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Channel Assignment Method for Maximizing Throughput in the Internet of Things System

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ABSTRAK

Pertumbuhan jumlah perangkat nirkabel seperti *Internet of Things* (IoT) terhubung terus meningkat dalam berbagai sektor seperti *smart building, smart city* dan lain-lain. Diperkirakan pada tahun 2030 setidaknya terdapat 50 miliar perangkat akan saling terhubung melalui jaringan. Peningkatan jumlah perangkat nirkabel yang tidak bisa terkontrol akan menimbulkan berbagai permasalahan seperti *interference*, *collision* dan kehilangan data yang menyebabkan penurunan performa system secara keseluruhan. Penelitian ini bertujuan untuk mengusulkan skenario sebagai alternatif solusi mengoptimalkan performa jaringan secara keseluruhan sistem dengan cara penugasan *channel* pada setiap pasangan nirkabel yang saling terhubung untuk mengurangi pengaruh interferensi melalui pendekatan komputasi. Meminimalisir pengaruh akan secara langsung meningkatkan performa *throughput* system secara keleluruhan. Dari hasil penelitian ini diperoleh bahwa skenario yang diusulkan berhasil meningkatkan performa *throughput* sistem sebesar 39.75% dibandingkan dengan kondisi semua pasangan nirkabel bekerja pada saluran yang sama sekaligus mengungguli beberapa algoritma pembanding lainnya.

Kata Kunci:

Nirkabel, Internet of Things, Interference, Throughput

ABSTRACT

The growth in the number of wireless devices, such as the Internet of Things (IoT), interconnectedly continues to rise across various sectors like smart buildings, smart cities, and others. It is estimated that by 2030, at least 50 billion devices will be interconnected through networks. The escalating number of uncontrollable wireless devices can lead to various issues such as interference, collisions, and data loss, resulting in an overall system performance decline. This research aims to propose scenarios as an alternative solution to optimize the overall network performance through channel assignment for each interconnected wireless pair, reducing the impact of interference through a computational approach. Minimizing this impact will directly enhance the overall system throughput performance. The research results demonstrate that the proposed scenarios successfully improved the system throughput performance by 39.75% compared to the condition where all wireless pairs operate on the same channel, surpassing several other comparative algorithms.

***Keywords* :**

Wireless, Internet of Things, Interference, Throughput

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INTRODUCTION

The rapid development of wireless technology, such as the Internet of Things (IoT), in various fields, including smart homes, manufacturing, agriculture, and smart cities, has driven the growth of connected devices within networks (Rinanda Saputri et al., 2023; Saputri & Rahawarin, 2022). According to Statista data, the number of IoT devices connected to the internet reached 22 billion in 2018 and is projected to reach 50 billion by 2030 (Forbes, 2016). This signifies an annual expansion of approximately 15.4 billion IoT devices within 12 years, translating to an average growth of around 1.28 billion IoT devices. Other sources also project a similarly rapid growth. Gartner estimates that the number of IoT devices connected to the internet reached 20.8 billion in 2020 and is projected to reach 25.1 billion in 2021. This indicates an increase of around 4.3 billion IoT devices within a single year (Intersystems, 2020).

However, the increasing number of IoT devices also brings forth new challenges in network management. The escalation in the count of IoT devices connected to networks exacerbates this issue. If the quantity of IoT devices continues to rise, the network's ability to accommodate demands will decrease. This can lead to a decline in service quality, longer response times, and even system failures (Shi et al., 2016). Furthermore, the data traffic density within the network is inversely correlated with the system's throughput performance. Figure 1 depicts a conventional configuration of an Internet of Things (IoT) network, wherein a pair of IoT devices is situated within a densely populated region, leading to substantial interference with adjacent pairs of IoT devices. Consequently, this interference culminates in a reduction of the overall throughput performance of the system.

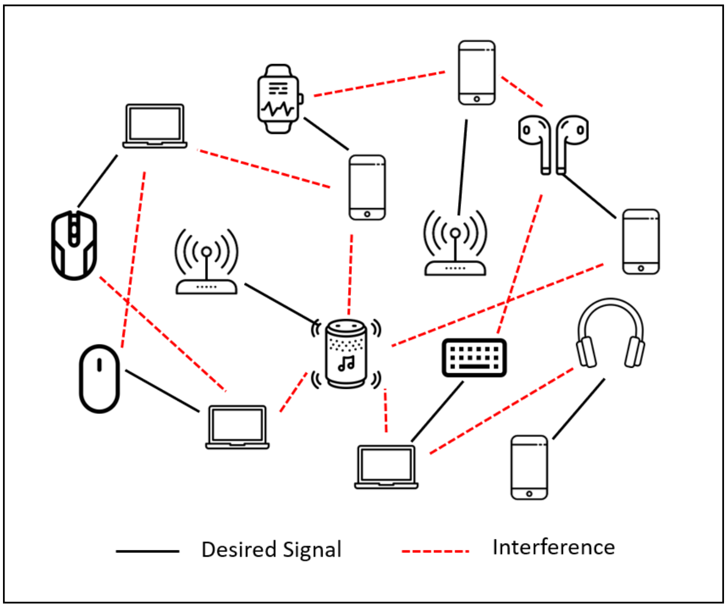


Figure 1. An illustration of eight pairing devices on an IoT Network

Poor channel allocation in IoT devices can lead to interference, collisions, and data loss, ultimately resulting in a decline in network throughput performance within the system. To address this issue, research and development in the field of network technology continue to enhance system efficiency and throughput. One of the solutions under development involves the utilization of Machine Learning (ML) to optimize frequency usage (Pedhadiya et al., 2019). Through ML, IoT networks can be managed more effectively by regulating the allocation of channels for each IoT device within the system. This method is commonly referred to as channel assignment. Channel assignment refers to the techniques employed to determine the frequency and channel that each IoT device will use to transmit and receive data. Numerous methods have been proposed to select the most optimal channel for each IoT device. In this study, we will attempt to propose a channel assignment method and compare it with several other channel allocation approaches for IoT devices within a given area of operation. Thus, we expect that the proposed method will exhibit enhanced network throughput performance for IoT.

Research on optimizing system throughput has garnered significant attention from researchers in recent years. As a result, various methods have been developed to enhance the performance of IoT networks. Some of these methods include utilizing Machine Learning (ML) (Das et al., 2023) to optimize frequency usage, and employing Multiple-Input Multiple-Output (MIMO) technology (Panda, 2020) to broaden bandwidth, as well as optimizing routing to reduce delays. All of these methods aim to enhance system throughput and provide better services to IoT users. In developing these methods, researchers need to consider various factors such as cost, complexity, and system security, and ensure that the resulting solutions can be easily implemented on a large scale. Regarding efforts to enhance the efficiency of frequency channel utilization in IoT networks, the following are recent studies that discuss Channel Assignment in IoT:

The study about distributed channel allocation and time slot optimization for the green internet of Things approach starts with a channel ranking algorithm enabling nodes to assess available channels based on properties. A decentralized channel allocation algorithm follows, allowing nodes to choose suitable channels considering ranking and energy. A coordinated optimization approach is applied to enhance normalized throughput and meet energy limits by refining sleep and spectrum sensing durations. The study aims to enhance network efficiency, reduce interference, and conserve energy through holistic channel allocation and time slot optimization within the IoT context (Ding et al., 2017).

Other research is presented for the assignment of partially overlapping channels on Multi-Radio Multi-Channel Wireless Mesh Information-Centric IoT Networks, using a Link-Based Variable Probability Learning strategy. This technique employs a reinforcement learning algorithm to establish an overlapping channel model, aiming to effectively manage channel capacity. The proposed scheme addresses the challenge of inter-channel over-capacity to optimize high throughput at both system and inter-channel levels. The application of reinforcement learning necessitates extensive information sharing, leading to potential weaknesses in terms of computational complexity and IoT power consumption. By adopting reinforcement learning as a trial-and-error framework to determine the optimal assignment of overlapping channel schemes, the primary objective of this approach is to enhance throughput performance (Zhao et al., 2019).

The study titled Utilizing Machine Learning for Uplink Wireless Channel Assignment aims to optimize user sum rates in uplink wireless transmission by combining Convolutional Neural Networks, Feedforward Neural Networks, Random Forests, and Gated Recurrent Units for effective channel assignment. Various learning techniques are integrated to enhance throughput performance, with a refined algorithm introducing adaptable constraints for temporal efficiency. However, this approach may trade computational speed for learning prediction accuracy. The results confirm significant improvements in throughput and temporal efficiency, affirming the effectiveness of the proposed channel assignment algorithm (Jia et al., 2020).

Then, the other researcher introduces the channel assignment algorithm for time-slotted channel hopping in the electric IoT approach and focuses on elucidating the integration of the Slotted Channel Hopping (TSCH) technology into Electric Internet of Things (IoT) applications, aimed at augmenting both network stability and efficiency. The proposed approach encompasses the accommodation of diverse data priorities and the introduction of a channel assignment algorithm that ensures optimal packet delivery for data with higher priority. The algorithm assigns weights to links based on packet traffic, constructs an interference conflict graph, and employs a maximum weight-independent set-based method for link-channel assignment. The empirical findings empirically underscore the effectiveness of the method in curtailing packet loss rates and advancing comprehensive network stability, particularly in the domain of power distribution (Yao et al., 2022).

Next, the research addresses the challenges arising from the additional overhead associated with multi-channel coordination in resource-constrained IoT devices, while simultaneously aiming to exploit the benefits of parallel transmission and interference reduction facilitated by the multi-channel technique. To surmount this challenge, a machine-learning-based channel assignment algorithm employing Tug-Of-War (TOW) dynamics is introduced. This algorithm selectively allocates channels for communication within extensive IoT scenarios. The proposed TOW-dynamics-based algorithm boasts a straightforward learning process, necessitating solely the reception of Acknowledge frames for learning purposes. Furthermore, it demands minimal memory and computational resources, predominantly involving rudimentary arithmetic operations such as addition and subtraction. This operational efficiency renders the algorithm viable for implementation on IoT devices with limited resources. The algorithm's feasibility is demonstrated through implementation on a severely resource-constrained Single-board Computer, serving as a representative cognitive IoT device. Subsequent evaluation experiments, conducted in dynamically fluctuating radio environments, exhibit the algorithm's rapid decision-making capability in channel selection, while concurrently ensuring equitable treatment among diverse IoT devices (Ma et al., 2019).

This paper addresses the resource allocation and power control optimization problem in 5G-enabled cellular networks supporting Device-to-Device (D2D) communication. The study proposes a resource allocation algorithm that employs fixed-target Signal-to-Interference-plus-Noise-Ratio (SINR) tracking for power control. In the proposed scheme, a D2D device is assigned a preallocated cellular channel once it achieves the predefined SINR level, ensuring the Quality of Service (QoS) requirements of cellular users (CUEs) are met. The CUEs aim to maximize throughput, while the D2D devices aim to minimize power consumption. Numerical experiments demonstrate the significant improvement in CUE throughput and D2D power savings achieved by the proposed method. Future research will explore distributed approaches with minimal overhead to further enhance system performance (Sanusi et al., 2019).

This article introduces a channel assignment strategy in the context of Internet of Things (IoT) networks, utilizing opportunistic spectrum access through cognitive radios. The primary contribution of this research lies in the utilization of traffic history as a guide for distributed channel allocation, effectively reducing interference in links with significant traffic history. Performance evaluations reveal that employing historical network traffic as a decision criterion yields superior results compared to solely utilizing network topology as a criterion. Additionally, this study paves the way for potential future research avenues, such as incorporating Quality of Service (QoS) metrics, optimizing channel allocation algorithms for vehicular networks, and analyzing the impact of weight distribution in various scenarios (Shigueta et al., 2015).

This study focuses on the channel assignment problem in multihop wireless mesh networks with routers equipped with multiple radio interfaces. The objective is to minimize network interference through channel assignment. Despite its known difficulty, centralized and distributed algorithms are developed, and linear programming is utilized to gauge the quality of the solutions. Experimental results indicate that our algorithms closely approach optimal solutions, especially with an increased number of radio interfaces. Simulations and experimental studies further demonstrate the potential for network throughput improvement using our approaches. As future research, the assignment of multiple channels for each link will be considered (Subramanian et al., 2008).

On the whole, research on Channel Assignment for IoT networks continues to evolve with increasingly innovative and effective approaches. Despite several challenges still prevailing in optimizing the utilization of frequency channels within IoT networks, the aforementioned studies provide a contemporary overview of endeavors underway to enhance the efficiency and performance of IoT networks through improved Channel Assignment techniques. Moreover, research on Channel Assignment constitutes a profoundly intricate non-linear conundrum. The forthcoming investigation will center on implementing methods that are tailored to effectuate channel allocation for each cluster constituent, thereby aspiring to yield optimal throughput across the entirety of the IoT device network within the designated operational domain.

RESEARCH METHODS

This research employs a computational approach using the Python programming language due to its robust support for data analysis and data science. With libraries such as NumPy, Pandas, and Matplotlib, researchers can easily process and implement algorithms or functions. The study underwent several systematically executed stages, thus enabling the research to achieve the anticipated outcomes. These stages are as follows:

1. Literature Review: This phase involves a series of activities encompassing the search and assessment of relevant and credible sources in alignment with the topic of the channel assignment method, which serves as a reference for structured scientific research.
2. Data Preparation: During this stage, data will be prepared alongside the creation of research scenarios. These scenarios will encompass various parameters to be observed in this study, research objectives, and applied limitations.
3. Method Development and Testing: The subsequent phase involves constructing methods that align with the research objectives. In this phase, channel assignment methods will be developed utilizing computational tools within the Python programming language. Additionally, we will endeavor to test our proposed methods against other approaches to gauge the performance level attainable by our proposed method.
4. Results Analysis: The analysis phase is where researchers scrutinize the outcomes of the conducted study. This stage yields various types of conclusions, determining whether the research methods employed align with the initial research hypotheses or necessitate specific improvements to enhance the results. This phase is of paramount significance as it can serve as a foundation for future research endeavors.

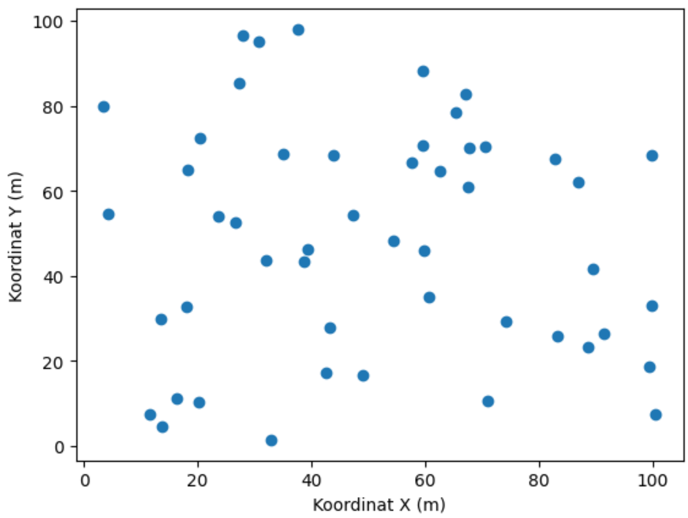


Figure 2. All IoT device pairs in the same channel

The data utilized in this research is generated randomly, consisting of 100 pairs of IoT devices placed within a 100m x 100m working area, as depicted in Figure 2. Each point contains information regarding the positions of the IoT device pairs engaged in data exchange, where points of the same color represent IoT device pairs operating on the same channel. The primary concept behind this study is to distribute the IoT device pairs across three distinct orthogonal channels. Orthogonal channels are channels that do not experience interference with each other, thus minimizing interference effects even when IoT device pairs are near their neighbors. The extent of interference impact is contingent on the distance to neighboring devices; the closer the IoT device pair is to its neighbor, the greater the interference effect when they operate on the same channel.

When all device pairs communicate on the same frequency channel, mutual interference occurs among them. The magnitude of the interference can be determined by calculating the average Signal-to-Interference-plus-Noise Ratio (SINR), as shown in Equation (1).

$$SINR_a = \frac{G_{a,a}P_a}{\sum_{b\in\varphi(a)} G_{a,b}P_b + Z_a} \quad (1)$$

Where $G_{a,b}$ represents the channel gain between Receiver a and Transmitter b, P_a signifies the transmission power from Transmitter m, Z_a indicates noise, and $\varphi(n)$ denotes the IoT device pairs transmitting simultaneously.

Furthermore, to evaluate the performance of the proposed channel assignment method, we aim to maximize the system's Sum Rate. The Sum Rate (Throughput) can be calculated using equation (2):

$$\mathcal{R} = \sum_{a=1}^{A} \log(1 + SINR_a) \quad (2)$$

The proposed method of channel assignment is developed based on the Simulated Annealing Algorithm. This algorithm constitutes a metaheuristic optimization technique that is extensively utilized to approximate solutions for intricate and time-consuming optimization problems. In the context of channel assignment studies, the Simulated Annealing approach can be employed to minimize interference and optimize the throughput performance of the system.

This algorithm operates iteratively until the most optimal outcome is achieved. The fundamental idea behind the assignment of channels for pairs of IoT devices is that if the new interference level is lower than the current interference level, or based on a random probability determined by temperature, the solution is updated with the new solution. This implies that the new solution is accepted when interference diminishes by changing channel assignment to orthogonal channels. Should the new solution exhibit a lower interference level than the best solution identified thus far, the best solution is then updated. This segment of the method effectively manages the channel reconfiguration process to mitigate interference. It assesses whether alterations in channel assignment (solution) should be embraced based on interference reduction or probabilistic criteria influenced by the temperature parameter. Should the alteration be accepted, the solution is revised, potentially yielding improved channel assignment that minimizes interference.

RESULT AND DISCUSSION

In this study, we compare the throughput performance of our proposed method with several other methods, including the Unassigned channel as a baseline comparison. The Unassigned channel refers to a scenario where all device pairs operate on the same channel without division into multiple orthogonal channels. Furthermore, we compare our proposed method with the channel assignment methods based on the K-means and the random assignment. These methods allow IoT device pairs to be divided into three groups operating on distinct orthogonal channels to minimize the influence of interference on the system. From the conducted experiments, the following results have been obtained:

Unassigned Channel

Figure 2 illustrates the distribution of positions of 100 wireless device pairs operating on the same channel within a $100m \ x \ 100m$ working area. This scenario serves as the baseline for comparing the channel assignment methods under investigation. In this scenario, interference is significantly high as each pair of IoT devices interferes with one another. The closer the distance between neighboring IoT device pairs, the greater the interference effect, leading to a substantial reduction in the system's throughput value. From the evaluation results of this Unassigned Channel scenario, a maximum system throughput value of 468.99 bps/Hz is obtained when the transmitting devices operate with power greater than $-20dBm$, as depicted in Figure 3.

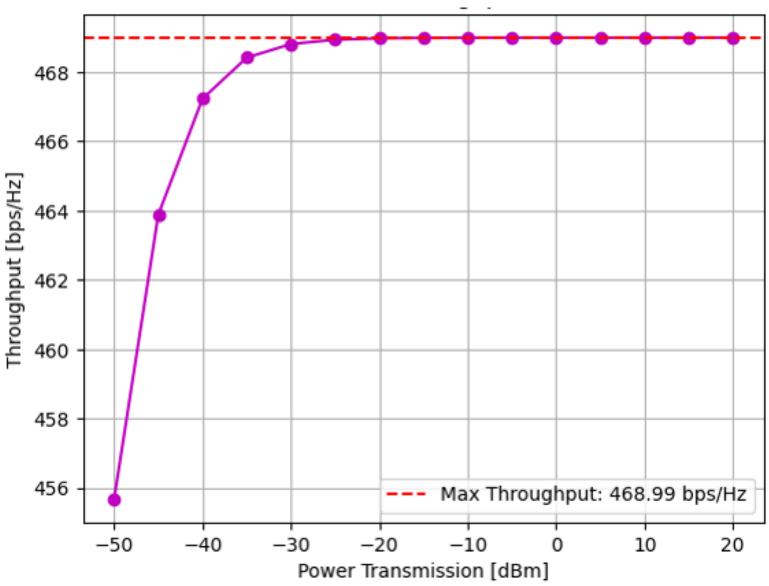
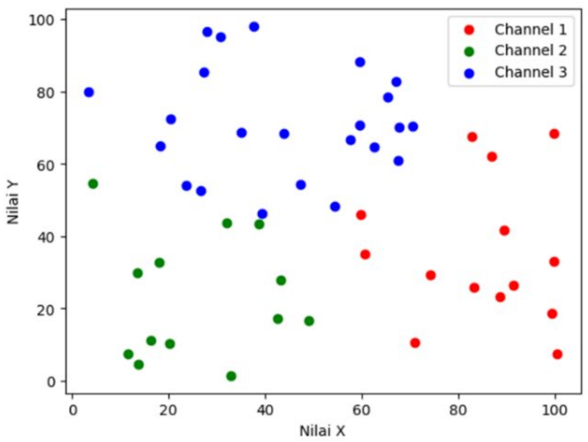


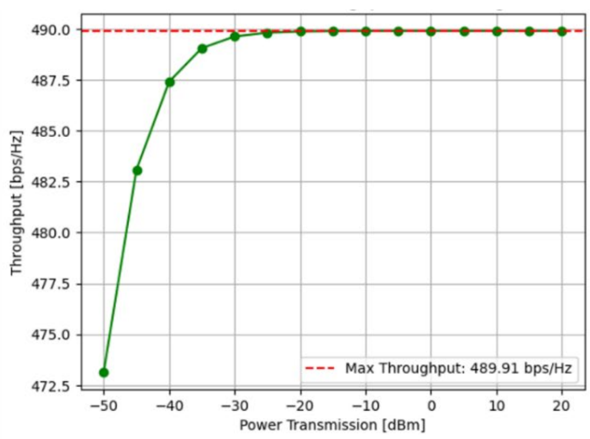
Figure 3. Throughput vs Power Transmission on an unassigned channel

K-Means Assignment

K-Means is a clustering algorithm that can be adapted for channel assignment in wireless communication networks. The main objective of K-Means in the context of channel assignment is to cluster pairs of IoT devices into different channels to minimize interference. Figure 4(a), depicts the spatial distribution of 100 pairs of IoT devices assigned to three distinct orthogonal channels using the K-Means assignment. Figure 4(a), illustrates that the system throughput performance increases $to\ 468.99\ bps/Hz$ compared to the Unassigned Channel scenario after the channel assignment for these pairs of IoT devices. However, significant interference still occurs among pairs of IoT devices operating on the same orthogonal channel. The distribution of wireless pair assignments is more evenly spread to mitigate interference and optimize the overall system throughput performance.



(a)



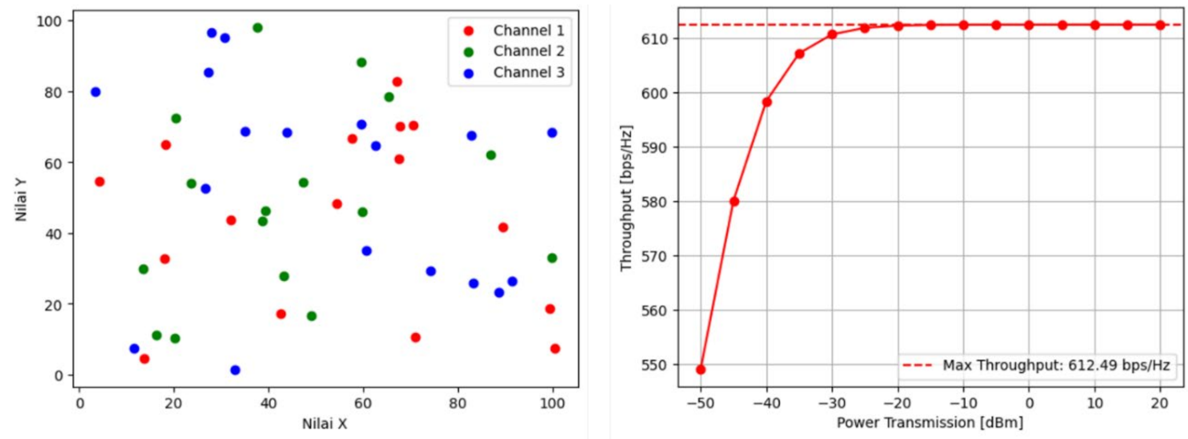
(b)

Figure 4. Distribution of IoT Device Pairs (a), Throughput vs Power Transmission (b) with K-Means Assignment Method

Random Assignment

The use of the random assignment in this experiment yielded better performance compared to K-Means, as demonstrated in Figure 5(b). This performance improvement is attributed to a more evenly distributed arrangement of IoT device pairs within the observed area, as depicted in Figure 5(a). However, this algorithm's outcomes can vary depending on the random channel assignments it generates. Because the algorithm assigns channels randomly, it does not assure the quality of the resulting solutions.

In this case, the random assignment achieved a better performance of 612.49 bps/Hz compared to K-Means. This improvement can be attributed to the more uniform distribution of channel assignments for IoT device pairs across the working area, allowing for greater minimization of interference.

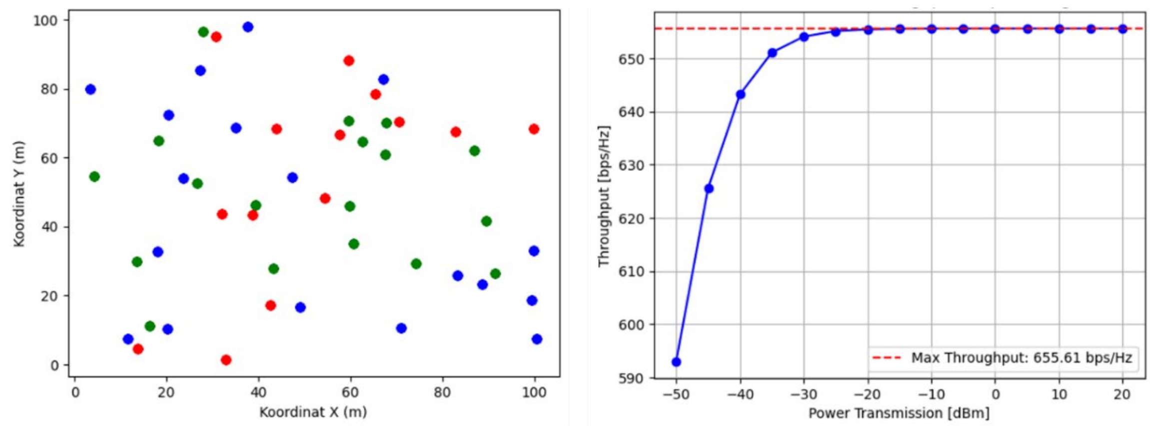


(a) (b)

Figure 5. Distribution of IoT Device Pairs (a), Throughput vs Power Transmission (b) with Random Assignment Method

Proposed Method

By applying optimization using the proposed method, Figure 6(b) demonstrates the superior system performance, reaching up to 655.61 bps/Hz compared to other benchmark methods. This is attributed to the arrangement of IoT device pairs working on the same channel, which has been reassigned to different orthogonal channels, resulting in a more evenly distributed arrangement as depicted in Figure 6(a). This directly contributes to a significant reduction in interference across the entire system, ultimately yielding a positive impact on achieving a higher maximum system throughput performance.



(a) (b)

Figure 6. Distribution of IoT Device Pairs(a), Throughput vs Power Transmission(b) with Proposed Method

Table 1. illustrates a summary of the performance comparison results of the proposed method for system throughput against other methods, where in this study, the proposed method

successfully enhances the system throughput performance by 39.75% compared to the scenario where all IoT device pairs operate on the same channel (Unassigned Channel).

Table 1. Method performance comparison

No.	Method	Throughput [bps/Hz]
1	Unassigned Channel	468.99
2	K-Means	489.91
3	Random assignment	612.49
4	Proposed Method	655.41

CONCLUSION AND SUGGESTION

Conclusion

This research aims to propose a method as an alternative solution to optimize the overall performance of IoT device pairs network by assigning them to three orthogonal channels to reduce interference impact and enhance the overall system throughput performance. The findings of this study reveal that the proposed method successfully improves the system throughput performance by 39.75% compared to the scenario where all IoT device pairs operate on the same channel (Unassigned Channel).

Suggestion

For further research, it is necessary to analyze the impact of channel allocation not only on orthogonal channels but also to examine the algorithm's performance in terms of complexity and scenarios involving moving IoT device pairs.

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