2016 International Conference on Computer & Communication Engineering

An Improved Indoor Positioning Algorithm Based on RSSI-Trilateration technique for Internet of Things (IOT)

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***Abstract*—Indoor positioning system (IPS) allows an object to be located and tracked within an indoor environment. With the introduction of Internet of Things (IoT), the business interest in location-based application and services has also increased. Hence, the demand for accurate indoor localization services has become important. Until now, researches related to IPS are still being conducted with the objective to improve the performance of positioning techniques. Trilateration is one of the techniques available to determine the location of an object. This paper proposes an improved WiFi trilateration-based method for indoor positioning system. The improved model is based on the test results which was conducted by using Intel Galileo (Gen2) board as an access point. The signal blocking problem caused by obstacles existed inside the building is resolved by improving received signal strength measurement. The proposed model includes implementation of trilateration technique to determine the position of users and then using specific reference points to improve the positioning results.**

Keywords-Indoor Positioning System, Trilateration method, Wi-Fi technology, IOT board, access point, Improved positioning model.

I. INTRODUCTION

Positioning System has always been in people's thought throughout the history, tracing back to the old days when people used to follow the ancient guiding-star navigation. Since then, a lot of technological growth has been seen and finally, Global Positioning System have practically solved the problem of outdoor localization. However, limitation of GPS (Global Positioning System) leads to a challenge for developing a new tracking system for indoor environment [7].

GPS functions through satellites which are located thousand miles away from the ground. When signals from satellites are transmitted to device, they are obstructed on the way resulting on weak signals [8, 3]. These transmitted weak signals are reflected due to different barriers such as trees and buildings which causes multipath interference. In addition, the building materials cause extra problems that make it very difficult to perform indoor tracking through GPS. As a result, a lot of studies have been done to provide similar system like GPS for indoor environment but yet to develop a full featured effective and accurate Indoor Positioning System.

Indoor Positioning System (IPS) is referred to a navigation system which is made of network devices to locate objects or people inside indoor environment [8]. After a great success in adopting with GPS which is very effective and accurate for outdoor environment, developing Indoor Positioning System has become popular research area due to its increasing demand. People want to use indoor positioning system for various purposes such as security, finding location of materials, emergency and etc [1].

Traditionally, location estimation or positioning frameworks for indoor environments are designed based on different infrastructure such as WiFi, Bluetooth and RFID. Recently, WiFi has become the center of interest for positioning techniques mainly because of its existing infrastructure to support IPS as well as it is easily deployable and cost-effective [9].

This paper will focus on analyzing results obtained from various tests which was done in the area with obstacles by using IOT board as an access point. The outcome of the analyzing results are compared to observe the improvement in positioning of the proposed model.

II. INDOOR POSITIONING TECHNIQUE

The most widely used technology for Indoor Positioning System is WiFi [9]. It is a common and accessible technology used by many people which has the basic components for IPS and at the same time, WiFi does not require additional hardware to provide support for IPS [10]. This technology supports an electronic device to exchange information over the air using radio waves. WiFi devices usually communicate over 2.4 GHz, but nowadays, 5GHz is widely being used for communication because connections with 5GHz are less noise, less interference, better speeds and more stable connection [5].

978-1-5090-2427-8/16 $31.00 © 2016 IEEE
DOI 10.1109/ICCCE.2016.28

Different methods of measuring position and determining location are used in WiFi technology. However, in the case of WiFi based indoor localization, the fingerprinting method based on WiFi signal strength is often employed [2]. In addition, the trilateration algorithm is also adopted which uses distance to surrounding access points and its co-ordinates for localization [6].

Trilateration method is used to determine the relative location of user by measuring distances using geometry. This method makes use of the point of intersection formed by three circles of WiFi access points to determine the exact position. It basically provides an area of localization based on given distances. The distances are calculated using various signal measurement techniques such as Received Signal Strength (RSS), Time of Arrival (ToA), Time Difference of Arrival (TDoA) and etc. [4].

Trilateration method does not have an offline phase unlike fingerprinting method [10]. However, it still needs respective co-ordinates location of Access Points (AP) as well as AP's Mac address stored in a centralized database [10]. Received signal strengths from all existing access points are calculated and then converted into distances. Based on this distance, the system trilaterate the devices location as shown in Figure 1. It is very important to note that the RSSI values received by this technique are live and therefore prone to have error when converting RSSI values to distance. Signal propagation due to obstacle is another reason that cause error in calculating RSSI values.

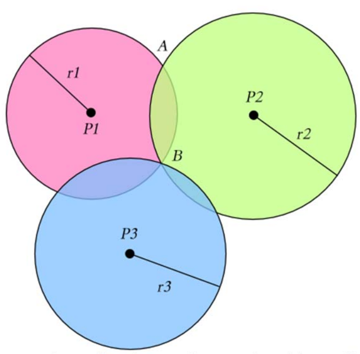

Figure 1: Location of point B determined by Trilateration Technique with 3 different Access Points (P1, P2, P3).

Trilateration method uses RSSI (Received Signal Strength Indication) value to calculate the distance between application user and the WiFi routers or access points. A WiFi analyser application on android-based devices can obtain the signal strength in dBm and convert it to distance (r) using the following equation:

$$r_i = 10 \wedge ^{((27.55-(20*log10(f))+s)/20)} \quad (1)$$

where,

r = distance in meter, f = frequency in MHz

s= Signal level in dBm, i = 1,2,3…..

The computed distances from access points to android application (user) form 3 circles intersect with each other. The intersection of the circles is the position of the user. From Figure 1, if the location of point $B(x,y)$ need to be computed, then the formulated circles are calculated using mathematical computations. To simplify the calculations, the equations are formulated so that intersection of circles is occurred at Cartesian plane. The equation for each circles is as follows (assuming z = 0):

$$(x - x_i)^2 + (y - y_i)^2 = r_i^2 \quad (2)$$

Where (x_i, y_i) is the location of the AP and i is the ID for the access point.

The intersection of 3 circles is obtained by solving systems of linear equations for 2 variables simultaneously. Hence, by solving the linear systems location of $B(x,y)$ can be determined. Nevertheless, the accuracy of co-ordinate $B(x,y)$ merely depends on the measurement of distance conversion from RSSI value. Therefore, it is important to measure several measurements of the online RSSI values and determine the average value to minimize the error.

III. Proposed Model

This model is based on trilateration technique with the introduction of using reference point (RP) to improve the position of the device in the environment where obstacles block the signal between device and access point. The online calculated distances from device to each AP is compared to the distances from reference point to each AP to minimize the error rate that is caused by the signal interference. Figure 2 explains the flow of process of the proposed model. The processes are listed below:

i. The AP Co-ordinates with their MAC addresses are stored offline in the database.
ii. The reference points are chosen at important location and the distances from AP to reference points along with its co-ordinate are calculated offline and stored in the database.
iii. A WiFi analyser application sends data (i.e. MAC address + signal level + Frequency of first three AP) to server.
iv. Server matches the MAC address of AP in the database and retrieve the co-ordinate of AP. Then it trilaterates these data to get the distances to device from all APs and the observed co-ordinate of the device.
v. Server again gets the data (i.e. Distance to RP + Co-ordinate) from database and match distance to RP with observed distance to device using best matching algorithm. Then, the matching RP co-

ordinate and observed device co-ordinate are averaged to get the improved co-ordinate.

vi. The improved co-ordinate are being sent to device and then showed show the location on map

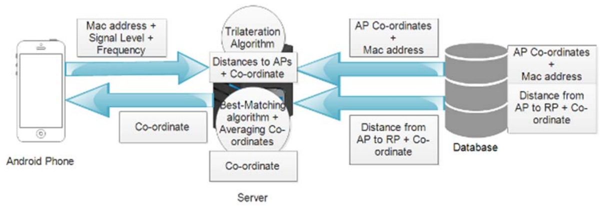

Figure 2: Improved model for indoor positioning system

IV. Testing

Indoor Positioning engine which is based on trilateration technique can be divided into two phases. In phase I, primary data collection is done which includes information about the location of the routers or access points and its corresponding MAC address. Phase II is the live calculation of distance between routers and application or user. Consequently, the results of the calculation used along with the information stored in Phase I to calculate the user's position mathematically.

Three Intel Galileo (Gen2) boards are set up as a router in an area with less obstacle. As shown in Figure 3, A, B and C are the three routers placed in a particular room where P is the mobile application used by a user. The data from this mobile application are collected offline and it is then used to find out the co-ordinate for *P(x,y)*. The actual measurement of the distances from A, B and C to P are measured offline and then compared with the observed distances to find out the error rate of the algorithm.

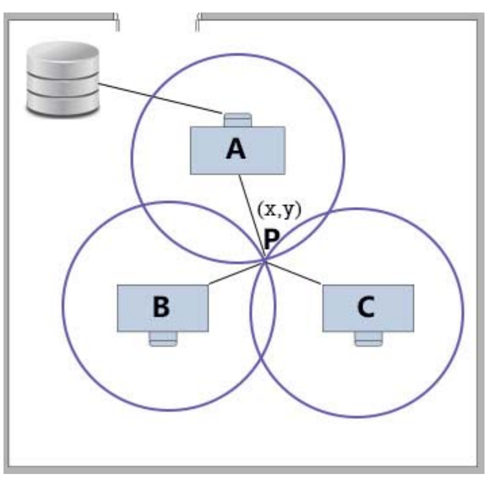

Figure 3: Experimental Setup

During the data collection period, the signal levels from the WiFi analyser for each AP are collected 10 times and then the average results of the signal level are considered for the next phase. For each different areas, two testing are done to see the error difference and to find out the average error rate caused by signal interference.

Based on experimental research, the data collection are done by changing the position of the mobile device. The device is placed in various positions for different testing. The output of the testing are statistically analyzed to see the variance in distance measurement.

A. Test 1 (Trilateration technique)

A test-bed was set up in male hostel of Universiti Tenaga Nasional whereby three access points were placed relatively near to each other with obstacle in between. For this test, an access point AP1 is placed inside a bedroom while other two access points AP2 and AP3 placed in the corridor of the apartment. As shown in Figure 4, AP2 is located 5.5 meters away from AP1 on the same Y axis while AP3 is located at the co-ordinate (3, 4.5) and approximately 5.3 meters away from AP1. Since AP1 is placed inside the room, all access points are not visible to each other as a wall is in between AP1 and AP2 as well as between AP1 and AP3.

For this test, data was collected at the co-ordinate (1, 2) so that the mobile device is in line of sight with AP1 and AP3 while blocked by a wall in between with AP2. The signal strength from access points to the device was observed via Wifi Analyzer application in order to get the observed co-ordinate by using Trilateration algorithm.

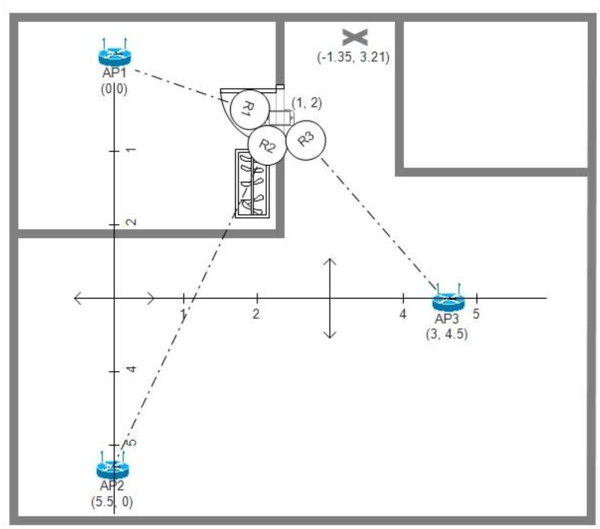

Figure 4: Test-bed for Test 1.

As shown in Figure 5, the observed average signal levels from AP1, AP2 and AP3 are respectively -51, -62 and -56 dBm. These signal levels along with its corresponding frequency are being used to convert into distances as shown in equation (1).

By using the calculated distances with equation (2), the formulated equations become as follow:

$$(x-0)^2 + (y-0)^2 = 1.97^2 \quad (3)$$
$$(x-5.5)^2 + (y-0)^2 = 7.00 \quad (4)$$
$$(x-3)^2 + (y-4.5)^2 = 3.51^2 \quad (5)$$

From equation (3), (4) and (5), the observed co-ordinate x and y are being solved by using system of linear equation which are respectively -1.35 and 3.21 meters as shown in Figure 5.

In Figure 4, the cross sign represents the observed position of the device while the mobile device sign represent the actual position of the device. The cross sign in Figure 4 is quite far from mobile device which means there are signal blocking somewhere between access points and mobile device. From Figure 4 also, it can be noted that the signal blocking is between AP2 and mobile device which caused an error rate of 2.4 meters in distance from AP2 to device. This signal blocking result in an error rate for X and Y co-ordinates which are 2.35m and 1.21m respectively.

Access Point	Co-ordinates
AP1	0,0
AP2	0,5.5
AP3	3,4.5

Access Point	AP1	AP2	AP3
Signal Level	-51	-62	-56
Frequency	2412	2412	2412
Observed Distance	R1 1.97	R2 7.00	R3 3.51
Observed Coordinate	X -1.35	Y 3.21	

Exact Distance	R1 3.5	R2 4.6	R1 1.8
Exact Coordinate	X 1	Y 2	
Error rate	2.35	1.21	

Figure 5: Test results for Test 1

B. Test 2 (Proposed model)

A test was done with the same set up as Test I for area with less obstacle to observe the improved positioning compared to Test I. For this test, several reference points were chosen as shown in Figure 6. The reference points were strategically chosen at important places such as entrance points so that it helps to improve the positional accuracy. In Figure 6, three reference point RP1, RP2 and RP3 were chosen and the co-ordinates of these reference points were calculated manually by a meter tape. The distance form all access points to the reference were also calculated manually and noted down.

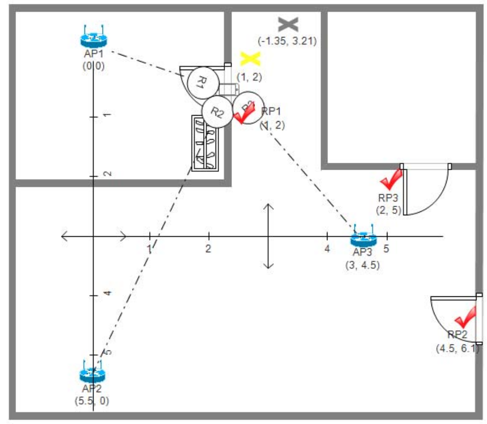

Figure 6: Test-bed for Test 2.

Once the data for reference points and the observed distance of the device from all access points are noted down, this data can be processed to find the position of the device.

Reference Point Co-ordinates	Distance (Meter)
RP1 (1, 2)	2.2, 5, 3.3
RP2 (4.5, 6.1)	9.35, 5.35, 1.35
RP3 (2, 5)	5.4, 6.5, 1.9

Access Point	AP1	AP2	AP3
Signal Level	-51	-62	-56
Frequency	2412	2412	2412
Observed Distance	R1 1.97	R2 7.00	R3 3.51
Observed Coordinate	X -1.35	Y 3.21	
Improved Coordinate	-0.17	2.6	

Exact Distance	R1 3.5	R2 4.6	R1 1.8
Exact Coordinate	X 1	Y 2	
Error rate	2.35	1.21	

Figure 7: Test results for Test 2

As shown in Figure 7, the observed distance of the device from access points R1, R2 and R3 are respectively 1.97, 7.00 and 3.51 meters which were calculated offline. Next, if these observed distances are compared with the reference point's distances, the best matching reference point can be obtained in following manner.

i) R1, R2 and R3 are compared with all Reference points for their distance to AP1, AP2 and AP3. The comparing result does not include direction. Hence, negative value is changed to positive.

Difference between Observed distance R1 and distance of (RP1 to AP1): 1.97-2.2 = 0.23 (*R1P1*)
Difference between Observed distance R1 and distance of (RP2 to AP1): 1.97-9.35 = 7.38 (*R1P2*)
Difference between Observed distance R1 and distance of (RP3 to AP1): 1.97-5.4 = 3.43 (*R1P3*)

Difference between Observed distance R2 and distance of (RP1 to AP2): 7.00-5 = 2.00 (*R2P1*)
Difference between Observed distance R2 and distance of (RP2 to AP2): 7.00-5.35 = 1.65 (*R2P2*)
Difference between Observed distance R2 and distance of (RP3 to AP2): 7.00-6.5 = 0.5 (*R2P3*)

Difference between Observed distance R3 and distance of (RP1 to AP3): 3.51-3.3 = 0.21 (*R3P1*)
Difference between Observed distance R3 and distance of (RP2 to AP3): 3.51-1.35 = 2.16 (*R3P2*)
Difference between Observed distance R3 and distance of (RP3 to AP3): 3.51-1.9 = 1.61 (*R3P3*)

ii) The calculated difference of RP1, RP2 and RP3 for all AP1, AP2 and AP3 are added and then averaged to find the reference point (RP) with smallest difference.

RP1 = (R1P1 + R2P1 + R3P1)/3 = 0.813
RP2 = (R1P2 + R2P2 + R3P2)/3 = 3.73
RP3 = (R1P3 + R2P3 + R3P3)/3 = 1.846

Since *RP1* has the smallest difference, it is the best matching reference point.

The co-ordinate of *RP1* (1, 2) and the observed co-ordinate (-1.35, 3.21) are then processed to find out the average co-ordinate which is (-0.17, 2.6). In Figure 6, this co-ordinate is marked in yellow cross sign and it can be seen that the position of the device is improved.

V. Results and Findings

It is found from Test 1 that surrounding signals and obstacles such as wall and wardrobe can cause little to big difference in positioning results. In addition, the positioning results also depend on the number of obstacles between the device and access points. Table 1 shows the summarized results from Test 1 and Test 2. Based on these results, it can be concluded that by using trilateration technique, the average error in positioning is approximately 2 meters while with the proposed model, the average error in positioning is approximately 1 meters.

Table 1: Summary of Test results

Test	Exact Location. (x,y) in meters	Observed location (x,y) in meters	Error in positioning (x,y) in (meters)
Test 1 (Trilateration Technique)	(1, 2)	(-1.35, 3.21)	(2.35, 1.21)
Test 2 (Proposed model)	(1, 2)	(-0.17, 2.6)	(1.17, 0.6)

I. Conclusion and Future Work

The testing results show that positioning of any object in indoor environment by using trilateration technique is error prone due to the signal interference by various obstacles. This error rate are being reduced by using some reference points as proposed in the model. The reference point must be chosen based on location which is considered to be important and demandable for localization to user. In our research, all the reference points were at the entrance doors.

The proposed model takes into account of the reference points whereby the distances from access point to reference point is compared to observed distances from access point to device. This model provide a useful improvement in positioning than a model with only having trilateration algorithm. The proposed technique can be further improved in the future by conducting more tests.

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