

# Performance Analysis of Indoor Localization Algorithm Using Virtual Access Points in Wi-Fi Environment

Boney Labinghisa<sup>†</sup> · Dong Myung Lee<sup>††</sup>

## ABSTRACT

In recent years, indoor localization has been researched for the improvement of its localization accuracy capability in Wi-Fi environment. The fingerprint and RF propagation models has been the main approach in determining indoor positioning. With the use of fingerprint, a low-cost, versatile localization system can be achieved without the use of external hardware. However, only a few research have been made on virtual access points (VAPs) among indoor localization models. In this paper, the idea of indoor localization system using fingerprint with the addition of VAP in Wi-Fi environment is discussed. The idea is to virtually add APs in the existing indoor Wi-Fi system, this would mean additional virtually APs in the network. The experiments of the proposed algorithm shows the positive results when 2VAPs are used compared with only APs. A combination of 3APs and 2VAPs in the 3rd case had the lowest average error of 3.99 among its 4 scenarios.

**Keywords :** Wi-Fi, Indoor Localization, Fingerprinting, Virtual Access Points

# Wi-Fi 환경에서 가상 Access Point를 이용한 실내 위치추정 알고리즘의 성능분석

Boney Labinghisa<sup>†</sup> · 이 동 명<sup>††</sup>

## 요 약

실내 Wi-Fi 환경에서 위치추정 정확도를 향상시키기 위한 위치추정에 대한 연구가 수년 동안 계속되어 오고 있다. 핑거프린트 기법 및 전파모델은 실내 위치추정에 있어서 매우 중요한 기술이다. 추가적인 하드웨어 없이 저비용으로 핑거프린트 기법을 사용하는 다양한 위치추정 시스템에 대한 연구가 진행되고 있다. 그러나 실내 위치추정 모델에서 VAP (virtual access points) 개념을 사용하여 이러한 목표를 실현한 사례는 매우 드물다. 본 논문은 Wi-Fi 환경의 핑거프린트 기반에서 VAP를 사용한 실내 위치추정 시스템의 아이디어를 제시하였다. 이 아이디어의 핵심은 실제 실내 Wi-Fi 환경에서 VAP를 사용하여 AP의 역할을 수행 할 수 있다. 제안 알고리즘의 성능분석을 위하여 4 개의 시나리오를 사용하여 실험한 결과, 1개의 AP 대신에 2개의 VAP를 사용했을 때 가장 우수한 결과가 도출되었으며, 실험의 3번째 경우인 3개의 AP와 2개의 VAP를 사용했을 때 3.99 미터의 가장 낮은 위치오차가 발생하였음을 확인하였다.

**키워드 :** 와이파이, 실내 위치추정, 핑거프린트, 가상AP

## 1. Introduction

Recently, the location based services (LBS) have been a

great impact in our daily lives. It also progresses with the innovation of internet of things (IoT), which refers to a network of internet enabled devices such as everyday objects with ubiquitous intelligence. As the localization system based on the wireless signal strength as discussed in [1], it is important to propose the indoor positioning system under the low-cost and low-complexity using Wi-Fi technology.

The Wi-Fi is popularly used to most of indoor buildings or large scale markets to provide mobile services to the customers by connecting Internet. Researchers has utilized

※ This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (No. 2015R1D1A1A01061369).

※ 이 논문은 2016년도 한국정보처리학회 추계학술발표대회에서 'Indoor Localization Algorithm using Virtual Access Points in Wi-Fi Environment'의 제목으로 발표된 논문을 확장한 것임.

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Manuscript Received : December 16, 2016  
Accepted : January 2, 2017

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the Wi-Fi to acquire positioning services in closed indoor environment because of its availability and capability of smart phones and tablets on the Wi-Fi. In addition to this, many schemes in the Wi-Fi have been developed to acquire a much accurate, precise and low-cost indoor positioning based on fingerprint scheme or RF propagation method.

Because the layout of the indoor environment may be often changed, it is necessary to move the location of access point (AP) for the proper connection in the Wi-Fi. Therefore, the determination of the exact location of APs in creating the fingerprint map and application of VAPs is also seen as an alternative in this paper.

Localization systems based on measuring of signal strength in Wi-Fi environment was firstly proposed in [2]. The functions of this system are divided into the training phase (offline phase) and the fingerprint based localization phase (online phase). A radio map is constructed based on the received signal strength (RSS) of existing APs in the indoor environment in the training phase, and the location is estimated by K-nearest neighbors (KNN) algorithm to find the nearest Euclidean distance of the radio map from the observed RSS vector in the localization phase, respectively.

The other topic in this paper is the virtual access point (VAP). VAP is defined as a virtual machine running on a single physical AP with different service set identifier (SSID). It can be virtually constructed to the AP on a certain location in the indoor environment through statistical models. Because the VAP can be constructed with relation to the current existing APs in the structure by linear correlation regression, this proves the advantage of VAP in fixed WLAN infrastructure since there will no longer be a need in deployment of actual APs [3].

In the fingerprint based localization phase, the data collection phase is a very important and time consuming process, especially with the addition of VAPs. But since VAPs are created by statistical analysis, no additional hardware will be needed in the study. This has motivated the research to create a VAP in the current existing Wi-Fi environment, creating an algorithm that will make use of VAP and fingerprint scheme to achieve a better performance compared to the conventional fingerprint scheme.

This paper is organized as follows. Chapter II reviews indoor localization based on fingerprint scheme and VAP studies. Chapter III proposes the indoor localization algorithm using VAPs in Wi-Fi environment. Chapter IV discusses and analyzes the experimental results. Chapter V finally concludes this paper.

## 2. Related Studies

### 2.1 Wi-Fi Fingerprint Scheme

The indoor positioning techniques using Wi-Fi has seen many approaches with low-cost, high accuracy, low-complexity and robustness. In [4], the information of the physical layer in the scheme can be easily obtained in the Wi-Fi fingerprint scheme. The measured and obtained RSS reflects the distance information of the transmitter and the receiver. Because each location in an indoor environment receives a unique signal strength due to multi-path effect, the signal property, especially the signal strength, has its own fingerprint. A fingerprint map is built up actually using this property.

Wi-Fi fingerprint scheme has been a popular localization technique since the idea of RADAR [2] and has since been improved with different approaches and ideas added to its concept. A study on the properties of Wi-Fi signals in finding the user location [6], was done, and it provided results that the certain factors may affect the properties of Wi-Fi signals that can affect the location estimation. The accuracy of the location estimation varies on the orientation of user or mobile unit, the temporal and spatial variations of Wi-Fi signals, the time dependency, the device hardware and a number of samples.

### 2.2 Virtual Access Points

Another study [5] points out the importance of the proposing of the new Wi-Fi fingerprint scheme to improve the accuracy of the localization. It had been identified that the certain factors such as the weather conditions, building layout and frequency bandwidth significantly affects the accuracy of localization. The study also proposed the encouraging results on the use of VAPs as it has higher accuracy compared to using only APs. The addition of VAPs had indeed a positive impact to the study with minimal effort in preparation.

In [3, 7-8], VAP is created in an open spaced indoor environment without any obstacles. Two VAPs were added to the existing 3 APs, whereas one VAP was placed in the exact opposite of one existing AP and the other VAP was placed in the middle of the indoor environment. Though the experiments cause the best results, it was done with a series of trials and simulations in order to determine the VAP location. This was done during the data collection phase for the fingerprint map and takes more time than conventional data collection where RSSIs of the existing APs are collected. In the same manner, the creation of the

VAP also requires much time as in the case of VAP location.

### 3. Proposed Model and Algorithm

Even though the increasing of APs has been one of popular idea in order to improve the Wi-Fi fingerprint scheme, the VAP can be used to solve this problem for cost-effective solution. The VAP can be realized by a statistical model with correlation. However, because the creation of VAP requires a great amount of time, the indoor localization algorithm for decreasing the amount of time to make VAP is proposed to overcome this problem in this paper.

#### 3.1 Design Considerations

The VAP model will be dependent on the indoor floor plan and structure. The optimal VAP placement will be in accordance with how the floor structure is laid out while the path loss of signal varies on indoor environment.

Knowing the number and locations of existing APs should be also considered in making the suggested model because the VAP placement depends on the locations of the existing APs. The received signal strength indicator (RSSI) values of VAPs will be generated based on its correlation to existing APs. It is very important that the floor plan of the experimental testbed, known as the VAP placement, is dependent to the existing APs locations. Several attempts for seizing the VAP placement was made and some locations has low correlation to existing APs causing low placement accuracy. It is confirmed that the VAP correlation with at least 1 or 2 APs is should be greater than 70% in order to achieve the desired placement accuracy.

Inter-AP spacing should be 40ft to 70ft between APs to have an accurate sensing of signal strength and avoid overlapping. This is observed based on RSSI and distance relationship factors, as RSSI values show little differentiation at distances greater than 80ft. Having RSSI values greater than 80ft will result in inaccurate localization results.

#### 3.2 System Architecture of Proposed Model

The overall system architecture for the suggested model is showed in Fig. 1, where the processing steps are follows: 1) Acquiring of the floor plan to determine the placement of the VAP; 2) Correlation creation with added VAPs by calculating the number of existing APs in the indoor environment; 3) Data collection phase; 4) Fingerprint based localization phase.

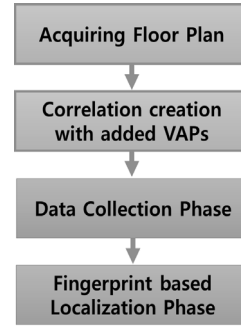


Fig. 1. Overall System Architecture of Proposed Model.

In order to make the VAP model, a statistical method will be used. The VAP related data added in the fingerprint map is the collected data during the data collection phase making one AP plus some VAPs matrix. From the collected RSS data, the regression coefficient of VAPs with respect to APs can be calculated.

However, on the Fingerprint based localization phase, the RSS data for VAPs is dependent on the RSS values of the collected APs. The RSS data for VAPs is equal to the sum of all existing APs with respect to their corresponding regression coefficient. These collected RSS data for APs and VAPs is compared with the fingerprint map database matrix for APs + VAPs collected during the Data collection phase. Finally, the user location can be estimated by executing the Fingerprint based localization phase using the collected RSS obtained in the Data collected phase.

The equation for generating RSSI of VAP can be described in Eq. (1).

$$VAP_{target} M = VAP_0 + Creg AP_n \quad (1)$$

In Eq. (1),  $VAP_{target}$  is the RSSI of VAP in dBm at distance  $VAP_0$ , with respect to AP, existing AP.  $n$  is the number of AP available in the indoor environment with  $Creg$ , as the regression coefficient.  $VAP_{target}$  value will depend on the  $Creg$  and AP gathered during the data collection phase.  $Creg$  will be a constant value while AP will be the RSSI value of  $n$  number of  $AP_s$ . The required number of  $VAP_{target}$  will be the same as the number of reference point per  $M$ , which refers to the number of  $VAP_s$  added in the system.

The concept of the Data collection and the Fingerprint localization phases are as follows.

#### 1) Data collection phase

In the proposed model, it is required to collect labeled data (fingerprints) to create a fingerprint map. The fingerprints

are the measured received signal strengths (RSSs) at certain coordinates. The RSS data can be obtained by walking using smart phones with pre-installed application capable of detecting RSS.

On the data collection phase, any devices capable of emitting Wi-Fi signals will act as  $VAP$  placed in strategic locations. That is to say, these devices will act as if actual  $AP_s$  but will only be used temporarily. RSS data will be collected from existing  $AP_s$  and the device acting as  $AP$  or  $VAP$ .

## 2) Fingerprinting based localization phase

In the fingerprint based localization phase, known as the online phase, the acquired RSSI is compared with the existing fingerprint map to estimate the user location. On this phase, the devices acting  $VAP_s$  as temporary  $AP_s$  will leave only the existing  $AP_s$  emitting the Wi-Fi signals. Fig. 2 shows the pseudo codes of the proposed indoor localization algorithm as expressed in Eq. (1) used to calculate the regression coefficient ( $C_{reg}$ ) and the  $VAP$  ( $VAP_{target}$ ) in order to obtain the error distance from the fingerprint map. These codes also utilize the measured RSS to create a statistical model of the  $VAP$ . The error distance ( $Der$ ) is defined to the nearest distance from a reference point (RP).

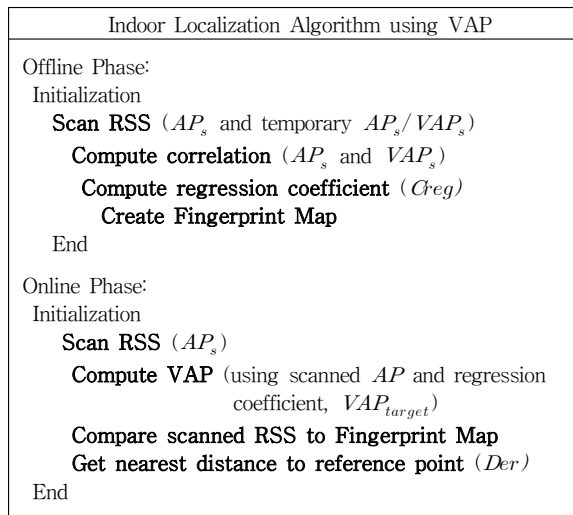


Fig. 2. Indoor Localization Algorithm Using VAPs.

## 4. Experiment Results and Analysis

### 4.1 Experimental Environment

The experiments are executed on the engineering building of University. Fig. 3 shows the selected experimental environment for the indoor localization. The lobby of the

first floor of the building is selected as the testbed for the experiments. 74 reference points (RPs) are used as the fingerprint map, and the area of each RP is defined to  $1 \times 1 \text{ m}^2$  space. The VAPs are strategically placed in the indoor environment to provide an optimal coverage together with the existing 3 APs. The experiment was executed on three cases that have its own scenarios.

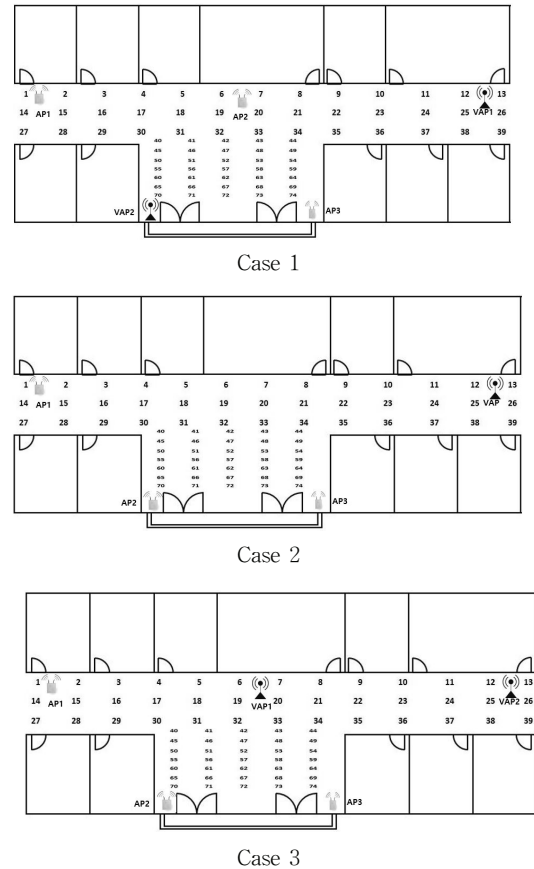


Fig. 3. Experimental Environment in 3 Cases with Added VAPs.

The 1<sup>st</sup> case of the experiment was executed with only 1 VAP added in the system. It was placed in the exact opposite of AP#1. The 2<sup>nd</sup> case of the experiment was executed using 2 VAPs with VAP#2 on the opposite of AP#3 and VAP#1 on the exact opposite of AP#1. The 3<sup>rd</sup> case of the experiment also utilizes 2 VAPs but were placed in a different position compared to the previous case. This was executed to determine how correlation and position of a VAP in regards to existing APs affects the performance of localization.

The testing was executed where the user is randomly standing in the experimental testbed and its position will be located using the proposed algorithm. The method of experimentation chosen is a scenario where the user is in a static state and not moving. Multiple experimental

cases were conducted at different times of the day using LG G4 smart phone as the mobile device held by the user simulating reading or composing a text message. The IP Time A104s were used to AP model and some APs were used to act as the VAP.

During the data collection phase of the proposed algorithm, two devices acting as temporary APs are used as VAPs in the experiment. These two devices has a role of VAP are used together with the existing APs to create a 3APs + 2VAPs matrix for computing the correlation after power on. In this situation, the RSS data is collected from 3APs and 2VAPs in 74 RPs. In addition to this, the fingerprint map is also constructed together with the calculation of the regression coefficient in this phase.

During the fingerprinting based localization phase, VAPs will be powered off, leaving only the 3APs to provide the RSS for the mobile user. Once RSS is obtained by the user, the measured RSS of the 3 APs will also be used to calculate the VAP value with the help of the regression coefficient. Once the RSS of VAP is calculated, it will then be compared with the fingerprint map to determine the least Euclidian distance. The RP with the least Euclidean error distance is determined to the current location of the user.

#### 4.2 Result Analysis

After obtaining the fingerprint map during the data collection phase, the absolute correlation values in all 3APs and VAPs are shown in Table 1. In Table 1, all 3 cases were shown where the correlation of VAPs with APs are measured. In the 1<sup>st</sup> case, only 1 VAP is added in the system and it doesn't really show significant correlation value. In the 2<sup>nd</sup> case where 2 VAPs were added, it is seen that correlation value of VAP#1 and VAP#2 with AP#1, AP#2 and AP#3 are not very high. This indicates that the VAPs have lower correlation with the existing APs. This can also be interpreted that the location of the VAPs are not optimal in the indoor environment. For the 3<sup>rd</sup> case, in can be seen that VAP#2 has high correlation value with AP#3, it is regarded as a better result. The VAP#1, on the other hand, has a lower correlation with all other APs. This indicates that the VAP#1 position is not optimal.

Determining the correlation values of VAPs with the existing APs is considered as an important factor in the study. After observing the correlation values in 3 cases, the error distance is computed and compared in different scenarios (S1-S4) presented in each cases as seen in Table 2.

Table 1. Correlation of APs and VAPs in 3 Cases

CASE1	AP#1	AP#2	AP#3	VAP
AP#1	1	0.3369	-0.42439	0.307673
AP#2	0.336923	1	-0.59238	0.530898
AP#3	-0.4243	-0.592	1	-0.31145
VAP	0.307673	0.5308	-0.31145	1

CASE 2	AP#1	VAP#2	AP#3	AP#2	VAP#1
AP#1	1	-0.449	-0.4659	0.362684	0.25154
VAP#2	-0.449	1	0.4327	-0.409	-0.1804
AP#3	-0.4659	0.4327	1	-0.70845	-0.3620
AP#2	0.362684	-0.409	-0.70845	1	0.54827
VAP#1	0.25154	-0.1804	-0.3620	0.54827	1

CASE 3	AP#1	VAP#2	AP#3	AP#2	VAP#1
AP#1	1	0.3490	-0.48103	-0.15011	0.28303
VAP#2	0.34904	1	-0.70854	-0.31261	0.56929
AP#3	-0.4810	-0.708	1	0.362526	-0.3919
AP#2	-0.1501	-0.312	0.362526	1	-0.1111
VAP#1	0.28303	0.569	-0.39199	-0.11113	1

Case 1 has two localization scenarios (S1-S2), the 1<sup>st</sup> scenario uses only 3 APs while the 2<sup>nd</sup> scenario uses 3 APs and the VAP. The overall error distance average of S1 is 4.891m while S2 has 4.524m. This indicates that using VAP reduces the error distance which means a higher accuracy but only very little.

Case 2 has four scenarios (S1-S4). The placement types using 3APs and 2VAPs for producing the error distances are defined as follows: 1) only 3APs; 2) 3APs + VAP#1; 3) 3APs + VAP#2; 4) 3APs + 2VAPs as shown in Table 2. The average error distances in S1-S4 are measured to 8.1675m, 10.33m, 10.55m and 11.55m, respectively. The values on these 4 scenarios proved that even the addition of VAPs can result to higher error distance which is the goal of the localization algorithm. This is mainly due to low correlation or VAPs with APs which was affected by the placement of the VAP. Due to these results another experiment was done to locate a better location of the VAPs.

In Case 3, the error distances are also measured in 4 scenarios (S1-S4). The placement types using 3APs and 2VAPs for producing the error distances are defined as shown in Table 2 as follows: 1) only 3APs; 2) 3APs + VAP#1; 3) 3APs + VAP#2; 4) 3APs + 2VAPs. The error distance values for measuring the localization accuracy are measured in 4 scenarios of the experiment. It can be seen that the error distances of the proposed indoor localization algorithm in 4 scenarios such as 3APs, 3APs + VAP#1, 3APs + VAP#2 and 3APs + 2VAPs are measured to average 4.3484m, 5.2048m, 4.0716m and 3.9904m, respectively, as



Table 2. Error Distances Comparison in 3 Cases with Different Scenarios

CASE1	S1	S2
Placement Types	3APs	3APs + VAP
Error Distance(m)	4.891	4.524

CASE 2	S1	S2	S3	S4
Placement Types	3APs	3APs + VAP#1	3APs + VAP#2	3APs + 2VAPs
Error Distance(m)	8.1675	10.33	10.55	11.55

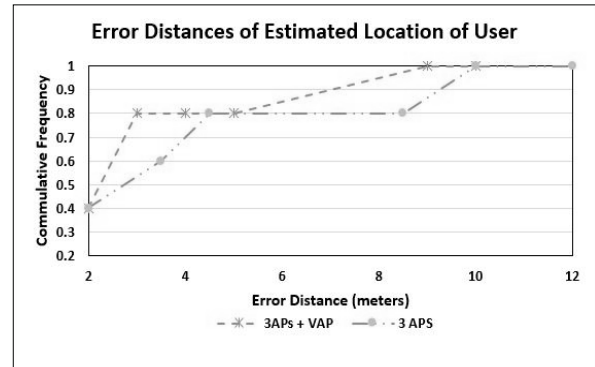
CASE 3	S1	S2	S3	S4
Placement Types	3APs	3APs + VAP#1	3APs + VAP#2	3APs + 2VAPs
Error Distance(m)	4.3484	5.2048	4.0716	3.9904

shown in Table 2. In this, the highest error distance in placement type of 3APs + VAP#1 proves that the lowest correlation affected the localization accuracy.

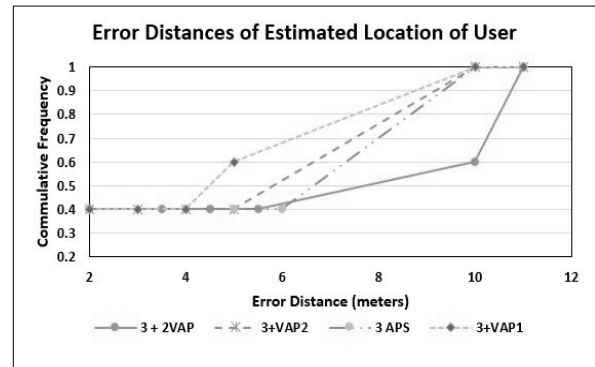
However, the placement type of 3APs + VAP#2 showed the low error distance compared with VAP#1 since VAP#2 has high correlation with AP#3 as shown in Table 1. With the high correlation of VAP#2 to AP#3, it compensated the low correlation of VAP#1 to all 3APs when both VAPs and 3APs were used in the scenario 4 resulting to the lowest error distance as indicated in Case 3 of Table 2.

The experimental results in all cases with different scenarios are presented to the form of cumulative frequency graph as shown in Fig. 4. This shows the error distance in meters and on how much the said error occurs in the experiment. In case 1, even though the added VAP has low correlation, it still has higher accuracy compared with the case of using only APs during localization. It was observed that using VAP pin points the random locations of the user closer than that of only APs.

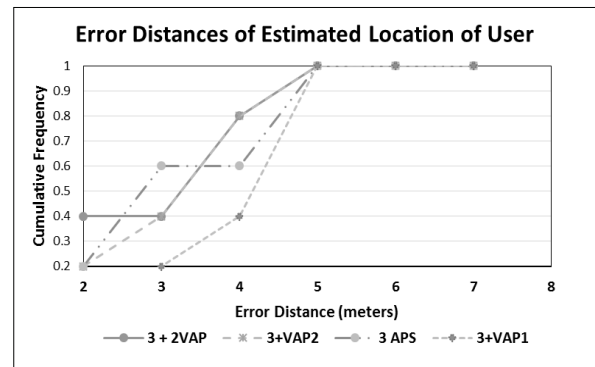
In the 2<sup>nd</sup> case, the results were undesirable with all 4 scenarios having an error distance occurring close to 4m-6m in determining the different random locations of the user. And even has error distance reaching more than 8m. It is also observed that S4 with 3APs + 2VAPs has the worst result while 3APs + VAP#1 has the best result in the experiment. The higher correlation of VAP#1 compared with VAP#2 might have caused it to have better performance. 3APs + VAP#2 also showed a better result compared with 3APs. It might be due to the combination of the low performance of 3APs and the low correlation of 2VAPs that resulted it to have the highest error distance.



Case 1



Case 2



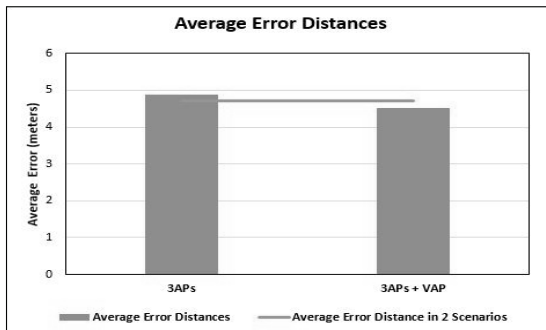
Case 3

Fig. 4. Error Distances of Estimated Location of the User in 3 Cases with Different Scenarios.

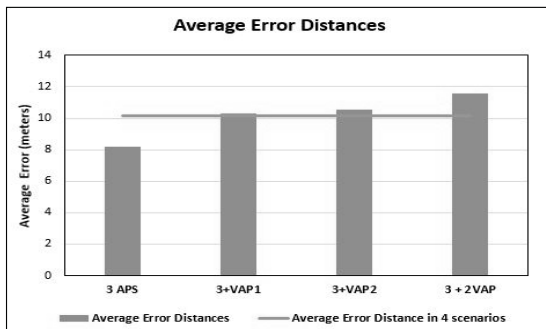
The experiment for 3<sup>rd</sup> case of Fig. 4 was executed with 2VAPs placed in the testbed. VAP#1 had a lower correlation with the existing 3 APs while VAP#2 had a higher correlation with AP3. Fingerprint map data made is composed of RSS from 3 existing APs and 2 VAPs. Upon execution of the algorithm in real time, the RSSI of VAP#1 and VAP#2 is computed based on the RSSI received by the user from the 3 existing APs. This shows that due to the correlation of VAPs from the APs, higher correlation provides a higher accuracy than standard AP fingerprint localization. Compared with the previous cases, case 3 has the best performance and it was due to the optimal

placement of the VAPs that yielded to high correlation. It can be seen that the error distances of the user in random locations were lower than 5m with only several instances that exceeds up to 7m. The proposed localization algorithm has the best result as seen in the figure as 3APs with 2VAPs, and it has error distances occurrences from 2m to 4m compared with other scenarios.

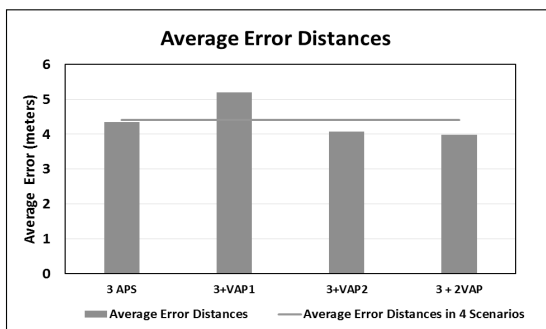
The average error distances in 4 scenarios are shown and these are compared with the average error distance in 4 scenarios in Fig. 5. In all cases, the error distance in different scenarios were averaged and compared with each other. The average of the overall error distance of these scenarios is represented as a horizontal line. This horizontal line indicates the difference of the error distance above or below it as seen as a whole.



Case 1



Case 2



Case 3

Fig. 5. Comparison of Average Error Distances in 3 Cases with Different Scenarios.

In case 1, it is seen that there is not much difference between the two scenarios but using a VAP reduced its error distance even just a little. In case 2, all scenarios with VAP is passing the horizontal line. This indicates that adding VAP caused the error distance to be increased. This result is undesirable and also proved how much VAP can affect the localization accuracy. In case 3, all scenarios with VAP#2 does not pass the horizontal line. VAP#2 greatly affected the localization accuracy by lowering the average error distance as seen in all three scenarios. It can be also seen that 3APs with 2 VAPs has lower error distance with only 3APs proving the increase in performance of the proposed localization algorithm.

As a result of using 4 different scenarios, it proved that adding a single VAP may not always improve the localization accuracy. In fact, it was observed in the 2<sup>nd</sup> case, where the addition of VAPs lowered the localization accuracy. We know that the localization accuracy of traditional fingerprint scheme is better than that of the proposed algorithm in this case. It is also observed in the 3<sup>rd</sup> case that using VAP#1 in the system resulted in the high error distance. This points out that its position which affects its correlation is a problem seen in the proposed VAP.

## 5. Conclusion

Adding VAPs in an indoor environment with fixed APs results in an increased localization accuracy compared with only the fixed APs. In addition, creating VAPs only needs a temporary AP to be placed in a certain location thus not needing to have a fixed AP in that location. This reduces the cost of deployment of additional AP to be added in the system while increasing localization accuracy. Another improvement on this situation is to propose getting 4 direction data for the fixed APs during the data collection phase. This will help reducing the RSS fluctuations experienced due to different orientation of user's mobile devices. It is believed that reducing RSS fluctuations can also improve performance of localization.

Adding VAPs and collecting 4 direction data during the data collection phase will have greater performance compared with fingerprint based localization system using fixed APs and data using only a single direction in the data collection phase.

This study proves that increasing of the AP count during localization improves the localization accuracy. Furthermore, additional AP can be achieved using VAPs making it possible to increase AP counts in a system with

already fixed APs. However our research also shows that the localization accuracy can be also decreased unlike the good correlation of VAP#2 to the 3APs due to poor correlation of VAP#1 to the 3APs. The poor performance of VAP#1 was compensated by VAP#2 still achieving a desired output when both VAPs are used in localization.

The correlation of VAPs to APs is a big factor when adding VAP to the system. Therefore, it can be concluded that adding more than 2VAPs will make localization accuracy higher, taking into consideration the placement of VAPs with high correlation to existing APs.

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