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Accurate Bluetooth Positioning Using Weighting and Large Number of Devices Measurements

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Abstract In this paper it considers using the built-in Bluetooth in the cellphone as the positioning device; it is able from the measured received signal strength indication strength to locate the target or the cellphone position. From experimental measurements using Bluetooth positioning technique in various environments we measure signal fading condition and propose signal fading model; three-point localization method is then developed to determine potential target locations. Two specific processes, one is the introduction of weighting factors for the potential target locations and the other is to generate more test points, are then exploited to determine the target final location. With these two specific processes it is possible by using Bluetooth technique to reduce the distance determination error down to 1 m range.

Keywords Blue tooth · Positioning system · Cellphone · Accuracy positioning

1 Introduction

When GPS or Wi-Fi (Wireless Fidelity) is used in location determination it needs to have satellite signals in the GPS application while in Wi-Fi application it works only if there have base stations to transmit/receive signals and then the resulting location determined in using either GPS or Wi-Fi application has high probability in error. In this paper we use Bluetooth in the distance calculation and location determination it not only improves the accuracy in the positioning but also could be used in the disaster environments such as tsunami, earthquake etc. when there are no base stations are available but in this situation the rescuers still can use Bluetooth to carry out their rescue mission.

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In our study of using Bluetooth in the positioning we try to reduce the resulting location error down to 1 m range when using the point-to-point positioning technique under the P2P (peer-to-peer) architecture. We will collect measurement data from field trials, possibly removing the effects of human being and outside environment, between the transmitting and receiving among cell phones, and analyze these data to propose proper signal fading model for Bluetooth signal transmission and then to develop suitable localization algorithm so as to accomplish our task to reduce the resulting location error down to 1 m range. With our developed system architecture and localization algorithm in using Bluetooth technique for distance measurement it will promote the use of Bluetooth technique in the position determination between cell phones.

The Bluetooth technique is developed by the joint effort of Ericsson and Nokia in the project of inter- connecting their mobile phones and other portable devices; Bluetooth technical protocols have also been established. It is light, thin, short, and small, low price in Bluetooth device to provide people a transmission format, other than the wireline transmission, without using any wire transmission line or network to connect various digital equipment so as to improve people's transmission convenience. In addition to point-to-point transmission, Bluetooth also provides point-to-multipoint transmissions and when the information is transmitted it is broadcasted in all directions; also through omni-directional wireless transmission and the cipher-scripted process enable any person who equips with Bluetooth device can, through Bluetooth, proceeds to secured wireless transmission [1].

Some exemplified Bluetooth applications have been examined and analyzed in the literature as discussed in the following. Subhan et al. [2] from measured indoor data to analyze the relationship between signal strength and distance in connection–based and inquiry-based Bluetooth signal transmission and then to proposed a system model with associated system parameters to enable the estimation of the transmission distance from its measured received signal strength indication (RSSI) values. Iera et al. [3] used Bluetooth to establish a short distance wireless communication system to provide emergency, multi-media or games application; it specifically concluded that in short distance transmission by using Bluetooth technique it can effectively reduce the power transmission. In [4] the authors discussed the use of Weibull function to approximate the RSSI distribution obtained in Bluetooth transmission; they also in indoor transmission environment measured the RSSI values with Bluetooth and WLAN transmissions; they then compared the distributions generated from the measured data with the Weibull function. In [5], the authors considered the privacy issue in proximity service, which is an important and burgeoning type of location-based service in social networking. In 3GPP standard, it mentioned in document 22.803 [6] that it can enable proximity service to enhance the location and presence services.

This paper is organized in the following. In this section we had briefly discussed the reason and its advantages of using Bluetooth as the positioning technique its transmission formats are also described. In Sect. 2 we will measure the signal fading phenomena of Bluetooth signal in the field trial in several communication environments. The signal fading model will be proposed from analyzing the measured data and the possible relation between the measured RSSI values and the transmission distance will be derived. In Sect. 3 two-point localization method is introduced, it shows that it is not only the target location but also its symmetric location will be identified simultaneously from using the two-point localization algorithm. Three-point localization method is then introduced; it will generate three pairs of potential target locations from three set of test points by using two-point location method. The final target location is then determined from the central point of these potential target locations. In Sect. 4, two specific processes, namely, the use of weighting factors among potential target locations and the generation of large number of test points, are proposed and utilized in the determination of target location as described in Sect. 3 through three-point location method to reduce its distance determination error. A conclusion is drawn in Sect. 5 and it is our intention to use the developed location determination algorithm by using Bluetooth technology into other location-based services so as to increase their accuracy in the target positioning.

2 Field Trial Scenario and Data Measurement Functional Flock Diagram

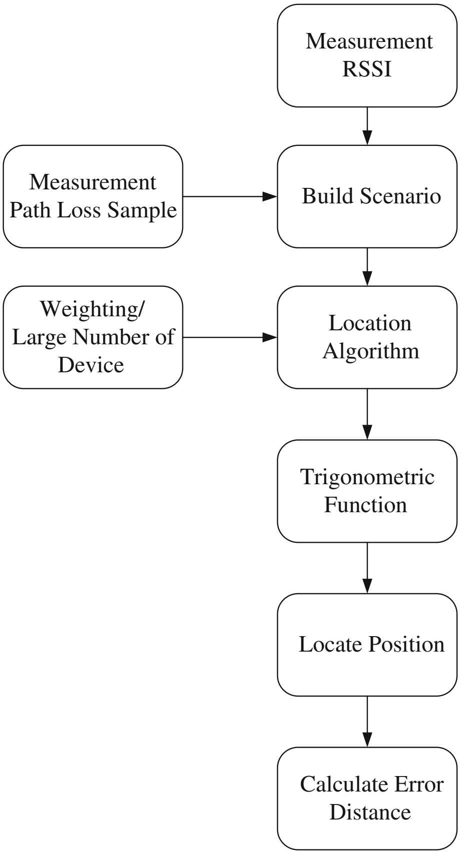
The experimental measurement is conducted in the third floor of the Engineering Building of Tamkang University, Tamsui Campus as shown in Fig. 1 and the data measurements are taken in the evenings to reduce all possibly incur interferences. The Samsung Galaxy S3 cellphones, as shown in Fig. 2, are selected as the phones in the experiment in the transmission and receiving of Bluetooth signals. Version 4 Bluetooth is built-in in these phones its transmission distance determination and its stability are far better than its version3's phones. Also in the experimental measurement the cellphone is placed in the same height and transmits in the same direction to reduce possible measurement errors due to the angle and the height variations in the placement of cellphones.

The functional blocks in conducting the experimental measurement is shown in Fig. 3. In the first step it derives the path loss model when it uses Bluetooth signal transmission. We then collect through measurements the target locations and their received RSSI values. From the derived path loss model we convert the measured RSSI values into distances information. Trigonometric function is then introduced to

Fig. 1 Measurement environment—Third floor, Engineering Building, Tamsui Campus, Tamkang University

Fig. 2 Device used in the transmission test: Samsung Galaxy S3 Version 4 Cellphone

Fig. 3 System functional block diagram in target location determination



form the basis of distance determination method. The target location is then calculated through our developed distance determination algorithm; the differences between the actual targets locations and their estimated locations are then calculated and compared.

3 RSSI Measurement

The installed ceramic tiles in the third floor, Engineering Building, Tamsui Campus, Tamkang University, are used as the distance references in the experimental measurements. It has length 40 cm and width 40 cm in the ceramic tile as shown in Fig. 4. The cellphones are placed on the same height stool to maintain the same height in measurement. It takes three RSSI measurements at the same test point; the average of these three measurements is then counted as the RSSI value at that point. After record the RSSI value at one test point, it takes backward with distance of one ceramic tile, 40 cm $\times$ 40 cm, to make another new measurement as shown in Fig. 5. It totally takes 50 grids of ceramic tiles measurements or equivalent having transmission distance extended to 20 m.

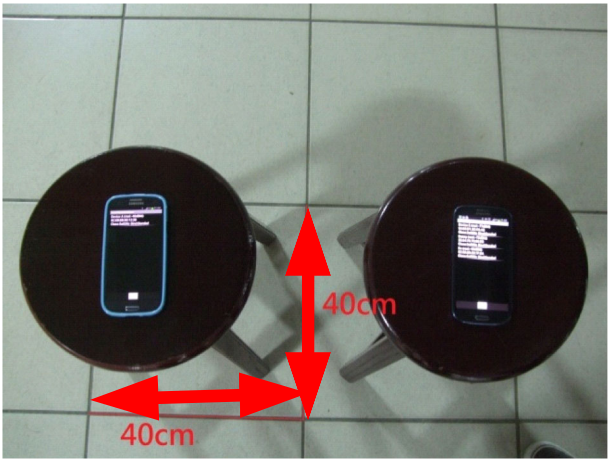


Fig. 4 Signal strength measurement environment

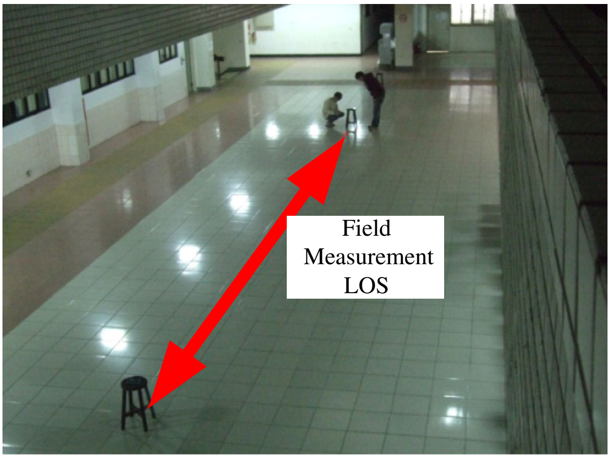


Fig. 5 LOS field measurement

The RSSI measurement is read in dBm and the relationship in RSSI and its associated power reading P_r has the following relationship:

$$P_r = 10^\wedge \left(\frac{RSSI_r}{10}\right) \tag{1}$$

$$AVGP = AVG(P_r) \tag{2}$$

$$RSSI_a = 10 \times \log 10(AVGP) \tag{3}$$

where

$RSSI_r$: Measured received power (RSSI) in dBm
P_r: Measured received power in milliwatt
$AVGP$: Average measured received power in milliwatt
$RSSI_a$: Average measured received power (RSSI) in dBm

In Bluetooth technology it uses 8 bits to represent the RSSI value and it considers that the RSSI reading is within the Golden Receiver Power Range (GRPR) [7,8]; the GRPR uses upper and lower threshold values to designate the status of the read RSSI value. In the specification it states that it has 20 dB differences between the upper and lower thresholds with ±6 dB variation [7]. With this specification we include in the average RSSI derived in Eq. (3) a reference parameter $\chi_\sigma = 6dB$ as shown in Eq. (4):

$$RSSI_a = 10 \times \log 10(AVG_p) + \chi_\sigma \tag{4}$$

In [9] it describes that the relation between the measured RSSI value and its associated transmission distance can be expressed in natural log form as shown in Eq. (5). From this equation the transmission distance can be then calculated from its measured RSSI value as shown in Eq. (6)

$$RSSI = -((10n)\log 10(d) + A) \tag{5}$$

$$d = 10^\wedge(-(RSSI_a + A)/(10n)) \tag{6}$$

where

n is the path loss exponent.
d is the distance in meters.
A is the RSSI in -dBm at 1 m location.

From our measured data pairs in the RSSI value and its associated transmission distance and express their relation as in Eq. (6) and using the minimum mean square error criterion to find the two parameters n and A in the equation we have n = 1.558 and A = 66.67, or more precisely in our test environment the transmission distance and its associated received RSSI has the relation as shown in Eq. (7):

$$MD = 10^\wedge(-(RSSI_a + 66.67)/(15.58)) \tag{7}$$

where $RSSI_a$ is the measured average RSSI value in dBm and MD is determined distance in meters.

The measured data, i.e. the measured average RSSI value versus transmission distance is plotted in Fig. 6 and in the plot it also overlays the results, from Eq. (7), the derived target distances from the measured average RSSI values; from the plot it reveals that both the measured data and the curve fitting values are quite matched and similar.

From [10] it shows that the path loss can be calculated as $Path\ Loss\ (PL) = P_t - RSSI$ where P_t is the maximum RSSI value when the transmission distance is 0 cm, i.e. $PL =$

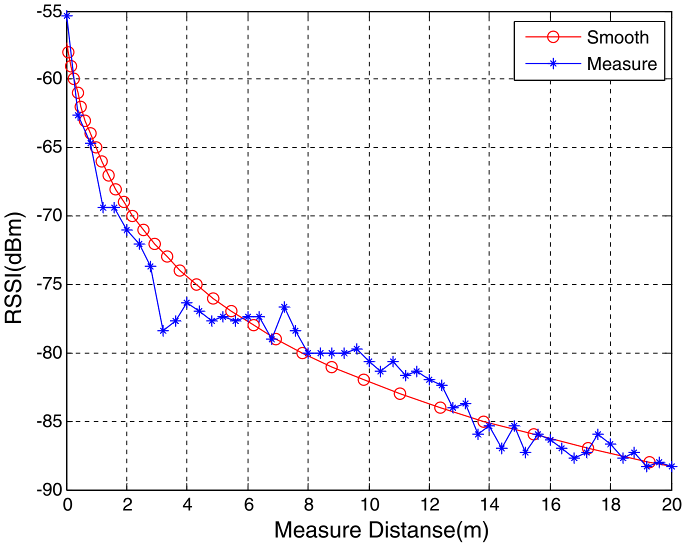


Fig. 6 Measured and simulated fading condition

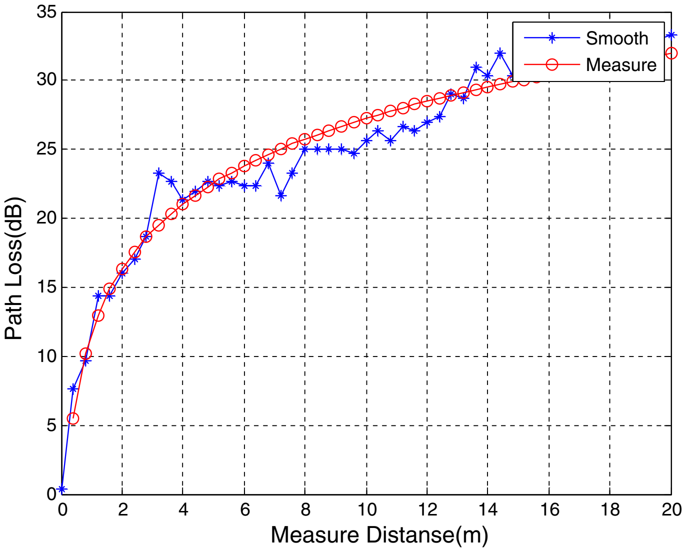


Fig. 7 Path loss model

$-55 - RSSI_a$ and when the $RSSI_a$ is expressed in terms of its relation with the measured distance, from Eq. (6) for MD, the relation between PL and MD has the following relation:

$$PL = 15.58 \times \log 10(MD) + 11.67 \tag{8}$$

The measured path loss PL and its approximated calculated counterpart, from Eq. (8), versus measured distance are plotted in Fig. 7

4 Localization Scheme

When a cellphone under test (target cellphone) is turned on its Bluetooth signal will be radiated in a great circle in all directions with the target cellphone at the circle center and multiple cellphones can use this Bluetooth feature to receive the target cellphone transmitted RSSI value as shown in Fig. 8 [11,12]; every cellphone from its received target cellphone's RSSI can estimate and determine the target cellphone location. If relative locations of two cellphones are known and also these two cellphones receive the target cellphone's RSSI value then we can covert these RSSI values into relative locations between these two cellphones with the target cellphone and then use the triangular function to determine the target cellphone location [13].

We use one cellphone as the transmitter and another cellphone as the receiver; these two cellphones are pointed in the same direction and maintained motionless when they are under test so as to remove the possibility of generating interference due to cellphone's angle motion; ten test points, A to J, as shown in Fig. 9 are selected as the test points. Five RSSI values are measured at each test point and its average value is calculated and taken as the RSSI value for that test point. The final RSSI values at selected test points are calculated and tabulated in Table 1. By selecting several points from this table and use these points RSSI values we can determine the target cellphone's location if the target cellphone is located in the neighborhood of the field trial area.

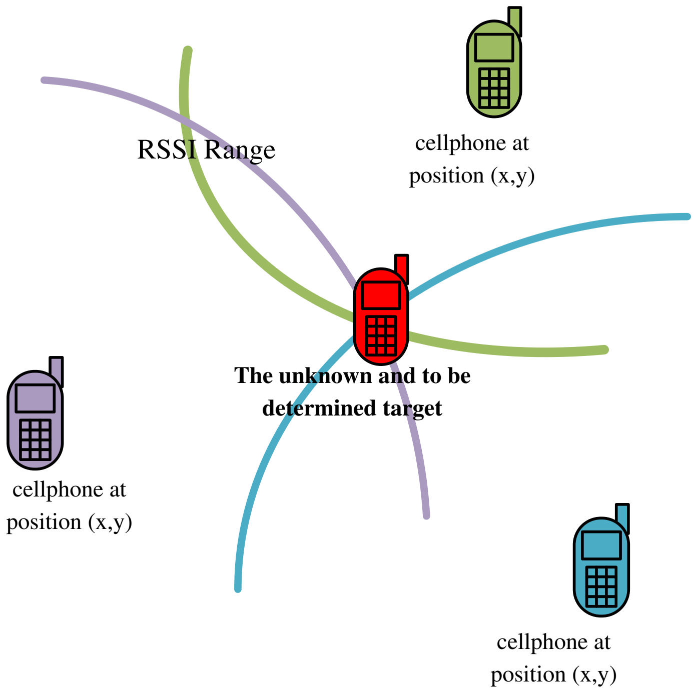


Fig. 8 Locating a cellphone from multiple cellphones

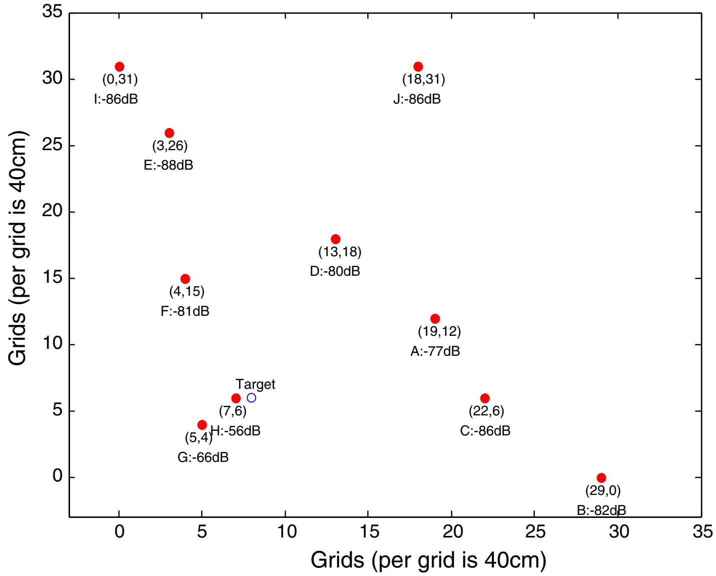


Fig. 9 Field trial environment

Table 1 Points information

Point position	X axis (number of grids)	Y axis (number of grids)	RSSI (measured RSSI) (dBm)
A	19	12	−77
B	29	0	−82
C	22	6	−86
D	13	18	−80
E	3	26	−88
F	4	15	−81
G	6	4	−66
H	7	6	−56
I	0	31	−86
J	18	31	−86

4.1 Two-Point Positioning Method

When we use two test points measured RSSI values to determine the target possible location we will get two possible target locations, one is at the actual target location and the other is at the target symmetric location. And consequently it will have 50 % error rate in using two-point positioning method to locate the target location. It concludes that we will obtain two potential target locations when we use two-point method as the localization method as shown in Fig. 10.

In the figure:

i, j: the position index of a given cellphone.
$UK(x, y)$ the unknown and to be determined target at location (x, y).

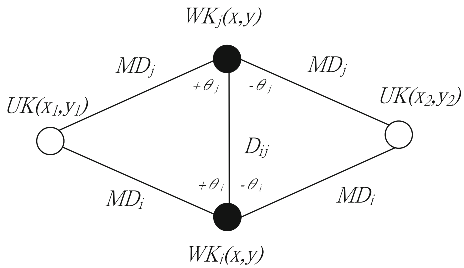


Fig. 10 Two-point positioning method

WK(x, y): the given cellphone at position (x, y).
D_{ij}: distance between the given cellphone i, at location WK_i and the given cellphone j, at location WK_j.
MD_i: the measured/estimated distance from measured $RSSI_a$ value between the known cellphone i to the location of the unknown cellphone

The true target location $UK(x_1, y_1)$ and its symmetric location $UK(x_2, y_2)$ can be determined from the following equations.

$$\begin{aligned} UK(x_1, y_1) &= ((MD_i Cos(\theta_i) + MD_j Cos(\theta_j) + WK_i(x) + WK_j(x))/2, \\ &\quad (MD_i Sin(\theta_i) + MD_j Sin(\theta_j) + WK_i(y) + WK_j(y))/2) \end{aligned} \tag{9}$$

$$\begin{aligned} UK(x_2, y_2) &= ((MD_i Cos(-\theta_i) + MD_j Cos(-\theta_j) + WK_i(x) + WK_j(x))/2, \\ &\quad (MD_i Sin(-\theta_i) + MD_j Sin(-\theta_j) + WK_i(y) + WK_j(y))/2) \end{aligned} \tag{10}$$

4.2 Three-Point Positioning Method

In two-point positioning method it will get two potential target locations for a target object and then if it uses a third cellphone to make RSSI measurement it is possible to estimate or calculate the most potential target location. In three- point positioning method it uses two-point localization algorithm for every two points among the given three points therefore it can get six potential target points information and then we use the following developed algorithm to find the most potential target point. In other words, in three- point positioning it will get a pair of symmetric points from every two points among the given three points when two-point positioning method is exploited. From the following algorithm we can calculate the most potential target location from the three sets of symmetric points.

In the environment when two points, point 1 and point 2, are selected from the given three points then we can from Eqs. (9) and (10) to calculate and get $UK(x_1, y_1)$ and $UK(x_2, y_2)$; and consequently if point 1 and point 2 are available we can calculate to get the distance between point 1 and point 2 as UK_2^1, (x_m, y_m), similarly we get UK_3^2, (x_m, y_m) from given point 2 and point 3, and finally to get UK_1^3, (x_m, y_m) from given point 3 and point 1. Finally from UK_2^1, UK_3^2, UK_1^3 we can find the closest location for the target location.

In three-point positioning method we generate three possible target points $UK_1(x, y)$, $UK_2(x, y)$ and $UK_3(x, y)$ and then find the central location of these three points, this central point will then be the target location. The central location is calculated from the following averaging equation, Eq. (11):

$$PP(x, y) = \frac{\sum_{i \in N} UK_i(x, y)}{N} \tag{11}$$

where N is the number of potential target points used in the averaging operation. And *PP(x,y)* is the most potential location for the unknown location target cellphone.

5 Accuracy Enhanced Positioning Method

5.1 Weighting Among Measured Data

In the previous three-point positioning method we calculate the central point, as shown in Eq. (11), of three potential target locations and consider the obtained central point as the final target location; this algorithm can be further modified to reduce possible error in the location determination. In Eq. (7) of the path loss model it reveals that it exists exponential relationship between the received RSSI value and its measured transmission distance therefore in the localization test when the test signal has long transmission distance its received RSSI will have less percentage variation comparing with that of shorter distance transmission and consequently if RSSI variation is set at a fixed level then the distance estimation error for test signal in long distance transmission may be larger than the resulting distance estimation error when the signal is transmitted over a shorter distance. With this characteristic considered we then introduce a weighting factor based on Eq. (7) for each estimated potential target distance in the localization measurement before performing the final target location calculation from three measured potential target locations. A large weighting factor is imposed for the potential target location which has shorter estimated distance in the final target location calculation and vice versa. The weighting factor for the pth potential target location can then be calculated from following equation:

$$W_p = \frac{\left(\sum_{i \in N} MD_i\right) - MD_p}{\left(\sum_{i \in N} MD_i\right)(N-1)} \tag{12}$$

where MD_i is the ith measured or calculated potential target distance and N is the total number of potential target locations.

After introducing the distance weighting factor for each tested potential target location the final estimated target location can be calculated by modifying Eq. (13) as:

$$PPW_{(}x, y) = \frac{\sum_{i \in N} W_i \times UK_i(x, y)}{N} \tag{13}$$

5.2 Generation of Large Number of Test Points

When it happens that it has many test positions are available for the processing of positioning measurements; then all data processed from these test positions are available for use in the localization algorithm; we will base on the measured RSSI strengths among all available test points to select three locations that have the strongest RSSI values and use these three selected locations to perform weighting summation to get the final location determination. In our simulation we use random number generator to generate 10 test locations and then select three positions with strongest RSSI values from these 10 measured data to perform the final location determination.

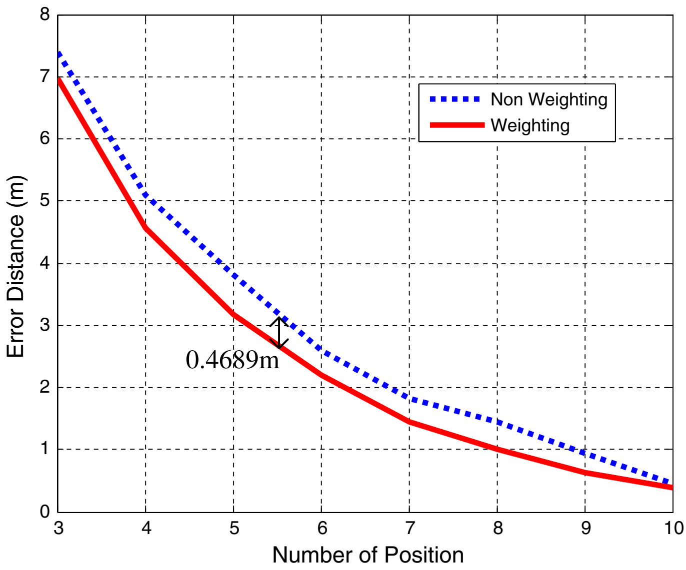


Fig. 11 Distance determination errors with and without implementing the weighting factors and RSSI selection processes

6 Simulation Results

Ten test points, as shown in Fig. 9, have been selected and their received RSSI values have been collected and proceeded in the location determination algorithm after through the processes of introducing the weighting factor for each RSSI value and the selection of 3 largest RSSI values from these test 10 points as introduced in V.1 and V.II we have the simulation results as shown in Fig. 11 after averaging 1,000 realizations. In Fig. 11 the resulting distance determination errors with and without implementing the processes of RSSI weighting factor and RSSIs selections are compared, it appears that we can reduce the distance determination error down below 1 m when a large number of test points with weighting factors are included in the localization algorithm.

In [9] Huang et al. exploited the multi-lateration method in their positioning algorithm it has the simulation results to improve the distance determination error down to 1.5–2 m range. In our localization algorithm it can have the distance determination error down below 1 m when three-point localization algorithm is implemented and the distance estimation error can be further reduced to around 0.4689 m as shown in Fig. 11 when RSSI weighting factor and RSSIs selections are also implemented in the algorithm

7 Conclusion

In this paper we considered the use of three-point localization method to determine the location of a target node, in this method three RSSI values were collected from three test points. It then used two-point positioning method for every two points among the given three test points to determine the possible target location; a pair of potential target locations at symmetric locations were obtained from two-point location method. Then in the three-point localization method it generated three pairs of potential target locations and the target location was finally determined from these three pairs of potential target locations. Two extra processes were then proposed, one was the introducing of weighting factor for each potential target location and the other process was to generate more test points and then to select some strongest RSSI values for using in the localization algorithm. From simulations we can reduce the location determination error down below 1–0.4689 m. This localization algorithm by using Bluetooth technique as we proposed in this paper can have many applications such as in the searching for the missing children, finding the lost cellphone, locating the restaurant etc.

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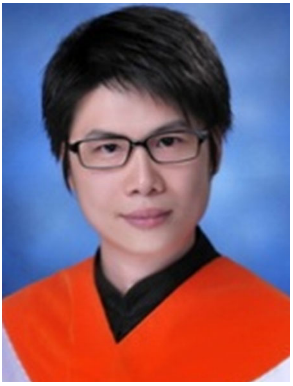

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