LOAD BALANCING IN THE COMBINED TECHNOLOGY OF LI-FI AND WI-FI BASED ON COLLABORATIVE GAME

Payam Porkar Rezayie[1], Hamid Shokrzadeh[2], Mehdi Dehghan Takht Foladi[3], Amirmasoud Rahmani[4], Sepideh Moosavi Nasab[5]

[1,4]Department of Computer Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

[2,5]Department of Computer Engineering, Pardis Branch, Islamic Azad University, Pardis, Iran

[3]Amirkabir University of Technology, Tehran, Iran

ABSTRACT

Wireless networks have become increasingly important in today's digital age. The combination of VLC and RF technologies, such as local Wi-Fi and Li-Fi networks, has emerged as a significant technology in this field. This combination enhances the coverage of weak points and strengthens the strong points of local wireless networks, resulting in higher data rates and increased coverage. However, load balancing is a crucial issue that can enhance network efficiency, especially when there are multiple access points from both networks. The selection of the appropriate access point at any given time by different nodes can significantly impact network performance. This research proposes a game theory-based method for selecting an appropriate access point, which uses multiple stages of computation and policy changes to achieve a Nash equilibrium in the game and subsequently in the network. The results show that this method can improve the quality of service in the local network by over 6% compared to previous methods such as the fuzzy method and by over 20% compared to the higher signal power selection policy.

KEYWORDS:

Hybrid local networks, Li-Fi network, Wi-Fi network, access points, load balancing, game theory, participatory game

1.INTRODUCTION

Despite the benefits of hybrid wireless local networks, one of the most significant challenges is selecting suitable access points to create7 appropriate coverage and network efficiency, which can provide adequate quality of service for users. Load balancing is crucial in a combined network to create equality among nodes, ensure network efficiency, and maintain fairness among users. Mathematical analysis and modeling of Wi-Fi and Li-Fi channels are required to improve the efficiency of local networks, especially in user connections to the internet. However, the coverage range of Li-Fi nodes is limited in an indoor scenario, resulting in the use of a large number of access points, which can increase costs and potential interference. Therefore, an optimized hardware solution for a Li-Fi network or combined network is not feasible, and software methods

✉ Corresponding Author Email: Shokrzadeh@gmail.com

DOI: 10.5121/ijdps.2023.14602

are required to establish the best possible balance and reduce communication interference in the network. A game theory-based method for access point selection can significantly improve network efficiency and quality of service for users by dynamically selecting the most appropriate access point based on network conditions and user demands. This approach has the potential to enhance performance and efficiency in other areas of wireless networking and could be explored further in different contexts.

The use of hybrid wireless local networks has become prevalent, demonstrating satisfactory performance in both domestic and industrial applications. Typically, these networks do not interfere with each other as they utilize different frequencies and technologies for communication [1]. For example, radio frequency (RF) networks represented by wireless fidelity (Wi-Fi) and visual light communication (VLC) networks represented by light fidelity (Li-Fi) are two different technologies with different characteristics that can complement each other well. It is expected that in an indoor scenario, they can provide coverage for each other and significantly increase overall efficiency in terms of coverage and maximum usable capacity [2]. Coverage discussions are also present in technologies such as controlled LED networks in optical networks [3], with an emphasis on increasing coverage. However, it is never possible to achieve perfect coverage, Its coverage cannot be at the level of RF networks and, on the other hand, in terms of bandwidth and transmission speed, RF networks have relatively lower performance compared to VLC [4]. Furthermore, VLC networks can increase the overall system performance by providing coverage in dead zones [5].

A combined dual-networking system enhances coverage of weak points and strengthens positive points, resulting in increased system efficiency and user productivity. It also creates a challenge in heterogeneous access point process flows. These technologies are suitable for use in local networks connected to large networks such as the internet and a combination of them can be very effective in important networks like the Internet of Things and Wireless Sensor Networks [6].

One of the most important issues in such networks is selecting suitable access points to create appropriate coverage and network efficiency, which can provide adequate quality of service for users [7]. If the access point is chosen inappropriately, a combined network will not be able to cover the nodes or may severely impact multiple network environments, resulting in reduced productivity in some cases. Load balancing in a combined network is crucial for creating equality among nodes and ensuring the efficiency of network points. Load balancing can also help maintain fairness among users [8].

Dynamic load balancing in an indoor scenario [9] by trying to achieve a suitable threshold of data rate, changing the Wi-Fi frequency and using technologies such as WiGiG [10] to increase the speed and bandwidth, decomposing and mathematical modeling of the channel. Wi-Fi and Li-Fi [11] have been among the activities to increase the efficiency of the local network, especially in the connection of users with the Internet. It is worth noting that in an internal scenario, the coverage range of Li-Fi nodes is very limited [9], resulting in the use of a large number of access points. This creates challenges such as increased cost and potential interference. Therefore, it is not feasible to find an optimized hardware solution for a Li-Fi network or combined network, and software methods are required to establish the best possible balance and reduce communication interference in the network.

From a configuration perspective, the way and extent of node communication and behavior towards each other and the resulting performance provides a suitable opportunity for improving network performance. By utilizing artificial intelligence-based methods such as game theory, it can be executed intelligently. This concept is referred to as strategic objects in the current research. However, substantial research has not been conducted to implement this approach, and only limited work has been done based on network topology and node performance, with most research focusing on communication theories.

On the other hand, game theory offers a solution for considering the strategic behavior of agents and objects in a multi-agent system [12]. Real objects, in addition to their own characteristics, can also be described by their mutual relationships in a specific domain [13]. The strategic behavior of objects determines the relationships between agents, and all these interactions impact each other, leading the system towards a specific state. Adaptive strategies have been used in computer networks before, for example, in intrusion detection [14]. In this environment, agents, as attackers and defenders, affect each other and go through a series of actions and reactions to reach an intermediate state. Reinforcement learning plays a crucial role in some games, such as Markov games, to achieve equilibrium [15]. Game-based strategies, such as the Markov game model, can be used to make fundamental choices in systems where traditional models are not responsive to changes and interactions between objects. This can improve efficiency [16].

In the base system of this research, considering the changes in the topology of wireless networks at any given time, the possibility of user and local network node substitutions, as well as changes in traffic and overall behavior of network nodes, if the choice of access points along the network is incorrect, the efficiency significantly decreases. For example, when the user leaves the Wi-Fi access range, we will see a decrease in the load on the mentioned network and an increase in the load on the Li-Fi access point. As a result, in this research, by considering the capabilities and limitations of the Wi-Fi and Li-Fi technologies, a load balance is achieved, and an appropriate strategy for access point selection on nodes is proposed using co-operative game theory. In this model of a combined network and load balancing algorithm, users apply load balancing on shared resources between Wi-Fi and Li-Fi networks when moving and transitioning between access points. This proposal, by considering the existing network conditions and node location learning for access point selection, increases the utilization of the environment dynamically towards an appropriate level.

Advantages of this system include dynamic access point selection in network conditions, consideration of object strategic behavior based on obtained outputs, efficiency of the system, providing the desired quality of service for users through independent decisions, simultaneous coverage of nodes, and considering the simultaneous benefits of Wi-Fi and Li-Fi technologies without the need for complex mathematical relationships (only through network performance of nodes). The innovation of this system also includes access point selection based on object strategic behavior, utilization of an intelligent selection algorithm based on co-operative games, utilization of the system's efficiency in node decision-making time, and creating load balance by selecting the maximum quality of service for each user.

In the following sections of this article, in the second section, we discuss the general specifications of combined Wi-Fi and Li-Fi networks, previous studies in this field, and load balance. The third section describes the proposed method of access point selection, a mechanism using game theory to increase efficiency and network transmission. The results of simulations and evaluations are included in the fourth section, and finally, the conclusion and future research direction are discussed in the fifth section.

2.LITRETUE REVIEW

In Figure 1 below, you can see a combination of access points belonging to two communication platforms, Wi-Fi and Li-Fi, where a Wi-Fi access point is combined with several nearby Fi-Li access points. In this design, a scenario of homogeneous random distribution is observed. All access points in this design are connected to each other without any errors. Considering channel state information (CSI) and forward fluctuations during operation, dynamic users should implement load balancing or load adjustment methods at regular intervals. It is assumed that the CSI of both Li-Fi and RF systems remain stable for a short period, and this state is defined as a stable state. Changes in the state are considered as another factor, taking into account the time interval between two adjacent locations. In each user presence state, a balanced or average configuration is assumed in a hypothetical place where users have received a constant rate of data. The natural number N represents the number of existing state sequences.

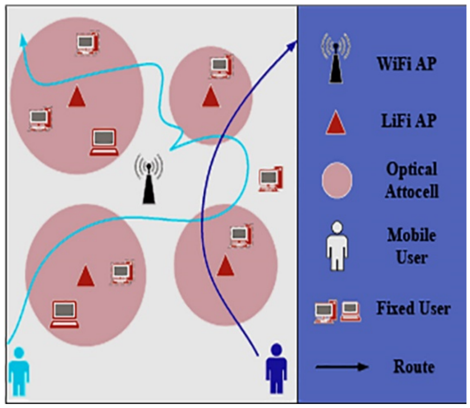

Figure 1. Hybrid system performance

Each Li-Fi access point is formed by a plate or what is called a light-emitting diode (LED) composed of multiple low-power LEDs, along with light detectors (PD) responsible for maintaining the load balance in a Li-Fi network access point (AP). In this communication platform, the propagation angle is suitable for the location angles of the light detectors. Existing walls separate and partition the Li-Fi network communication platform. Load balance must be properly implemented in both Li-Fi and Wi-Fi scenarios. In this model, C is a set of access points belonging to both Li-Fi and Wi-Fi, where C = 0 represents Wi-Fi access points, and $1 < C < N_c$ represents Li-Fi access points, and a set of users is represented by U_0. A full buffer traffic model is considered while evaluating the maximum accessible data rate for each user at any given time.

Channel analysis, by calculating signal quality in each network based on parameters such as SINR, leads to more accurate estimation of the effective parameters in both Wi-Fi and Li-Fi technologies and is utilized in signal quality-based methods. For Li-Fi:

$$SINR_{Li-Fi}^{i,u} = \frac{(R_{pd} H_{Li-Fi}^{i,u} P_{opt}/k)^2}{N_{Li-Fi} B_{Li-Fi} + \sum_{j\neq i} (R_{pd} H_{Li-Fi}^{i,u} P_{opt}/k)^2} \quad (1$$

In this case the parameter N_{Li-Fi} indicates the level of existing noise, which has a negative impact and will be effective relative to the bandwidth of the access point B_{Li-Fi}. The value of R_{pd} responsiveness is related to the detector's detection. The parameter P_{opt} indicates the power of emitted light and the coefficient *k* is the conversion factor from light to power. Overall, P_{opt}/k determines how much optical signal power enters the environment. *H* is also the characteristic of the Li-Fi channel for each user *u* and access point *i*. For Wi-Fi:

$$SINR_{Wi-Fi}^{i,u} = \frac{G_{Wi-Fi}^{i,u} P_{Wi-Fi}}{N_{Wi-Fi} B_{Wi-Fi}} \quad (2$$

Here, N_{Wi-Fi} is a value with a negative effect and indicates the level of noise in the Wi-Fi receiver. The parameters P_{Wi-Fi} and B_{Wi-Fi} which are positive and negative values, respectively, also show the transmission power in Wi-Fi and the bandwidth of the Wi-Fi network, and $G_{Wi-Fi}^{i,u}$ with a positive effect indicates the productivity of each user *u* for the access point *i*.

2.1.PREVIOUS WORKS

In recent years, load balancing in networks has been a topic of interest for researchers. Traffic distribution based on proportional distribution algorithms, known as load balancing operations, plays a significant role in network performance. Load balancing is said to be achieved when it is embedded in software or hardware. Hardware load balancing using a load balancer router, which can be applied to data transmission resources with various wireless or wired technologies such as optical fiber, can also increase the reliability of the system and prevent internet disconnection when one of the lines is cut [3], [5], [8], and [9]. Typically, a load balancer router increases bandwidth and improves traffic transmission efficiency to the internet through two or more high-speed internet connections. However, the use of a load balancer router does not involve all load balancing decisions in the network, and a significant part of the decisions is made before the traffic reaches the router.

Load balancing algorithms work based on several factors, such as resource accessibility and channel conditions. Each method operates through either borrowing channels or traffic transfer. Due to the fundamental differences in channels related to the two combined technologies used in this study, channel borrowing does not make sense. Therefore, traffic transfer becomes a method that can be used. LB algorithms are optimization-based methods that aim to improve the conditions of user sets. According to these algorithms, in general, if the condition of meeting the needs and satisfaction of users is fulfilled in all AP , the AP that provides a higher signal-to-noise ratio (SNR) takes priority. If the condition of meeting the needs is not fulfilled, priority is given to the AP that provides the highest level of user satisfaction. This AP can provide the highest or even the lowest SNR. However, if the user satisfaction condition is fulfilled for multiple AP , the AP with the highest SNR is chosen. In simple terms, the first priority in selecting an AP is user satisfaction, and the next criterion considered is channel quality.

With a little attention, it can be understood that the subject is not so simple because different methods vary greatly in terms of details and the criteria used in them also change significantly. Measurements of channel quality and user satisfaction also differ, and the calculation criteria for them are completely distinct. However, the goal is almost common. Overall, load balancing improves the efficiency and speed of communication for all users, reduces response time, and optimizes resource utilization.

The response time is composed of waiting time and service time. Of course, network delay usually occurs in this timeframe, which is part of the network system latency, but it is usually small relative to the total service time. The different applications of these time differences vary, and especially in their online applications, they present many challenges. Load balancers can especially improve system performance in terms of wait times. However, load balancing algorithms themselves have an additional burden on the system, which is undesirable. Using a central node for load balancing instead of distributed methods can somewhat alleviate the additional burden imposed on the system due to the required information exchange.

In article [1], a proposed method suggests that each processor must be aware of the status of other processors (e.g. address, etc.). Each processor has its own processing queue which is empty at system startup, so for the initiation of each processor, all system processors are idle. Now, if the processing queue becomes full, it sends its extra work to the list of available processors for another processor to perform or not. If it is not executed, it sends a message back to the first processor. However, the first processor temporarily changes the status of this processor in the list of idle processors, so its purpose is not to send work and interact with other processors. Therefore, the number of sent messages is much lower than the disconnected common mode, as sending 2(n-1) messages is necessary in that case, while the proposed method in the article only sends one message, considering the best conditions.

Load balancing in a hybrid network with this method has its own advantages and disadvantages, and perhaps the most significant advantage is the lack of need for calculations on the user side, which of course will also be a weakness to some extent because all the processing load is handled by the access points. Additionally, the conditions of each node can be very different from the perspective of the access point. There is a significant difference between this research and our proposed approach, as its foundation is fundamentally different in terms of the load point perspective. It is worth mentioning that load balancing is done automatically, so all connections are disconnected from the host and then the clients are connected to the regular host. This process occurs without the user noticing any disruption. Therefore, in general, access to the service is maximized to the extent that a server only responds to requests, and in the end, there is a reduction in server disruption [10].

In the discussed methods, load balancing has been considered for some wired networks and some wireless networks. However, due to the expansion of wireless networks and their special features, especially resource constraints, load balancing in these networks has gained more importance. Nevertheless, many load balancing methods for wireless networks have been proposed for homogeneous networks, and in heterogeneous networks, we specifically need a load balancing mechanism. Some studies have focused on similar combinations of networks, as in [8], where this has occurred. This method uses an optimization algorithm with extensive calculations and a relatively heavy load to create load balancing, which is challenging. Furthermore, utilizing the distinctive features of Li-Fi and Wi-Fi networks in selecting access points is an important principle that has been less considered. The combination of Li-Fi and Wi-Fi networks has several different aspects that considering them at the time of APS (Access Point Selection) can be a breakthrough. For example, a Wi-Fi access point has a wider coverage area in which attracting users who are closer is easier, but a Li-Fi access point has a more limited coverage area in which there is usually not much difference between users in terms of distance. Due to the higher expansion, the additional burden on the Wi-Fi network creates higher importance and sensitivity. Additionally, the number of users covered by this network is higher, which increases the burden. Having analytical calculations and neglecting the burden caused by it, especially for a Wi-Fi network, is the most prominent difference between this research and our research, which will have many weaknesses, including reduced flexibility and scalability.

In the proposed method in article [7], an APS method is used for the hybrid Li-Fi and Wi-Fi network, which makes decisions using fuzzy logic. The method used in this study consists of two stages. In the first stage, fuzzy logic is used to select users who will be connected to Wi-Fi. In the next step, users who have not been selected to connect to Wi-Fi should connect to Li-Fi. This algorithm makes decisions at a central point and does not impose additional burden on the distributed communications and extra repetitions. This method has also significantly reduced the processing load through the fuzzy algorithm. The scenario used in this study is an internal scenario, unlike the study [11], and it has been generalized by adding some general parts. This method has been optimized as much as possible according to the characteristics of the networks. The article claims that in their proposed method, computational complexity has been greatly reduced compared to other methods and is very close to the simple APS method in this regard. The use of fuzzy logic at the beginning of the communication creates a different process compared to our research, which will have disadvantages such as low analytical power, while there is no process for potential dynamics and learning, whereas in most games, including collaborative games, these aspects are noticeable.

Research [17] has focused on the performance and efficiency of VLC in different configurations and geometric dimensions, and has compared it with advanced RF technology using femtocells in an indoor scenario. In a modified scenario used in office buildings, both of these technologies have been employed, and the necessary condition for the VLC system is to provide sufficient light throughout the room, which can be achieved by using multiple sources and essentially creating optical access points in suitable areas. Additionally, multiple RF access points have been used to ensure complete radio coverage. This article aims to demonstrate the efficiency of VLC technology compared to RF, as determined by the Area Spectral Efficiency (ASE) metric. In general, the objective of this research is fundamentally different from our previous research, as it focuses on improving performance when combining two technologies by selecting access points.

5G networks with better connectivity and coverage can be achieved using a technique called Non-Orthogonal Multiple Access (NOMA), which modifies the power level for each user. In research [18], the authors propose an algorithm based on swarm intelligence and a dedicated search for reusing the combined Wi-Fi-Li-Fi network frequency to address limited bandwidth in Wi-Fi and Li-Fi. The combined Wi-Fi-Li-Fi system is modeled in an outdoor environment with Line-of-Sight (LOS) propagation. As a fundamental difference from our research, this research work is based on 5G network techniques and aims to reuse frequencies to increase the desired bandwidth, without discussing the selection of access points.

In research [19], the communication of 5th and 6th generation networks, which utilizes a combination of several network technologies including RF and VLC networks, has been considered and efforts have been made to optimize and enhance the VLC network for indoor scenarios. This research focuses primarily on the deployment of the VLC network and does not make any attempts to improve the combined VLC and RF method.

Research [20] discusses the selection of access points in a 5G hybrid network composed of MmWave, Wi-Fi, and Li-Fi technologies. It proposes a method that assigns scores to each access point based on channel analysis, bandwidth, and data rate calculations, and then selects the best technology for communication by the user equipment (UE) based on a fuzzy logic approach. User fairness and satisfaction are considered as the evaluation metrics for the network. Unlike our research, this study utilizes channel analysis and throughput for decision-making rather than strategic behavior and performance metrics. Additionally, this method is based on fuzzy logic, while our approach is based on cooperative game theory. Furthermore, the calculations and overall algorithm for evaluating access point suitability are completely different. Our method has the advantage of being simpler in calculations and encompasses intelligent decision-making and learning theory in cooperative games.

Research [21] focuses on the design and analysis of an efficient Li-Fi network by taking into account various equipment angles, data rates, distances, frequencies, and different pulses to achieve optimal configuration. Although the general idea of this research seems interesting, it would not be possible to achieve an ideal configuration for all scenarios and networks due to the varying conditions of networks from different perspectives. In general, the goal of optimizing efficiency for a specific network like Li-Fi differs from the objectives of our research, which aims to improve the performance of a combined network and does not prioritize the selection of access points.

Study [22] presents an RPL-based method to minimize the power consumption of Internet of Things devices, where a low-power and low-energy routing protocol (PriNergy) is proposed. This method is based on the Routing Protocol for Low-Power and Lossy Networks (RPL) that considers QoS for Internet of Things applications and utilizes time-division multiple access (TDMA) for synchronization between the sender and receiver, reducing power consumption.

This method considers Internet of Things QoS applications, so that it can be used for multi-access based on Time Division Multiple Access (TDMA) for synchronization between the transmitter and receiver and reducing power consumption.

There are also other articles that have used different technologies in the network and have examined the selection of access points in these networks. Including articles number [23] to [32]. For example, in research [30], a hybrid load balancing and power allocation (PA) method is proposed for a combined Visible Light Communication (VLC) and radio frequency system consisting of an RF access point and multiple points. The connection of this research with these studies is that all of these articles have discussed how to combine networks and channels in a network and have tried to improve the choices in a wireless network, of course, in terms of technology. There are relatively significant differences that will also be explained later and these differences distinguish the proposed method from previous methods.

The first difference is the use of a combined Wi-Fi and Li-Fi network and improving load balancing through the selection of access points, which in some researches has only focused on one specific network, or the goal and method of performance improvement are different. Using a central unit for calculations can prevent the increase in communications and the need for calculations in all nodes. Also, the computation load in the central unit is not too high to create a specific overhead. Another difference is the method of calculations in the proposed method using the strategic behavior of things and considering the performance of each node as a vital objective. In many studies, they have tried to select the appropriate access point through the analysis of the communication channel and the analysis of performance using relatively complex mathematical equations, while the ultimate subject is the performance and operation of networks. Therefore, performance criteria can simplify the processes and also be closer to effective performance. Another aspect of this research is the dynamic and learning aspect, which distinguishes it from a significant portion of the research, and all of these are also counted as advantages of this method.

One of the simplest methods of *APS* (Access Point Selection) strategy is the *SSS* (Signal Strength Selection) strategy, which considers the signal level of access points for decision making in access point selection. This strategy is clear for homogeneous networks, and since the noise level in the environment is constant for coexisting signals, the user's selected *AP* is the one with the highest signal strength in the area. However, in heterogeneous networks, the nature and type of signals are different and cannot be easily compared. Additionally, the power of the noise in heterogeneous networks that use different signals and spectra is not the same. Another issue is the difference in bandwidths of different networks. Therefore, in the *SSS* method for a hybrid heterogeneous Wi-Fi and Li-Fi network, measurement based on signal-to-noise ratio (SNR) is used, which in these conditions serves as a suitable substitute for signal strength and determines the state of a communication channel at any given moment.

3. RESEARCH APPROACH

In this study, a game theory-based method has been used to improve the allocation of access points to customers in a combined Wi-Fi and Li-Fi environment, where the allocation of channels is managed by a central management unit based on the conditions and distributed game data in the network. The next section first presents the system model, followed by the allocation of resources in the network in the discussed model, and then the proposed method is described.

3.1 SYSTEM MODEL

Consider a combined Li-Fi and Wi-Fi network used for communication in multiple rooms within a building. This model is shown in Figure 2. Several LED lamps are embedded on the ceiling of each room, and each lamp covers a specific range as a Li-Fi access point. Additionally, a Wi-Fi access point is placed in each room of this building.

Although Li-Fi access points may be irregularly placed in practice, they are arranged in a rectangular shape for simplicity, with the Wi-Fi access point placed at their center. Each Wi-Fi access point has multiple access capabilities with carrier-sense multiple access with collision avoidance [10]. Therefore, no information collision or interference occurs in the Wi-Fi access point. Considering the system used in Li-Fi, all Li-Fi access points use the same bandwidth. Since light does not pass through walls, information collisions only occur between Li-Fi access points in the same room. Each Li-Fi access point has time-division multiple access (TDMA) capability to provide simultaneous services to multiple users. Figure 2 shows a schematic of the combined and heterogeneous Wi-Fi and Li-Fi network, including users, different devices, and IoT devices.

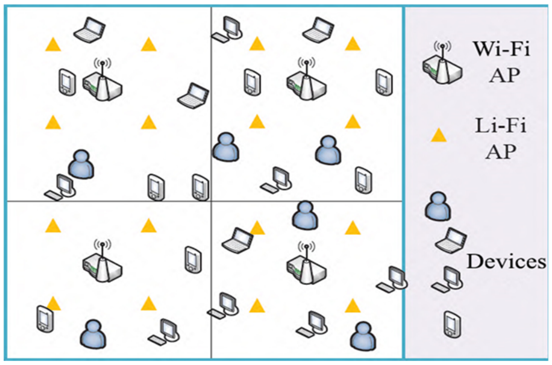

Figure 2. System Model

The interference model and signal strength in Li-Fi and Wi-Fi channels are governed by equations (1) and (2), respectively. Although in an indoor scenario, the assumed node model allows for mobility and movement, this research does not consider the motion variations of the nodes to avoid complicating the discussions. The node displacements, due to increased changes in the network, on one hand, increase the number of decision-making instances for access point selection, but on the other hand, require the examination of certain cases such as switching between access points with the same technology and the mixing of concepts.

3.2 Time Division for User Allocation

There are several methods available for users to access the wireless channel, with one of the most common being time division. The main method in this area is Time Division Multiple Access (TDMA), which serves users in a sequential order and in fixed time slots. To model, when an access point (AP) serves user p showed by $t_{p,ap}$, also $\sum_{p\epsilon P_{ap}} t_{p,ap} \leq 1$ and $t_{p,ap} \in [0,1]$, where P_{ap} represents the set of users being served by AP. Both normal and relative fairness schemes are used for allocating time resources, and when the following condition is met, the system performance reaches its maximum:

$$t_{p,ap}=\frac{1}{M_{ap}}. \qquad (3$$

where M represents the number of modulation levels in the corresponding channel in a network. It can be inferred that these conditions apply to all TDMA channels.

3.3 Switching or Handover

In a dynamic Li-Fi and Wi-Fi network, a node, known as a responsible node (RN), assigns users to APs when needed, and each user's service is provided semi-statically by the APs. Switching or handover occurs when two or more different APs in the user's vicinity are servicing, and the current AP provides a weaker service compared to the other AP. During the handover phase, the user usually receives more signaling related to handover than any other data, resulting in the handover overhead causing a significant drop in performance in network applications. Here, we denote t_{Ho} to model the handover time, which is typically in the range of milliseconds in a local network, and usually, this time is less than the semi-static state duration, T_{ss}. With the dynamic transmission of data by users, traffic and network conditions change, leading to variations in AP conditions and consequently affecting the service received by users Therefore, there is a possibility of needing relocation. If we define the integer number m as the ordinal number of the state, and consider that user p is assigned to access $ap_p^{(m-1)}$ point in state *m-1*, we can write the switching efficiency between state *m-1* and *m* as follows:

$$swf_i = \begin{cases} \left[1 - \frac{t_{Ho}}{T_{ss}}\right]^{Mx0}, i \neq ap_p^{(m-1)} \\ 1, i = ap_p^{(m-1)} \end{cases}, i \in Ap \quad (4)$$

A place where access point *i* is expected to provide service to user *p* at position *n* and operator demonstrates$[x]^{Mx0}$maximum (x) and minimum (0).

3.4 ACCESS POINT SELECTION BASED ON GAME THEORY

Here, a load balancing scheme based on game theory and specifically cooperative game [33], [34] is proposed for access point selection and switching [35]. The game theory-based design is performed at the beginning of each state to determine the assigned access point for each user. The overall design scheme of this method is illustrated in figure 3.

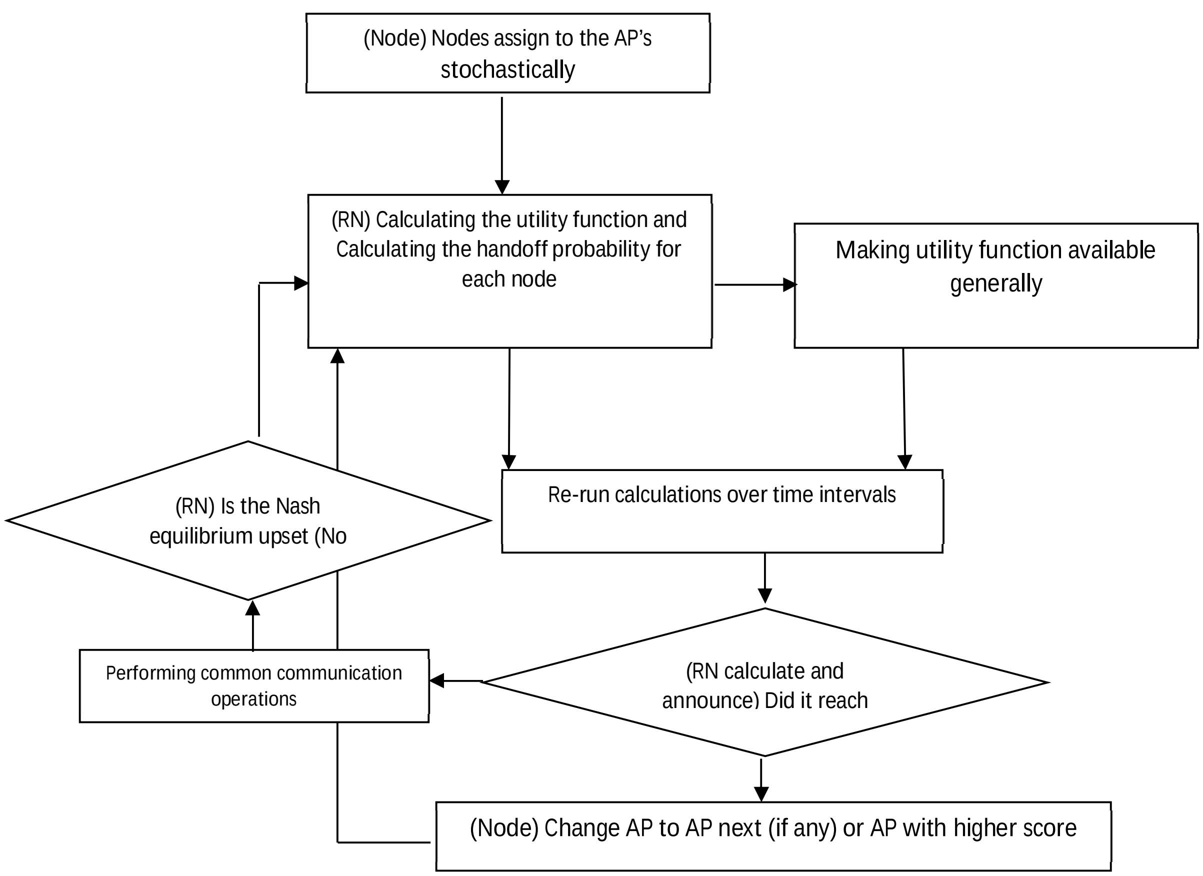

Figure 3 provides a general overview of the participatory game method.

The game-based design initially starts with random allocation and based on the initial AP signals to users. It is then managed by the responsible RN node to apply changes that drive the network towards improved efficiency through simple calculations in time intervals. The cooperative game is modeled by several parameters:

1) Set of players (P): The players of the game are the Li-Fi and Wi-Fi users in the network, represented by the set of players P={$p|p \in [1, N_{UE}]$}.

2) Set of policies (S): In a mixed network, the policy set for each player consists of a heterogeneous set of network access points. Therefore, S = Ap =$ap \in [1, N_l]$.

3) Affiliated Group: In this collaborative game, a group of players is assigned to an AP, which represents the total number of users displayed with Pap, and their number is M_{ap}.

4) Income Level (U): Income in games is used to determine the impact of adopting strategies and decision-making for the future. In the collaborative game APS, each user has the goal of improving performance, so there is a need to determine a parameter that specifies this performance. In agent-based network applications, service quality is important in determining performance. Therefore, here QoS is considered as the income of players, and decisions are made based on it. Usually, the higher the received data rate by the user, the higher the expected service quality. However, this is only until the user receives their maximum required data rate λ_p, and after that, increasing the data rate does not create any change in service quality. Therefore, the income performance provided by the AP is calculated using the following formula:

$$U_{p,ap} = min\,\{t_{p,ap}\frac{r_{p,ap}}{\lambda_p}, 1\} \quad (5)$$

During APS, this policy continuously aims to improve the results of cooperation. The process of aligning the APS policy and related collaborations can be modeled as follows: In each iteration r, the average overall income of all players is determined as follows:

$$\bar{U}^{<r>} = \frac{1}{N_{UE}}\sum_{p\in P}\Delta_{p,ap}^{<r>} \quad (6)$$

In this case,$U_{p,ap}^{<r>}$ is the income of player p in rth iteration. The policy of choosing access points for each user in rth iteration is based on the player's utility and the average overall utility in the last iteration, indicated by $U_{p,ap}^{<r-1>}$ and $\bar{U}^{<r-1>}$ respectively. Each user's policy is randomly adjusted and follows the principle that a player with the least expected return has the highest probability of changing their policy. This is known as the "improvement mechanism" in game theory. Therefore, in rth iteration, the probability of changing the policy is determined as follows:

$$SC_p^{<r>} = \begin{cases} 1-\frac{U_{p,ap}^{<r-1>}}{\bar{U}^{<r-1>}}, U_{p,ap}^{<r-1>} < \bar{U}^{<r-1>} \\ 0, U_{p,ap}^{<t-1>} \geq \bar{U}^{<r-1>} \end{cases} \quad (7)$$

When improvement occurs, a new AP will be selected based on the maximum estimated profitability in the current iteration, which is described as follows:

$$ap_p^{<r>} = arg_{i\in S_p}\, max\, \hat{U}_{p,ap}^{<r>}$$
$$\hat{P}_{p,ap}^{<t>} = \begin{cases} swf_i U_{p,i}^{<r-1>}, i = ap_p^{<r-1>} \\ swf_i U_{p,i}^{<t>}, i \neq ap_p^{<r-1>} \end{cases} \quad (8)$$

In the above formula $ap_p^{<r>}$ is the selected access point for player p is in rth iteration. $P_{p,ap}^{<r>}$ is the estimated user utility; if provided by a different AP from $ap_p^{<r-1>}$, indicated by υ. When a new user enters the set of users served by AP according to (3), the allocated resource portion for each user will be as follows: $t_{p,\upsilon}^{<r-1>} = \frac{1}{M_\upsilon^{<r-1>}+1}$

Therefore, the estimation of player *p*'s income in repetition *r* is expressed as follows:

$$U_{p,i}^{<r>} = min\,\{\frac{r_{p,\upsilon}}{\lambda_p(M_\upsilon^{<r-1>}+1)}, 1\} \tag{9}$$

This game is managed and implemented in the RN. In this game, the choice of AP is practical and performed by the players, and of course, it is controlled by the RN unit and based on interactive gameplay. In fact, it is the interaction point between the players and the RN. In the end, by striving for higher performance in the game, all players benefit from this collaboration.

The proposed APS algorithm, based on cooperative game theory, consists of the following stages:

a) Users change their policies to find the best service.

b) Resources related to data transmission are equally allocated to users served by the same AP program.

c) Stages a) and b) are repeated until no user can change their strategy to improve profit. The APS algorithm based on game theory is described in algorithm 1.

ALGORITHM 1:

The inputs of the algorithm 1 is the access points that are randomly selected and the output of the algorithm is the introduction of the optimal access points that provide the most efficiency.

1: Start and initialization:

- An Access Point (AP) assigns itself to a desired or randomly chosen player, *p*.
- Each AP equally allocates its respective resources for data transmission to connected users.
- The RN unit calculates the average utility of each $U_{p,ap}^{<0>}$user as well as the average $\bar{U}^{<0>}$ utility, and r ← 1.

2: For all players, p∈ P:
3: RN calculates the probability of displacement $SC_p^{<r>}$ based on equation (7).
4: RN generates a random number with a uniform distribution between 0 and 1, denoted as θ.
5: If θ <$SC_p^{<r>}$ then:
6: A change in policy occurs and player p is assigned to an AP based on equation (8) (or in other words, an AP is assigned to player p).
7: Otherwise:
8: Player p is still allocated to the main AP.
9: End If
10: End For
11: For all APs ap ∈ S do:
12: In each cell, allocate resources equally to all players based on (3).
13: End For
14: t→t+1 and repeat from step 2 until no AP changes occur.

3.5 Achieving Load Balance in the Network

In general, an evolutionary equilibrium (EE) balance, also referred to as a non-Nash equilibrium, can be achieved through convergence.

Definition 1: The policy parameters $\varepsilon = \{a_p | p \epsilon P\}$of an evolutionary equilibrium of the desired interactive game are identified if in equilibrium E, no player can increase their reward by unilaterally changing their strategy, that is,

$$U_{p,a_p} \geq \Delta_{p,\beta_p}, a_p \neq \beta_p, a_p, \beta_p \in S_p \quad (10)$$

Considering the concept of AP selection fairness in a hybrid network, which is also mentioned in Algorithm 1, this formula is equivalent to no changes in AP by RN in one round of algorithm execution. This means that in such a situation, the utility calculated by RN for all users is at its best.

Computer simulation is used to evaluate the number of required iterations in the proposed APS scheme. In this study, the NS-3 simulator software has been used for this purpose. Simulation parameters are provided in section 4 and tables 1 and 2. It is assumed that users are evenly distributed and randomly send their traffic. In the first case, initial APs are randomly selected for user service. Also, no difference is considered between access points with different channels in the initial allocation of users. As shown in Figure 3, to achieve NE, generally about 5 or 6 iterations are required for all three schemes: SSS, PL-LB [30], and FL-LB [7], and for the cooperative game algorithm, this iteration is equal to 3. This means that the proposed game theory-based theory achieves rapid convergence.

If user connection is only available from one channel compatible with an AP, NE is obtained after the first iteration. However, this is not practical in a general scenario. Using game theory-based APS, each UE is allocated to the AP with the best received signal power after the first iteration. If the network does not change, the next iterations are not proportional to the APS strategy. In other words, in a homogeneous system with constant traffic, APS results based on game theory will be the same as the results obtained from an SSS system. For different-angle receivers (ADR), the CG scheme combines the received signals from each device with equal weights, so the SINR performance is similar to a system with the same technology receiver. From Figure 4, it can be observed that the CG scheme converges after the first and second iterations, while more iterations are required for other methods. Additionally, ultimately, these methods achieve a lower service quality.

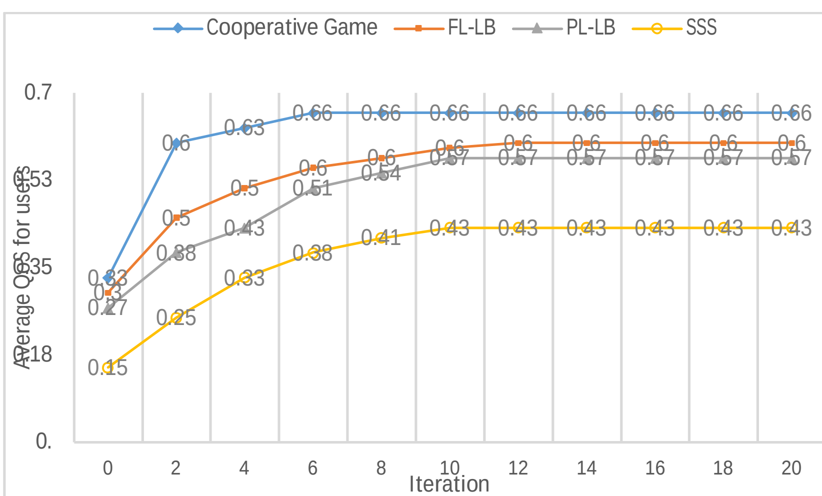

Figure 4. Analysis of convergence methods and their comparison

3.6. THEORETICAL ANALYSIS OF METHOD EFFICIENCY

In game theory, when the system reaches its optimal state, which is balanced among the players, we face a state of stability or equilibrium. In this state, with small changes, the players of the system try to reach a better state, which leads to decision-making by the players towards achieving a stable situation. The improvement of the desired network system in this study, through game theory, may temporarily result in a reduction of certain network performance parameters in some cases and from the perspective of some users, and this means it may not be the best locally. However, it obtains a state close to the optimum for the entire system. In fact, from the perspective of justice and quality of service provision for all users, this method is logical and effective. In this case, even when a user tries to receive more data from the network, this request for more bandwidth leads to changes in the network and creates a new Nash equilibrium in a way that preserves the benefit for other players, and as a result, the minimum quality of service is provided for each user. On the other hand, considering the improved performance of the entire network and the balance it creates, this matter spreads to all parts of the network, as balancing the load on the nodes also reduces errors due to congestion, and we will witness a universal improvement in the network and nodes.

3.7. SIMULATION VALIDATION

Considering the random nature of computer networks, especially wireless networks, there is no deterministic result regarding the efficiency of a method in all scenarios, situations, and different times. Therefore, in order to prove the efficiency of a method, the use of a number of scenarios and executions can cover the requirements of understanding the efficiency of that method. On the other hand, the nature of simulation seeks to simplify and abstract the system, which is used to extract an appropriate model from it. However, this simplification must contain the essential elements of the system. In this study, a model based on Wi-Fi and Li-Fi networks in the NS-3 simulation software is used, which includes these elements. This model is available in the simulator and requires some changes in order to implement specific methods to prove their efficiency. In this study, specific changes to the methods have been integrated into the simulation software, which covers the fundamental concepts of the methods being simulated. Each piece of code includes a part of the methods, which of course must be compatible with the functioning of the simulation software in order to be executed correctly and cover the functional requirements. There is no specific standard for implementing changes, and it is executable and traceable based on experience. Therefore, the simulation is performed based on the model and according to the principles of simulation, which include simplification and abstraction. The elements of the intended methods have been integrated into the simulation and ultimately created results. According to the initial statements, these results are certainly not generalizable, but they can demonstrate the efficiency of the methods at least under certain conditions.

4.RESULTS AND DISCUSSION:

As shown in Figure 5, section A considers a scenario of a 16-meter by 16-meter area with a height of 3 meters inside a house, where 16 Li-Fi access points are deployed in a square topology and a Wi-Fi AP is located at the center. All users are randomly distributed and operate with a variable traffic model. Additionally, each access point has 6 connected diodes and the angle of the diodes on the AP is set to 30 degrees, forming a 30-degree ADR. However, the coverage of an AP is similar to an AP with a single diode and forms a circular environment. Other parameters used in the simulation are mentioned in Tables 1 and 2. The results, considering the implementation of methods, configuring the necessary settings in the simulation software, and averaging the outputs from 10 runs, are reported.

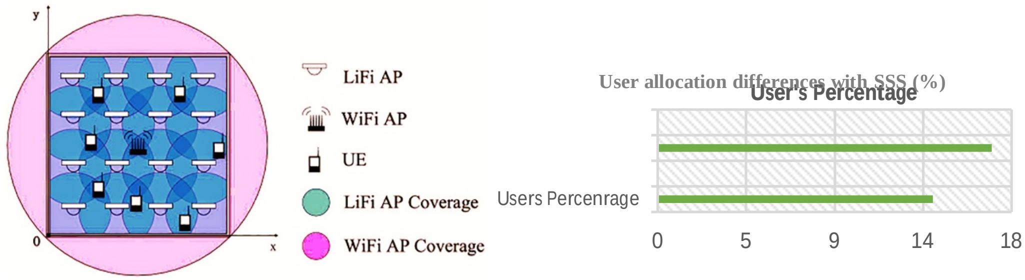

Figure 5. Overall network design: a) Overall design of access point locations
b) Percentage of users who, when adopting APS based on game theory, connect to other APS besides the AP assigned by SSS.

Figure 5 in Section B shows the difference in the number of users connected to APS for each method compared to the SSS method. In this context, if the network is homogeneous, ADR with CG has a 0% difference with SSS, indicating that all users are connected to APS that provide the highest signal level for them. Therefore, there will be no difference between this method and SSS. The reason for this is that in such networks, there is a significant amount of Co-channel Interference (CCI), and as a result, the only AP that can serve the user is the one that has the highest signal level for the user. However, when heterogeneous designs, such as combining Wi-Fi networks with multiple channels, are considered, CCI is reduced, and users choose other APS in the proposed cooperative game method as well as the FL-LB method. This is less than 15% in the cooperative game and more than 15% in FL-LB.

Table 1: Li-Fi Simulation Settings for Network Configuration

#	Parameter	Value
1	Room height (vertical distance between ceiling and user)	**2 meters**
2	Physical surface of photon diode	**1 square centimeter**
3	Light filter efficiency	**1**
4	Failure index	**1.5**
5	Half intensity radiation angle	**60 degrees**
6	Half-angle domain of photon diode	**90 degrees**
7	Optical transmission power at any point of access	**3 watts**
8	Optical conversion factor to electronic force	**3**
9	Tracker sensitivity	**0.53 A / W**

10	The reflection on the wall	**0.8**
11	Bandwidth	**40 MHz**
12	Power spectral density (PSD) of noise	**10^{-21} A^2/Hz**

Table 2: Wi-Fi Simulation Settings for Network Configuration

1	**Breakpoint distance (dBP)**	**5 meters**
2	The standard deviation of shadow fading before dBP	**3 dB**
3	The standard deviation of shadow fading after dBP	**5 dB**
4	Central carrier frequency	**2.4 GHz**
5	LOS entrance and exit angle	**45 degrees**
6	Transmission power	**20 dBm**
	Bandwidth in channels	**20 MHz**
	Power spectral density (PSD) of noise	**-174 dBm/Hz**

Average QoS as a function of the required user data amount is shown in Figure 6. The number of UES is assumed to be 200, which is logical considering the large number of devices in the future. CG represents an APS scheme based on game theory for Wi-Fi and Li-Fi systems using ADR. FL-LB and SSS are similarly defined for APS. CG-PD also shows cooperative game theory when using PD, and SSS-PD identifies an APS scheme based on SSS with an optical diode for Li-Fi systems. All four designs of CG, FL-LB, PL-LB, and SSS receive QoS 1 when the average required data volume is low. It can be seen that CG design performs better than the other schemes. FL-LB design performs approximately 15% better QoS than SSS and PL-LB performs approximately 10% better, as expected. Similarly, compared to the FL-LB scheme, game theory design achieves a 6% increase in service quality. Further increase in data demand leads to improved performance of game theory-based APS design compared to FL-LB, PL-LB, and SSS-based APS schemes.

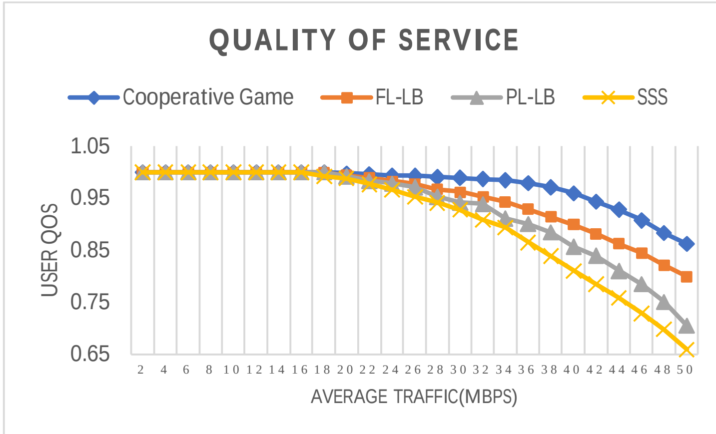

Figure 6: Users' quality of service versus average data rate (NUE = 200)

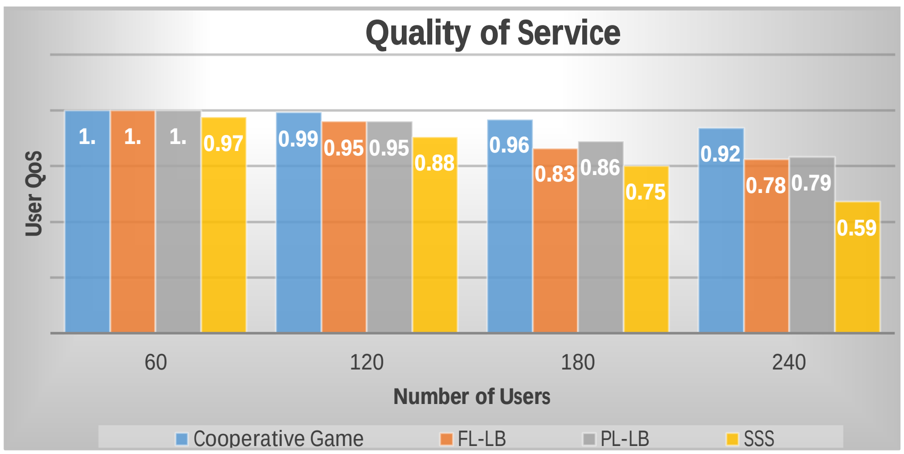

Figure 7: Service quality for users in relation to the number of users (λ = 50 megabits per second)

Figure 7 compares the quality of user service against increasing number of users with a data rate of 50 Mbps. According to this graph, the received service quality of users in the CG scheme has a larger difference with other schemes as the number of users increases. Initially, with 60 users, both FL-LB and PL-LB methods receive a QoS of 1, and no difference is observed. With 120 users, the minimum difference with FL-LB and PL-LB methods is 0.04, while with 240 users, this difference reaches 0.13 with PL-LB and 0.14 with FL-LB, which is a significant amount. In all cases, the difference with the SSS scheme is higher.

The graph shown in Figure 8 represents a function of the cumulative average data rate density based on APS and game theory. It can be observed that the CG scheme, using the proposed channel management method, achieves a performance very close to the desired state. Therefore, although there is still a gap, it is possible to achieve better performance with a minor modification and combination with a very simple hybrid circuit. The proposed CG scheme has better performance compared to the other two schemes, with over 90% of users achieving a data rate higher than 70 Mbps, while approximately 80% of users reach a data rate higher than 60 Mbps in the FL-LB scheme, and this percentage is around 65% for PL-LB.

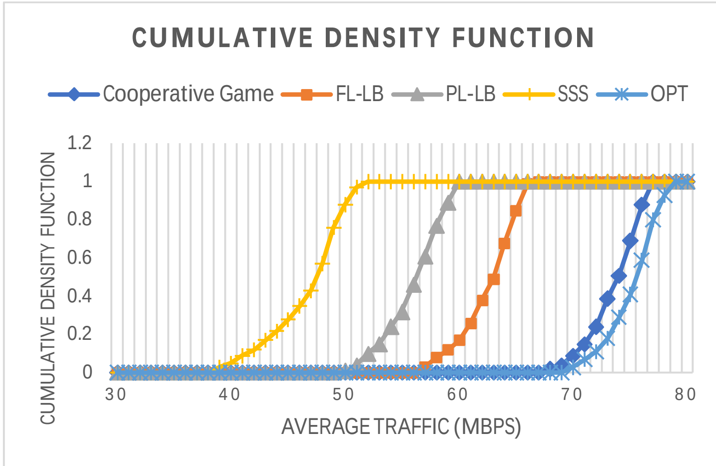

Figure 8: Cumulative density function (CDF) vs average user data rate for various APS schemes (NUE = 200) (λ = 50 Mbps).

Based on the obtained results, the effectiveness of the proposed method can be evaluated as highly beneficial in terms of the quality of service received by the users, and compared to previous methods, this plan can distribute traffic among users in a better way, enabling them to connect to access points that can provide a better service. The adaptation to the network configuration and the dynamism of this method, along with the use of game theory in AP selection, ensure that, even if the network becomes congested, the necessary resources are available to the nodes and network users. However, it should be mentioned that, like any other method, this method may also have weaknesses, including being adaptable based on only certain specific network conditions or the possibility of drawbacks due to centralization, requiring a method to recover if the responsible node for RN experiences problems. Moreover, in terms of efficiency, this method can be improved and may yield weaker results in certain network conditions and scenarios.

In general, as traffic increases, the need to employ methods with a higher balance in the network and tailored to its conditions becomes more evident. According to the charts, overall efficiency decreases with an increase in average traffic, leading to a decrease in user satisfaction. A method that can dynamically prevent a significant decrease in performance due to better decision-making regarding the selection of access points on user devices will be more successful. It is evident in figures 6 and 7 that the quality of service degradation in collaborative gaming is less due to changes in the selection of access points, and in figure 8, it is also evident that by employing access point selection based on collaborative gaming, the average data rate for users is above 70 Mbps, indicating the satisfactory performance of this method in achieving network balance.

5. Conclusion

In this article, a hybrid network of Li-Fi and Wi-Fi using multi-channel and multi-relationship technology, especially on access points, has been investigated. A collaborative game theory-based AP selection scheme considering location changes due to network conditions has been proposed to achieve the desired load balancing. In this scheme, each node in the network acts as a player in game theory and then, based on the calculation of utility function and probability of movement, user policies are determined and decisions are made for each user so that the network reaches an equilibrium state. By introducing changes in the network and disrupting the equilibrium, we enter the computational phase to restore the balance.

For a homogeneous network with constant conditions and ADR with CG, the proposed scheme has similar performance to the SSS-based APS scheme. However, when it comes to Wi-Fi technology and dynamic network conditions with variable traffic, the proposed method works much better than SSS-based APS and previous schemes such as FL-LB and PL-LB. With an increase in the number of users and the amount of data and traffic required for growth, the performance difference will increase. The proposed CG scheme, with proper network analysis, is very close to desired conditions and has better conditions compared to other schemes.

It is estimated that, overall, a minimum 30% improvement can be achieved compared to the SSS method and more than a 10% improvement compared to PL-LB and FL-LB mechanisms. One of the advantages of this method, in addition to its efficiency, is its dynamism and intelligence in the face of network changes. Furthermore, the performance of the proposed scheme is more apparent with increased network traffic and congestion at access points, indicating a better load balance in the hybrid network.

As for future research, we can focus on specific networks that use this technology and specifically modify signal behaviors, then experiment with the network. We can use a combination of other networks as a local network and even test this method on larger networks. For example, expanding this method and improving its capabilities and feasibility by modifying parameters of different networks and scenarios. A combination of this method with different approaches, using other games, and providing more comprehensive analysis can also be included in future studies.

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