Bluetooth Positioning using RSSI and Triangulation Methods

Yapeng Wang, Xu Yang
MPI-QMUL Information Systems Research Centre
Macao Polytechnic Institute
Macao S.A.R.
xuy/yapeng@mpi-qmul.org

Yutian Zhao
International School
Beijing University of Posts and Telecommunications
Beijing, China
ee07b249@bupt.edu.cn

Yue Liu, Laurie Cuthbert
School of Electronic Engineering and Computer Science
Queen Mary University of London
London, United Kingdom
yueliu/laurie.cuthbert@eecs.qmul.ac.uk

Abstract*-Location based services are the hottest applications on mobile devices nowadays and the growth is continuing. Indoor wireless positioning is the key technology to enable location based services to work well indoors, where GPS normally could not work. Bluetooth has been widely used in mobile devices like phone, PAD etc. therefore Bluetooth based indoor positioning has great market potential. Radio Signal Strength (RSS) is a key parameter for wireless positioning. New Bluetooth standard (since version 2.1) enables RSS to be discovered without time consuming pre-connection. In this research, general wireless positioning technologies are firstly analysed. Then RSS based Bluetooth positioning using the new feature is studied. The mathematical model is established to analyse the relation between RSS and the distance between two Bluetooth devices. Three distance-based algorithms are used for Bluetooth positioning: Least Square Estimation, Three-border and Centroid Method. Comparison results are analysed and the ways to improve the positioning accuracy are discussed.

***Keywords*-Bluetooth Positioning; RSSI; Triangulation**

I. INTRODUCTION

Wireless position tracking has been exploited in many areas. A classic example is the Global Positioning System (GPS). Orbit satellites are used to send signals to GPS receivers on Earth (such as “Satellite Navigation” used in vehicles), and these signals are used by the receivers to compute navigation information. Position tracking enables the possibility of delivering personalised and location-based services, which have been increasingly popular in recent years. For instance, Google™ Maps allows users who have GPS on their mobile devices to search for their current locations as well as place-of-interest nearby. However, as the communication between the satellites and GPS receivers requires line-of-sight radio propagation, GPS generally only works well in outdoor environments.

There have been increasing interests in researches for indoor position tracking. The aim is to develop low-cost and easy-to-deploy location-aware applications. These applications can be used in many scenarios such as assets management, staff tracking, indoor tourist guiding in museums, train stations, airports, shopping complex etc. For example in European IST project ADAMANT [1], the researchers built an indoor information system for airport travellers and tailored location bases services were provided. IEEE 802.11 WLAN (also called WiFi) based indoor positioning technique was used to track individual travellers and provide them location based services such as informing travellers their check-in desks, security gates, boarding gates etc.

Wireless positioning algorithms can be broadly divided into three classes: cell ID tracking, triangulation and signal strength based probability. Cell ID methods are the simplest; they map the physical location of the mobile terminal to the cell IDs of mobile network, normally the users are proximately located inside a large circle centred by the location of the base station. Triangulation methods calculate the location based on the distances between specific reference points, where these distances yield an intersecting point where the mobile is located. Signal strength based probability methods combine signal strength measurements to calculate the probability of user’s positions and determine the most likely location.

Triangulation based positioning method is a well-studied method. The method forms circles centred at the access points, where the radius of each circle is determined by 1) the measured signal strength of the mobile terminal or 2) the time elapsed transmitting the signal between the access point and the mobile terminal. An intersection point arises when there are three or more access points within a certain range, and the intersection point gives the estimated location of the mobile terminal. In practice, it is almost impossible to obtain a single interaction point due to errors in measurements. The signal strength measurement can be affected by obstacles and imperfect propagation models used. For example in Fig. 1, there are three intersections points, the final position estimation of point x will be the average coordinate of intersection points x1, x2 and x3.

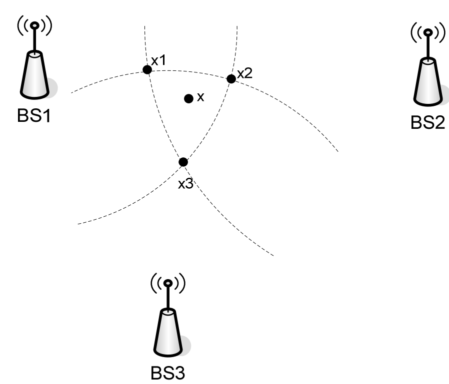

Fig. 1. An example showing multiple intersection points existence using triangulation.

Four popular techniques have been developed based on the triangulation method. They utilise time, time difference, angle of signal arrival and signal strength for estimating the distance between a mobile terminal and base stations.

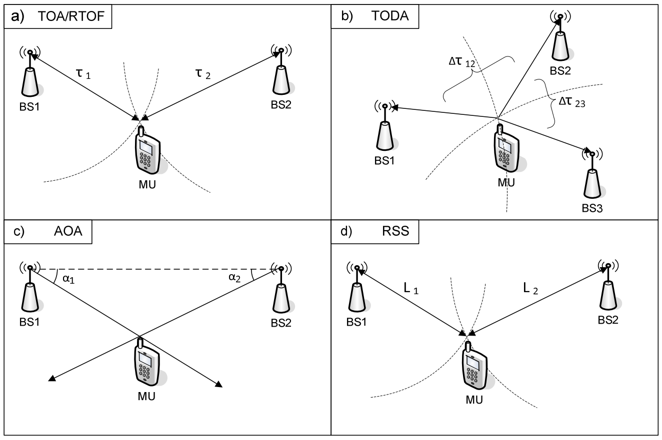

Fig. 2. Four measuring methods for triangulation.

In TOA systems, shown in Fig. 2 a) (such as [2, 3] using direct sequence spread-spectrum (DSSS) measurements, and [4] using ultra-wide band measurements), the time needed to transmit a signal from base station to mobile terminal (at the speed of light) is recorded and used for calculating the distance. However, it requires precise time synchronisation of all involved fixed and mobile units. In TODA systems (Fig. 2 b)) such as proposed in [3] for WiFi, the mobile sends positioning signals to surrounding measuring units and the time-difference of arrival of the received signals is evaluated. The main benefit of TODA systems is that it is only necessary to synchronise the measuring units (i.e. the base stations). This synchronisation is normally done through backbone network. In AOA systems (Fig. 2 c)) [5, 6], the position is calculated using goniometry. The measuring units use directional antennas or antenna arrays to measure the angle of incoming signals send by mobile. The intersection of several measuring direction pointers yields the positioning of the mobile. Received Signal Strength (RSS, also called Received Signal Strength Indication, RSSI) based method (Fig. 2 d)) utilise the characteristic of radio propagation over space. Using a proper propagation model, we can calculate the distances between a mobile to base stations, thus derive the location of the mobile.

II. Bluetooth Based Positioning

Bluetooth is a short-range wireless technology which was developed in order to provide low-cost and low-bandwidth communication scenarios such as acting as a cable replacement to connect devices such as mobile phones, headsets and portable computers. Bluetooth devices can also be used to connect several devices into a Personal Area Networks (PANs). Bluetooth nowadays has a large penetration in the market, it can be seen in most mobile phones, and also in printers, computers, cameras etc. Bluetooth has been continuously evolving, by July 2010, there are total six versions of Bluetooth standards been developed: v1.1/1.2/2.0/2.1/3.0/4.0.

Wireless positioning has been well studied using WiFi. As WiFi has a comprehensive API designed for developers to retrieve all kinds of parameters related to positioning. Bluetooth is an alternative technology for indoor positioning. Compares to WiFi based positioning, Bluetooth has several advantages: a) Cost: the cost of Bluetooth chip is lower than WiFi and b) Power consumption: Bluetooth consumes much lower power than WiFi, Bluetooth uses a fifth of the power of WiFi as it requires a lower transmission power and provides a mechanism for automatic power control. This makes Bluetooth a more attractive positioning technology as power is critical in mobile devices.

Therefore, in some scenarios where positioning precision and response time is not critical but device operation time (or battery power) is more important, Bluetooth positioning is a more preferable technology than WiFi. For example, city and tourism guild programs for smartphones, daily people and logistic tracking in hospitals, company and large firms etc.

However, compares to WiFi, there are much fewer Bluetooth based positioning system. The reason is that compares to WiFi, there are several technical hurdles to overcome for Bluetooth based positioning systems.

- Bluetooth is designed for low cost communication, the Bluetooth standard lacks precise time synchronisation, therefore time based triangulation methods such as TOA, TODA are not difficult to implement.
- Bluetooth is designed to be used in low footprint devices. Directional or array antennas are rarely used. There for it is difficult to use angle measurement methods like AOA.
- RSSI reading is not well defined in Bluetooth standard. The RSSI reading is unreliable and device dependent, especially for early Bluetooth standard. Furthermore, it requires two devices to be connected in order to measure the RSSI values, and connecting two devices may take dozens of seconds. However, since Bluetooth 2.1, there is a new method to measure RSSI without connection.

Before Bluetooth 2.1, the RSSI query result is the difference between the real received signal in dB and the optimal receive power range, also known as Golden Receive Power Range (GRPR). RSSI values reported through the HCI are also vendor dependent. Bluetooth has a feature called automatic power control. The transmitter and receiver negotiate so that the transmitter can adjust its transmitting power to ensure the receiver to receive at an optimum power level. However, if the distance between the transmitter and the receiver is too close or too far, the automatic adjustment mechanism cannot work out an optimum power level and in that case, the RSSI readings are higher or lower than zero. Power control should only be used if both parties in the connection support the feature.

In [7], a Bluetooth dongle with Cambridge Silicon Radio (CSR) [8] chipset is measured for studying the relationship between the RSSI and the actual received power, the relationship and golden range concept for a Bluetooth dongle is shown in Fig. 3. From the figure we can see that we cannot use RSSI directly to calculate distance, as there is range in where if you put the mobile, you will always get the RSSI reading as zero.

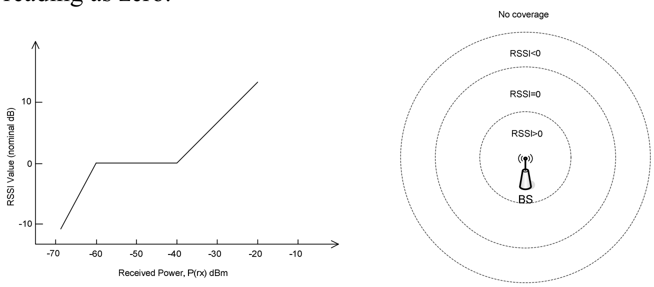

Fig. 3. RSSI readings compares to the golden receive range.

Although technically, Bluetooth is less favourable positioning technology than WiFi, Some Bluetooth positioning systems have been studied in recent years. In [9], The IcING project developed a Java Bluetooth spotter to scan for any Bluetooth devices in range, and compare them with a known database to decide the user's approximate location . This cell ID based J2ME solution provides a simple and easy way to implement a positioning system that can used for approximate indoor guiding. The work in [10] proposed an indoor positioning architecture by interconnecting several Bluetooth stations using Ethernet. These stations work as master Bluetooth devices and periodically scan for slaves (mobile devices). These mobile devices then can be located within the approximate range of the Bluetooth stations. These cell ID based approaches provide a simple and easy way to achieving Bluetooth positioning; however the accuracy is the major drawback.

RSS based Bluetooth positioning also has been studied in some researches. In [7], Pollard et al studied the Bluetooth dongle based on CSR chipset and found that by disabling the automatic transmission control, using RSSI readings can estimate the distance between two Bluetooth devices with a mean absolute range error of 1.2 m. The work in [11] developed a RSSI distance estimation based Bluetooth positioning system based on a free space propagation model. Using triangulation accuracy of 3 meters is achieved (not considering environment change though). The work in [12] has found that by using Ranger's BT 2100 Bluetooth USB adapter (which uses CSR chipset), it is possible to retrieve the absolute RX power level through inquiry. Therefore it can be used to calculate the distance between two devices. All of these RSS based approach utilise the RSSI feature in old Bluetooth standard (before 2.1), therefore they inherit the drawbacks: need pre-connection, RSSI is not reliable or need special method/modification to Bluetooth in order to get a proper RSSI value.

III. Desining the Positioning System

In this research, we targeted the new Bluetooth 2.1 (or newer) standard, as they are now covering major consumer electronics. Since Bluetooth 2.1, a new Bluetooth HCI interface was introduced called *Inquiry_With_RSSI*. By using this HCI command, a program could sense all surrounding Bluetooth devices in one go and a list of all sensed Bluetooth devices alone with their RSSI values can be found. In order to achieve this function, we have studied different APIs to get it working. And finally we found that Android is the perfect platform to implement.

Android is an open source mobile operation system (OS) that developed by Google. In the last few years it has dramatic growth and now it is top one mobile OS for smart phones. Compares to other mobile OS or API, it offers free API for developer to developing their own applications with accessing to different resources including the latest Bluetooth API. The Java-style programming also makes Android an extendable and easy-to-learn developing platform. Most of all, it is open source and free for developers.

For this research, we have found that it is possible to use *Inquiry_With_RSSI* method on mobile phones running android 2.0 or above. A program has been written to utilise this function. As shown in Fig. 4, one of the features of the program is called "Start to search". It will utilise *Inquiry_With_RSSI* command inquiry nearby Bluetooth devices. When we click this button, a list of nearby Bluetooth devices names, MAC addresses and the corresponding RSSI values were retrieved.

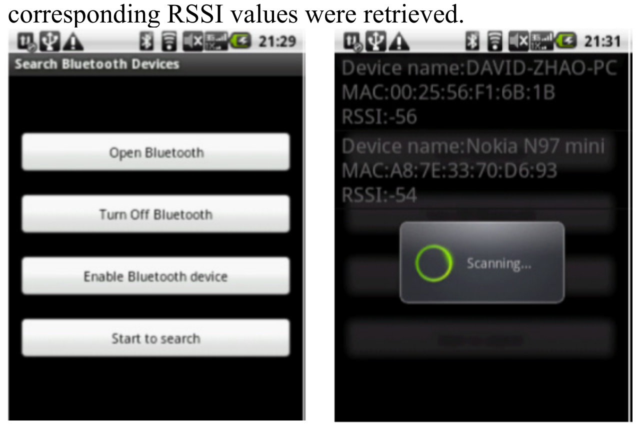

Fig. 4. Four measuring methods for triangulation

In this research, a 6*8 square meters area in a classroom is used for the Bluetooth positioning system to work on. An Android mobile phone acts as the mobile and four other mobile phones act as the reference node. The layout of the testing area is shown as Fig. 5.

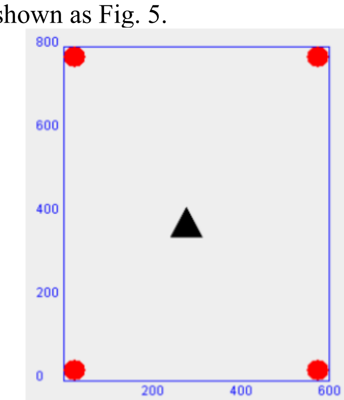

Fig. 5. Testing area layout

In order to calculate the distance between two radio devices using RSSI, we must use a proper radio propagation model. When radio transmit in outdoors, especially when there are few obstacles, the main contribute to path loss is free space propagation loss (the air absorption loss is negligible) and it can be calculated using free space path loss equations. Therefore, many RSS based systems are based on free space radio propagation lost equations. For example, the free space propagation loss is proportional to $1/r^2$, where r is the distance between the transmitter and receiver. However, in indoor situations, as there are many obstacles between transmitter and receiver like walls, furniture and even human bodies. The propagation loss due to radio signal absorption and diffraction by these obstacles cannot be ignored. Therefore, we have adopted a more sophisticated indoor propagation model described in [13] our for location estimation, it is shown in (1):

$$RSSI = -(10n\log_{10} d + A) \tag{1}$$

The Radio Frequency (RF) parameters A and n are used to describe the network environment. the RF parameter A is defined as the absolute energy which is represent by dBm at a distance of 1 meter from the transmitter, which is RSSI reading at 1m from the transmitter; n is the signal transmission constant, and it is relevant to signal transmission environment; d is the distance from the transmitter node to the receiver node. The RSSI value can be measured in Android based Bluetooth phone as discussed before. In order to calculate d using (1), we need to estimate environmental factor n first.

When the mobile does not enter the positioning area, there are only the reference nodes in the positioning area. Therefore the environmental factor n_i between two reference nodes can be estimated as (2):

$$n_i = \left(\frac{RSSI-A}{10\log_{10} d_i}\right) \tag{2}$$

RSSI is the received power of reference node, d is the distance between the two reference nodes and it is known. We can get environmental factors between the two reference nodes *i, j*. For every positioning area we can get some pairs of environmental factors. Because fluctuations in the *RSSI* measurements exist, so the final result of environmental factors is not the same. Suppose in t time n stay in the same value. N of the nearest reference node, we get N environmental factors, taking mathematical expectation we have:

$$\hat{n} = E\left(\frac{RSSI_i-A}{10\log_{10} d_{ij}}\right) = \frac{1}{N}\sum_{i=1}^{N}\frac{RSSI_i-A}{10\log_{10} d_{ij}} \tag{3}$$

$i = \{1 \dots N\}$ is the set of all reference nodes, the *RSSI*, A is updating as time t as period. In order to reduce the error of environmental factors generated by measured data, take the expectation of measurement result of n time. Take period T, let updating time $n=T/t$, so the estimated environmental factors are:

$$\hat{n} = E\left(\frac{RSSI_i-A}{10\log_{10} d_{ij}}\right) = \frac{1}{N}\sum_{i=1}^{N}\frac{E*RSSI_i-A}{10\log_{10} d_{ij}} \tag{4}$$

The $\mathrm{E(RSSI)} = 1/\mathrm{n}\sum \mathrm{RSSI}$, when the mobile enter the positioning unit, the reference nodes transmit the value A and n to the mobile as the environmental factor. In this work, we gathering different distances and RSSI value among the four reference nodes in the testing area. Using (4) we finally get A=40, n=2.3 to represent our special testing area, so (1) can be transformed into (5):

$$RSSI = -(10 * 2.3\log_{10} d + 40) \tag{5}$$

Using (5), when we get the RSSI value, we can easily calculate the distance d. However, as mentioned before, if we get all distances between the mobile and reference nodes, they are not likely intersecting into one point. Therefore we need some algorithms to calculate the estimated location of the mobile. In this research we used three different algorithms to calculate the position.

A. Least square estimation

In wireless positioning systems using distance triangulations, the most widely used algorithm is called Least Square Estimation (LSE) [14]. LSE is widely used in the distance based positioning system. In the cellular network, as long as you establish the corresponding characteristic equation basing on the measurement, we can solve the location of the mobile. Setting the equation which is based on measurements:

$$Y = AX \tag{6}$$

Here, Y is a known *N*1* dimensional vector, A is *N*M* matrix. If *N>M*, the number of equation is greater than the number of unknown numbers, we can obtain the optimal X using LSE. The idea of LSE is to make the least value of sum of square of error, then:

$$f(x) = (AX-Y)^2 = (AX-Y)^T(AX-Y) \tag{7}$$

We get the minimum of the above function, if A^TA is non-singular, we get:

$$X = (A^TA)^{-1}A^TY \tag{8}$$

In practice implementation, according to the accuracy of each measurement, the LSE has different weights. By choose a reasonable weighting matrix W, we can improve the positioning accuracy. Theory shows that when the measurement obtains the inverse of matrix of error variance, the estimated error variance will be smallest. But in practical application, how to define the weighted matrix W remains to be further studied.

B. Three-border positioning

We know the coordinates of reference nodes *A, B, C* are $(x_1, y_1)(x_2, y_2)(x_3, y_3)$ and the distances between these nodes to the mobile are d_1, d_2, d_3. Suppose the coordinates of the mobile are (*x,y*), the equations (9) can be established:

$$\begin{aligned}(x-x_1)^2+(y-y_1)^2=d_1^2\\(x-x_2)^2+(y-y_2)^2=d_2^2\\(x-x_3)^2+(y-y_3)^2=d_3^2\end{aligned} \tag{9}$$

Through solving the equation we can get the coordinated of the mobile.

C. Centroid positioning

The geometric centre of a polygon is called the centroid. The average value of polygon vertex is the coordinates of the centroid node. For the Centroid positioning algorithm we need firstly determine the region that contains the mobile, and then calculate the centroid of the region. The centroid acts as the location of mobile. For example in Fig. 6, the measured RSSI values from the mobile to reference nodes can yield four distances. We can draw four arcs using these distances from the corresponding reference nodes and we can get four intersecting point *A, B, C* and *D*.

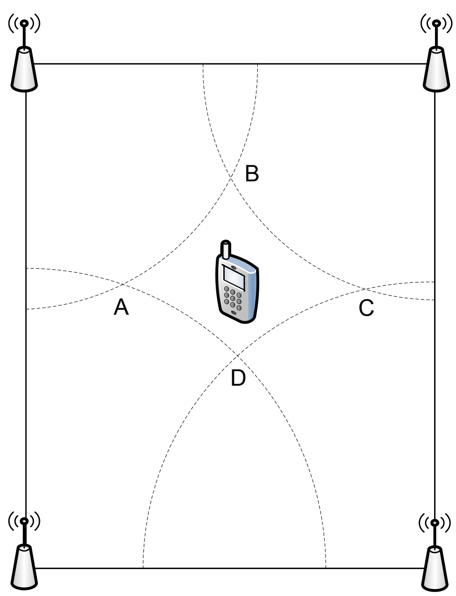

Fig. 6. Centroid positioning concept

Set the polygon defined by *A, B, C* and *D* with coordinates $A(x_1, y_1), B(x_2, y_2), C(x_3, y_3), D(x_4, y_4)$, the coordinates of the mobile *(x, y)* is the polygon's centroid:

$$(x, y) = \left(\frac{x_1+x_2+x_3+x_4}{4}, \frac{y_1+y_2+y_3+y_4}{4}\right) \tag{10}$$

IV. Result and Analyese

A. Positioning results

In the positioning experiments, we first put the mobile in the middle of the testing area, i.e. at the coordinates (300,400), by getting RSSI (average of 6 scan readings) from four reference nodes and calculates the corresponding distances, we use three different algorithms to estimate the mobile's location, here is the first result showing in Table 1:

TABLE I

Real/estimated position	LSE	Three-border	Centroid
(300,400)	(297, 400)	(296, 384)	(269,364)

We can see that, by using the same distances in these three methods, we can get three different results. These three results are all performs well with small positioning error. However the position calculated by LSE is the most closed point to the real position.

Instead of the central point, we also tested points at different locations of the testing area. They are (100,240), (300,300), (450,200), (600,700), (150,300) and (250,600). The estimated positions of the mobile using three different algorithms are recorded. The estimated positions vs. the real positions are plotted as Fig. 7.

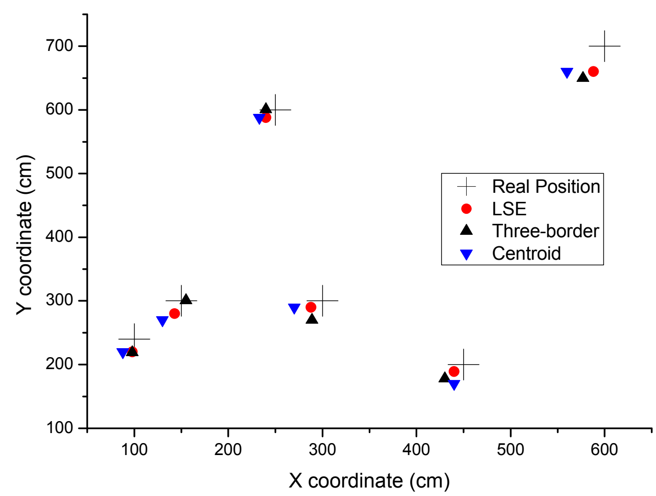

Fig. 7. More testing point's estimated position vs. real position.

From the chart we can see that all three algorithms perform well in terms of positioning accuracy, however, LSE yields slightly better results. The reason LSE performs a bit better may because our special experiments. From our view, in general, if we can get accurate RSSI readings, a proper path loss model and then calculate the distances (between the mobile and reference points) accurately, all three positioning algorithms yields satisfied results.

B. Effect of human body

In this part, the testing of effects by human body on RSSI readings is performed. We put the mobile node at position (300,400), the distances between the mobile and the other reference nodes are equally 5 meters.

We then cover the antenna part at the top of the mobile phone, and at same position we collect RSSI for 6 times. These readings are compared with RSSI without covering the antenna part. The RSSI readings for these two methods are shown in Fig. 8. The chart clearly shows that when the human body covers the mobile phone, the signal are weakened and the RSSI readings are dropped by about 6-8 dB.

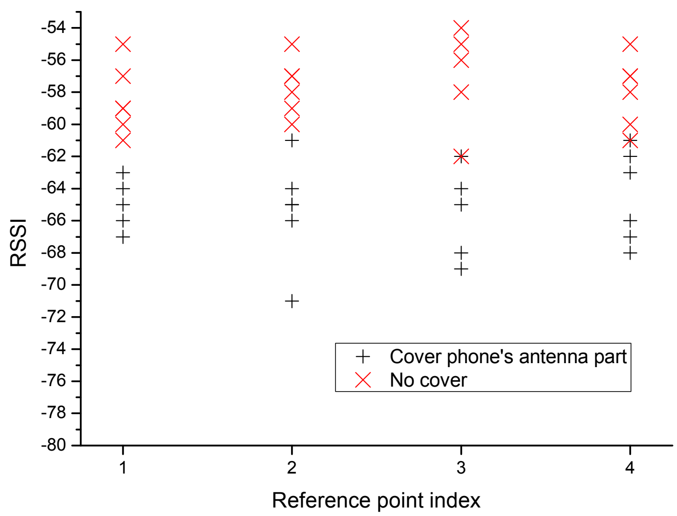

Fig. 8. More testing point's estimated position vs. real position.

C. *Improve estimation accuracy*

There are two main approaches to mitigate positioning error, the first is to choose and formulate a proper position algorithm, and the second is to improve the RSSI reading accuracy. As the radio signals changes quickly duo to fast fading effects, the instant RSSI readings may fluctuate and may not fit our path loss model. However, we can choose a filter to smooth the RSSI readings. The most commonly and easily achieved filters are average filter and weighting filter. These filters take several readings and average those to get a more accurate result that reflects the path loss model. In this study, we choose 6 scan readings to get a relatively accurate RSSI reading. However, as taking more readings need time. A trade-off between the positioning accuracy and the positioning speed must be taking into consideration.

D. *Future work*

The current work uses only the RSS and triangulation based methods for Bluetooth positioning. The initial work is based on a simple indoor environment in a classroom. Further testing in different environment and more detailed result analyses have been planned.

For the triangulation methods, we need to know the exact location of the reference nodes. Another category of algorithms use probability based approaches. These algorithms do not need the locations of the reference nodes. However, a training phase is needed in order to make the positioning working properly. These algorithms on Bluetooth positioning are potentially useful and they need to be studied.

IV. Conclusion

In this work, we analysed different indoor wireless positioning methods, especially the RSS based Bluetooth positioning. After analysis, a novel approach utilise a feature in new Bluetooth standard to get RSSI readings was designed and implemented for mobile Android platform. After finding a proper propagation model, a RSS and triangulation based positioning scheme was defined and three distance based triangulation algorithms were implemented. Result analyses show that the RSS based triangulation positioning yields very good results. More work has been planned to extend this research to more complicated scenarios and with more algorithms.

References

[1] Y. Wang, *et al.*, "An Agent-based Passenger Support System over Heterogeneous Wireless Infrastructures in an Airport Environment," in *IASTED International Conference on Networks and Communication Systems (NCS 2006)*, Chiang Mai, Thailand, Mar 2006, pp. 240-244.

[2] B. B. Peterson, *et al.*, "Spread spectrum indoor geolocation," *J. Inst. Navigat.,* vol. 45, pp. 97-102, 1998.

[3] X. Li, *et al.*, "Comparison of indoor geolocation methods in DSSS and OFDM wireless LAN," in *IEEE Veh. Technol. Conf.*, Sep. 2000.

[4] N. S. Correal, *et al.*, "An ultra wideband relative location system," in *IEEE Conf. Ultra Wideband Syst. Technol.* , Nov 2003, pp. 394-397.

[5] B. D. V. Veen and K. M. Buckley, "Beamforming: A versatile approach to spatial filtering," *IEEE ASSP Mag.,* vol. 5, pp. 4-24, Apr. 1988.

[6] P. Stoica and R. L. Moses, *Introduction to spectral analysis*: Englewood Cliffs, NJ: Prentice-Hall, 1997.

[7] J. Pollard and S. Zhou, "Accurate indoor position determination," Department of Electronic and Electrical Enginnering, University College London.

[8] Cambridege Silicon Radio. Bluecore Bluetooth chipset.

[9] S. Rooney, *et al.*, "An open source approach to wireless positioning techniques," in *The 5th International Symposium on Mobile Mapping Technology (MMT'07)* Padua, Italy, May, 2007, pp. 28-31.

[10] G. Anastasi, *et al.*, "Experimenting an indoor Bluetooth-based positioning service," in *Proceedings of the 23rd International Conference on Distributed Computing Systems Workshops (ICDCSW'03)*, 2003.

[11] J. G. Castano, *et al.*, "Local positioning for wireless sensors based on Bluetooth," presented at the Radio and Wireless Conference, 2004.

[12] A. K. M. M. Hossain and W.-S. Soh, "A comprehensive study of Bluetooth signal parameters for localization," in *The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC' 07)*, 2007.

[13] J. Albowicz, *et al.*, "Receive position estimation in sensor network," presented at the IEEE International Conference on Network Protocols, 2001.

[14] I. Manolis and A. Lourakis, "A Brief Description of the Levenberg-Marquardt Algorithm Implemented by levmar," pp. 564-572, 2005.