Trilateration Technique for WiFi-Based Indoor Localization

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***Abstract*—In recent years, due to the increasing number of computers and smartphones which can detect Wi-Fi signals, wireless local area networks (WLAN) have been installed almost everywhere. WLAN based indoor positioning systems have been widely investigated and used, because of their accessibility, low cost and not requiring any additional hardware support. This study presents a Wi-Fi based trilateration method for indoor positioning using Received Signal Strength (RSS) measurements. The distances between Access Points (AP) and the mobile device were estimated from evaluated RSS values by signal propagation model. The position of the mobile device was estimated using these distances through trilateration method. The application was carried out in the line-of-sight region.**

Keywords- Indoor Positioning; Wi-Fi; Trilateration; RSS.

I. INTRODUCTION

Indoor positioning systems are used to determine the position of people and objects in indoor environments. Nowadays, many people are spending most of their time in gigantic structures [1], thus the importance of indoor positioning systems is increasing. People want to reach accurate positioning in indoor environment which is obtained by Global Navigation Satellite System (GNSS) systems for the outside of the buildings. In the GNSS system, the conditions needed are a direct line of sight between the receiver and the satellites and the connection of at least four satellites simultaneously. The desired accuracy cannot be possible to achieve with GNSS systems in indoors environments. Hence, the emergence of other systems and approaches in determining indoor positioning has become inevitable. In the indoor environment, some technologies have started to use systems, such as; Wi-Fi [2]-[7], GNSS like systems [8], radio frequency identification (RFID) [9], Ultra Wide Band [10], ZigBee [11], Camera [12] and infrared. Among these technologies, Wi-Fi based indoor positioning is a very popular technology because of its widespread utilization in mobile devices (laptop, smartphone, etc.). Moreover, wireless signals are accessible everywhere like shopping malls, campuses, airports, exhibition halls, office buildings, warehouses, underground parking and even homes. So, Wi-Fi based indoor positioning does not require any additional equipment and associated cost for indoor positioning applications.

This paper proposes an indoor positioning system to estimate the position of the mobile device by using trilateration method which uses Received Signal Strength (RSS) data from Wi-Fi access points. The study consists of two main stages; the first stage is distance estimation. In this stage, the distance between APs and the mobile device is obtained by RSS values simultaneously from 4 access points by signal propagation model. In the second stage, the position of the mobile phone is calculated by four distances via trilateration algorithm.

The rest of this paper is structured as follows. In the next section, we present the distance estimation stage. Path loss model were also described in this section. Section 3 explains the position estimation stage using trilateration technique. Application has been presented in Section 4. Finally, Section 5 concludes with a summary of results and gives possible future research.

II. DISTANCE ESTIMATION

In Wi-Fi based indoor positioning, establishment of correct relationship between distance and received signal strength is very important in order to obtain accurate positioning. However, due to the reflection, refraction and attenuation effects of signals, modelling of this relationship is very difficult in an indoor environment. RSS-based indoor positioning is also affected by environmental changes and the fluctuation of the RSS values restricts the accuracy of the estimation. Even in line-of-sight area RSS values are

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continuously changing because of the signal attenuation. In literature, many Wi-Fi based signal propagation models have been used to model signal propagation. In this study, a model proposed by Chipcon [1][7] was used. The formulas of this approach are explained below.

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

$$n = -\left(\frac{RSSI - A}{10 \log_{10} d}\right) \quad (2)$$

The value n is the signal propagation constant, where d is the distance between the mobile phone and access points, and A is the received signal strength in a meter's distance from the AP. The value A was obtained experimentally from a meter's distance to the AP. The constant n was calculated using (2). Using (1), the distances between AP's and the mobile phones are calculated in terms of RSSI values.

III. POSITION ESTIMATION

Trilateration is a method that determines the position of an object based on simultaneous range measurements from at least three references APs at known locations. To calculate the position of the mobile devices through trilateration technique, (3-8) were used [5][6];

$$d_i = \sqrt{(x_i - X_1)^2 + (y_i - Y_1)^2 + (z_i - Z_1)^2} \quad (3)$$

$$A\vec{x} = \vec{b} \quad (4)$$

$$A = 2\begin{bmatrix} (X_2 - X_1) & (Y_2 - Y_1) & (Z_2 - Z_1) \\ (X_3 - X_1) & (Y_3 - Y_1) & (Z_3 - Z_1) \\ (X_4 - X_1) & (Y_4 - Y_1) & (Z_4 - Z_1) \end{bmatrix} \quad (5)$$

$$\vec{b} = \begin{bmatrix} (X_2^2 - X_1^2) + (Y_2^2 - Y_1^2) + (Z_2^2 - Z_1^2) - (d_2^2 - d_1^2) \\ (X_3^2 - X_1^2) + (Y_3^2 - Y_1^2) + (Z_3^2 - Z_1^2) - (d_3^2 - d_1^2) \\ (X_4^2 - X_1^2) + (Y_4^2 - Y_1^2) + (Z_4^2 - Z_1^2) - (d_4^2 - d_1^2) \end{bmatrix} \quad (6)$$

$$\vec{x} = [x \quad y \quad z]^T \quad (7)$$

$$\vec{x} = (A^T A)^{-1} A^T \vec{b} \quad (8)$$

where d_1, d_2, d_3 and d_4 are established distances between AP's and mobile device. (X_1, Y_1, Z_1), (X_2, Y_2, Z_2), (X_3, Y_3, Z_3) and (X_4, Y_4, Z_4) are the known coordinates of APs. The $\vec{x}$ is the coordinates of the mobile phone. Figure 1 depicts the design of the trilateration based indoor positioning system.

IV. APPLICATION

The test-bed is the Line of Sight (LoS) indoor environment that covers a 7.87m x 10.28m area. This system consists of 4 access points which were placed in corners of the area and a mobile phone. The mobile phone which has an android operating system is capable of Wi-Fi access and receiving Wi-Fi signals from all AP's in the vicinity. Four similar access points transmit the 2.4 GHz Wi-Fi signals (IEEE 802.11n) simultaneously. These signals are received by the mobile phone and are regulated through Java codes (Mac Address of AP's, signal frequency, signal rate in dBm) which works integrated into Android operating system. Using (1) and (2), the distances between the access points and the mobile phone were estimated using RSSI values. Using these distance data, the position of the mobile phone was estimated through trilateration technique. This application was carried out at 34 different points and the geometric distribution of the points was shown in Figure 2. Measurements were conducted 100 times for each of these points and the mean values were depicted in Figure 3. Known coordinates of these points were obtained by precise geodetic method.

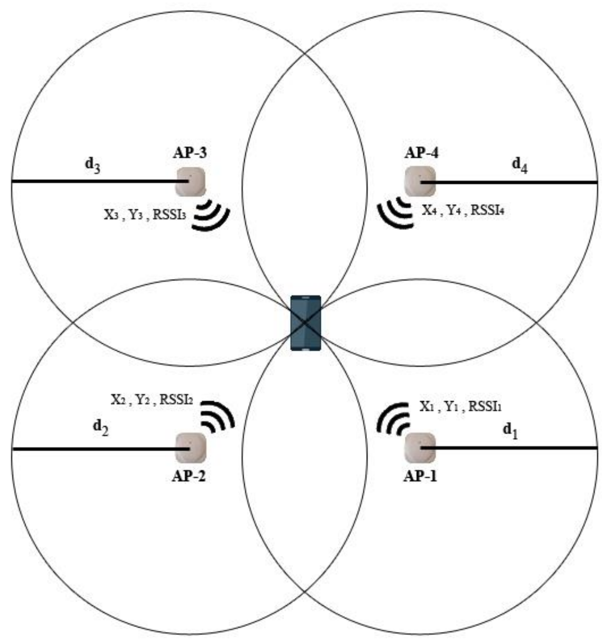

Figure 1. Trilateration method.

The results show that positioning accuracy of this system ranges from 1.3 m to 8.6 m in an indoor environment and the mean accuracy of the system is 4.2 m (red line in Figure 3). The standard deviation of the mean is 1.845 meters and it passed the $\chi 2$ test at 95% confidence level. Although some of the values are enough for many indoor positioning applications, it is very difficult to say that the system has enough accuracy for most of the points.

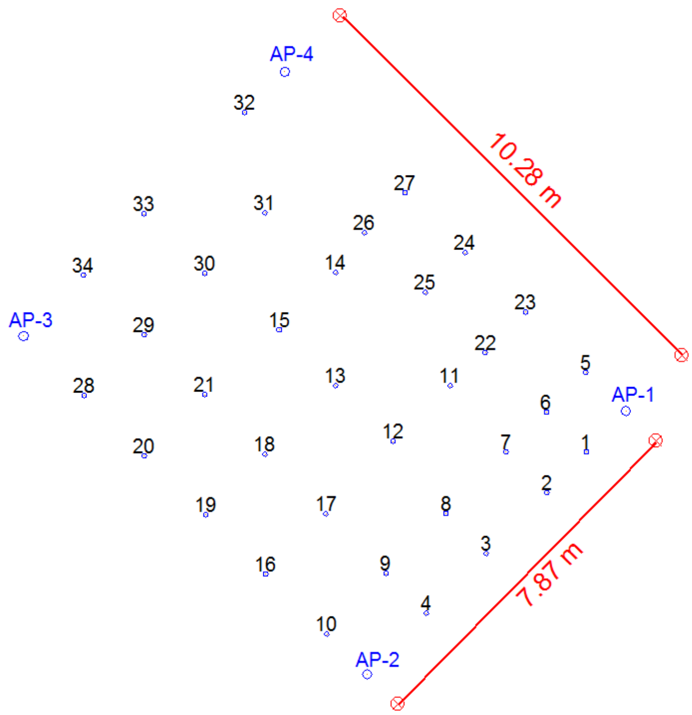

Figure 2. The geometric distribution of APs and observed points by trilateration method.

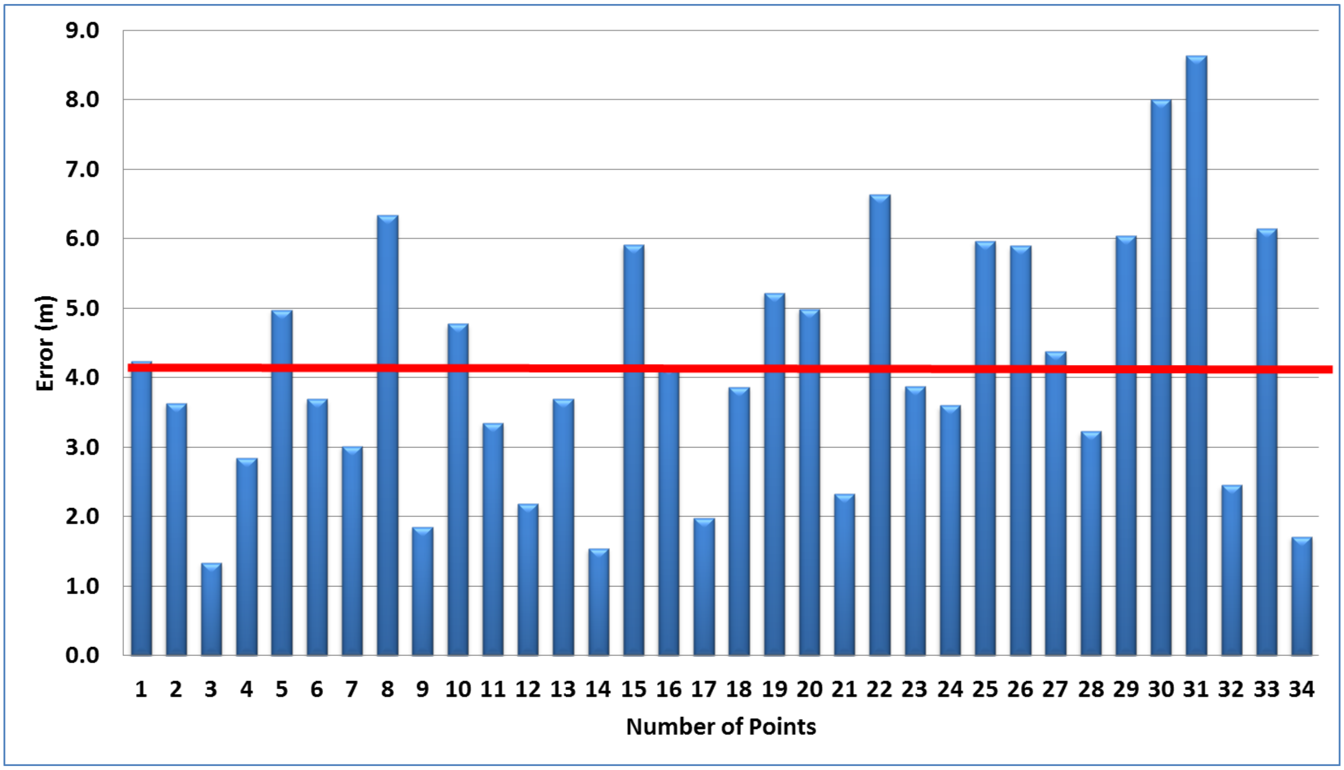

Figure 3. The errors indicates the differences between known coordinates and estimated coordinates of the points. Red line shows the mean value of these errors.

V. CONCLUSION AND FUTURE WORK

Wi-Fi is prevalent in most public buildings, such as campuses, shopping malls, hospitals, museum, exhibitions and even homes. So, Wi-Fi based indoor positioning systems do not require any additional infrastructure and cost. The user can use these systems using their mobile devices which can reach Wi-Fi signals.

This method proposes the cost effective solution to the users. This experiment was carried out along the hallways where all AP's were located at the line-of-sight to the mobile device. The Wi-Fi signals between APs and a mobile device are very sensitive to extraneous noise, thus the estimated distances are very inaccurate, even in the LoS area. Due to errors in the received signal strength, the distance between the transmitter and the receiver cannot be correctly calculated, and this leads to incorrect position estimation. To obtain a more accurate solution, the fluctuations of signals should be regulated by using other methods and algorithms.

This application was conducted in Line-of-Sight area and static measurements were evaluated. In our future work, we will apply kinematic application at more complicated area. Moreover, we intend to perform other path loss models and position estimation methods with the integration of inertial sensors to obtain more accurate position estimation.

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