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Optimal Positioning of Wi-Fi Access Points towards Effective Indoor Positioning Systems

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ABSTRACT

Indoor positioning systems (IPS) have garnered substantial attention in recent years, offering valuable location-based services within indoor environments. The performance of IPS is heavily reliant on the optimal positioning of Wi-Fi access points (APs), as they serve as key infrastructure components for wireless communication. The objective of this study is to develop an optimal access point placement configuration using the mean and variance of the RSS power within an indoor location to achieve a superior Wi-Fi access point strategy. Additionally, the study takes into account the architectural layout, building materials, and potential obstacles within the indoor environment, ensuring that 1 m^2 *square grid intersections were utilized throughout the floor of the study location. The findings of this research will make a significant contribution to the development of effective and efficient indoor positioning systems by providing guidelines for the optimal placement of Wi-Fi APs. The proposed strategies aim to enhance user experience in various indoor applications such as asset tracking, navigation, and location-based services. Furthermore, the method introduced in this study produced a mean value of 0.2041 and a variance value of 0.0322, thereby generating an optimal function of 1.5714 and providing a coverage of 45% compared to the pre-existing placement. Moreover, it guarantees complete Wi-Fi signal coverage in all areas of the study location, as it is devoid of any dead zones. It is highly recommended to employ this optimal placement strategy on an existing IPS.*

1. Introduction

Indoor positioning systems have gained significant attention in recent years due to their potential applications in various domains, including navigation, asset tracking, and location-based services. These systems rely on the accurate determination of a user's position within indoor environments, where GPS signals are often unavailable or unreliable [1].One crucial aspect of indoor positioning algorithms is the placement of access points (APs) or beacons, which serve as reference points for position estimation. The strategic deployment of APs plays a vital role in achieving optimal performance and accuracy in indoor positioning systems. This placement should consider factors such as coverage, signal strength, interference, and cost-effectiveness [2], [3].

The main objective of access point placement is to ensure maximum coverage and minimize localization errors. To achieve this, several considerations need to be taken into account. These include the layout and characteristics of the indoor environment, the positioning algorithm being used, and the specific requirements of the application [4], [5]. The layout of the indoor environment, including the size, shape, and presence of obstacles, directly impacts the placement of APs. The goal is to ensure that APs are strategically positioned to cover the entire area while minimizing signal attenuation caused by obstacles. Techniques such as site surveys, floor plans, and computer simulations can assist in determining the optimal AP locations [6], [7].

Signal strength and interference are critical factors affecting the accuracy and reliability of indoor positioning systems. APs should be positioned in a way that minimizes signal attenuation and maximizes the signal-to-noise ratio. This can be achieved by considering factors like the transmit power of the APs, the propagation characteristics of the wireless signals, and the presence of other devices or sources of interference in the environment [8], [9]. The choice of positioning algorithm also influences AP placement. Different algorithms have varying requirements in terms of AP density and distribution. Some algorithms may require a higher density of APs for accurate positioning, while others can achieve satisfactory results with fewer APs [10]–[12]. Understanding the characteristics and limitations of the chosen algorithm is essential for optimizing AP placement [13]. Cost-effectiveness is another important consideration. Deploying a large number of APs can be costly in terms of equipment, installation, and maintenance. Therefore, it is necessary to strike a balance between the number of APs and the desired level of accuracy [14], [15]. Cost-effective AP placement can be achieved by considering the trade-off between accuracy requirements and the available resources [16].

In conclusion, optimal access point placement is a critical factor in the design and implementation of indoor positioning algorithms. By considering factors such as coverage, signal strength, interference, and cost-effectiveness, it is possible to strategically position APs to achieve accurate and reliable indoor positioning systems [17]. Careful planning, analysis of the environment, and understanding of the positioning algorithm are essential for successful AP placement and the overall effectiveness of indoor positioning solutions [18].

1.1. Related Concept

The deployment of indoor positioning systems has gained significant attention in recent years due to their potential applications in various domains, including navigation, asset tracking, and location-based services. One crucial aspect that directly impacts the performance and accuracy of these systems is the optimal placement of access points (APs) or beacons. This Section aims to explore and summarize existing research on the topic of optimal access point placement for indoor positioning algorithms.

Achieving accurate and efficient indoor location-based services through optimal positioning of Wi-Fi access points for indoor positioning systems is of utmost importance. While traditional methods rely on predefined radio maps, which can be labor-intensive and time-consuming [19], recent advancements in crowdsourcing provide a promising solution for Wi-Fi positioning. By merging traces collected from normal users through crowd sensing techniques, original walking paths can be recovered, thus resulting in high positioning accuracy [20]. Another approach involves optimizing access points based on multi-dimensional RSS feature fuzzy mapping and clustering, which not only improves positioning accuracy but also reduces positioning overhead [21]. Fine time measurement protocols supported by Wi-Fi access points offer a novel way to develop accurate indoor positioning algorithms. Leveraging multi-dimensional scaling and adjusting the weight of fine time measurement ranging can achieve high precision indoor positioning [22]. Also, an indoor positioning method based on Wi-Fi signals considers the stability of access points, improves positioning precision and robustness, and minimizes computational complexity using two iterative algorithms that minimize localization error using signal level probabilities was also conducted [23].

An indoor mapping system that aids in generating an algorithm for automatic access point placement is another concept which optimizes the sum of Euclidean distances of fingerprints among reference points; it is an indoor map system with vector graphic technology which improves positioning accuracy and the algorithm assumes that the indoor radio propagation model is accurate, which may not always be the case [24]. A method that employs Deep Deterministic Policy Gradient Algorithms (DDPG) to achieve the optimal deployment of access points with the aim of maximizing the Euclidean distance of the reference signal. This method converges quickly compared to other deployment methods and also improves positioning accuracy. Further research is needed to explore the scalability and generalizability of the proposed method and to evaluate its performance in different environments [25]. In addition, a Genetic Algorithm technique that adjusts access point positions to ensure the uniqueness of the combined received signal strengths in each predefined block of the area was also suggested. The technique demonstrated that the uniqueness of the combined RSS exceeded 90% which indicates significant improvement in the accuracy of indoor navigation systems. It is important to note that the effectiveness of the algorithm may depend on various factors such as the size and complexity of the indoor environment, the number and placement of obstacles, and the type and quality of the access points used [26]. Mathematical model and an algorithm for optimal access point placement based on Bayesian algorithms was studied by considering different localization strategies [4]. All these methods collectively contribute to the optimal positioning of Wi-Fi access points for indoor positioning systems.

2.0. Methodology

2.1. Calibration of the Environment

The detail map of the study location was carried out by measuring the entire perimeter resulting into 42 m by 25 m. Each indoor area features where accessed and identified. This serves as the foundation for diving the environment into square grids. A 1 m grid size was considered based on literature to provide finer-grained positioning and to improve accuracy too. It was also ensured that all the grids were of equal sizes and align with architectural features in the space. Figure 1 shows the perimeter of the study location, while Figure 2 shows selected interior space of the location with the square grids as tag by the tape on the floor. Each square grid is denoted by Equation 1.

$$SQ_i = (x_i, y_i); \qquad i = 1, 2, 3, \dots, T \tag{1}$$

Where $SQ_i =$ Square Grid, $x_i =$ Coordinate of SQ on x-axis, $y_i =$ Coordinate of SQ on y-axis and $T =$ Total number of SQ on the study location.

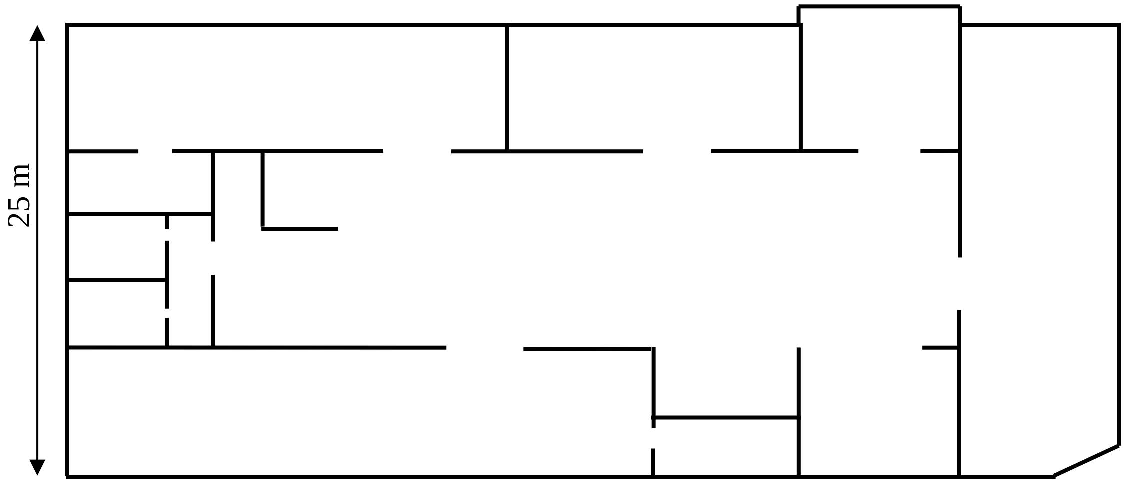


Figure 1: The Perimeter of the Study Location

2.2.Deployments of Access Points

An AP is placed at a location based on design preference and such a location is chosen as the reference point that will remain so throughout the experimental duration. At each SQ intersection the signal strength of the first AP is measured as stored in Equation 2.

$$Q_i = [\omega_i, \dots, \omega_T] \tag{2}$$

Where Q_i = Wireless Database, ω_i = RSS value of the AP at i-th SQ, ω_T = RSS value of the AP at t-th SQ.

Distance and RSS value condition were set in equation 3 to convert Equation 2 into a matrix of element "zeros" and "ones". This is done to eliminate dead spot and to also ensure that there is wireless coverage at each SQ point.

$$C = \begin{cases} 1, & If - 80\ dBm \le \omega_i \le 15\ m \\ 0, & Otherwise \end{cases} \tag{3}$$

Evaluating Equation (2) and (3) resulted into Equation (4).

$$Q_i = \begin{Bmatrix} \omega_{il} \cdots \omega_{TN} \\ \vdots \ \ \ddots \ \ \vdots \\ \omega_{il} \cdots \omega_{TN} \end{Bmatrix}; \begin{matrix} i = 1, 2, 3, \dots, T \\ l = 1, 2, 3, \dots, N \end{matrix} \tag{4}$$

Where Q_i = Wireless Database, ω_{ij} = RSS value at i-th SQ from j-th AP, ω_{TN} = RSS value at T-th SQ from N-th AP, N = Total number of AP.

2.3.Experimental Measurements

The Experimental measurement was carried at Second floor of NLNG Building of the Faculty of Engineering and Technology located in University of Ilorin. The experimental setting, as depicted in Figure 1, spanned approximately 42m x 25m and featured laboratories, a lobby, sections of staircase, and a seminar area. While the corresponding few of the real surroundings are shown in Figure 2.

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 seconds. To minimize any potential orientation bias, the smartphone was positioned randomly and stabilized on a tripod.

Figure

Figure 2: Sample of selected view of the study environment

At the end of the measurement the following equations where used to determine the optimal access points configuration.

$$P_A = \frac{P - p_i}{p_m - p_o} \tag{5}$$

$$\overline{P_A} = \frac{1}{SQ_T - 1} \sum_{m=1}^{M} \sum_{n=1}^{N} P_A \tag{6}$$

$$\sigma_A^2 = \frac{1}{SQ_T - 1} \sum_{i=m}^{M} \sum_{i=n}^{N} \left(P_A - \overline{P_A}\right)^2 \tag{7}$$

$$\min APOC = \sum_{m=1}^{M} \sum_{n=1}^{N} w_1 \frac{1}{\overline{P_A}} + w_2 \sigma_A^2 + L \tag{8}$$

Where $p_A =$ Power received at the location, $p_m =$ saturated power at the reference SQ and $p_0 =$ the minimum received power. The optimal access point configuration is function of average and variance power of the RSS. Both are evaluated with Equation (6) and (7) respectively. Also, Where $SQ_T =$ Total number SQ, $APOC =$ Access point optimality configuration function, w_1 and w_2 = weighted variables and L = Penalty function; 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 APOC to produce a large value, and so such a configuration will not be optimal.

3.0.Result and Discussion

925 square grid intersection were gotten due to some internal partition of the interior building. The research uses 1 m space to ensure that at every time there is at least 6 neighboring SQ intersections. Figure 3 shows six APOC with the star symbol depicting the AP locations while the APOC, mean, variance, and the number of dead zones, is tabulated in Table 1. APOC 5 has been selected as the optimal since it has a zero number of dead zones and yields the lowest optimal function.

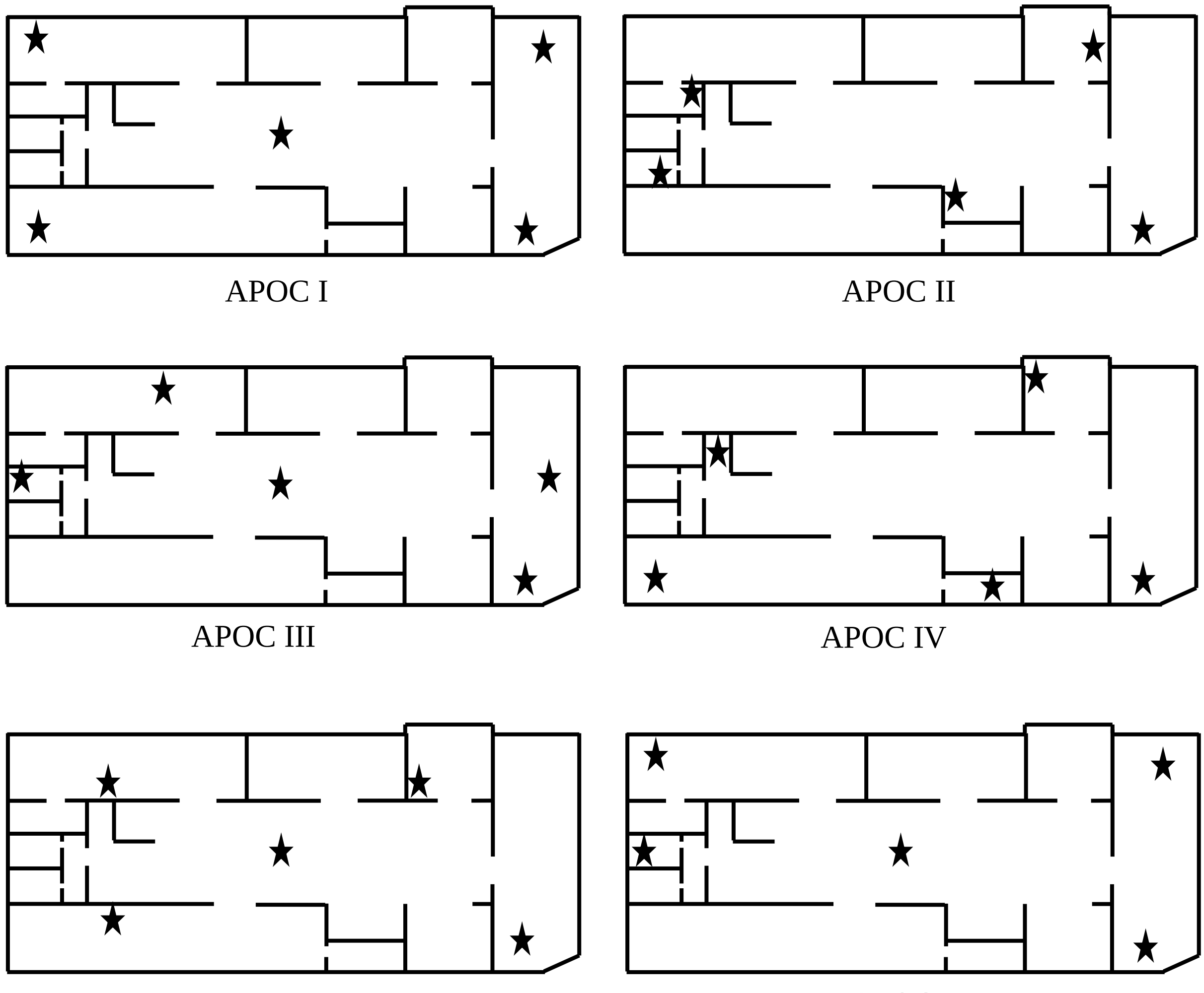
Table 1: Optimal Function of the Placement results

APOC	**Mean, $\overline{p_{mn}}$**	**Variance, σ_{mn}^2**	**APOC Value**	**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 shows a comprehensive comparison amongst various pre-existing deployment patterns. The symmetrical placement was implemented and the APOC was calculated for each pattern utilizing Eq. (8). Any location experiencing an RSS value exceeding -120 dBm is considered to be a dead zone. 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, $\overline{p_{mn}}$**	**Variance, σ^2_{mn}**	**APOC Value**	**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


APOC I

APOC II

APOC III

APOC IV

APOC V

APOC VI

Figure 3: Optimal AP Placement Locations

4.0.Conclusion

In conclusion, this study delved into the ideal placement of Wi-Fi access points (APs) for indoor positioning systems (IPS) and the significant impact it has on achieving better performance. The study utilized a methodology that employed the mean and variance of received signal strength (RSS) power within indoor locations, using a 1 m^2 square grid to cover the entire floor of the study area. The results presented the efficacy of the proposed method, yielding a mean value of 0.2041 and a variance value of 0.0322. This optimal setting produced a function value of 1.5714, representing a significant enhancement compared to the pre-existing AP placement strategy. Furthermore, the suggested placement strategy ensured complete Wi-Fi signal coverage, eliminating any dead zones within the study area. The findings of this research provide valuable insights and guidelines for the development of effective and efficient indoor positioning systems. By implementing the recommended AP placement strategy, IPS can enhance user experiences in various indoor applications, including asset tracking, navigation, and location-based services. It is highly recommended to employ the optimal AP placement strategy proposed in this study in existing IPS. By doing so, IPS can benefit from improved positioning accuracy, minimized signal interference, and comprehensive coverage, ultimately resulting in an enhanced user experience. Future research can explore the adaptability of this optimal placement strategy in dynamic environments and further investigate its performance under different scenarios and constraints.

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