JJEE

Volume 10 | Number 1 | March 2024 | Pages 48-59

Jordan Journal of Electrical Engineering

ISSN (print): 2409-9600, ISSN (online): 2409-9619

Homepage: jjee.ttu.edu.jo

Enhancing Indoor Positioning Systems Accuracy with Optimal Placement of Wi-Fi Access Points

A. A. Isa[1*], J. Akanni[1], A. Y. Abdulrahman[1], R. A. Alao[1]

[1] Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Nigeria
E-mail: abdurrhaman49@gmail.com

Received: May 25, 2023 *Revised: July 25, 2023* *Accepted: August 03, 2023*

Abstract— The indoor positioning system (IPS) has generated a considerable amount of interest in recent times, and the prosperity of the system's development is heavily reliant on its ability to accurately locate objects. The performance measure is significantly impacted by the location of access points (APs). However, the bulk of previous studies have tended to overlook the matter of optimal AP placement and efficient design for IPS due to the dependence on pre-existing installed APs, which were chiefly formulated for coverage objectives. In this investigation, an optimal placement function - which is reliant on mean and variance - has been developed using received signal strength (RSS) measurements data. The performance evaluation in this research is based on experimentation and compared with currently employed placement methods. The results indicate that the most optimal function value for the suggested method is 1.5714, which is substantially smaller than the values for rectangular, triangular, and triangular II, which are 12.468, 5.5364, and 8.5147, respectively. When the recommended placement strategy is employed instead of the existing ones, the weighted K-nearest algorithm (WKNN) for location error, using average RSS as the fingerprint radio map database, yielded a heightened degree of precision.

Keywords— Wi-Fi; Fingerprinting; Access point; Indoor positioning system.

1. INTRODUCTION

The growing interest in wireless technologies has brought Indoor Positioning Systems (IPS) to the forefront as a noteworthy area of investigation [1], which represents a significant advancement in current wireless technologies. As a result, there has been a heightened focus on analyzing the propagation characteristics of indoor and outdoor wireless network environments [2, 3]. In situations when global positioning system (GPS) signals are difficult to reach receivers within buildings, IPS that employ radio frequency (RF) waves for indoor wireless systems are often recommended as viable replacements. [4, 5]. However, it's crucial to keep in mind that, in contrast to outside situations, indoor conditions frequently prohibit line-of-sight connection among the reference nodes and receivers. As a result, the effect of multipath and attenuation of various barriers have a substantial impact on radio signal transmission within indoor environments. These factors could potentially lead to the degradation of indoor positioning systems' accuracy [6, 7], which presents significant design challenges for these systems.

The location fingerprinting technique is the easiest strategy among the several approaches that use radio frequency for indoor positioning, such as Angle-of-Arrival (AOA) and Time-of-Arrival (TOA) measurement. This technique is based on the assumption of a substantial relationship amongst received signal strength (RSS) variations and their

* Corresponding author

Article's DOI: 10.5455/jjee.204-1685026962

corresponding locations [8]. It is appealing because practically all wireless transceivers are capable of measuring RSS, eliminating the requirement for specialized devices for mobile users. In design, obtaining or computing location information is critical.

The remainder of this article is organized as follows. The second section includes an overview of important studies. Section 3 describes the technique of the experiment, while Section 4 gives the results and discussion. Section 5 concludes with a quick overview of the research.

2. RELATED WORK

Initial design of Wi-Fi networks did not prioritize the implementation of locating services, leading to a decline in localization accuracy. The use of triangulation has become a common method for locating mobile devices; however, this technique requires a strong signal from three reference Access Points (APs), which are generally unavailable in Wi-Fi networks [2, 3]. In the context of location sensing, the precision of position calculation is impacted by the quantity and placement of reference sites [9]. This necessitates a revaluation of Wi-Fi installation strategies to enhance IPS accuracy.

It is pertinent to note that the number and location of APs have a significant influence on the accuracy of IPSs utilizing wireless networks [10, 11]. Previous initiatives [12-14] have primarily focused on optimizing Wireless Local Area Network (WLAN) performance through AP location for data services. However, this paper specifically addresses the deployment of APs for indoor positioning. Our study proposes a method for enhancing Wi-Fi AP placement to increase IPS accuracy.

In [15] a simulated annealing approach in determining the optimal configuration of Wi-Fi access points for IPS was proposed. The proposed framework entails the placement of an access point (AP) at every intersection of the finite grid that covers the territory map. Utilizing models of wireless signal propagation, the coverage area of each Access Point (AP) is determined. The optimization of AP placement is achieved by approximating the total number of APs that are expected to be in close proximity to a given mobile terminal location. It should be noted, however, that the technique may not be suitable for real-time applications due to its computational requirements and it is based on the presumption that the environment is stable and unchanging., without taking into account dynamic barriers or interference on Wi-Fi signal transmission. Additionally, prior knowledge of the environment is required, rendering it infeasible for situations that are unknown or constantly changing.

The improvement of an IPS's overall performance was pursued through the introduction of a novel optimization approach in [16], which aimed to place reference nodes (RNs) in the best possible location. The method puts forth an arithmetical problem that formulates the placement of RNs, with the objective of reducing the number RNs and locating them within the IPS. Binary integer linear programming (BILP) is used to solve this problem. To gauge the effectiveness and efficiency of this strategy, an extensive simulation model comparison was conducted, inclusive of node placements from additional research and ideal node placement methods from the optimal process. It is crucial to point out that the simulation model used in the study was unable to precisely recreate the variety of real-world indoor situations, which may have implications for the generalizability and application of the results.

In [17], the author developed a three-dimensional (3D) coverage location model for Wi-Fi access APs in indoor environments that incorporates a generic radio propagation model and considers normal building obstructions included in the typical coverage framework. The proposed methodology utilized 3D Euclidean distance to characterize radio signal penetration and create an effective AP placement strategy for a multi-story structure on a university campus. The study's empirical findings included 3D renderings of options for multi-floor Wi-Fi AP placement, expected to offer a helpful modeling framework for merging facility location models with wireless network architecture in a 3D environment. However, it should be noted that the model may not apply to other types of buildings or environments, as this was not explicitly addressed in the study. Moreover, the lack of comparison of the proposed model with other existing models or tools for Wi-Fi access point planning is a potential avenue for future research.

In [18], a Genetic Algorithm technique was proposed to improve the quality of IPS by carefully altering the placements of the access points. The goal of this modification is to ensure that the combination of received signal intensities in each set area block is distinct, accomplished using a Fitness Function that considers the observable changes in signatures across neighbor blocks. The log-normal shadowing path loss model was used in each block to estimate the values of the Received Signal Strength Indicator (RSSI). However, it must be noted that this technique may not be universally applicable to all indoor environments, as the results may depend on the structure of the building and the number of access points employed.

A system was presented by [19] for a managerial device that can proficiently employ the positions of both the indoor positioning monitor device and the Wi-Fi access node (WFAN) in an experimental setting. The system was meticulously designed to incorporate BLE beacons for indoor positioning, while the mobile device carries the WFAN to suitable locations within the indoor environment. The results obtained from experimentation revealed that the estimated position and the actual position of the managerial device had a mean difference of only 0.807 m. This observation indicates that the proposed system has the potential to significantly enhance wireless access quality by relocating the WFAN to optimal positions in the indoor environment relative to other environment devices. Notably, the experiments were conducted in a limited area.

Researchers in [20] have developed an innovative approach to enhance the performance of Wi-Fi APs for indoor location. The method, named Fast Water-filling algorithm Group Power Constraint (FWA-GPC), takes into account the critical issue of power consumption during AP optimization, which is particularly significant in large indoor spaces where signal coverage is required. Unlike the conventional practice of assigning a single AP to each potential AP site, FWA-GPC enhances scalability by considering spare APs when existing APs fail. To demonstrate the scalability of the recommended technique, the same experimental procedure was replicated in a different location, measuring 57 m by 25 m, on the same level of a building. The results indicate that the proposed strategy outperforms conventional methods in terms of localization precision and power consumption. Despite these advantages, it is important to acknowledge the limitations of this proposed method. Specifically, it may not be feasible to set the entire number of APs at each potential site to an integer, as required by the recommended technique, leading to potential localization errors. Furthermore, the research lacks a comprehensive comparison with other indoor locating methods. A more in-depth evaluation of the benefits and drawbacks of the suggested methodology can be achieved by comparing it to existing methods. Nonetheless, this approach shows great potential for enhancing the precision and scalability of indoor positioning systems.

The Wireless Optimization Algorithm for Indoor Placement (WOAIP) is a multi-level optimization technique that is based on Binary Particle Swarm Optimization (BPSO) and was presented in [21]. The primary aim of this algorithm is to efficiently distribute APs across multiple floors, resulting in a seamless coverage that maintains Quality of Service (QoS) while being cost-effective. To evaluate the effectiveness of the complete network, five RSS criteria were defined: the total number of APs, the overall percentage of TPs covered, the coverage ratio, the fitness of the coverage, and the fitness of the AP location. The algorithm was subjected to extensive testing by comparing the data obtained by Wireless In-Site (WI) software to the current wireless simulated actual AP installation of the chosen building. The test findings indicate that the WOAIP performed exceptionally well in terms of AP placement and optimization, increasing the wireless coverage ratio from 58.5% of existing AP coverage to 92.93%. Furthermore, it was demonstrated that the quantity of AP devices required is directly related to the RSS signal level. It is worth noting that the suggested technique was specifically evaluated in a building in University of Baghdad; therefore, the findings may not be generalizable to other structures or situations.

This particular study propose a flexible and cost-effective approach to augment the precision of indoor positioning, through the utilization of Wi-Fi infrastructure. Further, the proposed scheme can be implemented in various indoor areas, subject to their complexity and dimensions, thereby rendering it a versatile option for diverse applications. Experiments conducted in a real-world setting were employed to evaluate the efficacy of the suggested technique

3. METHODOLOGY

3.1. The Proposed Optimal Access Point Placement

This section presents the optimal APs placement based on the summation of variance and mean of the most optimal configuration. Fig. 1 is the framework of the proposed placement.

In order to determine the optimal locations for Wi-Fi access points (APs) within an indoor environment, it is imperative to partition the space into square blocks. These blocks are demarcated by up to eight adjacent cells, a method employed to optimize computations and ensure uniformity in size. Additionally, each cell is denoted by a unique received signal strength indicator (RSSI) signature, which is a vector consistently indicating the RSSI values of all Wi-Fi APs. The principal objective of this research is to identify the most advantageous positions for Wi-Fi APs to minimize the number of cells with distinct signatures, or at the very least, guarantee that neighboring cells possess dissimilar signatures. These will ensure the IPS precisely locates the device or detect its movement between different cells. The point of intersection of each cell is labelled as Reference Point (RP).

$$RP_j = (x_j, y_j) \qquad j = 1, \cdots, N \tag{1}$$

where (x_j, y_j) are the coordinate points of the RPs and N is the total number of RPs.

AP is placed at any desirable point and the initial received signal strength (RSS) called P_f is computed as shown in Eq. (2)

$$P_f = \begin{bmatrix} \varphi_i \\ \vdots \\ \varphi_N \end{bmatrix} \tag{2}$$

Two state threshold "λ" is defined to convert Eq. (2) into a new matrix of zeroes and ones.

$$\varphi_i = \begin{cases} 1, & if -55\, dBM \geq P_{AP1} \geq -60\, dBM\ and\ P_D \leq 10\, m \\ 0, & otherwise \end{cases} \tag{3}$$

where φ_i is the RSS value at each RP, P_{AP1} stand for RSS of AP1 and P_D is the distance of AP1 from RPs; Eq. (3) is the "λ" condition in terms of RSS and distance.

If the value of P_f(i) is equal to zero, it can be considered logically false, and as a result, the RSS for all index i fails to meet the th condition. Conversely, if the value is equivalent to one, it can be deemed as logically true, thereby indicating that the RSS satisfies the condition. The deployment algorithm in Fig. 2 is then used on every point that satisfies the condition.

$$A(i) = \begin{bmatrix} x_i & y_i \\ \vdots & \vdots \\ x_l & y_l \end{bmatrix} \tag{4}$$

where $A(i)$ is the number data base recorded at each increment of AP as deployed in the experiment. The optimal access point selection criteria are formulated as follows. Recall that the inverse square power law states that the characteristics of the received signal intensity are inversely proportional to the distance separation.

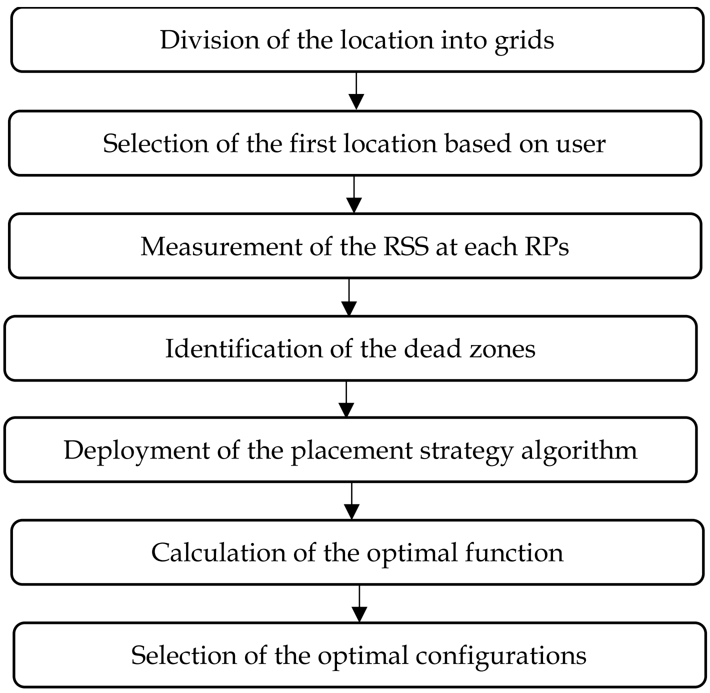

Fig. 1. Framework of the proposed optimal placement of APS.

Consequently, an optimal selection technique utilizing a diffusion approach is implemented. For the K number of AP located in an indoor environment, the received power is calculated by a situated path loss model. So, there will be k number of path loss. Eq. (5) is selection criteria and using a negative path loss value is undesirable, hence the need for an absolute version is depicted by the equation [22].

$$|p_{mn}| = \frac{p_{mn}-p_{min}}{p_{max}-p_{min}} \quad (5)$$

Where p_{mn} is the power received at the location, p_{max} is saturated power at the reference distance d_o and p_{min} is the minimum received power. The optimal selection function is derived from the average and variance of the RSS received from the access points. The mean and variance are computed with Eqs. (6) and (7) respectively.

$$\overline{p_{mn}} = \frac{1}{N_T-1}\sum_{m=1}^{M}\sum_{n=1}^{N}|p_{mn}| \quad (6)$$

$$\sigma_{mn}^2 = \frac{1}{N_T-1}\sum_{m=1}^{M}\sum_{n=1}^{N}(|p_{mn}| - \overline{p_{mn}})^2 \quad (7)$$

$$\min O = \sum_{m=1}^{M}\sum_{n=1}^{N} w_1 \frac{1}{\overline{p_{mn}}} + w_2\sigma_{mn}^2 + L \quad (8)$$

where N_T is the total number of reference points, O denotes the optimal selection function, w_1 and w_2 are weighted variables and L is a No function to be accommodated in case of a dead zone where Wi-Fi RSS is not detected, if this happens, L will be assigned a big integer value, causing O to produce a large value, and so such a configuration will not be optimum. $\mathrm{w}_1 = 0.5\mathrm{w}_2$ while w_2 is inversely proportional to the number of APs.

Algorithm: APs deployment technique
Input: AP1 = (x, y) & Total $APs = AP_T$
Output: All detected location A {1: Stop}
i. Compute RSS at RPs from AP1
ii. Perform the conditions
iii. Save the detected locations in A{i}
LOOP Process
iv. **for** i = 1 to AP_T – 2 **do**
v. Acquire points from A{i}
vi. Compute RSS
vii. Perform the conditions
viii. Save in A {I + 1}
ix. **end for**
Stop LOOP Process

Fig. 2. Optimum APs deployment algorithm.

3.2. Evaluation of the Proposed Optimal Access Point Placement

In this section, the measurement of positioning accuracy is conducted for the optimal placement configuration. The weighetd k nearest neigbor (WKNN) algorithm is utilized, where K RPs with the smallest values are selected in conjunction with a weighted average employing Eq (9). The rationale behind this selection is based on its superior positioning accuracy compared to k nearest neigbor (KNN), as well as its widespread adoption as a matching algorithm [23].

$$w_{iT} = \frac{\frac{1}{D_{iT}}}{\sum_{i=1}^{K}\frac{1}{D_{iT}}} \quad (9)$$

Where

$$D_{iT} = \left[\frac{\sum_{j=1}^{m}\left(\left|RSS_T^j - RSS_i^j\right|\right)^t}{m}\right]^{\frac{i}{t}}, i = 1,2,3, \dots, n \quad (10)$$

From Eq. (10), RSS_T^j is the measured RSS value from APs at TP; RSS_i^j is the measured RSS value from the APs at the RPs, t is a distance form, if 't' is one D_{iT} is Manhattan distance whereas if 't' is two D_{iT} is Euclidean distance and m denote the total number of APs.

3.3. Experimental Setup

A trial was conducted to examine the proposed arrangement on the second floor of the NLNG Building, situated within the Faculty of Engineering and Technology at the University of Ilorin, in Ilorin, Nigeria. The experimental setting, as depicted in Fig. 3, spanned approximately 42mx25m and featured laboratories, a lobby, sections of staircase, and a seminar area. Fig. 3 depicts the floor plan, while the corresponding of few of the real surroundings are shown in Fig. 4.

The heterogeneity of the structures of various devices resulted in varying signals received from a singular access point. To address this concern, a single type of smartphone (Tecno Camon 18P) was utilized in the measurement process. The sampling rate was fixed at 2 s. To minimize any potential orientation bias, the smartphone was positioned randomly and stabilized on a tripod.

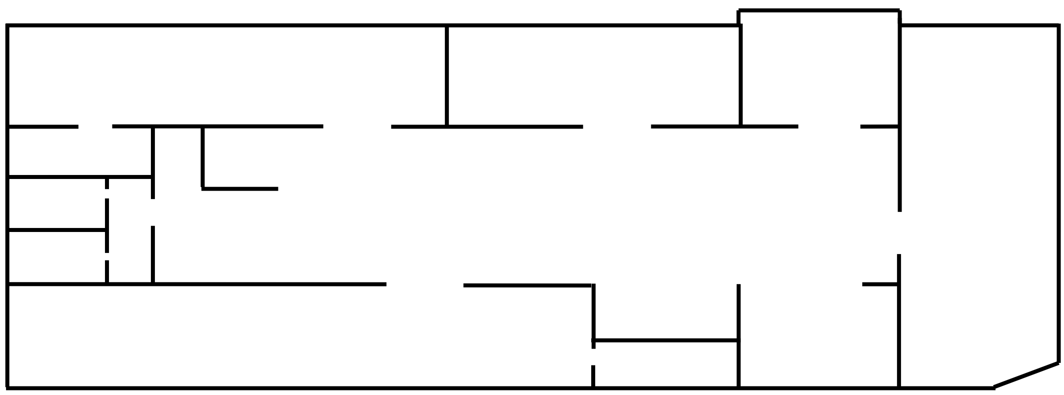

Fig. 3. Floor plan of the study location.

4. RESULT AND DISCUSSIONS

In this section, the result of the outcome and experimentation of the proposed optimal Access Point (AP) placement has been analyzed. The proposed technique is calculated on the RSS measurement based on the procedures accentuated in Section 3. Fig. 5 shows all the six optimal placement with the star symbol depicting the AP locations and the optimal placement function of the six derived configurations, including the mean, variance optimal function, and the number of dead zones, is tabulated in Table 1. Placement 5 has been selected as the optimal since it has a zero number of dead zones and yields the lowest optimal function.

Fig. 4. Sample of selected view of the study environment.

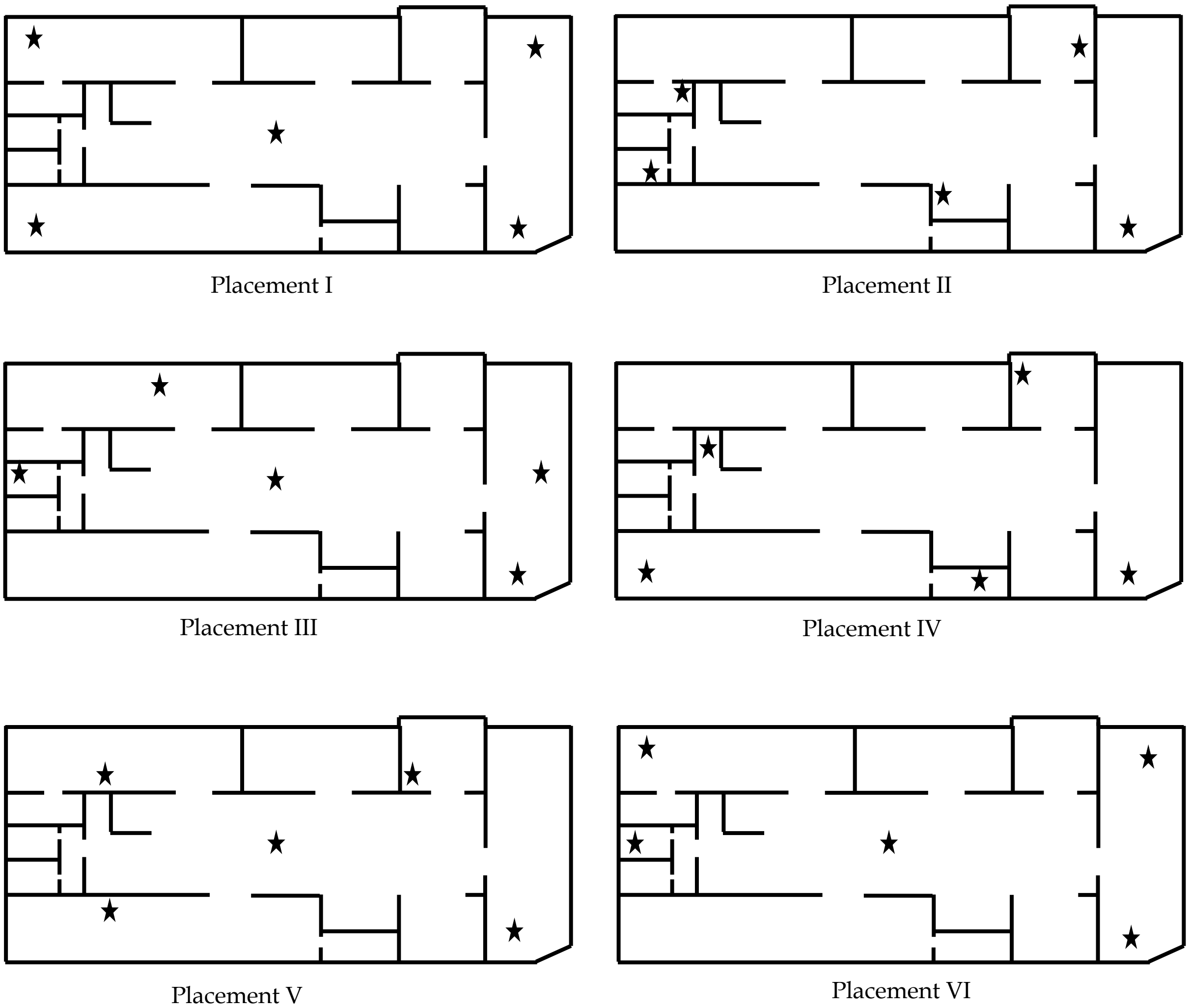

Fig. 5. Optimal AP placement locations

Table 1: Optimal function of the placement results.

Placement	Mean $[\overline{p_{mn}}]$	Variance $[\sigma_{mn}^2]$	Optimal function, O	Number of dead zone
I	0.1820	0.0401	1.6463	1
II	0.1786	0.0322	1.6605	2
III	0.1038	0.0243	2.2516	3
IV	0.2007	0.0360	1.6080	1
V	*0.2041*	*0.0322*	*1.5714*	*0*
VI	0.1846	0.0254	1.6263	1

Table 2 displays a comprehensive comparison amongst various pre-existing deployment patterns. The symmetrical placement was implemented and the optimal placement was calculated for each pattern utilizing Eq. (10). Any location experiencing an RSS value exceeding -120 dBm is considered to be a dead zone, because some of the areas such in the top left and right rooms have fairly low coverage signals, roughly at about ≤−120 dBm. This poor signal may result from the thickness of the surrounding walls, which absorb about 14 dBm of transmitted signal [24]. The method introduced in this study shows a mean value of 0.2041 and a variance value of 0.0322, thus generating an optimal function of 1.5714 and providing a coverage of 45% compared to the pre-existing placement. Additionally, it guarantees complete Wi-Fi signal coverage in all areas of the study location, as it is devoid of any dead zones.

Table 2: Comparison between proposed optimal placement with pre-existing deployment patterns.

Placement	Mean $[\overline{\mathrm{p}_{\mathrm{mn}}}]$	Variance $[\sigma_{\mathrm{mn}}^2]$	Optimal function, O	Number of dead zone
Proposed	0.2041	0.0322	1.5714	0
Rectangular	1.2078	0.0544	12.468	13
Triangular	0.9658	0.0187	5.5364	0
Triangular II	1.0072	0.0183	8.5147	15

Fig. 6 presents the boxplots of the position errors for the four placements, (proposed, rectangular, triangular, and triangular II placement). The boxplots incorporate various metrics such as the 90th, 75th, mean, 25th, and 10th percentile errors. The results indicate that the mean position error for the proposed placement is 2.50 m, which is superior to the 2.80 m for the rectangular placement, 2.73 m for the triangular placement, and 2.59 m for the triangular II placement technique. This superiority can be attributed to the proposed placement's ability to amplify the identification of the nearest high-quality RPs' point, thereby enhancing the IPS's positioning accuracy.

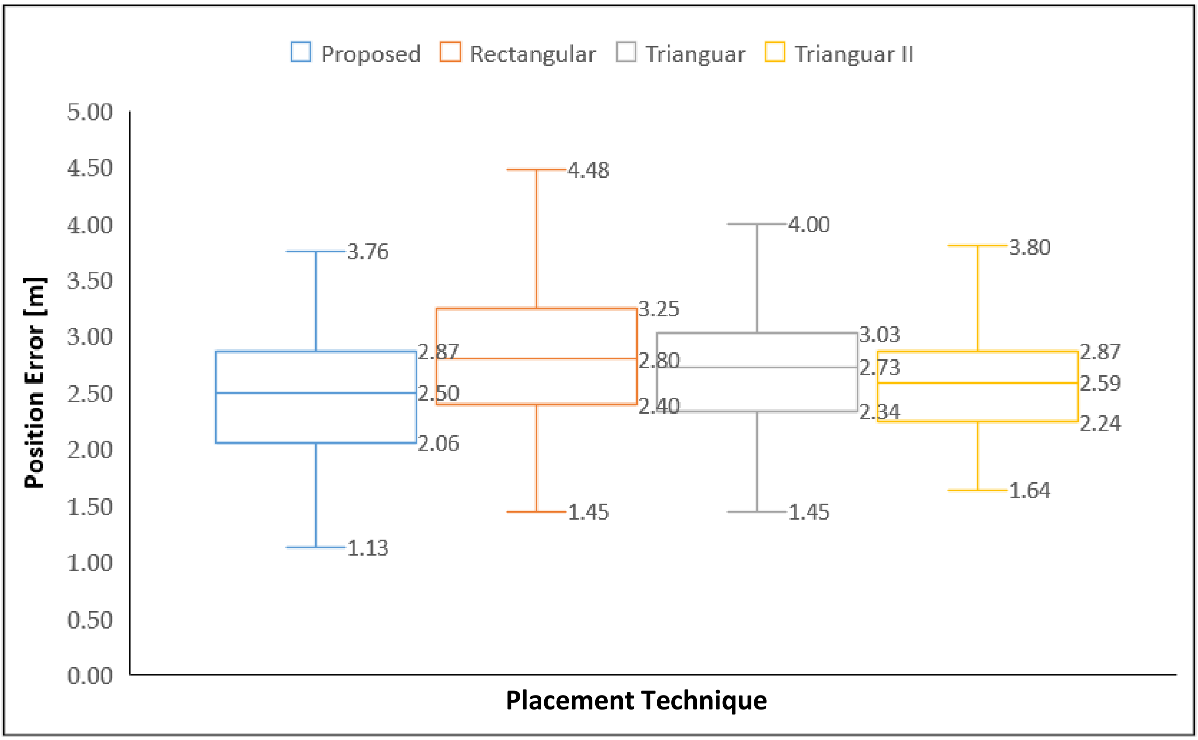

Fig. 6: Comparison of the position accuracy in terms of placement techniques by boxplots.

5. CONCLUSION

The accuracy of indoor positioning technologies is heavily influenced by the placement of access points. In this article, we have undertaken an investigation into the most effective methods for positioning access points for IPS. Specifically, we have explored approaches for positioning access points that will enable the signal to be obtained from the best reference APs within an indoor environment, while minimizing the number of APs required. Through the computation of the mean and variance, we have established an optimal placement function, which has been subjected to experimental verification. The results of this experiment demonstrate that our proposed strategy - which employs the WKNN algorithm and has a mean error of 2.50 m - offers the lowest optimal function and 45% coverage when compared to existing placement strategies. As compared to traditional methods of uniformly distributing Wi-Fi access points, the outcomes of this methodology reveal a significant enhancement in the precision of indoor positioning.

REFERENCES

[1] A. Adikpe, I. Matthew, A. Caleb, B. Ishaya, O. Bankole, B. James, E. Chukwudi "A Review on wireless fidelity co-location technology adopted indoors for technology-based contact tracing," *Jordan Journal of Electrical Engineering*, vol. 8, no. 2, pp. 133-150, 2022, doi: 10.5455/jjee.204-1635982606.

[2] L. Sahoo, M. Ray, B. Ganthia, "Occupancy detection in a building using hybrid models," *Jordan Journal of Electrical Engineering*, vol. 9, no. 2, pp. 228-240, 2023, doi: 10.5455/jjee.204-1669195686.

[3] H. Wang, P. Zhang, J. Li, X. You, "Radio propagation and wireless coverage of LSAA-based 5G millimeter-wave mobile communication systems," *China Communication*, vol. 16, no. 5, pp. 1–18, 2019, doi: 10.23919/j.cc.2019.05.001.

[4] G. Djuknic, R. Richton, "Geolocation and assisted GPS," *Computer*, vol. 34, no. 2, pp. 123–125, 2001, doi: 10.1109/2.901174.

[5] B. Jang, H. Kim, "Indoor positioning technologies without offline fingerprinting map: a survey," *IEEE Communications Survey and Tutorial*, vol. 21, no. 1, pp. 508–525, 2019, doi: 10.1109/COMST.2018.2867935.

[6] Y. Gu, A. Lo, I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," *IEEE Communications Survey and Tutorial*, vol. 11, no. 1, pp. 13–32, 2009, doi: 10.1109/SURV.2009.090103.

[7] S. He, S. Chan, "Wi-Fi fingerprint-based indoor positioning: recent advances and comparisons," *IEEE Communications Survey and Tutorial*, vol. 18, no. 1, pp. 466–490, 2016, doi: 10.1109/COMST.2015.2464084.

[8] S. Aomumpai, C. Prommak, "On the impact of reference node placement in wireless indoor positioning systems," *International Journal of Electrical and Computer Engineering*, vol. 5, no. 12, pp. 1704–1708, 2011, doi: 1307-6892/9036..

[9] O. Baala, Y. Zheng, A. Caminada, "The impact of AP placement in WLAN-based indoor positioning system," *Proceedings of IEEE International Conference on Networks*, 2009, doi: 10.1109/ICN.2009.50..

[10] T. Vanhatupa, M. Hannikainen, T. Hamalainen, "Genetic algorithm to optimize node placement and configuration for WLAN planning," *Proceedings of IEEE International Symposium on Wireless Communication Systems*, 2007, doi: 10.1109/ISWCS.2007.4392413.

[11] A. Barolli, S. Sakamoto, L. Barolli, M. Takizawa, "Performance analysis of simulation system based on particle swarm optimization and distributed genetic algorithm for WMNs considering different distributions of mesh clients," *Innovative Mobile and Internet Services in Ubiquitous Computing*, vol. 773, pp. 32–45, 2019, doi: 10.1007/978-3-319-93554-6_3.

[12] X. Ling, K. Yeung, "Joint access point placement and channel assignment for 802.11 wireless LANs," *IEEE Wireless Communications and Networking Conference*, 2006, doi: 10.1109/WCNC.2005.1424750.

[13] X. Du, K. Yang, "A Map-Assisted WiFi AP placement algorithm enabling mobile device's indoor positioning," *IEEE System Journal*, vol. 11, no. 3, pp. 1467–1475, 2017, doi: 10.1109/JSYST.2016.2525814.

[14] C. Jiang, Y. Chen, K. Liu, Y. Ren, "Renewal-theoretical dynamic spectrum access in cognitive radio network with unknown primary behavior," *IEEE Journal on Selected Areas of Communications*, vol. 31, no. 3, pp. 406–416, 2013, doi: 10.1109/JSAC.2013.130307.

[15] K. Farkas, A. Huszák, G. Gódor, "Optimization of Wi-Fi access point placement for indoor localization," *Journal of IIT (Information IT Today)*, vol. 1, no. 1, pp. 28–33, 2013, https://api.semanticscholar.org/CorpusID:11714983.

[16] S. Aomumpai, K. Kondee, C. Prommak, K. Kaemarungsi, "Optimal placement of reference nodes for wireless indoor positioning systems," *Proceedings of International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology*, 2014, doi: 10.1109/ECTICon.2014.6839894.

[17] G. Lee, "3D coverage location modeling of Wi-Fi access point placement in indoor environment," *Computer Environment and Urban System*, vol. 54, pp. 326–335, 2015, doi: 10.1016/j.compenvurbsys.2015.05.002.

[18] A. Alsmady, F. Awad, "Optimal Wi-Fi access point placement for RSSI-based indoor localization using genetic algorithm," *Proceedings of International Conference on Information and Communication Systems*, 2017, doi: 10.1109/IACS.2017.7921986.

[19] H. Shen, P. Cheng, "An ambulatory Wi-Fi access node by indoor positioning approach," *Proceedings of IEEE International Conference on Software Engineering and Service Science*, 2017, doi: 10.1109/ICSESS.2017.8342894.

[20] Q. Pu, M. Zhou, F. Zhang, Z. Tian, "Group power constraint based Wi-Fi access point optimization for indoor positioning," *KSII Transaction on Internet Information System*, vol. 12, no. 5, pp. 1951–1972, 2018, doi: 10.3837/tiis.2018.05.003.

[21] O. Naif, I. Mohammed, "WOAIP: wireless optimization algorithm for indoor placement based on binary particle swarm optimization (BPSO)," *Baghdad Science Journal*, vol. 19, no. 3, pp. 605–605, 2022, doi: 10.21123/bsj.2022.19.3.0605.

[22] A. Ismail, R. Tasaki, H. Kitagawa, K. Terashima "Optimum placement of wireless access point for mobile robot positioning in an indoor environment," *Journal of Robotics and Mechatronics*, vol. 28, no. 2, pp. 162–172, 2016, doi:10.20965/jrm.2016.p0162.

[23] M. Brunato, R. Battiti, "Statistical learning theory for location fingerprinting in wireless LANs," *Computer Networks*, vol. 47, no. 6, pp. 825–845, 2005, doi: 10.1016/j.comnet.2004.09.004.

[24] *Propagation data and prediction methods for the planning of indoor radio communication systems and radio local area networks in the frequency range 300 MHz to 450 GHz, ITU-R P.1238*, 2019, https://standards.globalspec.com/std/13487739/ITU-R%20P.1238.