An Efficient Approach for Localization using Trilateration Algorithm based on Received Signal Strength in Wireless Sensor Network

Niharika Singh Matharu **Avtar Singh Buttar**
ECE Department Punjab Institute of Technology Kapurthala, India

Abstract
In this work, an efficient approach without additional hardware and improved accuracy is proposed Trilateration based algorithm is a distributed beacon-based localization algorithm uses distance estimation to compute the 3-D position of nodes in a network with help of Received Signal Strength. The blind node can estimate its distance from anchor node using received signal strength and the position (x, y, z) in 3-D of the node can be computed from the position information obtained from the three and four anchor nodes using trilateration. Signal propagation model is used to find out the received power i.e. received signal strength from different sensor nodes. This method uses this received signal strength. This received signal strength information is used in the trilateration method to find out the exact location of the blind nodes in the sensor field. The average localization error is coming to be 0.0119 computed with 100 anchor nodes.

Index Terms
Trilateration, RSS

1. Introduction

Wireless Sensor Networks (WSNs) has become an emergent area of interest among the academic and industry in the last era. The Wireless Sensor Networks have many applications in buildings, air traffic control, engineering automation, environment observing, industry and security and have a wide range of potential applications to industry, science, transportation, domestic substructure, and security. A wireless sensor network is comprised of large number sensor nodes which are small in size, low power device, low costing and have low processing capabilities that can communicate and work out signals with other nodes. A WSN consists of densely distributed nodes that provide sensing, signal processing, embedded computing, and connectivity. Sensors are sensibly linked by self-organizing means.

Location of sensor node is very essential in a wireless sensor network since many application such as observing forests and/or fields, where a large amount of sensor nodes are deployed. Localization is the most important issue in wireless sensor network because the location information is useful in deployment, routing, target tracking, coverage and rescue. . Localization is the process of finding the position of nodes as data and information are useless if the nodes have no idea of their geographical positions. Sensor nodes can determine their location by extracting the information received from the infrastructure, and by making nodes to send signals periodically. Global positioning system (GPS) is the simplest node localization method, but it becomes very expensive if large number of nodes exists in a network and also these devices have huge energy consumption. There are three different phases in localization: (1) Distance/Angle Estimation (2) Position Computation and, (3) Localization Algorithm. for location discovery in a sensor network, there must be a set of specialty nodes known as beacon (Anchor) nodes. These nodes know their location, either through a GPS receiver, or through manual configuration, which these provide to other sensor nodes. Using this location of beacon nodes, sensor nodes compute their location using various techniques. In this paper, range-based localization techniques are used to determine the position of a node in a network. Range based techniques are as follow:

- Angle of Arrival (AOA): The angle between a signal's propagation and some reference direction. They need an additional hardware, multipath reflections causes an error in estimating the directions, need very high resolution clock and is not scalable.

- Time of Arrival (TOA): Speed of wavelength and time of signals travelling between anchor node and blind node is measured to estimate the location of blind node. Good level of accuracy but can be affected by multipath signals and shadowing.

- Time Difference of Arrival (TDOA): Uses the same methodology as TOA but the difference is that it use two different signals say RF and ultrasound signal of different velocity.

- Received Signal Strength Indicator (RSSI): The attenuation in signal strength is measured by received signal strength indicator (RSSI) circuit. RSSI

Manuscript received August 5, 2016
Manuscript revised August 20, 2016

measures the received power and the calculated power is translated into the estimated distance. This technique is simple, cheap and it doesn't need an extra hardware. The main disadvantage is the signal gets interrupted by noise, causing high inaccuracy in locating the position of nodes in the Wireless Sensor Networks.

In this paper the aim is to determine the 3-D position of the blind nodes (a node that is unaware of its position) using a simple localization algorithm that uses distances estimation (Range based) and compare it from existing techniques for the accuracy and performance.

2. Related Work

A lot of work related to localization techniques has already been done in previous years. So many techniques have been developed to locate the blind node. But still they produce a considerable amount of localization error. In this research work after the survey of previous works done in this field a better algorithm for localization of sensor nodes has been proposed.

Hongyang Chen, Pei Huang, Marcelo Martins, and Hing Cheung So, and Kaoru Sezaki in 2008 [1] proposed a localization technique which improves the location accuracy with low communication traffic and computing complexity. In this paper it is shown that the performance of the proposed algorithm is superior to the conventional centroid algorithm as the performance is tested in the three dimensional scenario.

In 2010 Chia-Yen Shih and Pedro Jos´e Marr´on [2] proposed a technique called Complexity-reduced 3D trilateration Localization Approach (COLA) that is based on RSSI values. The objective was to develop an effective 3D localization technique by extending existing approaches for 2D localization and it simplifies the 3D positioning process by reducing the complex 3D trilateration operation to 2D trilateration computation. The COLA approach can tolerate more errors and achieve higher location accuracy than that of the typical 3DT approach.

Oguejiofor O.S, Aniedu A.N, Ejiofor H.C and Okolibe A.U in 2013 [3] proposed a trilateration based localization algorithm for wireless sensor networks (WSNs) for determining the position of nodes. Whenever anchor nodes broadcast packets containing their locations and other parameters, the blind node within the broadcast range store the positioning packet and compute the estimated its distance to the anchor and broadcast the anchor node position to other blind nodes. The blind nodes receive packets from at least three anchor nodes and hence the blind node performs trilateration and blind node becomes converted into anchor node and sends the location to sink.

Pratik S. Patel and Jignesh R. Patel in 2014 [4] proposed a range-based 3D localization algorithm that is accurate, anchor-free, scalable and physical position available. Distance and direction measurement techniques are introduced to estimate ranges between anchor nodes and blind nodes. They have shown that the performance of proposed algorithm is better i.e. it achieves good trade-off between localization error percentage and precision.

Labyad Asmaa, kharraz Aroussi Hatim and Mouloudi Abdelaaziz in 2014 [5] proposed two different localization algorithms using Trilateration and Multilateration mathematical techniques and compared according to the number of anchor nodes. It has been found that increasing the number of anchor nodes could enhance the accuracy of the mean location error of location algorithm based on Multilateration technique. Performance measures have been taken against mean location error and energy consumption.

3. Trilateration Technique

Range-based localization needs multiple pair wise range measurements to estimate the locations of nodes. Multiple range measurements between unknown node and its neighbors anchor/beacon nodes can be used to improve the accuracy of the location estimate. Localization techniques vary, depending on the ranging technique. If an unknown node has distance measurements between its neighbors anchor nodes, then trilateration techniques can be used to estimate its location. In a 3-D space four anchor/beacon nodes with known locations are necessary to localize a node through distance measurements. Each distance measurement defines a circle around an anchor node with radius equal to the measurement, on which the node should lie. The intersection of three such circles from four nonlinear anchor nodes defines the exact location for the node. However, this technique accepts perfect distance measurements, which is not feasible in WSNs because of ranging errors. Hence, more than four nodes are required for localization.

A. Mathematical Model for 2-Dimensional and 3-Dimensional

Considering the figure 1 shown below.

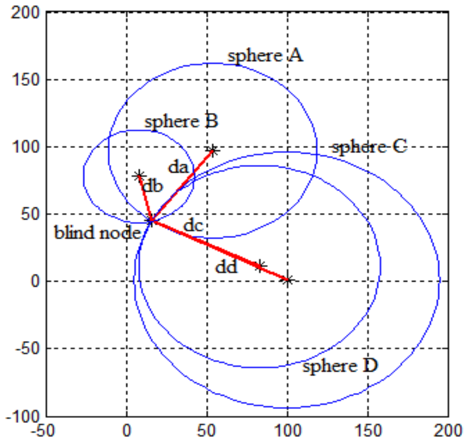

Fig 1. Diagram showing intersection of four spheres

The general equation of a sphere centered at a point (0, 0, 0) as given as

$$d^2 = x^2 + y^2 + z^2 \quad \text{-----------} \quad 1$$

general equation of a sphere centered at a point (xa, ya, za) is given as

$$d^2 = (x - x_a)^2 + (y - y_a)^2 + (z - z_a)^2 \quad \text{-----} \quad 2$$

Now considering four anchor nodes (a, b, c, d) that have distance (da, db, dc, dd) from blind node as shown in the figure 1. The equations for all spheres are given as.

Sphere A:

da2 = (x – xa)2 + (y - ya)2 + (z – za)2 --------- 3

Sphere A:

db2 = (x – xb)2 + (y – yb)2 + (z – zb)2 --------- 4

Sphere A:

dc2 = (x – xc)2 + (y – yc)2 + (z – zc)2 --------- 5

Sphere A:

dd2 = (x – xd)2 + (y – yd)2 + (z – zd)2 -------- 6

Equation 3, 4, 5 and 6 can further be expanded to bring about the following equations:

$$(xd - xa)x + (yd - ya)y + (zd - za)z = u = \frac{(da2 - dd2) - (xa2 - xd2) - (ya2 - yd2) - (za2 - zd2)}{2} \quad \text{------} \quad 7$$

$$(xd - xb)x + (yd - yb)y + (zd - zb)z = v = \frac{(db2 - dd2) - (xb2 - xd2) - (yb2 - yd2) - (zb2 - zd2)}{2} \quad \text{-----} \quad 8$$

$$(xd - xc)x + (yd - yc)y + (zd - zc)z = w = \frac{(dc2 - dd2) - (xc2 - xd2) - (yc2 - yd2) - (zc2 - zd2)}{2} \quad \text{-----} \quad 9$$

Equations 7, 8 and 9 can be written as

xda.x + yda.y + zda.z = u ------------------- 10
xda.x + yda.y + zda.z = v ------------------- 11
xda.x + yda.y + zda.z = w ------------------- 12

where,

$$x_{da} = x_d - x_a$$
$$y_{da} = y_d - y_a \quad \text{.... etc}$$

In matrix form it can be written as

$$\begin{bmatrix} x_{da} & y_{da} & z_{da} \\ x_{db} & y_{db} & z_{db} \\ x_{dc} & y_{dc} & z_{dc} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} u \\ v \\ w \end{bmatrix} \quad \text{----------} \quad 13$$

B. Signal Propagation Model

Signal propagation model is also known as free space model.While electromagnetic signals when traveling through wireless channels experience fading effects, but in some cases the transmission is with a direct line of sight such as in satellite communication. Receiver can receive the data packet. Distance of one node from the other node can be determined by measuring received signal strength of the received radio signal. In received signal strength the transmitted power (Pt) at the transmitter directly affects the received power (Pr) at the receiver.

Free space model prophesies that the received power decreases as negative square root of the distance. According to frii’s free transmission equation, the detected signal strength decreases with square of the distance.

$$P_{r(d)} = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \quad \text{--------------} \quad 14$$

Where Pt is the transmitted power, Pr is the received power, Gt and Gr are the transmitting and receiving antenna gain respectively, λ is the wavelength and d is the distance between the transmitting and receiving antenna

4. Proposed Methodology

The objective of this algorithm is to determine blind node’s location within the scattered nodes.

The Proposed Methodology consists of two stages:

A. Initialization Stage:

This Initialization stage is introduced at all anchor nodes by making them transmit their data, location position and other parameters. The blind node within the range of the transmission store and estimate the anchor node location based on the received signal strength. By this all blind nodes will know the location of the anchor nodes.

B. Final Stage:

A blind node estimate its distance from at least three anchor nodes, then trilateration is perform to get its position in 3D with at least four anchor nodes or more. Then this blind node is transformed into anchor node and the position is sent to the sink. These two stages are performed till all the blind nodes are transformed into anchor nodes.

The procedure is summarized in steps:

Step 1: Random deployment of anchor nodes and blind nodes.

Step II: Calculate actual distance between anchor nodes & blind nodes using Euclidean distance formula.

$$d = \sqrt{((x(i)-x(j))^2 + (y(i)-y(j))^2 + (z(i)-z(j))^2}$$

Step III: Measure received signal strength at each blind node from all anchor nodes.

Step IV: Consider any node and calculate estimated distance from received signal strength using power distance formula.

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

Step VI: Calculate coordinates of blind node using trilateration method in 3-D starting from 4 anchor nodes.

Step VII: Increase number of anchor nodes by 1 and repeat the process till number of anchor nodes = N.

Step VIII: Calculate MSE for x, y, z individually starting from 4 anchor nodes for 3-D.

$$\text{MSE} = \frac{(x_{a-}\ x_{e1})^2+(x_a-x_{e2})^2+\cdots+(x_a-x_{eN})^2}{N}$$

Step IX: Repeat step VII till N number of anchor nodes

5. Simulation result

To study the strength of the proposed localization algorithm, a MATLAB program is developed. The proposed algorithm is implemented with a MATLAB which includes many input parameters. To compute the location of the blind node some input parameters are required.

TABLE-I. Table of input parameter taken for implementation

S. No.	Parameters	Values
1.	Length	100 m
2.	Width	100 m
3.	Height	10 m
4.	Power Transmitted	100*10^-3 Watts
5.	Frequency of Transmitted Signal	100*10^6 Hz
6.	Transmitted Antenna Gain	1
7.	Received Antenna Gain	1
8.	Speed of Light	3*10^8 m/s

Performance evaluation has been done by calculating Mean Square Error of x, y, and z coordinates individually using the formula given in step III and calculating average location error and comparing it with fuzzy logic technique using the formula given below

$$Average\ location\ error = \frac{\Sigma\sqrt{(x_{est}-x_a)^2+(y_{est}-y_a)^2}}{N}$$

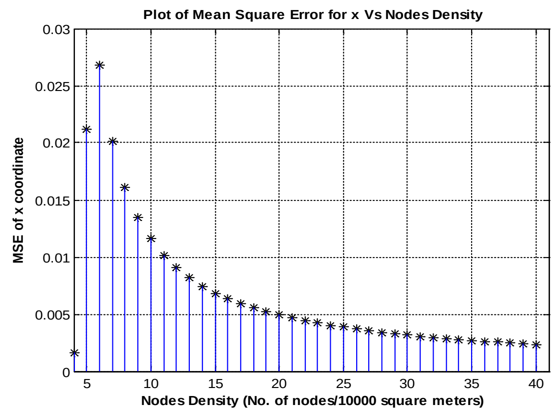

Figure 2. Plot for MSE of x coordinate with 40% of anchor nodes

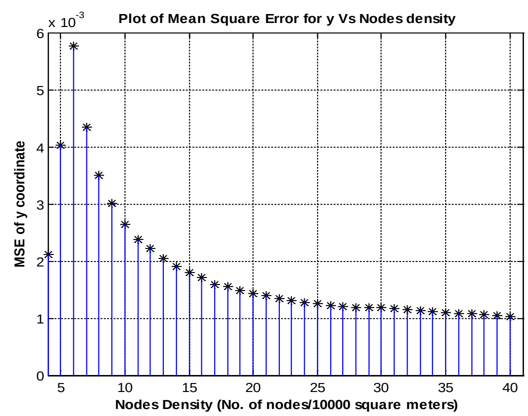

Figure 3. Plot for MSE of y coordinate with 40% of anchor nodes

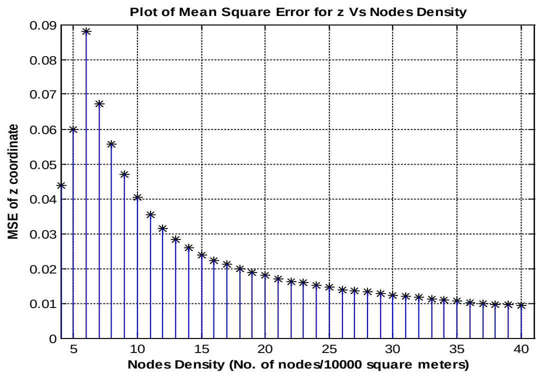

Figure 2. Plot for MSE of z coordinate with 40% of anchor nodes

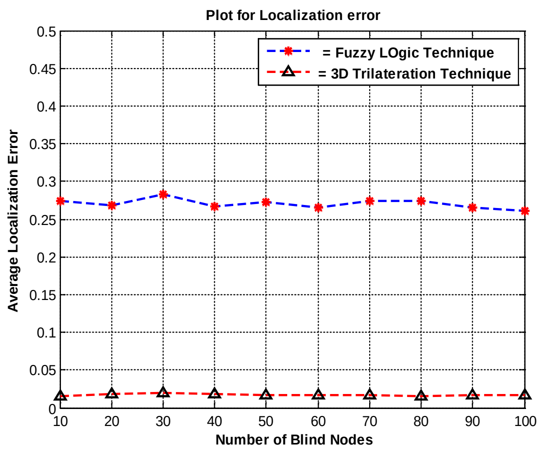

Figure 4. Plot of comparison between Fuzzy and 3D trilateration technique.

TABLE-II Comparison table

S. No.	Average Localization Error	
	Fuzzy Logic Technique	3D Trilateration Technique
1.	0.2745	0.0123
2.	0.269	0.0135
3.	0.2825	0.0128
4.	0.2675	0.0116
5.	0.2725	0.0120
6.	0.266	0.0125
7.	0.2735	0.0125
8.	0.2745	0.0123
9.	0.266	0.0120
10.	0.263	0.0119

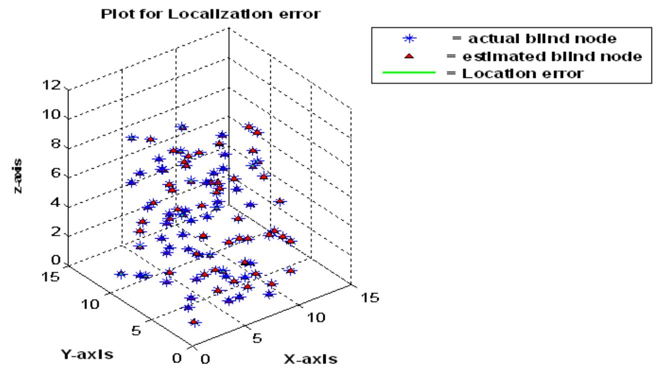

Figure 4. Plot localization error

6. Conclusions

The MSE of x, y and z coordinates is calculated for each number of anchor nodes starting from 4 and the graph is plotted between number of anchor nodes and MSE. It is seen that as the number of anchor nodes are increasing, the MSE is decreasing. As per the three scenarios it can be seen that as we increase the nodes the value for MSE (minimum square error) decreases.

At last the localization error of 3-D trilateration and fuzzy logic technique is compared. It is seen that proposed technique gives much better results that fuzzy logic technique. It is also seen that the minimum and maximum values of Average Localization Error for 3-D trilateration technique are 0.0116 and 0.0315 respectively. Hence it can be concluded that 3-D trilateration technique is better than fuzzy logic technique.

REFERENCES

[1] Hongyang Chen, Pei Huang, Marcelo Martins, Hing Cheung So, and Kaoru Sezaki," Novel Centroid Localization Algorithm for Three-Dimensional Wireless Sensor Networks", IEEE, 2008.
[2] Chia-Yen Shih, Pedro Jos´e Marr´on," COLA: Complexity-Reduced Trilateration Approach for 3D Localization in Wireless Sensor Networks", 2010 IEEE Fourth International Conference on Sensor Technologies and Applications.
[3] Oguejiofor O.S, Aniedu, Ejiofor H.C, Okolibe A.U,"Trilateration based Localization Algorithm for Wireless Sensor Networks", IJISME, 2013.
[4] Pratik S. Patel, Jignesh R. Patel," Localization Algorithm for Mobile Sensor Nodes Using 3D Space in Wireless Sensor Network", International Journal on Recent and Innovation Trends in Computing and Communication, 2014.
[5] Labyad Asmaa, kharraz Aroussi Hatim, Mouloudi Abdelaaziz," Localization Algorithm Research in Wireless Sensor Networks Based on Multilateration and Trilateration Techniques", IEEE, 2014.

[6] C.Y.Chony and S.P Kumar, 2003 “sensor networks. Evolution opportunities and challenges”, proceeding of the IEEE, VOL.91.
[7] J. Bachrach and C. Taylor,” Handbook of Sensor Networks: Algorithms and Architectures”, chapter Localization in Sensor Networks, Wiley, 2005.
[8] Holger Karl, Andreas Willig, “Protocols and Architectures for Wireless Sensor Networks”, chapter Localization and positioning, Wiley, 2005.
[9] Aspnes,J., T. Eren, D.K. Goldenberg, A.S. Morse, W. Whiteley, Y.R. Yang, B.D. Anderson, and P.N. Belhumeur, “A theory of network localization”: IEEE Transactions on Mobile Computing: 2006,1663–1678.
[10] Yao-Hung Wu and Wei-Mei Chen,” An Intelligent Target Localization in Wireless Sensor Networks”, IEEE, 2014.
[11] Ian F.Akyildiz, Mehmet Can Vuran, “Wireless Sensor Networks”, Wiley, 2010.
[12] Amitangshu Pal,” Localization Algorithms in Wireless Sensor Networks: Current Approaches and Future Challenges”, Network Protocols and Algorithms ISSN 1943-3581 2010, Vol. 2, No. 1.
[13] Nabil Ali Alrajeh, Maryam Bashir, Bilan shams, 2013.”Localization Techniques in Wireless Sensor Networks”, Hindawi Publishing Corporation.
[14] Zenon Chaczko, Ryszard Klempous, Jan Nikodem, Michal Nikodem, “Methods of Sensors Localization in Wireless Sensor Networks”, 14th Annual IEEE International Conference and Workshops on the Engineering of Computer-Based Systems (ECBS'07), 2007.
[15] Vishal Garg, Mukul Jhamb,” A Review of Wireless Sensor Network on Localization Techniques”, International Journal of Engineering Trends and Technology (IJETT) - Volume4Issue4- April 2013.
[16] Mostafa Arbabi Monfared,” Localization in Wireless Sensor Networks Based on Fuzzy Logic”, Institute of Graduate Studies and Research, 2012.
[17] Yuan Zhang, Wenwu Wu, Yuehui Chen,” A Range-Based Localization Algorithm for Wireless Sensor Networks”, Journal of Communications and Networks, vol. 7, no. 4, December 2005.
[18] Weerat Katekaew, Chakchai So-In, Kanokmon Rujirakul, Boonsup Waikham,” H-FCD: Hybrid Fuzzy Centroid and DV-Hop Localization Algorithm in Wireless Sensor Networks”, 2014 IEEE Fifth International Conference on Intelligent Systems, Modeling and Simulation.
[19] Baohui Zhang, Jin Fan, Guojun Dai, Tom H. Luan,” A Hybrid Localization Approach in 3D Wireless Sensor Network”, Hindawi Publishing Corporation International Journal of Distributed Sensor Networks, 2015.