RSSI based Node Localization using Trilateration in Wireless Sensor Network

Rukaiya Javaid, Rehan Qureshi, and Rabia Noor Enam

***Abstract* – Wireless Sensor Network (WSN) is an ad-hoc network generally used to perform various monitoring tasks deployed randomly in different environments. There are various applications of WSN which require the knowledge of the location of sensor node makes the sensing data more significant. This aspect of information increases the diversity of applications. In most of the Wireless Sensor Networks where nodes are deployed randomly, estimating the location of these nodes is a difficult task. Trilateration is one of the common localization methods. In this method usually Received Signal Strength (RSS) is used to estimate the nodes distances. Although this method is a very simple technique but create significant error in localization estimations. This paper proposes a method to minimize the error in location estimations. The experiments have been done on wireless IRIS motes testbeds. The procedure has been applied in both indoor and outdoor environment using RSS ranging method, considering the nodes in Line of Sight (LOS). Results have shown that the distance estimation error in indoor was 83.32% which reduced to 3.21% for indoor and from 82.6% to 4.14% for outdoor. The minimum node localization error was 0.126 meter in indoor and 0.218 meter in outdoor.**

***Index Terms* – Data Acquisition, Line of Sight (LOS), Localization, Localization Algorithms, Received Signal Strength Indicator (RSSI), Trilateration, and Wireless Sensor Network (WSN).**

I. INTRODUCTION

Wireless Sensor Network (WSN) refers to a group of homogenous or heterogeneous sensing nodes. Each sensor node consists of a radio transceiver, antenna, microcontroller, energy source and usually a battery. These sensing nodes operate as a mesh network in which all nodes are connected with each other in a same communication range. WSNs are installed to monitor environmental characteristics such as temperature, pressure, sound, humidity, light etc. to provide bridge between real physical and virtual worlds. In large environmental 2D or 3D space, when the nodes are deployed randomly (i.e. tossing nodes from an aircraft etc.), it is left on nodes to do self-localization. The process of finding the geographical location of nodes is called localization.

Generally in node localization the location of some nodes are needed. These nodes are called anchor nodes. Usually three anchor nodes are sufficient for this purpose. Each node possesses sufficient energy and accurate information about its position. In localization these nodes are used as reference nodes. Global Positioning System (GPS) is the straight forward solution for finding node location. But it requires direct Line of Sight (LOS) communication which makes it unfeasible for many multi-terrain outdoor applications (i.e. dense forests, mountains and other obstacles) environments rather indoor.

In the process of localization three anchor nodes and the target node should have LOS among them. There are usually three different phases in localization. First one is data acquisition in which range, angle and connectivity about the network is gathered. The second phase is about acquiring information for finding distance between the anchor and target node. Here different ranging methods are used. In third phase, relative position of target node is estimated. If Received Signal Strength (RSS) is considered for ranging the nodes then the position of a node could be find using an intersection of three circles called trilateration.

Localization algorithm based on Received Signal Strength Indicator (RSSI) using trilateration technique has become the mainstream localization algorithm in WSN and has a wide range of applications. Trilateration is the common and considerably fastest method for estimating node position. In trilateration if the target node is inside the communication range of the anchor nodes, distances of the target node to all three anchor nodes based on their distances can be calculated. By using RSS, a localization method could become less expensive in terms of hardware and communication cost. But the key problem is the influence of the channel conditions such as attenuation of signal, multipath fading and shadowing effects etc. These factors cause large calculation errors in RSS based distance estimation which eventually effect the localization computation.

This paper proposes an improved RSSI based localization method which increases the localization accuracy without any additional hardware support. The proposed method was built in an indoor and outdoor environment having three anchor nodes and a target node. The pathless model was used for estimating distances between target node and anchor nodes. These resulting distances have a large error which was minimized up to some extent for better position computation of target node. Trilateration method was used to compute the coordinate of target node by calculating intersecting point of three circles.

The paper is divided into five sections; in section I intro-diction of the topic was discussed. Section II contains the background and related work. The proposed method for node localization is discussed in section III. Testbed results and discussion are covered in section IV and the conclusion in section V.

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II. BACKGROUND AND RELATED WORK

Localization is the method of estimating the position of a node residing in a network. The number of node localization methods in WSN have been proposed in past few years. These methods can be categorized as (I)Range based methods use timings or strength of the signal to require point to point distance/angle information and (ii)Range free methods which work on proximity to a reference point and finding approximate coordinates of a node. Several range free methods have been proposed e.g. Centroid, APIT (Approximate Point in Triangle), DV-Hop, MDI (Multi-dimensional), Bounding Box etc. [1] [2] [3] [4] [5]. The range based methods are less expensive and more accurate than range free methods. In range free methods sensor nodes rely on neighbors to determine their position and have error in accuracy up to 10% of the communication range of individual node and requires high computation cost [6] [7]. In general, location discovery process of a node is divided into three main stages, (I) data acquisition (ii) distance estimation and (iii) position computation. There are several localization algorithms which are used for mapping the information into real world location.

A. DATA ACQUISITION PHASE

For gathering data from different nodes several data gather- in protocols have been proposed [8]. These protocols follow the simple way of collecting data from sensor nodes and sending it to the sink node (base station). In between these transmissions multiple data are aggregated into one packet on intermediate nodes. Many data aggregation techniques (e.g. sum, average, min, max, count etc.) could be used by nodes to achieve energy efficiency. These techniques are classified according to the network structure and protocol operation based on routing protocols [9] [10].

B. DISTANCE ESTIMATION PHASE

It involves the measuring of distance between target node and anchor nodes using some ranging techniques. The ranging techniques depend on available information such as (I) Time of Arrival (Toad) [11], (ii) Time Distance of Arrival (Today) [12], (iii) Angle of Arrival (AOA), a complementary technique for Toad and Today and (iv) Received Signal Strength (RSS) [13]. Among these techniques RSS is the simple and inexpensive technique for ranging which is based on RSS of Radio Frequency (RF) signals. RSS is always inversely proportional to the distance between transmitter and receiver.

C. POSITION COMPUTATION PHASE

Once the distance between anchor nodes and target node is estimated, one of the following localization methods can be used to determine absolute or relative coordinates of target node. (I) Triangulation [14], (ii) Trilateration [15] and (iii) Multilateration [16]. Where Multilateration is an iterative approach of trilateration.

In large scale networks good localization methods should meet some requirements such as it should be self-organizing, tolerant to node failure and energy efficient.

Many algorithms have been proposed for finding node location based on trilateration technique. A localization algorithm [17] for indoor environment was proposed. This algorithm was based on a degree similar to the RSSI vector. In [18], an algorithm was proposed to find node location by dividing it into two phases, (i) initialization and (ii) final phase. In initialization phase, all anchors broadcast their data packets including position information and sensed parameters. In final phase, distances among target and anchor nodes were found to perform trilateration. This was a simple method and gave less localization error but in spite of all, the errors and variations caused by shadowing and multipath reflection were not dis- cussed. Each anchor node cannot be capable of broadcasting packets at constant strength so, what was the method for handling that were missing. Another method was proposed in [19] which includes distance and angle information of nodes by using ultrasound-based transceivers and digital compass to indicate node's direction. It requires that the nodes should be

$$n = \frac{-\sum_{i=1}^{k} P_L(d_i) - P_L(d_o)}{\sum_{i=1}^{k} 10\ log(d_i)} \tag{2}$$

III. PROPOSED METHOD

For node localization in indoor and outdoor environment, we used the IRIS XM2110 motes, MDA100 data acquisition board and MIB520 interface board. The IRIS nodes are deployed in grids of 6 meter x 4 meter area, all three anchor nodes are kept static and placed at defined coordinates. The target node placed at each coordinate of the grid one by one. Starting from each anchor, the actual distances from target node to the three anchor nodes were determined by using the following formula

Where, n= number of nodes, dn is the distance from anchors *n* to target node t. The xt and yt are the x and y coordinates of target node. The xn and yn are the x and y coordinates of *n* anchor nodes shown in figure 1.

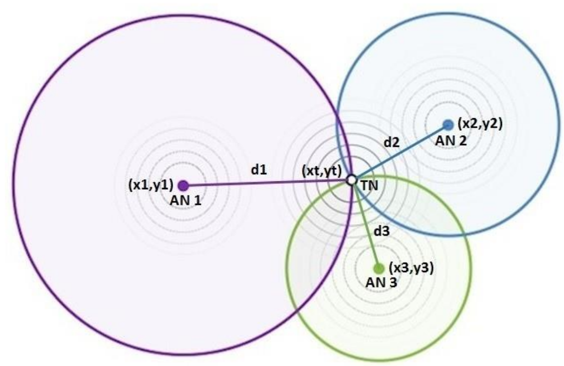

Fig. 1: Distance Estimation from Anchors to the Target Node

The RSS of RF signals can be read from the AT86RF230 radio at the time of getting payload. These RSS values were measured in dBm from each anchor to the target node and averaged due to the variation among values. It basically measures the signal power at the receiver and based on the transmitted power, the effected propagation loss can be calculated (RSSI is sensitive to channel interference, attenuation, reflection, fading and shadowing [21]). To

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provide better ranging estimation, the IEEE 802.15.4 [22] [23] has provided a standard for low- power, long-distant, low-data-rate service for precise ranging and localization applications. The path loss exponent n for both the environments was calculated which is used to characterized how fast the signal attenuates with respect to the distance. The path loss exponent was calculated by using the following formula

Where,
do= reference distance
PLo= path loss at the reference distance
k= number of measurements which is 0, 1, 2, 3, 4 and 5

The pathloss model was used to calculate the distance between anchors and target node which is

$$PL(d) = PL_o + 10\ n\ log_{10}\ (\frac{d}{d_o}) \qquad d \geq d_o \qquad (3)$$

Where,
do= reference distance
PLo= path loss at the reference distance
n = path loss exponent (depend on the environment)

The estimated distances were in error due to the above defined factors. So, the errors were calculated in terms of distances and plot in graph to find the equations for minimizing errors. After finding equations the distances were estimated again by putting errors and RSS values in equations. The resultant distances were used to find the node location by calculating intersecting point D of three circles A, B and C created by RSS ripples shown in figure 2. Sometimes due to the interferences or other issues three circles may not intersect at a common point as shown in figure 3, the two circles A and B are intersecting at a point but circle C is not. Similarly we can see that in figure 4 all three circles are not intersecting at a common point either so in that case increasing number of anchors could give the better result.

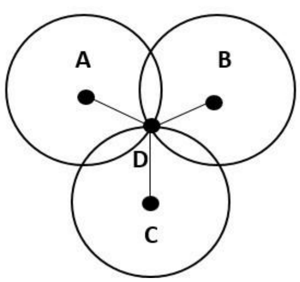

Fig. 2: Intersection of three circles at a common point

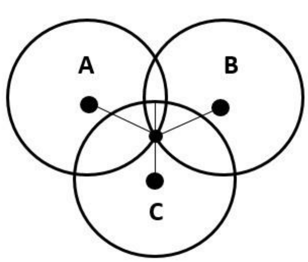

Fig. 3: Intersection of only two circles at a common point

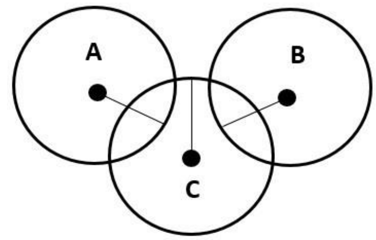

Fig. 4: Three circles are not intersecting at a point

These measured distances were considered as radii of three circles with centers at every anchor node. The target node was basically the intersection point of all three circles. The trilateration method was converted into linear equation of circles to determine target node position (xt,yt). The error distribution of the estimated coordinates was evaluated and correction factor was calculated. The calculations indicated the ratio of the actual distances from one node to the other node. The localization error was found by using the following formula

$$Localization\ error = \frac{1}{n}\sum_{i=1}^{n}\sqrt{(x-x_i)^2+(y-y_i)^2} \quad (4)$$

Where, n= number of nodes. x and y are the actual and xi and yi are the estimated coordinates of target node.

A. EXPERIMENTAL SETUP

In the experiment, the anchor nodes kept static at three coordinates (1, 3), (3, 5) and (3,1) of area depicted in figure 5. The non-anchor node or target node changed its position having minimum 1 meter to maximum 5 meter distance from anchor nodes and set at 32 different locations one by one with in that area.

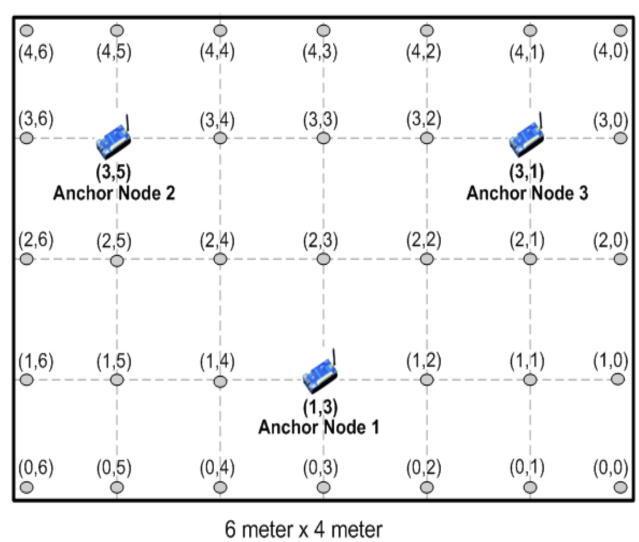

Fig. 5: Nodes Placement Area.

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The setup was made for both indoor and outdoor environments shown in figures 6 and 7.

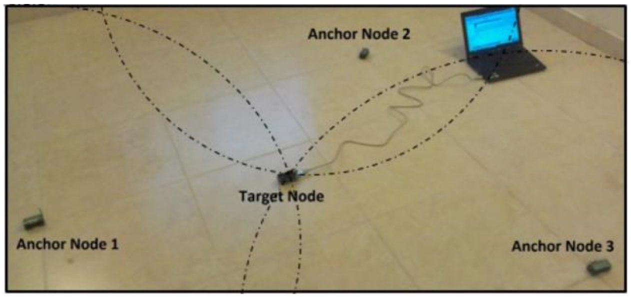

Fig. 6: Nodes Placement in Indoor

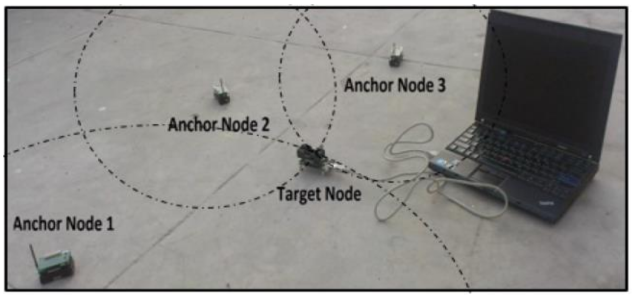

Fig. 7: Nodes Placement in Outdoor

Each sensor node broadcasts data packets and automatically transmit node health information periodically to the BS (the health packets were sent after every 2 minutes in our case).

IV. TESTBED RESULTS AND DISCUSSION

For data acquisition, the anchors (beacons) AN1, AN2 and AN3 sent the health packets and sensed data from the environment to the BS, monitored. The packets contained the node ID, time, battery voltage, parents node RSS, path cost, quality tx, quality rx and board id. When all this information was received at BS through serial port, and displayed on a java based GUI application Moteview 2.0 [24].

The calculated path loss exponent for residential indoor environment was **3.21** and for outdoor environment was **3.11.** The averaged RSS of all anchors on distances between anchors and target node in both indoor and outdoor environments is shown in figure 8.

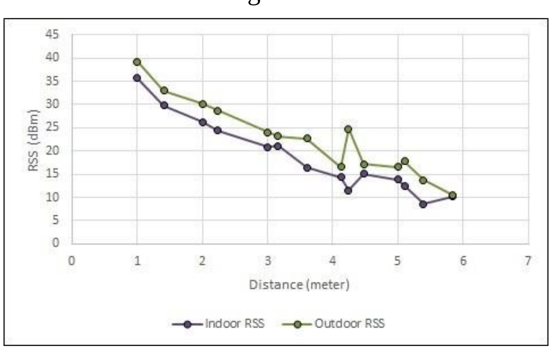

Fig. 8: Comparison of all Anchors RSS in Indoor and Outdoor.

We observed that RSSI has larger variation due to the effect of fading and shadowing. In indoor environment signal strength of WSN nodes was lower than in outdoor because in indoor there was more reflection due to walls and other metallic objects present in there. Since each of the signals which were reflected take a different path having different amplitude and phase. Depending on that phase, multiple signals were received at the receiver which caused variations in increased power value. So, even a slight change in node's position resulted a significant difference in phase and in the total received power.

After calculating estimated distances, these distances were compared with the actual one so that the errors can be evaluated and reduced. The system provided the distance estimation with an average error of **2.07 meters** in indoor and **2.62 meters** in outdoor environment. The equations were found to reduce the error in distances so that the location of target node got approximated.

For indoor environment

$$y = -0.1555x + 5.9628 \tag{5}$$

For outdoor environment

$$y = -0.1548x + 6.5423 \tag{6}$$

The average distance error in terms of RSS was calculated in figures 9 and 10 for indoor and outdoor environments for finding equations.

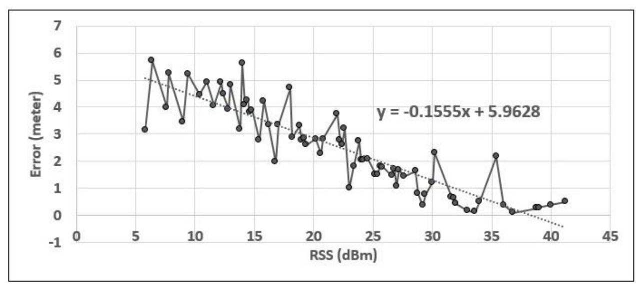

Fig. 9: Distance Error in Indoor Environment

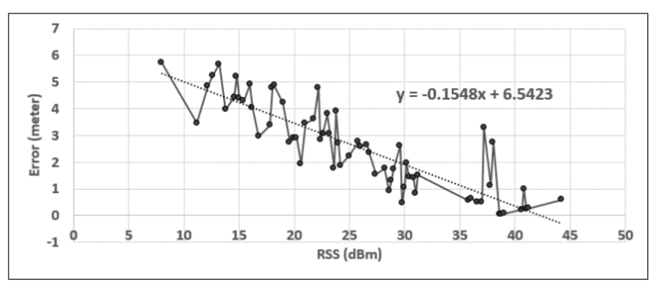

Fig. 10: Distance Error in Outdoor Environment

After finding equations 5 and 6 the average distances error was reduced to **0.68 meters** for indoor and **0.55 meters** for outdoor. The relative error for indoor and outdoor environment was calculated which gives an indication of how good a measurement was relative to the actual measurement. The relative errors for the environments were calculated by using averaged error

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values occurred at different distances and actual maximum distance. In indoor environment the average error was **83.32%** which was reduced to **3.21%**. For outdoor environment, the average error **82.6%** was reduced to **4.14%**.

The comparison between actual and re-computed distance for anchor node 1 in indoor is shown in figure 11 and for outdoor in figure 12. It shows that the RSS of nodes decreases as the distance increases because the signal strength is dependent on the distance between anchor node and target node.

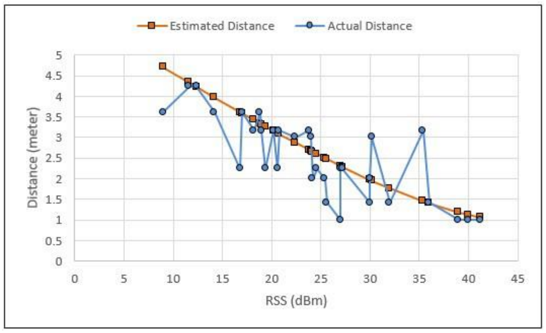

Fig. 11: Actual and estimated distances of anchor node 1 in Indoor.

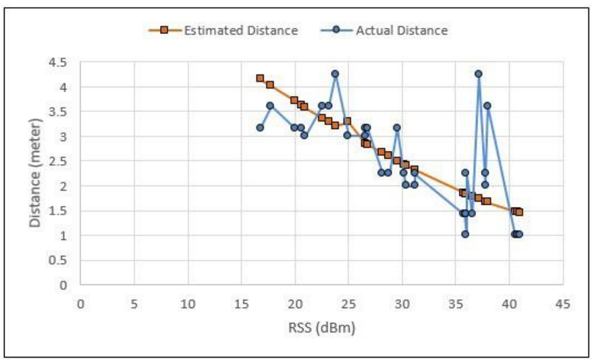

Fig. 12: Actual and estimated distances of anchor node 1 in Outdoor.

The re-estimated distances between anchor node 2, anchor node 3 and target node are compared with the actual distances in figures 13, 14, figure 15 and 16 for indoor and outdoor respectively and satisfies the relation between RSS and distance.

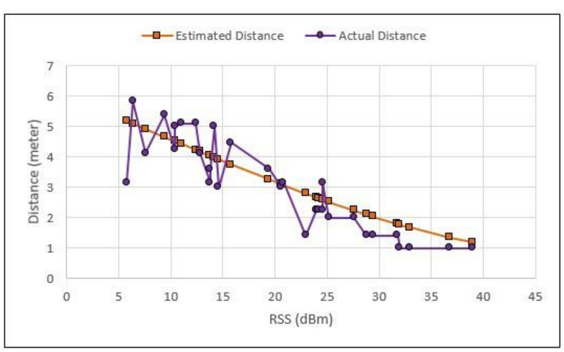

Fig. 13: Actual and estimated distances of anchor node 2 in Indoor.

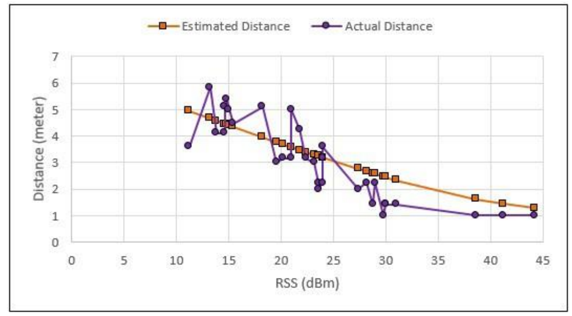

Fig. 14: Actual and estimated distances of anchor node 2 in Outdoor.

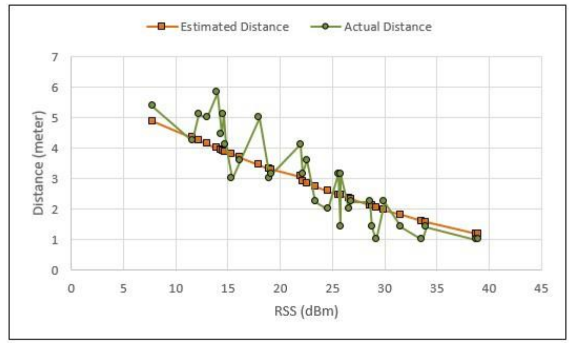

Fig. 15: Actual and estimated distances of anchor node 3 in Indoor

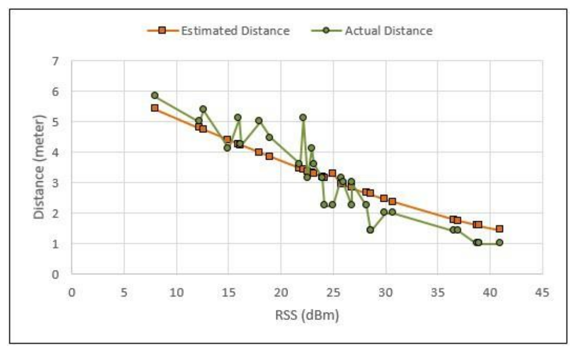

Fig. 16: Actual and estimated distances of anchor node 3 in Outdoor

After distance estimation phase, target node knew the shortest distance to three anchors. We found the relative positions of each node, shown in figure 17 and figure 18 for indoor and outdoor environment respectively.

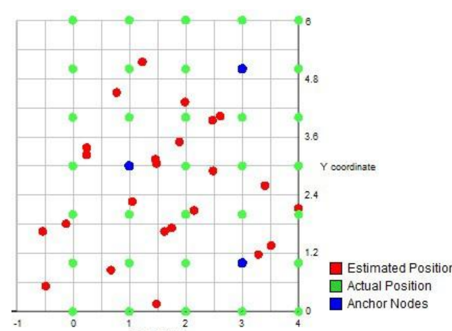

Fig. 17: Comparison of actual and estimated positions of target node in Indoor environment.

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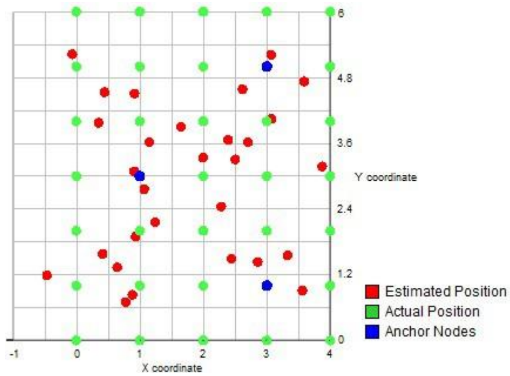

Fig. 18: Comparison of actual and estimated positions of target node in Outdoor environment.

Position accuracy is the largest distance between the estimated and actual position of a node. Figures 19 and 20 show the error in node localization.

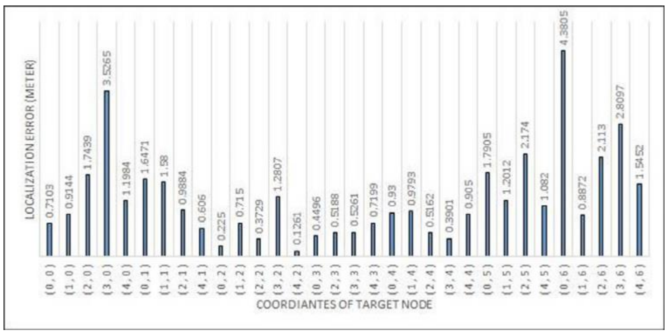

Fig. 19: Node Localization Error in Indoor.

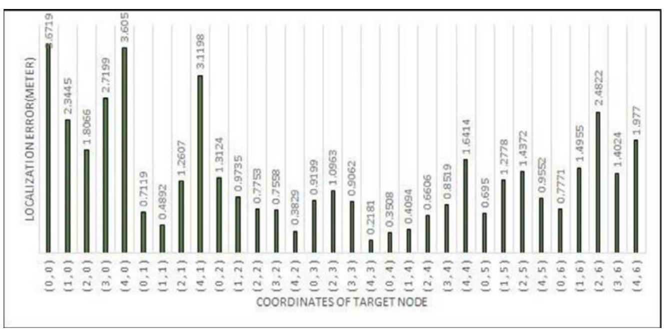

Fig. 20: Node Localization Error in Outdoor.

The minimum localization error in indoor was **0.1261 meter** and **0.2181 meter** in outdoor environment. The different factors like environmental and multipath interferences were more instance in indoor rather outdoor environment. The distance estimation phase of node localization was challenging due to the issues obscured in the environment. The errors occurred in calculation and averaging values for distance estimation were added in the next phase of node localization method.

V. CONCLUSION

The localization of a node is an active topic in WSN. Different localization techniques in WSN get significant error in distance and position estimations of the nodes. These errors occur due to different environmental and multipath interferences and due to energy consumption problem during position estimation. Most importantly location estimation in different environment gives different ranges of error. The limitation of parameters used in well-known path loss model cannot give error estimation that can be applied in all scenarios.

In this paper we have proposed a method of error reduction in trilateration based localization technique in WSN, using RSS of anchor nodes. The goal was to estimate the error in location estimation of a node according to the area under consideration. First the aim was to figure out the unknown coordinates of target node using intersecting point of the three signal circles. Error distribution was evaluated by comparing the estimated coordinates of target node and its original one. The procedure has been applied using wireless IRIS motes testbeds in indoor and outdoor environments. The results obtained through the proposed location estimation method can significantly minimize the error normally occur in distance estimations.

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