Proposed APs Distribution Optimization Algorithm: Aware of Interference (APD-AI)

Rawaa Akram Mohammed¹, Omar Nameer Mohammed Salim², Aseel H Al-Nakkash³, Ali A S AlAbdullah⁴

¹,²,³ Department of Computer Engineering, Electrical Engineering Technical College, Middle Technical University, Iraq.
⁴Ninevah University, University of Bradford. Landon.

Abstract. Indoor networks became the focus of attention of many researchers due to its important role to connect to the wide networks. Many algorithms have been applied or proposed to maximize the coverage of indoor networks. In this paper, a multi-objective algorithm has been introduced to optimize the coverage and maximize the Signal-to-Interference Ratio (SIR) based on Binary Particle Swarm Optimization (BPSO) using Matlab software. It has been applied to the installed network which is consist of four AP with a heterogeneous distribution. It has been evaluated the optimized network and proves its reliability. The results obtained show the flexibility and efficiency of the proposed algorithm which produce an optimal network maximizes the coverage area and enhances the SIR by 9.03 dB.

1. Introduction
Many reasons motivate Internet Service Provider (ISP) to design an indoor network with a high-quality signal. One of these reasons is that Wireless Local Area Networks (WLAN) became widely used in office buildings, exhibition halls, factories [1]. Whereas signal propagation in the indoor environments prone to many factors such as the furniture distributed within it and their sizes which are lead to reflect, diffract and scatter the signal [2,3]. On another hand, some applications require good signal strength to provide good service. ISP needs to apply the designed network with different configurations in the environment. In other words, ISP must test how many Access Points (AP) need to cover the environment to provide high coverage areas with less interference and retry designing the network with different positions of these APs until determining the optimum positions [4]. This method costs time and effort. One of the biggest problems that face indoor network designing is the interference between the signals transmitted from many APs. Whereas the receiver receives multiple signals which lead to overlapping and attenuated them [5]. Many optimization algorithms have been proposed to optimize the number of APs and their positions according to the indoor environments to achieve high coverage areas with high SIR [6]. One of these algorithms is BPSO [7-9]. In this paper, an algorithm has been proposed to increase SIR and coverage area in an indoor environment and evaluate the performance of the proposed algorithm by applying the optimal network in the real environment. This algorithm is implemented based on BPSO at 2.4 GHz.

The rest of this paper will be organized as following: related work will be introduced in section 2 followed by theoretical background in section 3. In section 4 a proposed algorithm will be present to solve interference problem. The results of the proposed algorithm will be discus in section 5. Finally, the conclusion of this work produced in section 6.

2. Related work
Many researchers work to optimized different types of networks. Some of the researchers proposed new algorithms and the other part of them applied existed algorithms.

Signal strength and SIR have been investigated in [10] in an adopted environment using Netspot software. The authors found that the installed network has a low signal level and low SIR since the
installed APs are placed far away from the adopted environment. While the authors in [11] used the Self-Organizing Feature Map (SOM) neural network method to optimize the interference of WLAN by train this method and achieve the optimal position of APs. They can improve the proposed scheme efficiency to minimize interference of the WLAN using simulation results.

The authors in [12] worked to optimize frequency interference and coverage area of WLAN by optimizing APs positions and frequency planning. They have proposed the WLAN planning algorithm and evaluate its efficiency. In addition, they improved coverage area and throughput in multiple scenarios.

A proposed multi-objective algorithm has been introduced by the authors in [13] based on Biogeography Based Optimization (BBO) in order to maximize the coverage area and minimizing exposure in the office environment. They can prove the proposed algorithm performance by comparing its results with other algorithm results.

3. Theoretical Background

In order to analyse, study and design an optimal indoor network, some indoor propagation models have to be adopted and applied. Radio signal behaviour in the indoor environment is difficult to determine due to the complexity of the case study represented with building structure and the distribution of the presented furniture in the environment [14]. One of these models is the deterministic models that employ Maxwell's equations to compute the characteristics of radio signal propagation [15,16]. It is adopted to predict the coverage area in the adopted indoor environment based on Ray Tracing (RT) method. In addition, the experimental model has been applied to evaluate the optimal indoor network performance.

3.1 Ray Tracing (RT)

Radio signal behavior during its propagation in the indoor environments can be simulated using the RT method. RT can define the paths of the signals propagated from AP towards the receiver. This method takes into consideration all of the multipath phenomena such as diffraction, reflection, and scattering [17].

The received power ($P_r$) represents the accumulated power of all paths taken into account the phase. It can be calculated by equation (1)[18]:

$$P_r = \sum_{i=1}^{N_p} P_i$$

Equation (1)

$P_i$ is the time averaged power in watts of the $i$th path, $N_p$ is the number of paths. $P_i$ is given by equation (2)[18]

$$P_i = \frac{\lambda^2 \beta}{8\pi \eta_0} \left| E_{\theta,i} \cdot g_{\theta}(\theta_i, \phi_i) + E_{\phi,i} \cdot g_{\phi}(\theta_i, \phi_i) \right|^2$$

Equation (2)

where $\lambda$ is signal wavelength, $\eta_0$ is the impedance of free space at 377 $\Omega$, $E_{\theta,i}$ and $E_{\phi,i}$ are components of the electric field for each path at received point, $\theta_i$ and $\phi_i$ give arrival direction of $i$th path, the quantity $\beta$ is an overlap of the waveform, and $g_{\theta}(\theta_i, \phi_i)$ is the direction of arrival waveform.

3.2 Binary Particle Swarm Optimization (BPSO)

Particle Swarm Optimization (PSO) algorithm is an optimization algorithm that is inspired by organism behaviours to lead organisms group toward the most suitable regions [19,20]. All particles head for a more suitable location. Each one of them has its best location according to its previous experience. Moreover, each one modifies its position in the algorithm rounds towards the optimal solution. The optimization solution is the location of the organism with the highest fitness value. In the BPSO, the velocity of the particle is modified to be between 0 and 1, and hence limits the position
values also between 0 and 1 [21]. At each round, the particle updates the velocity and position according to pbest and gbest. The velocity can be calculated by:

\[ v_i(t+1) = \omega v_i(t) + c_1 \times \alpha_1 \times (pbest(t) - x_i(t)) + c_2 \times \alpha_2 \times (gbest(t) - x_i(t)) \]  

(3)

\[ x_i(t+1) = x_i(t) + v_i(t+1) \]  

(4)

where \( v_i \) is the velocity of the \( i \)th particle, \( x_i \) is the initial position of the \( i \)th particle, gbest is the global best position for all the particles and pbest is the best position for the \( i \)th particle. \( \omega \) applies weighting to initial velocity, \( \alpha_1 \) and \( \alpha_2 \), are random numbers between 0 and 1, \( c_1 \) and \( c_2 \) determine the pull of the particle to pbest and gbest respectively, and \( t \) indicates the round number for which this velocity is applied. In order to convert current position to 0 and 1, equations (5) and (6) are employed [21]

\[ \text{sigmoid} (v_i(t)) = \frac{1}{1 + e^{-v_i(t)}} \]  

(5)

\[ x_i(t) = \begin{cases} 1, & \text{rand} < \text{sigmoid} (v_i(t)) \\ 0, & \text{otherwise} \end{cases} \]  

(6)

3.3 Signal-to-Interference-Ratio (SIR)
In indoor environments with many installed APs are prone to interference. SIR can be defined as the ratio of signal power transmitted from one AP to the total power of the signals transmitted from all neighbour’s APs. It is measured with (dB) unit [22].

\[ SIR_{i,j} = \frac{P_i}{\sum_{j \neq i} P_j} \]  

(7)

where \( SIR_{i,j} \) is the power of AP\(_i\) to the power of the neighbour AP\(_j\).

4. AP Distribution-Aware of Interference (APD-AI) Algorithm Design
Initially, Wireless Insite (WI) simulator has been used to simulate the adopted indoor environment and predict the coverage area of the installed network in this environment based on the RT method. After that, and based on BPSO, a proposed AP Distribution-Aware of Interference (APD-AI) algorithm has been introduced to optimize the position of M APs and provide high coverage area with high SIR. The TPs deployed as a grid with (2 m) separation distance include 252 TP to simulate \( P_r \) at each point. \( P_{r_n} \) represent receiver power at each receiver from M APs to be the input to optimize the interference as shown in equations (8) and (9):

\[ P_{r_n} = [\alpha_1 P_{r_{n,1}}, \alpha_2 P_{r_{n,2}}, \ldots, \alpha_m P_{r_{n,m}}, \ldots, \alpha_M P_{r_{n,M}}] \]  

(8)

each \( P_{r_n} \) product by \( \alpha_m \) where:

\[ \alpha_m = \begin{cases} 0 & \forall AP_m \in \text{inactivated set} \\ 1 & \forall AP_m \in \text{activated set} \end{cases} \]  

(9)

The crucial part of proposed the algorithm is to find a suitable fitness function. APD-AI algorithm is a multi-objective function. So many fitness function needs to be determined carefully to cover the case study with less interference and high coverage area. Therefore \( f_1 \) will be calculated by equation (10):

\[ f_1 = \max \frac{\sum_n P_{T_n}^{cov}}{\sum_n P_{T_n}} \]  

(10)

where \( P_{T_n}^{cov} \) is number of TPs equal or higher than predefined threshold \( (P_{r_n}^{th}) \) which is represented by equation (11):

\[ s.t. P_{T_n} = P_{T_n}^{cov} \quad \text{if max } (P_{r_n}) \geq P_{r_n}^{th} \]  

(11)
while \( f_2 \) can be calculated by equation (12):

\[
f_2 = \max_n \sum \text{SIR}_n
\]  

(12)

where:

\[
\text{SIR}_n = \frac{P_{r_{n,i}}}{\sum_{j \neq i} P_{r_{n,j}}}
\]

and

\[
P_{r_{n,j}} = \max \{P_{r_{n,1}}, P_{r_{n,2}}, \ldots, P_{r_{n,M}}\}
\]

(13)

whereas \( f_3 \) can be find by equation (14):

\[
\text{Cost} \ f_3 = w_1 * f_1 - w_2 * f_2
\]

(14)

while equation (16) will guarantee that APs number will equal to \( M \):

\[
N_{AP} = N_{AP}^M
\]

(15)

According to the equations above, it can be deduced that each TP in the optimum network receives the highest SIR from \( j \)-th AP with signal strength higher or equal to \( P_{th} \). Moreover, the APs overlapping can be obtained from the relation between the variance of the received power from the neighbor APs and the maximum received power from the parented AP as calculating by equations (16) and (17).

\[
V = \frac{1}{N-1} \sum_i (P_{r_i} - P_{max})^2
\]

(16)

\[
\text{Overlap\%} = \frac{100}{V}
\]

(17)

APD-AI algorithm can be summarized in Figure (1).

![APD-AI algorithm flowchart](image)

Figure (1): APD-AI algorithm flowchart.
5. Proposed APD-AI Algorithm Results and Discussions

5.1 Simulation Results
As aforementioned, the WI simulator has been used to simulate the 2nd floor of "departments building" at "Electric Engineering Technical College" based on the RT method and predict the received power at each TP in the grid and then BPSO is used to optimize the network using Matlab software. The dimensions of the adopted environment are (25m*41m*3.2). The installed network includes 4 APs distributed in the floor at 1 m high as clarified in Figure (2). APD-AI algorithm redistributes the APs to new locations in order to maximize SIR and enhance the signal strength. In order to apply the APD-AI algorithm and evaluate the simulation results, \( w_1=0.3 \) and \( w_2=0.7 \) at \( \text{Pth}=-55 \) have been adopted.

![Figure (2): APs positions before and after APD-AI optimization.](image)

After the APD-AI optimization, Rx number equal to 246 and the mean of these received power equal to -45.0826. This indicates that the proposed APD-AI increases the number of covered users who are still within Pth. Figure (3) clarifies that after implementing APD-AI, the powers received by TPs occupy a wide range. This again proves the effectiveness of APD-AI in distributing the power in an optimal manner.

![Figure (3): Received power range at selected TP after APD-AI optimization.](image)

After implementing APD-AI algorithm, the results in Figure (4) indicates that more optimal distribution has been done due to reduction outliers and received range extended.
5.2 Experimental Results

In order to evaluate the reliability of the proposed scheme and the optimized network performance, the experimental model has been applied. APs positions obtained from APD-AI algorithms are installed to measure coverage area and SIR. These optimized positions can be clarified in Figure (5).

Figure (4): Received power range transmitted by the four APs after APD-AI optimization.

Figure (5): APs positions after APD-AI optimization in the real environment

A comparison is a test conducted by measuring signal strength before and after implementing the APD-AI algorithm using NetSpot software. Figure (6) shows the coverage area of the adopted environment before APD-AI optimization. The figure exhibits that many areas do not have signals or
receive weak signal strength which are known as the dead zones. That means the installed APs are not enough to cover the area or their position does not help to achieve high coverage area. While Figure (7) shows the SIR of the adopted network before implement optimization. It's clear that this network needs to be optimized.

Figure (6): Coverage area before optimization.

Figures (7): SIR of the installed network.

Therefore APD-AI algorithm redistributes the installed APs to increase coverage area and solve signal interference by increase the SIR. APD-AI algorithm produce good coverage area and high SIR which
are clarified in Figure (8) and Figure (9). Thus the TPs in each position in the area can receive strong signal with less interference and ultimately receive high throughput.

Figure (8): Coverage area after APD-AI optimization.

Figure (9): SIR after APD-AI optimization.

Figure (10) shows that average measured SIR of the optimal network by APD-AI algorithm is higher than the average measured SIR of installed network and optimized network by (9.03 dB). The results verify the powerful of APD-AI to achieve the higher SIR without increasing the number of APs.
Figure (10): Comparison between average measured SIR after and before APD-AI optimization.

6. Conclusion

The coverage area of an adapted indoor environment has been analysed based on the 3D RT method in order to be optimized. Based on the results obtained, a proposed APD-AI algorithm has been introduced to maximize the coverage area at predefined received power threshold equal to -55 at high SIR at each TP. It has been found that APD-AI algorithm produced an optimal network with high coverage area and increased the SIR from 3.6 dB to 12.6 dB.

7. References

[1] Wang H, Zhang P, Li J, You X. Radio propagation and wireless coverage of LSAA-based 5G millimeter-wave mobile communication systems. China Communications. 2019 Jun 10;16(5):1-8.

[2] Shafl M, Zhang J, Tataria H, Molisch AF, Sun S, Rappaport TS, Tufvesson F, Wu S, Kitao K. Microwave vs. millimeter-wave propagation channels: key differences and impact on 5G cellular systems. IEEE Communications Magazine. 2018 Dec 7;56(12):14-20.

[3] Guo C, Liu F, Chen S, Feng C, Zeng Z. Advances on exploiting polarization in wireless communications: Channels, technologies, and applications. IEEE Communications Surveys & Tutorials. 2016 Sep 7;19(1):125-66.

[4] Llairo EG, Papagiannaki K, Grunenberger Y, inventors; Telefonica SA, assignee. Method and a system for bandwidth aggregation in an access point. United States patent US 9,276,718. 2016 Mar 1.

[5] Gruber M. Scalability study of ultra-dense networks with access point placement restrictions. In 2016 IEEE International Conference on Communications Workshops (ICC) 2016 May 23 (pp. 650-655). IEEE.

[6] Rodrigues RF, da Silva AR, da Fonseca Vieira V, Xavier CR. Optimization of the Choice of Individuals to Be Immunized Through the Genetic Algorithm in the SIR Model. International Conference on Computational Science and Its Applications 2018 May 2 (pp. 62-75). Springer, Cham.

[7] Alyasiri H, AL-Samarrie AK, AL-Nakkash AH. Interference Mitigation of Heterogeneous Networks by Proposed Combined Optimal Frequency and Power Allocations Scheme. International Journal of Applied Engineering Research. 2016;11(24):11925-34.

[8] Debnath SK. Throughput Estimation Models under Various Conditions and MIMO Host Location Optimization Approach for Wireless Local-Area Network Ph.D. Thesis 2018.

[9] Aseel Hameed, “planning and optimization of Wimax and LTE networks for Baghdad city”, Ph.D. thesis, 2017.

[10] Suryani AT, Pantjawati AB. Analysis of the Coverage Area of the Access Point Using Netspot Simulation. In IOP Conference Series: Materials Science and Engineering 2018 Jul (Vol. 384, No. 1, p. 012001). IOP Publishing.

[11] Yao H, Yang H, Zhang A, Fang C, Guo Y. WLAN interference self-optimization using som neural networks. Concurrency and Computation: Practice and Experience. 2017 Feb 10;29(3):e3913.

[12] Farsi A, Achir N, Boussetta K. WLAN planning: Separate and joint optimization of both access point placement and channel assignment. annales des télécommunications. 2015 Jun 1;70(5-6):263-74.

[13] Goudos SK, Plets D, Liu N, Martens L, Joseph W. A multi-objective approach to indoor wireless heterogeneous networks planning based on biogeography-based optimization. Computer Networks. 2015 Nov 14;91:564-76.
[14] Ahamed MM, Faruque S. Propagation factors affecting the performance of 5G millimeter wave radio channel. In 2016 *IEEE International Conference on Electro Information Technology (EIT)* 2016 May 19 (pp. 0728-0733). IEEE.

[15] Iskander MF, Yun Z. Propagation prediction models for wireless communication systems. *IEEE Transactions on microwave theory and techniques*. 2002 Aug 7;50(3):662-73.

[16] Oni OO, Idachaba FE. Review of Selected Wireless System Path loss Prediction Models and its Adaptation to Indoor Propagation Environments.

[17] An I, Choi JW, Manocha D, Yoon SE. Reflection and Diffraction-Aware Sound Source Localization. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops* 2019 (pp. 13-16).

[18] Akram MR, Al-Nakkash AH, Salim ON. A comparative study of indoor propagation models for IEEE 802.11 n network. In *Proceedings of the International Conference on Information and Communication Technology* 2019 Apr 15 (pp. 69-73). ACM.

[19] Zhang H, Ren Y, Chen KC, Hanzo L. Thirty years of machine learning: The road to pareto-optimal next-generation wireless networks. arXiv preprint arXiv:1902.01946. 2019 Jan 24.

[20] Bhuwania A, Subba P, Roy UK. Positioning wifi access points using particle swarm optimization. In *2016 Second International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN)* 2016 Sep 23 (pp. 112-115). IEEE.

[21] Rauniyar A, Engelstad P, Moen J. A new distributed localization algorithm using social learning based particle swarm optimization for Internet of Things. In *2018 IEEE 87th Vehicular Technology Conference (VTC Spring)* 2018 Jun 3 (pp. 1-7). IEEE.

[22] Al-Badareneh YH. *On the Application of Extreme Value Theory to the Performance of k-th Best Link Selection in Wireless Communication Systems* (Doctoral dissertation).