RSSI Method: Estimation & Analysis of Communication Range Parameter for Localization in WSNs

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***Abstract-* Presently, Wireless Sensor Networks (WSNs) have notably emerged as one of the forefront areas of technical research because of the diverse applications of WSNs includes monitoring, controlling, navigation and surveillance. Essentially, a WSN consists of numerous tiny sensor nodes that are randomly distributed across a designated area. These nodes are capable of collecting and transmitting data to a sink node. The performance efficiency of a WSN in the aforementioned applications largely hinges on several key parameters: the Number of Nodes (NN) or Node Density, Communication Range (CR) and Anchor Nodes (AN). In this research paper, we aim to minimize errors in a WSN by calculating the communication range estimates between sensor nodes using Root Mean Square Error (RMSE) simulation analysis. This analysis for varying communication ranges is conducted using the Received Signal Strength Indicator (RSSI) method in MATLAB.**

***Index Terms* – AN-Anchor Nodes, CR-Communication Range, NN-Number of Nodes, RSSI-Received Signal Strength Indicator, RMSE-Root Mean Square Error. WSNs-Wireless Sensor Networks**

I. INTRODUCTION

The field of Wireless Sensor Networks (WSN) is a multidisciplinary area of research that offers a diverse array of applications, spanning from domestic settings to industrial uses, as well as medical and military domains. Sensors can be integrated into structures [1], deployed across battlefields [2], or embedded in forests [3], effectively delivering sensed information that enables prompt action for specific applications. Typically, these applications necessitate large-scale networks comprising hundreds of small, battery-powered, and wirelessly connected nodes.

A WSN is a network of tiny sensor node devices that can communicate the information gathered through wireless links in a specified area. Generally, the sensor nodes are deployed randomly and hence precise location information of sensor nodes is critical for the success of the WSN [4, 5]. Hence, the position of the sensors is unknown and must be estimated by localization techniques. Localization in sensor networks is to identify the location or position of the sensor nodes which are deployed randomly in a specified region [6]. The environment in a WSN is monitored by the sensor nodes which are deployed and possess an onboard processor. The deployed sensors in the network are connected to the Base Station which acts as a processing unit in the WSN System. Base Station in a WSN System is connected through the Internet to share data. WSNs are a very promising tool for monitoring events and are used in many fields-such as agriculture, environmental monitoring of air-water pollution, greenhouse, health monitoring, structural monitoring etc [7-13].

Since the sensor nodes are randomly deployed, the efficiency of a WSN relies on the localization of sensor nodes. Several localization techniques have been proposed to provide location information of the unknown sensor nodes in WSNs. Broadly, localization techniques are divided into two categories: Range based and Range free methods. In range based method, the location of the sensor node can be determined by distance or angle estimates. These methods include Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of AoA) and Received Signal Strength Indicator (RSSI) [14-17]. The location information provided by these methods is accurate but requires additional hardware for computation which results in increase of bulkiness and cost of the device. In range-free method, the location of the sensor is estimated on the basis of hop information. APIT, DV-Hop and Centroid are some of the methods. The advantage of these methods is that they do not require any additional hardware and hence are cost effective and consume less energy [18].

1.1. Localization of Sensor nodes and its stages

Estimating the exact position of sensor nodes deployed in a specific area is a challenging and important research problem. The accuracy of the location of sensor nodes impacts the efficiency of the WSN. The three different stages in localization of nodes are, (i) Distance/Angle estimation between the nodes (ii) Position computation of a single node (iii) Localization algorithm - used for localization of all the nodes in the network [18]. From the inception of WSNs- many different techniques with varying accuracy and complexity were proposed at each stage.

I Stage: Distance/Angle Estimation: The estimation of distance /angle is a pre-requisite for the next two stages of localization of nodes. These methods refer to the measurement of distance or angle between the transmitter and receiver nodes.Different techniques include - Time of Arrival (ToA), Time Difference of Arrival (TDoA), Received Signal Strength Indicator (RSSI) and Angle of Arrival (AoA).

II Stage: Position Calculation: GPS an existing method-cannot be used for the localization of wireless sensor nodes due to various constraints. Initially, estimation of a nodes distance or angle is computed and its own position can be computed using any one of the methods such as - central position, trilateration, multilateration, triangulation and probabilistic approaches. Selection of a method for an application depends upon the information available and the processors limitations [19].

III Stage: Localization algorithm: This is an important stage of localization system – a localization algorithm utilizes the information collected in the previous two stages. Broadly, localization algorithms in WSNs are divided into two categories: (*i*) Distributed, and (*ii*) Centralized. Centralized localization requires the migration of internode ranging and connectivity data to a sufficiently powerful central base station. Centralization is much more complex than a distributed environment. It defines a method of transformation of information to localize sensor nodes cooperatively. The efficiency and accuracy of this stage is affected by three parameters- deployment environment, the ranging method, and the relative geometry of unknown nodes to the anchor nodes [20, 21].

Range based and Range free localization is the two most common methods of localization. Range based localization algorithms use the range – distance or angle information from the anchor node to estimate the location. Several ranging techniques exist to estimate an unknown node distance to three or more anchor nodes. Based on the range information, location of a node is determined. Some of the range based localization algorithm includes: Received signal strength indicator (RSSI), Angle of arrival (AoA), Time of arrival (ToA) [22]. Time difference of arrival (TDoA). Range-free localization algorithms use connectivity information between unknown node and landmarks. A landmark can obtain its location information using GPS or through an artificially deployed information. Some of the range-free localization algorithm includes: Centroid, Appropriate point in triangle (APIT) and DV-HOP [23].

In the experiment, simulation of range based method using received signal strength is considered for sensor nodes localization. The measured range in the above mentioned methods are based on the establishment of mathematical models [24]. The localization algorithm, adaptive information estimation strategy is proposed in which, the unknown sensors are localized by an estimator that includes pair-wise measurements between all the sensors in the network. The determination of range estimates is computed and plotted against the range estimated error calculated by RMSE [25].

II. METHODOLOGY

Adaptive Information Estimation Strategy AIES-RSSI Algorithm - sensors work together in a peer-to-peer manner and pair-wise measurements are calculated. Also, an estimator estimates all positions of the sensor nodes. Measurements between any pairs of sensors aids the location estimate and enhances the accuracy of the localization system.

By means of statistical models based on the pairwise measurements, distances can be estimated. The distance error added to the true pairwise distances can be based on a statistical model for RSSI. The AIES-RSSI methodology is divided into two modules-

2.1. Module 1: WSN Deployment

2.2. Module 2: RSSI statistical model implementation with AIES

2.1. Module 1: WSN Deployment

The number of anchor nodes and unknown nodes are specified. The coordinates of each node is generated randomly and the communication between one node to another is defined to obtain the set of nodes within the communication range to form a subset of the WSN.

Step 1: Specify the number of anchor nodes and unknown nodes

Step 2: Randomly generate the coordinates value (x,y) for the defined number of nodes

Step 3: Define the communication range

Step 4: Deployment of nodes for WSN

Step 5: Filter the nodes having more than the communication range to form the subset of nodes.

Step 6: Connected WSN

2.2. Module 2: RSSI Statistical Model Implementation with AIES

RSSI estimates the distance traversed by a signal to the receiver by measuring the power of received signal. Radio signal attenuates as the distance between the transmitter and receiver increases. With the increase in distance, strength of radio signal decreases exponentially. The attenuation in signal strength is measured by the receivers received signal strength indicator (RSSI) circuit. The advantages of this method is that it requires no additional hardware and the energy consumption, sensor size and cost does not affect the functioning of the WSN. The main disadvantage being that it is sussceptible to interference and noise. A radio propagation model ideally predicts the distance d as

$$\bar{P}(d) = P_0 - 10n_p \log \frac{d}{d_0}, \text{------}1$$

where P_o is the received power in dBm at a short reference distance d_o. The log-normal model is based on measurement results and analytical analysis [26, 27]. The standard deviation of the received power is expressed as σ_{dB} , it is relatively constant with disatnce and has a low of two and a high of four. Thus, the received power at *i*, when transmitted by a sensor *j*, $P_{i,j}$ is represented as –

$$f(P_{i,j}=p \mid \Theta) = N\ (\ p;\ P(d_{i,j}),\ \sigma_{dB}^2\ ) \text{ ------}2$$

where $P(d_{i,j})$ is the mean and σ_{dB}^2 is the variance. From the log-normal model the variance determined are proportional to the distances. The actual transmitter – reciever seperation distance $d_{i,j}$ is given by,

$$d_{i,j} = \sqrt{(x_i-x_j)^2 + (y_i-y_j)^2} \text{ -----}3$$

Lastly, the computation of the RMSE is achieved to determine the localization performance

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Loc_{real}^{i} - Loc_{est}^{i})^2}{n}} \text{ -----}4$$

Algorithm :

Step 1: Sensor nodes are deployed in a specific area

Step 2: Selection of subset

Step 3: Using RSSI model, the received power is represented

Step 4: Ɵ-variances are determined

Step 5: Submatrices-Calculation of Fisher Information

Step 6: Submatrices are merged to form the FIM

Step 7: Invert FIM to obtain variance of the estimators.

Step 8: Computation of RMSE

III. SIMULATION ANALYSIS & RESULTS:

The range estimates are determined using MATLAB simulation by varying the network parameters that affect the localization error calculated by RMSE. The parameters that affect localization are -

3.1. Node Density (NN)

These are the total number of nodes in a network, and in this simulation study they are varied from 10-1000 nodes.

3.2. Anchor Nodes (AN)

These are the nodes whose location is known and are deployed grid-wise; they are varied from 3-20.

3.3. Communication Range (CR)

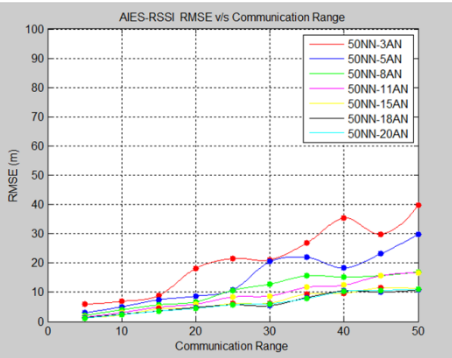
This is the range or the propagation distance between the nodes and is varied from 5-50.

Range estimates are determined using MATLAB Simulation. In this research paper, to study the performance of localization in a WSN - the analysis of the network parameter - Communication Range (CR) which affects localization is observed - by varying CR in the range 5 to 50 and keeping the NNs and ANs as constants. Variations in the above parameters are considered as cases1, 2 & 3 – a set of graphs - CRs Vs RMSE are plotted. The consolidated values are tabled and the corresponding graphs are as shown below.

Case - 1: NN=50; AN=3 to 20; CR is varied between 5 to 50 and keeping the NNs and ANs as constants, the observed consolidated values w.r.t. RMSE and the corresponding set of graphs - CR Vs RMSE are plotted as shown below.

Table 1: AIES-RSSI - Consolidated values for NN=50

Sl. No.	C-R	AN=3 RMSE	AN=5 RMSE	AN=8 RMSE	AN=11 RMSE	AN=15 RMSE	AN=18 RMSE	AN=20 RMSE
		NN=50						
1.	5	5.953152	2.940704	2.047045	1.493841	1.350085	1.299369	1.144805
2.	10	6.897137	5.026278	3.997373	3.061867	2.219597	2.507322	2.363684
3.	15	8.901229	7.434464	5.719645	4.922899	4.381991	3.571261	3.544117
4.	20	18.176007	8.658182	6.713432	5.931977	4.690728	4.818232	4.499235
5.	25	21.550440	10.811668	10.702497	8.384304	6.089568	5.679371	5.737313
6.	30	21.108081	20.458122	12.800921	8.737487	6.299958	5.435975	6.080849
7.	35	26.882098	21.933753	15.649684	11.719204	9.483961	8.201165	7.886189
8.	40	35.384906	18.268143	15.165430	12.431083	9.623265	10.463306	10.340047
9.	45	29.904663	23.248077	15.703225	15.671772	11.567387	10.075013	10.596974
10.	50	39.677180	29.810443	17.012702	16.620464	11.068082	10.791991	10.985938

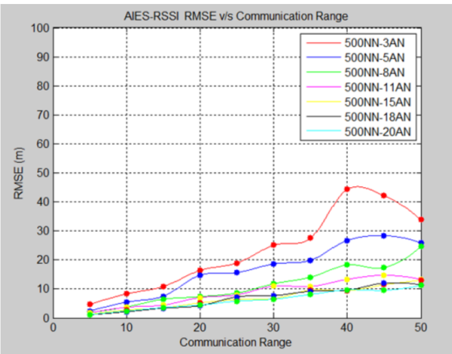


Graph 1: AIES-RSSI - Consolidated graph for NN=50

Case - 2: NN=500.

Table 2: AIES-RSSI - Consolidated values for NN=500

Sl. No.	C-R	AN=3 RMSE	AN=5 RMSE	AN=8 RMSE	AN=11 RMSE	AN=15 RMSE	AN=18 RMSE	AN=20 RMSE
		NN=500						
1.	5	4.668519	2.428628	1.871999	1.730256	1.210276	1.102056	1.200694
2.	10	8.294152	5.452690	3.813900	3.692578	2.722393	2.160591	2.381321
3.	15	10.845833	7.487469	6.465530	4.424118	3.481079	3.388765	3.580676
4.	20	16.420757	14.774899	7.333109	7.053858	5.193718	4.228664	4.474219
5.	25	18.947237	15.640802	8.588472	7.990321	6.355650	7.290048	5.805442
6.	30	25.069014	18.631638	11.781900	11.016083	6.584704	7.709838	6.471456
7.	35	27.509285	19.885031	14.050730	10.811620	9.635259	9.200683	8.109705
8.	40	44.329931	26.741284	18.286695	13.329345	9.412837	9.586224	9.693590
9.	45	42.124687	28.375110	17.360003	14.733029	11.438217	12.029916	9.534431
10.	50	33.868337	25.917376	24.576016	13.283915	13.013148	11.394681	11.230206

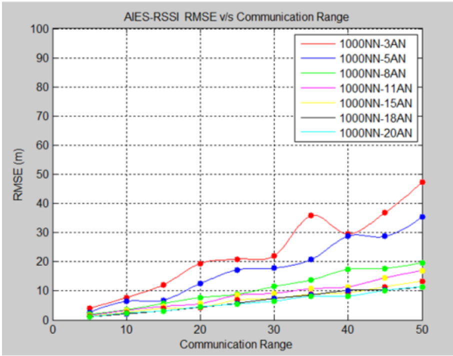


Graph 2: AIES-RSSI - Consolidated graph for NN=500

Case - 3: NN=1000.

Table 3: AIES-RSSI - Consolidated values for NN=1000

Sl. No.	C-R	AN=3 RMSE	AN=5 RMSE	AN=8 RMSE	AN=11 RMSE	AN=15 RMSE	AN=18 RMSE	AN=20 RMSE
		No. of Nodes=1000						
1.	5	4.074227	2.582733	1.955239	1.564238	1.244568	1.083038	1.083038
2.	10	7.694370	6.390050	3.520446	3.320575	2.613344	2.354306	2.354306
3.	15	12.076983	6.794679	5.655617	4.700764	4.022228	3.150979	3.150979
4.	20	19.393704	12.518765	7.715369	5.602963	4.329927	4.531993	4.531993
5.	25	20.917727	17.229214	8.809320	8.538359	6.821552	5.491490	5.491490
6.	30	22.072816	17.767699	11.497007	9.182346	7.358259	6.495798	6.495798
7.	35	35.822025	20.764914	13.754292	10.757984	8.871778	8.161466	8.161466
8.	40	29.488557	28.835730	17.368052	11.418904	9.390252	8.215754	8.215754
9.	45	36.888069	28.731232	17.760998	14.477190	11.411451	10.174076	10.174076
10.	50	47.370761	35.445617	19.682436	16.990376	13.355991	11.404088	11.404088



Graph 3: AIES-RSSI - Consolidated graph for NN=1000

From the above graphs, it is observed that, for the same number of nodes, if the communication range is increased, RMSE increases. Also, as the number of Anchor Nodes increases, RMSE value decreases for the corresponding communication ranges.

IV. CONCLUSION

To estimate positions of sensor nodes for the evaluation of localization errors, the range based technique RSSI was employed. For the simulation results using MATLAB,various localization parameters are considered like sensor nodes deployment area, number of nodes to be deployed, number of anchor nodes and communication range. Since localization error is the deviation of the estimated node location from the actual node location, the metric RMSE was computed and tabulated. Using the statistical RSSI model- based on the pair-wise measurements, distances are estimated. Case studies with different conditions- for different ANs and CRs were considered and graphs for CRs versus RMSE are plotted. The simulation results using MATLAB indicate an optimization of CRs to maintain an average RMSE error for different scenarios. This indicates minimization in localization errors of the sensor nodes used in the wireless sensor network.

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