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Particle Swarm Optimization for Dynamic Channel Allocation in IEEE 802.11 WLAN Networks: Minimizing Co-Channel Interference

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***Abstract:** This paper introduces a dynamic channel-assignment algorithm to minimize interference among Access Points (APs) in Wireless Local Area Networks (WLANs). The algorithm utilises Particle Swarm Optimisation (PSO) to efficiently optimise channel allocation, ensuring a positive Signal-to-Interference Ratio (SIR) and Signal-to-Noise Ratio (SNR) for all users, thereby guaranteeing reliable communication. The process commences with an initial channel assignment, followed by iterative refinement using PSO to reduce inter-AP interference. PSO is employed to accurately compute SIR and SNR values for each user, thereby providing a precise assessment of signal quality. Experimental results demonstrate substantial improvements in both SIR and network throughput, confirming the algorithm's effectiveness in reducing interference. Furthermore, the proposed approach is adaptable to various WLAN scenarios, making it suitable for diverse user distributions and network loads, thereby ensuring wide-ranging applicability in real-world settings.*

***Keywords:** Dynamic Channel Assignment, Wireless Local Area Network (WLAN), Access Points (APs), Interference Minimization, Particle Swarm Optimization (PSO), Signal-to-Interference Ratio (SIR), Signal-to-Noise Ratio (SNR), Network Throughput Optimization, Wireless Communication, Metaheuristic Optimization.*

Abbreviations:
APs: Access Points
PSO: Particle Swarm Optimization
SIR: Signal-to-Interference Ratio
OFDM: Orthogonal Frequency Division Multiplexing
SNR: Signal-to-Noise Ratio
WLANs: Wireless Local Area Networks

I. INTRODUCTION

Mobile communication has become an essential part of daily life. Wireless networks use radio waves or microwaves to enable communication between computers. As wireless technology continues to improve, its cost steadily decreases. The most common wireless networking products adhere to the IEEE 802.11 (Wi-Fi) standards [1].

Wireless communication operates through radios that function on specific frequencies. Its primary advantages include mobility and the elimination of cables. However, one significant drawback is the high risk of interference, which can arise from weather conditions, other wireless devices, or physical obstacles such as walls. The behaviour of radio waves in a given environment depends on factors such as frequency, distance, and obstructions.

Researchers have extensively studied frequency assignment and interference. In [2], the authors observed that Access Points (APs) and channel assignments are often addressed separately. They proposed a model that integrates both, leading to better outcomes. The model in [3] introduces a dynamic channel assignment approach using Particle Swarm Optimization (PSO) to minimize interference between APs. Meanwhile, the study in [4] applies a graph colouring algorithm to improve spectrum usage in Wi-Fi networks, arguing that merely selecting the least congested channel becomes ineffective as network traffic grows. Since higher congestion leads to lower throughput, more advanced channel allocation strategies are necessary to improve performance.

In this paper, we build upon the work in [5] by developing a mathematical model for channel assignment that reduces interference between APs while ensuring that both the Signal-to-Interference Ratio (SIR) and Signal-to-Noise Ratio (SNR) remain positive. Improved network throughput is attainable, as [6] demonstrated a direct relationship between SIR and throughput.

The rest of this paper is organized as follows: Section 2 discusses channel interferences. Section 3 defines our mathematical model. Section 4 analyzes and explains the results obtained, while Section 5 presents findings from three different scenarios. Finally, the conclusions are outlined in Section 6.

II. CHANNEL INTERFERENCE IN IEEE 802.11

A. The IEEE 802.11g Standard

The IEEE 802.11g is the most recent wireless standard ratified by the IEEE for wireless local area networks (WLANs). It builds upon the widely adopted IEEE 802.11b standard, extending its capabilities. IEEE 802.11g supports data rates of up to 54 Mbps in the 2.4 GHz band by employing Orthogonal Frequency Division Multiplexing (OFDM). To design And to deploy a WLAN effectively, it is crucial to follow a precise deployment procedure to ensure adequate coverage and optimal network performance in

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Terms of capacity, interference, and other factors.

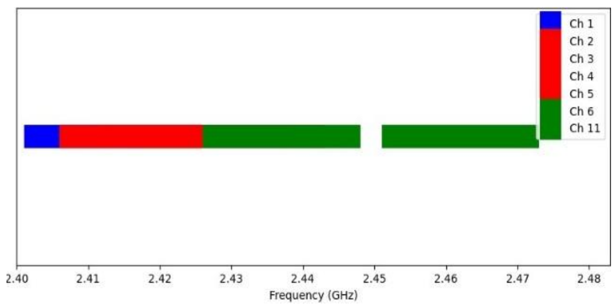
While wireless devices are often marketed with their theoretical signalling rates (e.g., 54 Mbps for IEEE 802.11g), the actual data throughput is usually much lower. Research in [7] revealed that throughput performance can vary significantly due to factors such as the proximity of access points (APs) or clients to interfering sources, as well as poor frequency planning. Various environmental and device-specific factors can also restrict throughput, including:

- Distance between WLAN devices (APs and NICs)
- Transmission power levels
- Effects of waveguides (e.g., in hallways)
- Building materials [8]
- Radio frequency interference
- Signal propagation
- Antenna type and location

Although IEEE 802.11g devices can theoretically achieve a signalling rate of 54 Mbps, the actual throughput is typically much lower, often ranging from 10 to 12 Mbps. In a previous study [9], we found that co-channel interference significantly reduces TCP throughput (from 9 Mbps to 2 Mbps) and UDP throughput (from 9.7 Mbps to 8.6 Mbps). TCP throughput is more severely affected than UDP due to delays caused by retransmissions and error detection. In contrast, UDP throughput decreases more gradually because it lacks error detection and retransmission mechanisms

B. Channel Overlapping in IEEE 802.11g

In the IEEE 802.11g standard, there are 14 available channels. As illustrated in Figure 1, channels 1, 6, and 11 are non-overlapping, while channel 1, covering a frequency range from 2.412 GHz to 2.435 GHz, overlaps with channels 2 through 5. Each channel utilises 30 MHz of bandwidth, which must be shared among access points using overlapping channels.



[Fig.1: IEEE 802.11g Channels: Non-Overlapping (1,6,11) and Overlaps]

The frequency centre of the two frequencies of two adjacent channels is only separated by 5 MHz. The following formula gives the coefficient of overlapping:

$$Max(0,1-\frac{|f_j-f_k|}{c}) \quad \dots \quad (1)$$

Where f_j is the channel assigned to AP_j, f_k is the channel assigned to AP_k, and c is the nonoverlapping portion of two adjacent channels. It is approximately equal to 5.

III. THE PROPOSED MODEL

The frequency assignment challenge can be framed as an optimisation problem, with the primary objective of minimising the total interference experienced by users while ensuring compliance with signal-to-interference ratio (SIR) and signal-to-noise ratio (SNR) constraints. The formulation includes the following components :

A. Parameters

- Access Points (APs): Let $AP = \{AP_1, AP_2, \dots\dots\dots\dots, AP_m\}$ Is the set of m Access points.
- Users: Let $U = \{U_1, U_2, \dots\dots\dots U_n\}$ Is the set of n Users.
- Channels: Let $C = \{C_1, C_2, \dots\dots\dots, C_k\}$ It is the set of k available frequency channels.
- Distance: Let d_{ij} Represent the distance between the access point. AP_i and the user U_j.

B. Decision Variables

Let x_i Denote the channel assigned to the access point. AP_i, where $x_i \in C$ and $C = \{C_1, C_2, \dots\dots, C_k\}$ represents the set of available channels .

C. Objective Function

The channels are assigned to APs in a way that minimises interference between APs, maximises the SIRs for users, and ensures that SIRs are always positive.

Minimize the total interference experienced by all users, expressed as follows:

$$\text{Minimize } I = \sum_{j=1}^{n} I_j \quad \dots \quad (2)$$

Index I_j represents the interference experienced by the user U_j :

$$I_j = \sum_{i=1}^{m} I_{ij} \quad \dots \quad (3)$$

And I_{ij} denotes the interference from the access point AP_i to user U_j : [10]

$$I_{ij} = \begin{cases} \frac{P_{AP_i}}{d_{ij}^2} & \text{if } x_i = x_j \ (same\ channel) \\ 0 & otherwise \end{cases} \quad \dots \quad (4)$$

And P_{AP_i} Represent the transmission power of the access point. AP_i [11].

D. Constraints

SIR Constraint: The Signal-to-Interference ratio for each user must be above a defined threshold. SIR_{min} :

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$$\frac{S_j}{I_j} \geq SIR_{min} \quad \forall j \quad \dots \quad (5)$$

Where S_j Does the user receive the signal strength? U_j From the assigned access point [12]

- SNR Constraint: The Signal-to-Noise Ratio for each user must also exceed a specified threshold SNR_{min}:

$$\frac{S_j}{N} \geq SNR_{min} \ \forall j \quad \dots \quad (6)$$

Where N Is the background noise level [13]

- Channel Assignment Constraint: Each access point must be assigned a channel from the set of available channels :

$$x_i \in C \ \forall i$$

- Channel Reuse Constraint: Channels can be reused only if they meet the major SIR Requirements, meaning that two access points using the same channel must not interfere significantly:

If $x_i = x_j$ for $i \neq j$, then d_{ij} must be sufficiently large to satisfy SIR

IV. METHODOLOGY

A. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is a metaheuristic optimization algorithm inspired by the collective intelligence observed in natural systems, such as bird flocking and fish schooling [14]. The algorithm simulates the social dynamics of a swarm, where individual agents (called *particles*) collaborate to locate optimal solutions in a multidimensional search space. Below is a detailed breakdown of its mechanics:

i. Population-Based Structure

- Swarm Initialization: A population of$N$ Particles are generated, each representing a candidate solution to the optimisation problem. Each particle i Has :
  - A position vector indexed by ix_i In the solution space.
  - A velocity vector v_i Governing its movement.
  - A memory of its best position ($pbest_i$).
- Solution Space: The search space is defined by the problem's constraints and dimensionality. For example, in a wireless network channel assignment problem, each dimension could represent a candidate frequency channel.

ii. Social Behavior and Movement Rules

- **Particles Adjust Their Trajectories Based on Two Sources of Information**
  - Individual Experience: Each particle remembers its own best historical position ($pbest_i$), which represents the best solution it has encountered.
  - Collective Experience: Particles share knowledge with neighbours. In the *global best* ($gbest$) variant, the entire swarm shares the best position found (gbest). In the *local best* (lbest) variant, particles communicate within a topological neighbourhood.

- **Velocity Update Equation**

$$\boldsymbol{v_i^{t+1} = \omega . v_i^t + c_1 . r_1 . (pbest_i - x_i^t) + c_2 . r_2 . (gbest - x_i^t)} \quad \dots \quad (7)$$

  - ω: Inertia weight (controls exploration vs exploitation).
  - c_1,c_2Acceleration coefficients (cognitive and social components).
  - r_1,r_2Random numbers in [0,1] To introduce stochasticity.

- **Position Update**

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad \dots \quad (8)$$

B. Algorithm Implementation: Frequency Assignment

i. Initialization

- Randomly initialize the positions of particles (channel assignments for each access point).
- Assign random velocities to each particle.

ii. Fitness Evaluation

- For each particle, calculate the interference III, SIR, and SNR based on the current channel assignments.

iii. Update pbest and gbest

- If the current fitness (interference) is better than the particle's best-known fitness, update pbest.
- If a particle's fitness is better than the global best fitness, update gbest [16].

iv. Velocity and Position Update

Update particle velocities and positions using the following equations:

$$v_i^{t+1} = \omega . v_i^t + c_1 . r_1 . (pbest_i - x_i^t) + c_2 . r_2 . (gbest - x_i^t) \quad \dots \quad (9)$$

And,

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad \dots \quad (10)$$

Where ω Is the inertia weight, c_1 and c_2 Acceleration coefficients, and r_1 and r_2 are random numbers [15].

v. Iteration

- Repeat steps 2-4 until a stopping criterion is met (e.g., a maximum number of iterations or convergence).

V. NUMERICAL ANALYSIS

A. Scenario 1

Figure 2 shows the distribution of 8 APs with a service area of 100 m *70 m and 80 users uniformly distributed.

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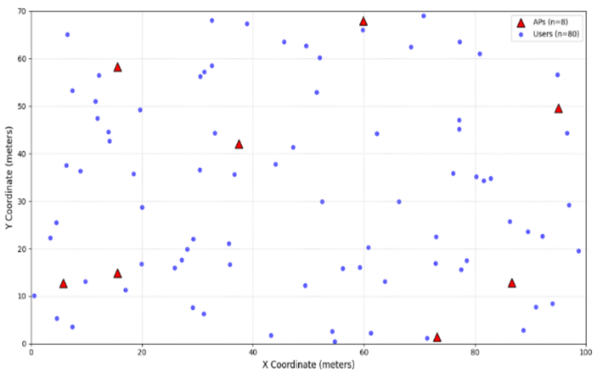
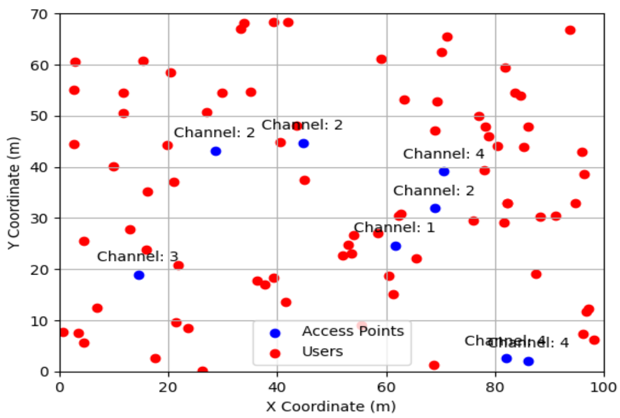


[Fig.2: Network Distribution: 100 m*70m service Area and Scenario 1 with 8 Aps]



[Fig.3: Distribution of Access Points and Users (Scenario 1)]

- **Best Channel Assignment**: [4 4 2 2 3 1 2 4], Minimum interference: 0.00
- **Total interference (in dB)**: -8.89
- **Average SIR for users (in dB):** -13.86
- **Average SNR for users (in dB):** 37.2

Table-I: Interpretation of Each Key Metric Scenario 1

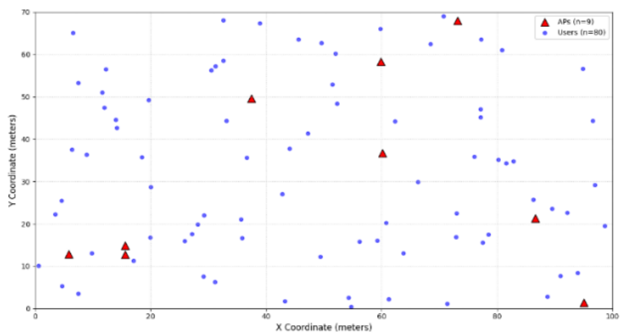
Metric	Interpretation
Best Channel Assignment: [4 4 2 2 3 1 2 4]	This indicates the optimal distribution of channels across the access points (APs) or users to minimize interference.
Total Interference (in dB): -8.89	Negative interference values suggest that the network experiences significantly reduced co-channel and adjacent-channel interference.
Average Signal-to-Interference Ratio (SIR) for Users: 13.86 dB	A value of **13.86 dB** indicates that the signal is significantly stronger than the interference, ensuring reliable communication with minimal packet loss.
Average Signal-to-Noise Ratio (SNR) for Users: 37.26 dB	A value of **37.26 dB** is excellent, indicating a very high-quality connection with minimal noise interference.

- Discussion Of Results

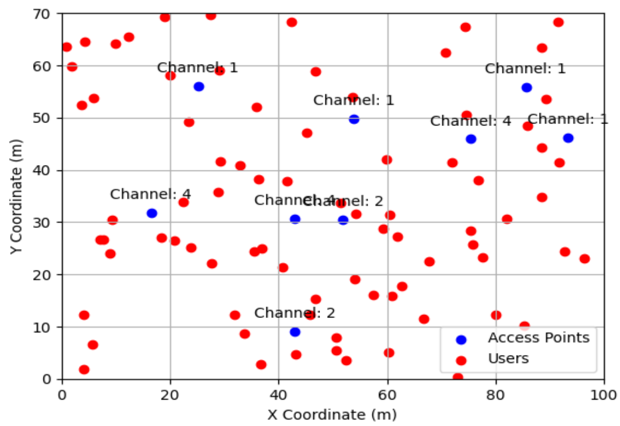
The findings highlight the efficacy of particle swarm optimization (PSO), which successfully enabled the utilization of all available channels (1–13), surpassing the limitations observed in prior work by [9].

B. Scenario 2

Scenario 2 depicts the position of 9 APs distributed in different locations.



[Fig.4: Network Distribution: 100 m*70 Service Area and Scenario 2 with 9 Aps]



[Fig. 5: Distribution of Access Points and Users (Scenario 2)]

- **Best Channel Assignment:** [1 4 4 1 2 2 4 11], **Minimum interference:** 0.00
- **Total Interference (in dB):** -15.4
- **Average SIR for Users (in dB):** 5.60
- **Average SNR for Users (in dB):** 38.92

i. Interference and Performance Metrics

- **Minimum Interference**: 0.00 dB

Indicates that at least one node/user experiences no measurable interference from neighbouring channels, suggesting optimal spatial separation or channel isolation for that node.

- **Total Interference**: -15.49 dB

A negative value signifies that the cumulative interference across all nodes is very low (below the reference power level).

This reflects successful interference mitigation through channel assignment and spatial planning.

- **Average SIR (Signal-to-Interference Ratio)**: 5.60 dB

Users experience a signal power that is 5.6 dB stronger than the interference on average.

While positive, this is relatively low for high-reliability applications (ideal SIR often exceeds 10–20 dB). This may suggest room for improvement in densely deployed systems.

- **Average SNR (Signal-to-Noise Ratio)**: 38.92 dB

Extremely high SNR indicates excellent signal quality relative to ambient noise.

This implies strong signal transmission, minimal environmental noise, or effective noise suppression.

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Table-II: Comparison to Prior Work [9]

Metric	This Work (PSO)	Prior Work [8]
Channels Used	1–13 (full range)	1, 6, 11 (static subset)
Interference	-15.49 dB	Likely higher (not quantified)
Flexibility	Adaptive to network density	Fixed, rule-based assignment
SNR	38.92 dB	Not reported

VI. CONCLUSION

Optimization problems demand robust, effective, and flexible methods. By overcoming the complexities of these problems,
the results obtained have been promising, demonstrating the efficiency of Particle Swarm Optimization (PSO). This approach enables the utilisation of all available channels, ranging from channel 1 to 13. However, the study will be completed only after addressing two additional planning problems:

- **Power Management Problem (PMP):** Assuming optimal frequency allocation, this problem involves assigning five distinct power levels to access points (APs) to minimize overall network interference while ensuring the required Quality of Service (QoS) is achieved.
- **Load Balancing Problem (LBP):** Following the allocation of frequency and power, this problem involves formulating a load-balancing strategy to minimise the maximum number of users assigned to any single access point (AP). This approach aims to guarantee consistent QoS for all users.

These challenges will be addressed in future work.

DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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