POSITIONING IN BLUETOOTH NETWORKS USING LATERATION APPROACH-A COMPARATIVE STUDY

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ABSTRACT::This paper presents a comparative study of indoor positioning algorithms using Received Signal Strength Indicator RSSI in Bluetooth networks. The main focus of this article is to select a simple and efficient algorithm which provides good accuracy with low computational cost in indoor environment. Experimental analysis of Trilateration, Min-Max and Least Square based positioning algorithms is carried out in two different sets of indoor environment, using three and four fixed anchors nodes. For each environment, ten and four random positions are selected in order to track the position of target node. Root Mean Square Error (RMSE) for each target position is calculated using three and four anchor nodes. Based on the numerical results obtained from two different sets of environments using Bluetooth network, Min-Max provides better accuracy and low computational cost compared to Trilateration and Least Square.

1. INTRODUCTION

Bluetooth is a short range wireless communication protocol developed for low cost, low energy consumption. Bluetooth enables electrical devices to wirelessly communicate in the 2.45 GHz ISM (license free) frequency band [1]. Originally Bluetooth networks are designed for short range wireless communication, however due to it's easily availability and low cost, this technology can be worth for use in positioning [2]. Global Positioning System (GPS) is a US based military navigation system specially designed to support soldiers and armed forces automobiles etc [3]. GPS is standard developed for navigation and outdoor environment. GPS signals are not available in indoor environment because, it does not penetrate in the hard surface and inside buildings and hence, it is not suitable for indoor applications [4]. Researchers are working to provide an alternative technology for indoor applications. The main focus paper is to develop a low cost and highly accurate positioning system.

In Bluetooth specification, there is no standard profile yet available for indoor positioning system however, the specification provides built in support for RSSI, which can be used to estimate the object position [5]. This parameter does not require any expensive hardware setup in order to track the position of target node [6, 7, 8]. This paper presents a comparative study of the well-known lateration based localization techniques. The main objective of this paper is to select the best lateration approach which estimates the object position in indoor environments with low cost and easily available Bluetooth hand held devices. The numerical comparisons in terms of accuracy and complexity obtained by implementing Trilateration, Min-Max, and Least Square algorithms will provide a basis for real time solution of object tracking in indoor environment both for short range or large scale industrial application [9].The remainder of this paper is structured as follow. Section 2 discusses existing indoor positioning algorithms, Section 3 presents experimental setup and data collection, Section 4 presents numerical results of RSSI based lateration algorithms and finally conclusion and future research direction are presented in Section 5.

2. Positioning algorithms

Position estimation techniques can be categorized based on the sensing technologies they are using i.e position estimation algorithms, and performance parameters [10, 11]. These classifications provide guidelines for evaluation of positioning systems. These sensing technologies are Infrared, ultrasonic waves and radio frequency. This paper considers radio frequency, as a sensing technology for position estimation, which is based on lateration based position estimation technique. Lateration based position estimation technique requires RSSI. This RSSI, received from the anchor node is converted to distance estimates using radio propagation model. The second parameter is the measurement method based on radio standard for tracking the object position [12]. In [20] the author further classified measurement techniques in to two main categories, i.e. geometric or trigonometric based and the statistical methods such as Kalman filter or Extended Kalman filter based position estimation. In this paper, the main focus is on lateration based indoor positioning algorithms, for example Trilateration, Min-Max, and Least Square based solution for position estimation [13, 14]. Following subsections describe each technique in a more detail.

2.1 Trilateration and Multi-lateration

Trilateration and Multi-lateration are both trigonometric based position estimation algorithms. Trilateration algorithm computes object position from at least three anchor nodes, the location of each anchor node is already fixed. For Multi-lateration more than three anchor nodes are required to locate an object [15]. Both algorithms require distances from the target node to the anchor nodes [16]. The distance d is obtained from RSSI received at the anchor nodes. The standard radio propagation model is used to convert RSSI readings into distances for locating their position. The mathematical equations of Trilateration and Multi-lateration are given as under [5]. Figure 1, explains the concept of Trilateration and Multi-lateration.

Let $A(X_1, Y_1), B(X_2, Y_2), C(X_3, Y_3)$, and $D(X_4, Y_4)$ are the anchor nodes, and $T(x, y)$ be the target node then distance between anchor nodes and target nodes can be obtained using the following equation [15].

$$R_i = \sqrt{(x - X_i)^2 + (y - Y_i)^2} \quad , for\ i = 1,2,3 \ldots \ldots n - 1. \qquad (1)$$

The solution set of equation (1) using Minimum Mean Square Error (MMSE) become

$$A\vec{x} = \vec{b} \qquad (2)$$

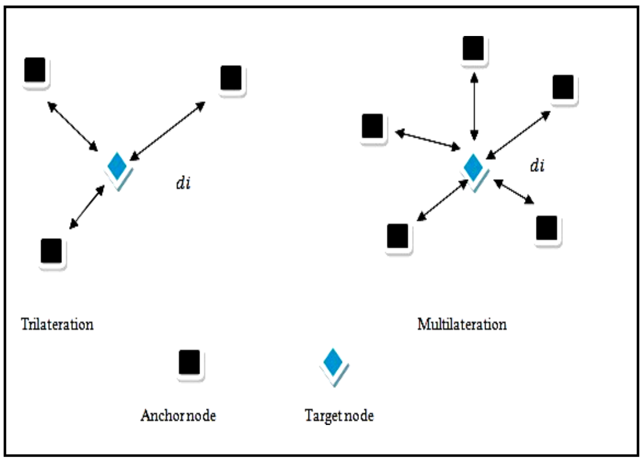

Figure 1 Trilateration and Multilateration

2.2 Min-Max Algorithm

Min-Max is a very simple lateration based position estimation technique, which construct bounding boxes for each anchor node based on the given distance. Three boxes are constructed, and based on these boxes, the point of intersection from the anchor nodes is the estimated position. Radio propagation model is used to convert signal estimates to distance. The bounding box is generated for each anchor node by adding and subtracting the estimated distance d from the anchor fixed nodes. The mathematical formulation of the Min-Max algorithm is as follows,

$$\left(max_{(x_i - d_i)}, \quad max_{(y_i - d_i)}\right) * \left(min_{(x_i + d_i)}, \quad min_{(y_i + d_i)}\right) \qquad (3)$$

where (xi, yi) represents the position of the anchor device while di is the distance between anchor and target device [17].

2.3 Least square Algorithm

Least square is a mathematical technique which is used to estimate the position of a target node by estimating the distance from the anchor nodes. In two dimensional tracking systems, three distances are required to compute the object position [18]. If there are three anchor nodes then least square estimation gives good result, in case more than three anchors nodes for tracking a target node, then the linear system generated using least square becomes over determine. In [18] the authors formulate the mathematical equations of least square estimation.

3. EXPERIMENTAL SETUP AND DATA COLLECTION

This section discusses the experimental setup for collecting RSSI samples for Lateration algorithms. Two different experiments were being conducted in order to test the algorithms in different environmental conditions and also to check impact of environmental effects on accuracy. Figure 2 and Figure 3 depict the experimental setup. The location of the testbed lies in second floor of department of Computer and Information Sciences, wireless communication lab. The dimensions of both the labs were same but the anchors setting and physical environment of both the labs were different. The dimension of lab is (14.20 * 16), having area 227.2 meter square. Out of this area (10 *10) area was selected for the first experiment and (12 *14) meter square for the second experiment. Four anchor nodes were used for data collection. The lab consisted of desktop workstations for students and the experiments were conducted in the presence of these workstations. At each 1 meter square grid 100 samples were collected. The data collector program running on fedora 10 under SSH was simultaneously run for data collection.

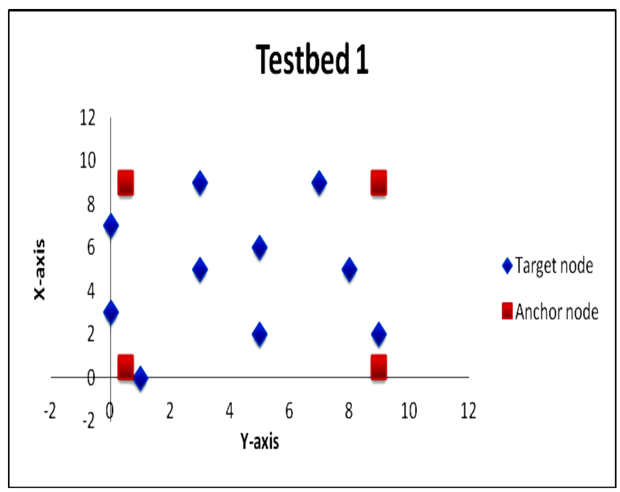

Figure 2: Testbed 1 with ten target nodes and four anchor nodes

At each grid of 1 meter square, the mobile device was placed in the middle of the grid and 100 readings of RSSI were collected. The data collector program was programmed for collecting of RSSI readings using Inquiry mode. The same setting was used for both tests. The RSSI samples collected by the data collector program were stored in the excel sheet. The average value for each grid was being calculated for using in the comparative study. Figure 2 and Figure 3 represent the experimental scenario of test bed 1 and 2 respectively. In test bed 1, the numbers of target nodes were ten while in test bed two four target nodes were taken. The results obtained from Trilateration, Min-Max, and Least square algorithm are presented in the next section.

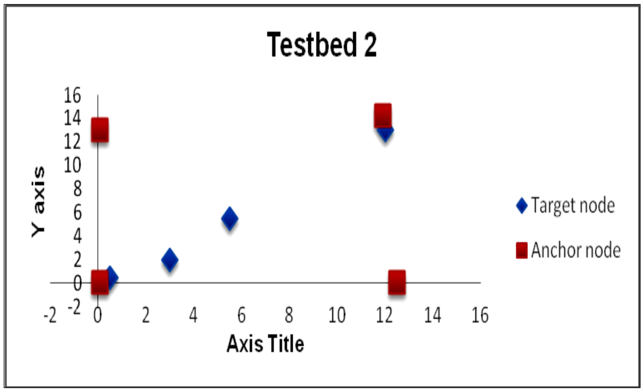

Figure 3: Testbed 2 with four target and four anchor nodes

4. RESULTS AND DISCUSSIONS

This section discusses the numerical results generated from lateration algorithms. Lateration algorithms require distance estimation between anchor nodes and target node. To convert RSSI samples to distance estimates, standard radio propagation model was used. This paper carries forward the idea of Goldoni [17], for modeling the channel characterization to establish a mathematical relationship between RSSI and distance using radio propagation model. The relation between RSSI and distance based on Friis' equation is

$$RSSI(anchor, target) = -(10.n.\log_{10} d - A) \quad (7)$$

Where, n is the radio propagation constant, d is the distance between anchor and target node, and A is the distance taken at 1 meter between two devices. Normally both parameters can be fixed in advance [17, 19].

4.1 Bluetooth Channel Modeling

Bluetooth channel modeling is used to characterize the environmental variables A, and n empirically. The main idea behind characterization of environmental variables is to identify the best suitable parameter for distance estimation. However the theoretical values for both parameters exist which is from 1 to 4 for the value of n, while the parameter A is calculated at 1 meter distance between anchor node and target node. However this is applicable under ideal condition in free space. Both parameters are strongly dependent on the environmental characterization. For environmental characterization, 10 RSSI samples were collected between two nodes. The distances between both devices were increased from 1 meter to 10 meters. The grid size was fixed to 1 meter square. After collecting the RSSI samples, the average, mean, and standard deviation were calculated. After calculating all the required parameters, logarithmic interpolation was performed using poly-fit function which generates the specific propagation constant A, and n[17].

4.2 Numerical Results

A comparative analysis of well known lateration based localization techniques are compared in two separate test beds. The accuracy, complexity, and performance metrics are compared. Based on the experimental observations, Min-Max performs better than Trilateration and Least square algorithms in terms of accuracy and performance CPU execution time, as well as the complexity of Min-Max algorithm compared to Least square and Trilateration techniques is also better [17].

4.2.1 Accuracy

The accuracy of all the algorithms is measured in terms of RMSE, which is mean square error between actual and calculated coordinate. Figure 1 and figure 2 show the RMSE for ten target nodes calculated using Trilateration, Min-Max, and Least square estimation algorithms. The number of anchor nodes in each algorithm is varied from three to four. For each target node the respective RSSI samples are calculated 100 times and the average value are selected for target estimation. Figure 4 clearly indicates that the RMSE for Min-Max algorithm is better than Trilateration and Least Square. The accuracy of Min-Max increases when the anchor nodes become four, the same is for Trilateration and Least square. The RMSE for Trilateration and Least square for three anchor nodes are same, because the estimation techniques used in Trilateration and Least square method are the same, while for four anchor nodes the RMSE for Trilateration is better than Least square method due to the over determined scenario appearing in Least square solution when the number of nodes exceeds from three to four. The accuracy of lateration techniques is also greatly dependent on the environmental parameters. In this article the Bluetooth channel models empirically estimate the propagation parameters based on the samples taken at the test bed. The idea of using channel modeling is taken from [17], which improves the accuracy instead of manually selecting the propagation constant. The computed values of A and n computed in both test beds are approximately same.

The numerical values for

$$A = -56.000, while\ for\ n = 2.000$$

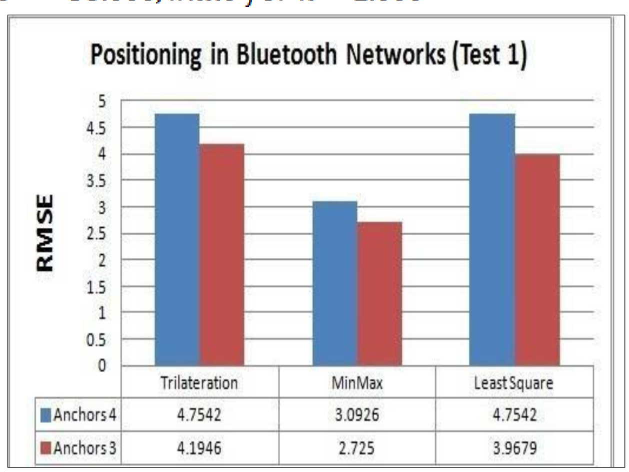

Figure 4: RMSE error for test bed 1 using three and four anchor nodes

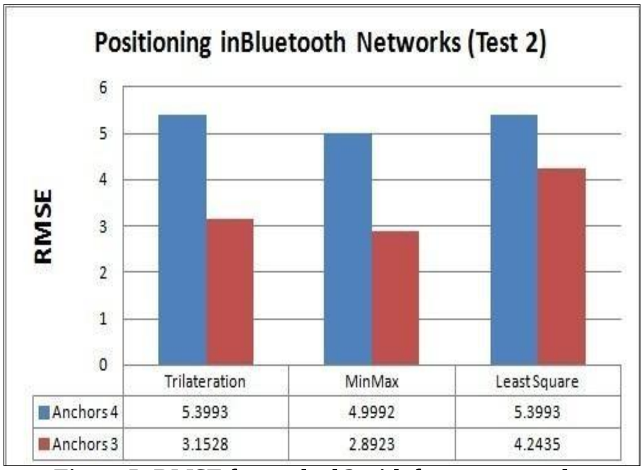

Figure 5: RMSE for testbed 2 with four target nodes

Figure 5 represents the RMSE calculated from test bed 2. The difference between test bed 1 and test bed 2 are physical settings of furniture, desktop computers and human influence, which are relatively more than test bed 1. Other than this the target nodes for test beds are only four. The numerical results calculated for test beds are almost same; however, the RMSE is quite different due to the location of target node and other environmental changes. The same results are obtained for Trilateration and Least square for three anchor nodes while it is different for four anchor nodes. The RMSE for Min-Max algorithm calculated is comparatively better for three and four anchor nodes.

4.2.2 Computational complexity

The computational complexity Trilateration, Min-Max and Least square are obtained manually by counting the number of operations performed through loops, square roots, square operations, and addition subtractions. The complexities of all these algorithms are same due to the number of operations performed, however the complexity of the algorithm increases with the number of anchor nodes but on the other hand the required parameter accuracy also increases with the increase in anchor nodes.

Computational complexity increases with the number of inner loops required or call back functions required to perform the required operations. Overall the complexity of all these algorithms is O (n), which is considered as optimal.

4.2.3 Performance based on CPU execution time

The performance of each algorithm is measured using Matlab *tic/toc* function, which is used to measure the CPU execution time based on the iteration performed. Each algorithm is separately iterated hundred times using for loop and the time of execution is being calculated. Figure 6 represents the execution time for each algorithm using three and four anchor nodes.

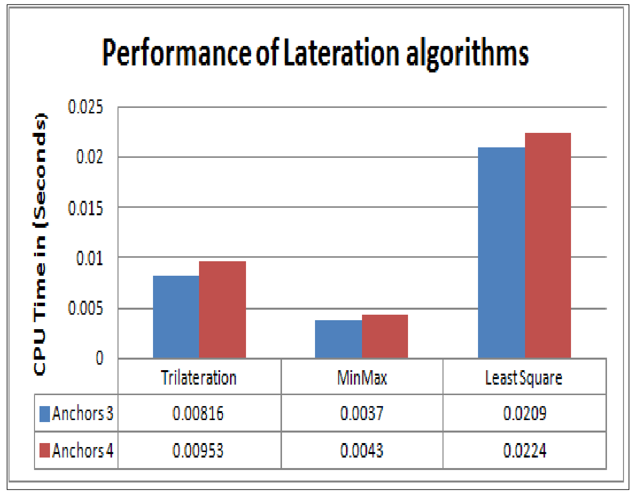

Figure 6: Performance of lateration algorithms based on CPU execution time

Similarly the execution time of algorithm also depends on the number of operations performed. Other than this the execution time calculated is based on processor speed; however, the relative performance can be measured. According to calculated time for each algorithm, Min-Max performance is better than Trilateration and Least square algorithm both for three and four anchor nodes. This comparison proves that Min-Max algorithm execution time is compared to standard Trilateration and least square algorithms, which proves the significance of Min-Max.

5. CONCLUSION AND FUTURE WORK.

This article presents a comparative study of Trilateration, Min-Max and least square based position estimation algorithms. The detailed experiments were performed in two different scenarios for three and four anchor nodes. Based on the numerical results obtained based on accuracy, complexity and performance it is clear that Min-Max is comparatively better than other lateration based algorithms. The algorithm performs when the number of anchor nodes exceeds from three to four. In this article the data from two test beds is presented with limiting the anchor nodes to four. The outcome of this study verifies the results of previous studies [17], in terms of accuracy and performance metrics; however, due to the difference in domain the results obtained are significantly dependent on the environmental conditions where the algorithms are tested. The accuracy of lateration algorithms is greatly dependent on the propagation constant, A and n, while the idea of channel modeling is worth for noise environment where the manual selection of propagation parameters is difficult to fix.

The problems that occurred during the collection of RSSI samples in both test beds are the nature of RSSI readings which suffer from the environmental conditions, the signals become week and in some points within in the communication ranges of Bluetooth nodes the communication blockage occur. The anchor nodes do not receive the signal transmitted by the target node due to the environmental changes which occur continuously. Therefore designing mathematical model to handle the variations in RSSI due to the environmental changes is needed to further improve the accuracy in real time scenario. The accuracy can be improved further.

Our future work is to design a mathematical model to handle the variations occurring in RSSI due to environmental changes, other than this, integration of Lateration techniques with fingerprinting approach may contribute more in terms of accuracy and performance for real time applications.

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