# Optimization of Resource Allocation Algorithms in Heterogeneous Networks of Optical Communication and WiFi

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***Abstract*—A delay-based proportional fairness algorithm for VLC/WiFi networks improves user fairness and throughput while ensuring data rate. Simulation analysis shows that this scheme effectively improves the fairness and throughput of users in scheduling.**

***Keywords—Heterogeneous network, Visible light communication (VLC), Resource allocation.***

## I. INTRODUCTION

In order to achieve efficient communication, communication experts have designed a novel green information technology called Visible Light Communication (VLC), which makes use of the fast response characteristics of light-emitting diode (LED) to realize wireless high-speed data transmission [1, 2]. With the advantages of a rich spectrum, high frequency, and fast transmission rate, VLC can complement the shortcomings caused by the severe shortage of traditional wireless spectrum resources [3]. However, due to the low penetration depth of visible light in non-transparent media, VLC is still limited in practical applications, such as excessive influence by the external environment and inferior coverage of a single VLC access point compared with WiFi.

Given these limitations, a VLC/WiFi heterogeneous network is proposed, combining the advantages of VLC and WiFi communication. In contrast to traditional network structures, a heterogeneous wireless network contains overlapping parts [4]. Researching resource allocation algorithms for heterogeneous wireless networks requires a reasonable allocation of network resources and system power. Therefore, resource allocation is critical in VLC/WiFi heterogeneous networks.

In general, metrics to measure the quality of a scheduling algorithm include the following aspects: delay, throughput, fairness, and resource utilization. The maximum carrier-to-interference ratio algorithm is one of the methods that can maximize channel utilization. The proposed algorithm can achieve the maximum data transmission rate and the minimum bit error rate by dynamically adjusting the modulation and coding modes [5]. However, although the maximum carrier-to-interference ratio algorithm can achieve the optimal throughput, users with good channel conditions will always occupy the resources, resulting in unfair scheduling among users [6]. A proportional fairness algorithm for resource allocation aims to allow each player access to the same proportion of resources. Based on the instantaneous rate of data transmission and channel quality, the strategy makes users obtain resources as much as possible to increase the gain of users, which is long-term fairness. For a single user, especially some users with an upper access delay limit, its short-term fairness cannot be guaranteed; that is, it cannot obtain efficient resource allocation and high-quality service within the range of its recommended access time card [7, 8]. Therefore, this work provides an improved proportional fair scheduling strategy and intends to compare the improved PF algorithm, the maximum load-to-interference ratio algorithm, and the traditional proportional fairness algorithm.

National Natural Science Foundation of China (No. 61705260) and the 211 5 Talent Development Program of China Agricultural University.

## II. ALGORITHM OPTIMIZATION

### *A. Traditional Proportional Fairness Scheduling Algorithm*

The Proportional Fair (PF) algorithm is a popular method for managing resources in wireless networks, including heterogeneous networks. Its primary objective is to enhance the system's fairness by allocating resources to users proportionally based on their request rates while also considering the scheduling situation.

At its core, the PF algorithm calculates a utility function for each user in the system, which measures the ratio of the user's instantaneous data rate to its average data rate over time. The user with the highest utility function is then scheduled to receive resources next. This approach ensures that users with a higher request rate are prioritized while also considering the past data rates to balance fairness in resource allocation.

However, the PF algorithm also introduces the concept of user resource priority, which is positively correlated with the request rate. This priority value is used to calculate the utility function of a user. The higher the priority value, the higher the user's utility function and, consequently, the higher the chance of being scheduled next.

The PF algorithm reduces the priority value of a user each time it is scheduled to prevent situations in which a user is scheduled excessively frequently at the expense of other users. It thus ensures that other users have a fair chance to utilize network resources and avoids users with lower request rates from starving the system. Hence, the user priority is calculated as follows:

$$P_i(t) = \arg\max \frac{R_i(t)}{\overline{R}_i(t)} \tag{1}$$

where $P_i(t)$ is the priority of user i at time t, $R_i(t)$ is the instantaneous transmission rate of the current request and $\overline{R}_i(t)$ is the average request rate. Once the user scheduling is complete, the average transmission rate is changed by a low-pass filter.

$$\overline{R_i(t+1)} = \begin{cases} (1-\frac{1}{t_c})\overline{R_i(t+1)} + \frac{1}{t_c}R_i(t) \\ \text{, The user was scheduled at time } t. \\ (1-\frac{1}{t_c})\overline{R_i(t+1)} \\ \text{, The user was not scheduled at time } t. \end{cases} \quad (2)$$

Where $t_c$ is the length of each time period.

*B. The improved proportional fair scheduling algorithm*

It is vital to consider the impact of user latency. Users often need better network performance in areas where the channel quality could be better. To address these issues, guarantee the fulfillment of transmission data rate requirements, ensure fairness, and enhance overall throughput, a delay-based proportional fair scheduling algorithm is proposed in this paper. The algorithm incorporates the following parameters and steps.

$$P_i(t) = \begin{cases} \frac{K_i(t)R_i(t)}{\overline{R_i(t)}} & , a_i(t) > 0 \\ 0 & , a_i(t) = 0 \end{cases} \quad (3)$$

where $P_i(t)$ represents the priority of user i at time t, $R_i(t)$ represents the instantaneous transmission rate of the current request, $\overline{R_i}(t)$ represents the average request rate, and $K_i(t)$ represents the time delay weight. As indicated by the previously mentioned equation, when a user with an empty cache seeks resources, they cannot access them. However, for a user with a non-empty cache, after incorporating the time delay weight, the user with a greater remaining capacity will have a higher priority due to a longer delay. This mechanism helps ensure that users with infinite priority do not monopolize resources for an extended duration and promotes fair and continuous scheduling. The expressions for $\overline{R_i(t)}$ are as follows:

$$\overline{R_i(t+1)} = (1-\frac{1}{t_c})\overline{R_i(t+1)} + I_i(t) \times \frac{1}{t_c}R_i(t) \quad (3)$$

The variable $I_i(t)$ denotes the feasibility of scheduling the user pair i at time t, represented as a binary value of 0 or 1.the expression for $a_i(t)$ can be described as follows:

$$a_i(t) = \begin{cases} 0 & , t = 0 \\ a_i(t-1) - R_i(t-1) + C_i(t) & , t > 0 \end{cases} \quad (4)$$

Consider the case where $C_i(t)$ represents the size of data at the moment of arrival of the ith user at time t, assuming that the data arrives in the cache before each scheduling moment.

The expression for the time delay compensation factor $K_i(t)$ is expressed as follows:

$$K_i(t) = e^{(\frac{W_i(t)}{M_i})^{\mu}} \quad (5)$$

The equation consists of two parts: the first term represents the waiting time $W_i(t)$ that user i spends in the queue, while the second term represents the timeout period $M_i$ for user i to be processed, where $\mu$ is a constant greater than 1. The larger the value of $\mu$, the more concave the curve becomes, leading to a slower increase in the curve and longer processing time.

After each scheduling round, users are ranked based on their latency to determine whether their data rates are being met. Thus, compensation factors are allocated to increase users' resource priorities with significant latency in subsequent scheduling rounds.

Figure 1 depicts a heterogeneous network in which the coverage of VLC is limited in practical application scenarios and has certain constraints. In this context, we assume that there is an area A where users are not covered by VLC and can only rely on WiFi for communication, while area B allows users to utilize both VLC and WiFi resources.

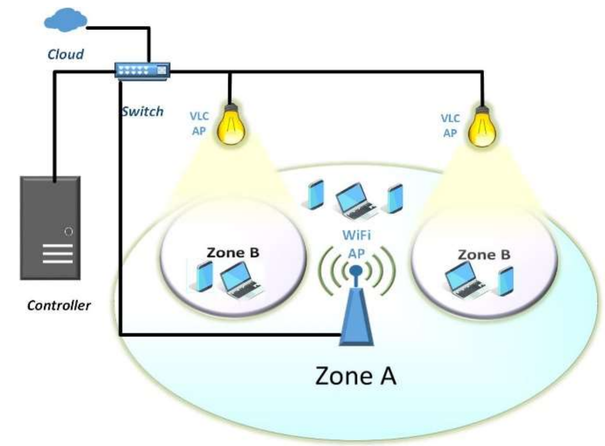


Fig. 1. Heterogeneous network system model

In heterogeneous networks, ensuring fairness through the joint allocation of resources is crucial. In region A, where users can only use WiFi resources, their priority is described by formula $P_i^{A(WIFI)}(t)$ with the calculation shown in (3). In region B, as the number of VLC users increases, the available resources decrease, however the priority of WiFi resources increases. In order to effectively address this problem, adjustments are made to the priority of VLC and WiFi resources in area B.

$$\alpha_i = \frac{1}{1+e^{-\frac{i+\frac{N}{2}}{N^{\lambda}}}} \quad (6)$$

$$\beta_i = \frac{1}{1+e^{\frac{i-\frac{N}{2}}{N^{\lambda}}}} \quad (7)$$

The equation can be revised as follows for better clarity:

where N is the total number of users in region B, i is the number of users assigned to users after sorting by descending order of priority, and $\lambda$ is a parameter that is dynamically adjusted based on the actual number of VLC and WiFi access points in the system.

In this way, the top-ranked users have priority access to VLC resources. As the number of users increases, limited by the total amount of resources, some users will use WiFi resources for communication.

The resource matching constants $m_{\mathrm{i}}^{\mathrm{VLC}}$ and $m_{\mathrm{i}}^{\mathrm{WIFI}}$ are presented. When $\alpha_i > \beta_i$, users prioritize VLC resources and users prioritize $\mathrm{P}_i^{B(VLC)}(t)$ ,when $m_{\mathrm{i}}^{\mathrm{VLC}}$ =1 and $m_{\mathrm{i}}^{\mathrm{WIFI}}$ =0. On the other hand, users prioritize WiFi resources. Their priority is their priority order is $\mathrm{P}_i^{B(WIFI)}(t)$ . $m_{\mathrm{i}}^{\mathrm{VLC}}$ =0， $m_{\mathrm{i}}^{\mathrm{WIFI}}$ =1.

Therefore, the priority of the user in area B is:

$$\begin{cases} \mathrm{P}_i^{B(VLC)}(t) = \mathrm{P}_{\mathrm{i}}(t) \times \alpha_i \\ \mathrm{P}_i^{B(WIFI)}(t) = \mathrm{P}_{\mathrm{i}}(t) \times \beta_i \end{cases} \tag{8}$$

Users using VLC can allocate resources directly based on priority, while WiFi users in Region B will need to be weighted by users in Region A.

$$\mu(t) = S^{A(WIFI)}(t) \cdot e^{k\frac{W_{\mathrm{A(WIFI)}}(t)}{W_{\mathrm{B(WIFI)}}(t)}} / [S^{A(WIFI)}(t) + S^{B(WIFI)}(t)] \tag{9}$$

Where $S^{A(WIFI)}(t)$ and $S^{B(WIFI)}(t)$ are the total number of WiFi users in Area A and Area B respectively, and k is a parameter that is dynamically adjusted based on the length of time WiFi users in Region A and Region B are waiting in the queue. Therefore, the weighted WiFi priority is:

$$\begin{cases} \mathrm{P}_i^{A(WIFI)'}(t) = P_i^{A(WIFI)}(t) \times (1-\mu(t)) + \overline{P}_i^{B(WIFI)}(t) \times \mu(t) \\ P_i^{B(WIFI)'}(t) = P_i^{B(WIFI)}(t) \times \mu(t) + \overline{P}_i^{A(WIFI)}(t) \times (1-\mu(t)) \end{cases} \tag{10}$$

Where $\overline{\mathrm{P}}_i^{B(WIFI)}$ and $\overline{\mathrm{P}}_i^{A(WIFI)}$ are the average of the user priorities in their respective zones. The system allocates WiFi resources on a priority-weighted basis.

The improved pf algorithm is processed as follows：

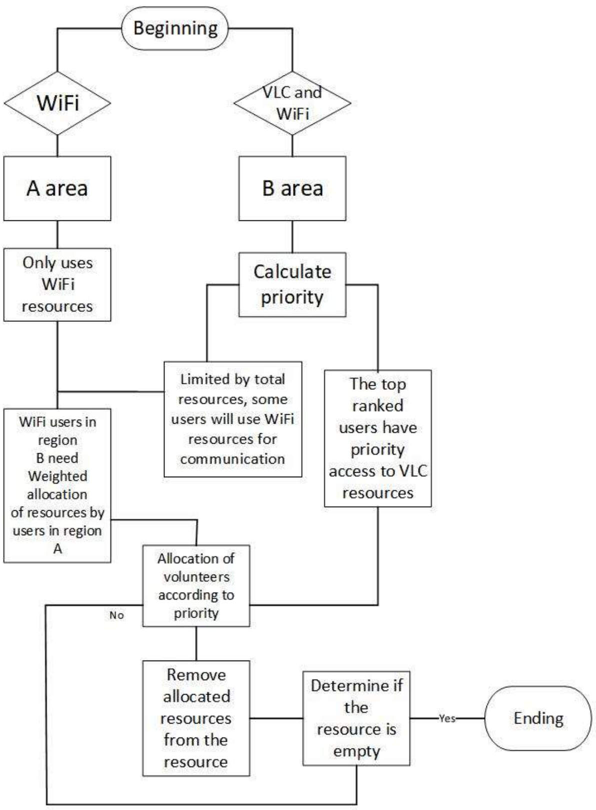


Fig 2 Flow of the resource allocation algorithm

## III. System simulation and analysis

### *A. Simulation environment configuration*

Table 1 Simulation data

| Parameters | Numerical values |
|---|---|
| Simulation time/s | 100 |
| Scheduling time/ms | 5 |
| Separate WiFi role (Users in zone A) | 20 |
| Vlc works with WiFi(Users in zone B) | 50 |
| Vlc Access Points | 20 |
| WiFi Access Point in Zone A | 30 |
| WiFi Access Point in Zone B | 15 |
| System bandwidths/Mbps | 8 |
| User request rate/Mbps | 1~3 |

Regarding the simulation comparison, the heterogeneous network model was simulated in MATLAB using the above analysis results. The simulation mainly focused on the fairness of user utilization for the improved PF algorithm, the proportional fair scheduling algorithm (PF), and the maximum load-to-power ratio algorithm, as well as throughput, utility value, and user data rate requirements. In the simulation scenario, it was assumed that users were randomly distributed in the room. Due to the limited coverage range of VLC, it was assumed that the area where users were not covered by VLC and could only communicate using WiFi was A. The area where users could simultaneously use VLC and WiFi resources was B.

### *B. Simulation result analysis*

Figure 3 compares the changes in system fairness among the three algorithms as the scheduling increases. Overall, the fairness of the three algorithms increases with the scheduling, but the improved PF algorithm gradually increases and stabilizes at 0.99s. In contrast, the traditional PF algorithm cannot solve the problem of low channel quality for users, resulting in a fairness index of 0.94s. The Max C/I algorithm does not consider the channel quality of users, resulting in lower overall fairness but higher throughput; hence, the fairness index has a low value.

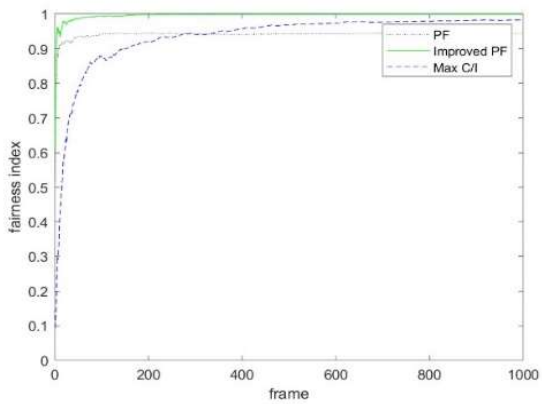


Fig. 3. System simulation fairness index

By integrating the channel state of all users and modifying the parameters, the improved PF algorithm in Fig.4 significantly increased the system throughput to 3.5 Gbps, ultimately benefiting the clients.

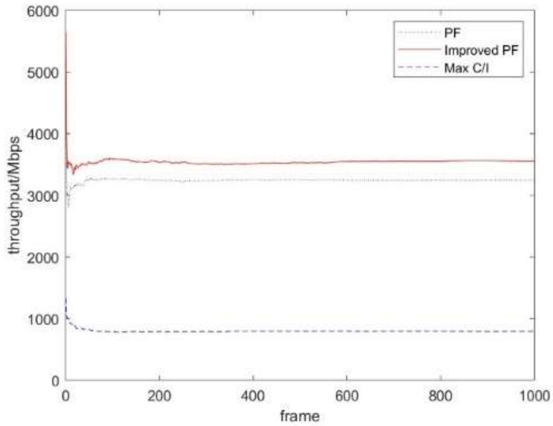


Fig. 4. System simulation throughput

Figure 5 illustrates that with increasing scheduling, the utility value of the improved PF algorithm stabilizes at 0.965. In contrast, the classical PF method cannot solve the problem of users with low channel quality, resulting in these users needing help to obtain resource allocation in the long term.

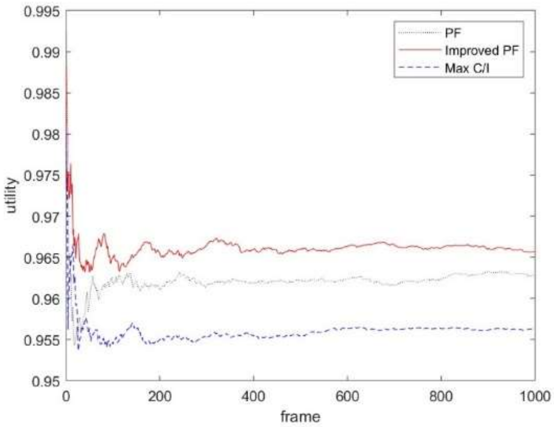


Fig. 5. System simulation utility

The average delay for each algorithm is illustrated in Figure 6. The improved PF algorithm has the best delay performance, according to the results shown in the figure, with an average value of around 4ms.

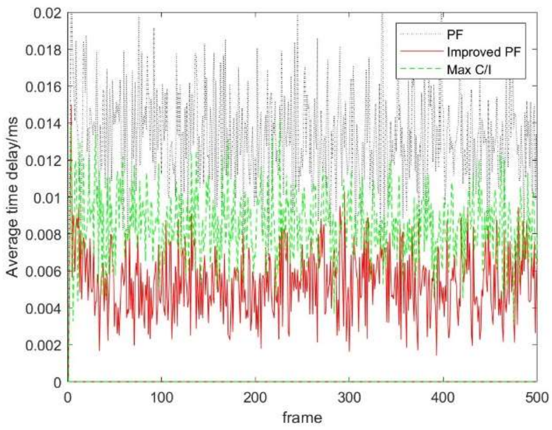


Fig. 6. System simulation Average time delay/ms

The Min-Max fairness index can be used to evaluate the fairness of queue scheduling mechanisms. The smaller the Min-Max fairness index, the more significant the difference between the lowest and highest throughput, indicating decreased performance in allocating resources to users. As shown in Figure 7, for frames with the same number of frames, the improved PF algorithm has a significantly better Min-Max fairness index than the traditional PF algorithm.

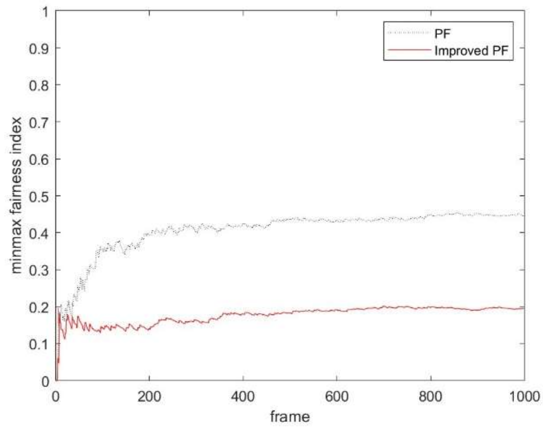


Fig. 7. System simulation min-max fairness index

## IV. CONCLUSION

This work suggests an improved PF algorithm for allocating resources between VLC and WiFi networks. We used Matlab simulations to evaluate the algorithm's performance and measured various indicators, including throughput, resource utility values, and fairness index graphs. The results show that the improved algorithm can achieve satisfactory simulation results in all indicators. Therefore, the proposed algorithm enhances the fairness and throughput of heterogeneous networks and ensures a better user experience, indicating that heterogeneous networks have broader application prospects.

## ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (No. 61705260) and the 2115 Talent Development Program of China Agricultural University.

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