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A Hybrid Fingerprint Scheme for a Reliable WLAN Positioning System

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ABSTRACT

One of the key infrastructures for the pervasive computing, which enables the real-time location of a user to be inferred is a reliable indoor positioning system. Positioning system based on the WLAN technology using fingerprinting technique is considered as the option of choice for indoor based positioning due to its affordability, simple configuration and high accuracy. The problem always is how to sustain the operation of the system in case one of the access points used on training fails during location estimation. Where such provision has been made, it is usually based on a mixture of different technologies to augment the Wi-Fi infrastructure. The approach borne out of such union defeats the advantages associated with the WLAN based positioning system. To this end, this study proposes a hybrid scheme to tackle the problem of reliability in Wi-Fi based location estimation system by providing a fail-over feature for the case where one AP fails during positioning phase. The scheme uses the signal strength difference (SSD) and improved signal strength difference (iSSD) fingerprints to form the hybrid framework. The performance of the hybrid fingerprinting scheme when used in an indoor positioning was investigated using a testbed. From the analysis, the hybrid scheme could be able to estimate the position of mobile devices with an accuracy of 2 meters in 90% of the tested points.

Keywords: *Indoor Positioning, Fingerprinting, Issd, Radio Map.*

1. INTRODUCTION

Positioning in an indoor environment has been an important subject since it is needed to estimate the real-time location of people, objects, guide persons to a certain place, assist companies and organisations with their assets management among other benefits. A number of applications today benefit from location service in indoor environments and as such, indoor location system plays an important role in the development of pervasive and ubiquitous computing. The advances in wireless technologies and the consequent proliferation of wireless devices in indoor buildings has made the use of radio frequency signals to perform localization an interesting and promising technique. Wi-Fi provides a means by which mobile applications achieve context-aware implementations [1]. Hence in the work of Liu, et al.,[2], WLAN has been highlighted as the preferred technology due to its accuracy even though a wide range of other technologies have been proposed to be used for indoor positioning such as Radio Frequency Identification (RFID), Ultra wideband (UWB), wireless LAN (WLAN) and Bluetooth. WLAN infrastructure is a widely accepted and implemented communication standard of which many indoor environment, are already equipped with IEEE 802.11 WLAN access points.

The main goal for localization process is estimating the position of a user and or Wi-Fi mobile device in its environment based on a set of anchors with known positions. Modern mobile devices, most smartphones and PDAs are produced with one or more wireless communication interfaces, such as Bluetooth or Wi-Fi in order to communicate with other computing infrastructure or mobile devices. To this end, in WLAN an easily available signal characteristic; the received signal strength (RSS) has been driving the implementation of location fingerprint.

To implement a Wi-Fi Positioning System, one of four positioning techniques could be used. The positioning techniques include proximity, triangulation, trilateration and scene analysis. In Proximity technique, the location of a mobile node is achieved using the highest received signal strength of an anchor node. The Wi-Fi mobile device to be located is in proximity of this anchor node where the highest signal strength came from. To this end, the proximity method estimates position by logging which device comes into proximity of the fixed anchor node. The positioning of the mobile devices is then estimated as the position of the fixed node which last logged it [3]. In triangulation approach, the angle of incidence or Angle of Arrival (AoA) of at least two reference points are measured. The estimated position corresponds to the intersection of the lines defined by the angles. Henniges [4], using trilateration approach opined that the position of the target device is estimated by evaluating its distances from at least three reference points. Finally, in the scene analysis, a Wi-Fi client is used to gather the signal strength information from a number of access points within its range and used to create a location fingerprint (i.e. radio map). A fingerprint is the signal strength signature that differentiates a spot in the scene from other ones. In other words, a fingerprint is the unique collection of the signal characteristics of selected spots in the scene. It works by collecting some information from the scene and comparing the collected information with the existing database records for a match.

In this study, we adopted the use of scene analysis or pattern recognition technique based on fingerprinting.

Location Fingerprinting method is composed of two phases: (a) Training (also known as Offline or Calibration) phase and (b) Positioning (also known as Online, localization, location estimation) phase. The training phase, signal strengths from APs are collected at pre-identified locations, which are called or referred to as the reference points (RPs). The objective of this operation is to build a location radio map database which will be used in the location determination phase. Since the mobile user's location is determined based on the surrounding reference points, the radio map performs better when the RPs are evenly distributed in the target area. It should be pointed out the that the phase one precedes phase two and must be completed before the positioning system comes into operation in phase 2. In the Positioning phase, the Wi-Fi device captures from the surrounding access point (AP) received signal strengths (RSSs) which are compared with that of the radio map dataset collected in the training phase to identify the best matching RP using a location algorithm. The location determination algorithm could use deterministic or probabilistic method to match real-time RSS readings with the reference points signal data.

The theoretical basis for RSS is that the attenuation of emitted signal strength is a function of the distance between the emitter and the receiver. The RSS based systems usually need on-site training in order to reduce the severe effects of multipath fading and shadowing in indoor environments.

The RSS can be used to determine the distance between a transmitter and a receiver in two ways. The first approach is to map the path loss of the received signal to the distance traveled by the signal from the transmitter to the receiver. With the knowledge of the RSS from at least three transmitters, we can locate position of the receiver by using triangulation; [5]. In this method, there is no database search and the positioning delay is associated with the communication and computation. However, inside a building, the inaccuracy of the path loss model results in the variation of the RSS with distances which is significant due to obstructions and multipath fading effects. As such, it is usually not reliable to use the RSS in this way. Owing to this harsh multipath environment in indoor areas, the techniques that use triangulation or trilateration are not attractive and often can yield highly erroneous results. To improve the accuracy of the positioning system that is based on the Wi-Fi RSS, another approach becomes inevitable. The second approach is to use the RSS in a fingerprinting technique. The fingerprint of different locations is stored in a database and matched with measured fingerprints at the current locations of a mobile station using location algorithm.

In this paper, we propose a single and effective Wi-Fi based indoor positioning using hybrid fingerprinting scheme. The scheme combines the signal strength difference (SSD) and improved Signal Strength Difference (iSSD) to produce a hybrid fingerprint for the Wi-Fi based localization system. In signal strength difference (SSD), the difference between RSS values measured simultaneously from two access points is used as the fingerprint. While for the improved signal strength difference (iSSD), the fingerprint is formed by capturing the RSS values simultaneously from three access points, and subsequently, denoting the RSS value with the highest number as the reference RSS, and then subtracting the two RSS values of the remaining two APs from reference RSS; sum the difference and obtain the mean value. Then the mean value is used as the fingerprint of a given location. This positioning method uses the existing WLAN infrastructure and does not need any extra hardware attached to the target device. This is because the network card in the mobile device continuously measures the RSS of the AP in its reach. This information is available due to beacon broadcast which occurs several times in a second by every AP.

This scheme will solve the problem associated with failure of one of the access points during positioning phase either because it is disabled, local power failure, upgrade, outright failure due to old age or component malfunctioning. In such situations, if no provision is made within the design of the localization system, the system will no longer be reliable and therefore will not accurately provide the position location services requested by the users. Hence, this hybrid scheme will in normal operation depends on the iSSD technique while it will recourse to SSD in the event of failure of one of the access points used in the scheme. Based on the foregoing, the paper is set to contribute:

- a fault tolerance Wi-Fi based positioning system that functions even when one access point fails.
- increased accuracy due to coverage improvement since three access points are used.

2. RELATED WORK

Bahl and Padmanabhan [6] proposed RADAR which is the foremost research on using WLAN fingerprinting indoor positioning system. RADAR applied the WLAN RSS in fingerprinting construction. In the offline phase, the radio map is constructed; while the system is put into operation in the online phase. The result of the experiment shows the validity of using the WLAN's signals in the indoor positioning systems with distance error between 2m to 3m. Although RADAR achieved acceptable accuracy, its offline radio map database which is manually created is a time consuming process and this radio map becomes an outdated database due to any environmental change occurrence.

The work of [7] focused on the application of location information on context-awareness. The study observed that the current indoor localization systems need to be manually adapted to work optimally with specific hardware and software. One type of context information is position information of wireless network clients. The study then focuses on Research in indoor localization of wireless network clients based on signal strength. Not much of this research is directed towards handling the issue of adapting signal strength based indoor localization system to the hardware and software of a specific wireless network user, it can be a tag or a PDA or a laptop. Therefore, current indoor localization systems need to be manually adapted to work optimally with specific hardware and software.

Liu [2] proposes an effective technique in locating a source, which is based on intersections of hyperbolic curves defined by the time differences of arrival of a signal received at a number of sensors and developed a simple method using a relative signal-strength capacity that is, the difference in inactive signal strength measured at the user position from multiple base transceiver stations (BTSs). This approach is non-iterative and also gives an explicit solution. Received signal strength (RSS) is combined with a signal propagation model to find the user location.

Hung-Huan and Yu-Non [8] combined the fingerprinting method and path loss models for multi floor environment, because most of the WLAN based indoor positioning system (IPS) did not consider the multi floor environment. Selected samples per floor were chosen to create the radio map in the online phase while the floor member is localized based on searching the radio map. After determining the floor, the mobile device location is determined by triangulation methods based on the AP's location, estimated by the path loss model. The results of the experiment of the proposed solution show that the floor positioning is highly accurate, close to 1.6m, with 5m distance between each point. Although a high accurate result is important in floor positioning, in any fingerprinting system the main drawback is that the database is usually required to be rebuild for accurate localisation, if change occurs in the environment.

In the work of [9], they proposed algorithm to handle the extensive and time-consuming RSS calibration process in designing the radio map for the indoor localisation systems. The proposed algorithm combines the concept of the reference point (feedback point) and the one-slope-model (OSM): $PL(d) = PL(do) + 10n\log(\frac{d}{do})$, and it overcomes loss signal prediction to get time-efficient calibration process. It starts by calibrating the RSS of the available APs by the feedback points, then it estimates the location of the APs with the strongest RSS based on the distance between the prediction point and it closes the feedback point where the RSS can be predicted by using OSM. However, the results from experiment show efficiency of the proposed algorithm in reducing the RSS calibration time without reducing the location prediction accuracy. From the study, the solution has few drawbacks which includes increase in the cost of indoor positioning system by using a feedback point. Also, the algorithm increases the computational complexity by searching for the strongest APs and determining its locations. And lastly, it uses the OSM model which assumes ideal wireless media which will not fluctuate nor attenuate due to many known and unknown reasons.

A system using an SSD approach was proposed by Sindhu and Jasil [10] with the aim of identifying best matched tower from the user's point of position. The user's signal strength is calculated, so that the difference of the signal strength between the user with the different towers were analyzed to identify a best matched or nearest tower from the user point of view. Two well-known localisation algorithms (K-nearest neighbor (KNN) and Bayesian inference) were used to demonstrate the robustness of SSD. The difference of the Signal Strengths between the user with the different access points were analysed to identify the highest and nearest access point from the user's point of position. While user requesting data from one access point and moving to the next access point, the signal strength difference (SSD) will be calculated, then automatically the data will be delivered to the user from the highest and nearest access point, which has strongest signal. This reduces the data loss problem in mobile computing.

Sun [11] in his work used Fishers' Linear Discriminant (FLD) and K-nearest neighbor (KNN) as a floor discriminative model. FLD model is based on the manual collected fingerprint database and the output of this model is matched with the fingerprint database by using weighted KNN (WKNN). After floor determination, the positioning accuracy increased and the average distance error reduced from 4.8 to 1.2 meters. However, the high localisation accuracy and the low distance error of the proposed model is considered as a complex solution model and time consuming for fingerprint database creation.

In summary, these related works used different techniques and technologies to improve on the accuracy of fingerprinting method. Although they achieved high positioning results, they used either complex solution and or expensive technology which defeats some of the major advantages of Wi-Fi based positioning system; in addition, most did not consider reliability of operation when one of the access points fails. Hence, this paper proposes a model which can overcome the fingerprinting problem with promising positioning result without any extra infrastructure and cost by combining two fingerprint metrics.

3. THE PROPOSED SYSTEM

The proposed system will operate in two independent phases of Offline and Online. During the Offline phase, a Wi-Fi mobile device is used to capture RSS values from the three access points designated for the study. The captured RSS are recorded as the fingerprinting for each reference position.

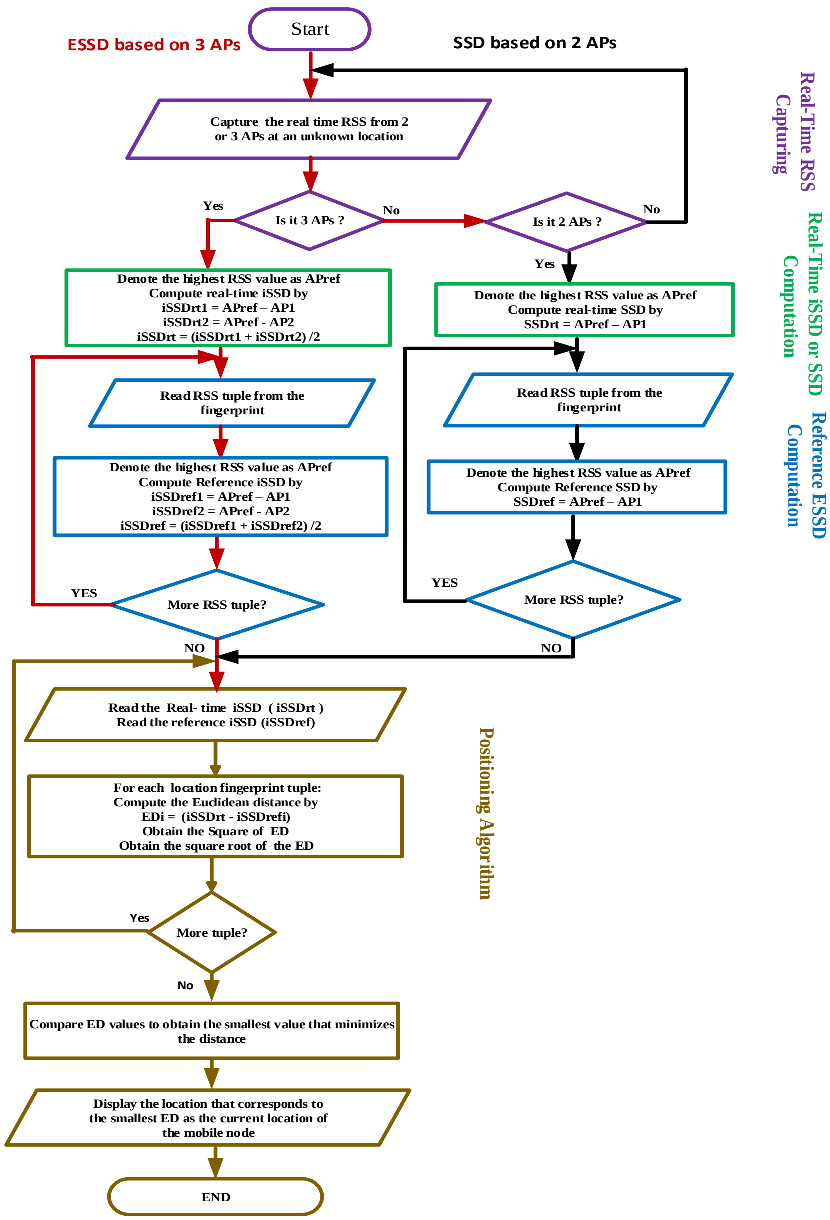

Fig. 1. Hybrid Fingerprint Algorithm.

In the Online phase, where the system is put into operation, the Wi-Fi mobile device at an unknown location captures the RSS from the available APs. The real-time iSSD is computed based on the number of access points that are active at that moment. To this end, to compute the real-time iSSD if three access points are reachable, the AP with the strongest signal presence at the unknown location is designated as the reference AP (APref). The values of the other two RSS sets from the other two APs are subtracted from the APref respectively. The differences are summed and averaged. In case, if only two out of the three access points are active, then the AP with the highest value of RSS is denoted as the reference access point (APref). The SSD is obtained by subtracting the RSS value of the remaining AP from the APref. Thereafter, based on the number of the surviving access points, the RSS values saved in the radio map during offline phase are extracted and likewise used to compute the reference iSSD and or SSD for each of the known reference location. To infer location of the mobile device, the Euclidean distance is applied to each set of reference values and real-time fingerprint values. The position that minimizes the value is regarded as the current location of the device.

4. EXPERIMENTAL TESTBED

The testbed is a bungalow corridor housing some offices in Enugu State College of Education (Technical), Enugu, South East, Nigeria. The building has a long corridor that divided the ground floor into two equal parts with each side containing some offices. The corridor provides a common access to the offices and the wireless network access points were hanged at three different locations along the corridor. The access points infrastructure was originally installed to provide WLAN infrastructure for data communication and ensure Wi-Fi network coverage to offices in the buildings. The details of the hardware as well as the software specifications used in the experiments are presented below.

3.1 Hardware Specifications

Table 1: Testbed hardware specifications

S/N	NAME OF DEVICE	DESCRIPTION
NETWORK ACCESS POINTS (APS)		
1	TP-Link	2.4GHZ, 150Mbps Outdoor Wireless Access Point. Model No: TL-WA 721DN
Wi-Fi MOBILE DEVICE		
1	ASUTEK Computer Inc. - ASUS mini-notebook	Intel Atom CPU 2GB DDR3, 32G HDD, Windows 8 Professional,
WIRELESS NETWORK CARDS		
1	D-Link	Wireless N 150 Pico, USB Adapter- TL-WN725N

In addition to the hardware specified above, the WiFiInfoView is used to captures the RSS in dBm.
The captured RSS values were subsequently recorded in Microsoft Excel file as the radio map. The results were analysed and subsequently plotted using cumulative distribution function (CDF) of the error distance using a program routine written in Matlab 2015a.

3.2 Testing and Analysis

To investigate how the hybrid fingerprinting scheme can be used in Wi-Fi based positioning system within an indoor setting, two Test Cases were formulated. The Test Cases were designed to investigate the performance of the hybrid solution proposed in this paper and by so doing evaluate its performance in real life situation. The experiments are conducted in two stages of Training and Online phases respectively. The details of the experimental evaluations are hereby presented.

3.2.1 Training Phase

In this phase, the radio map of the environment was constructed. The corridor was measured and marked into 12 reference points with two meters' interval in each case. This was achieved by conducting a signal survey of the designated area using the ASUS Notebook installed with D-Link Wi-Fi NIC. We stationed the Notebook at each of the Twelve (12) marked location reference points and the RSS valueswere captured from the three APs designated for the study in the testbed using WiFiInfoView. This we repeated until the 12 reference points were covered. Table 2 shows the various RSS values obtained during the training as well as the computed values of the reference iSSD, when the three APs were functional.

3.2.2 Location Estimation Phase

For the Location estimation phase, the ASUS Notebook was again used together with D-Link Wi-Fi NIC. The Wi-Fi mobile node was taken to the randomly selected locations within the coverage area and the RSS values obtained at each of the random location were used for the computation of real-time iSSD and thereafter, the location determination was undertaken.

Test Case 1: The use of iSSD to Locate a Wi-Fi Mobile Device.

This test was conducted to investigate the ability of the iSSD method to accurately locate a mobile user at an unknown location within the calibrated area when the three access points are working.

To obtain the real-time RSS reading, the reference location points 5, 7 and 12 were randomly selected. The Wi-Fi mobile node was taken to each of the randomly selected reference positions and the real-time RSS values were simultaneously captured and subsequently used in the computation of the real-time iSSD. The outcomes of the measurements are tabulated in Table 3.

Reference Location (RL)	APref	AP1	AP2	iSSDrt1 = (APref - AP1)	iSSDrt2 = (APref - AP2)	iSSDsum = (iSSD1 + iSSD2)	iSSDrtmean = (iSSDsum/2)
5	74	71	58	3	16	19	9.5
7	67	60	45	7	22	29	14.5
12	83	73	57	10	26	36	18

Table 3: Real-Time iSSD when 3 access points are active

Using the trained dataset contained in the Table 2 and each of the real-time values presented in the Table 3; the results of the location determination exercise are presented in Table 4.

Further, analysis is conducted on the results using the cumulative distribution function (CDF) as shown Figure 4. From the analysis, 90% of the position estimates have errors within 2 meters which is a good result. The error curve increases sharply and becomes steady which translates that the error of the positioning scheme increases sharply and stabilizes.

Reference Location(RL) IDs	APref	AP1	AP2	iSSD1 = (APref - AP1)	iSSD = (APref - AP2)	iSSDsum = (iSSD1 + iSSD2)	iSSDrefmean = (iSSDrefsum/2)
1	79	59	48	20	31	51	25.5
2	69	58	56	11	13	24	12
3	60	57	56	3	4	7	3.5
4	70	63	56	7	14	21	10.5
5	64	57	51	7	13	20	10
6	71	57	52	14	19	33	16.5
7	71	69	45	2	26	28	14
8	79	75	51	4	28	32	16
9	79	72	55	7	24	31	15.5
10	77	75	47	2	30	32	16
11	83	83	58	0	25	25	12.5
12	90	87	56	3	34	37	18.5

Table 4: Positioning Results for the Test Case 1

Actual Location	5	7	12
Reference Location (RF)	Estimated location	Estimated location	Estimated location
1	16	11	7.5
2	2.5	2.5	6.0
3	6.0	11	14.5
4	1.0	4.0	7.5
5	0.5	4.5	8.0
6	7.0	2.0	1.5
7	4.5	0.5	4.0
8	6.5	1.5	2.0
9	6.0	1.0	2.5
10	6.5	1.5	2.0
11	3.0	2.0	5.5
12	9.0	4.0	0.5

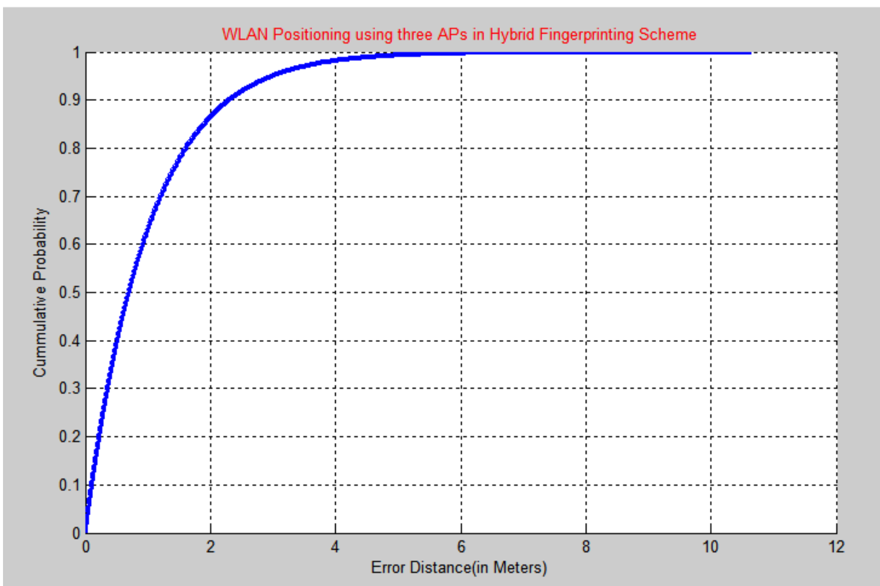

Fig. 4. CDF of the Error Distance of WLAN Positioning using 3 APs

Test Case 2: Performance of the iSSD Scheme When one of the AP used in Training Failed during Location Estimation

One of the cardinal objective of this study is to provide a reliability mechanism that will sustain the operation of the system when one of the AP fails in location estimation phase. To provide this functionality, the hybrid scheme adopted the computation of both reference and real-time fingerprint values in the online phase so that the number of live APs could have been established. If three APs are available, the iSSD is computed or else if two APs are available, SSD is used.

To investigate the performance of the hybrid scheme in this context, one of the network APs was switched-off. Four locations (2, 4, 7 and 11) were randomly selected as unknown positions to be determined. In this context, at the four randomly selected spots, real-time RSS were collected using the ASUS notebook and D-Link Wi-Fi NIC. The collected RSS values were used to compute the SSD while the RSS values corresponding to the two remaining APs were looked up from the radio map and used to calculate the reference SSD.

The results of the measurements for the reference SSD values as well as the real-time SSD values are contained in Table 5 and Table 6 respectively.

Table 5: Training Dataset corresponding to 2 Access Points (SSD) and extracted from Table 2.

Reference Location (RL)	AP1	AP2	iSSDrefmean
1	59	48	11
2	58	56	2
3	57	56	1
4	63	56	7
5	57	51	6
6	57	52	5
7	69	46	23
8	75	51	24
9	72	55	17
10	75	47	28
11	83	58	25
12	87	56	31

Table 6: Real-time data for the two access points (SSD).

Reference Location (RL)	AP1	AP2	iSSDrtmean
2	63	61	2
4	58	50	8
7	64	45	19
11	71	45	26

From the results of the study in Table 7, it can be seen that the fail-over mechanism in the hybrid scheme achieved a good result. Out of the three locations, two (i.e. 2, 4 and 11) while one (i.e.7) was not. This loss of location accuracy may be due reduction in the number of access points in line with the observation by Hossain, et, al., (2014) and or due to fluctuation prevalent with the Wi-Fi signal transmission. The result was further analysed using the CDF of error distance as shown in Figure 5.

Table 7: Positioning Results for Test Case 2

Actual Location	2	4	7	11
Reference Location (RF)	Estimated location	Estimated location	Estimated location	Estimated location
1	9.0	3	8.0	15
2	0	6	17	24
3	1.0	7	18	25
4	5.0	1.0	12	19
5	4.0	2	13	20
6	3.0	3	14	21
7	21	15	4.0	3.0
8	22	16	3.0	2.0
9	15	11	9.0	9.0
10	27	20	16	2.0
11	23	17	6.0	1.0
12	29	23	12	4.0

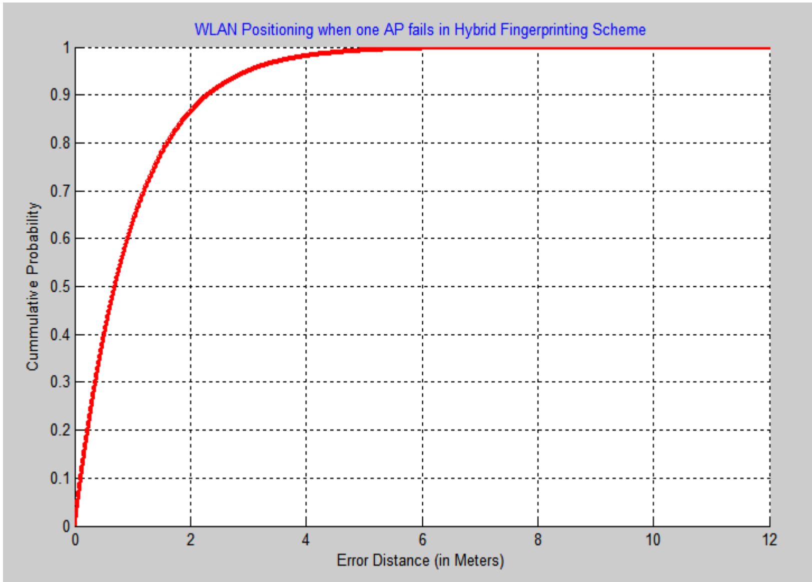

Fig. 5. CDF of Distance Error for the SSD case

The figure shows that the 50% of the error values lie below 1 meter, and that it could be able to estimate the position of the Wi-Fi mobile device with an accuracy of 2 meters in 90% of the requests.

5. CONCLUSION

In this study, it has been shown that the combination of different fingerprinting technique could be harnessed for an improved performance of the Wi-Fi based positioning system. The hybrid fingerprinting scheme in this study has been tested under several conditions with the results analysed. Based on the analysis, it could be shown that the hybrid fingerprinting scheme is capable of providing service even in the event of failure of one of the access point thereby guaranteeing the reliability of the system built using the scheme.

REFERENCES

[1] Fuicu, S., Marcu, M., Stratulat, B., and Girban, A., "Effective and Accuracy of Wireless Positioning Systems". Retrieve from www.wseas.us/e-library/transactions/ computers/2009/29-649.pdf
[2] Liu, Y."Location, Localization and Localizability. Journal of Computer Science and Technology, Vol.25, No.2, 2010, pp 274 – 297.
[3] Tom Van Haute, Eli De Poorter, Ingrid Moerman, Filip Lemic, Vlado Handziski , Adam Wolisz, Niklas Wirström and Thiemo Voigt . "Comparability of RF-based indoor localisation solutions in heterogeneous environments: an experimental study", Int. J. Ad Hoc and Ubiquitous Computing, Vol. 23, Nos. 1/2, 2016. Pp.92-114
[4] Robin Henniges , "Current approches of Wifi Positioning " in Service-Centric Networking – Seminar Ws2011/2012., Tu-Berlin, 2012. https://www.snet.tu-berlin.de/fileadmin/fg220/courses/WS1112/snet-project/wifi-positioning_henniges.pdf
[5] K. Pahlavan and P. Krishnamurthy Principles of Wireless Networks Prentice Hall PTR, Upper Saddle River, New Jersey, 2002.
[6] Bahl, P. and Padmanabhan, V "RADAR. An in-building RF-based user Location and Tracking System". Proceedings of IEEE Infocom , vol 2, 2000.pp775-784..
[7] Kjaergaard, M. . "Automatic Mitigation of Sensor variations for Signal Strength based Location Systems". Proceedings of second International Workshop on Location and Context Awareness. 2006
[8] Hung-Huan and Yu-Non " Wi-Fi based Indoor Positioning for Multi-Floor Environment" In TENCON IEEE Region 10 Conference, 2011
[9] Narzullaeu, A., and Park, Y.,. Novel Calibration Algorithm for Received Signal Strength based Indoor Real-Time Locating Systems. International Journal of Electronics and Communications, Vol. 67, No. 7,(2013) pp 637-644.
[10] P.V.Sindhu and .S.P.Godlin Jasil "A Robust SSD Position Fingerprint Approach for Wireless Networks" International Journal of Engineering Trends and Technology (IJETT) – Vol 8 No. 9 2014.pp 506-508
[11] Sun, L., Zheng, Z., He, T., & Li, F. (2015). Multifloor Wi-Fi Localization System with Floor Identification. International Journal of Distributed Sensor Networks. https://doi.org/10.1155/2015/131523N
[12] Ashwnin, B. and Usha, J., "Location based Services-Positioning Techniques and its Applications".. International Journal of Application and Innovation in

Engineering and Management, Vol (3), Issue 12014. Retrieved from www.ijaiem.org.

[13] Hossain, A., Jin, Y., Soh, W., and Van, H., (2014). "SSD: A Robust RF Location Fingerprint Addressing Mobile Devices' Heterogeneity". Retrieved from https://www.researchgate.net/publication/258225393.

[14] Kjaergaard M., (2011). Indoor Positioning with Radio Location Fingerprinting. Retrieved https://www.researchgate.net/publication/45914279

[15] Lahiru L., H., "Wi-Fi Based Indoor Device Location System for Android based Devices" in Proceedings of APIIT Business, Law & Technology Conference. Colombo, Sri Lanka., 2017