Improving Accuracy in Indoor Localization System Using Fingerprinting Technique

Saddam Alraih and Abdulraqeb Alhammadi
Faculty of Engineering
Multimedia University
Cyberjaya, Selangor, Malaysia
eng.alraih@hotmail.com, abdulraqeb@ieee.org

Ibraheem Shayea and Ahmed M. Al-Samman
Wireless Communication Centre, Universiti Teknologi Malaysia, UTM
Skudai, Johor, Malaysia
{Ibr.shayea, ahmedsecure99}@gmail.com

Abstract: **Indoor localization system is an important topic in the wireless navigation system. Many technologies, such as Wi-Fi, Bluetooth, and ZigBee, have been developed for the indoor localization system; however, these systems still demonstrate poor accuracy and performance. The indoor localization system using Wi-Fi signals is the best option for indoor localization because most of the buildings are covered by Wi-Fi access points. In this paper, we proposed a clustering algorithm to improve the system accuracy for indoor environment and reduce computational time. Fingerprinting technique was used to evaluate the performance of the proposed algorithm. Results show that the clustering algorithm achieves an average distance error of 2.4 m compared with the non-clustering algorithm, which has an average distance error of 3.4 m. In particular, the clustering algorithm improves the system accuracy by 41% compared with the conventional algorithm. Moreover, the clustering algorithm reduces the computational time of the system that requires computing the prediction of mobile user location.**

Keywords: Bayesian, indoor localization, fingerprinting.

I. INTRODUCTION

Localization technology is used to localize and determine the location of the objects, such as devices and people. Global positioning system (GPS) is the most popular system used for positioning and navigation purposes [1]. GPS is used in many different applications, such as navigation, mapping, timing, tracking, and positioning, and in military and civilian fields. Despite these applications and features, GPS is inefficient in the indoor environment because of the non-line-of-sight channel. Researchers and developers have formulated a solution, namely, an indoor localization system, to overcome this issue. This system is working in the indoor environment to find the location of the objects. Many technologies and techniques are used for the indoor localization system.

Many techniques are used for localizations, such as Bluetooth, Wi-Fi, ultrawide band (UWB), ZigBee, lateration, and fingerprinting are all localization systems for the indoor environment. Bluetooth is a technology that uses low power and changes data over a short distance at a frequency band between 2400 and 2480 MHz and it is using low power [2]. Wi-Fi is also a technology that uses the indoor localization system. This technology achieves a 1 m accuracy [3]. UWB is another technique used for positioning in the indoor environment. This method uses a small transmit power, approximately -41.4 dBm/MHz. UWB reaches up to 150 m and operates at 3.1–10.6 GHz [4]. ZigBee technology is used for extended transmission distance. This technology builds on IEEE standard 802.15.4, which is line-of-sight based, and registers low power consumption. The transmission distance of ZigBee is 10–100 m [5].

Lateration and fingerprinting technologies are the most popular techniques used for indoor localization. Lateration algorithm requires at least three fixed reference points (RPs) to find the location of the object by calculating the distance between the access point (AP) and the object device [6]. The measurement distance of this method can be obtained by measuring the properties of the signal, such as received signal strength (RSS), time of arrival of the signal, phase of the arrival of the signal, or arrival signal angle. Fingerprinting technique is the most popular technique in the indoor localization system [7]. This technique does not use radio signal propagation geometry but requires data collection and built-in radio map in the off-line phase. Fingerprinting technique consists of two main phases, namely, off-line and online. In the off-line phase, data are measured based on the RSS and then collected and stored in a database, which is used later in the online phase to locate the object device. The most important issue facing these technologies is the accuracy, in which all indoor localization systems are still experiencing poor accuracy. Thus, this study proposes an algorithm that can improve the accuracy in the indoor localization system.

In [7], the authors proposed a clustering algorithm for indoor localization system to reduce the size of the radio map. The proposed algorithm depends on comparing the signal space of all RSS in the radio map and has achieved a good accuracy, while the RPs have been reduced by 50%. In [8], the authors introduced particle swarm optimization (PSO) based on generating several particles in a circular distribution form around AP for indoor localization system. The PSO algorithm generates particles where the distance from each particle to the AP is the same distance from the AP to the target. The proposed algorithm significantly improves the system accuracy compared with [7], which is experimental based. In [9], the differences between simulation- and experimental-based results, which introduced three types of RSS data (measurement, simulation, and hybrid), that could be predicted at an inaccurate location are investigated. The RSS is directly affected by line-of-sight and non-line-of-sight path scenarios in indoor or outdoor environments [10]. The result showed that the system obtained a better accuracy than the measurement data when using simulation data given the effectiveness of the environment structure. However, in particular, the experimental study with empirical data is more efficient than simulation results.

The rest of this paper is organized as follows: Section II explains the proposed clustering algorithm based on the fingerprinting technique. Section III discusses the experimental design. Section IV presents the results of the proposed algorithm. Section V concludes and summarizes the work of this study.

II. PROPOSED ALGORITHM BASED ON THE FINGERPRINTING TECHNIQUE

The indoor localization system based on fingerprinting technique is the most effective method for predicting mobile devices in the indoor environments. The fingerprinting technique consists of two phases, namely, off-line and online. In the off-line phase, the RPs collect at certain places in the testbed. These RPs contain information, such as the RSS from each AP and (x, y) coordinates, where the data will be stored as a radio map. In the online phase, the current RSS is compared with the RSS values that were stored previously in the off-line phase and obtain the matched value and then estimate the mobile user.

The most important issue of this technique is requiring a database (radio map) to store the collected RSS data in the off-line phase. The number of APs and RPs increases the size of the database increases. In particular, this issue led to several studies; these studies [11] aim to create a new technique and improve the overall accuracy of the indoor localization performance and reduce the computational time for predicting the mobile user using Important AP (IAP). This technique considers only one AP which has a highest level of RSS in the radio map, instead of considering all available APs.

The proposed algorithm reduces the computational time and radio map size. This algorithm consists of two stages, namely, clustering and searching stages in the off-line and online phases, respectively, as illustrated in Fig. 1. In the first stage, the RPs divide into n clusters, in which each cluster contains the same or different number of RPs. Then, the average of the strongest RSS is determined in each cluster to be selected for adaptive radio map. The adaptive radio map depends on the AP in each cluster. In the online phase, the mobile device receives and determines the strongest current RSS from all available APs. The radio map is selected based on the strongest AP, which the system searches, and predict the user location in that radio map rather than using the whole size of the radio map.

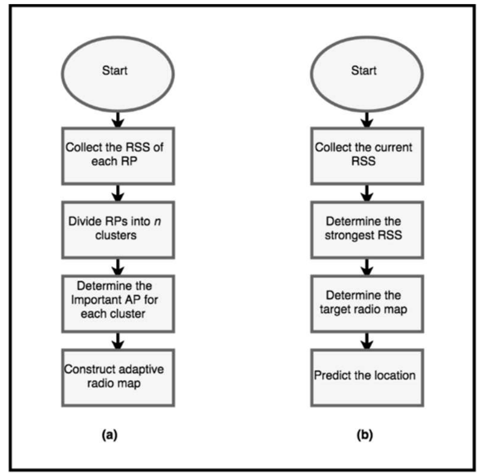

Figure 1. Proposed algorithm for predicting user location (a) off-line phase (b) online phase

The distance error can be provided by Euclidean distance in Equation (1):

$$D_i = \sqrt{\left(X_a - x_p\right)^2 + \left(Y_a - y_p\right)^2}, \tag{1}$$

where the total system accuracy is expressed by the following equation:

$$System\ Accurcy = \sum_{i=1}^{N} D_i\,, \tag{2}$$

where $(X_a,\ Y_a)$ and $(X_a,\ y_p)$ is the actual and predicted locations for the mobile device, respectively. N is the number of the testing points in the online phase.

III. EXPERIMENTAL DESIGN

The experiment was conducted on the ground floor (wing B) of the Engineering Faculty, Multimedia University (MMU), Cyberjaya campus. The dimensions of the area were 52 m^2 × 22 m^2. Four Linksys-Cisco-WRT54G2 802.11 b/g APs operating at 2.4 GHz were used in the experiment and located, as depicted in Fig. 2.

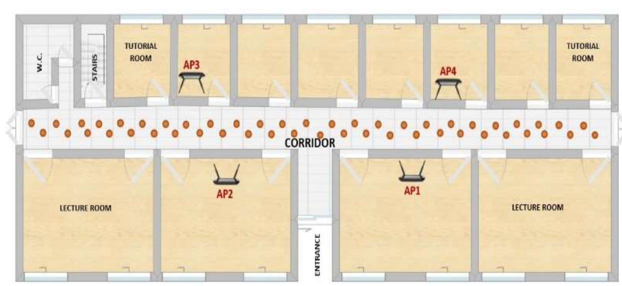

Figure 2. Layout of the experiment testbed.

The APs were distributed according to [12] to achieve the best coverage distribution, which included most of the area. The construction and materials of the building in the experiment were as follows: the outer walls were concrete and glass, whereas the inner walls were made from plaster partition boards and light wood doors with a small glass aperture. Table 1 lists the details. An Acer laptop supporting IEEE 802.11 a/b/g/n standards was used as a data collection device in the off-line phase during the study experiment. Table 2 summarizes the specifications of the mobile device used for data collection.

Table 1. Testbed specifications.

Parameter	Specifications
Area Dimensions (m^2) No. APs Wall Type Wall Thickness (cm)	52 m^2 × 22 m^2 4 Concrete, glass, and several plasterboard walls Inner (15 cm)

Table 2. Specifications of the mobile device used for data collection.

Parameter	Specifications
Brand WLAN Card IEEE Standards Speed RAM	Acer Atheros AR5007EG IEEE 802.11 1/b/g/n 2.5 GHz 4 G

A total of 30 samples in a 360° rotation with a 1 s time interval at each RP (orange circle in Fig. 2) were collected. The radio map was created once all the required information were acquired, thus completing the online phase. The radio map was created by collecting the RSS of each RP coordinate for all the RPs. Table 3 presents a sample of the data collected at one point for 7 s using a Wi-Fi scanner software. OpenBUGS (Bayesian inference using Gibbs sampling) [13] software version v3.2.1 was used to predict the mobile user location using the proposed clustering algorithm. This software is based on the Bayesian network using Gibbs sampling.

Table 3. Sample data collected at coordinates (23, 10) for 7 s.

X	Y	MAC Address	SSID	Channel	Signal
23	10	00:25:9c:14:41:e7	AP-2	6	−54
23	10	00:21:29:9d:db:f5	AP-4	6	−70
23	10	00:25:9c:14:3f:0e	AP-1	6	−74
23	10	00:25:9c:14:3f:f2	AP-3	6	−61

In this study, we divided the experimental location, which contains 50 RPs, into five clusters. Each cluster contains 10 RPs with a different reading of AP where only one AP is considered the IAP, as displayed in Table 4. The selected IAP depends on the highest RSS in each cluster, as depicted in Fig. 3. However, similar cluster sharing IAPs are combined as one cluster because cluster 1 with cluster 2 and cluster 4 with cluster 5 have the same IAP, IAP = AP3 and IAP= AP4, respectively. AP1 and AP4 in cluster 1 and 2 have same level of RSS due to the first 20 RPs are located at far away from AP1 and AP4. Similarly, AP2 and AP3 have almost same level of RSS RSS in cluster 4 and 5 due to the last 20 RPs are located at far away from AP2 and AP3.

Table 4. IAP for each cluster

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
RPs	1–10	11–20	21–30	31–40	41–50
IAP	AP3	AP3	AP2	AP4	AP4

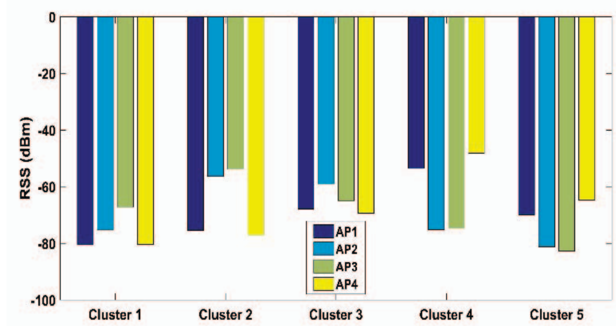

Figure 3. RSS of the APs for each cluster

IV. RESULTS AND DISCUSSION

Fig. 4 illustrates the RSS of the four APs for the 50 RPs along the testbed area. The RSS mean varies along all the distances of the location; thus, a unique RSS mean is presented for each location. Moreover, a high RSS mean is obtained when the location of the receiver is near the APs. Considering this feature, the fingerprinting technique is a good, or maybe the best choice in the indoor localization system.

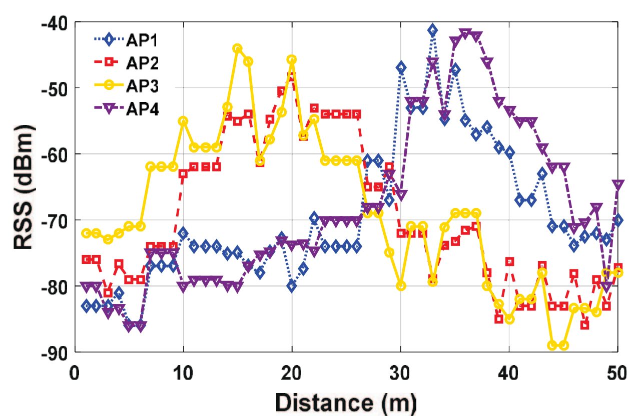

Figure 4. RSS (dBm) of all APs in terms of distance (m)

The proposed algorithm has been evaluated using 20 randomly selected RPs as testing points to determine the system accuracy. The 20 testing points were divided into four groups (5, 10, 15, and 20 RPs) to study the effect of the number of testing points on the system accuracy. Fig. 5 depicts the average of distance error for two algorithms (without and with clustering). The system accuracy when using clustering algorithm (proposed algorithm) is much better than without clustering. Moreover, the proposed algorithm is more stable than without clustering. The distance error of the system when using clustering algorithm is approximately 2.4 m, where the distance error of the system when clustering is not 3.4 m. Therefore, the clustering method has improved the system accuracy for up to approximately 41% compared with the accuracy of the system without the clustering method.

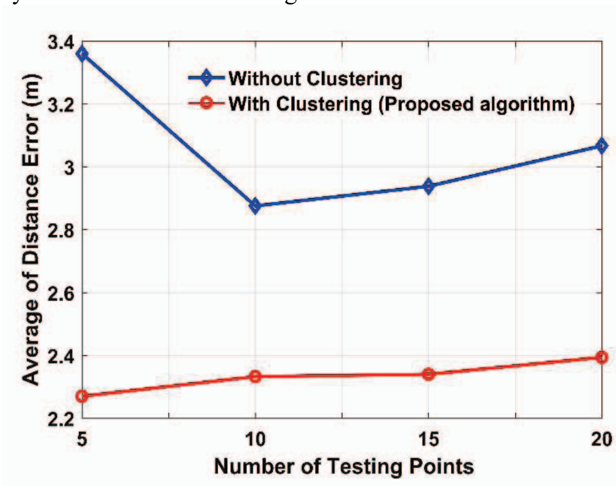

Figure 5. Average distance error (m) of the two algorithms

Fig. 6 demonstrates the total average of distance error for clustering and without clustering algorithms. The total average distance error when using clustering algorithm has less maximum and minimum distance error compared with without clustering algorithm. Furthermore, the proposed algorithm also reduced the computational time for predicting mobile user location, which considers only part of the entire radio map.

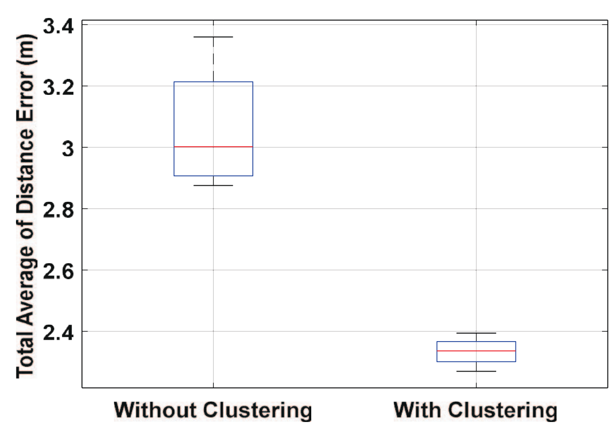

Figure 6. Accuracy of the two algorithms

V. CONCLUSION

Localization systems are still experiencing poor accuracy in the indoor environments. Wi-Fi system using the fingerprinting technique is the most effective approach for the indoor localization given its availability in most of the indoor environments. In this study, we proposed a clustering algorithm based on the fingerprinting technique to improve the system accuracy for indoor environment and reduce the computational time. The proposed algorithm achieved an average distance error of 2.4 m compared with the non-clustering algorithm, which has an average distance error of 3.4 m. In particular, the proposed algorithm improved the system accuracy by 41% compared with the conventional algorithm. Moreover, the clustering algorithm reduced the computational time of the system that requires for computing the prediction of mobile user location.

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