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Outdoor Localization System Using RSSI Measurement of Wireless Sensor Network

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Abstract- This paper present a system that utilizes RSSI based trilateration approach to locate the position of blind nodes (nodes that are not aware of there positioning in the network) amongst other nodes in the network. The system automatically estimates the distance between sensor nodes by measuring the RSSI (received signal strength indicator) at an appropriate number of sensor nodes. Through experiments, we clarified the validity of our data collection and position estimation techniques. The results show that when the anchor nodes were increased from three to four, the localization error decreases from 0.74m to 0.56m.

Index terms- localization, nodes, Trilateration, RSSI

I. INTRODUCTION

Wireless Sensor Network (WSNs) has been widely considered as one of the most important technologies for the twenty – first century [1]. Enabled by recent advances in micro electromechanical system (MEMS) and wireless communication technologies, tiny, cheap, and smart sensors deployed in a physical area and networked through wireless links and the internet provide unprecedented opportunities for a variety of civilian and military applications, for examples, environmental monitoring, pipeline monitoring, battle field surveillance, and industry process control [2]. If sensor nodes are appropriately designed, they can work autonomously to measure temperature, humidity luminosity and so on. Sensor nodes send sensing data to a sink node deployed for data collection. In future, sensors will be cheaper and deployed everywhere: thus, user-location-dependent services and sensor locations will be important. Distinguished from traditional wireless communication network, for example, cellular system and mobile adhoc networks (MANET), WSNs have unique characteristics for example denser level of node deployment, higher unreliability of sensor nodes, and severe energy, computing and storage constraints [3], which presents many new challenges in the development and application of WSNs. A WSN typically consists of a large number of low-cost, low-power, and multifunctional sensor nodes that are deployed in a region of interest [4]. These sensor nodes are small in size but are equipped with sensors, embedded microprocessors, and radio transceivers, and therefore have not only sensory capability, but also data processing and communicating capabilities.

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They communicate over a short distance via a wireless medium and collaborate to accomplish a common task. Sensor locations are important too, because sensing data are meaningless if the sensor location is unknown in environmental-sensing application such as pipeline monitoring. Methods using ultrasound or lasers achieve high accuracy, but each device adds to the size, cost, and energy requirements. For these reasons, such methods are not suitable for sensor networks. An inexpensive RF-based approach with low configuration requirements has been studied[5,6].These studies showed that the received signal strength indicator (RSSI) has a larger variation because it is subject to the delirious effects of fading and shadowing. A RSSI-based approach therefore needs more data than other methods to achieve higher accuracy [7].In this paper tpr2420 ca sensor node will be used for the experiments because our technique was implemented in it. This device was developed by the University of California, Berkeley.

II. LOCALIZATION SYSTEM MODEL

This section presents localization system model that can be used to establish the 2D Cartesian coordinates of the blind nodes. Real time experiments were also carried out on an experimental TinyOS-based WSN testbed environment to measure Received Signal Strength Indicator (RSSI) at the receiving nodes in other to estimate distance between communicating nodes. In this paper, the focus is on a pipeline segment which runs on a few kilometers (1-2 km); the sensor nodes on a pipeline segment are assumed to transmit their sensed data (temperature, light and humidity) to one base station (sink) located in a distance far away from the remote site; and the sensed data is collected through a multihop forwarding scheme. Consider a case where sensor nodes are deployed along a pipeline consisting of **N** sensor nodes $\{N_1, \text{------}, N_n\}$. This is used to monitor an oil pipeline segment of length (**L**= 1km). Here, the pipeline segment is assumed to be a straight line. The closest to the sink is N_n and node N_1 is the farthest one as shown in Fig1. It was further assumed that sensor nodes transmit the sensed data in a multihop fashion towards the base station. Let S_{1x} and S_{1y} refer to the X and Y co-ordinates of the location of sensor N_1 in 2-dimensional (2D) plane.

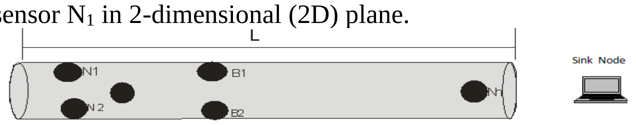

Figure1: A pipeline segment with nodes

To determine location of sensor nodes along the pipeline constitutes the localization problem. However, some sensor nodes are aware of their own positioning through manual configuration or by placing it in an already known position; these nodes are known as anchor or beacon nodes.

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All other nodes that are not aware of their position are called blind nodes; these nodes localize themselves with the help of location references received from the anchors. It was assumed that there are a set of **B** beacon nodes among the **N** sensors, and there positions (x_b, y_b) for all b Є **B**. The positions (x_n, y_n) for all blind nodes n Є **N** would be found. The localization system model is comprised of both the signal propagation model and the trilateration model. Trilateration is a localization technique used when there is an accurate estimate of distance between a node and at least three anchor nodes in a 2D plane. This method finds the intersection of three circles centered at anchor as the position of the node.

A. TRILATERATION MODEL

Considering the basic formula for the general equation of a sphere as shown in equation (1);

$$d^2 = x^2 + y^2 + z^2 \qquad (1)$$

For a sphere centered at a point (x_a, y_a, z_a) the equation is simplified as shown as in equation (2);

$$d^2 = (x - x_a)^2 + (y - y_a)^2 + (z - z_a)^2 \qquad (2)$$

Since we assume all the nodes spans out on the same plane, consider the three anchor nodes (a, b and c) that has distance (d_a, d_b, d_c) to the blind node as illustrated in Fig. 2;

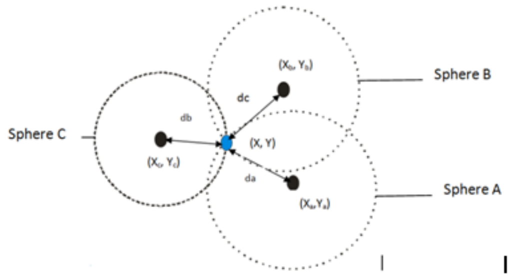

Figure 2: Intersection of three spheres in 2D

The formula for all spheres on one plane is shown below in the following equations:

$$\text{Sphere A; } {d_a}^2 = (x - x_a)^2 + (y - y_a)^2 \qquad (3)$$

$$\text{Sphere B; } {d_b}^2 = (x - x_b)^2 + (y - y_b)^2 \qquad (4)$$

$$\text{Sphere C; } {d_c}^2 = (x - x_c)^2 + (y - y_c)^2 \qquad (5)$$

Equations (3), (4) and (5) can further be expanded to bring about the following equations:

$${d_a}^2 = x^2 - 2x.x_a + x_a^2 + y^2 - 2y.y_a + y_a^2 \qquad (6)$$

$${d_b}^2 = x^2 - 2x.x_b + x_b^2 + y^2 - 2y.y_b + y_b^2 \qquad (7)$$

$${d_c}^2 = x^2 - 2x.x_c + x_c^2 + y^2 - 2y.y_c + y_c^2 \qquad (8)$$

The three equations (6), (7) and (8) are independent non-linear simultaneous equations which cannot be solved mathematically; however, using method proposed by Dixon [8] to obtain radical plane for sphere intersection, equation (8) was subtracted from equation (7) to get the following linear equation:

$${d_b}^2 - {d_c}^2 = 2x\,(x_c - x_b) + x_b^2 - x_c^2 + 2y\,(y_c - y_b) + y_b^2 - y_c^2 \qquad (9)$$

And subtracting equation (6) from equation (7), the following linear equation is obtained:

$${d_b}^2 - {d_a}^2 = 2x\,(x_a - x_b) + x_b^2 - x_a^2 + 2y\,(y_a - y_b) + y_b^2 - y_a^2 \qquad (10)$$

Rearranging the equation (9) to produce a new equation and a new variable as follows,

$$x(x_c - x_b) + y\,(y_c - y_b) = \frac{({d_b}^2 - {d_c}^2) - ({x_b}^2 - {x_c}^2) - ({y_b}^2 - {y_c}^2)}{2} = v_a \qquad (11)$$

Rearranging the equation (10) to produce a new equation and a new variable as follows,

$$x(x_a - x_b) + y(y_a - y_b) = \frac{({d_b}^2 - {d_a}^2) - ({x_b}^2 - {x_a}^2) - ({y_b}^2 - {y_a}^2)}{2} = v_b \qquad (12)$$

Resolve the equation (11) and equation (12) to gain the intersection point 'x' and 'y' of these two equations as the following equation for 'y' value and equation for 'x' value respectively:

$$y = \frac{v_b(xc - xb) - v_a(xa - xb)}{(ya - yb)(xc - xb) - (yc - yb)(xa - xb)} \qquad (13)$$

$$x = \frac{v_a - y(yc - yb)}{(xc - xb)} \qquad (14)$$

The values for x and y gives us the accurate position in two dimension (2D) for the blind node. This Model is developed using MATLAB and programmed into tpr 2420ca nodes, hence after initialization of the nodes, once the blind node can receive packets from at least three anchor nodes, it can localize its position using references received from the anchors. But these values can't be obtained without the signal propagation model.

B. SIGNAL PROPAGATION MODEL

In this section the signal propagation model in wireless sensor network will be addressed. The most common signal propagation model in wireless sensor Network (WSN) is the free space model. The free space model assumes that the receiver within the communication radius can receive the data packet. One possibility to acquire a distance of the node from another node is by measuring the received signal strength of the incoming radio signal. The idea behind Received Signal Strength (RSS) is that the configured transmitted power (P_t) at the transmitter device directly affects the received power (P_r) at the receiving device. According to frii's free space transmission equation [9], the detected signal strength decreases quadratically with the distance to the sender.

$$P_{r(d)} = \frac{p_t G_t G_r \lambda^2}{(4\pi d)^2} \qquad (15)$$

Where $P_{r\,(d)}$ = Received power at the receiver

P_t = Transmission Power of sender

G_t = Gain of Transmitter

G_r = Gain of Receiver

λ = Wavelength

d = Distance between the sender and the receiver normally $G_t = G_r = 1$, in embedded devices.

Power Law Model

The majority of embedded system operates in a non-line-of sight (NLOS) environment. Based on empirical data, a fairly general model has been developed for NLOS propagation. This model predicts that the mean path loss $P_L(d_i)$ [dB] at a transmitter receiver separation d_i is:

$$P_L(d_i)\ [dB] = P_L(d_0)\ [dB] + 10n\ \log_{10}(\frac{d_i}{d_0}) \quad (16)$$

Where n = pathloss exponent

$P_L(d_0)$ = pathloss at known reference distance d_0

For free space model n is regarded as 2. The free-space model however is an over idealization, and the propagation of a signal is affected by reflection, diffraction and scattering. Of course, these effects are environment (indoors, outdoors, rain, buildings, etc.) dependent. However, it is accepted on the basis of empirical evidence that it is reasonable to model the pathloss $P_L(d_i)$ at any value of d at a particular location as a random and log-normally distributed random variable with a distance-dependent mean value [10]. That is:

$$P_L(d_i)\ [dB] = P_L(d_0)\ [dB] + 10n\ \log_{10}(\frac{d_i}{d_0}) + S \quad (17)$$

Where S, the shadowing factor is a Gaussian random variable (with values in dB) and with standard deviation σ[dB]. The path loss exponent, n, is an empirical constant which depends on propagation environment.

To determine the pathloss coefficient n of the test bed area/ environment. Equation (17) can be used to manually compute as:

$$n = \frac{\{P_L(d_i) - P_L(d_0)\}}{10\log_{10}\left(\frac{d_i}{d_0}\right)} \quad (18)$$

Received Signal Strength is related to distance using the equation below.

$$RSSI\ [dBm] = -10n\ \log_{10}(d) + A\ [dBm] \quad (19)$$

Where n is the propagation pathloss exponent, d is the distance from the sender and A is the received signal strength at one meter of distance. In other to determine the pathloss exponent to be used in this paper, the RSSI values within 10m of the sink will be measured with a step size of 1m and the root mean square (RMS) of the measured RSSI values will be calculated and then the best value for the pathloss exponent n for the test bed area will now be determined.

III. EXPERIMENTAL TESTBED ENVIRONMENT

The test bed environment is depicted in figure 3. The Environment consists of the outdoor environment of the faculty of engineering wing B, (Area around the packing site for staff). The test bed has four(4) telos B motes(TPR 2420CA) equipped with a chipcon CC2420 radio chip operating in the 2.4 GHz frequency band and running on tiny operating system(tiny OS). The nodes both anchor and blind are deployed at the test bed. The sink node is located at the department of Electronics and Computer Engineering which is situated at the First floor of the faculty of engineering building. The sink node is usually attached to an Hp personal computer where the monitoring is carried out.

Figure 3: Experimental Testbed Environment

The environment is located at awka, Anambra state of south-east of Nigeria. Most of the measurements were carried out during the later end of the rainy season (August) and early october.The area is not a level ground but somewhat sloppy, and the temperature ranges between 28-33 degree centigrade. The area also has high rise buildings scattered around

A.MEASUREMENT INSTRUMENT

The instrument used for measurement includes:

- Four crossbow's TelosB node TPR2420 which offers features including; IEEE 802.15.4 compliant RF transceiver, 8MHz T1 MSP430 microcontroller, 1MB External flash for data logging, sensor suite including integrated light, temperature and humidity, Runs TinyOS 1.1.11 or higher, programming and data collection via USB and powered by two AA batteries. Figure 4 shows a crossbow TelosB node.
- An Hp laptop where the sink node is slotted for data collection and programming of nodes.
- Measuring Tape
- CC2420 Module

Figure 4: crossbow telosb node

B. RSSI/DISTANCE MEASUREMENT

To determine the pathloss exponent n of the testbed area, RSSI measurements with respective distances were carried out. In this case four telosb nodes were used for the measurement. The nodes were programmed to have different identification numbers (ID'S). This is done using a cygwin bash which provides an interface were commands can be typed in. Figure 5 shows the interface for programming the nodes. The nodes ID's is what identify each node when transmitting to the sink.

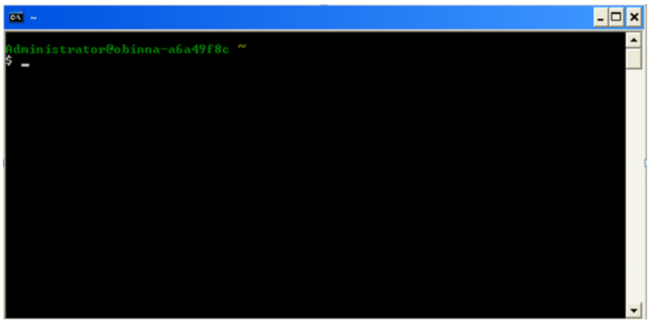

Figure 5: Cygwin bash for node programming

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Hence, for this paper, the following node ID's were adopted; 100,200, 300 and 700. The node ID 700 is sorely reserved for the sink node.

Since the pathloss exponent *n* is to be determined, every direction was considered by placing node 100 at $180^0$of the sink node, node 200 at $90^0$of the sink node and node 300 at 270^0 of the sink. The respective nodes senses environmental parameters such as temperature, humidity and light intensity and send to the sink node, the hp laptop housing the sink has a program in it that can be called up by double clicking the *run sensor app* at the desktop to produce an interface were various measurement such as RSSI [dBm], LQI e.t.c. carried out can be seen. Figure 6 shows the interface used for monitoring live measured data from the different nodes.

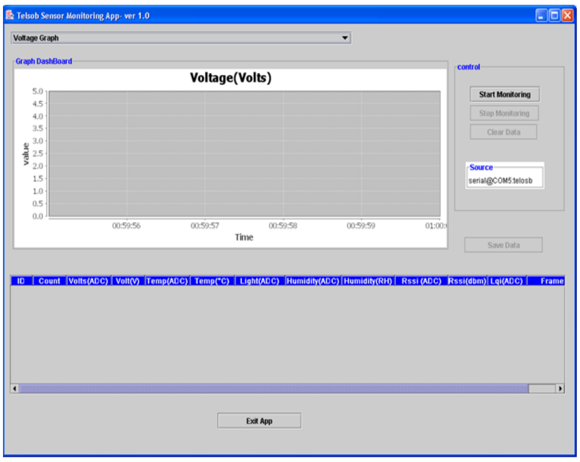

Figure 6: Interface used for monitory

Through the above interface the various nodes and what they sensed can be monitored, by seeing how their respective values vary. It also has the option of saving the data gotten and also clearing the data not saved.

The RSSI values within 10 meters of the sink from the respective nodes were measured with a step size of 1 meter and collected for two months.

IV. DATA COLLECTED AND PRESENTATION

This section shows the entire data collected throughout this work. Some of the data will be used to determine the pathloss exponent *n* of the testbed area while others will be used to find the RSSI and the estimated distance between a blind node and an anchor node based on the known pathloss exponent *n* without assuming it to be 2 as in free space

Table 1 shows the average values of the receive signal strength of the three nodes for the first month

Distance (m)	RSSI[dBm] for Node 100	RSSI[dBm] for Node 200	RSSI[dBm] for Node 300
1	-44.8	-43.4	-45.8
2	-48.4	-47.8	-47.2
3	-48.6	-48.8	-47.6
4	-51.4	-53.4	-55.0
5	-53.6	-55.2	-58.0
6	-62.6	-60.8	-62.2
7	-66.6	-67.2	-66.6
8	-64.8	-65.6	-66.6
9	-69.0	-70.0	-69.4
10	-65.2	-64.6	-67.8

Table 2 shows the average values of the received signal strength of the three nodes for Second Month

Table 2: Average Received Signal strength measurement for Second Month

Distance (m)	RSSI[dBm] for Node 100	RSSI[dBm] for Node 200	RSSI[dBm] for Node 300
1	-44.2	-44.6	-46.0
2	-47.8	-47.8	-47.2
3	-49.2	-49.4	-48.8
4	-51.4	-51.2	-56.4
5	-53.4	-53.6	-59.6
6	-61.4	-61.8	-62.2
7	-67.6	-68.4	-66.8
8	-68.4	-67.2	-66.6
9	-68.8	-68.2	-68.6
10	-69.2	-68.2	-68.6

Table 3 shows the total average Received signal strength measurement for First and Second Month for each distance

Table 3: Total Average Receive signal Strength measurement for First and Second Month

Distance (m)	RSSI[dBm] for Nodes100,200,300
1	-44.8
2	-47.7
3	-48.7
4	-53.1
5	-55.6
6	-61.8
7	-67.2
8	-66.5
9	-69.0
10	-67.3

The tables 1 – 3 present the various RSSI values for nodes with respect to the sink. From Table 3 the data collected was used to develop a matlab script for computing the pathloss exponent *n* of the testbed area. From the computation *n* was computed to be 2.2. Hence, $n = 2.2$ will be used as the pathloss exponent in this research work. The results of the measurements for first and second months are depicted in figure 7 and figure 8 respectively. While figure 9 shows the result of the total average measurements for first and second month combined

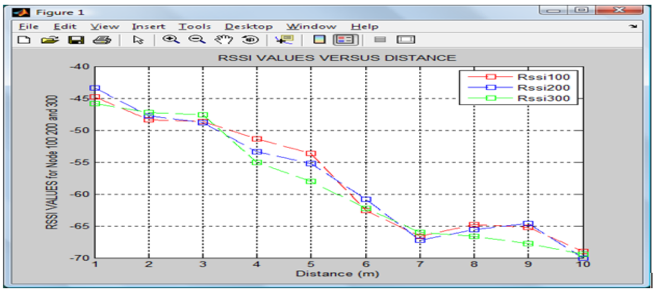

Figure 7: Average RSSI versus Distance Measurement for the First Month

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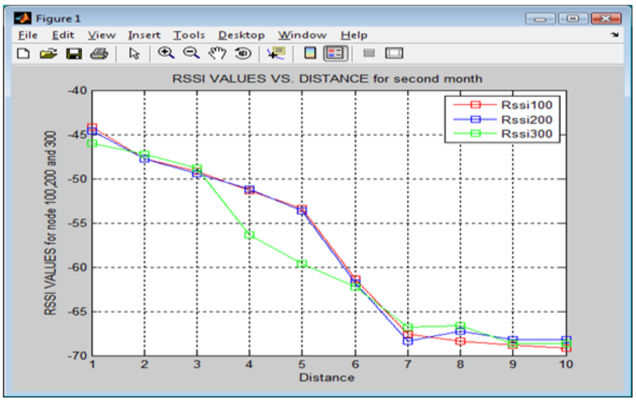

Figure 8: Average RSSI versus Distance Measurement for Second Month

Figure 9 shows the total average of the RSSI values for all the nodes with respect to distance for the first and second month

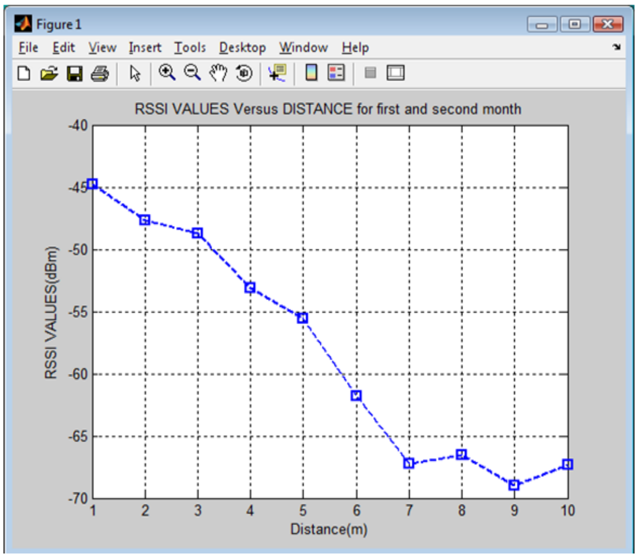

Figure 9: Total Average values of RSSI versus Distance

V. EXPERIMENTAL RESULTS

Based on the data collected, we can express distance as x (m) and the measured RSSI as y (dBm) for the test bed area. We can now model the relationship between distance and Received signal strength as:

y = $-22\log_{10} x$ – 44.8 (modified from equation 19).

V1. LOCALIZATION SYSTEM IMPLEMENTATION

For a node in a network to be localized by our proposed system, there must be at least three anchor nodes and other blind nodes communicating in the network. The signal propagation model helps to estimate the distance between two communicating nodes using equation 19.If Anchor node A is communicating with a blind node by sending packet to it, based on the equation 19, the blind node can estimate its distance to anchor node A,. Hence equation 20 is modified from equation 19.

y = $-22\log_{10} x$ – 44.8 (20)

Using equation 20, the blind node can easily estimate the distance(x(m)) between itself and the anchor node since while receiving the packet from the anchor node A the RSSI will be known.

However, if the blind node also receives packets from anchor nodes B and C respectively; the blind node can as well estimate its distance to the anchors. The blind node having estimated the distance to the respective anchors (say da, db and dc) can now perform trilateration to actually locate its position in 2D.

In other to evaluate the performance of the proposed system, let's consider a case where 3 anchor nodes are deployed together with blind nodes within the testbed environment; the goal is to determine how accurate this localization system is. Experiments were carried out in the test bed area. The dimension of the testbed area is taken to be 36inch (approximately100cm) width and 100m length, (our assumed pipeline dimension).The actual distance between the blind nodes and the anchors are measured and recorded, the estimated distances between the blind nodes and anchor nodes were also gotten through our proposed system and recorded. The table below shows the summary of data collected while figure 10 shows the accurate position of the blind node at (32.27, 43.87), and figure 11 shows the estimated position (inaccurate) at (31.79, 44.43). The localization error of this algorithm for this case is 0.74m (Using equation 21).

Localization Error (LE) = $\sqrt{(x^i{}_{est} - x^i{}_a)^2 + (y^i{}_{est} - y^i{}_a)^2}$

(21)

The error is not that much, and is usually caused by distance error which normally depends on the RSSI values between the communicating nodes.

Table 5: Node Distance Measurement

Anchor nodes	Actual distance	Estimated distant	Actual position
A	13.8	14	(20,40)
B	19.4	20	(50,50)
C	15	16	(35,30)

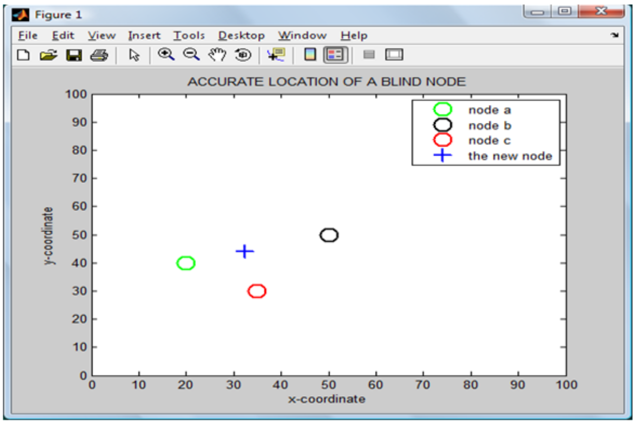

Figure 10: Actual position of Blind node

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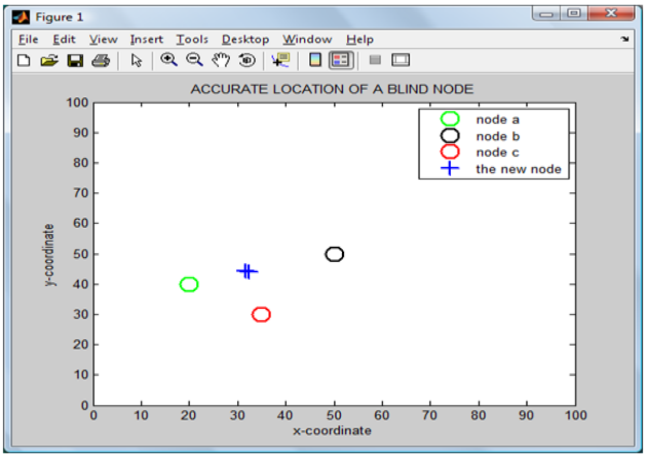

Figure 11: Estimated position of Blind node

Due to the limited number of nodes available for experiments; assumptions were made to see how anchor density affects the localization error. In the experiment carried out, the Localization errors for three and four anchor nodes for this localization system were 0.74m and 0.56m respectively. Hence, it means that with the addition of one anchor node to the three anchor nodes present in the network, the localization error reduces by 0.18. Based on this fact, we assume to have anchors (Na= 3, 4, 5, 6, 7) and the localization errors will now be (Le= 0.74, 0.56, 0.38, 0.20, 0.02). The position errors are shown in figure 12

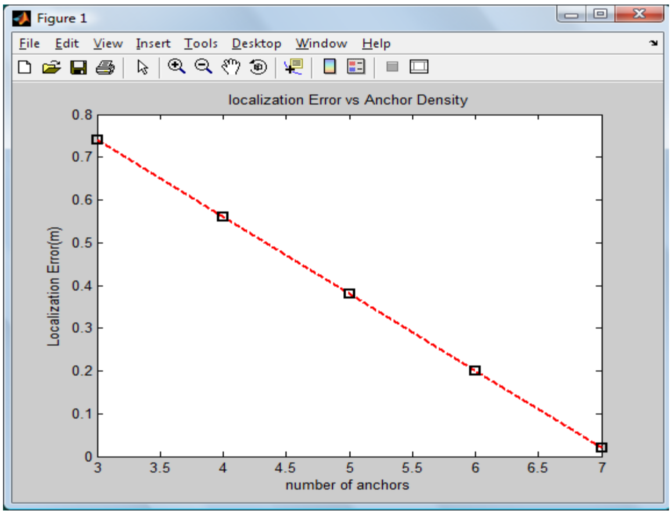

Figure 12: localization Errors vs. Anchor density

VII. CONCLUSION

We have implemented a localization system that uses a RSSI trilateration approach in a wireless sensor network. The system position estimation accuracy was also evaluated. We conclude that for the proposed system to work there must be the availability of at least three anchor nodes within the network and whenever anchor nodes broadcast packets containing their locations and other sensed parameters, the blind node within the broadcast range can always estimate its distance to the anchor nodes, and if peradventure the blind nodes receive packets from at least three anchors, the blind node can localize its position.

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