Localization in WSN

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Introduction

- Location systems provide a new layer of automation called automatic object location detection
- Real world applications relying on such layer are many:
  - location of products stored in a warehouse;
  - location of medical personnel or equipment in a hospital;
  - location of firemen in a building on fire;
  - detecting the location of monuments/shops nearby the user
  - ...

Introduction

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- Different applications may require different types of location information:
  - physical/symbolic
  - absolute/relative
- Various wireless technologies are used. These may be classified on the base of:
  - the location positioning algorithm (the method of determining location) making use of various types of measurement of the signal such as Time Of Flight (TOF), angle, and signal strength;
  - the physical layer or location sensor infrastructure, i.e., the wireless technology used to communicate with the mobile devices or static devices.
- In general, measurement involves the transmission and reception of signals between hardware components of the system.

Introduction

- There are four different system topologies for positioning systems:
  1. *remote positioning*: the signal transmitter is mobile and several fixed measuring units receive the transmitter's signal. The results from all measuring units are collected, and the location of the transmitter is computed in a master station.
  2. *self-positioning*: the unit receives the signals of several transmitters in known locations, and has the capability to compute its location based on the measured signals.
  3. *indirect remote positioning*: if a wireless data link is provided in a positioning system, it is possible to send the measurement result from a self-positioning measuring unit to the remote side.
  4. *indirect self-positioning*: the measurement result is sent from a remote positioning side to a mobile unit via a wireless data link.

Introduction

- What is Localization in WSN?
  - Ability to determine the Positioning of Sensors and Events
  - Utilize some help from localization services like GPS ?

- Support Location Aware Applications
  - Track Objects
  - Report event origins
  - Evaluate network coverage
  - Assist with routing, GF
  - Support for upper level protocols

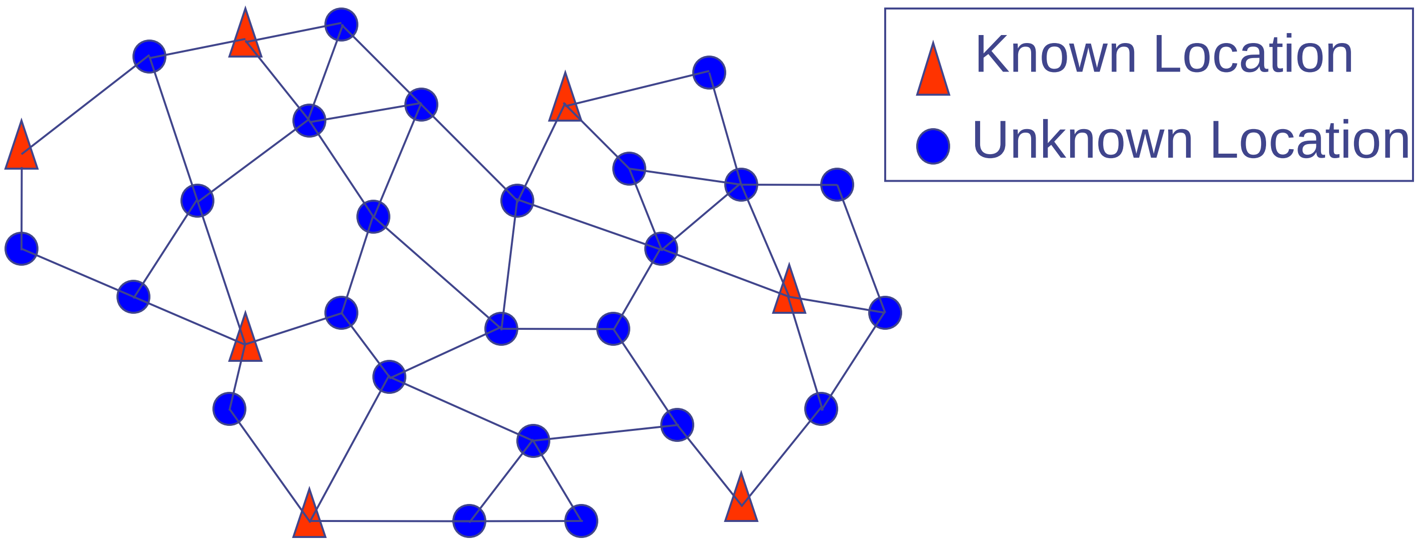
Introduction

- Some Localization Challenges
  - Accuracy VS Complexity/Cost
  - Availability and Feasibility of accurate location systems

- GPS is not practical
  - Do not work Indoor or if blocked from the GPS satellites
  - Spend the battery life of the node
  - Issue of the production cost factor of GPS
  - Increase the size of sensor nodes

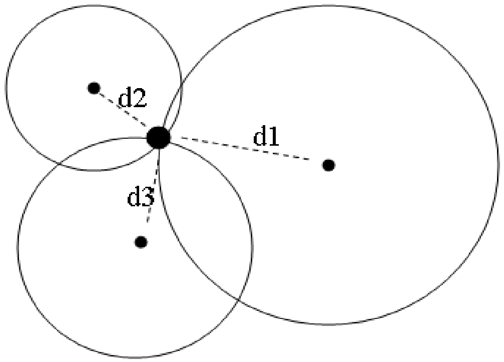
Introduction

- Localization in WSN is an active research area
- Several proposals of localization methods
- Most proposals utilize some sensors to work as reference nodes (anchor-based)

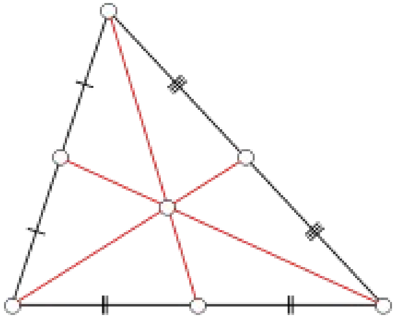


Introduction

- ... usually evaluating the distance between sensors and anchors using:
  - Lateration (Range-based)



  - Centroid (Range-free)



Range-Based Methods

- Location discovery consists of two phases:
  - Ranging phase
  - Estimation phase
- Ranging phase (distance estimation)
  - Each node estimate its distance or angle from its neighbors
- Estimation phase (distance combining)
  - Nodes use ranging information and beacon node locations to estimate their positions

Ranging phase

- Distance measuring methods
  - Signal Strength
    - Uses RSSI readings
  - Time based methods
    - ToA, TDoA
    - Used with radio, acoustic, ultrasound
  - Angle of Arrival (AoA)
    - Measured with directive antennas or arrays

Received signal strength

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- Estimate the distance from some set of neighbors using the attenuation of emitted signal strength.
- In free space, the RSS varies as the inverse square of the distance *d* between the transmitter and the receiver

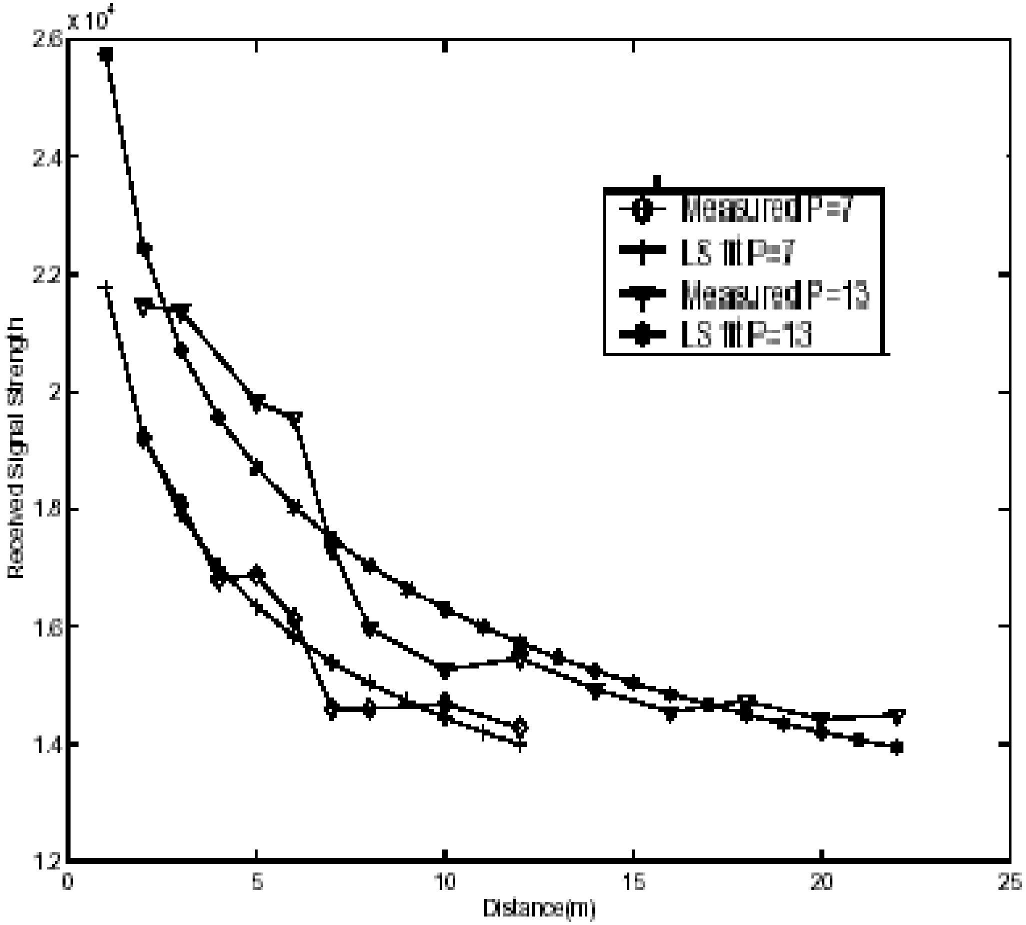
$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2}$$

- Due to multipath fading and shadowing present in the indoor environment, background interference, irregular signal propagation, path-loss models do not always hold. The parameters employed in these models are site-specific.

Received signal strength

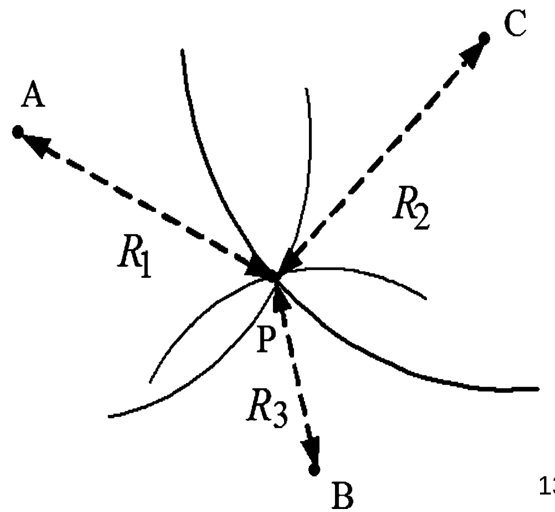
- RF signal attenuation is a (reverse-proportional) function of distance
- A Model is derived by obtaining a least square fit for each power level

$$P_{RSSI} = \frac{X}{r^n}$$



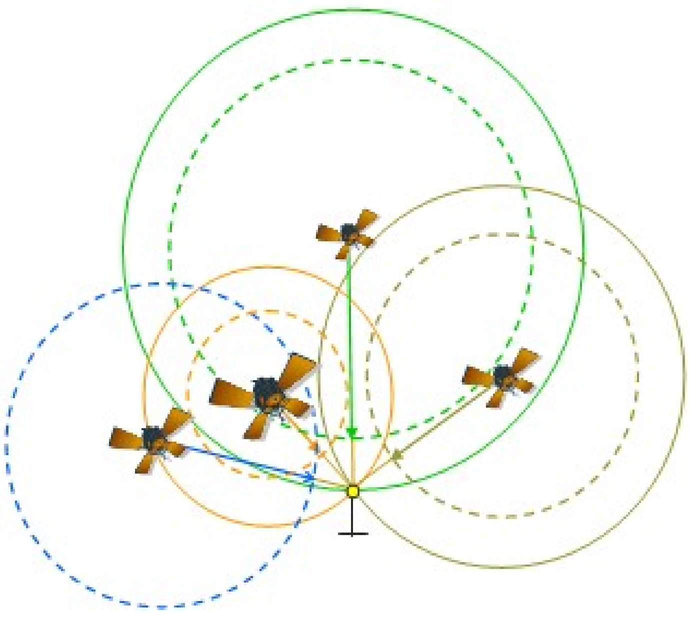
Time of Arrival (ToA)

- The distance from the mobile target to the measuring unit is directly proportional to the propagation time. In 2-D positioning, ToA measurements must be made with respect to at least three reference points.
- The one-way propagation time is measured, and the distance between measuring unit and signal transmitter is calculated.
- Problem: all transmitters and receivers in the system have to be <u>precisely synchronized</u>.
  - at light speed 1ms → 300km



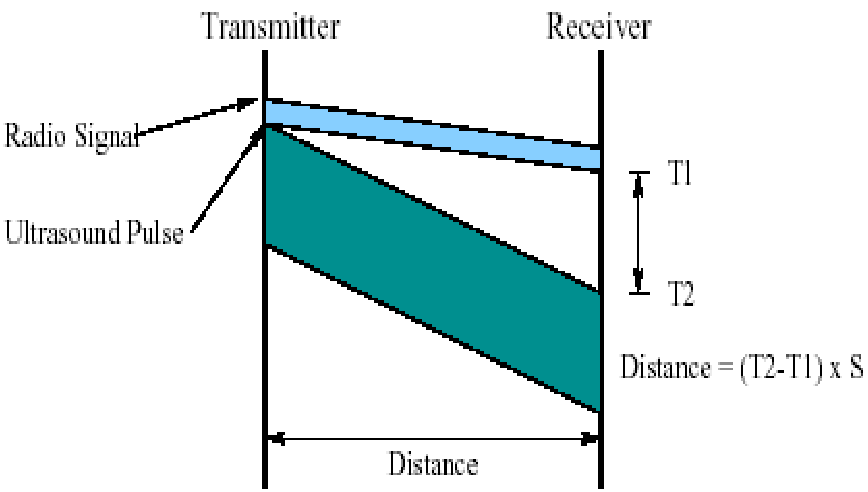
Time of Arrival (ToA)

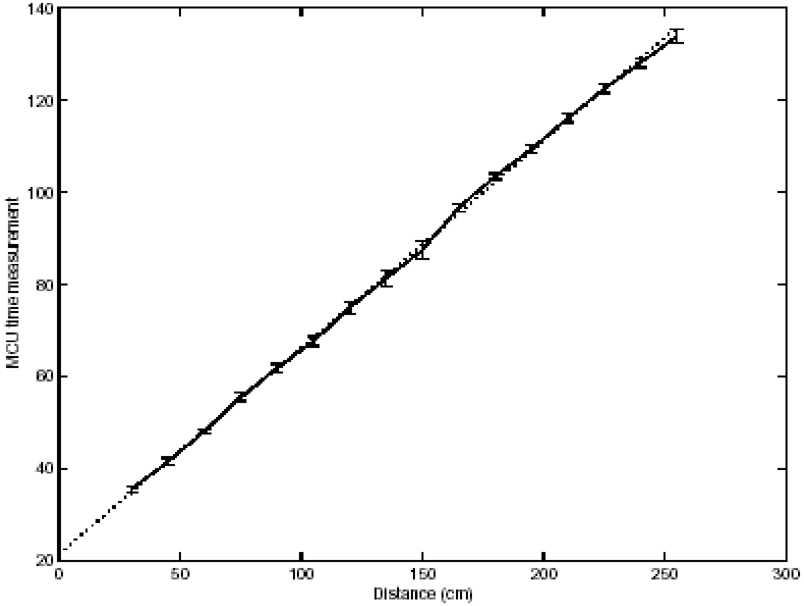
- Example: GPS
- Uses a satellite constellation of at least 24 satellites with atomic clocks
- Satellites broadcast precise time
- Estimate distance to satellite using signal ToA
- Trilateration



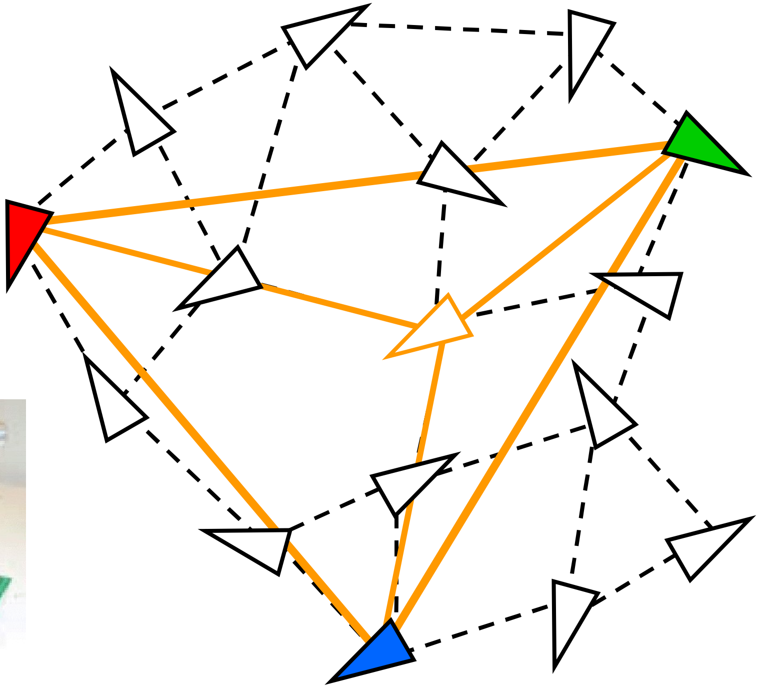
Time of Arrival (ToA)

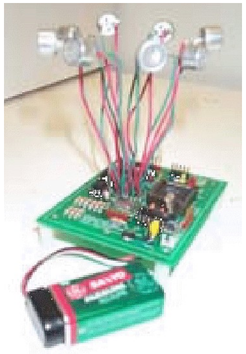
- ToA using RF and Ultrasound
  - The time difference between RF and ultrasound
  - To estimate the speed to sound, perform a best line fit
- Expensive in hardware and energy-consuming
- TDOA: Extra hardware.





Angle of Arrival (AoA)





- Location derived from the intersection of several pairs of angle direction lines
- Estimate relative angles between neighbors
- Use directional antenna or array of antennas
- 3 measuring units for 3-D and 2 measuring units for 2-D positioning
- no time synchronization needed

Require additional hardware and is expensive to deploy In large sensor networks

Estimation phase

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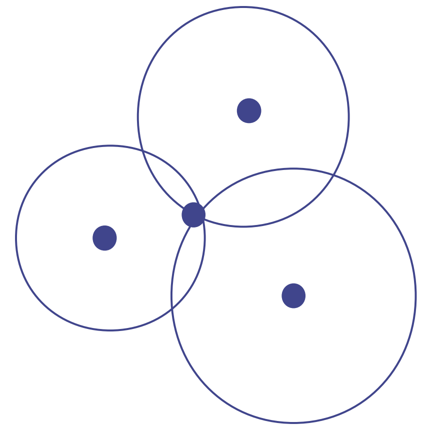
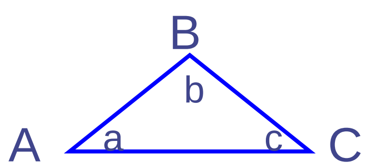
- Triangulation
  - Determine the location by measuring angles from known points.
- Trilateration
  - Determine the location by measuring distance between reference points.
- Multilateration
  - Determine the location by measuring time difference of signal from reference points.

Estimation phase

- Hyperbolic Trilateration



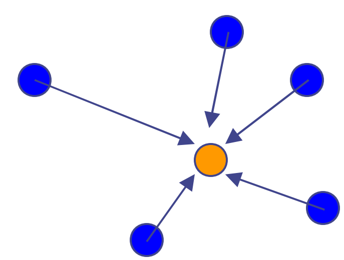
- Triangulation



Sines Rule $$\frac{A}{\sin a}=\frac{B}{\sin b}=\frac{C}{\sin c}$$

Cosines Rule
$$C^2=A^2+B^2+2\,AB\cos(c)$$
$$B^2=A^2+C^2-2\,BC\cos(b)$$
$$C^2=B^2+C^2-2\,BC\cos(a)$$

- Multi-lateration
  - Considers all available beacons



Performance metrics

- *Accuracy:* mean distance error, usually the average Euclidean distance between the estimated location and the true location.
- *Precision:* reveals the variation in algorithm's performance over many trials. Usually, the cumulative probability functions (CDF) of the distance error.
- *Complexity:* can be attributed to hardware, software, and operation factors. Usually, location rate is an indirect indicator for complexity.
- *Robustness:* the system works even when some signals are not available, or when some of the RSS value or angle character are never seen before.
- *Scalability:* the positioning performance degrades when the distance between the transmitter and receiver increases. A location system may need to scale on two axes: geography and density.
- *Cost* infrastructure, maintainance, additional nodes...

Related work

- Outdoor
  - Automatic Vehicle Location (AVL)
    - Determine the position of police cars
    - Use ToA, Multi-lateration
  - Global Positioning System (GPS) & LORAN
    - GPS:24 NAVSTAR satellites
    - LORAN: ground based beacons instead of satellites
    - Time-of-flight, trilateration
  - Mobile phone position
    - Cellular base station transmits beacons
    - Use TDoA, Multi-lateration

Related work

- Indoor
  - RADAR system
    - Track the location of users within a building
    - RF strength measurements from three fixed base stations
      - Build a set of signal strength maps
      - Mathing the online readings from the maps
  - Cricket location support system
    - Use Ultrasound from fixed beacons
    - Multi-lateration
  - The Bat system
    - Node carries an ultrasound transmitter
    - Multi-lateration

Range-Free Methods

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Many localization schemes proposed solutions are based on assumptions that do not always hold or are not practical:

- circular radio range
- symmetric radio connectivity
- additional hardware (e.g., ultrasonic)
- lack of obstructions
- lack of line-of-sight
- no multipath and flat terrain

Range-Free Methods

- Sensors never tries to estimate the absolute point to-point distance between anchors and sensors.
- Advantages
  - Cheap sensor hardware
  - Low computational power
- Disadvantages
  - Less accuracy than Range-Based methods

Range-Free Localization Methods

- Several Proposal:
  - **DV-HOP [2001]**
  - **Centroid Localization [2000]**
  - **APIT (Approximate Point-In-Triangle test) [2003]**
  - **SeRLoc (Secure Range-Independent Localization) [2004]**
  - ...

Range-Free Localization Methods DV-HOP [2001]

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- Proposed by Niculescu and Nath in [2001] as Ad-Hoc Positioning System
- Uses a distance-vector flooding technique to determine the minimum hop count and average hop distance to known anchors' positions.
  - Each anchor broadcasts a packet with its location and a hop count, initialized to one.
  - The hop-count is incremented by each node as the packet is forwarded.
  - Each node maintains a table of minimum hop-count distances to each anchor.

Range-Free Localization Methods DV-HOP [2001]

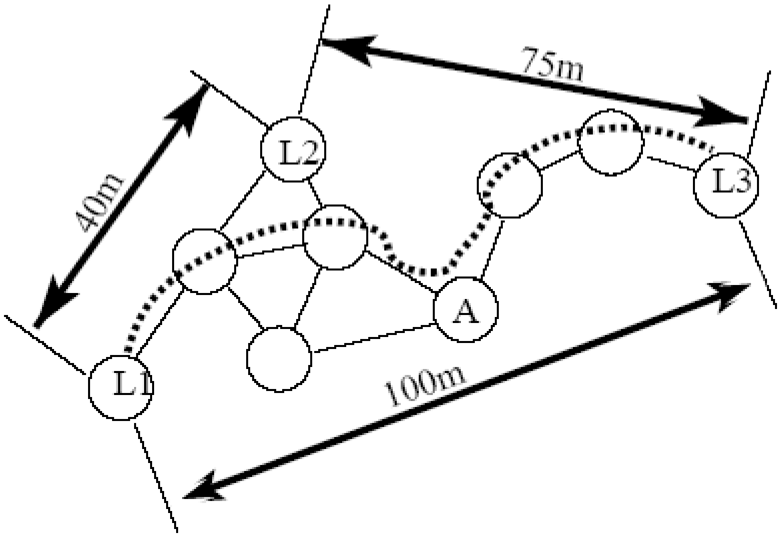
- Once an anchor gets distance information from all other anchors, it calculates a correction to the average hop distance based on the following equation

$$c_i = \frac{\sum \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum h_i}$$

Where anchor *i* is the anchor that calculates correction, j are other known anchors for *i*

- Individual nodes use the average hop distance calculated from nearest anchor, along with the hop count to known anchors, to calculate their local position using lateration.

Range-Free Localization Methods DV-HOP [2001]



L_1 computes the correction $\frac{100+40}{6+2} = 17.5$.

L_2 computes a correction of $\frac{40+75}{2+5} = 16.42$

L_3 a correction of $\frac{75+100}{6+5} = 15.90$.

A gets its correction from L_2

Distance to L1 = 3 x 16.42, to L2 = 2 x 16.42, to L3 = 3 x 16.42

Range-Free Localization Methods DV-HOP [2001]

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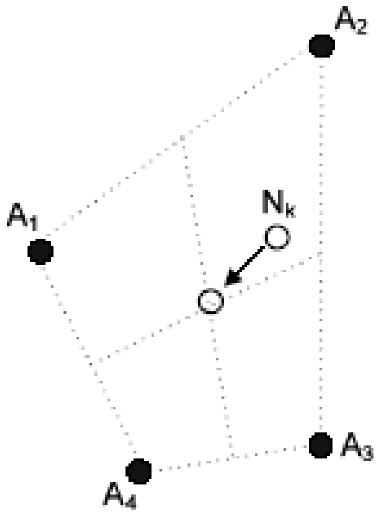
- Advantages
  - Simple
- Drawback
  - Works only for isotropic networks
  - Estimation error depends on the number of anchors that a node can hear
  - Large overhead

Range-Free Localization Methods
Centroid Localization [2000]

- Proposed by Bulusu and Heidemann in [2000]
- Each sensor estimates distance from the heard anchors using center of gravity (centroid) method



Range-Free Localization Methods Centroid Localization [2000]

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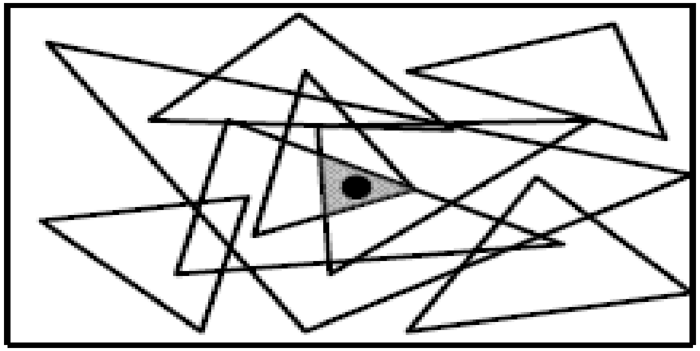
- Advantages
  - Simple and easy to implement
  - Less Overhead than in DV-HOP (Fewer beacons)
- Drawback
  - Needs lot of overlapped anchors for correct estimation

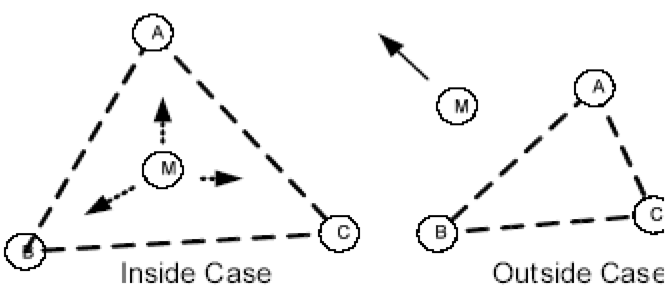
Range-Free Localization Methods APIT [2003]

- Proposed by He, Huang, Blum, Stankovic and Abdelzaher in [2003]
- *Approximate Point-In-Triangulation* (APIT) employs a novel area-based approach to perform a centroid location estimation by isolating the environment into triangular regions between anchor nodes as shown



Range-Free Localization Methods APIT [2003]

- The theoretical method used to narrow down the possible area in which a target node resides is called the *Point-In-Triangulation Test* (PIT)
  - The Point-In-Triangulation test determines whether a point M with an unknown position is inside triangle formed by points A, B and C or not.



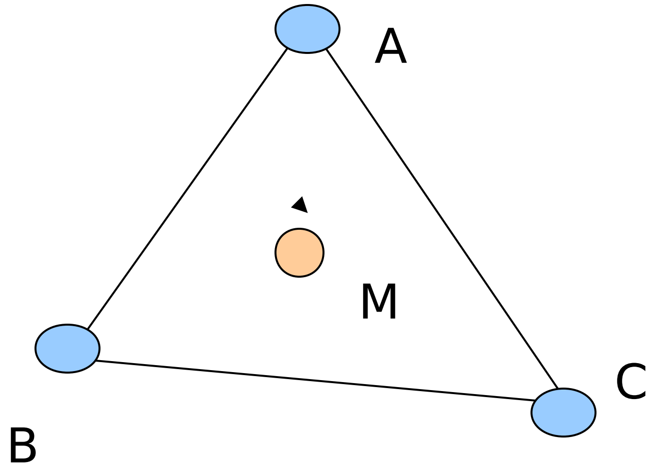
Range-Free Localization Methods APIT [2003]

- The theoretical method works as following

Receive location beacons (X_i, Y_i) from N anchors;
$InsideSet = \emptyset$;
for each triangle $T_i \in \binom{N}{3}$ triangles do
  if Point-In-Triangle-Test (T_i) == TRUE then
    $InsideSet = InsideSet \bigcup T_i$;
  end if
end for
Estimated Position = CenterOfGravity($\bigcap T_i \in InsideSet$);

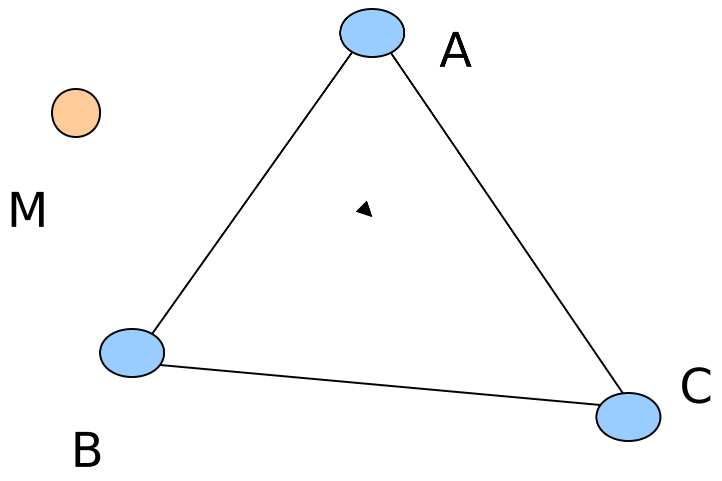
Perfect PIT Test

- Proposition 1: If M is inside triangle ABC, when M is shifted in any direction, the new position must be nearer to (further from) <u>at least one</u> anchor A, b or C



Continued…

- Proposition 2: If M is outside triangle ABC, when M is shifted, there must exist a direction in which the position of M is further from or closer to all three anchors A, B and C.



Performing the PIT Test

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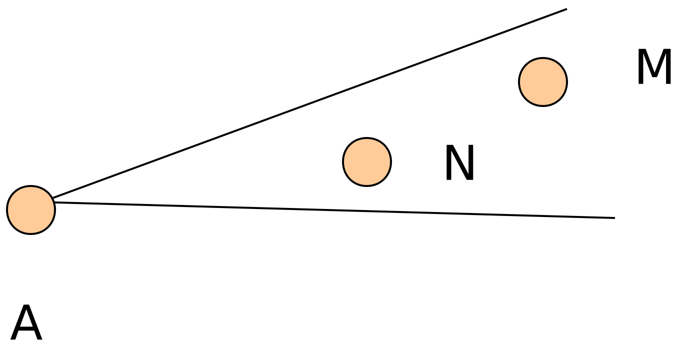
- If there exists a direction such that a point adjacent to M is further/ closer to points A, B, and C simultaneously, then M is outside of ABC. Otherwise, M is inside ABC.
- Perfect PIT test is infeasible in practice:
    - Nodes can’t move, how to recognize direction of departure
    - Exhaustive test on all directions is impractical

Departure Test

- Experiments show that, the receive signal strength is decreasing in an environment without obstacles.
- Therefore the further away a node is from the anchor, the weaker the received signal strength.



Appropriate PIT Test

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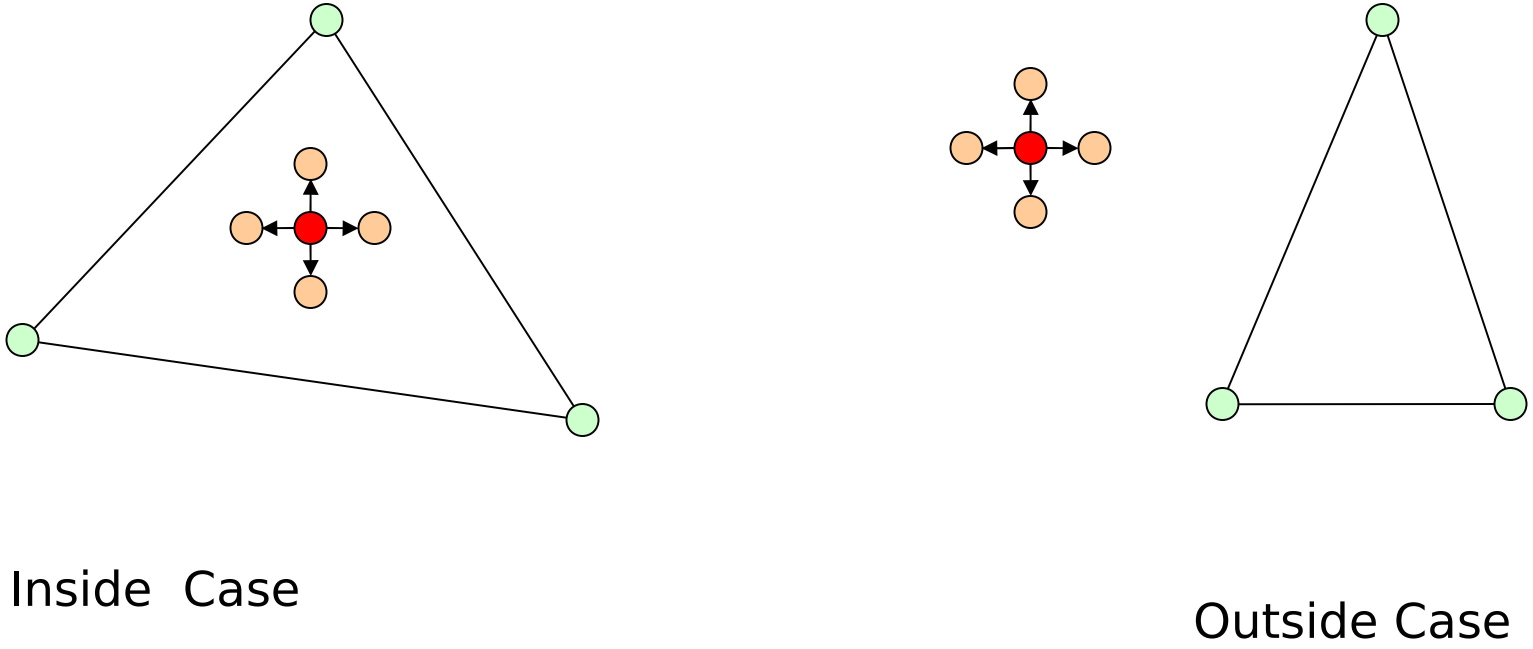
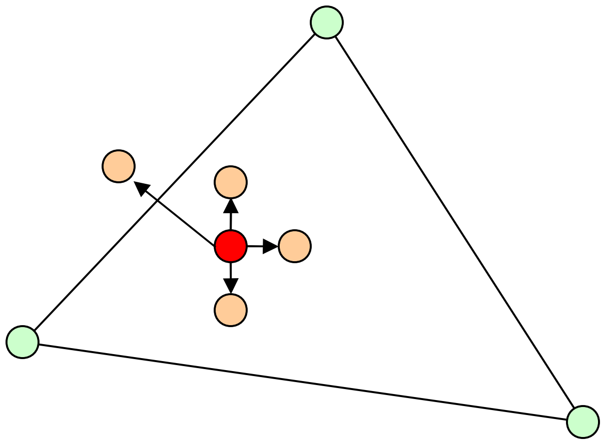
- Use neighbor information to emulate the movements of the nodes in the perfect PIT test.
- *If no neighbor of M is further from/ closer to all three anchors A, B and C simultaneously, M assumes that it is inside triangle ABC. Otherwise, M assumes it resides outside this triangle.*

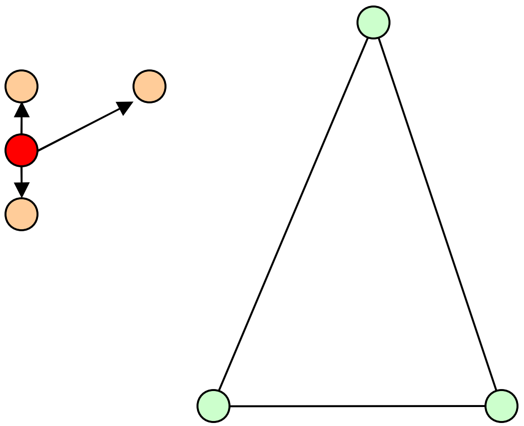
Range-Free Localization Methods APIT [2003]



Error Scenarios for APIT test



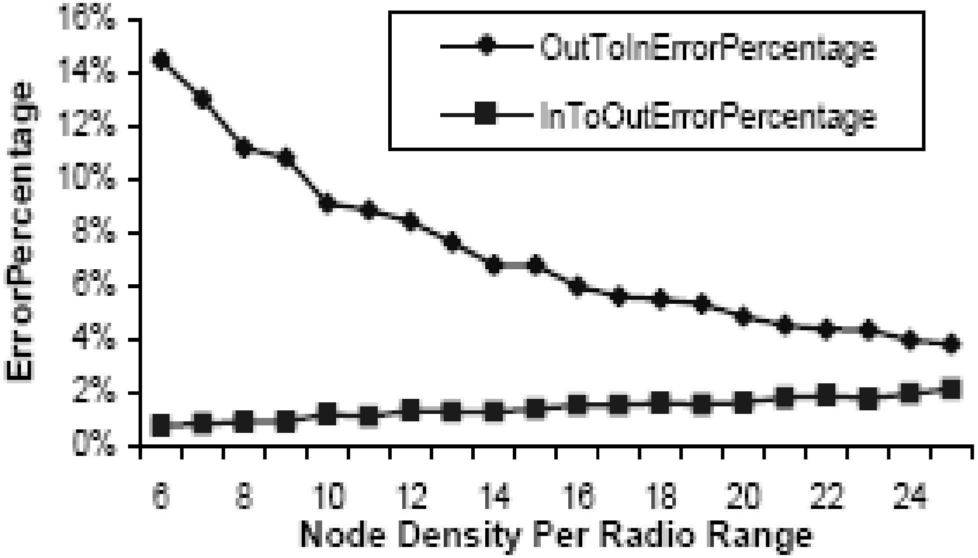
In to out error



Out to in error

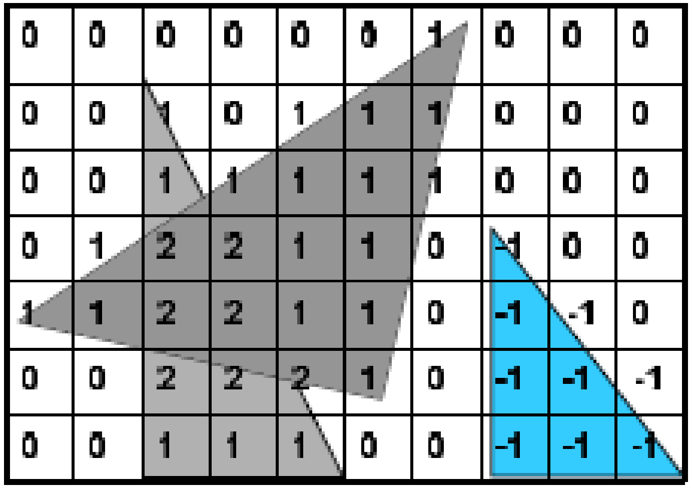
Range-Free Localization Methods APIT [2003]

- However, from experimental results it is seen that the error percentage is small as the density increases.



APIT aggregation

- Represent the maximum area in which a node will likely reside using a grid SCAN algorithm.
  - For **inside** decision the grid regions are incremented.
  - For **outside** decision the grid regions are decremented.



Range-Free Localization Methods APIT [2003]

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- Advantages
  - Small overhead
  - More accurate results than centroid method
- Drawbacks
  - Problem determining a sensor located out of all anchor triangles (undetermined sensor)

Range-Free Localization Methods SeRLoc [2004]

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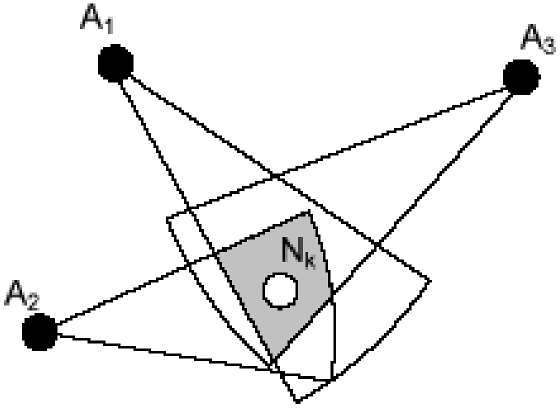
- Proposed by Lazos and Poovendran in [2004]
- Mainly targets the security problems in WSN (avoiding wormhole attacks)
- Sensors are equipped with Omni-directional antennas, while anchors are equipped with directional sectored antennas.



Range-Free Localization Methods SeRLoc [2004]

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- The method works as following

Receive beacons from locators; each beacon contains the position of locator and the angles of sector boundary.

Find four values: $(X_{min}, Y_{min}, X_{max}, Y_{max})$ among all the locator positions heard.

Set the search area as the rectangle $(X_{min} - R, Y_{min} - R, X_{max} + R, Y_{max} + R)$, where R is the radio range.

Partition the search area into grids.

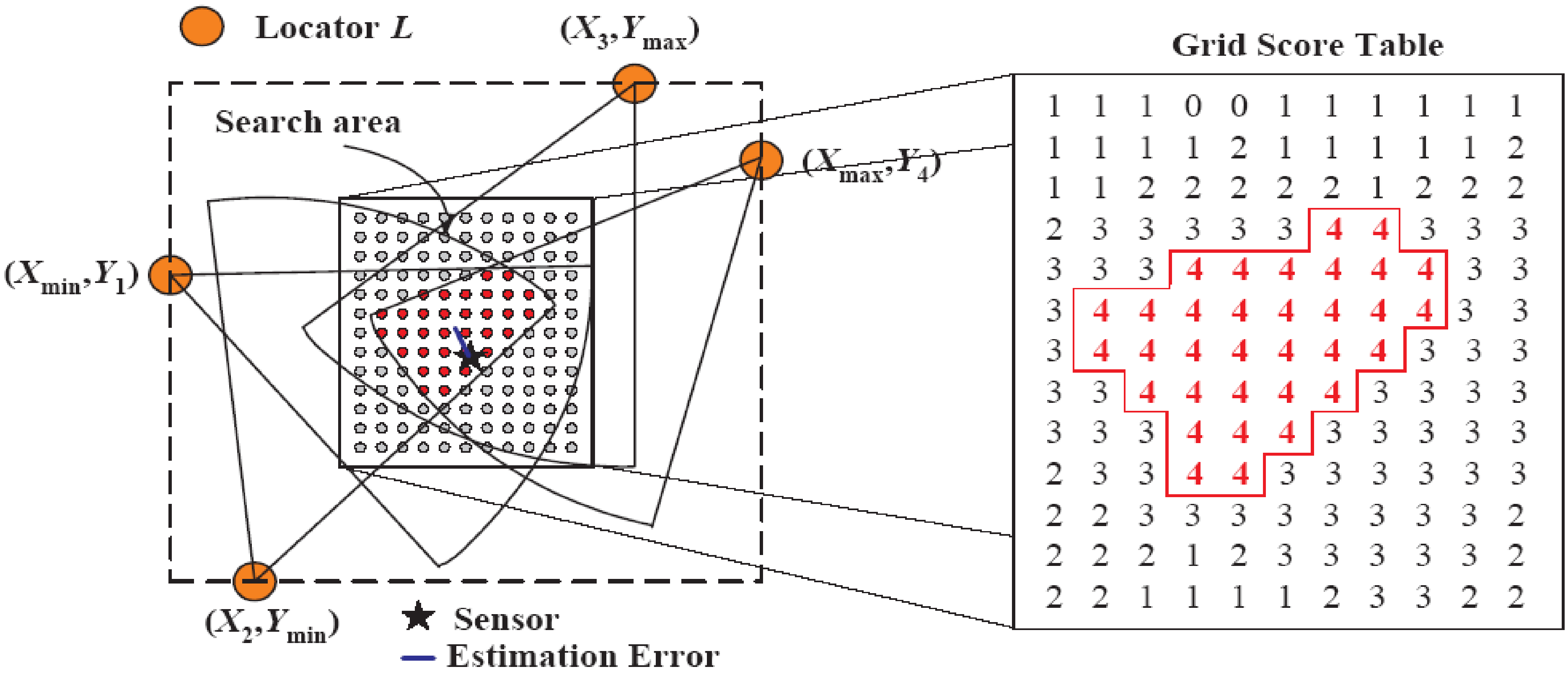
for each beacon received do

  Increase the value of a grid point by one if this grid point is within the sector defined in this beacon.

end for

Estimated Position = CenterOfGravity(the grid points with the largest values)

Range-Free Localization Methods
SeRLoc [2004]



1	1	1	0	0	1	1	1	1	1	1
1	1	1	1	2	1	1	1	1	1	2
1	1	2	2	2	2	2	1	2	2	2
2	3	3	3	3	3	4	4	3	3	3
3	3	3	4	4	4	4	4	4	3	3
3	4	4	4	4	4	4	4	4	3	3
3	4	4	4	4	4	4	4	3	3	3
3	3	4	4	4	4	4	3	3	3	3
3	3	3	4	4	4	3	3	3	3	3
2	3	3	4	4	3	3	3	3	3	3
2	2	3	3	3	3	3	3	3	3	2
2	2	2	1	2	3	3	3	3	3	2
2	2	1	1	1	1	2	3	3	2	2

Range-Free Localization Methods SeRLoc [2004]

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- The security mechanism is implemented as:
  - Encryption using shared symmetric key
  - Anchor ID authentication
    - Each anchor has a unique hashed password
    - All sensors maintain anchor id – hashed password tables

Range-Free Localization Methods
SeRLoc [2004]

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- Advantages
  - Secure
  - Small overhead
  - More accurate than APIT
- Drawbacks
  - Needs a special anchor design
  - Deployment of anchors to cover all sensors
  - Maintaining of security tables in case of network changes (e.g. new anchors added)

Conclusion

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- WSN becomes important in many fields
- Localization is an important factor in WSN
- Several proposals presented to Address localization issue in WSN
- Range-Based localization proposals are accurate but costly
- Range-Free localization proposals are inaccurate but cheap

Some References

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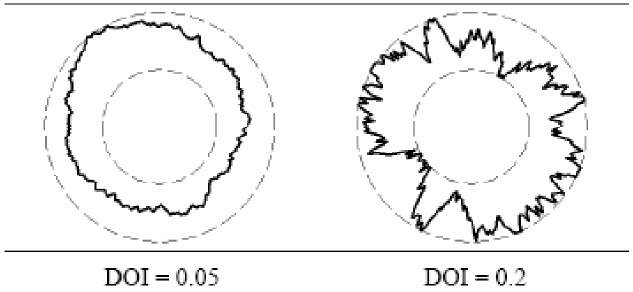
- [3] R. Nagpal, Organizing a Global Coordinate System from Local Information on an Amorphous Computer, A.I. Memo 1666, MIT A.I. Laboratory, August 1999.
- [4] R. Nagpal, H. Shrobe, J. Bachrach, Organizing a Global Coordinate System from Local Information on an Ad Hoc Sensor Network, In the 2nd International Workshop on Information Processing in Sensor Networks (IPSN '03), Palo Alto, April, 2003.
- [5] T. He, C. Huang, B. Blum, J. Stankovic and T. Abdelzaher, Range-Free Localization Schemes in Large Scale Sensor Network, In Proc. of MOBICOM 2003, San Diego, CA, USA, September 2003
- [6] L. Lazos and R. Poovendran. SeRLoc: Secure range independent localization for wireless sensor networks. In ACM workshop on Wireless security (ACM WiSe ’04), Philadelphia, PA, October 1 2004.

Comparison of Presented Methods

Definitions

- DOI: Degree of Irregularity

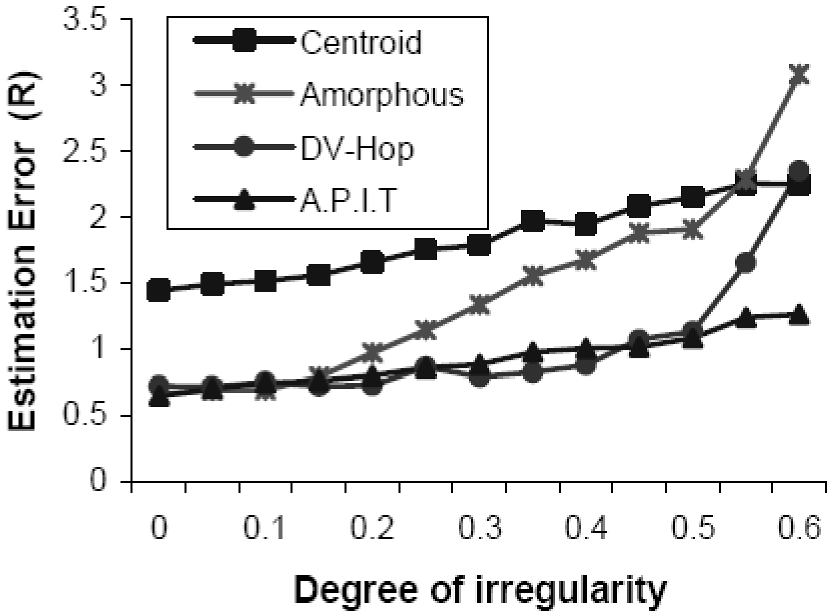


- AH or LH: Number of Anchors Heart by Sensor
- ANR: Average Anchor to Node Range Ratio
  - 1 means that range of anchors is same as other nodes
- ND: Node Density or Number of Neighbors that Node Hears
- Estimation Error is normalized as units of node radio range R

$$\overline{E} = \frac{1}{|S|}\sum_{i}\frac{\|\hat{s}_i - s_i\|}{r}$$

Comparison of Presented Methods

Simulation Results [From APIT Paper]



B. ANR = 10, ND = 8, AH=16, Random

Comparison of Presented Methods

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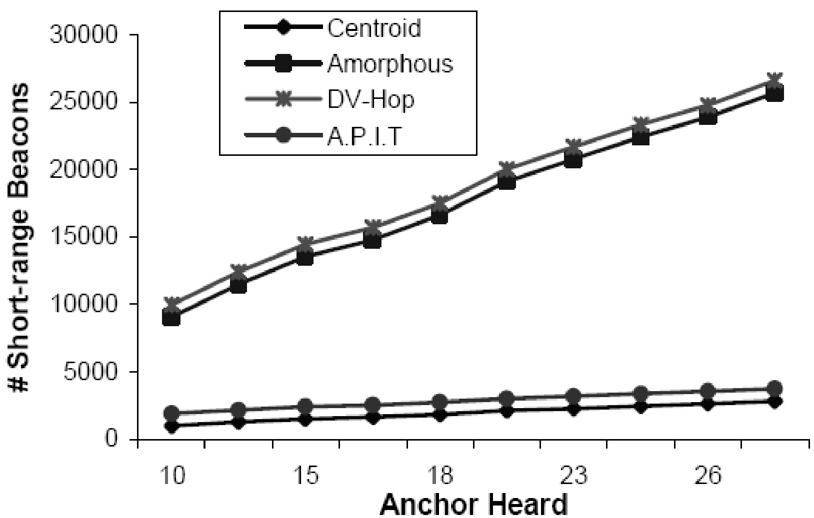
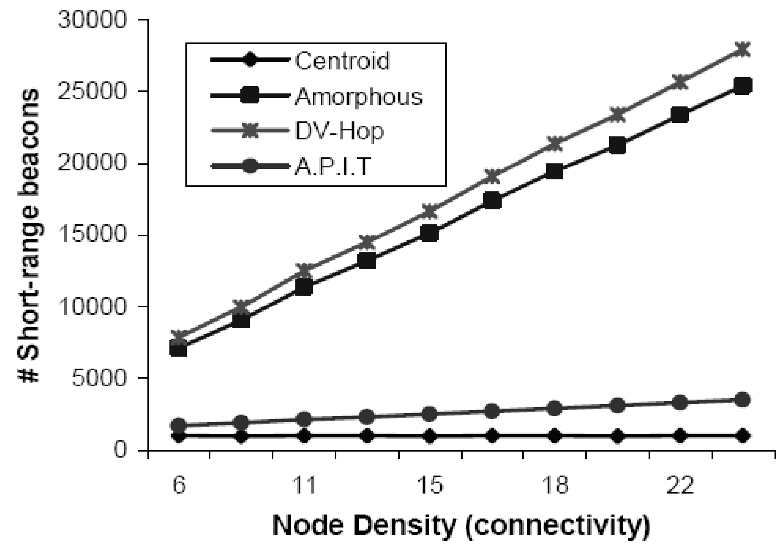
Simulation Results [From APIT Paper]



ANR=10, ND = 8, DOI = 0.1, Uniform

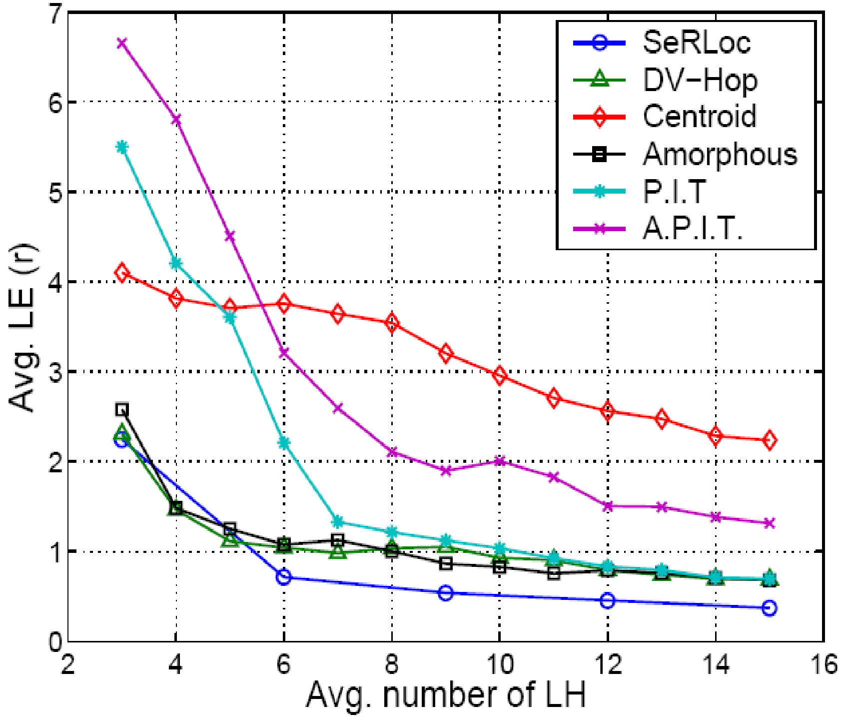


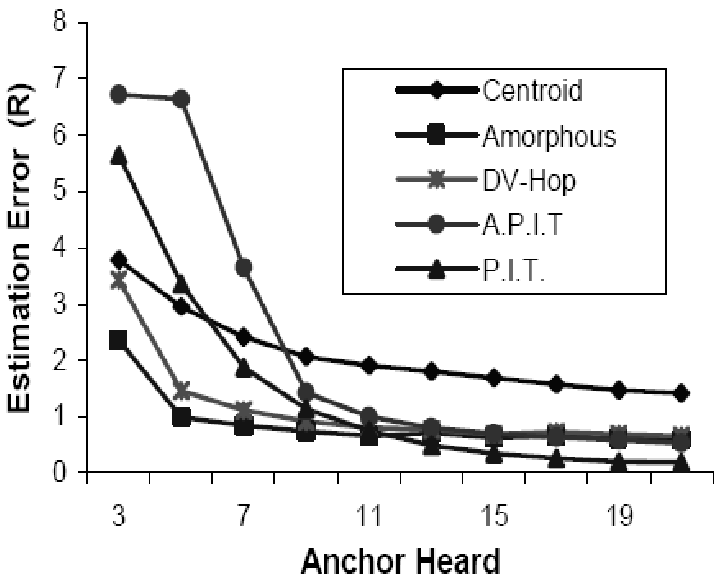
ANR=10, AH = 16, DOI = 0.1, Uniform

Comparison of Presented Methods

PerLab

Simulation Results [From SeRLoc, APIT Papers]





A. AH=3~21, DOI=0, ANR = 10, ND = 8, Random