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Superior Reference Selection Based Positioning System for Wireless Sensor Network

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Abstract— Positioning is emerging as one of the more important tasks in wireless sensor network, as it has been observed` and shown that accurate location information can greatly improve the performance of other WSN tasks such as routing, energy conservation, or maintaining network. The cost and limited energy resources associated with common, low cost sensor nodes prohibits them from carrying relatively expensive and power-hungry location-sensing devices such as GPS. We address these challenges in the context of applications where the accurate location estimation of the sensor nodes is essential. In this paper we have proposed an efficient positioning system for wireless sensor network which locates the position of the node without GPS with the help of other nodes who knows their position in global coordinates. Proposed method minimizes the communication by reducing the communication overhead by using only productive message communication. Main contribution of the work is the perfect selection of the reference nodes who participate in calculation of coordinates. The performance of the proposed scheme is evaluated by simulating it using NS2. Proposed method along with the previous method is simulated. Many experiments were performed with different topologies and random deployment of the nodes. Simulations with our approach have shown significant reductions to the required processing and communication overhead..

Index Terms— Localization, Positioning, Trilateration, BRV, Anchor

1 INTRODUCTION

Wireless technology is rapidly spreading all around the world. Mobility, portability, cheapness and the ease of network installation are the keys to success. A very particular kind of Wireless Network is the Wireless Sensor Network (WSN). WSNs are generally composed of small, and cheap, devices that can communicate with each other, collect and process data. The presence of one or more sensors, often associated with the node itself, characterizes these devices.

The research area of Wireless sensor networks (WSN) is an advancing technology which has opened new research issues. The wireless sensor network comprises of number of sensor nodes which are equipped with a radio transceiver. The wireless sensor nodes are constrained in energy supply, computational memory space, speed and bandwidth. In spite of limitations sensor nodes can reliably and accurately report the surrounding environmental changes.

There are quite a number of possible ways to deploy a WSN into an environment. Basically, nodes can be placed manually or they can be dropped by a human controlled or autonomous vehicle. The former method is suitable for indoor systems or for small fields. However, if the aim is to monitor and control a large environment such as a forest, the latter method is more feasible. When the environment is large and deployment is achieved by means of a vehicle the energy consumption becomes a very crucial factor that directly affects the lifetime of a sensor network because in such cases it is not possible to change batteries once they are used-up. Deployment method is closely related to localization problem that is studied in this work.

A WSN has a variety of applications wherever it is necessary to monitor an environment or the subjects within it. Sensors nodes sense various phenomenons within the environment. The typical purpose of a sensor network is to collect data via sensing interfaces and propagate those data to the sink node, allowing easy monitoring and controlling of an environment.

Examples include territory monitoring, health-care applications, home automation, traffic control, etc. although the problems are quite similar. The type of data collected is dependent on the function of the network i.e. what the WSN has to monitor. For example, a sensor network may be deployed into a forest to predict or detect a fire event. A possible network for this problem would contain nodes with sensors for measuring the CO2 level, the humidity and of course, the temperature.

Although a node is capable of dealing with a variety of jobs, it has many shortcomings as well. All of the nodes currently available in the market are battery-operated, and hence they have a limited life-time. Moreover, the memory capacity of a node is also limited. There is a number of telecommunication problems which needs to be overcome when using wireless, such as understanding, modeling and anticipating the wireless channel. A balance needs to be realized between the quality of service provided and the cost of the devices, these are the determining factors when providing a product. The overall objective is to use a simple wireless sensor network to calculate the position of a mobile node by using minimum resources and communication overhead. The main focus of this paper is

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to propose a system for positioning of the sensor nodes.

Position estimation means to determine location of nodes in a network. With the support of some infrastructure, a node can determine its location in the network by extracting information received from the infrastructure; also, by making a node to send signals periodically, the infrastructure can calculate the location of the node.

There are basically two types of positioning system.

GPS Based Estimation: GPS is a typical localization system. There are 24 satellites [1] positioned at the altitude of 20200 km and distributed in 6 orbital planes [2]. These satellites share the high accurate atomic clocks and they know exactly their coordinates. A GPS receiver can receive signals from at least 4 satellites if the receiver is not hidden from the line of sight. By matching the code pattern in the signal, a receiver can calculate the time shift and know the distance away from that satellite by multiply the time shift to the speed of light. After that, the GPS receiver can figure out its coordinate based on some localization algorithm.

GPS Free Estimation: Wireless sensor nodes are very small having very short energy, that's why they cannot carry GPS devices. In order to do position estimation in a network, generally some beacons, also known as anchor notes should be set up. These anchors know exactly their coordinates. If a node with unknown coordinate can measure by some approaches the distances away from these anchors, the node can calculate its coordinate using trilaterlation [3] algorithm.

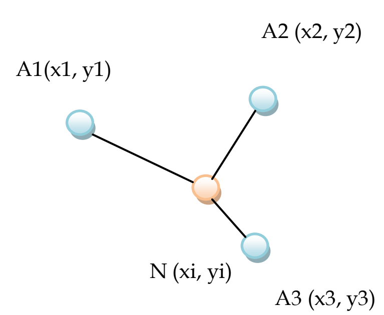

Figure 1: the geometrical meaning of trilaterlation: if N knows the exact distances to A1, A2, and A3, it can calculate it's coordinate.

The rest of the paper is organized as follows. In section 2, a brief introduction to the recent work on positioning algorithm is given. Section 3 gives the proposed algorithm and numerical computation of the coordinates. In Section 4 Simulation setup for the NS-2 and the simulation results are given. Section 5 concludes the paper and possible future enhancement is discussed.

2 Literature Reveiw

The following is a brief outline of the different implementation methods of the different theoretical approaches of positioning. Two large classes of localization systems have been proposed:

2.1 Range based approach

Range based approaches rely on range measurements to compute the position of the unknown nodes. Most existing approaches assume exact (or almost exact) range measurements and are shown to perform very well when this assumption is satisfied. Some range based protocols are discussed bellow.

In [5], the authors use the angle of arrival (AOA) to estimate the angle of received signal. They use a set of directional beacon nodes to transmit the signal to the whole network. When the sensor nodes of a network receive the beacon signals, the sensor node evaluates its location by triangulation. This method requires high cost beacon nodes to do the localization.

In [6], the time difference of arrival (TDOA) technique is used to estimate the difference time of two sensor nodes. The authors measure the time difference between two simultaneously transmitted radio signal and ultrasound signals. Based on the time difference, the distance of two sensor nodes can be calculated by multiplying the time difference and the speed of sound. The TDOA technique does not depend on the synchronization of the transmitting time of two sensor nodes. Like TOA technique, TDOA relies on additional hardware that is high cost and energy consuming.

The GPS [7] uses the time of arrival (TOA) to measure the difference in the time of arrival of signals from several satellites and use the triangulation to infer the position. However, using GPS to locate sensor nodes may not feasible due to cost, energy prohibition, and indoor constraints.

In [9] author shows how AOA capability of the nodes can be used to derive position information. A method proposed for all nodes to determine their orientation and position in an adhoc network where only a fraction of the nodes have positioning capabilities, under the assumption that each node has the AOA capability. Two algorithms were proposed DV-Bearing and DV-Radial, each providing different signaling accuracy coverage capabilities tradeoffs. The advantages of the method are that it provides absolute coordinates and absolute orientation, that it works well for disconnected networks, and doesn't require any additional infrastructure.

In [12] Cramer-Rao bound (CRB) used to compare the minimal attainable variances of unbiased sensor location estimators for the cases of RSS and proximity measurements. For completeness, author also present the CRB for sensor localization with systems using K-level quantized RSS (QRSS) measurements, of which proximity measurements are the special case: $K = 2$.

The RADAR system [13] uses RSSI technique to estimate the distance to some known landmarks (anchor nodes). It first records the received signal strengths with respect to the landmarks at various locations. It then computes the location of the sensor node by finding the best fit data of the received signal strengths. Since the radio signal strength is unstable and varied under different environments, it is difficult to measure the distance.

2.2 Range free approach

Range free (or proximity based) approaches infer constraints on the proximity to anchor nodes. These approaches, although attractively simple (they do not require any additional hardware and most require only simple operations), have inherently limited precision.

In Centroid scheme [11], each sensor node locates itself to the centroid of the anchor nodes that the sensor node can directly communicate with. In this paper, author proposed localization techniques and evaluate the effectiveness of a very simple connectivity-metric method for localization in outdoor environments that makes use of the inherent radio-frequency (RF) communications capabilities of sensor nodes. A fixed number of reference points in the network with overlapping regions of coverage transmit periodic beacon signals. Nodes use a simple connectivity metric that is more robust to environmental vagaries, to infer proximity to a given subset of these reference points. Nodes localize themselves to the centroid of their proximate reference points. This scheme is easy to be implemented.

The APIT scheme [14] uses anchor nodes to divide a sensing area into triangular regions. A sensor node locates itself according to whether it is inside or outside these triangular regions. Both Centroid and APIT schemes need anchor nodes equipped with powerful radios and a high density of anchor nodes deployment in a WSN to achieve better accuracy of locations.

In [8],author inquired about the RSSI solutions on indoor localization, and proposed a Closer Tracking Algorithm (CTA) to locate a mobile user inthe house. The proposed CTA was implemented by using ZigBee CC2431 modules. The experimental results show that the proposed CTA can accurately determine the position with error distance less than 1 meter.

The GRIPHON scheme [10] also uses hop-count to estimate the distance to the anchor nodes. The GRIPHON scheme is similar to the RADAR system. In the GRIPHON scheme, each sensor node estimates the shortest-hop to the anchor nodes rather than signal strengths. The Probability Grid scheme, in addition to the hop-count information, also exploits the deployment information, such as the grid distance and grid size, to estimate the location of the sensor node accurately. The Amorphous scheme can calculate more accurate hop-distance by assuming that the sensor nodes know the sensor node density of a WSN.

3 Proposed System

The algorithm assumes a network of nodes where a small percentage of the nodes are aware of their positions either through manual configuration or using GPS. We define these nodes as anchor nodes. The rest of the nodes are not aware of their locations and they are defined as unknown. An unknown node can estimate its position by the processes described below. All unknown nodes depend on anchor for their position estimation and sends request for positioning. Anchor nodes respond with required information. Then unknown node calculates its position in global coordinates. Once a node estimates its position it can become an anchor and broadcast its location information to the rest of the nodes, thus enabling more and more nodes to calculate their locations. The localization process is complete when all the unknown nodes that meet a certain set of criteria can compute their locations.

Many proposed system uses the information from all the reference nodes to update their location which involve high traffic overhead, heavy computation and energy consumption. In the proposed system we have used only subset of the reference nodes which can contribute on accurate positioning. In The accuracy of the algorithm depends upon the selection of the reference nodes. Some localization system utilizes the nearest three reference nodes [15] to calculate the position.

Previous method discussed above gives inaccurate result if nearest reference nodes having big location error. To overcome these deficiencies we have used best three references to update the location of the node. We have assumed that the nodes are stationary. Each node has an attribute which shows whether it is anchor node or not. Each node also has another additional attribute which shows the accuracy of the node L_{acc}.

Our method works on four steps.

A. Location Request
B. Location Response
C. Reference selection
D. Location calculation

Step1. Initially anchor nodes provided accuracy level L_{acc}=1, and all other nodes are assigned value 0. In first face a nodes broadcast the location request message. Which consist of its node_id, and its probability of accuracy L_{acc} .

Step2. On receiving the location request from the known node each node will not respond if its accuracy level is higher than the required accuracy level L_{acc}.

ie.

$$L_{acc[res]} > L_{acc[req]}$$

Only nodes with higher accuracy responds to location request hence total communication overhead reduced in this method.

The location response message includes accuracy level, location and node_id of the sender.

$$Loc\_res = (L_{acc}, z, id)$$

Step3. In the third step, on receiving location response from all reference nodes, Node selects the subset of the reference which can give highest accuracy level. This step is the most important face because we perform calculation on the most accurate responses only, hence the computation time and cost reduced. If total incoming response is set R, and we select a subset S than

$$S \subset R$$

Only such nodes should be selected which can give better location estimation. Location accuracy depends upon two parameters.

- Accuracy of the references
- Distance of the reference

A node should be selected for calculation which has minimum distance and maximum accuracy.

Best Reference Value (BRV): We have assigned a metric called "Best Reference Value (BRV)" to all incoming reference .Which is the measure of the suitability of the node to be chosen as a reference. A node with low BRV is better than the node with high BRV. The value of BRV can be calculated by using the accuracy level of the reference L_{acc} and distance of the reference.

Calculating Distance: On receiving the responses from the different reference node calculate the distance suing RSSI method. For calculating the distance from the reference we use RSSI method.

Received Signal Strength Indicator (RSSI): RSSI measures the power of the signal at the receiver and based on the known transmit power, the effective propagation loss can be calculated. Next by using theoretical and empirical models we can translate this loss into a distance estimate. This method has been used mainly for RF signals. Any sensor technology meeting the homogeneity and socialistic information goals of Section 3 and providing distance estimates between two arbitrarily placed nodes may be suitable for our ad-hoc location sensing research. Given our target scenario, we believe applying received radio signal strength information to the problem is reasonable.
The idea behind RSS is that the configured transmission power at the transmitting device (**P_T**) directly affects the receiving power at the receiving device (**P_R**). According to Friis' free space transmission equation, the detected signal strength decreases quadratically (n is usually two) with the distance to the sender.

$$P_R = P_T \cdot G_T \cdot G_R \cdot \left(\frac{\lambda}{4\pi}\right)^2 \cdot \left(\frac{1}{d}\right)^n$$

P_T and **P_R** are the power of the transmitter and receiver, **G_T** and **G_R** are the gains of the transmitter and receiver antennas respectively. **λ** is the wavelength and **d** the distance between transmitter and receiver. The received power increases with the square of the wavelength (or decrease with the square of the frequency). The free space equation is valid only for values of d that are relatively far from the transmitting antenna. For values of d_0 within the so called close-in distance, the path loss can be assumed to be constant. d_0**.** In practical scenarios, the ideal distribution of P_R is not applicable, because the propagation of the radio signal is interfered with a lot of influencing effects e.g.

- Reflections of metallic objects;
- Superposition of electro-magnetic fields;
- Diffraction at edges;
- Refraction by media with different propagation velocity.

BRV Calculation: After calculating distance the BRV for the reference is calculated by using following formula.

$$\mathbf{BRV_i = D_i * (1 - L_{acc})}$$

Calculated BRV values are stored in an array in ascending order of BRV. And then the three references with minimum BRV are selected for applying trilaterlation the three references which have minimum value of BRV.
We also calculate the accuracy level of the node by following formula-

$$\mathbf{L_{acc(node)}} = 1 - \frac{1}{\sum_{i=0}^{i<j} \mathbf{Lacc(ref[i])}}$$

Where j is cardinality of the subset, *i*.e. j=3;

Step4. Final face is to estimate the position of the node in global coordinate using trigonometric formulas. We use a maximum-likelihood (ML) estimation to estimate the position of a target by minimizing the differences between the measured and estimated distances. ML estimation of a target's position can be obtained using the mini-mum mean square error (MMSE) [16], which can resolve the position from data that includes errors. We explain the calculation for a two-dimensional case as follows. MMSE needs three or more sensor nodes to resolve a target's position. First, the sink node searches for the same data in terms of a target ID and a packet number by collecting data from sensor nodes. The difference between measured and estimated distances is defined by:

$$f_i(x_0, y_0) = d_i - \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}, \quad (1)$$

Where x_0, y_0 is the unknown position of the target node, x_i, y_i for i= 1,2,3 is the sensor node position, and N=3 is the total number of data that the node has selected, and d_i is the distance between sensor node i and the target. The target's position (x_0,y_0) can be obtained by MMSE. By setting f=0 , Eq. (1) is transformed into

$$-x_i^2 - y_i^2 + d_i^2 = (x_0^2 + y_0^2) + x_0(-2x_i) + y_0(-2y_i). \quad (2)$$

After getting Eq. (2), we can eliminate the $x_0^2 + y_0^2$ terms by subtracting k_{th} equation from the rest, as follows.

$$-x_i^2 - y_i^2 + d_i^2 - (-x_k^2 - y_k^2 + d_k^2) = 2x_0(x_k - x_i) + 2y_0(y_k - y_i) \quad (3)$$

Then Eq. (3) is transformed into Eq. (4), which can be solved using the matrix solution given by Eq. (5). Position (x_0,y_0) can be obtained by calculating Eq.(5).

$$y = Xb \quad (4)$$

$$b = (X^T X)^{-1} X^T y, \quad (5)$$

Where

$$X = \begin{bmatrix} 2(x_k - x_1) & 2(y_k - y_1) \\ \vdots & \vdots \\ 2(x_k - x_{k-1}) & 2(y_k - x_{y-1}) \end{bmatrix} \quad (6)$$

$$y = \begin{bmatrix} -x_1^2 - y_1^2 + d_1^2 - (-x_k^2 - y_k^2 + d_k^2) \\ \vdots \\ -x_{k-1}^2 - y_{k-1}^2 + d_{k-1}^2 - (-x_k^2 - y_k^2 + d_k^2) \end{bmatrix} \quad (7)$$

$$b = \begin{bmatrix} x_0 \\ y_0 \end{bmatrix} \quad (8)$$

4 Simulation Setup And Result

We have used NS2 to simulate the proposed system. NS-2 is extended to support positioning in [17]. The *NS-2* simulator is a discrete event simulator widely used in the networking research community. We have implemented our algorithm along with the recently proposed algorithms, nearest reference algorithm [16].

2.1 Simulation Setup

To satisfy the applicability of proposed algorithm in large scale WSNs we have performed experiment in different setups. The Unknown nodes and anchor nodes are distributed across the field. All nodes have limited transmission range of 50 m. We have performed simulation on different density of anchor nodes. Figure 2 shows the deployment of anchors and anchors in NS2. At each experiment the simulation were run 100 times; the duration of each run was600 second. We have performed experiment in 10 different densities of anchors.

2.2 Results

Figure 2 shows the graph between average error and node density. From figure 2 it is clear that our algorithm perform with better accuracy than the other in low anchor density. Result shows that our algorithm performs localization with better accuracy level and power consumption reduced in our method.

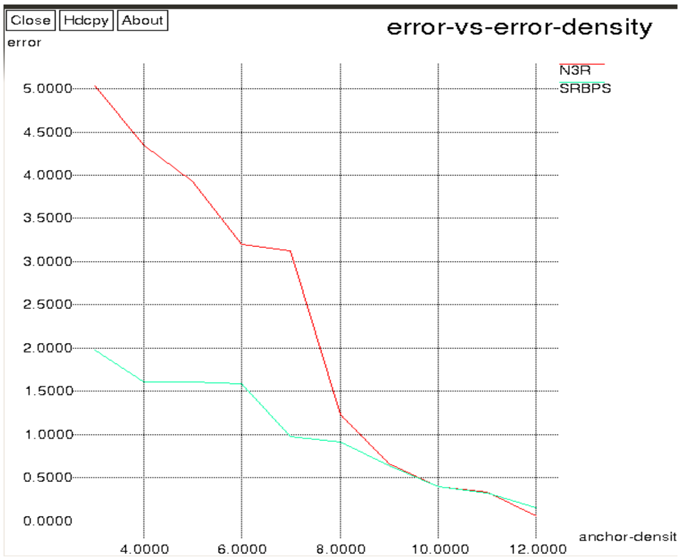

Figure 2: Average error vs Node density

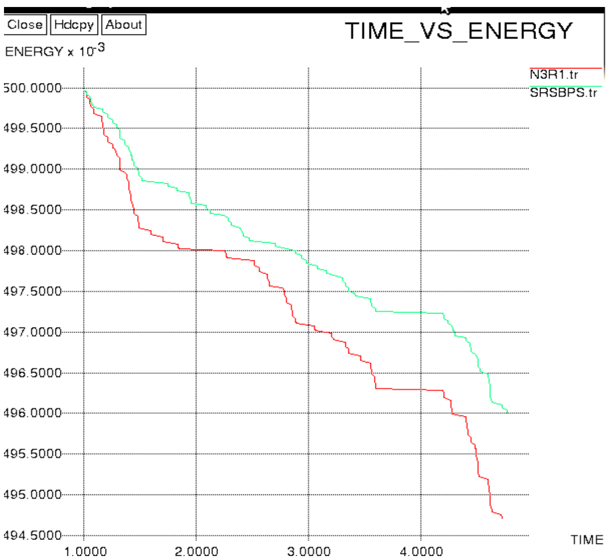

Figure 3: Time vs Energy

Energy consummation is the most critical issue in wireless sensor networks. In figure 3 the graph between the Time and Energy is given.

5 Conclusion

We have implemented a localization system that uses RSSI for the Wireless sensor network. The aim of this study was to create a practical, robust and accurate localization algorithm by selecting superior reference to Wireless Sensor Network localization. In the proposed system various efforts to minimize the computation and communication overhead have done. And also the accuracy of the location was improved.
Only most accurate nodes are selected for the computation of the coordinates. Hence the accuracy of the positioning improved the nodes with errors are excluded which restricts the location error from to be propagated throughout the network. Reference node responds only if its accuracy is better than the accuracy of the requesting node. Hence overall communication overhead reduced by filtering the ineffective responses.

However, the project is open to further development that may increase the accuracy of the localization estimate and the quality of service provided by the system. Furthermore, our algorithms assume sensors are static in most time, future researches should also focus on localizing sensors with mobility.

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