RESEARCH ARTICLE OPEN ACCESS

Estimation of Error Minimization of Anchor Nodes in WSNs Using Range Based Method

Dr.Sudha H.Thimmaiah and Dr.Vidya Honguntikar
Dept. of Electronics & Telecommunication Engineering, Dr.Ambedkar Institute of technology, Malhathahalli, Bengaluru-560056, Karnataka, India.
Corresponding Author Email ID: sudha.tce.ait@gmail.com

ABSTRACT
The broad spectrum of applications– such as surveillance, monitoring and controlling has resulted in Wireless Sensor Networks (WSNs) as one amongst the leading technologies of research interest in recent years. One of the basic challenges of WSNs is the localization of sensor nodes in the network. Localization or positions of nodes in the network significantly influences the performance of the network. The effective efficiency of a WSN system is influenced by the performance of its parameters - Node density, Anchor Nodes and Communication Range. Many factors influence the node position or localization of anchor nodes which significantly impacts errors in the network. Subsequently, it is very essential to minimize localization errors. RMSE can be computed to estimate error minimization of anchor nodes by computing ranges between the various nodes. In this research paper, simulation analysis for determination of range estimates and RMSE for Anchor nodes using Range based - RSSI method is computed using MATLAB.

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

Date of Submission: 13-03-2024 Date of acceptance: 27-03-2024

I. INTRODUCTION

A Wireless Sensor Network (WSN) is formed when small devices called wireless sensor nodes are deployed in a given area (indoors or outdoors). Recent MEMS technological advances have led to the development of very small and low-cost sensor devices which are capable of functions such as- computation, communication processing and data storage [1]. The environment in the network is monitored by sensor nodes which are equipped with 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 [2]. 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.

Since the advent of WSN technology, a number of localization algorithms have been proposed. To mention a few, based on the methods of computation and ranging measurements, we have-

- *Distributed* and *Centralized* – Distributed algorithms - Computing is equally distributed among all the sensor network nodes. Here, location information is received by each node from its neighboring node, performs computation, and retransmits the obtained results to other nodes. In the Centralized approach, Computing is performed by a single centralized node and all nodes broadcast localization information to a single computer. Centralization is much more complex than a distributed setting.
- R*ange based* and R*ange free* - Range-based [3] techniques require ranging information that can be used to estimate the distance between two neighboring nodes. Therefore, range measurements such as time of arrival (ToA), angle of arrival (AoA), received signal strength indicator (RSSI), and time difference of arrival (TDoA) are used to measure the distances between the nodes in order to estimate the location of the sensors. Range-free [4] techniques use connectivity information between neighboring nodes to estimate the nodes' position, also, do not require any additional hardware and use proximity information to estimate the location of the nodes in a WSN, and thus have limited precision. Some of the range-free localization algorithm includes: Centroid, Appropriate Point in Triangle (APIT) and DV-HOP**.**

In this research paper, Received Signal Strength Indicator (RSSI) - a range based method is considered for sensor node localization. Mathematical models are used to measure range in the above mentioned methods [5]. A localization algorithm, Adaptive Information Estimation Strategy (AIES) 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 range estimates computed using the AIES model is plotted against the RMSE (Root Mean Square Error) [6]. In this paper, analysis of anchor nodes is performed.

Stages in Localization of Sensor Nodes

To determine the exact position of sensor node, there are three different stages –

I-Stage: Distance/angle estimation between the nodes - Distance/Angle estimation is the pre-requisite for remaining two phases of localization. This refers to the measurement of distance or angle between the transmitter and receiver node. The different techniques for distance/angle estimation include - Time of Arrival (ToA), Time Difference of Arrival (TDoA), Received Signal Strength Indicator (RSSI) and Angle of Arrival (AoA).

II-Stage: Position computation of a single node - GPS (Global Positioning System) cannot be used for the localization of wireless sensor nodes due to various constraints Once the initial calculation of a nodes distance or angle is estimated, the nodes position can be computed using any one of the following methods - trilateration, multilateration, triangulation, probabilistic approaches etc. [7].

III-Stage: Localization Algorithm - The most important and last stage of localization is the choice of localization algorithm which is used for localization of whole network [8]. Here, at each stage, different techniques with varying accuracy and complexity exist. The information collected in previous two stages is utilized to localize sensor nodes cooperatively. Mostly, accuracy of this stage is affected by the ranging method, deployed environment, and the relative geometry of unknown nodes to the anchor nodes.

II. METHODOLOGY

The proposed Range-based-RSSI Algorithm is implemented in this research paper. AIES-RSSI Algorithm- In the Adaptive Information Estimation Strategy methodology, pairwise measurements between peer-to-peer sensors are computed by an estimator. The pair-wise distance measurements are estimated by a statistical model. The distance error is computedon the basis of the statistical model AIES-RSSI. Measurements between any pairs of sensors aids the location estimates and enhances the accuracy of the localization system.

The AIES-RSSI implementation is as follows.

1.1. WSN Deployment
1.2. AIES-RSSI statistical model

2.1. WSN deployment

The number of anchor nodes and unknown nodes are specified and the coordinates of each node is generated randomly. To form a subset of nodes in the WSN, the communication range between nodes is defined. The following procedure was followed

- The total number of nodes-anchor and unknown are defined.
- Random coordinate values (i,j) are generated for the defined number of nodes.
- Communication Range between peer-to-peer nodes is defined
- Selection of subset of nodes based on communication range defined.
- Connection between nodes is established.

2.2. AIES-RSSI Statistical Model Implementation.

RSSI is a distance related measurement technique which estimates the distances between peer-to-peer sensors from the received signal strength measurements [9]-[13]. These techniques are based on a standard feature found in most wireless devices, a received signal strength indicator (RSSI). RSSI estimates the distance covered by a signal to the receiver by measuring the power of received signal. Decrease in transmitted power at the receiver can be calculated and translated into an estimated distance. Let us denote d_{ij} as the estimated distance between two peer nodes i and j, then maximum likelihood estimate is a biased estimate of the true distance and is represented as equation – (1)

$$\hat{d}_{ij} = d_0 \left(\frac{P_{ij}}{P_0(d_0)} \right)^{-1/n_p} \text{------------------------} \quad (1)$$

Also, an unbiased estimate is given by equation – (2)

$$\hat{d}_{ij} = d_0 \left(\frac{P_{ij}}{P_0(d_0)} \right)^{-1/n_p} e^{-\frac{\sigma^2}{2\eta^2 n_p^2}} \text{---------------------} (2)$$

Where P_0 (d_0) [dBm] is a known reference power value in dB milliwatts at a reference distance d_0 from the transmitter, n_p is the path loss exponent that measures the rate at which the RSSI decreases with distance and the value of n_p depends on the specific propagation environment, σ is the standard deviation for a zero mean Gaussian distributed random variable, and accounts for the random effect of shadowing.

This implies that the distance is modelled as Gaussian and is represented as above. Lastly, the localization performance of the algorithm is evaluated by computing RMSE by using the below equation – (3)

AIES-RSSI Algorithm :

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (Loc_{real}^{i} - Loc_{est}^{i})^2}{n}} \text{------------------------} \quad (3)$$

Step 1: Deployment of Sensor nodes and selection of subset
Step 3:Representation of distance using RSSI model
Step 3: Estimation of distances are determined
Step 4: Calculation of Fisher Information Submatrices
Step 5: Merge Submatrices to form the FIM
Step 6: Invert FIM to obtain variance of the estimators.
Step 7: Compute RMSE

III. SIMULATION RESULTS.

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 to 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 to 20.

3.3. COMMUNICATION RANGE (C-R)

This is the range or the propagation distance to the rest of the nodes. It is varied from 5 to 50.
To determine the range estimates, simulation using MATLAB is considered by varying the network parameters that affect the localization error - RMSE. In this experiment, considering AN (Anchor Nodes) - a parameter which affects localization, a set of graphs - No. of ANs Vs RMSE are plotted-by varying AN in the range 3 to 20 and keeping the NNs and CRs as constants. Variations in the above parameters are considered as cases-1,2,3,4,&5. The consolidated tabled and figures are as shown below.

Case1: NN=50 and CR=5,25,50

Table 1: Consolidated values for No. of Nodes=50

Sl. No.	NN=50	RMSE		
	AN	CR=5	CR=25	CR=50
1.	3	5.953151	19.237482	39.129616
2.	4	2.821747	13.054180	34.520252
3.	5	2.960957	14.273794	24.936982
4.	6	2.529759	12.673054	19.029242
5.	7	2.221645	12.554039	24.874602
6.	8	1.831013	9.8252602	19.707457
7.	9	1.749731	10.124067	16.467896
8.	10	1.731917	7.6047113	19.676095
9.	11	1.591006	8.0925991	14.064001
10.	12	1.471185	7.4848085	15.732999
11.	13	1.409603	6.4893224	12.474892
12.	14	1.467092	6.5513547	11.278426
13.	15	1.235257	5.6402730	11.508468
14.	16	1.106057	5.3301373	11.508598
15.	17	1.128837	6.4173051	10.520264
16.	18	1.238771	6.0623485	10.269173
17.	19	1.168544	5.6512137	11.425952
18.	20	1.048601	6.2204672	10.807859

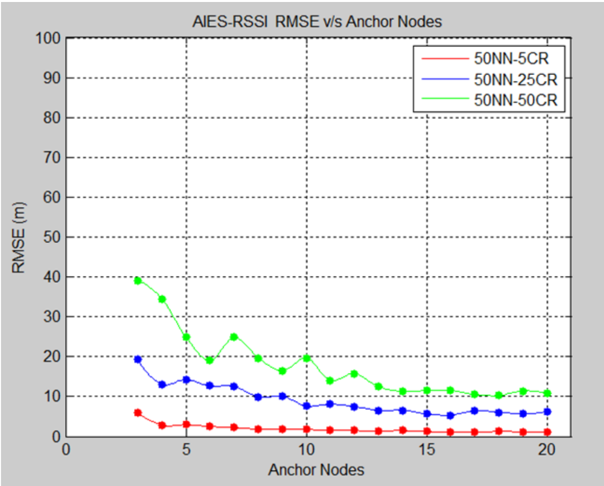

Figure 1: Consolidated graph for No. of Nodes=50

Case2: NN=250 and CR=5,25,50

Table 2: Consolidated values for No. of Nodes=250

Sl.	**NN=250**		**RMSE**	
No.	AN	CR=5	CR=25	CR=50
1.	3	5.469887	18.887724	42.210198
2.	4	2.969398	16.348247	25.373395
3.	5	2.678434	11.962529	29.161686
4.	6	2.915172	12.815085	39.299021
5.	7	2.484314	11.294445	24.492242
6.	8	1.540445	9.7150053	19.144082
7.	9	1.868511	9.7975768	17.090378
8.	10	1.520942	9.9703692	15.663573
9.	11	1.910027	7.5177194	14.940916
10.	12	1.505874	8.7630835	13.843758
11.	13	1.497459	6.8789024	12.669319
12.	14	1.355693	6.1845539	12.990643
13.	15	1.153480	5.6029495	13.279041
14.	16	1.164862	5.7375851	12.119469
15.	17	1.377347	6.4081805	11.105274
16.	18	1.033796	6.1760776	12.199137
17.	19	1.106654	5.3317257	10.110061
18.	20	1.010895	5.0180784	11.865234

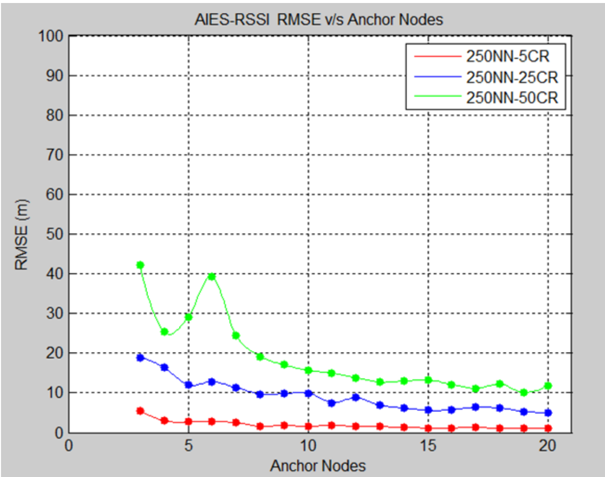

Figure 2: Consolidated graph for No. of Nodes=250

Case3: NN=500 and CR=5,25,50

Table 3: Consolidated values for No. of Nodes=500

Sl. No.	NN=500 AN	RMSE CR=5	CR=25	CR=50
1.	3	4.053435	22.834505	48.893794
2.	4	2.506675	16.304542	30.473704
3.	5	2.774731	14.449380	26.467303
4.	6	2.027185	12.133174	23.505441
5.	7	2.291052	10.376762	21.619731
6.	8	1.829499	10.804111	19.779065
7.	9	1.763275	9.105011	19.396379
8.	10	1.701512	7.914542	17.410193
9.	11	1.730952	8.155664	16.153580
10.	12	1.972270	7.450414	13.842163
11.	13	1.538088	6.984029	12.686838
12.	14	1.353770	5.895079	11.920846
13.	15	1.175870	6.068707	11.646154
14.	16	1.325148	6.335636	12.191633
15.	17	1.147423	5.734063	10.813564
16.	18	1.122070	5.869960	11.062036
17.	19	1.148408	5.440799	13.147904
18.	20	0.997436	6.006958	12.675135

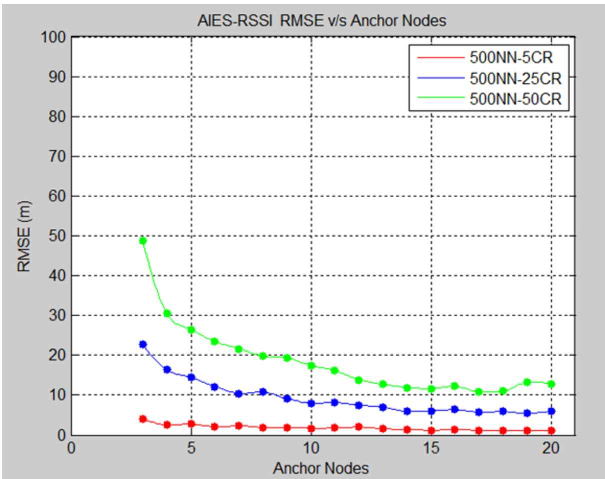

Figure 3: Consolidated graph for No. of Nodes=500

Case4: NN=750 and CR=5,25,50

Table 4: Consolidated values for No. of Nodes=750

Sl. No.	NN=750 AN	RMSE CR=5	CR=25	CR=50
1.	3	4.445773	16.289826	39.747897
2.	4	3.036321	15.276661	26.818578
3.	5	2.375317	11.023839	22.458803
4.	6	2.393269	12.088473	23.934686
5.	7	2.361574	10.024851	23.426724
6.	8	2.375838	11.040459	20.474875
7.	9	1.820939	8.416435	19.279944
8.	10	1.526815	8.940496	16.472266
9.	11	1.987013	6.757975	17.412086
10.	12	1.378258	7.973612	14.434348
11.	13	1.591728	6.802360	14.536231
12.	14	1.422004	6.868210	13.813995
13.	15	1.526186	6.194133	12.028522
14.	16	1.258398	5.752659	12.029386
15.	17	1.332766	5.845070	11.069651
16.	18	1.160508	6.271100	10.915484
17.	19	1.255101	5.176991	10.778057
18.	20	1.127895	5.465581	10.822220

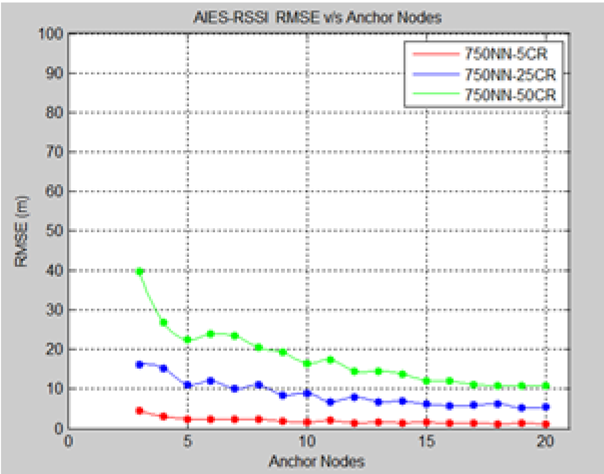

Figure 4: Consolidated graph for No. of Nodes=750

Case5: NN=1000 and CR=5,25,50

Table 5: Consolidated values for No. of Nodes=1000

Sl. No.	NN=1000 AN	RMSE CR=5	RMSE CR=25	RMSE CR=50
1.	3	4.603400	20.425433	45.742669
2.	4	2.901249	16.626924	25.902546
3.	5	2.996322	15.855265	24.012465
4.	6	3.284794	11.064289	25.292532
5.	7	1.967711	12.255649	25.320004
6.	8	1.977211	8.781587	19.249915
7.	9	1.745496	8.950027	18.465921
8.	10	2.113757	8.943440	19.460651
9.	11	1.651553	8.964781	13.207915
10.	12	1.388125	8.380448	15.864717
11.	13	1.248265	6.971479	13.993947
12.	14	1.265031	6.848232	13.971161
13.	15	1.200075	5.573475	12.510094
14.	16	1.199988	5.382378	12.301735
15.	17	1.200669	5.271338	11.239638
16.	18	1.134805	5.677820	12.015889
17.	19	1.076268	6.014278	9.956138
18.	20	1.230248	6.037522	10.743483

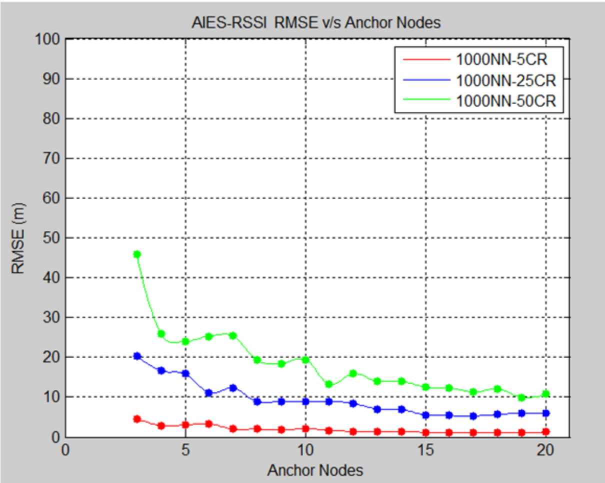

Figure 5: Consolidated graph for No. of Nodes=1000

From the above figures, it is observed that as the number of anchor nodes increase, for different communication ranges, the RMSE values decreases, which is the desired result. Also, as the communication range increases, the corresponding RMSE values increase due to the random deployment of both Anchor Nodes and Number of Nodes.

IV. CONCLUSION

The localization parameters which were considered for the evaluation of localization errors, for the range based technique RSSI are - number of nodes to be deployed, number of anchor nodes and the communication range. Using the statistical RSSI model based on the pairwise measurements, distances are estimated. Case studies- for different values of NNs and C-Rs, graphs for ANs versus RMSE are plotted. MATLAB was used as the simulation tool , the metric RMSE was computed, which represents the localization error.The simulation results using MATLAB indicate an optimization of ANs to maintain an average RMSE error for different scenarios, to determine range estimates using RSSI. This implies minimization in localization errors of the sensor nodes used in the wireless sensor network.

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