A Two-Level Adaptive Resource Allocation Algorithm for Quality of Service Guarantee in Home WiFi Networks

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Abstract. Aiming at the problem that the service quality of audio and video, large file transmission and other services is difficult to guarantee in the home Wireless Fidelity (WiFi) network, this paper proposes a two-level adaptive resource allocation algorithm for quality of service guarantee (TRAQ), which can effectively avoid the starvation of large file transmission, to improve the success rate of audio and video service establishment and the fairness of multiple large file transmissions. Firstly, the quality-of-service guarantee problem of audio and video, large file transmission is modeled as the resource allocation problem in the scheduling period, with the goal of minimizing the Gini coefficient of multiple large file transmission rates and the constraint of ensuring the average transmission rate of all large files and the call loss rate of audio and video. Then, the arrival and service process of audio and video services is modeled as a M/M/m/m queuing model, and the first-level resource allocation ratio between the audio and video services and the large files services is obtained. Secondly, the second-level resource allocation ratio minimizing the Gini coefficient of large file transmission services is derived. Finally, the simulation results show that the proposed TRAQ not only balances the service requirements between the two types of services, but also achieves a certain transmission fairness within the large file transmission services.

Keywords: Home WiFi Network · TRAQ · Call Loss Rate · Services Starved

1 Introduction

In recent years, Wireless Local Area Network (WLAN) has penetrated into all aspects of life. Institute of Electrical and Electronics Engineers (IEEE) 802.11 WLAN is one of the most deployed wireless networks, and it has developed to IEEE 802.11 ax [2]. In the home network, this wireless network is also the most common one. In the current home WiFi network, there are various of network

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services, such as video, games, file transfer, etc. They can be divided into two categories according to their characteristics, namely audio and video services and large file transfer services. Among them, the characteristics of audio and video services are that the data transmission bandwidth needs to be guaranteed within a certain period of time. As for the large file transmission services, although they can tolerate the transmission for a period of time, they still need to ensure the transmission rates. Although 802.11 has proposed a scheduling access transmission mode, which characterized by the overall planning of the central control node. But it does not consider the fact that large file transfer services' transmission drops sharply and starves to death as the equipment becomes denser, and the traffic gradually increases.

The current research and related works on scheduling and transmission in 802.11 are as follows. Reference [3] proposed a utility optimization algorithm based on resource migration for the lack of efficient resource allocation methods for scheduling and random hybrid access with IEEE 802.11ax in a single-cell environment. Reference [4–8] analyzed the throughput and other performance of IEEE 802.11 wireless network scenarios in random access mode. Reference [9] designed an enhanced wait-for-select access method based on the access point (AP) scheduling-based framework of the IEEE 802.11ax draft. In reference [10], aiming at the related problems of uplink scheduling in IEEE 802.11ax, it optimized the research method in traditional cellular network and integrated it with the resource allocation of 802.11ax. In order to maximize the uplink transmission throughput, reference [11] combined the uplink transmission demand reporting and the uplink scheduling data transmission, and proposed a related maximization algorithm. References [12–14] studied the related technologies of hybrid access with coexistence of scheduled access and random access in the case of IEEE 802.11ax and 5G.

At present, there are still some problems related to scheduling access in IEEE 802.11ax. The problems to be solved are: 1. Various types of services have different characteristics, and there is no distinction between access services. Therefore, the current resource allocation plan is not targeted for different types of services. 2. There is also an unfair problem between multiple large file transfers. Because different services have different arrival times, varied sizes of files to be transferred, and relative priorities. So the bandwidth allocation between different file transfers is also a very important part.

Aiming at the above problems, this paper proposes a two-level adaptive resource allocation algorithm for quality of service guarantee. This algorithm effectively solves the problem that the completion time of large file transmission services cannot be guaranteed with the increase of audio and video services. This paper's core contributions are as follows: 1. The service guarantee problem of each service in the home WiFi network is modeled as the resource allocation problem in the scheduling period in IEEE 802.11ax. 2. A two-level resource allocation algorithm is proposed. The first level optimizes the ratio between audio and video services and large file transmission services, and the second level makes the allocation between large file services fairer. 3. The two-level resource allo-

cation algorithm is simulated and verified. The results show that the first-level resource allocation algorithm can effectively prevent large file transmission services from being starved to death, and can ensure the access congestion probability of audio and video services. And the second-level resource allocation algorithm has balanced transmission fairness between the various services of large file transmission services.

The structure of the remaining chapters of this paper is arranged as follows. In the second section the composition of the network is first introduced, and the system model of scheduling and transmission under the IEEE 802.11ax architecture is established. In the third Section, a two-level resource allocation algorithm is introduced. Section 4 carries out simulation verification and performance analysis of the proposed two-level resource allocation method. The fifth Section summarizes the full text.

2 System Overview

2.1 Home WiFi Networks

In a wireless home WiFi network, there is often only one router, namely the AP, which is an integral part of the entire network. It is not only responsible for forwarding data, but also needs to download data from the supplier and deliver it to the device according to the needs of the device. Figure 1 shows a basic wireless home WiFi network.

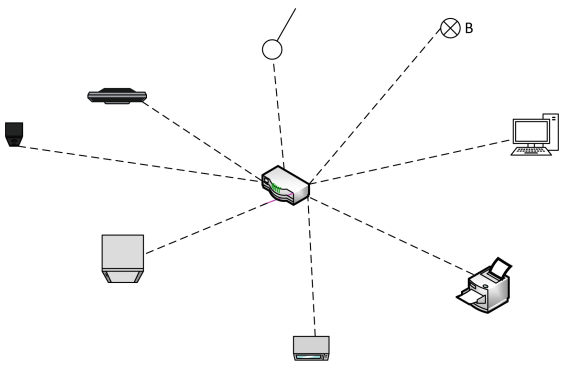

Fig. 1. Home WiFi network

Each wireless devices in the home network sends or receives numerous services through the AP. Currently, according to the characteristics, in the scheduling stage, there are two categories, audio and video services and large file transmission services. Here, the audio and video services is set as a type A service flow, and the large file transmission services is set as a type B service flow. Obviously, type A services need to guarantee their transmission bandwidth. They often have

an apply bandwidth to indicate the size of the application. If the AP agrees, it must meet the apply bandwidth size, and reserve the corresponding bandwidth resources on the time-frequency. The type B services does not have such a rigid requirement, and its priority is lower than the type A service. For example, when the device version is updated, the size of the update file is generally above several hundred MBytes.

At present, there are N_A type A services and N_B type B services in the network with the total amount of resources D, all of which are single-hop services. The network channel is ideal, that is, there is no hidden terminal. There is only one AP in the network, and other nodes are called stations (STAs). The services of these STAs are all uplink services. The apply bandwidth of the type A service flow is W, the duration is μ. The size of the packet that needs to be transmitted for the type B service is S_B. The arrivals of the two types of service flows obey the Poisson distribution, and their mean values are λ_A and λ_B respectively. At the same time, the priority of type A is higher than that of type B, so with the addition of type A service flow, the resources transmitted by type B service flow will be compressed step by step until starved to death.

Factors such as different arrival times, data sizes, and priorities of type B services will also lead to greatly different completion times of type B services. According to this parameters, a Gini coefficient G will be used to represent the fairness between the type B service transmissions.

2.2 Transmission Mode of IEEE 802.11ax

With the development of IEEE 802.11, the related content of the 802.11ax protocol has been increasingly improved in recent years. Its representative innovative technology is that IEEE 802.11ax comprehensively enhances the multi-user medium access control (MAC) at the MAC layer. Figure 2 is the architecture of 802.11ax new technologies.

In WLAN, from the perspective of MAC, the current access methods are two types, including scheduling access and random access. In this paper, the access mode is the scheduling access. The scheduling access is that the central control node coordinates the overall situation, controls the access of all subordinate STAs, and allocates resources to the services that agree to access.

With the arrival of services, the AP performs resource scheduling and allocation according to the collected uplink transmission requirements of STAs. For type A service, if the current network resources are still free enough, it will be allowed to transmit data. As for the type B service, it can only use the remaining idle resources for transmission. Therefore, as the service flow increases gradually, the resources obtained by the type B service under the scheduling access are very scarce, the transmission rate R_B cannot be guaranteed, and the completion time becomes indefinite.

Since network resources are limited, and each type A service requires a certain bandwidth. The network resources are divided, and only m type A services can be accessed at the same time. Therefore, the subsequent access of type A will also be rejected due to insufficient resource allocation. The proportion of type

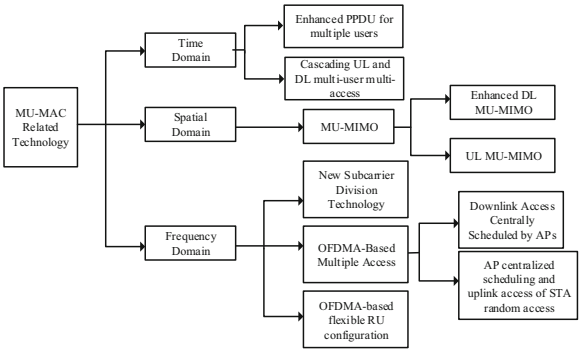

Fig. 2. Architecture of 802.11ax

A service that is denied access within a period of time is the call loss rate, that is, the congestion probability H_A. In this period, the proportion of resources occupied by the type A service is the type A channel utilization rate η.

2.3 Modeling Analysis

According to the analysis in the previous two sections, it is modeled as the resource allocation problem in the scheduling phase in IEEE 802.11ax to analyze and solve it.

The AP notifies each STA of the allocation result of each service in the next period of time in the form of a super frame. With the arrival of type A services, there are n_A services and n_B type B services that need to be scheduled and allocated. According to the priority and the arrival time, resources are allocated to the type A services in sequence. If there is still free time after the allocation, the remaining resources are allocated to the type B services. Figure 3 is a schematic diagram of resource allocation within a super frame in this case.

At this time, the channel utilization rate of type A service can be obtained $\eta = \frac{n_A \times W}{D}, (n_A < m)$, the average transmission rate of type B service $R_B = \frac{(1-\eta) \times D}{n_B}$.

Obviously, when a large number of type A services are accessed, the transmission rate of type B services tends to 0, which leads to the phenomenon of starvation.

The expression of the Gini coefficient G is designed according to its allocation ratio X_i in the remaining resources and the remaining packet size S_i, as well as the priority r_{ij} between each type B according to the priority:

$$G = \frac{\sum_{i,j}^{N} r_{ij} |k_i - k_j|}{\sum_{i,j}^{N} r_{ij} (k_i + k_j)} \tag{1}$$

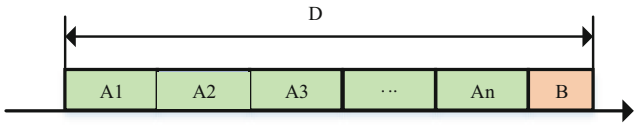

Fig. 3. Resource allocation

The sequence r_{ij} represents the difference in priority of the two types of B services. The priority of type B services is divided into four categories: 0, 1, 2, and 3. The smaller the value, the higher the priority. Its sequence is expressed as the following formula:

$$r_{ij} = \begin{cases} 0, i = j \\ \frac{|priority_i - priority_j|}{3}, i \neq j \end{cases} \tag{2}$$

Among them, k_i represents the time when the ith type B service flow is in this segment of resource Y and the remaining data is sent. Its expression is:

$$k_i = \frac{S_i}{Y \times X_i} \tag{3}$$

The value of Gini coefficient is the goal of algorithm design, G is as low as possible under the condition of ensuring R_B and H_A. As follows, where SET_{max}, SET_{min} are the maximum value of blocking probability and the minimum value of type B transmission rate respectively:

$$\min G = \frac{\sum_{i,j}^{N} r_{ij} \left| k_i - k_j \right|}{\sum_{i,j}^{N} r_{ij} \left(k_i + k_j \right)}, (i = 0, 1, 2 \cdots n_B, j = 0, 1, 2 \cdots n_B) \tag{4}$$

$$s.t. \quad \begin{matrix} H_A \leq \mathrm{SET}_{max} \\ R_B \geq \mathrm{SET}_{min} \end{matrix}. \tag{5}$$

3 Algorithm

3.1 Algorithm Overview

In the second section, we introduced the model of allocating the service under 802.11ax scheduling access. At the same time, it is found that with the gradual increase of type A services, R_B is decreasing, and the phenomenon of starvation occurs.

In order to guarantee R_B, this section proposes a two-level adaptive resource allocation algorithm. In response to the different characteristics and different quality requirements, the first-level algorithm adds the allocation ratio of type A services and type B services in the super frame, effectively solves the starvation problem of type B services. The second-level is to reasonably allocate the total resources of type B according to the parameters such as priority and packet size, so that G is as small as possible. The two-level resource allocation algorithm effectively not only solves the problem of starvation of type B services, but also makes each type B service as fair as possible. It effectively balances the service requirements between type AB services and improves the overall service quality of the network.

3.2 First-Level Algorithm

As can be seen from the above, because the network has the maximum available bandwidth D, the service flow will be scheduled according to the access time. And each accessed service flow will occupy a certain bandwidth W. In terms of the two types of services flow, the occupied size of type A service is determined according to W, while type B services share the remaining idle resources. When the network is busy, it will reject subsequent service flows that want to access. Therefore, the system can be regarded as M/M/m/m queuing system [1], which is a call loss system.

The idea of the first-level algorithm is to change the resource m that provides services for type A and free up space to allocate resources for type B. This algorithm can not only meet the hard transmission requirements of type A services, but also enable type B services to be transmitted as much as possible, to reach a balance. Next, we will analyze the performance of the queuing system without modifying the m value.

Since the network resources only support the access of m type A service flows at most. The state probability p of the current number of type A service services in the network can be calculated. First, the state transition diagram of the M/M/m/m system can be represented as Fig. 4.

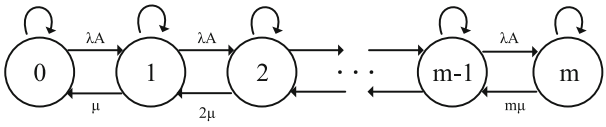

Fig. 4. State transition diagram

We can write the equilibrium equation for this state transition graph.

$$\begin{cases} \lambda_A p_{n-1} = n\mu p_n, n = 0, 1, \cdots, m \\ p_n = p_0 \left(\frac{\lambda_A}{\mu}\right)^n \frac{1}{n!}, n = 0, 1, \cdots, m \end{cases} \tag{6}$$

In this way, the congestion probability H_A is the probability that the subsequent type A access is rejected, that is, the probability that the access type A service flow is equal to m.

$$H_A = p_m = \frac{\frac{(\frac{\lambda_A}{\mu})^m}{m!}}{\sum_{n=0}^{m} \frac{(\frac{\lambda_A}{\mu})^n}{n!}} \tag{7}$$

And using Eq. 7, the busyness of each service time slot, that is, the resource utilization rate η, can be calculated. The formula is:

$$\eta_A = \frac{(1 - H_A) \times \lambda_A}{m \times \mu} \tag{8}$$

Then the bandwidth that can be used by type B is very simple to get from Eq. 9:

$$D_B = (1 - \eta_A) \times m \times W \tag{9}$$

With the increase of λ_A, H_A gradually increases, and R_B decreases greatly. In order to ensure the transmission rate, H_A is not less than the required value, and H_A must be not greater than the required value. Therefore, the first-level algorithm is proposed, which reserves a certain proportion of bandwidth resources to ensure the transmission of type B services, so that the number of resources serving type A services decreases from m to $m*$. New congestion probability H_A* and type B service transmission rate R_B*.

$$H_A* = p_{m*} = \frac{\frac{(\frac{\lambda_A}{\mu})^{m*}}{m*!}}{\sum_{n=0}^{m*} \frac{(\frac{\lambda_A}{\mu})^n}{n!}} \tag{10}$$

$$R_B* = R_{BControl} + R_{BIdle} = \frac{(D - m* \times W) + D_B*}{n_B} \tag{11}$$

From Eq. 11, it is easy to obtain that R_B* will no longer tend to zero. And although H_A* has increased, as long as H_A* is not greater than the limit value, the service quality of the type A service can still be guaranteed. Therefore, the first-level algorithm effectively allocates the proportion of type A and type B services in theory, avoiding the situation that type B services are starved to death.

3.3 Second-Level Algorithm

After coordinating the ratio between the type A services and the type B services to ensure a certain service quality of the two types of services, the average rate of the type B services is guaranteed. However, this method cannot average the completion time of each type B services. If a large file and a small file equally divide the type B services resources during this period, there will be a huge difference in the completion time. It will result in an unfairness between the two type B files.

The second-level resource allocation algorithm effectively solves the unfair problem of each type B business, and its derivation process is as follows.

According to the Gini coefficient given above, in order to make G as small as possible, the allocation ratios of different type B services in the resources are calculated.

To make G as small as possible, first calculate the minimum value in a super frame. First extract the molecular part $k_i - k_j$ in Eq. 1. Analyzing it, we get:

$$|k_i - k_j| = \left| \frac{S_i}{Y \times X_i} - \frac{S_j}{Y \times X_j} \right| \geq 0 \tag{12}$$

After merging it becomes:

$$|S_i \times X_j - S_j \times X_i| \geq 0 \tag{13}$$

Equation 13 can be equal to zero. When it is equal to zero, the denominator and the sequence can be ignored, indicating that the remaining resources are allocated according to the size ratio of the remaining data among the type B service flows. After such allocation, G in the super frame is zero, which achieves a certain degree of fairness.

Then the allocation ratio of type B services in type B resources is as follows:

$$\frac{S_1}{X_1} = \frac{S_2}{X_2} = \cdots = \frac{S_{n_B}}{X_{n_B}} = k \tag{14}$$

When assigned as Eq. 14, the Gini coefficient is equal to:

$$G = \frac{\sum_{i,j}^{N} r_{ij} |k_i - k_j|}{\sum_{i,j}^{N} r_{ij} (k_i + k_j)} = \frac{\sum_{i,j}^{N} r_{ij} |\frac{k}{Y} - \frac{k}{Y}|}{\sum_{i,j}^{N} r_{ij} (k_i + k_j)} = 0 \tag{15}$$

At this time, in each superframe, G reaches the minimum value.

The second-level algorithm achieves the fairness of the completion time of each type B service flow in general by achieving the fairness of different type B services in a single superframe.

Algorithm 1 Two-level Resource Allocation Algorithm.

Input:

Total resources,D
Established type A service,$Est_A = E_{A1}, E_{A2}, \cdots, E_{An}$;
Established type B service, $Est_B = E_{B1}, E_{B2}, \cdots, E_{Bn}$;
New arrival type A service, $New_A = C_{A1}, C_{A2}, \cdots, C_{Am}$;
New arrival type B service,$New_B = C_{B1}, C_{B2}, \cdots, C_{Bm}$;
Resource allocation result, $R = 0, 0, \cdots, 0$;
Type B service size, $Size_B = S_{B1}, S_{B2}, \cdots, S_{Bm+n}$;
Maximum number of type A after guarantee,$m*$;

Output:

Resource allocation result, R;

```
BEGIN
Reserve type B service resources according to m*
FOR each i ∈ [1, m*] DO
    FOR each j ∈ Est_A DO
        IF (i ≤ m*) THEN
            R(i) = Est_Aj
            i++
        ELSE
            BREAK
        ENDIF
    ENDFOR
    New_A is the same as Est_A
ENDFOR
Set B ratio according to size
Size = S_B1 + S_B2 ··· + S_Bm+n
FOR each i ∈ Size_B DO
    R(Bi) = S_Bi ÷ Size × (D − m*)
ENDFOR
return R;
```

3.4 Two-Level Resource Allocation Algorithm

With the arrival of the service in the network, the central control node allocates resources according to the rules of the two-level resource allocation algorithm, and allocates the resources in a superframe to the established and newly established AB type service flows in the service table in an orderly manner. The specific algorithm pseudocode is in this page.

4 Simulation

4.1 Simulation Platform Construction

Simulation tests are carried out in C++ software to verify the relevant performance optimization of the above two-level algorithm. Set the AP as the central control node. If there is a service request, it will directly check the busyness of

the allocated time slot. If it is all busy, it means that the service is rejected. And at the same time, it will allocate resources to the accessed service. After this setting, the effect of simulating service flow scheduling access is achieved.

4.2 Simulation Results

In order to verify the relative performance improvement of the two-level resource allocation algorithm, test verification is carried out under a Basic Service Set (BSS). It is verified that under the same resources, the average rate of the type B service gradually decreases with the access intensity of the type A service λ_A.

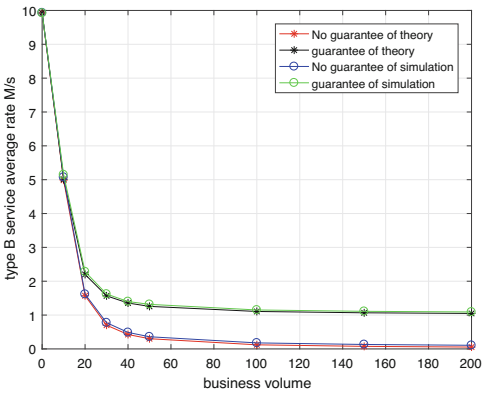

Fig. 5. Whether to guarantee the type B rate change

The abscissa in Fig. 5 is the product of the access intensity of type A services λ_A and the service time. The ordinate is the average transmission rate of type B services. It can be clearly seen from the figure that in theory and simulation, under the circumstance that type B service resources are guaranteed, as the service intensity increases, the rate can be guaranteed, and it will not tend to zero and cause starvation.

After ensuring R_B and H_A, the service quality between the two types of services is guaranteed. The second-level resource allocation algorithm makes the completion time of individual type B services as fair as possible. By changing the access intensity λ_B of type B services, the change of the total G under different λ_B is verified.

As can be seen from Fig. 6, under different type B guaranteed resource values, the difference between the Gini coefficients under the ratio of the remaining size of the package and the uniform distribution is obtained. It can be clearly seen from the curve that this algorithm effectively reduces the Gini coefficient, indicating that the transmission of each type B service is more fair.

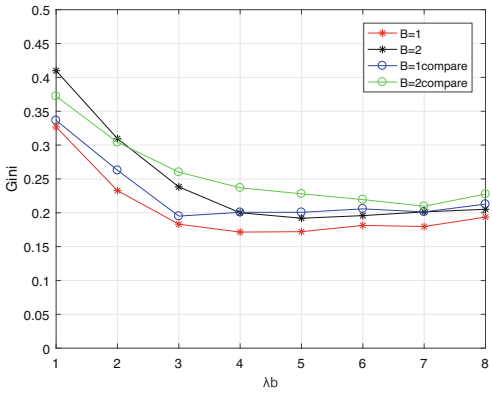

Fig. 6. Variation of Gini coefficient with type B service intensity

With the change of type B guaranteed resources, H_A will change to a certain extent, and according to the requirements, H_A should not be greater than the set value, and H_A under different guaranteed bandwidths is simulated and verified. The result is shown in Fig. 7.

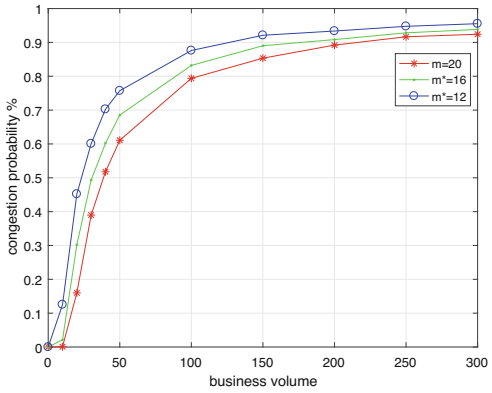

Fig. 7. Variation of congestion probability under different B service guarantees

It can be seen from Fig. 7 that the increase of type B guaranteed resources will indeed increase the congestion probability H_A. Therefore, while ensuring the transmission rate of type B services, the congestion probability of access to type A services should be reduced as much as possible, to achieve a certain balance between the two types of business.

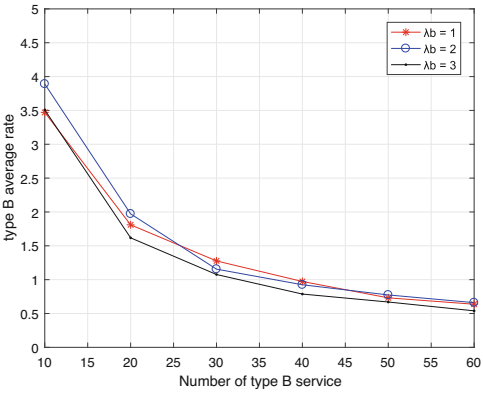

Fig. 8. Variation of type B average rate with type B service intensity

The optimization of the Gini coefficient has been verified and tested, and the overall Gini coefficient is made as small as possible. But the specific performance of different type B services cannot be seen in the Gini coefficient. Next, the transmission completion time of different type B services is simulated.

It can be seen from Fig. 8 that under different λ_B, R_B changes with the increase of the number of type B services. λ_B affects the arrival time of type B services. It can be seen the average rate decreases with the increase of type B services, which is in line with theoretical expectations.

To sum up, TRAQ solves the problem of more and more services in the home WiFi network to a certain extent, and effectively guarantees the different quality of service requirements.

5 Conclusion

This paper focuses on the problem that the quality of services such as audio and video and large file transmission in the home WiFi network is difficult to guarantee. Firstly, the distinctive audio and video services and large file services are divided. Subsequently, the queuing model is used to systematically analyze the performance of two types of services in scenarios. Next, the core ideas of TRAQ are introduced respectively.

Finally, the simulation verifies the performance optimization of the proposed TRAQ. The simulation results show that the first-level ensures the access of the audio and video service. At the same time, the average transmission rate of the large file transmission service will not be lower than the minimum value. The second-level algorithm effectively ensures the fairness between different large file transmission services. To sum up, the proposed TRAQ guarantees the service quality requirements of the business from two aspects, and effectively alleviates the starvation phenomenon of the large file transmission services.

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