1 Introduction


Recent advances in radio and embedded technologies has proliferated the wireless microsensor networks. With the increased use of sensor networks in diverse applications, there is a need for the sensor network to have a knowledge of their physical location. The need for location awareness is required in many diverse environments such as in movement of troops, location of cell phones, etc.

GPS is considered to be the straightforward solution, but its not viable as GPS requires clear sky for tracking, and it does not work indoors. Apart from that, it has a very high cost and is bulky.

2 Previous Works

Most of the previous Localization Algorithm works in 2 phases

- **Distance Estimation** - Distance is estimated between two nodes. Some of the well known methods are
  
  **Received Signal Strength Indicator** - It uses the relationship of signal attenuation and distance. It calculates distance by checking the power of signal after signal loss. The problems with this approach are multipath problem, fading and shadowing problem. Altitude of antenna plays an important role and propagation characteristics vary with environment and hence can affect the signal strength.

  **Time Based Method** - System records the time-of-arrival (ToA) or time-difference-of-arrival (TDoA). The distance can be calculated by using propagation time and the known signal propagation speed.

  **Angle of Arrival** - System calculates the distance between node by estimating the angle at which signal is received.

- **Distance Combining** - Some of the most popular alternatives are
  
  **Hyperbolic-Trilateration**(Fig. 1(a)) - Locates node by calculating the intersection of 3 circles. Trialateration is a 3 step process. In the initial phase, the unknown node tries
to find its location with respect to one of the Beacon Nodes. In this phase, the unknown nodes finds its position to be loci of points of circumference of the circle with center as known Beacon node with radius as the distance of unknown node with this beacon node that was estimated in the Estimation Phase. In the next phase, the unknown node finds its location with respect to 2 beacon nodes. The unknown nodes computes its position to be the two points where the both the circle of two known beacon nodes intersect. In the last phase, the unknown node finds it position by finding the intersecting point of the circle all all three beacon nodes. Since the intersection of all three such circle can be one point, the unknown node computes its position to be that intersecting point.

**Triangulation** (Fig. 1(b)) - Triangulation is used when the direction of the node is estimated. The node positions are calculated by using the trigonometry laws of sines and cosines.

**Maximum Likelihood estimation** (Fig. 1(c)) - It estimates the position of a node by minimizing the differences between the measured distances and estimated distances of the nodes.

Some of the previous works done are Cricket, GPS, LORAN, RADAR, etc.
3 Our Work - AHLoS

The paper provides a solution to localization in which a limited fraction of nodes (known as Beacon Nodes) are required to know their exact position. AHLoS (Ad-Hoc Localization System) has many benefits over other solutions

- Less Costlier than previous systems.
- Smaller in Size - AHLoS use sensor node "Medusa" equipped with ultra-sound.
- AHLoS can work indoors unlike GPS.
- Power Consumption is quite low.

AHLoS dynamically locate the position of nodes in two phases

- Ranging - Node estimate their distance with neighbors.
- Estimation - Unknown Nodes locate their position using ranging information and known beacon node locations.

3.1 Ranging

AHLoS uses ToA (Time of Arrival) method for ranging. The ToA works by calculating the time difference between two simultaneously transmitted Radio Frequency (RF) and Ultra-Sound signal. The distance is then calculated by multiplying the difference with the speed of ultrasound \(D = (T2 - T1) \times S\).

![Distance Measurement using Ultra Sound and Radio Signals](Figure 2: Distance Measurement using Ultra Sound and Radio Signals)

ToA using RF and Ultrasound signal can provide an accuracy of 2cms for node separation under 3 meters. This is a great achievement over earlier solutions. The reason for choosing ToA as the ranging technique was its accuracy, reliability and it is not affected by environment as much as signal strength does.
3.2 Estimation

In this phase, we try to estimate the position of unknown nodes. The unknown nodes are the nodes that do not know their position. The Beacon Nodes are the one that know their position. In this phase, we try to estimate the position of as many unknown nodes as possible using the information from ranging phase.

The AHLoS is an iterative process. The beacon nodes broadcast their locations to their neighbors once they are deployed. The neighboring unknown nodes measure their distance from their neighbors and uses the broadcasted beacon positions to estimate their own positions. The unknown node becomes Beacon Node once it estimates its position. This new beacon node then broadcasts its estimated position to other nearby unknown nodes, enabling them to estimate their positions. This process repeats until all the unknown nodes estimate their position.

This process works in 3 phases

3.2.1 Atomic Multilateration

This is the basic case, where unknown nodes estimate their location if they are within range of atleast 3 Beacon Nodes. If they are in range of more than 3 beacon nodes, they also estimate the ultrasound speed for their locality. To estimate their position they use Maximum Likelihood Estimation Technique. Let us suppose the coordinate of unknown node be \((x_0, y_0)\). Here, with respect to each beacon node, we define an equation \(d_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2 + err_i}\), where \(i\) is the known Beacon, \((x_i, y_i)\) is the location of known beacon node \(i\) and \(err_i\) is the error in estimation the distance between the unknown node and the beacon node \(i\) and \(d_i\) is the estimated distance between unknown node and beacon node \(i\) from ranging phase. After defining the equations for each corresponding beacon node(at least for 3 beacon nodes), the value of \(x_0\) and \(y_0\) can be calculated using general algebra. By using the equations, the unknown node can find its location.

3.2.2 Iterative Multilateration

In Iterative Multilateration, the unknown nodes that have become Beacon Nodes in Atomic Lateration, helps other unknown nodes to locate their position. This process continues iteratively until all the position of all unknown node that eventually can have three or more beacon nodes as neighbors, are estimated. In this phase, the unknown node in previous phase that finds its location, becomes beacon node. Once the node knows its position, it becomes a beacon node for other neighboring unknown nodes. Now, initially if an unknown node has only 2 beacon nodes or less, then the unknown can have 3 or more beacon nodes and using atomic multilateration the unknown nodes locate their position.

Error Accumulation looks to be an important problem, but on calculating the accumulated error, it shows the error accumulation is not very high.
3.2.3 Collaborative Multilateration

In random distribution of beacon, not all unknown nodes have 3 beacon and does not met with atomic multilateration condition, so Collaborative multilateration is required. Here, a node may attempt to estimate its position by considering use of location information over multiple hops.

The two requirements for collaborative multilateration are

- Participating node is either a beacon or is unknown with 3 neighboring participating node.
- Participating node-pair is a beacon-unknown node pair or a unknown-unknown pair where all unknowns are participating.

The collaborative lateration helps when beacon density is quite low. Figure 3(b) shows an ideal condition for collaborative multilateration. Figure 3(c) is bad option for collaborative multilateration.

3.3 Further Optimization

Error propogation can be further reduced by using weighted multilateration. In weighted multilateration, higher certainty nodes are weighted more than lower certainty nodes. In this way, propogation error can be optimized.