Resource Allocation for Hybrid Visible Light Communications (VLC)-WiFi Networks

LIWEI YANG, QI ZHANG, WENJIE ZHANG, LINING DENG, AND HUIPING YANG

ABSTRACT Visible Light Communication (VLC) is becoming a promising technology of wireless communication, due to high data rate, low cost, and immunity to Radio Frequency (RF) interference. However, the VLC systems often suffer from service disruptions because of the limited coverage of light. Therefore, the heterogeneous networks of VLC and WiFi are proposed to achieve high-speed indoor communication and seamless coverage. This paper investigates an efficient heterogeneous network resource management algorithm, which is not only significant to integrate the current network resources but also has practical significance to improve the performance of heterogeneous networks. We establish a distributed joint resource management system model and propose two kinds of resource management allocation strategies to allocate bandwidth among the users with maximum fairness. The simulation results show the feasibility of the heterogeneous network and the effectiveness of the algorithm.

INDEX TERMS Visible light communication (VLC), wireless fidelity (WiFi), resource allocation, heterogeneous network (HetNet).

I. INTRODUCTION

With the development of communication technology, the requirements for communication services have changed from audio services with narrow-spectrum resources to video services with wider spectrum resources. Considering the demand for quantity and quality, the network is developing towards high performance, high quality, high speed, and high throughput. VLC has emerged as a promising alternative for next-generation wireless networks (5G and beyond), due to its high data rate, flexible coverage, and immunity to radio frequency (RF) interference [1]–[3]. VLC uses light-emitting diodes (LEDs) to transmit data by modulating the intensity of visible light and can be used as complimentary wireless access technology to WiFi and cellular systems [4], [5]. However, the VLC systems suffer from service disruptions due to the limited coverage of light, and it also easy to be blocked due to misalignment or path obstruction.

The indoor installation of WiFi hotspot can provide multi-user high-speed of the network due to the limited spectrum resources. If installing several WiFi hotspots, it will cause the same frequency interference, which reduces the quality of service (QoS). Thus, VLC becomes a promising candidate for the indoor network, due to the vast unregulated available spectrum, low implementation cost, and immunity against interference compared to conventional WiFi systems [6]–[8]. Furthermore, the problem of spectrum shortage raises two issues, namely the disparity in the capacities of the two sub-networks as well as their coverage, since VLC has large capacity but limited cover. The trade-off between the achievable rate and fairness becomes more prominent due to the asymmetry.

To solve the above problems, we propose a hybrid VLC-WiFi network, which uses a WiFi network to solve the limited VLC coverage problem. Considering the VLC network alone, due to the lack of effective coordination between VLC and other existing networks, as well as its own small signal coverage range and unstable optical link, it reduces the user experience of mobile terminals (MT) [9], [10].
Compared with the traditional WiFi and VLC network, VLC-WiFi heterogeneous network has the following advantages: The first is the handover mechanism, which enables users to switch seamlessly. Secondly, VLC and WiFi don’t interfere with each other due to the different frequency spectrums, and also improves the network throughput [11]–[13]. Finally, they can promote each other and expand the spectrum efficiency and wireless capacity.

In VLC-WiFi heterogeneous network, the key to utilize the potential performance advantage effectively lies in the network selection, in which the handover algorithm is the focus of the research, and resource scheduling is closely related to handoff technology. With the reasonable allocation of resources, use the switching technology to optimize the management of resources. In terms of resource allocation, we construct the most appropriate resource scheduling scheme from the system perspective. We propose a novel joint resource scheduling algorithm to maximize fairness and dynamically allocate resources to maximize the utility of the network. We simulate the optimal resource management scheme and analyze the results to complete the joint resource scheduling scheme depending on the parameters and states of the network. We also verify the effectiveness of the produced method by simulation.

A. RELATED LITERATURE

VLC becomes a supplement to conventional RF communication due to its potential in high throughput, enhanced security, and low-frequency spectrum utilization. The integration of VLC and WiFi or cellular network (5G and beyond) is a major means to solve the last mile wireless access, and it’s also the direction of broadband access and short-distance communication in the future [14]. It is significant to construct a heterogeneous network of VLC and WiFi to realize high-speed communication and seamless coverage indoor.

The hybrid RF/VLC systems have been studied for years. For example, [18] studies the multipoint joint transmission and frequency planning in a VLC system. The hybrid RF/VLC resource allocation that promotes proportional fairness among users is described in [15] and uses large capacity. Cooperative load balancing to promoting fairness and dynamic load balancing through handover in a hybrid RF/VLC system is analyzed in [16] and [17], respectively.

Meanwhile, seamless switching of resources has been established for management, as in [14], it proved that the resource allocation algorithm plays an important role in the system performance. To deal with the handovers, developing a fast and effective resource allocation algorithm is a key issue. Cooperative load balancing achieve proportional fairness (PF) is proposed in [15] by using both centralized and distributed resource-allocation algorithms. Reference [16] proposed an energy-efficient resource allocation of a hybrid VLC-RF system, consisting of a single RF access point (AP) and multiple VLC APs, with the performance of the system’s power efficiency (PE).

In 2018, the simultaneous interpreting of HetNet was studied in [20], [21], it designed a femtocell sleep scheme according to the loss performance of the system, such as path loss, transmission loss, shadow loss, and mutual interference, considering the user noise, which can not only guarantee the QoS but improve the performance. Moreover, [22], [23] considered the transmission power, adjustment factors, transmission loss, and receiving efficiency of the base station (BS) in the resource allocation, it proposed a practical resource allocation algorithm based on maximum efficiency and predecessors, to balance the resource allocation and reduce the resource consumption of the BS.

A reasonable scheduling algorithm will provide users with better QoS, and improve the efficiency of the BSs. Resource management technologies of the heterogeneous network are discussed in [24]–[27], including collaborative radio resource allocation management, multi-access distributed radio resource allocation management, and joint radio resource allocation management. Three kinds of common scheduling algorithms were analyzed in [28], including Round-robini (RR) algorithm, the maximum C/I algorithm, and the proportional fair (PF) algorithm.

Paper [1], [28]–[35] studied various characters. In [28], the RR algorithm makes the terminals have the same fairness, at the expense of the performance, such as throughput. In [29], although Max C/I algorithm provides the maximum performance and resource utilization, it completely ignores the fairness and reduces the QoS. In [30], the PF algorithm considers both fairness and system performance. However, in [31], the study shows that the existing PF algorithms in resource allocation problems ignore fairness in the short term.

B. CONTRIBUTION

In this paper, we propose a novel heterogeneous network, which divides into two areas: area a and area b. Area a is the area covered by WiFi only, and area b is the area covered by both VLC and WiFi. VLC and WiFi networks are controlled by different subsystems respectively. We propose the flow chart of the joint system resource management algorithm and design the resource management algorithm for the system with a single WiFi AP and several VLC APs. Moreover, we also describe the weight-based maximum and minimum allocation algorithm (WBA) and the allocation algorithm with weights to reduce dynamic range (WWA).

We use MATLAB for simulation and optimize the optimal single system resource management algorithm through the fairness index. Then we use the optimal single system resource management algorithm to design the joint system resource management algorithm. Finally, we analyze the performance by the simulation experiment. We conclude that the allocation of resources can use the resource of heterogeneous networks effectively, which improving the efficiency of the network resources and the performance of the system.
The contributions of this paper can be summarized as follows:

1) We analyze the key technologies of VLC-WiFi heterogeneous network, compare with the resource management model of the traditional heterogeneous network, and establish the hybrid VLC-WiFi system model.

2) A novel joint resource scheduling algorithm is proposed to maximize fairness while dynamically allocating resources to the terminals, which maximizes the network utility.

3) We simulate the optimal resource management scheme, observe the network parameters and states, analyze the simulation results, and complete the joint resource scheduling scheme.

C. STRUCTURE

The remainder of the paper is summarized in the following: Section II introduces the HetNet resource management algorithm, WBA, and WWA. In section III, we establish the VLC-WiFi heterogeneous network model and use the utility function to analyze the single and joint system resource management algorithm. Section IV describes the handover decision algorithm. In section V, we discuss the optimal resource management strategy. Finally, we analyze the simulation results.

II. HETEROGENEOUS NETWORK RESOURCE MANAGEMENT STRATEGY

In general, user access, signal control, resource conversion, load balancing, channel allocation, are significant parts of the joint network resource management technology. The seamless handover of user resources and the provision of full service has a problem for resource management issues [25]. The existing resource allocation management modes are mainly divided into collaborative radio resource allocation management, distributed wireless resource allocation management, and joint wireless resource allocation management.

There is no unified centralized resource management system in distributed joint resource management architecture to manage resources under the whole network architecture. Each wireless resource management entity allocates bandwidth from the system through the resource management allocation strategy and interacts with other wireless resource management entities [26]. The distributed joint resource management architecture is more flexible than the centralized joint resource management architecture and is easy to expand. Even if some nodes in the network fail, it will not cause a destructive impact on other nodes [27]. In each radio resource management entity, although the extra signaling will cause some cost, it reduces the calculation amount of each network node and increases the reliability of the communication system. Collaborative joint resource management architecture is based on distributed joint resource management, which is distributed by a centralized resource management unit.

Based on the distributed joint resource management model, this paper considers the joint resource management algorithm for VLC and WiFi heterogeneous networks.

A. WBA: WEIGHT-BASED MAXIMUM AND MINIMUM RESOURCE ALLOCATION ALGORITHM

We assume the hybrid VLC-WiFi system with \( n \) users, marked as \( \{a_1, a_2, \ldots, a_{n-1}, a_n\} \), the corresponding weights of the user are marked as \( \{w_1, w_2, \ldots, w_{n-1}, w_n\} \), the request rates are \( \{c_1, c_2, \ldots, c_{n-1}, c_n\} \) and the total number of resources is \( C \). We assume \( w = w_1 + w_2 + \cdots + w_{n-1} + w_n \). Then, when the user is accessed into the system:

1) For the first time, the number of resources allocated by the \( nth \) user is \( r_n = \frac{Cw_n}{w} \);

2) For user \( i \), if the data rate satisfies \( c_i < r_i \), then \( d_i = r_i - c_i \);

3) Extract and update all the users who can’t satisfy the step 2) to step 1), so that they are equal to the sum of the extracted user weights;

4) Calculate the sum of the differences \( d \), set \( C = d \);

5) The resources acquired by users in each iteration process are superimposed, and the bandwidth allocated by users is updated as \( r_1 + r_2 + \cdots + r_{n-1} + r_n \);

6) Repeat steps 1), 2), 3), 4) until all the users are assigned a rate less than or equal to the request rate.

B. WWA: ALLOCATION ALGORITHM WITH WEIGHTS TO REDUCE DYNAMIC RANGE

We assume there are \( n \) users, marked as \( \{a_1, a_2, \ldots, a_{n-1}, a_n\} \), and the corresponding weights of the user are marked as \( \{w_1, w_2, \ldots, w_{n-1}, w_n\} \), the request rates are \( \{c_1, c_2, \ldots, c_{n-1}, c_n\} \), the total number of resources is \( C \). Then, when the user is accessed into the system:

Assuming the number of users is odd and even, the user request rate is arranged in sequence or reverse:

1) If the number of the user is odd, a “union” is formed by taking a value from the beginning to the end (the request rate), the request rate of the \( \frac{n+1}{2} \) user is multiplied by 2 to form a “union”, all the members of the joint request rate sum and form a new sequence, the number of elements is \( \frac{n+1}{2} \);

2) If the number of users is even, a “union” is formed by taking one value (the request rate) from the beginning and the end in turn. All the federations get the request rate sum of internal members and form a new sequence. The number of elements is \( \frac{n}{2} \);

3) In the first allocation, the number of resources is allocated in turn by the ratio of the values of each element in the sequence, that is, the number of resources obtained by each “union”;

4) In the second allocation, the number of resources obtained from each element of the sequence is allocated bandwidth to users according to the weight of the corresponding “union” internal members.
After allocating resources to all users, we calculate the fairness index of the joint system resource management algorithm, and analyze the performance of the joint system resource management strategy.

### III. ANALYSIS OF JOINT RESOURCE MANAGEMENT ALGORITHM

#### A. ESTABLISHMENT OF HETEROGENEOUS NETWORK MODEL

In this paper, we use a joint network model to establish the indoor VLC and WiFi heterogeneous network model. Meanwhile, for the distributed joint resource management architecture. The VLC and WiFi networks are controlled by different wireless resource management entities, and the two subsystems interact regularly. Based on the above, we put forward the basic assumptions for the heterogeneous network model:

a) Each radio resource management entity has ten scheduling times in a single scheduling cycle, and the system allocates bandwidth for users using the resource allocation strategy at each scheduling time;

b) At the end of each scheduling cycle, each radio resource management entity calculates its system capacity and interacts with each other to decide whether to compensate new users to the other system;

c) The internal channel interference and complex indoor signal attenuation are ignored. It is assumed that the signal received by the user is uniformly attenuated to 98% of the original network hotspot (AP) transmitted signal;

d) Although the channel interference and complex indoor attenuation are ignored, considering the different user locations in the model, it is assumed that the bandwidth allocated by users is affected by the distance between the user’s location and AP and the average request rate of single scheduling time. Here, the average request rate of users is affected by the request rate of all scheduling times before the scheduling cycle to which the scheduling time belongs.

#### B. ESTABLISHMENT OF UTILITY FUNCTION FOR HETNET

After the initialization of the system, the equivalent bandwidth resources are converted into resource allocation bandwidth by Shannon formula:

\[ C = B \cdot \log_2(1 + \frac{S}{N}) \]  

(1)

where B is the equivalent bandwidth of all resource blocks, and SNR is the signal-to-noise ratio.

Considering the different locations of users in the room, the bandwidth allocated by users is affected by the distance between the user’s location and AP, and the average request rate at a single scheduling time. Here, the average request rate of users is affected by the request rate of all scheduling times before the scheduling cycle to which the scheduling time belongs.

FIGURE 1. Proposed hybrid VLC-WiFi system.

As shown in Fig.1, several LEDs and a WiFi AP is distributed in the room, while all subscribers are distributed randomly. The WiFi AP is assumed to cover the whole room. We focus on indoor areas, such as houses, airports, offices, etc. There is a central controller for signal processing, scheduling in the indoor hybrid VLC-WiFi system to allocate resources. Supposing that each subscriber is designed with both VLC and WiFi transceivers, and at a given timeslot, the subscriber can only transmit or receive on one determined channel.

In the hybrid VLC-WiFi system, we need a handover mechanism to allow the subscriber to select the most appropriate network dynamically. Several parameters are considered to control the handover decision. For example, a channel-based handover decision considers the state of the wireless channel mainly [16]–[18]. The significant issue is to separate the load of subscribers over multiple APs. Therefore, this work proposes joint resource allocation to allow the MTs to choose either VLC AP or WiFi AP when moves in the indoor space. Multiple APs are controlled by a central controller, which performs the scheduling of resources and synchronization of transmitting frames. The average performance of the subscriber is calculated from its performance parameters when accessing to every single channel.

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Considering the different locations of users in the room, the bandwidth allocated by users is affected by the distance between the user’s location and AP, and the average request rate of single scheduling time in a single scheduling cycle.

We propose the concept of the weight of the user, which is the priority of each user. When the average request rate of users is the same, the farther the distance between users and AP, the lower the priority. At the same distance, the lower the average request rate, the higher the priority. It will take care of users with poor channel environment.

Since the influence factor is the average request rate of the user and the distance from the user’s location to the AP, we define the influence weight of the user’s average request rate as the mapping of the user’s average request rate to the (0,1) interval. If we set \( p \), the influence weight of the distance from the user’s location to the AP is \( 1-p \). We convert the two influence factors into the priority of users through the mapping of the utility function and the superposition of influence weights. Finally, we allocate resources through a joint allocation strategy.

Based on the above, we propose a new utility function, normalize the influence factor distance and user request rate to each user’s priority by using the neural network S-type
function built-in MATLAB:

\[ f(t) = \frac{1}{e^{-t} + 1} \]  

(2)

**FIGURE 2. Partial value of utility function.**

Fig. 2 shows the values of some utility functions. It can be seen that the values of this utility function in the interval \([-5, 5]\) are continuous in the interval \((0, 1)\).

**C. OPTIMAL SOLUTION OF SINGLE SYSTEM RESOURCE MANAGEMENT ALGORITHM**

We use a distributed joint resource management architecture, that is, resource allocation is performed independently in each wireless resource management entity. Only under certain conditions, each independent radio resource management entity exchanges information with each other. Therefore, before the joint system resource management algorithm flow, we need to design an optimal algorithm for the wireless resource management entity to ensure the fairness of resource allocation in the subsystem. Fig. 3 shows the flow chart of the single system resource management algorithm design:

**FIGURE 3. Single system resource management algorithm.**

After initializing the system, the user data (including the instantaneous request rate and the location information) is input into the system to judge whether to complete a scheduling cycle. If it is, it will interact with other wireless resource management entities. If not, it will calculate the average time between the current scheduling time and the instantaneous request rate of the previous user in the scheduling period. We assume that there are 10 schedule time in the scheduling period of the heterogeneous network model.

At the same time, the user average request rate and user location information are converted to user priority using formula 3:

\[ w = p \cdot \frac{1}{e^{-r} + 1} + (1 - p) \cdot \frac{1}{e^{-d} + 1} \]  

(3)

where, \( p \) is the influence weight of the request rate, \( r \) is the average request rate of the user, and \( d \) is the distance between the user and AP.

Due to the need for normalization, the formula 3) only represents the general expression. After getting the user priority, we use two resource management algorithms to allocate resources. After getting the results, we calculate the fairness index of the two resource management algorithms to determine the optimal resource management strategy.

\[ F = \left( \sum_{i} r_{get,i}^2 \right) / N \cdot \sum_{i} \left( \frac{r_{req,i}}{r_{get,i}} \right)^2 \]  

(4)

where \( N \) is the number of users, \( r_{req,i} \) is the average request rate of the user, \( r_{get,i} \) is the bandwidth allocated by users. The performance of the two resource management strategies is obtained by formula 4. After we compared and selected the optimal resource management algorithm, study the resource management algorithm of the joint system by using the selected algorithm.

**D. ALGORITHM FLOW OF JOINT SYSTEM RESOURCE MANAGEMENT**

Through the discussion of the optimal solution of a single system resource management algorithm and the fairness index after simulation, it can be concluded that the optimal algorithm of a single system resource management strategy is a reduced dynamic range resource allocation strategy with the weight attached. We use this algorithm to design the joint system resource management algorithm flow.

We initialize the system firstly, and then input user data (including the instantaneous request rate and the location information) into the VLC system and WiFi system respectively. After that, the two systems judge whether to complete a scheduling cycle (the system has already calculated the average request rate and the user priority). If so, they will calculate the sum of system capacity and user average request rate, and conduct information interaction to determine the saturation of their system, and decide whether to compensate users (user compensation includes reserving or placing new users on the user information that will be disconnected in the system will be deleted. If not, enter the resource allocation algorithm with weight to reduce the dynamic range. Fig. 4 is the flow chart of the resource management algorithm in the joint system:
IV. HANDOVER DECISION ALGORITHM

We designed a typical architecture of hybrid VLC-WiFi networks and focused on the handover decision issue. The use of fuzzy logic is not only to deal with imprecise input decision criteria but also to combine and evaluate multiple criteria simultaneously. Employ bandwidth, delay, jitter, and BER as fuzzy logic input parameters which are adequate for decision making of vertical handover (VHO).

A suitable handover mechanism can optimize system performance and enable more cooperation between different networks. The users can give priority to choose VLC as a serving network to make full use of the high data rate of VLC and reduce the traffic load of the WiFi network. In order to mitigate the influence of handover, propose a fuzzy logic (FL) based dynamic handover scheme. With this method, MTs can select a more suitable network based on the quality of service (QoS) when there are multiple networks available.

There are four steps in the fuzzy logic bases handover algorithm: fuzzification, rule evaluation, defuzzification, and decision making. In the decision method based on fuzzy logic, calculate the score of every candidate network by the QoS attributes, given by (5):

$$A = \arg \max_{i \in N} \sum_{j=1}^{M} w_j P_{ij}$$  \hspace{1cm} (5)

where $A$ is the best QoS cell, $N$ is the number of networks, $M$ is the number of QoS attributes, $P_{ij}$ represents the No. $j$ attribute of the No. $i$ network, $w_j$ is the priority of the parameter $P_{ij}$.

We use the fuzzy Logic Toolbox of MATLAB to simulate the handover mechanism. The QoS attributes contain four types of variables, namely, bandwidth, delay, jitter, and BER, which are combined to determine the score of the candidate networks. We represent each QoS attribute by three fuzzy sets: low, medium, and high, and apply he triangular function as the membership function. From Fig.5, network score value signifies that WiFi is the best network in $0 \sim 2s$ and $9 \sim 10s$, VLC$_1$ is better in $2 \sim 6s$, and VLC$_2$ is selected in $6 \sim 9s$, respectively.

From the simulation results, we can see that the user will always choose the network with the best QoS and the handover scheme works well in the hybrid VLC-WiFi network. By our scheme, the users are able to switch successfully at the edge of any network and will be served by the best candidate network when moving between different networks. VLC channels supplement WiFi communications well.

V. RESULTS AND DISCUSSION

A. SINGLE SYSTEM MODEL SIMULATION AND RESULT ANALYSIS

The single system resource management model is simulated based on MATLAB. The simulation needs to follow the basic assumptions of the heterogeneous network model. We select
the WiFi system as the single system resource management algorithm object:

1) The equivalent bandwidth of each resource block is 3 kHz;
2) The number of resource blocks is 25;
3) The number of initial users in the WiFi area is 10 and that in the VLC area is 0;
4) The signal to noise ratio (SNR) of AP transmitting signal is 10dB;
5) The requested rate of randomly generated users in the interval [1,3], unit: Mbps;
6) In the interval [10, 50], the distance between user location and AP is randomly generated, the order of magnitude is 10, and the unit is m.

The simulation results of the two bandwidth allocation distribution algorithms is shown in Fig. 6 and Fig. 7.

We propose the optimal solution of the single system resource management algorithm to use the performance of the equity index analysis algorithm, and obtain the line graph of the equity index of WBA and WWA through simulation:

From Fig.8, we can see that, with the increase of the number of users in the system, the fairness index of WBA decreases gradually. And the fairness index of WWA is close to 1. Therefore, for a single system, WWA is a reduced dynamic range algorithm with weight, which is the optimal resource management scheduling strategy.

B. JOINT SYSTEM MODEL SIMULATION AND RESULT ANALYSIS

The resource management algorithm of the joint system is simulated based on MATLAB, and the optimal resource management scheduling strategy is obtained through a single system model simulation. In addition to the basic assumptions, additional simulation environments set up as follows:

1) The equivalent bandwidth of each resource block is 3 kHz;
2) There are 25 resource blocks in each system;
3) The number of initial users in the area a is 5 in a single WiFi area, 10 in area B, and 10 in VLC;
4) The signal-to-noise ratio of the transmitted signal is 10dB;
5) At the end of each scheduling cycle, the change range of the number of people in the two networks is [-5,5];
6) The rate of randomly generated user requests in the interval [1,3], in Mbps;
7) In the interval [10, 50], it generates the distance between WiFi user and AP randomly in area a, the unit is m, and the order of magnitude is 10. The distance between WiFi user location and WiFi hotspot in area B is 20m, and the distance between VLC user location and VLC hotspot is 10m;
8) The simulation assumes that the threshold of decision-making between the two systems after information interaction is the average user rate and whether it reaches 60% of the system resources.

We compare the rate allocation and run the program to get the joint resource management bandwidth allocation graph.

**FIGURE 9. Bandwidth allocation for joint system resource management.**

The result of Fig.9 is the histogram obtained after 20 scheduling cycles. We can see that the number of users in the two systems are different, and the traffic loads are also different in the system. The system allocate more bandwidth for VLC users with lower request rate to take care of users with the poor channel.

At the same time, taking the number of scheduling cycles as independent variables, the fairness index of the joint system is observed:

Fig.10 shows that, with the increase of the scheduling period, the fairness index of the joint system is basically stable between the interval (0.9, 1).

Furthermore, interference is an important issue in VLC system. We consider the intercell interference among the VLC APs. We assume the desired cell is close to a receiver and the interfering cells are much farther away. The PD can hardly receive LOS signals from the two APs at the same time due to the narrow field-of-view (FOV). When a receiver is far from an interfering cell, the received interference is attenuated accordingly. From [36], we can conclude that the NLOS interference remains the same even if the position of a user changes vertically. The signal-to-interference-plus-noise ratio (SINR) is only a function of received signal power.

The inter-user interference is also considered. From [37], the received SINR of user $i$ can be given as

$$\gamma_i = \frac{\eta^2 P_i h_{0i}}{\sum_{j=1,j\neq i}^{N} \eta^2 P_j h_{ji}^2 + \sigma^2_n}$$

where $P_i$ is the transmitted power of AP $i$, $\sigma^2_i = \sigma_s^2 + \sigma_t^2$, i.e., the shot noise $\sigma_s^2$ and the thermal noise $\sigma_t^2$ [20], $\eta$ denotes the optical/electronic conversion efficiency.

**VI. CONCLUSION**

In this paper, we propose the joint resource allocation algorithm for VLC and WiFi heterogeneous network, select the optimal single system resource management algorithm through the fairness index, and design the joint resource management algorithm. We analyze the key technologies of the VLC-WiFi heterogeneous network, establish the hybrid network model by comparing with the traditional heterogeneous network resource management model, and propose a novel joint resource scheduling algorithm, which maximizing the fairness of the resources allocated to the terminals and improving the utilization of the resources. We also simulate the optimized resource management scheme, observe the network parameters and states, and analyze the results. Finally, we verify the effectiveness of the scheme. The simulation results show that the proposed resource management algorithm has better adaptability to the hybrid VLC and WiFi networks, and can realize a fairer experience.

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