Enhancing the Localization of Blind Node in Pipeline Network Using Trilateration Algorithm

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Abstract-Localization refers to the process of estimating and computing the positions of sensor nodes in some spatial coordinate system. Computation of geographical position of sensor nodes is the key challenge facing the design and deployment of WSN. Location information is used in many ways, including topology maintenance, medium access control (MAC) protocols and routing protocols and localization of event. In this work, pipeline network for blind node localization was developed. It was used as an experimental test bed for the implementation of trilateration algorithm. Trilateration based localization algorithm for blind node location and distance determination in a pipeline network was used. Details regarding the implementation of the algorithm were discussed. A test bed area of dimension 21m by 18m containing anchor and blind nodes deployed on it was used to characterize the path loss exponent and to determine the localization error of the algorithm. The path loss exponent of the test bed area was computed to be 3.25 while the localization algorithm is shown to have localization error of 4.7

Keywords: Trilateration, Signal Propagation Model, Power Law Model, Path loss exponent and Localization error

1.0 Introduction

Wireless Sensor Network (WSN) is composed of several sensor nodes which are deployed in inspecting field, and they form multi-hop self-configured network by wireless communication [1]. A sensor network is a large ad hoc network of densely distributed sensors that are equipped with low power wireless transceivers. Such networks can be applied for cooperative signal detection, monitoring, and tracking, and are especially useful for applications in remote or hazardous locations [2]. In WSN, the position information is crucial because the sensor node will be able to know when abnormal event occurs and from the position information, can locate the event, then report to the base station [3].

Computation of geographical position of sensor nodes is the key challenge facing the design and deployment of WSN. Location information is used in many ways, including topology maintenance, medium access control (MAC) protocols and routing protocols and localization of event [4]. If no location information is collected, data are meaningless. Location information is needed to identify the event of interest. The location of enemy's tanks in a battle field is a typical example [5]. Location awareness facilitates numerous application services such as location directory services that provide doctors with the information of nearby medical equipment and personnel in smart hospital. Traditional localization techniques such as Global Positioning System (GPS) cannot be used directly in WSNs because of its costly sophisticated equipments and higher energy consumption in order to ranging, which have constrained the application of the scale of WSNs [4]. GPS is applicable for the low-cost self-configured sensor networks and also it is impossible to install GPS for each sensor node [1].

Localization of sensor nodes in WSNs is essential since it reflects spatial context with which the data gathered by sensor nodes are used in application [6]. Localization refers to the process of estimating and computing the positions of sensor nodes in some spatial coordinate system [7]. To enhance the location discovery in a sensor network, there must be a set of specialty nodes known as Beacon (Anchor) nodes. These nodes know their location position in the network either through GPS or normal configurations that these provide to other sensor nodes [5]. Using this location of beacon nodes, sensor nodes compute their location using various techniques. In locating the blind node's (a node which is unaware of its position) position in wireless a sensor network, a good localization technique was adopted.

Trilateration algorithm is a rang-based algorithm that uses distance estimation to compute the 2-Dimension (2D) position of nodes in a network with the help of communicating signal from the sender to receiver called" received signal strength indicator" (RSSI) [5]. In this paper, we want to determine a blind node position and its distance from the anchor node using trilateration algorithm that makes use of distance estimation in computing the 2D position of wireless sensor node in a network.

2.0 Related Works

Several works has been done in the field of localization. These works tried to find out different available techniques for localization of sensor nodes. [8] Proved that better results were obtained based on node localization when time of flight measurements were used as ranged method especially if RF signal and acoustic signal were combined. Their report could be justified only if the nodes to be localized are not obstructed in terms of line-of–sight. Another limitation in their work is that the acoustic signal does not operate under a steady temperature. It shows that the accuracy of this algorithm will depend on temperature conditions. [9] used a minimum of four anchor nodes to get a positioning algorithm for wireless sensor network. In their work, they considered all nodes to be equal in terms of their processing ability with the centralized algorithms because all computations were done on the sensor nodes themselves and communication with each other to get their position in a network.

The developed positioning algorithm relies on range measurements to estimate the distances between neighboring nodes. The drawback in this algorithm is that it does not show categorically the range method that is used to locate the position of the node. [10] used RF (Radio Frequency) profiling technique for node localization. RF profiling requires a pre-deployment stage in which the RSS (Received Signal Strength Indicator) of each anchor node is recorded at each position in two dimensional regions to be localized. The reading taken at a particular position can be called the RF profile of the position already recorded. RF profiling is not considered a ranging-based technique because the RSS readings are never used to estimate distance: they are used to directly estimate the nodes location. It is also not multi hop because the mobile nodes must always have direct radio communication with the anchor nodes hence its main limitation is that it requires pre-collected data and dense infrastructure of anchor nodes. The Spot ON object tagging technology based on radio signal strength analysis which focuses mostly on the hardware and embedded systems aspects was created [12]. Such an approach combines the advantages of wireless location systems (fine granularity) with that of infrared-based systems (detection at a distance).

[5] used trilateration localization algorithm to compute the node position in a network. Trilateration algorithm is a range based algorithm that uses distance estimation to compute the 2-dimensional position of nodes with a communicating signal called Received Signal Strength Indicator (RSSI). It differs from time of Flight (TOF) and Angle of Arrival (AOA) in that TOF needs line-of-sight to effectively locate nodes and AOA needs extra hardware to be added to nodes before effective localization can take place. Also, time difference of arrival (TDOA) measurement accuracy can be affected by multipath. In their works, they proved that RSSI measurements don't need any extra hardware or line of sight to localize nodes. The limitation of their work is that they made use of TelosB sensor node which has a limited range to which it can measure RF signal within an environment.

3.0 Methodology

3.1 Measurement Environment

Trilateration is a geometric technique that uses distance between three anchor nodes and one blind node (unknown node) to determine the unknown node position. In trilateration, distance between three anchor nodes and one blind node (unknown node) is used to determine the blind node's location. A blind node is uniquely located when at least three reference points are associated with it in a two-dimension space [11]. The location of the blind node is estimated by calculating the intersection of three circles.

To demonstrate the concept of leak localization in pipeline system, a mini water pipeline Test bed was setup behind the block A wing of Prof. Gordian Ezekwe Faculty of Engineering building, Nnamdi Azikiwe University, Awka Anambra State. The rectangular test bed has a dimension of 21meter by 18meter with 15 pieces of 18 feet PVC pressure pipes of 2 inches diameter equipped with 6 valves. Both ends were terminated at water pump location; the thickness of the pipeline is 6mm. The pipeline was filled with high pressure water being supplied by 1.5hp water pumping machine.

The acceleration-based sensor nodes were attached at the uniformly spaced interval from the valves and the valves were used to emulate ruptures. In the experiments, rupture was emulated by the opening and closing of the valves. The valves were adjusted manually to three different stages: closed, half-opened and complete opened, where closing means high pressure and no water flow from the outlet of the valve; half-opened means medium pressure with water flowing; and complete opened means low pressure with water flowing. The acceleration-based sensor nodes were attached on the pipes, and pipe accelerations were measured during the process of opening and closing of the valves.

The measurements were carried out for three days and the average data was obtained. A blind node is estimated based on the calculations of RSSI from the respective nodes using the step size of 3. Using the linear regression analysis, the path loss exponent, n was determined from the measured data by minimizing the total squared error. A blind node is able to estimate its distance to at least three anchor nodes; the blind node can perform trilateration to get its accurate location in 2D, this blind node becomes a converted anchor node, its position is now sent to the base station via the sink. The readings of the sensor nodes were displayed at the base station. Fig.1 shows the screen shot of the GUI for data acquisition.

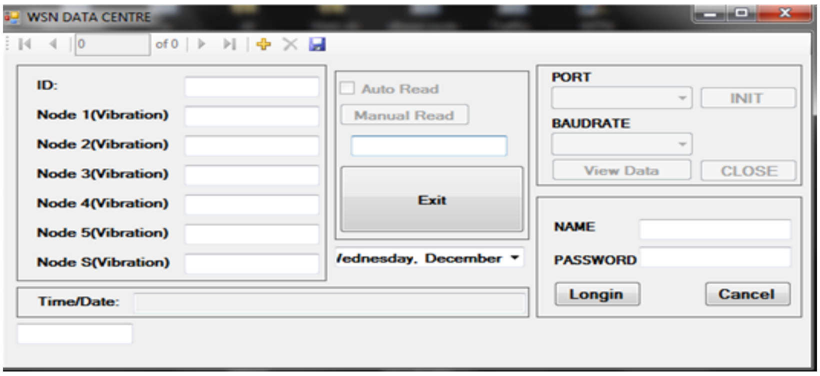

Figure 1: Screen shot of the GUI for data acquisition

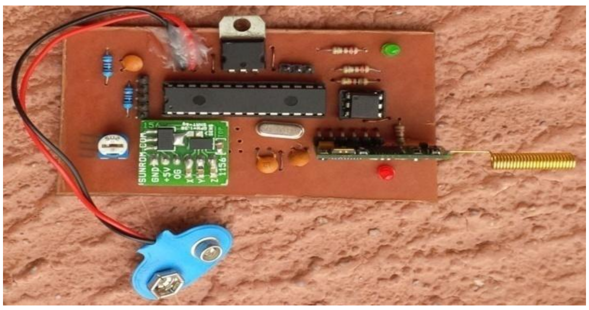

Fig. 2: The developed node before packaging

Fig. 3: The developed node after packaging

3.1.1 Measurement of RSSI Distance

To determine the path loss exponent n of the test bed area, measurement of RSSI with their respective distance was carried out. Each node was assigned a unique ID. The distance of the base station from the respective nodes and step size of 3m are presented in the Table 1

Table 1: RSSI versus Distance

Distance (m)	RSSI (dBm)
28.28	-21.03
33.28	-23.36
38.28	-25.33
43.28	-27.05
48.28	-28.53
53.28	-29.95
58.28	-31.23
63.28	-32.38

68.28	-33.44
73.28	-44.49

The Matlab script for computing the path loss exponent n and graph that shows the average value of RSSI versus distance, of the test bed area are shown in figures 4 and 5.

3.2 Development of System Models and Algorithm

3.2.1 Trilateration Algorithm

In trilateration algorithm, the estimated distance of an unknown node in a network is computed in 2D with the help of a communication signal from sender node to the receiving node called received signal strength indicator (RSSI). To determine the position of a blind node (an unknown node) in a network, signal propagation model and power law model are incorporated. The blind node is the point where the rupture is likely to take place.

3.2.2 Signal Propagation Model

The most common signal propagation model in wireless sensor network (WSN) is the free space model which assumes that the receiver within the communication radius can receive the data packet. One of the ways of acquiring 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 (Pt) directly affects the received power (Pr) at the receiving device. According to Frii's free space transmission equation, the detected signal strength decreases quadratically with the distance to the sender.

$$P_{r(d)} = \frac{P_t G_t G_r \lambda^2}{4\pi d^2} \quad (1)$$

Where $P_{r(d)}$ = Received power at the receiver, P_t = transmission power, G_t = Gain of the transmitter, G_r = Gain of receiver, λ = Wavelength, λ = distance between the sender and the receiver. $G_t = G_r = 1$ in the embedded devices [5].

3.2.3 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

$$P_L(d_i)[dB] = P_L(d_o)[dB] + 10n\log_{10}\left(\frac{d_i}{d_o}\right) \quad (2)$$

Where n = path loss exponent, $P_L(d_o)$ = path loss at known reference distance d_o. For free space $n = 2$. The propagation of a signal is affected by reflection, diffraction and scattering. Of course, these affects are environment (indoors, outdoors, rain, buildings, etc) dependent. However, it is accepted on the basis of empirical evidence that is reasonable to model the path loss $P_L(d_i)$ at any value of d at a particular location as a random variable with a distance dependent mean value. That is:

$$P_L(d_i)[dB] = P_L(d_o)[dB] + 10n\log_{10}\left(\frac{d_i}{d_o}\right) + S \quad (3)$$

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

To determine the path loss coefficient n of the test bed area. (3) can be used to compute it manually as:

$$n = \frac{P_L(d_i) - P_L(d_o)}{10\log_{10}\left(\frac{d_i}{d_o}\right)} \quad (4)$$

From linear regression analysis, the value of n can be determined from the measured data by minimizing total error, R^2 as follows:

$$R^2 = \sum_{i=1}^{m} \left[P_L(d_i) - P_L(d_o) - 10n\log_{10}\left(\frac{d_i}{d_o}\right)\right] \quad (5)$$

Differentiating (4) w.r.t. n

$$\frac{\delta 2R(n)}{\delta n} = -20\log_{10}(d)$$

$$\sum_{i=1}^{m}\left[P_L(d_i) - P_L(d_o) - 10n\log_{10}\left(\frac{d_i}{d_o}\right)\right] \quad (6)$$

Equating $\frac{\delta 2R(n)}{\delta n}$ to zero,

$$0 = -20\log_{10}(d)\sum_{i=1}^{m}\left[P_L(d_i) - P_L(d_o) - 10n\log_{10}\left(\frac{d_i}{d_o}\right)\right]$$

That is

$$\sum_{i=1}^{m}[P_L(d_i) - P_L(d_o)] - \sum_{i=1}^{m}\left[10n\log 10\left(\frac{di}{do}\right)\right] = 0$$

$$\sum_{i=1}^{m}[P_L(d_i) - P_L(d_o)] = \sum_{i=1}^{m}\left[10n\log 10\left(\frac{di}{do}\right)\right]$$

$$n = \frac{\sum_{i=1}^{m}[P_L(d_i) - P_L(d_o)]}{\sum_{i=1}^{m}\left[10n\log 10\left(\frac{di}{do}\right)\right]} \quad (7)$$

The above equation makes it possible to get the real value of the received signal strength during empirical measurement. Hence received signal strength is related to distance using the (7) to get

$$RSSI\ [dBm] = -10n\log_{10}(d) + A\ [dBm] \quad [8]$$

where *n* is the propagation path loss exponent, d is the distance from the sender and A is the received signal strength at one meter of distance. In order to determine the path loss exponent that will be used in this research work, the RSSI values within 70m of the sink node was measured with a step size of 5m and the root means square (RMS) of the measured RSSI values for the path loss exponent n for the test bed area will now be determined. The models described provide the simplest way of calculating the estimated distances from a receiving node to a transmitting node based on received signal strength indicator. The algorithm uses at least three anchor nodes. The blind nodes can estimate its distance from the anchor node using received signal strength, but the actual position in 2D of the node can be computed from the position information obtained from the three beacon nodes using trilateration technique.

3.2.4 Development of Blind Nodes Location Algorithm

The essence of this algorithm is to determine specific blind nodes location within the distributed nodes along the test bed. The algorithm consists of two phases namely: initialization and final phase. At initialization phase, all the anchor nodes will have their (IDs). The network is scalable for a very large number of nodes which is spread over the test bed. All anchor nodes broadcast their data which includes their location position and other parameters. The blind node within the range of broadcast stores the anchor location once for a particular node and estimate the range to anchors based on received signal strength; after which these also broadcast the anchor location to other blind nodes. By this process all blind nodes knows the location of anchors. At final phase, a blind node is able to estimate its distance to at least three anchor nodes; the blind node can perform trilateration to get its accurate location in 2D, this blind node becomes a converted anchor node, its position is now sent to the base station via the sink. Both initialization and final stage continues until all blind nodes become converted.

3.3 Localization Algorithm Implementation

1) When a positioning packet has been broadcast by anchors

2) If a blind node is within the range of broadcast.

3) Then store the positioning packet and compute the estimated range to the anchor using $d = 10\hat{}(A - \frac{RSSI}{10n})$

4) Else do nothing

5) If a blind node receives packet from at least three different anchors

6) Then perform trilateration

7) Else do nothing

8) If the trilateration is successful, blind node becomes converted to anchor node.

9) Then Go to1

10) Else repeat 6

11) End

4.0 Results and Discussion

From the average RSSI data collected in Table 1, it is clear that RSSI decreases with distance with as a result of attenuation and other transmission impairments. The graph of RSSI versus distance in Figure 4 shows that as the RSSI decreases with distance, at a certain point the RSSI values (67.93 and 68.04) seem to be constant. It means that attenuation has completely set in.

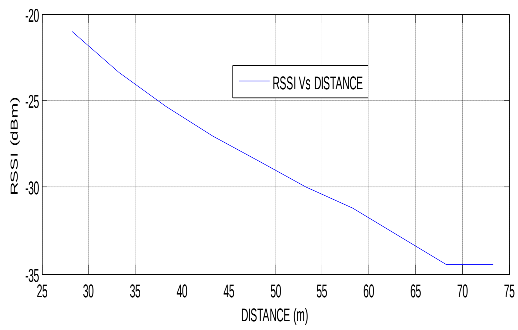

Fig. 4: Average values of RSSI versus Distance

4.1 Determination Of Path Loss Exponent, n

The data collected in Table 1 was used to develop the Matlab script for computing the path loss exponent n of the test bed area. From the computation as shown in figure 5, n was computed to be 4.23. The value of the path loss shows there is less attenuation when KYL500S radio is used as transceiver in the sensor node for localizing the rupture point in a linear pipe network compared to Telos B radio since attenuation is path loss dependent.

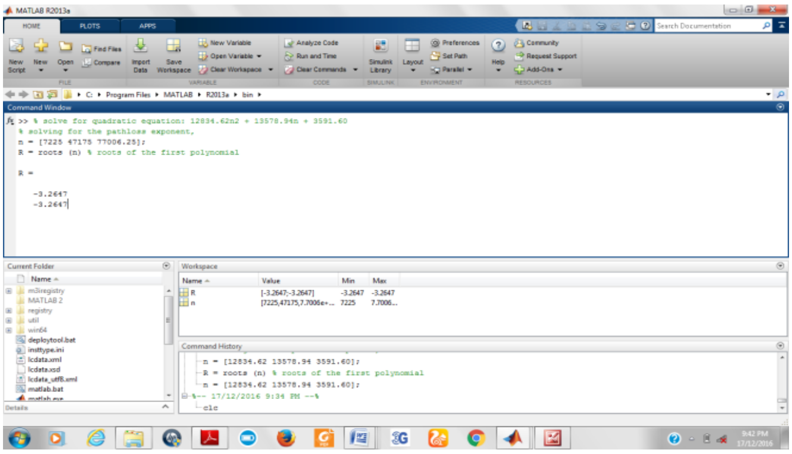

Figure 5: computation of path loss exponent n

Table 2: Input parameters to the algorithm

Name	Value	Description
A	-25.80	The RSSI value in dBm 1 meter apart from a transmitter
N	3.25	The value of path loss exponent
RSSI	-18.65 to-39.96	Received Signal Strength in dBm
X, Y	(0,0) to (50,50)	X and Y co ordinate relative point for anchor node.

From Table 2, the path loss exponent n was determined from the experiment, and A = -25.80 was also determined. The RSSI values will always vary and will be dependent on real values. (x,y) values are fixed points (positions for anchor nodes).

4.2 Evaluating Localization Error

Localization error is defined as the difference between the estimated and the actual distances between the co ordinates of the node. It is computed using the (7), where(x_{est}, y_{est}) and (x_a, y_a) are node's estimated and actual coordinate respectively. The Localization Error (E_L) is given by

$$E_L = \sqrt{(x_{est} - x_a)^2 + (x_{est} - y_a)^2} \qquad (9)$$

In other to evaluate the performance of the algorithm, 3 anchor nodes were deployed together with blind nodes. The goal is to determine the accuracy of the localization algorithm. The experiment was carried out in a test bed. The actual position between the blind nodes and the anchors are measured and recorded. The estimated distances between the blind nodes and anchor nodes were also calculated and recorded. Table 3 shows the data collected while Figure 5 shows the accurate position of the blind node (30.25, 41.81) with respect to x and y axis, and Figure 6 shows the estimated position (inaccurate) at (30.71, 42.42) with respect to x and y axis. The localization error of the algorithm was calculated using eqn 4. The error was found to be 0.76m. The little error was as a result of distance error which normally dependent on the RSSI values between the communicating nodes.

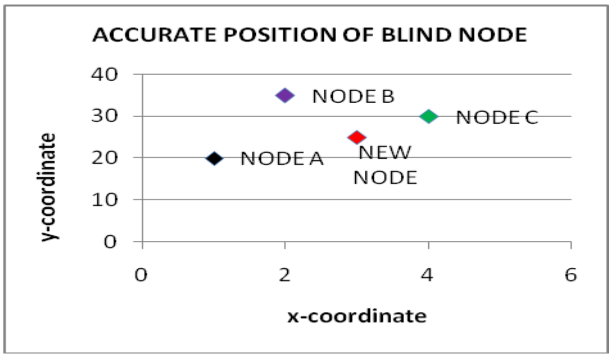

Figure 6: Actual position of the blind node

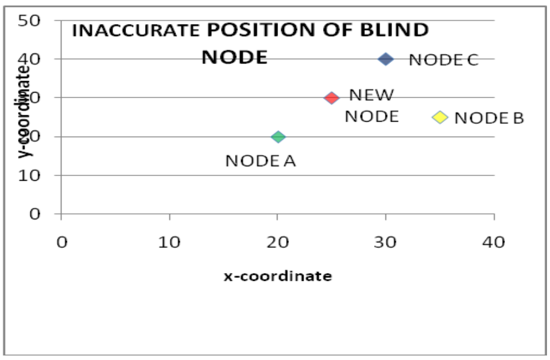

Figure 7: Estimated position of the blind node

5.0 Conclusion

In this research work, a Trilateration based localization algorithm for wireless sensor network was used in the experimental analysis. It has been observed from the analysis that whenever anchor nodes broadcast packets containing their locations, the blind node within the broadcast range can always estimate its distance to the anchor nodes using received signal strength indicator. If the blind nodes receive signal from at least three anchor node, the blind node can localize its position and send it to the sink. More works should be done in finding out the solution to shadowing and multipath fading as major constraints in using received signal strength indicator as a communicating signal in carrying out trilateration localization algorithm.

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