RSSI based 3D Localization in Wireless Sensor Networks

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Abstract: The authors in this paper present the development of a distance based 3D localization algorithm to localize a WSN. As it has already been established by the research till now that distance based localization techniques are more practical than employing complex AoA measurement requirements, we are proposing the RSSI based distance localization for a WSN deployed in a three dimensional topology. In this paper, it is observed that it is possible to localize a network in 3D with fraction of anchor nodes. We also observe that the proposed technique accurate and is acceptably immune to error in RSSI measurements compared to similar techniques.

Keywords: Three Dimensional Localization, 3D Localization, WSN, RSSI.

Introduction

For the last decade there has been a great focus on sensor networks, exploiting the advantages of wireless networks. Small sized ubiquitous nodes capable of sensing physical parameters, processing it and then sending it using one or Multi-hop wireless communication to the site where required is a result of these developments. This setup is known as Wireless Sensor Network (WSN). A typical WSN may consist of hundreds to thousands of sensor nodes with limited range of communication passing useful information to the sink node.

In a typical WSN, the sensed parameter is sent to the base node from depending upon time or event sensed. To make the data from sensor node meaningful, location information is added to it. This addition of location information is possible with the help of localization process. The aim of Position finding or Localization in WSN is to find the location or position of nodes. Depending upon the type of application of WSN involved, the location of the nodes may be presented in crude form like 'longitudinal, latitudinal, altitudinal' position or in a more refined form like 'at the centre of living room on first floor', 'towards opening gate of garage in the basement' etc.

To record the location of each node while deploying them is not practical for two reasons. One, because the WSN may scale up to thousands of nodes and manual localization may take many hours. Second, in some of the applications including hostile or tactical situation, manual localization may not be feasible at all [1]. Therefore a localization technique should be able to determine the location of all nodes in a WSN without any human intervention.

Related Work

Many localization algorithms for localization of WSN exist as of now and most of the localization techniques rely on some fraction of nodes knowing their location beforehand and are known as anchor nodes. These anchor nodes help all other non anchor nodes to determine their location and hence localize a WSN [2], [3], [4]. The average localization error decreases with increase in the number of anchor nodes. However, increasing anchors adds to the burden on node in terms of cost, size and other resources [1]. Anchor less localization techniques provide a relative locations of the nodes in a WSN, but their applications are limited [5], [6]. Some of the high accuracy techniques depend upon the high computation power of the base station to run the complex localization algorithm. Authors in [7] presented semi definite programming (SDP) based localization technique which uses inter-node measurements to create the probable regions of the nodes. The complexity of these algorithms can go up to $O(k^3)$ in two dimensional scenarios. Another MDS-MAP based algorithm uses inter-node distance to create localization points for the unknown nodes with $O(k^3)$ complexity [2]. Distributed algorithms exploit the inherent advantage of inter node communications between wireless nodes. It is always beneficial to do computation at node level instead of sending the measurements all the way to the base station saving node and network resources. However, the limited computation capability of nodes limits the complexity of algorithm and thus accuracy. Distributed algorithms are also classified into two types i.e. Range Free Algorithms and Range Based Algorithms. The algorithms for high accuracy of choice are Range based. These algorithms depend upon one or more of the internode measurements as mentioned in the table-1. We limit the discussions to the RSSI based measurement in the present work. Many factors add noise in the distance measurement using freely available RSSI measurement.

Authors in [8] presented a Distributed, Anchor and Range based algorithm. The proposed algorithm assumes there are some fraction of anchors present in the network, with all nodes knowing their internode distances. The problem of localization is formulated in terms of minimizing the Mean Square Error (MSE) between the actual and predicted internode distances. This is done by collaboration between nodes and then iteratively refining their position estimates. The authors did simulation in square two dimensional varying areas with varying node density. The results were for obtained for various parameters of performance metrics including accuracy with reference to the node density, maximum range of the nodes and Energy consumption.

A three dimensional (3D) localization algorithm based on Degree of Coplanarity (3D-IDCP) using RSSI is presented in [9]. The authors transform localization into an unconstrained optimization problem and then try to optimize the localization result with the Quasi-Newton method in an iterative way to meet the requirement of control error. The localization error in a testbench of 100m x 100m x 100m is well contained. The localization error decreases from 0.6m to 0.3m in the above testbench. This shows that the error depends heavily on the percentage of anchor nodes. There is a general consensus that the range based algorithm have better accuracy than range free algorithms [10].

Problem Formulation

The problem of localization can be formulated as:

"To develop a distance based three dimensional localization algorithm exploiting collaborative communication and distributed computation to achieve high accuracy."

The metric for accuracy is defined in terms of mean localization error (L.E) per node in a WSN and is given as:

$$L.E = \frac{1}{M}\sum_{j=1}^{M}\sqrt{\left(x_j - x_j'\right)^2 + \left(y_j - y_j'\right)^2 + \left(z_j - z_j'\right)^2} \tag{1}$$

Where (x_j, y_j, z_j) is the actual location of a j^{th} node, in an M node WSN and (x_j', y_j', z_j') is the estimated location of that node. One of the goal of a localization technique is also to minimize this error keeping in view of the computational and communication overhead involved.

Proposed Solution

The constraint based Localization used depends upon noisy distance measurements using RSSI between nodes in a wireless sensor network (WSN). The discrete constraint is propagated from one hop node to another and using collaborative exchange of constraints of neighboring nodes, a node can reduce the region of constrains. This helps in reducing the region of constraints of other nodes also. The process is repeated until fixed no. of iterations or exit condition is satisfied. Measurement errors of distance with a fixed mean and standard deviation are considered to understand practical effect of these errors in real scenario.

Pseudo Code for Localization

For all M^{th} hop nodes

1. Send own coordinates in all directions,
2. Receive coordinates of neighbouring $(m)^{th}$ hop node and form Probable region w.r.t neighbours within communication range,
3. Intersect old region with the new region w.r.t neighbouring first hop node,
4. Communicate with each other to further reduce the old regions

The proposed technique can take help of multiple anchors and the final probable point may be formed as intersection of points formed by multiple anchors.

Simulation Setup

The nodes are deployed in a region of 100m x 100m x 100m randomly with multiple anchor nodes. The Uniform distribution function used to deploy nodes in a simulation environment is:

$$f(x,y,z) = \frac{1}{XYZ}, \qquad x\epsilon[0,X], y\epsilon[0,Y], z\epsilon[0,Z], \qquad (2)$$

Where $f(x,y)$ is the p.d.f of node's location at (x,y) and X and Y determine the size of deployment area. Fig. 1 shows nodes deployed using uniform random distribution in three dimensions, with three anchors close to the centre.

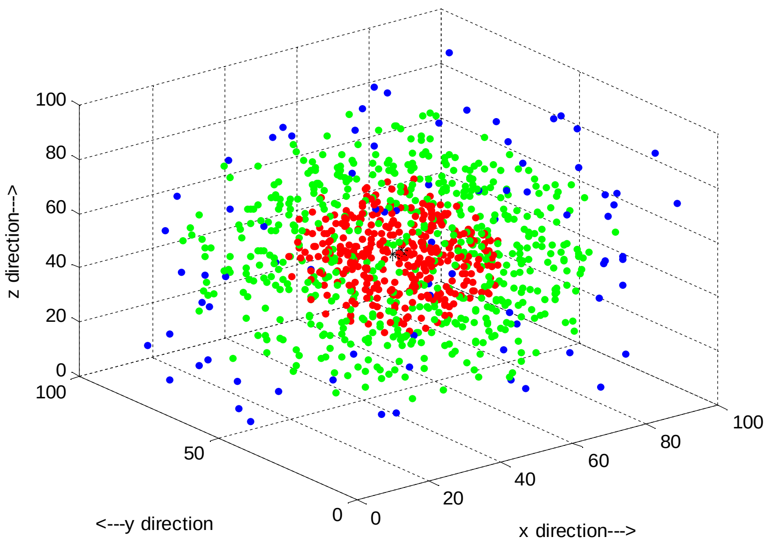

Figure - 1. Example of deployment of 3 anchors and unknown nodes shown by '*' in black and '.' respectively using Uniform distribution deployment. Same colour nodes belong to same hop no. from anchor

It is possible that any node may be one hop from first anchor, three hops from second anchor and 4 hops from third anchor. Maximum range of communication is fixed at 35 m to cover all area in four hops. A node can communicate with other sensors if it is within this range. The technique is evaluated for error of location, AoA error, distance error and number of iterations.

Results and Discussion

The distance error was introduced into the algorithm error varying from 5% to 30% of the total range of a node and its effect on the localization error was observed. As shown in fig. 2, it is apparent that the localization error is less for small error in the distance estimation and varies positively with increase in this error. This is better that the algorithm proposed in [12]. The advantage of proposed algorithm is its simplicity in computation.

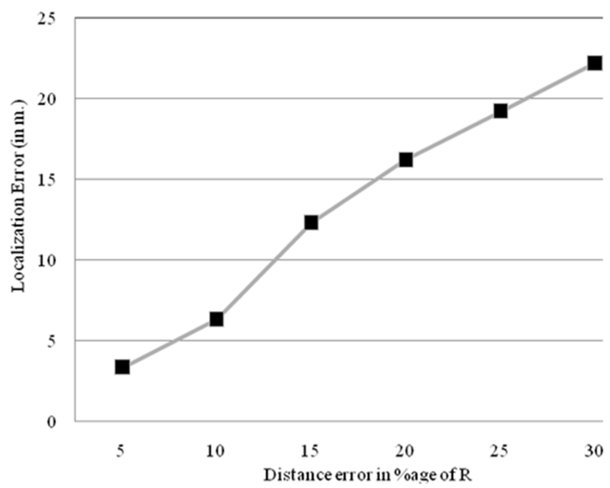

Figure - 2. Effect of Distance estimation error on Localization error

The Maximum range of communication of a node has its impact on the Localization error as seen in the fig.3. The localization error is lesser that in [11]. The increase in communication range increases the number of nodes in a hop resulting in decrease in the number of hops. This way the numbers of nodes which can collaborate with each other and determine their location with high accuracy also increase, resulting into the decrease in the localization error.

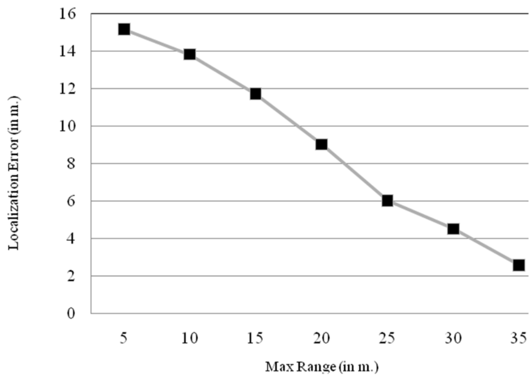

Figure - 3. Effect of Maximum Range on Localization error

Conclusion

A localization technique in three dimensional scenarios using inaccurate distance measurement was proposed. The proposed algorithm has also shown that using only few anchors, the desired accuracy is possible with small no. of iterations making it suitable for indoor localization applications. The distance error from inaccurate RSSI measurement is taken into consideration and it has limited effect on accuracy. The proposed algorithm is also robust to change in communication range compared to algorithm proposed in [11], [12].

Future Scope

The freedom from measurement hardware, its process and associated calculation opens up new area for implementation of range free localization in three dimensional spaces. The comparison of range free three dimensional range free localization algorithm as mentioned above and their comparison with range based algorithm is an area of research yet to be discovered.

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