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An Alternative Indoor Localization Technique Based on Fingerprint in Wireless Sensor Networks

Yetkin TATAR[1], Güngör YILDIRIM[2]

Assoc. Professor, Department of Computer Eng., Firat University, Elazig, Turkey[1]

Electrical and Electronic Engineer, DSI IX. Regional Directorate, Elazig, Turkey[2]

ABSTRACT: **Although several methods based on the RSSI measurement exist for localizing a mobile node in the WSN, a method which can produce precise results is still unavailable. In this study we present an alternative technique based on fingerprint which uses a minimum number of anchor nodes for the detection of the location of a mobile node. In this technique an indoor area is thought as a matrix consisting of rows and columns, and the location of the mobile node is expressed as a cell in this matrix. In the first phase the expanded RSSI map of the indoor area is constructed off-line. In the preceding phase on-line RSSI values and the expanded RSSI map are intersected to find possible cells. Then these cells are compared to the logical sub regions and the location of the mobile node is found. The proposed technique is tested in both simulation and in an experimental setup. The results are compared to the results of nearest neighbour method.**

Keywords: WSN, RSSI, Fingerprint, Localization, Indoor Area

I. INTRODUCTION

Today, in wireless communication technology, the importance of Wireless Sensor Networks (WSNs) has increased. Although measurement of physical quantities is base objective for WSNs, localization in WSNs is another important issue which has also been studied on. As known, positioning systems based on GPS technology are quite efficient in open areas, but it is not useful for indoor environments. In indoor places, the use of reference node (anchor), at which its coordinate is known is the most preferred method. Position detection is carried out according to the anchor nodes. In general, there are three localization techniques in indoor areas. These are: direction-based, distance-based and fingerprint-based localization [7].

Direction-based and distance-based techniques are made of two phases. The first one is based on the estimation of the distance between the anchor and the target nodes (or the incidence angle). The second one is the process of the localization phase by relating these distances [1].

The fingerprint-based technique consists of two phases as well. One of them is that the area of interest is divided into cells and the RSSI values obtained from the anchor nodes are recorded into a database for each cell. This phase is known as "Calibration Phase" or sometimes called as "Radio Map Phase" as well. The second phase is that the location of the target node (TN) is inferred from the comparison of the RSSI values in the database and the real-time RSSI values [4, 8].

In direction-based techniques, Angle of Arrival (AoA) method is used for determining the incidence angle. On the other hand, distance-based techniques deploy different methods such as "Time of Arrival (TOA)", Time Difference of Arrival (TDOA)" and "Received Signal Strength Indicator (RSSI)" [1, 3, 7]. RSSI data is often used in both the phases of fingerprint technique.

There are several general methods such as Hyperbolic Trilateration, Triangulation, Maximum Likelihood (ML) Estimation used in the localization phase in both direction-based and distance-based techniques [1,3]. On the other side, in the determination phase of on-line location of the fingerprint-based techniques, deterministic and probabilistic methods are used for the determination of the location by using RSSI value with Database relationship [4,7].

In the fingerprint technique, the preparation of radio map and the position detection generally depend on RSSI. One of the main reasons of this is that nowadays numerous node technologies have a standard function of RSSI measurement. Besides, depending on the distance between receiver and anchor, RSSI is not stabile because of some the factors, such as attenuation, antenna gain, position of node, and so on. This instability is an important problem especially for the distance estimation. In that case, several of disturbing parameters must be considered [2].

In this paper, a new RSSI-based fingerprint technique has been proposed. The technique uses logical inferences. In the study firstly, the closed area was divided into the cells of 1 x 1 mt. Next, the RSSI characteristics of each cell were recorded into a database in order to prepare a radio map. At real time, the RSSIs of anchor nodes received from TN were compared with

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radio map according to logical algorithms. Afterwards, the target localization was carried out mathematically.

As known, the more anchor nodes means the more accurate the position estimation. As the size of the closed environments grows, number of anchor nodes should be increased for a good locating. Of course, this will lead to an increase in the cost. The most important advantage of the proposed technique is that it employs minimum anchor nodes within closed areas having significant size. In this study, the experiments were carried out in a laboratory environment which has an area of 66 m2. In addition to this, MEMSIC TelosB was used as the sensor node and the application program was written in JAVA. Afterwards, the results were compared with those obtained from the K-nearest neighbour, well-known method used in deterministic technique.

This paper continues as follows: a review of the related works, fingerprinting, the explanation of the proposed technique, the experiments, interpretation of results and the future work.

II. RELATED WORKS

Although localization based-fingerprint is one of the important localization techniques, there are serious problems to overcome in this subject. One of the biggest problems is that the construction of radio map may not be made correctly because of the instable RSSI values. Even if many approaches to this problem exist, new algorithms based on both deterministic and probabilistic or logical are required.

In the study done by Chiang et al. [R4], truncation effect on RSSI is examined and a new method, called as Multivariate Truncated Gaussian Inference (MTGI), is proposed. The authors state that the proposed method reduces packet loss which stem from attenuation or collision, and gives better result than MGI method.

A wireless LAN localization method that enhances database construction based on weighting factor is suggested by Hur et al. [5]. At the same time, the results obtained from anechoic chamber tests have been analysed, and it examines the causes of the distortions.

Another study proposes a new locating algorithm that combines the calibration procedure with the fingerprint prediction model [8]. The paper expresses that the algorithm requires less RSSI values to construct the database. Therefore, construction time of the database has decreased significantly.

Pei et al. presents a new solution using the Weibull function for approximating the Bluetooth signal strength distribution in the data training phase [13]. Construction of the radio map and the estimation of the parameters of Weibull distribution can be carried out by less RSSI samples in the solution.

Malekpour et al. examine some factors on the RSSI behaviour and, propose improvement to the existing deterministic algorithm by considering these factors [R24]. In addition to this, a combinational method for detection of and dealing with the aliasing problem is also suggested. The method is stated to be 33% more successful than the other deterministic methods.

The paper presented by Dawes and Chint compares a range of received signal strength indication fingerprinting methods, utilized both probabilistic and deterministic paradigms, on a common WLAN test-bed. As result, some improvements are presented [R23d]. For example, with the proposed mode filtering technique, the error distance of the Bayesian algorithm is reduced.

In [6], new fingerprint techniques are presented for indoor location estimation. The first technique uses a statistical representation of the RSSIs by a multivariate Gaussian model. The system compares the data at the unknown position with the data of each cell by using the Kullback–Leibler Divergence (KLD) between their corresponding probability densities. The second approach uses compressive sensing (CS) reducing significantly the amount of information transmitted.

This study dwells on a different fingerprint-based technique which compares the RSSIs online-measured logically with the RSSIs in the database. The results obtained from the experimental setup have been compared and discussed to the results achieved by NN algorithm.

III. FINGERPRINTING

In fingerprint technique, firstly, the indoor area is divided into cells in which the coordinates are known. Next, for each cell, the RSSI values of all anchors are recorded into a database. The radio map is created in this phase. The mathematical form of the radio map can be denoted in Eq(1);

$$RMk = (Ck, Skr, \varepsilon) \quad k = 1,2,3,\ldots\ldots N \qquad (1)$$

This notation is the general form of the radio map of kth cell, where Ck is the cell of interest, Skr is a vector holding the RSSI values of the anchors and ε is an optional parameter containing the other information such as direction.

The second phase is the position estimation according to radio map. In the phase, the methods used for localization are generally based on deterministic, probabilistic or soft computing methods. The proposed method has implemented the two phases. The implementations are given as follows.

A. *RSSI Measurements and Radio Map*

In this study, the test area has been divided into 66 cells having the size of 1x1 m as shown in Figure 1 and it was assumed that there are no any transient RSSI distorting signals in the test area.

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The anchor nodes (A1, A2, A3, and A4) located in the each corners of the area and the mobile (M) node are the WS nodes of Memsic TelosB model. The information sent by M was collected by a basestation node. In addition to this, the information was analysed by the help of a computer having TinyOs 2.1.0 and a Java program.

For more accurate estimation, five RSSI samples are recorded at each cell and for each anchor, that is, 1440 RSSI values were used for calibration. The environment temperature was measured as 23 ^{0}C.

The vectorial notation of a cell has a form of;

$$C_{ij,z} = \{A_{1z}, A_{2z}, A_{3z}, A_{4z}\} \qquad (2.a)$$

$$\begin{aligned} C_{e2,3} &= \{59, 60, 68, 65\} \\ C_{e2,3} &= \{72, 45, 65, 75\} \\ C_{e2,3} &= \{59, 43, 74, 83\} \\ C_{e2,3} &= \{52, 47, 72, 69\} \\ C_{e2,3} &= \{62, 48, 68, 57\} \end{aligned} \qquad (2.b)$$

Where "i", "j" and "z" denote column, row and sample number, respectively. "p(x,y)" is the centre of the cell "Cij". "A1z", "A2z", "A3z" and "A4z" are the RSSI values of the Anchor1, Anchor2, Anchor3 and Anchor4 respectively. For example, RSSI values measured for five different location at the cell, "e2" is given in Eq.(2).

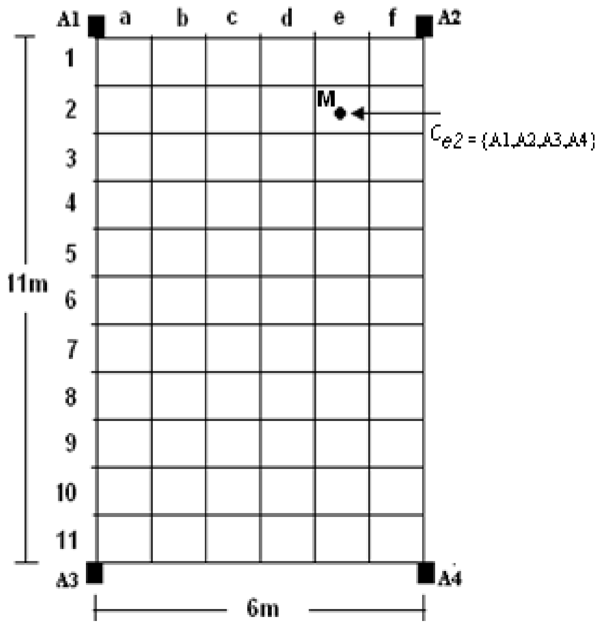

Figure1. Schematic Representation of the Test Area

As known, as the distance between the anchor and the target shortens, a RSSI value approaches to zero. In the experiments, RSSI values were observed to change between -40 and -85 dBm. Variation is not linear. As can be seen from the example, variation of the RSSI values belonging to the different locations in one cell may be unexpectedly very different. Besides, the same RSSI values can be measured at the other cells. Therefore, the algorithm to be used must be chosen carefully as well as the preparation of the radio map. There are many studies with respect to this problem [4, 5, 8, and 13].

This study aims to use a RSSI set according to the average value and an expansion range (µ). In this study, the data in the radio map was recorded as $M_{ij}(B_{ij}, R_{ij})$, where Bij and Rij represent the cell and fingerprint set of the cell, respectively. The "Rij" set depends upon both the average RSSI values obtained from the calibration phase and a coefficient (µ) which represents the expansion range of the average RSSI value. Thus, idle values are included into the cell. If any value measured in the calibration phase keeps out of the average and the value does not exist in any neighbour cell set, it is recorded separately into the database for the cell. That means that a cell is going to include at least (2µ+1) RSSI samples for each anchor.

$$Fij = \left\{ \frac{1}{n}\sum_{z=1}^{n} A_{1z}, \frac{1}{n}\sum_{z=1}^{n} A_{2z}, \dots \dots \frac{1}{n}\sum_{z=1}^{n} A_{kz} \right\} \qquad (3.a)$$

$$Fij = \{A_{1m}, A_{2m} \dots \dots \dots \dots \dots \dots \dots \dots \dots A_{km}\} \qquad (3.b)$$

In Eq. (3), "A_{km}" is the average of k_{th} anchor, "n" and "z" are the sample number, anchor respectively Thus, the general notation (F) of the view of the indoor area can be expressed as;

$$F = \{\{F_{a1}\}, \dots \dots \dots \{F_{e11}\}, \{F_{f11}\}\} \qquad (4)$$

The expanded RSSI set of each cell is created according to Eq (5). The general form of Rij is denoted in Eq (6) (7).

$$A^*_{km} = \{t \mid t \in Z^+ \ and \ A_{km} - \mu < t < A_{km} + \mu\} \qquad (5)$$

$$F^*_{ij} = \{A^*_{1m}, A^*_{2m}, \dots \dots \dots \dots \dots \dots \dots \dots A^*_{km}\} \qquad (6)$$

$$R_{ij} = \{\{F^*_{a1}\}, \{F^*_{a2}\} \dots \dots \dots \dots \dots \{F^*_{e11}\}, \{F^*_{f11}\}\} \qquad (7)$$

The radio map created was used in the next all phase. With the expanded values, the RSSI-cell histograms are denoted in Figure 2 a, b (µ=3). As seen in the histograms, the RSSI values between -55 and -65 dBm scattered over a lot of cells. Of course, these values affected the process of

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position estimation negatively. The values bigger than 73 were eliminated because of being measured as bad packets.

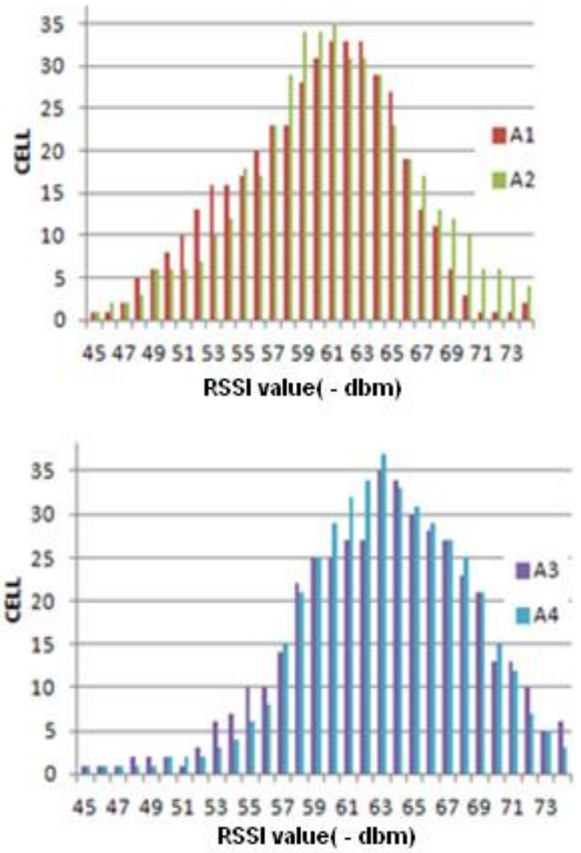

Figure.2 a) The histogram of A1, A2, b) The Histogram of A3,A4

B. *Localization*

In localization, firstly, all the cells matching up with the online RSSI values are achieved from the radio map. A large number of the cells can be available. The next process is that the cells are eliminated in order to obtain minimum cells for the position detection.

For this, in the proposed technique, the indoor area was separated into logical sub regions. The sub regions were created by the help of the calibration data. If the calibration data are gone over carefully, it is seen that some RSSI values have distinguishing features. For instance, the RSSI "-49 dB" of the anchor1 was finally measured in "a1, a2, b1, b2" and the value was not measured in the other cells at all. But, because of the error tolerance and instability of RSSI, the entire neighbour cells ("c1","c2","c3",) included into this cell set. Thus, for "49 dBm" of anchor1, the sub region was described as SS1= {a1, a2, a3, b1, b2, b3, c1, c2, c3}. Thus, if "49 dBm" is measured from anchor1, the other RSSI values have to be only searched in the sub region. According to the RSSI distribution in the calibration data, the indoor area was separated into 6 logical areas.

The localization starts with obtaining all cells in which TN can be from the radio map according to the online RSSI values. Next, the control of logical sub region is carried out and the cells are reduced to minimum numbers. After this step, the intersection cells which have an intersection of four or three are investigated. Finally, the position of the target node is estimated according to the central points of the intersection cells.

IV. IMPLEMENTATION AND TESTS

The implementations were carried out in a laboratory environment. In the tests, MEMSIC TelosB nodes (Figure 3) were preferred due to the fact that they are easy to use and need no extra equipments to be programmed. Because of the fact that the voltage levels of the nodes affected the RSSI values, the DC power supplies were employed instead of batteries.

Figure3. TelosB nodes

Besides, a laptop PC on which Ubuntu OS and TinyOS 2.1.0 were installed was utilized. The one of the sensor nodes was used as Basestation. The interface of the system and the proposed algorithm were created by JAVA. The flow diagram of the algorithm used is given in Figure 4.

The results of the proposed technique were compared with the results of Nearest Neighbour (NN) method used in deterministic technique. It was necessary to be built a new radio map according to the average values of the calibration data for NN.

As known, the distance in NN can be found by a few different norms such as p-norm, Mahalanobis-norm, infinity-norm [9]. In general, p-norm (Eq.8) has been used.

$$\|d\|_p = \left(\sum_{i=1}^{\partial} |d_i|^p\right)^{1/p} \quad \|d\| \left(d \in R^{\partial}\right) \tag{8}$$

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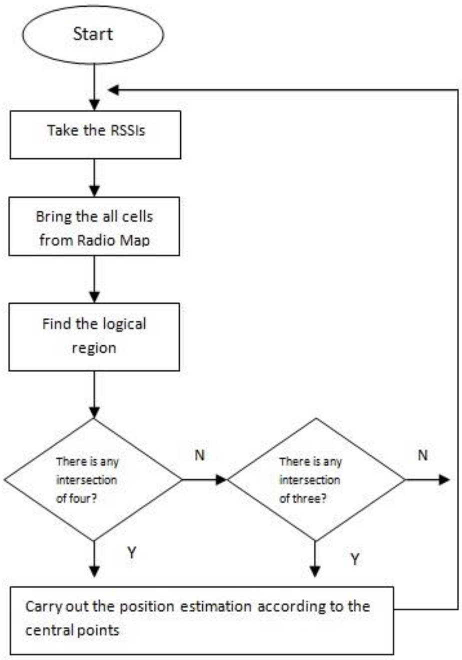


Figure4. The Flow Diagram of the Algorithm

If p = 1 is chosen, this norm is known as "Manhattan norm (1-norm)". This norm has been used commonly [9]. If p =2 is chosen, then this norm is called as "Euclidean norm (2-norm)". In this study, 2-norm was preferred. The results obtained from both techniques were analysed according to the mean error metric. The mathematical form of the mean error metric is given in equation (9).

$$MEr = \frac{1}{T}\sum_{i=1}^{T}\sqrt{(r_x - f_x)^2 + (r_y - f_y)^2} \qquad (9)$$

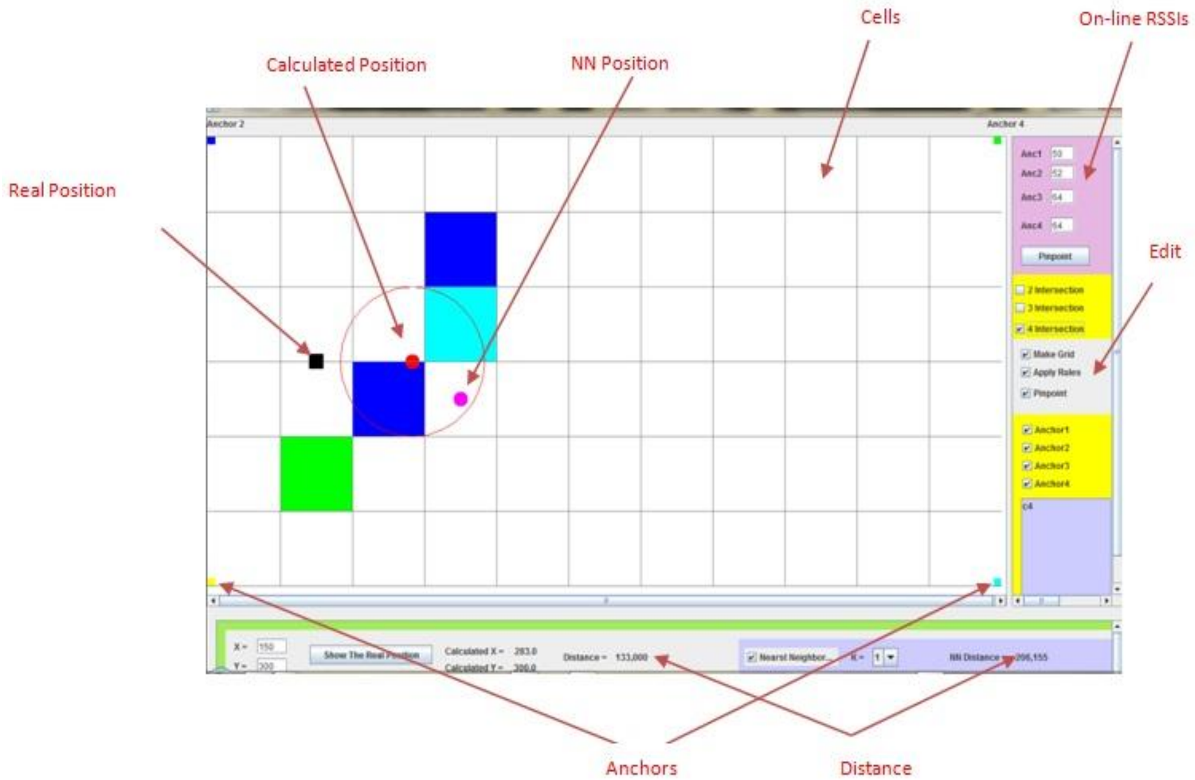
In Eq.(9) , "T" represents the number of the tests, "rx ,ry" are the real coordinates of the target and "fx,fy" are the coordinates calculated.

The interface (Figure 5) can show three different positions: the real position, the position calculated by the proposed technique and the NN position. On-line RSSI values in the interface are investigated in the radio map. The white area, which represents the indoor area, has a dimension of 1100 x 600 px. All coordinate datum (x,y) can be seen on the interface. Both the position calculated by the suggested technique and NN position are able to be denoted at the same time.

If requested, the RSSI-cells of each anchor can be shown separately. Thus, the general RSSI distribution of each anchor can be tracked easily. In addition to this, the control of logical sub region can be enabled or disabled.

Figure 6 is a view of the indoor test area. As seen in the figure, the area has many obstacles which could lead to erroneous measurement. For this reason, it is mandatory that many calibration values must be taken for each anchor nodes. During the tests, direction of the anchors was kept fixed due to the fact that the direction of anchors affected the RSSI values a lot.

Test data were collected from 31 different locations. The real position was compared with the results of both proposed technique and NN. The test results are given in Table 1. The table shows the approach distances (cm).



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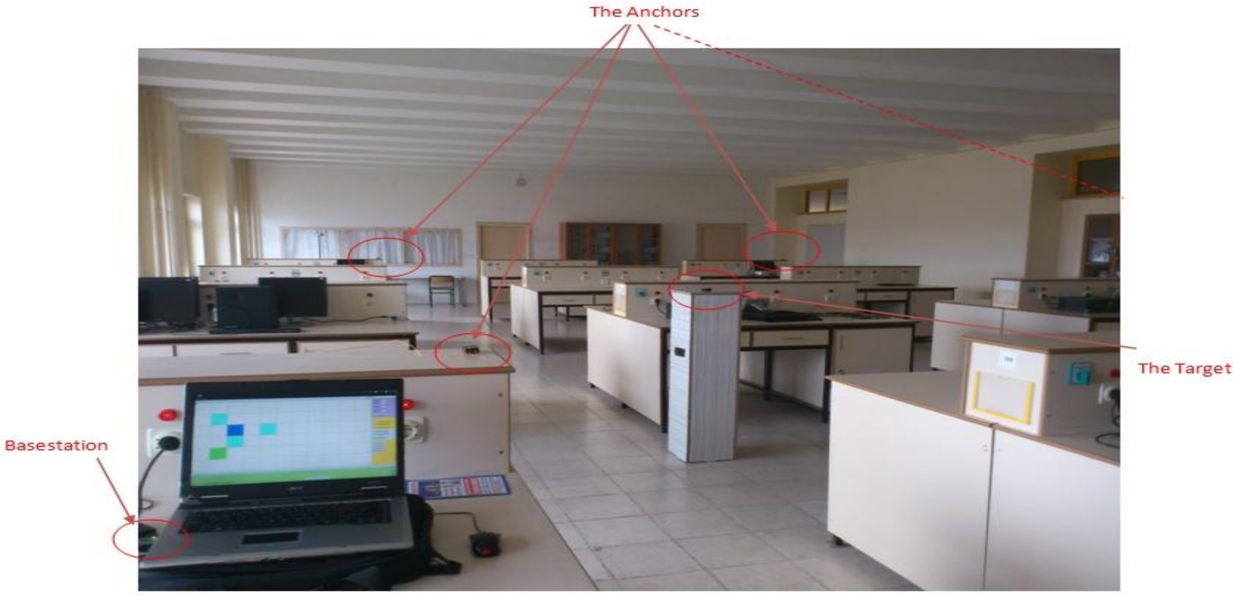

Figure 6. A view of the indoor area

TABLE I
TEST RESULTS OF BOTH TECHNIQUES

Experiment	Prp.Met. (cm)	NN (cm)
1	22.36	22.36
2	229.00	94.34
3	121.75	166.20
4	152.00	152.59
5	285.64	132.09
6	194.09	58.31
7	131.10	156.92
8	160.31	305.49
9	158.11	158.11
10	250.74	250.80
11	178.67	362.66
12	94.86	94.86
13	50.00	473.81
14	300.41	127.48
15	133.00	472.46
16	262.48	215.40
17	28.16	96.05
18	157.05	290.00
19	162.96	163.47
20	134.16	358.46
21	20.00	200.99
22	170.16	170.66
23	105.47	239.00
24	151.21	134.16
25	143.75	98.23
26	154.43	137.30
27	118.84	160.62
28	87.32	173.56
29	136.47	248.24
30	328.10	125.10
31	125.01	43.01
MEr =	**153.15**	**189.77**

As seen in the table, the proposed technique succeeded more than NN method according to the mean error value. The graphic in Figure 7 shows the approach distances of the proposed technique and NN. Especially, the suggested method gave better results in the middle and far locations.

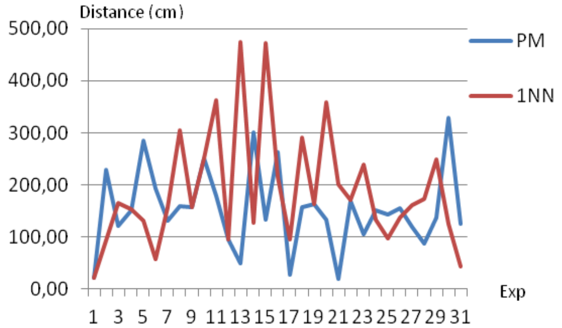

Figure7. The approach distances

According to x and y value, the error distance graphic of the proposed technique is given Figure 8. Figure 9 denotes the error distance graphic of NN.

As seen in Figure 8 and 9, although the suggested method generally more succeeded, NN gave better result in the locations which are very close to anchors. Besides, both techniques failed to estimate the position in the locations that are on the border line of the area.

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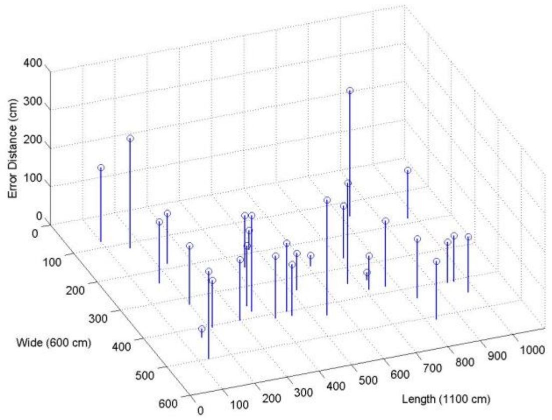

Figure8. The error distance graphic of the proposed method

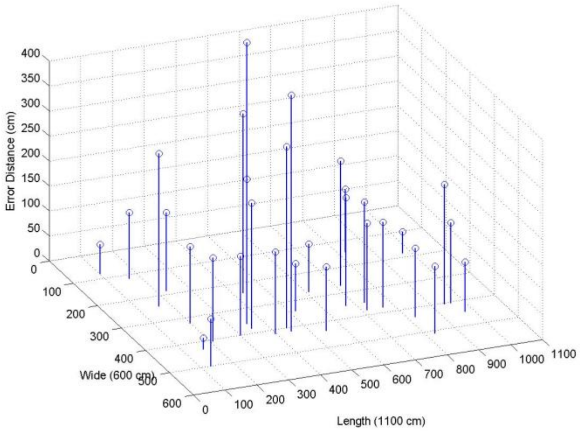

Figure9. The error distance graphic of NN

V. CONCLUSION

In this paper, an alternative fingerprinting-based technique which uses a minimum number of anchor nodes for the location of mobile sensor nodes in indoor areas has been proposed. One of the features of this technique is the extended RSSI mapping. Through the technique used in this work any value of the RSSI obtained in the online-phase is guaranteed to be found at least in one cell. In addition, with the logical subset approach developed the zone of the indoor area in which the mobile sensor node is traced has been narrowed. As a result, tracing time of the mobile sensor node has been reduced. Performance of the proposed approach has been compared with that of the K-Nearest Neighbour (KNN) technique.

As a result, the proposed technique has a better mean error value. But both techniques failed to estimate the position in the locations that are on the border line of the area. It is clear that although many approaches to reduce mean error rate exist, more studies on indoor localization are still needed.

The future works will involve different soft computing techniques in indoor localization.

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Biography

Yetkin TATAR has currently served as an Assoc. Professor in the University of Firat, Department of Computer Engineering, Elazig, Turkey. His research fields are Network Security and Wireless Sensor Networks

Güngör YILDIRIM received MS degree from the University of Firat, Department of Computer Engineering. He has currently worked as a project engineer in DSİ IX. Regional Directorate, Elazig, Turkey. His fields are Wireless Sensor Networks.