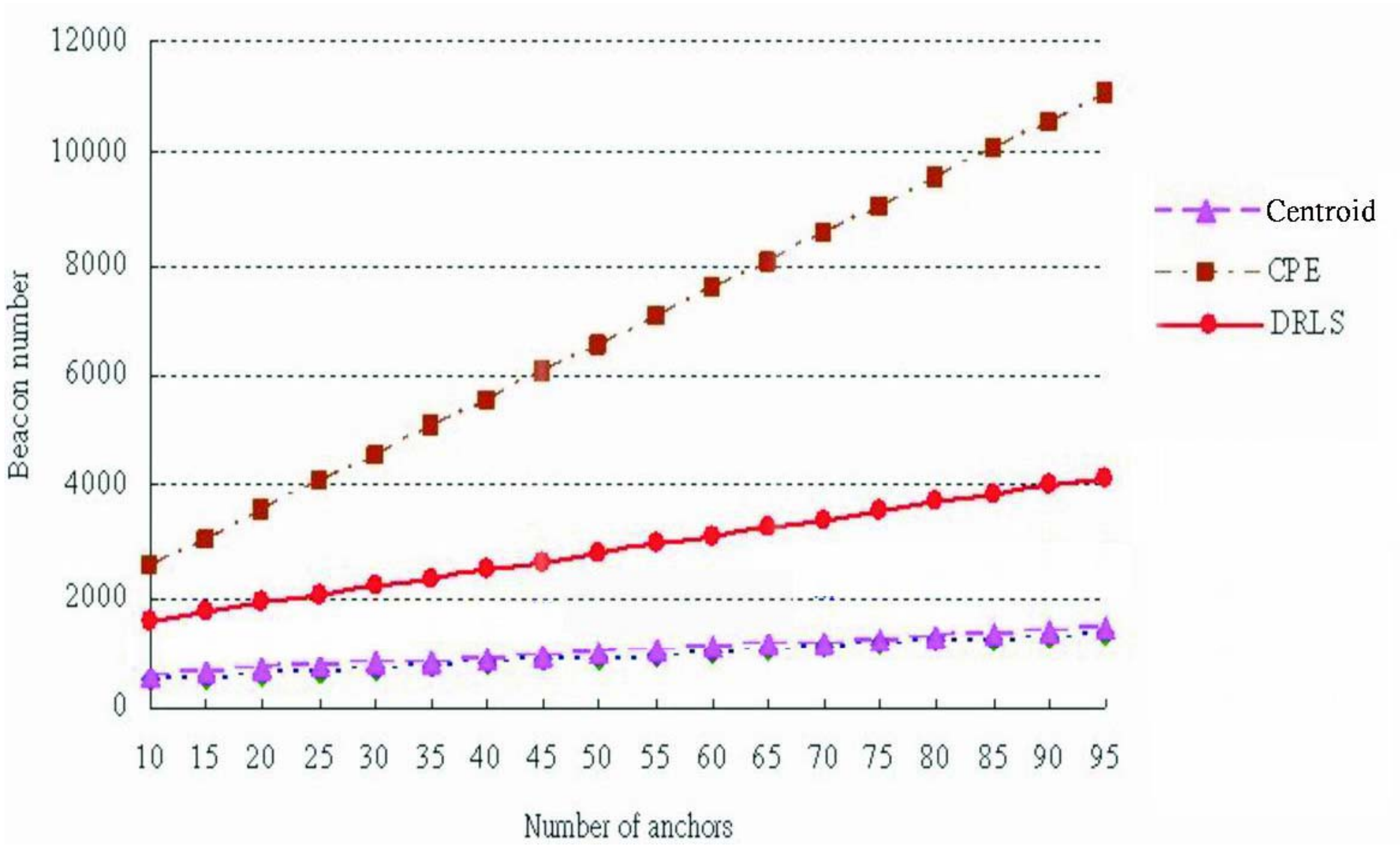


DOI vs. mean error

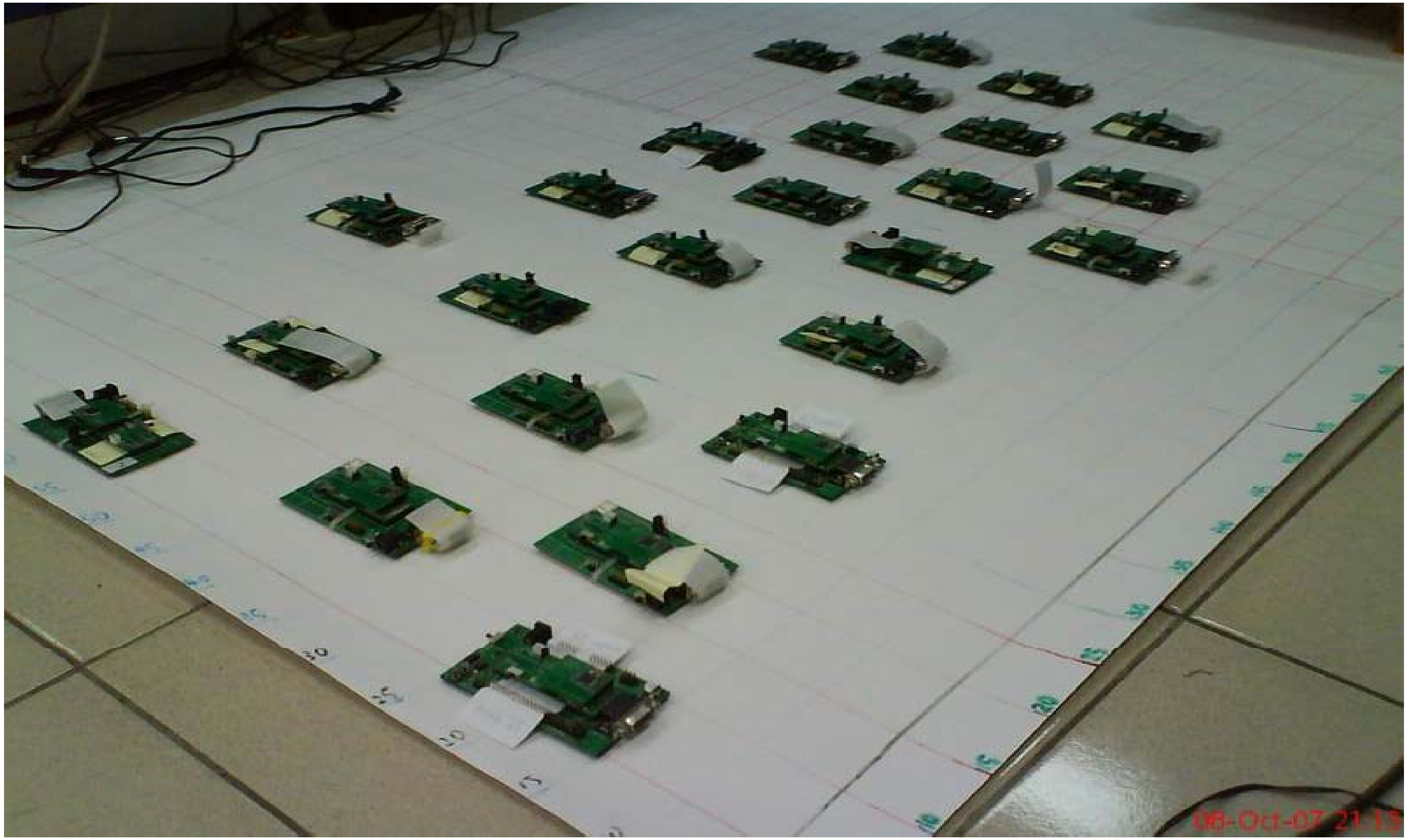
(anchor ratio= 7.5% or 47.5%)



Ratio of anchors vs. communication overhead

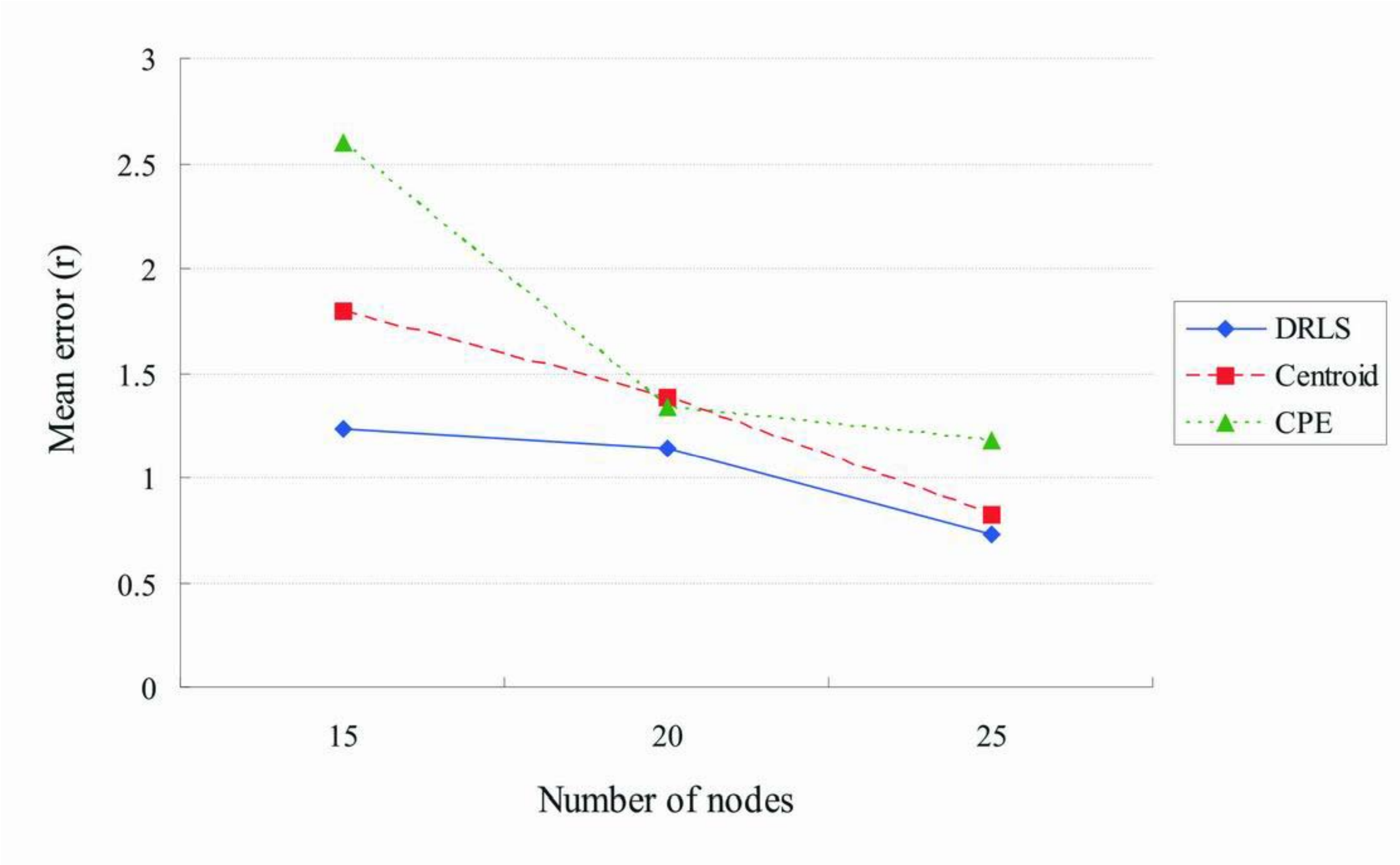


The testbed of our experiments



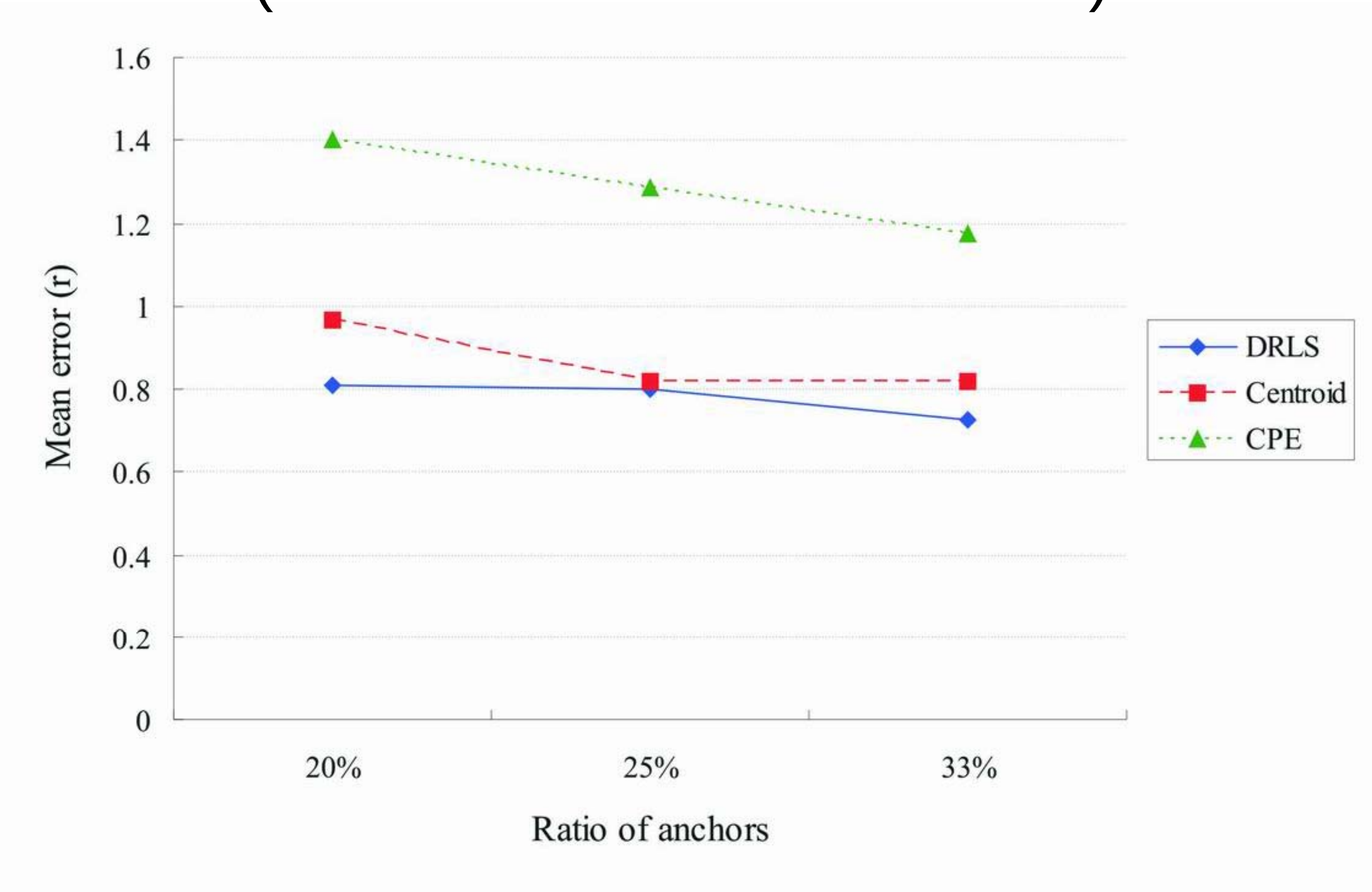
Node's density vs. mean error

(ratio of anchors = 33%)



Anchor’s ratio vs. mean error

(number of sensor nodes = 25)



Conclusion

- Analysis, simulation and experiment results have shown that
  - DRLS can acquire accurate estimative location.
  - DRLS is more stable than other localization schemes.
  - DRLS performs well when the communication range of the sensor node is irregular.

Thanks !!