WiFi Indoor Positioning with Binary Search Method

Santiphap Watcharasukchit*1, Tuul Triyason*2, Worarat Krathu†3, Anuchart Tassanaviboon*4,
and Chonlameth Arpnikanondt*5

*IP Communication Laboratory, †Data Science and Engineering Laboratory, School of Information Technology
King Mongkut's University of Technology Thonburi
Bangkok, Thailand
1santiphap.wat@sit.kmutt.ac.th, 2tuul.tri@sit.kmutt.ac.th, 3worarat.kra@sit.kmutt.ac.th, 4anuchart@sit.kmutt.ac.th,
and 5chonlameth@sit.kmutt.ac.th

***Abstract*—Indoor monitoring is one of the prevalent features in smart home contest. This paper provides a new practical approach for indoor position using WiFi. The approach uses the signal strength of a receiver from transmitters to calculate relative distances from the received signal strength. Finally, the position is calculated by applying the Binary Search algorithm and relative distances. In order to evaluate the performance of the proposed algorithm, the experimental test-bed on four-corner access points is conducted. The results show that the calculated positions at the border, or near the access points, are accurate. However, the results in the middle have some errors, due to a distance from access points. The preliminary observation shows that the errors came from the limitation of receiver hardware, which can be compensated by adjusting access points topology.**

Keywords—Indoor Position; WiFi; RSSI; Relative Distance

I. Introduction

Recently, indoor positioning comes to play the role in many fields. The general approach which widely used for positioning is the Global Positioning System or GPS. Unfortunately, GPS cannot be used accurately indoor. Therefore, indoor positioning is still one of the interesting topic for researching. There are many approaches to implement the indoor positioning technologies [1]. For instance, a simple approach is using cameras to record and track people [2]. However, there are a lot of limitations and constraints. One of the limitation is privacy. Using cameras recording all behaviors is violating the privacy. Thus, this approach is commonly unacceptable from users. In other words, an approach to track people with camera-free is needed. Many usages of wireless system have been used for indoor positioning instead of camera. There are many kinds of wireless signal which used for indoor positioning. For instance, FM-based Indoor Localization [3] uses FM Radio signal. They are more accurate than using WiFi, but come with many limitations to apply this approaches. For an example, the FM Radio signal transmitter may have some usage restrictions in some places. There are also the usage of Infrared [4] and Ultrasound [5] for indoor positioning. However, those approaches required specific hardware which may be impractical for many industries. So, they are not widely used for indoor positioning. The wireless signal which are widely uses for indoor positioning is Bluetooth and WiFi. However, they cannot achieve accuracy with simple approaches. Currently, several new approaches of using wireless for indoor positioning are still developed, including the approaches which are complex and impractical. Therefore, the indoor positioning topic is still challenging.

This paper proposes a new, simple, and practical approach implementing an algorithm of WiFi indoor position tracking system by using Binary Search algorithm. The WiFi is chosen instead of Bluetooth because of weaker the signal strength and lower working distance of Bluetooth. Moreover, WiFi access points are now popular, common, and affordable for every house. Our approach consists of calculating the relative distance instead of absolute distance to prevent the imprecise of absolute distance calculation and using those distances to calculate the position by applying Binary Search algorithm, which is fast, simple, and powerful. With this approach, the practical and accurate WiFi indoor positioning can be achieved.

This paper consists of the following topics. The second part provides a literature review regarding similar WiFi positioning approach and their limitations as well as some common knowledge, which is required in their methodology. The following section describes our proposed approach including algorithms and the experiments. The fourth section presents the results of our experiments, as well as the discussion, limitations, and adaptations. Finally, the conclusion and future work of this paper is provided in the last section.

II. Literature Review

There are many approaches for WiFi indoor positioning. This topic is about discussing those approaches. Many approaches use the similar principles, but different applications. So, this section discusses existing techniques of WiFi positioning as well as the equation commonly used to calculate position.

A. WiFi Indoor Positioning

Currently, there are many approaches for WiFi indoor positioning [6] However, each of them has their own limitations. In general, there are four categories of WiFi indoor positioning, Time of Arrival (ToA), Angle of Arrival (AoA), Hybrid ToA/AoA, and Received Signal Strength (RSS) and finger-print. The ToA approach uses triangulation method [7] to calculate the position. In detail, the received signal from at

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least three access points are measured and calculated the distance. Then, using triangulation method from those distances, the position will be determined. However, it may be inaccurate in calculation of the distances which causes some errors. The AoA approach could also be inaccurate to retrieve the precise angle due to the limitation of hardware. The Hybrid ToA/AoA approach also faces the same problems of ToA and AoA. Moreover, the RSS and finger-print approach is hard to set up. This paper will use the similar technique, triangulation method, which is one of the popular approaches [8][9][10]. As mentioned earlier, the calculation of received signal strength into the distance itself is inaccurate in practical usages. To tackle this problem, our approach uses the same equation, Free-Space Received Power equation, but the relative distance will be used to calculated the position instead of the absolute distance.

B. Free-Space Received Power

Free-space received power is the signal strength that a receiver receives from a transmitter through free space. This equation [11] shows the relations between signal strength and distance between transmitter and receiver. This equation in term of decibel or dB is:

$$\overline{P}_{R,dB}=P_{T,dB}+10\log_{10}g(d)+10\log_{10}G_T G_R \tag{1}$$

In free space, the term $g(d)$ is $1/d^2$ which d is the distance between transmitter and receiver. Since our approach uses the same model of transmitters, $P_{T,dB}$, the transmitted signal power in decibels and G_T, the power gained of transmitter are the same. Also, the same model of receiver is used. So, G_R, the power gained of receiver is also the same through the calculation. Therefore, they are derived into a constant k to make the equation more simple, which is:

$$\overline{P}_{R,dB}=10\log_{10}\frac{1}{d^2}+k \tag{2}$$

With (2), the received signal power in decibels is able to calculate by knowing distance. Our approach will calculate the relative distance instead of the absolute distance. Therefore, the k will be omitted later in the methodology topic.

III. Methodology and Experiments

In this topic, the details of our new WiFi positioning algorithm and experimental test-bed are described. The topic can be categorized into three parts. First, the concept of relative distance is defined. Second, the idea of positioning with Binary Search algorithm is elaborated on. In the last section, to evaluate the performance of this new approach, the error analysis from an experimental test-bed is presented.

A. Relative Distance

The precise access points' positions are needed to know before the calculation. Fig. 1 shows a position of four WiFi access points (AP1 to AP4) at the four corners of square room. All access points have to broadcast the frequency in the same channel. With this scenario, any positions in this square room can be calculated by the received recieved signal strength indicator (RSSI) from the four APs. The received RSSI of four APs are used to calculate the relative distance by using Free-space received power equation.

The relative distance is defined as the ratio of the distance between two different pairs of a transmitter and a receiver. For example, in Fig. 2, a relative distance between AP1-Receiver and AP4-Receiver is d_1/d_2 which d_1 is the distance from AP1 and receiver and d_2 is the distance from AP4 and receiver. If the relative distance is 1, it means the receiver have the same distance from AP1 and AP4, in other words, in the middle. If the relative distance is less than 1, it means the distance from AP4 is further than AP1, in other words, the receiver is nearer AP1 than AP4. If the relative distance is more than one, it means the distance from AP1 is further than AP4, in other words, the receiver is nearer AP4 than AP1.

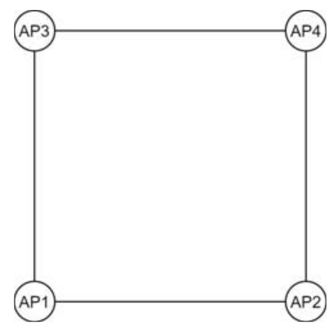

Fig. 1. Room with 4 access points

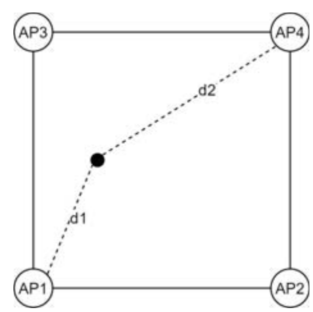

Fig. 2. Distance of AP1-Receiver and AP4-Receiver

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To calculate the distance, (2) is used as a base equation and altered into distance equation, which is:

$$\begin{aligned}
\overline{P}_{R,dB} &= 10\log_{10}\frac{1}{d^2}+k \\
\overline{P}_{R,dB} &= 10\log_{10}d^{-2}+k \\
\overline{P}_{R,dB} &= -20\log_{10}d+k \\
\frac{\overline{P}_{R,dB}-k}{-20} &= \log_{10}d \\
d &= 10^{\frac{\overline{P}_{R,dB}-k}{-20}}
\end{aligned} \tag{3}$$

From (3), the absolute distance cannot be calculated because of *k*. However, our approach wants only relative distance, which is d_1/d_2. So, the relative distance is:

$$\begin{aligned}
\frac{d_1}{d_2} &= \frac{10^{\frac{\overline{P}_{R,dB1}-k}{-20}}}{10^{\frac{\overline{P}_{R,dB2}-k}{-20}}} \\
\frac{d_1}{d_2} &= 10^{\frac{\overline{P}_{R,dB1}-k}{-20}-\frac{\overline{P}_{R,dB2}-k}{-20}} \\
\frac{d_1}{d_2} &= 10^{\frac{\overline{P}_{R,dB2}-\overline{P}_{R,dB1}}{20}}
\end{aligned} \tag{4}$$

The *k* constant is eventually omitted. So, the inaccuracy of *k* is also ignored. These relative distances are used in part of calculating the position with Binary Search Based Positioning.

B. Binary Search Based Positioning

Our approach applies the Binary Search algorithms. Basically, the Binary Search algorithm is a search technique which divides the search domain into halves and selects one of them and repeats the algorithm until the expected value found. However, instead of two, our algorithm divides the search domain in to eight parts as shown in Fig. 3.

The initial position is set at the center of search domain. Then, using relative distances which are calculated before, the algorithm determines which part should be the next search domain and the next iteration of Binary Search of the new search domain will be done. This iteration continues until the calculated relative distances and the real measured relative distances are equivalent.

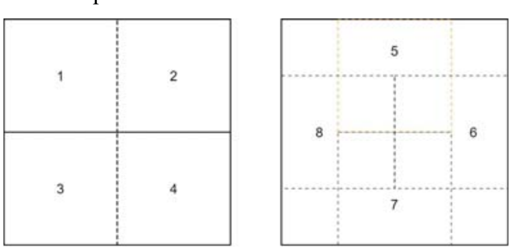

Fig. 3. Eight-direction boundaries

To determine which is the next search domain, the algorithm creates a 3×3 array to represent eight directions. The algorithm uses each real measured relative distance, which are calculated from the measured received signal power, to compare with the calculated relative distance, which are calculated from the assumed position and the transmitters, and then fill the weight in Fig. 4.

The cell of array which has the highest weight is the chosen direction of the next boundary of search domain, for instance, if the highest is the top-left cell, the next search domain is in the boundary 1 in Fig. 3. If the middle cell has the highest weight, it means that the calculated relative distances and the real measured relative distances are equivalent. Therefore, the iteration is finished and that final position are assumed to be the real position.

Different positions of pair of transmitters has different ways to fill the weight. Since there are six pairs of transmitters, there are six ways to fill the weight. Fig. 5 shows an example of one pairs of transmitter, AP1 and AP4.

Fig. 5a shows the positions of AP1, AP4 and the receiver. In these positions, if the real measured relative distance is less than calculated relative distance, it means the measured position should be closer to AP1 than the assumed position. Therefore, the next search domain should be at the bottom or left of current search domain. So, the weight will fill into the array in the same way as Fig. 5b. If the real measured relative distance equals the calculated relative distance, it means the measure position should be the same as the assumed position. Therefore, the weight will fill into the array in the same way as Fig. 5c. If the real measured relative distance is more than calculated relative distance, it means the measured position should be more closer to AP4 than the assumed position. Therefore, the weight will fill into the array in the same way as Fig. 5d.

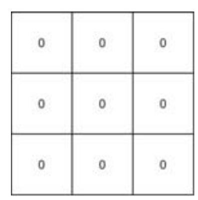

Fig. 4. 3×3 weight array

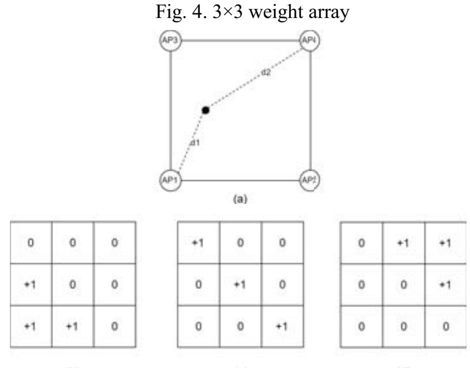

Fig. 5. Weight filling between AP1 and AP4

In the same way of other pair of transmitter, the weight filling ways for each pair are shown from Fig. 6 to Fig. 10. Finally, all of weight are summed and the next search domain will be determined.

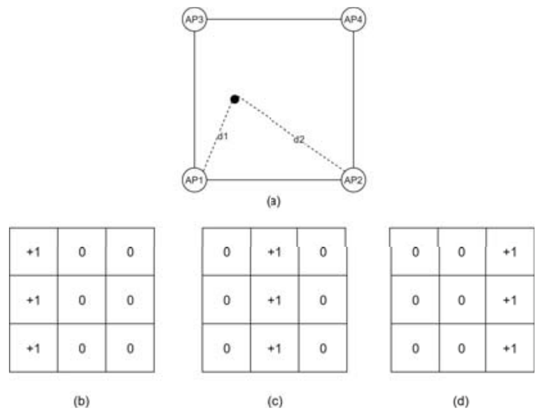

Fig. 6. Weight filling between AP1 and AP2

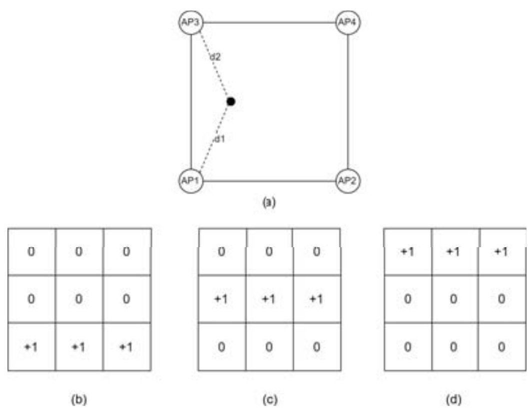

Fig. 7. Weight filling between AP1 and AP3

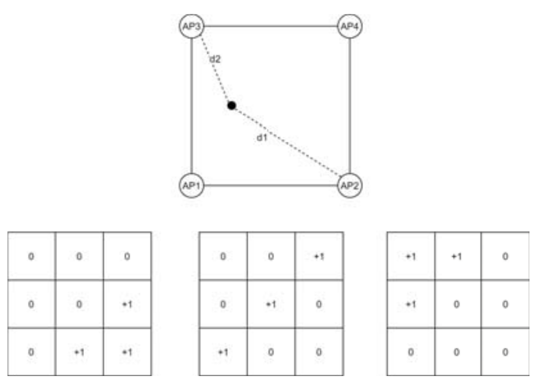

Fig. 8. Weight filling between AP2 and AP3

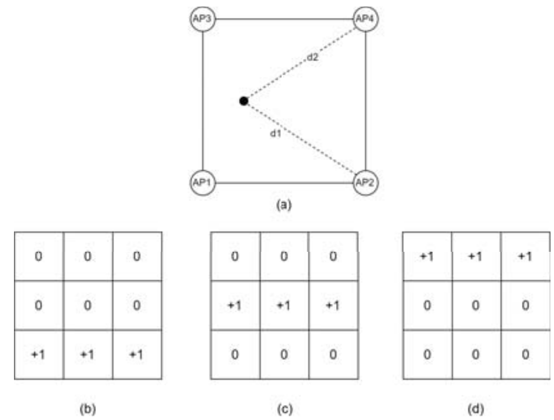

Fig. 9. Weight filling between AP2 and AP4

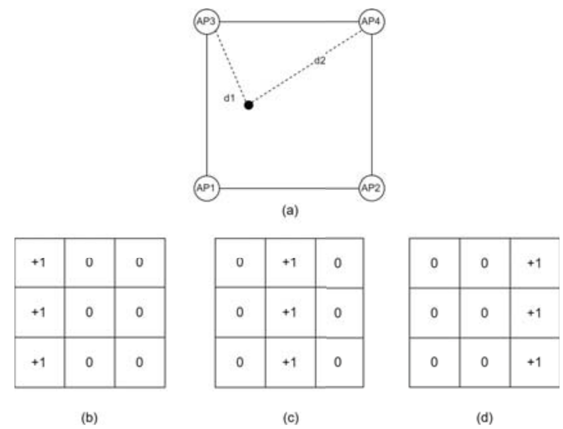

Fig. 10. Weight filling between AP3 and AP4

In some recursion, there may be multiple cells which have the highest weight. For instance, in Fig. 11a, the top left and top middle cell have the highest weight. Instead of choosing either top left of top middle, our algorithm chooses both as the next search domain, as shown in Fig. 11b, or boundary 1 and 5 in Fig. 3.

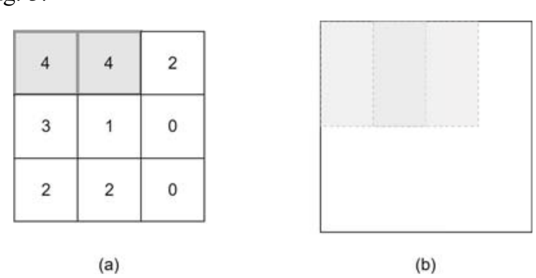

Fig. 11. Multiple max-weight array & chosen boundaries

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C. Experiments

The experiments aim for evaluating the accuracy of the approach. In detail, the results of the experiments are the average errors, which are the differences of real position and calculated position, at various position in the room.

In these experiments, four NodeMCU by ESP8266 chip-set are used as WiFi access points. A Moto G4 Plus model XT1642 is used as a receiver. The access points are placed in the corner of 8m × 8m and 5m × 5m empty room. The floor plan of the room and the labeled access points are shown in the Fig. 12.

Two different-size experiments are conducted because of awareness of the accuracy of receiver due to the low-powered transmitter and the environment, which may have various interrupted WiFi signal. In each experiment, the receiver is placed to measure and calculate the position for every one-meter intersection in a grid. In other words, 8m × 8m experiment is measured for 81 positions and 5m × 5m experiment is measured for 36 positions.

IV. RESULTS

This topic shows the results of experiment as well as a discussion related to the result. The Fig. 13 and Fig. 14 shows the results of the experiments.

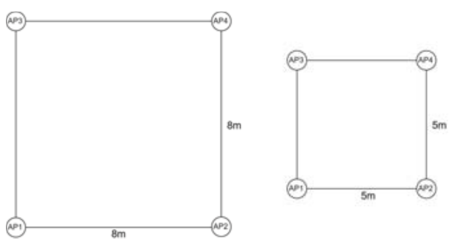

Fig. 12. Experiment floor plan

0.37	0.71	0.63	0.81	0.91	0.63	0.62	0.48	0.55
0.65	1.185	1.11	0.975	1.425	1.395	1.185	0.87	0.59
0.55	1.2	1.84	2.06	2.08	1.52	1.66	1.035	0.81
0.72	1.215	1.54	1.76	1.84	2.44	1.62	1.005	1.01
0.94	1.275	2.06	2.04	2.04	1.98	1.88	1.26	0.93
0.83	1.185	1.72	1.94	2.36	2.02	1.64	1.605	0.84
0.71	1.005	1.96	1.62	1.46	1.44	1.42	1.2	0.55
0.53	1.185	1.32	1.53	1.395	1.26	1.005	0.945	0.64
0.38	0.6	0.62	1.1	0.83	0.97	0.31	0.41	0.46

Fig. 13. Results of 8m × 8m room

0.1	0.28	0.25	0.44	0.23	0.08
0.33	0.35	0.39	0.4	0.32	0.27
0.38	0.71	0.83	0.97	0.67	0.31
0.29	1.11	1.1	0.81	0.47	0.49
0.25	0.69	0.32	0.37	0.32	0.27
0.08	0.27	0.23	0.52	0.38	0.14

Fig. 14. Results of 5m × 5m room

In particular, the numbers shown in the Fig. 13 and Fig. 14 show the average errors, which are the average of differences between real position and calculated position in every one meter of the room.

The average errors of the first experiment, which is the larger room, is 1.19m and the errors are appeared highly at the center. According to the algorithms equation, slightly errors of measurement cause a lot of errors of results, since there are other interrupted signals in the experiment environment, low transmission power of transmitters, and the inaccurate receiver, the measured signal powers have a high chance to have errors.

Also, there are some cases that false measurements lead to impossible position, for an example, Fig. 15 below.

The receiver received the same signal from AP3 and AP4. So, the possible positions were located in the middle between AP3 and AP4, in the other word, anywhere on the dash line. However, the receiver received more signal strength from AP2 than AP1. So, the possible positions are located nearer AP2 than AP2, which should be the right side of dash line, which is a contradiction to the previous assumption. These problems lead to the failure of algorithms which was mentioned earlier.

From those circumstances, the second experiment, which reduced the area size into 5m × 5m to enhance the accuracy, was decided to conduct. The results are similar to the first experiment, which errors are highly appeared at the center. However, they are acceptable. The overall average errors is 0.42m, which are more accurate than the previous experiment due to the accurate measurement. This can be a proof that room size can be one of the factor leading to errors.

Right now, the results may not applicable due to the significant errors in a large room. However, the errors come from the measured signal strengths, which rely on transmitters and a receiver, and the environment. Using more accurate receiver or making the receiver measure more accurate, for an example, adjusting the access points topology, can improve the results.

There are also some limitations. One of limitation is all transmitters must have the same transmission power and power gained. Furthermore, the room has to be clear enough, so that the position will be equally far from each transmitter. In other words, in the middle, the receiver must receive the same signal strength from every access points.

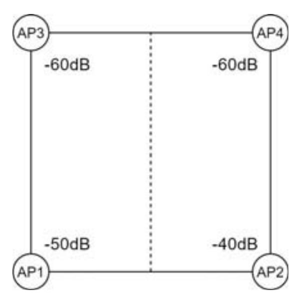

Fig. 15. Example of impossible position

The access points topology is also another limitation. Our algorithm purpose a square topology with four access points at the corner. With alternative topology, some parts of algorithm need to be changed, especially, weight filling part for determining the next search domain in the Binary Search algorithm part. The ways of weight filling and weight array shape have to be individually determined.

Fig. 16a is the example of rectangular topology with six transmitters. The weight array is also adapted to rectangular as shown in the Fig. 16b.

The weight filling approach also needs to changed. For instance, in Fig. 17a between AP3 and AP6, if the real measured relative distance is less than the calculated relative distance, it means that the real position should closer to AP3 than the assumed position. So, the weight array should be filled in the way of Fig. 17b. In the same way, if the real measured relative distance is equal to the calculated relative distance, fill the weight array in the way of Fig. 17c. If the real measured relative distance is more than the calculated relative distance, fill the weight array in the way of Fig. 17d.

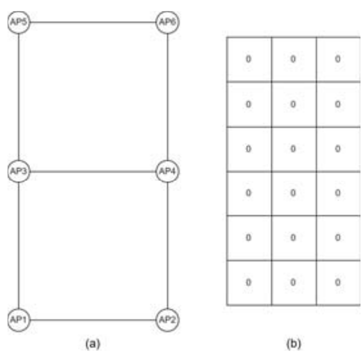

Fig. 16. Example of rectangle topology

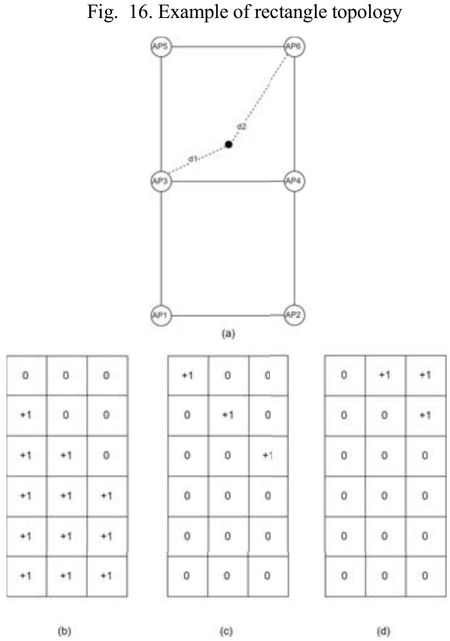

Fig. 17. Weight filling between AP3 and AP6

V. Conclusion

This paper proposes a new approach and algorithm for WiFi indoor positioning. Our approach uses the free-space received signal equation to find relative distances between each pair of transmitters and receivers and applies the Binary Search algorithm to locate the position from relative distances. From our experiment, the results are practical in a small area with acceptable errors due to some limitations on transmitter devices.

For future works, the experiments with various topology will be conducted to find better topology. Current approach uses a square topology with four access points at the corner. However, the results show the inaccuracy which causes by the inaccurate signal measurement. Therefore, adjusting the topology may improve the accuracy of measurement and give more accurate results. The experiments to find which is the optimal number of access points and topology to achieve the accurate results will aim to be conducted.

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