Access Point Localization Using Autonomous Mobile Robot

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***Abstract*—Identifying the location of an access point, whether it is legitimate or rogue, is an important research problem due to the wide range of applications that can solve critical security threats or enable a better and more efficient installation of access points within the service area. Though most suggested solutions have proven their efficiency using mathematical modeling and computer simulation, this paper presents a simple and efficient practical approach to identify the location of an access point in an indoor environment using an autonomous mobile robot. The proposed approach is based on taking a relatively small number of the access point's received signal strength samples at known locations. The experimental performance evaluation verified that the proposed approach can identify the location of the access point accurately and efficiently. Comparative analysis demonstrated that the proposed approach outperforms similar existing approaches in both time and accuracy.**

Keywords—Localization, Mobile Robot, Rogue access point, RSSI, Wi-Fi access point, WiMAP

I. INTRODUCTION

Wi-Fi networks are almost everywhere, at homes, work places, and even in public places like malls, parks, and bus stations. Though the technology is widely spread out, it still suffers from security threats and it also lacks the state-of-art ways of deploying it. Rogue access point, which is basically an unauthorized access point installed without prior authorization from network administrators for malicious purposes, is a well-known problem in Wireless Local Area Network (WLAN) security. It can negatively impact the experience of the users and more dangerously be potentially used to steal their credentials. The determination of the position of the Access Point (AP) usually involves human work at the site to take Received Signal Strength Indication (RSSI) values in different locations. The relationship between the collected RSSI values and the distance from the AP, d, is expressed as follows:

$$RSSI(d)[dB] = RSSI(d_0)[\text{dB}] - 10n\log\left(\frac{d}{d_0}\right)$$

where $RSSI(d_0)$ is the mean path loss at some reference distance d_0, and n is the path loss exponent, which indicates how fast received signal strength decreases with distance and it depends on the environment [1].

WiMAP [2] (stands for Where is My Access Point) algorithm introduced a simple solution for identifying the location of an AP. WiMAP relies on collecting a uniformly distributed set of RSSI samples at known locations without any prior knowledge of the AP configuration (e.g.; the transmit power) or the signal propagation characteristics of the surrounding environment (e.g.; path-loss exponent).

In this paper, WiMAP is experientially tested using an autonomous mobile robot in an indoor environment in multiple scenarios, and then we introduce an enhanced version of WiMAP called Dynamic WiMAP. Dynamic WiMAP uses a relatively small number of the most relevant non-uniformly distributed samples. The comparative analysis shows that the enhanced version outperforms the original one in both time and localization accuracy, delivering results that are excellent for the intended application.

The rest of the paper is organized as follows: Section II discuss the related works. Section III provides an experimental testing of WiMAP, Section IV presents the proposed approach. Section V shows the results of the experimental testing of the proposed approach. Section VI provides comparative analysis of the two approaches. Finally, Section VII concludes the paper and suggests some future work.

II. RELATED WORK

There are different methods to determine the location of an access point. And one of the most used practical method is to monitor the RSSI at different known locations inside the indoor premises [3]. The general operation of such methods goes as follows: the RSSI is monitored at number of locations around a given position in order to enhance the accuracy of the associated triangulation calculations. This is repeated for a fair number of positions within the premises. The triangulation calculation may be performed after each iteration. Such triangulation calculations render a vector directed toward the

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AP of interest. This operation is repeated until a sufficient accuracy of the vector is reached. Even though this method ensures an acceptable level of accuracy, the complex calculations of triangulation adds a considerable drawback to it since the power efficiency is of big concern nowadays, especially in mobile devices.

In [4], the relation between RSSI and distance was linearly approximated in order to find the estimated position of access points. The approach proposed in [5] uses crowdsourcing with nonlinear weighted least squares to estimate the location of the access point along with the signal propagation parameters.

Some large-scale AP localization systems use the Centroid and Weighted Centroid algorithms [6,7]. The Centroid algorithm determines the geometric mean of a large number of sample locations that are taken all around the AP coverage area. Hence, it determines the average of all locations around the AP regardless of the signal strength at these locations. On the other hand, the Weighted Centroid algorithm uses the RSSI at each location as a weight for the coordinates by multiplying a scaled version of the RSSI by each coordinate then dividing by the sum of the scaled RSSI values. Thus, more significance is given to the sample locations with stronger RSSI, which is intuitive since the stronger the RSSI, the closer the AP. However, even though the farther sample locations are given less weight, and hence have less significance in determining the AP location, they still contribute to the positioning error. It is worth mentioning that these methods are mostly used in metropolitan-scale outdoor environments.

There are other algorithms that focus on the simplicity of the operation, without sacrificing the accuracy. In WiMAP, the algorithm proposes to use the basic Centroid algorithm for AP localization in a simpler filtering process than the Weighted Centroid algorithm. WiMAP consists of three simple phases: collecting samples, filtering the collected samples, and estimating the AP location. Where in collecting samples, RSSI measures are being collected in different locations within the given place. In the filtering phase, the collected sample points are filtered in order to improve the location estimation and reduce positioning errors. And in estimating the access point's location phase, the centroid algorithm is being applied, except that the geometric mean is calculated only for the selected x percent of the collected sample points.

In this paper, we propose an enhanced version of WiMAP, called Dynamic WiMAP. We show the actual results of multiple tests for both algorithms conducted using an autonomous robot, and we prove that Dynamic WiMAP outperforms WiMAP in both time and accuracy.

III. TESTING AND EVALUATING WIMAP

We implemented WiMAP on Khepera III robot [8] which comes with standard embedded Linux Operating System. The robot base includes an array of 11 Infrared Sensors, as well as 5 Ultrasound Sensors. It is also able to host standard Compact Flash extension card, supporting Wi-Fi and Bluetooth wireless networking technologies. The implementation of WiMAP on the mobile robot was as follows:

1. Collecting RSSI samples: the robot will start scanning the area in which the AP is to be localized. During the scanning, the robot must store the RSSI readings with the locations in which the readings were taken. Multi readings in each location are taken and the average is stored. Until the whole area is covered and uniform distributed RSSI readings are taken within the area.

2. Filtering collected samples: the collected sample points are filtered in order to improve the location estimation accuracy and to reduce positioning errors. Filtering is done by keeping the best N percent of samples to use in the third phase and exclude the rest of the samples. N is to be changed as the environment changes. It will increase dynamically with increasing intensity of obstacles in the area and vice versa.

3. Estimating AP location: apply the centroid algorithm on the locations of the collected samples to find the estimated location of the AP. The Centroid algorithm determines the geometric mean of a number of sample locations that are taken all around the AP coverage area. Hence, it determines the average of all locations around the AP regardless of the signal strength at these locations. For n location sample coordinates (N percent of all samples from previous phase), the centroid is defined as

$$\overline{X} = \sum_{i=1}^{n} \frac{x_i}{n}$$

where x_i is the x coordinate of the i^{th} measurement location. The same operation is performed for the y coordinate. The result will be the location of the AP.

We tested WiMAP algorithm in different area sizes. The error between the actual AP location and the estimated one did not exceed 70 cm.

Figure 1 and Figure 2 show the results of applying WiMAP

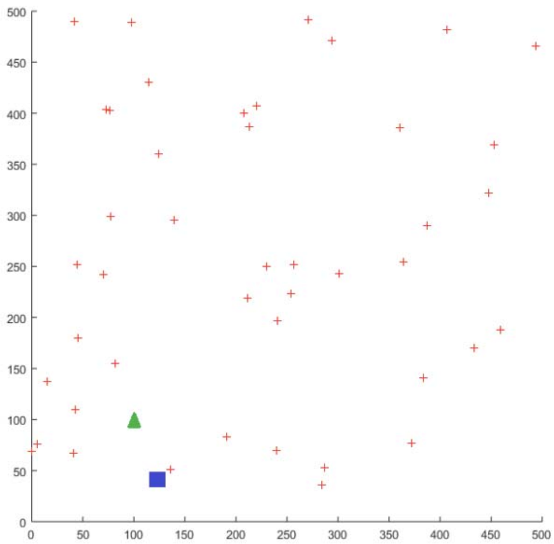

Fig. 1. WiMAP in 5m×5m area.

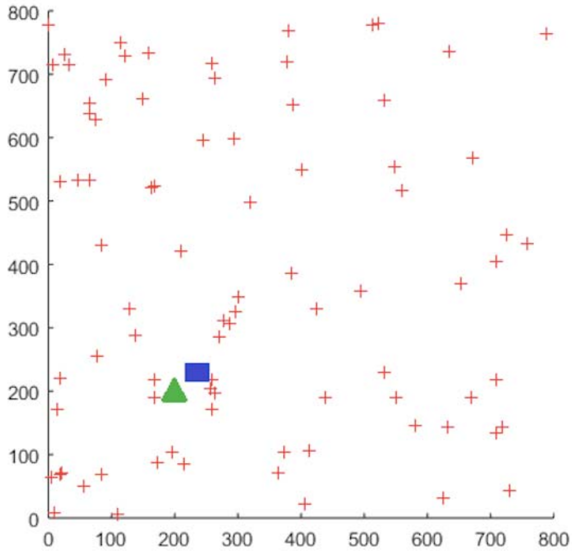

Fig. 2. WiMAP in 8m×8m area.

in 5m×5m and 8m×8m areas; respectively. The crosses signs represent the locations where the robot took RSSI samples, the triangle represents the actual position of AP, and the square represents the estimated location of AP using WiMAP algorithm. Elapsed time for 5m×5m was 9.8 minutes, and elapsed time for 8m×8m scenario was 16.5 minutes.

IV. The Proposed Dynamic WiMAP Algorithm

This paper introduces Dynamic WiMAP algorithm, which is an enhanced version of WiMAP. As explained earlier, WiMAP uses only a certain percentage of uniformly collected RSSI samples (i.e.; only the samples under a given threshold) as an input to the centroid algorithm to estimate the location of the AP. The rest of the collected samples are filtered out (i.e.; such samples turn out to be useless or even harmful to the location estimation accuracy). The basic idea of the proposed Dynamic WiMAP algorithm is that, unlike WiMAP, the samples are taken in a non-uniformly distributed random fashion such that only useful samples are taken at a proper density.

Based on the RSSI values, Dynamic WiMAP, theoretically, divides the area into virtual zones in the form of circular strips around the location of the AP. The sample density varies for each zone such that the closer the zone to the AP, the higher the sample density. By doing so, the total number of samples is decreased and the needed time for the complete area scanning and sampling is shortened. This is done without affecting the accuracy, since low RSSI values do not have considerable contribution in accurately detecting the location of AP (i.e.; these are the filtered samples in WiMAP). A flowchart of the proposed Dynamic WiMAP is shown in Figure 3.

Thus, the implementation of Dynamic WiMAP differs only in the RSSI sample collecting phase, as compared to WiMAP. To achieve this in a dynamic and practical way, after taking a

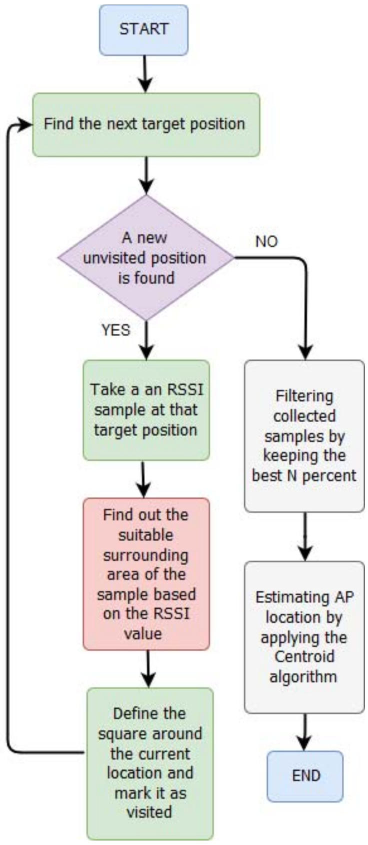

Fig. 3. A flowchart of the proposed Dynamic WiMAP algorithm.

sample, the algorithm generates a virtual square area around each RSSI sample and marks that area as visited, so that none of the points within this square will be visited again.

That is, no further RSSI sampling will take place inside the square area. The size of the virtual square varies depending on the value of the RSSI sample taken and it dynamically increases as the RSSI value decreases, and vice versa. This ensures that fewer number of RSSI samples are taken in areas far from the AP (i.e.; when the RSSI values are smaller) than the areas closer to the AP.

An illustration of the distribution of the RSSI samples using Dynamic WiMAP is shown in Figure 4, where the red dots represent the locations of the RSSI samples and the blue cross represents the actual location of AP. Note the higher density of the sample points around AP.

V. Experimental Testing of the Proposed Dynamic WiMAP

Dynamic WiMAP was implemented on Khepera III robot and was experimentally tested in the same area, and under the same circumstances used to test WiMAP. Figure 5 and Figure 6 show the results of testing Dynamic WiMAP in 5m×5m and 8m×8m areas, respectively. The crosses signs represent the locations where the robot took RSSI samples, the triangle represents the actual position of AP, and the square represents the estimated location of AP using Dynamic WiMAP algorithm. Elapsed time for 5m×5m was 5.4 minutes, and elapsed time for 8m×8m scenario was 13.8 minutes. Note that

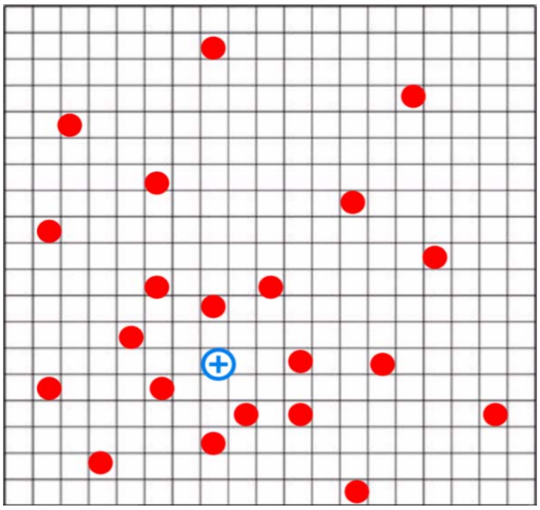

Fig. 4. Distribution of RSSI samples in Dynamic WiMAP.

the location estimation error (i.e.; the distance between the actual AP location and the estimated location) did not exceed 50 cm. The figures clearly show that there is higher density of RSSI samples around the AP, and how the density of samples gets smaller as the robot moves away from the AP. Also, that the total number of RSSI samples is decreased compared to WiMAP algorithm.

VI. COMPARATIVE ANALYSIS

We conducted multiple tests in multiple area sizes using the same robot. Each test was repeated at least 5 times for each algorithm and in each area size. The reported results represent the average of each set of tests. Performed experiments demonstrated that Dynamic WiMAP outperforms WiMAP in both time and localization accuracy.

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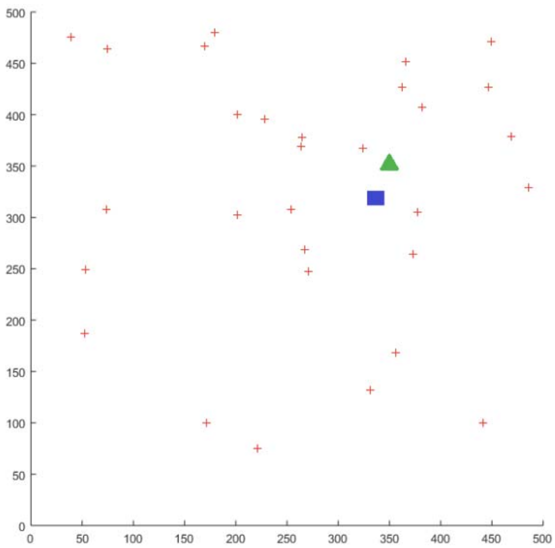

Fig. 5. Dynamic WiMAP in 5m×5m area.

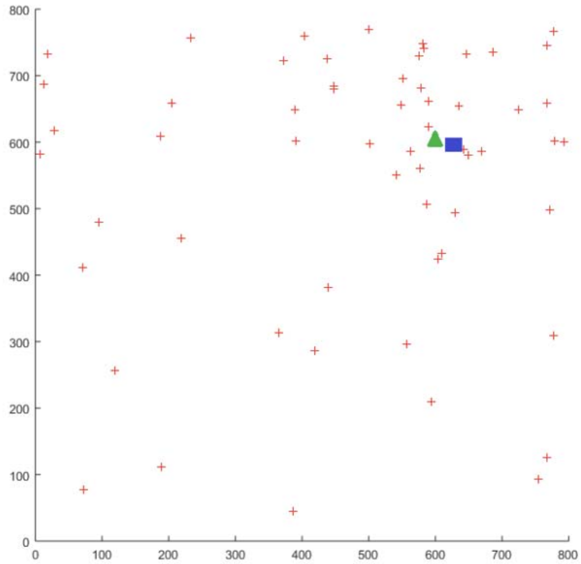

Fig. 6. Dynamic WiMAP in 8m×8m area.

Figure 7, Figure 8, and Figure 9 show a comparison between WiMAP and Dynamic WiMAP in terms of elapsed time, the number of samples taken by the robot, and the localization error; respectively. It is obvious that Dynamic WiMAP outperforms WiMAP in all performance metrics, especially as the area increases.

In Figure 7 and Figure 8, it can be observed that as the area size increases, the difference in elapsed time for each algorithm to complete the scan, collect the samples, and estimate the location of the AP also increases. In 10m×10m area size, the difference is about 10 minutes (i.e.; less by 35%). The same applies for the number of samples each algorithm collects. In 10m×10m area size, Dynamic WiMAP collected around 90 less sample points than WiMAP (i.e.; less by 47%).

Figure 9 shows that, even though both algorithms can estimate the AP location very accurately, Dynamic WiMAP achieved between 20% to 40% better localization accuracy than WiMAP in all cases.

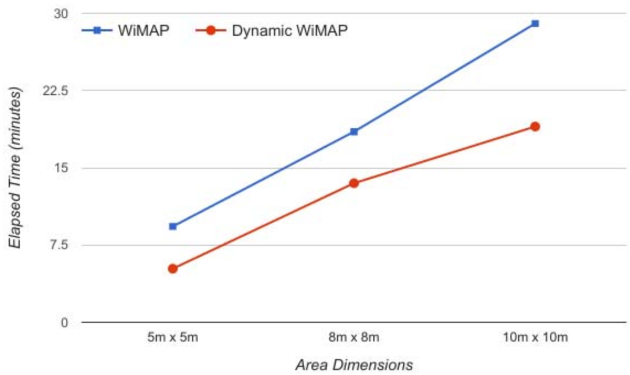

Fig. 7. Comparison in elapsed time.

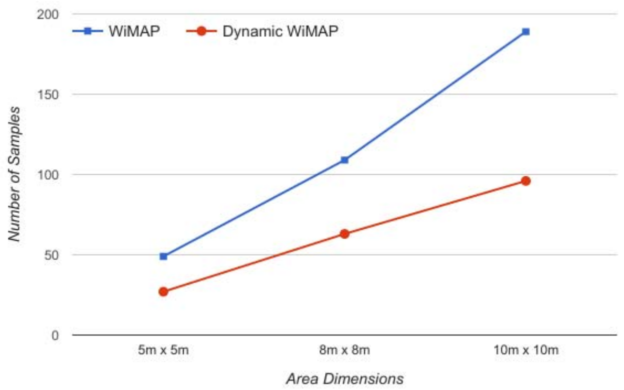

Fig. 8. Comparison in the number of samples use

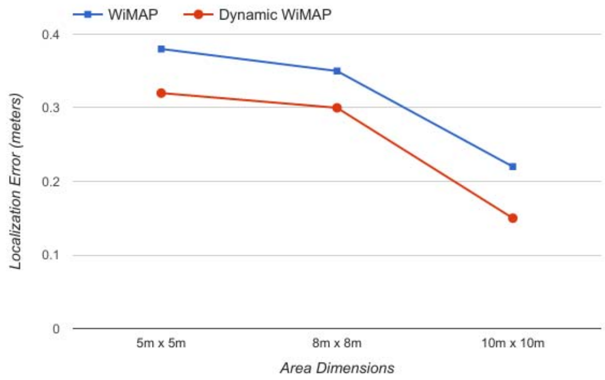

Fig. 9. Comparison in localization error

VII. CONCLUSION

The proposed Dynamic WiMAP algorithm introduces a very simple yet efficient method for locating indoor Wi-Fi access point based only on received signal strength samples at known locations. Its performance was experimentally evaluated in an indoor environment using Khepera III autonomous mobile robot and was compared against its predecessor WiMAP algorithm. Multiple tests were conducted in different areas with different dimensions, and the obtained results demonstrated that the proposed approach can achieve better positioning accuracy in all tested cases, with much less cost in terms of time and effort. This work can be extended to useful and critical applications such as using an autonomous mobile robot to locate a human being trapped under rubble in a disaster location using his or her mobile phone's Wi-Fi radio.

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