A Differentiated WiFi6 Access Resource Optimization Method for Power Internet of Things Services Based on Transmission Time Slot Scheduling

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Abstract. The scale of the power Internet of Things is developing rapidly, and the scale is also expanding. The emergence of WiFi6 technology makes high-quality, large-scale communication coverage and data transmission possible. Using OFDMA technology in WiFi6, this paper proposes a WiFi6 access resource optimization method based on transmission time slot scheduling to differentiate services for power communication scenarios with multiple types of services. Firstly, in order to improve system efficiency, a dynamic access selection model that distinguishes long and short frames is proposed. Then, service priority and time delay are introduced, and a scheduling access optimization model based on transmission time slot and service priority is designed. Finally, this paper designs a resource scheduling algorithm based on heuristic algorithm. The simulation results show that the model and algorithm proposed in this paper can realize resource scheduling with differentiated service QoS and improve the communication quality of the power IoT system.

Keywords: WiFi6 · OFDMA · Access resource optimization · Resource scheduling · Power IoT

1 Introduction

With the advent of the Internet of Everything era, the demand for fast and efficient wireless connections in various business scenarios continues to increase. Especially in the power Internet of Things scenario, multi-services and multi-terminals need to meet high-speed radio resource requirements at the same time, which poses challenges to wireless local area networks. As a new generation wireless LAN protocol, 802.11ax introduces new technologies such as OFDMA and uplink and downlink MU-MIMO for the first time [1]. Under the power Internet of Things, there are various service terminals, and each service terminal has different sensitivity to delay and priority. Therefore, it is necessary to design a reasonable scheduling method to solve the scheduling problem of

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wireless resources for specific service scenarios. OFDMA technology enables multi-user data to be transmitted simultaneously in the same time slot, which improves transmission efficiency and resource utilization. However, there are differences between different service frames, and different service types have different QoS. For a certain type of data frame, a certain level of transmission priority can be assigned to it to identify its relative importance [2]. By analyzing the differences between data frames and service types, the AP exchanges information with the STA, completes the effective scheduling of OFDMA resource blocks and the problem of resource allocation is still a major challenge we face. To sum up, how to use WiFi6 technology to distinguish different service types and data frame characteristics, complete AP's reasonable scheduling and optimization of resources, and ensure communication quality in power service scenarios has become an important research direction. Therefore, in view of the QoS of different services and the differences between data frames, this paper uses the OFDMA technology of WiFi6 to propose a differentiated WiFi6 access resource optimization method for power Internet of Things services based on transmission time slot scheduling. In this paper, a two-level scheduling model is established from the perspectives of resource transmission efficiency and service priority, and finally a clustering and heuristic algorithm are designed to solve the problem, so as to achieve a reasonable and efficient allocation of resources and ensure the transmission quality of power communication with multiple service types and different QoS levels.

2 OFDMA Uplink and Downlink Transmission Mode

As a new generation of WiFi technology, WiFi6 introduces OFDMA to perform uplink and downlink transmission between APs and STAs. When the AP performs OFDMA uplink transmission, there are two access methods. One is uplink random access (UORA). Under this mechanism, the allocation of RU resources is not the responsibility of the AP, but through random access. The feature of this mechanism is that it does not require real-time feedback of cache information on the terminal side, which has two advantages: one is that the AP do not need to know the terminal's cache situation; the other is that it does not need real-time feedback of the cache, which reduces the system overhead.

The other is UONRA. The traditional WiFi protocol adopts the Point Coordination Function (PCF) mechanism. This mechanism AP polls the client and performs uplink and downlink transmission [3]. In UONRA, the AP starts a TXOP time after successful competition. The difference from PCF is that the terminal can implicitly feedback the buffer information to inform the AP of the buffer situation.

The following figure shows the transmission process of UONRA. After the AP successfully competes for channel resources, a TXOP transmission time is opened. The AP first sends a BSRP request to request the BSR information of the terminal; the terminal feeds back the BSR information and reports its own Buffer information to the AP; after the BSR interaction is completed, The AP sends MU-RTS information, which includes the allocation of RU resources. The terminal feeds back that the CTS approves the current resource allocation. After this interaction is completed, the AP sends a TF frame to formally initiate this data transmission, and the frame includes the transmission time, power control information, and the corresponding RU resource allocation. The terminal uploads data in the PPDU. The shaded area represents the padding of the data frame. After the end, the AP feeds back a MU-ACK acknowledgement frame (this frame reduces a lot of overhead required to acknowledge all UL MU transmissions individually, and aggregates all the information needed by the transmitting station instead of sending an independent block ACK to each station) (Fig. 1).

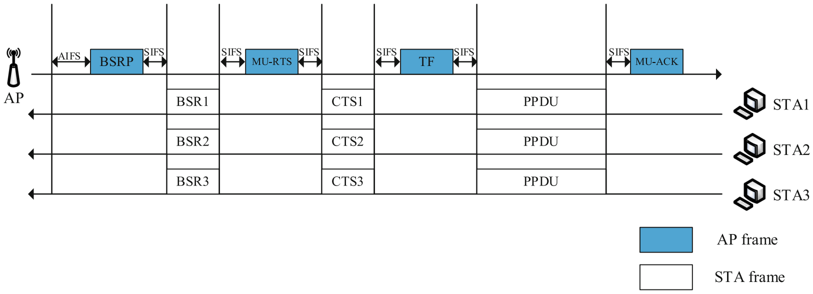

Fig. 1. UONRA transfer process

However, OFDMA technology still faces two major problems, one is synchronization, and the other is overhead [4]. This paper will study the above two problems, aiming to ensure synchronization and reduce overhead as much as possible.

3 Dynamic Access Selection Model for Power Internet of Things Service Frame

This paper mainly focuses on the resource scheduling problem in the PPDU time period. It can be seen from the figure that the use of scheduling to access UONRA requires a round of information exchange between BSR and RTS. If the terminal's access data frame is very short, that is, the data transmission phase is very short. This is undoubtedly a manifestation of inefficiency, as shown in Fig. 2. The UORA mechanism can alleviate the information interaction to a certain extent, and the literature [5] has proved that UORA is not suitable for the transmission of long frames.

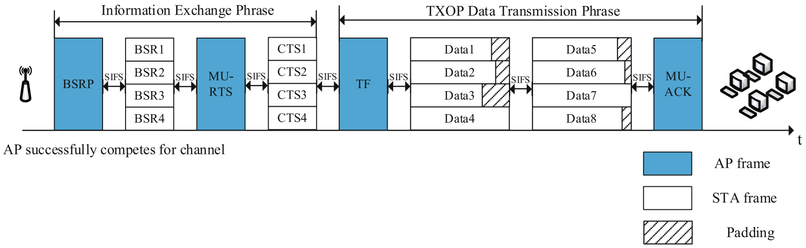

Fig. 2. OFDMA uplink multi-frame transmission mode

Based on the above analysis, this paper designs a dynamic access selection model for different data frames by weighing the balance between data transmission rate and information exchange overhead. Specifically, long frames perform scheduled access, while short frames perform random contention access, thereby improving data transmission efficiency and resource utilization. However, the definition of a long frame and a short frame is rather vague, and a definite value cannot be used to classify whether a data frame is a long frame or a short frame. And in scheduling and resource allocation, in order to improve the resource utilization of data transmission, it is definitely hoped that the blank fields of padding should be as few as possible. 802.11ax stipulates that the AP can adjust the time length of each TXOP according to the situation [6]. Therefore, multiple frames of data can be transmitted in one TXOP duration. In this model, the duration of each frame is set to the duration of the largest data frame in the current group. In order to synchronize the transmission, the rest of the remaining terminals are padding. The goal is to make the size difference of each group of data frames as small as possible to improve resource utilization.

Before information exchange, the AP obtains the buffer information of the terminal, and starts the first-level scheduling algorithm according to the buffer information reported by the terminal, that is, determines the resource allocation of scheduled access and random access. It is allocated according to the ratio of long frames and short frames in the number of requested users. The long and short frame boundaries are then broadcast to the STA, and the STA uses this to select the transmission mode of UORA or UONRA. In this paper, it is assumed that all APs use a 20 MHz bandwidth, but the MCS level of the RU in each frame and the power transmitted by the user on the RU are different. These all need to be determined according to the channel state information CSI of the STA terminal and the like. It will be described in detail in the scheduling optimization model in the next section.

The AP reserves a part of the RU resources for random access. In this paper, the number of reserved resources is reserved in an equal proportion to the total number of terminals. However, the reserved resources cannot be too small or too much. This paper defines the resource reservation variance var_S on the premise of ensuring a certain quantity ratio. The purpose is to make the resource reservation situation meet the scheduling access and random access as much as possible, and the difference between the two types of data is as small as possible. In order to prevent too many or too few random-access resources, constraints are considered in this paper, α_{sch} represents the percentage of the number of resources for scheduling access to the total number of scheduling. Its value is between 0 and 1. The optimization objectives and constraints are as follows:

$$\min var_S, S \in \{I, J\} \tag{1}$$

$$\text{Subject to}\, K_I \geq \alpha_{sch} K \tag{2}$$

where $var_S = \frac{1}{N}[\sum_{s=1}^{S}(Thr_s - \overline{Thr_S})]$, I and J represent the user sets for scheduling access and random access respectively. K is the total RU resources. Thr_s is the maximum completion delay threshold of the terminal service. $\overline{Thr_S} = \sum_{s=1}^{S} {Thr_s}\big/{|S|}$, $|S|$ is the total number of users.

4 Scheduling and Access Optimization Model Based on Transmission Time Slot and Service Priority

After the dynamic selection access scheduling is completed, the AP reserves a part of the resources for random access, and the short frame data is competed for access, which reduces the interaction of BSR frames and improves the efficiency. For scheduling access, this section establishes a scheduling utility function, the goal is to maximize the total utility of the system for each scheduling. In the scheduling access optimization model in this section, the user's delay and priority factors are also considered to optimize the scheduling function.

The modulation and coding scheme (MCS) assigned to the STA on RU depends on its radio condition, namely the signal-to-noise ratio SINR value. In this paper, the SNR is defined by the following formula. Firstly, for the uplink, the SNR of each STA uplink transmission is defined as:

$$SINR_i^k = \frac{Pow_i^k \left|h_i^k\right|^2}{N_0^k + \sum_{z \neq i} Pow_z^k \left|h_z^k\right|^2} \tag{3}$$

h_i^k represents the channel gain of user i's uplink transmission on RU K. Pow_i^k represents the uplink transmitted power of user i on RU K. N_0^k is white noise.

CSI is fed back through BSR frame exchange. In this paper, the following statistical modeling is carried out for the channel between STA's by referring to [7]:

$$h_i^k = G_t G_r L_p A_s A_f \tag{4}$$

where G_t and G_r represent antenna gain of transmitter and receiver respectively, L_p is path loss, A_s and A_f are shadow effect and fast fading effect, which are two random variables.

Each STA terminal feeds back the maximum delay required for the completion of the task to AP through BSR, that is, the cache data must be completed within this delay threshold; otherwise, the packet will be discarded and transmitted in the next frame.

Each terminal also feeds back the task type to the AP via the BSR to reflect the urgency of the task. The emergency level consists of five levels, which are numbered from 1 to 5. A smaller number indicates a higher priority. Referring to [8], this paper considers the following five services to set their priorities and matches the communication requirements of multi-service public network transmission for power IoT communication scenarios (Table 1).

Table 1. Various types of business priorities

The type of business	Priority	p_j
Administrative controls	Medium	3
Video	Low	5
Sensor information collection	Medium-low	4
Voice	High	1
Sensitive data	Medium-high	2

Finally, the formulation of the scheduling algorithm for maximizing the scheduling utility function proposed in this paper is as follows:

$$\max \sum\nolimits_{k\in K} \sum\nolimits_{i\in I} x_i^k U_i^k \tag{5}$$

$$\text{subject to}\, x_i^k \in \{0, 1\}, \forall i \in I, \forall k \in K \tag{6}$$

$$\sum\nolimits_{i\in I} x_i^k \le 1, \forall k \in K \tag{7}$$

$$\alpha_{dat} \sum\nolimits_{k\in K} \sum\nolimits_{i\in I} T_i^k \le d_i, \forall i \in I \tag{8}$$

x_i^k indicates whether the k RU resource block is allocated to user i, $x_i^k = 1$ indicates yes, otherwise 0. To ensure that resources are not wasted, define α_{dat} to represent the percentage of the resources allocated to STA that it sends at most the data it needs to upload. For example, $\alpha_{dat} = 1$ means all messages are sent.

In this paper, the utility function is equal to the signal-to-noise ratio (SNR) transmitted by each STA:

$$U_i^k = SINR_i^k QoS^{P_i} \tag{9}$$

At the same time, the delay threshold and urgency of each service are considered, and the delay threshold and service priority are considered comprehensively while the SNR of the system is maximized. U_i^k represents the utility function of user i when transferring on resource block k. The purpose of formula (5) is to maximize the total utility function of the system. Where $SINR_i^k$ represents the signal-to-noise ratio (SNR) transmitted by user i on resource block k. Qos is a constant with a value between 0 and 1. QoS^{P_i} is used to introduce priority and urgency of services.

The emergency factor $P_i = \alpha_{del}(\frac{Thr_i}{\sum_{i\in I} Thr_i}) + \alpha_{urg}(\frac{Pri_i}{\sum_{i\in I} Pri_i})$ is defined to ensure that users with higher priority can obtain a larger utility function, and QoS is between 0 and 1. If the value is 1, service priority and urgency are not considered. It can be seen that the smaller the P_i value, the larger the U_i^k value, the higher the priority.

5 Algorithm

The dynamic access selection model needs to distinguish between long and short frames. The goal is to minimize the internal differences between long and short frames and maximize the external differences between long and short frames. This paper uses PAM algorithm to classify. PAM algorithm is a clustering algorithm, which belongs to one of the K-Mediod algorithm, K-Mediod algorithm is an improvement of the K-means algorithm, the core idea and K-means algorithm is much the same, However, the biggest difference between the former and the latter lies in that the former calculates the minimum value of clustering from every point to all other points in the cluster to optimize the new cluster center, which optimizes the shortcoming of the K-means algorithm. The interference problem of noise is solved. It sacrifices the clustering time, but improves the accuracy of the algorithm. For the scenario proposed in this paper, the number of terminals within the range of a BSS is mostly dozens, which belongs to a small-scale value and conforms to the scenario proposed in this paper.

The clustering samples in this paper are set as the delay threshold of each terminal, namely THR $= \{Thr_1, Thr_2, \ldots, Thr_n\}$ and data size D $= \{d_1, d_2, \ldots, d_n\}$ First, randomly select k cluster centers in the sample (selected as 2 in this paper), and then calculate the distance to each cluster center for the sample points other than the cluster center. Classify the sample to the sample point closest to the sample center. This realizes the initial clustering; then calculates the minimum value of the sum of distances to all other points for other sample points in each class except the point at the center of the class, and finally uses the minimum point as the new cluster center, which implements a clustering optimization. Comparing the positions of the initial and optimized cluster center points, if the positions are different, perform another cluster optimization; if the positions of the two cluster centers do not change, the final clustering is completed. On this basis, this paper also considers whether it satisfies the constraint condition (2).

For the scheduling access optimization model, this paper proposes a low-complexity heuristic algorithm suitable for the scheduling model in this paper, that is, the maximum signal-to-noise ratio scheduling algorithm based on the heuristic integrated delay and priority. The specific process is to use formulas (3) and (4) to calculate the SINR, then calculate the scheduling function according to (9), and finally assign the currently selected RU to the STA user with the highest scheduling function value. The algorithm is based on iteration, making allocation decisions for all resources in turn.

After the AP obtains the data uploaded by the STA, it will calculate the data transmission rate allocated to each RU according to the MCS, and the MCS level is determined by the channel state information of the terminal. Among them, in the 802.11ax standard, the comparison table of MCS level and transmission rate (Mb/s) under GI = 3.2us is as follows [1] (Table 2):

Table 2. MCS for 20 MHz channel

MCS	MOD.	Coding rate	Bandwidth	MCS	MOD.	Coding rate	BanDwidth
			20 MHz				20 MHz
0	BPSK	1/4	3.6	4	16-QAM	3/4	43.9
0	BPSK	1/2	7.3	5	64-QAM	2/3	58.5
1	QPSK	1/4	7.3	6	64-QAM	3/4	65.8
1	QPSK	1/2	14.6	7	64-QAM	5/6	73.1
2	QPSK	3/4	21.9	8	256-QAM	3/4	87.8
3	16-QAM	1/4	14.6	9	256-QAM	5/6	97.5
3	16-QAM	1/2	29.3	10	1024-QAM	3/4	109.5
4	16-QAM	3/8	21.9	11	1024-QAM	3/8	121.9

In this paper, the AP must update the terminal service data before scheduling each time, and then update the data to be uploaded by the terminal. Finally, the AP selects the optimal user for resource allocation according to the principle of utility function. See Algorithm 1 and Algorithm 2 for data update algorithm and iterative resource allocation algorithm respectively (Table 3 and 4).

Table 3. Data update function

```
Algorithm 1 Data Update Function
Input:
    $d_i, \forall i \epsilon I$ , $Thr_i, \forall i \epsilon I$, $Pri_i, \forall i \epsilon I$, $Qos$ , $G_t G_r A_s A_f$;
Initialize parameters
  if $i \in I$ then
      $d_i \leftarrow d_i - T_i^k$;
      if $d_i == 0$
          $I \leftarrow I - \{i\}$;
      end
  end
```

Table 4. Heuristic resource allocation algorithm

```
Algorithm 2 Heuristic resource allocation algorithm
Input:
    $d_i, \forall i \epsilon I$ , $Thr_i, \forall i \epsilon I$, $Pri_i, \forall i \epsilon I$, $Qos$ , $G_t G_r A_s A_f$;
Initialize parameters
for $k \in K$ do
    if $I \neq \emptyset$ then
        $i^* = \max_{i \in I} U_i^k$;
        Allocate RU k to $i^*$
        Data update function ($i^*$)
    end
end
```

6 Simulation Results

In this paper, the matlab simulation platform is used to simulate the scheduling method mentioned above. Multiple STA terminals are randomly and uniformly deployed under one AP, the coverage of AP is 120 m radius, AP uses 20 MHz bandwidth, 9 RU per time slot, the maximum transmitting power of STA is 24 dBm, and the number of iterations is set to 300. Figure 3 and Fig. 4 respectively show the simulation comparison results of average throughput and average delay between the QoS-differentiated scheduling algorithm proposed in this paper and the SNR based scheduling algorithm (represented as QoS = 0.5 and QoS = 1 respectively in the figure).

Figure 3 is a comparison of the average throughput as a function of the number of terminals. With the increase of the number of terminals, the average throughput of both algorithms shows a downward trend, which means that with the increase of the number of terminals, some stations cannot transmit normally due to conflicts and other reasons. However, the performance of the algorithm for distinguishing QoS proposed in this paper is always better than the algorithm based on the signal-to-noise ratio, and the average throughput is higher than about 10%−15%.

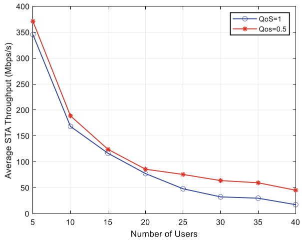

Fig. 3. Comparison of average throughout

Figure 4 is a comparison of the average delay as a function of the number of terminals. When the number of terminals is small, AP resources can meet the transmission of terminals, so the average delay of the two algorithms is relatively low, but with the increase of the number of terminals, the advantages of the algorithm proposed in this paper to distinguish QoS gradually manifest. When the number of terminals is more than 20, the algorithm in this paper distinguishes the service delay and priority, and the final average delay is 15% lower than that of the algorithm based on the signal-to-noise ratio, which can meet the requirements of high-quality and low-latency power services.

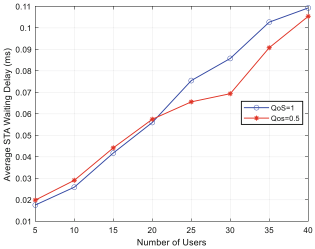

Fig. 4. Comparison of average delay

7 Conclusion

In view of the business requirements and characteristics of the power Internet of Things system, this paper designs a method for optimizing WiFi6 access resources for power Internet of Things services based on transmission time slot scheduling. First, starting from the OFDMA resource division characteristics of WiFi6, this paper designs a method for optimizing WiFi6 access resources based on transmission time slot scheduling for differentiated WiFi6 access resources for power Internet of Things services. Firstly, a dynamic access selection model is designed by distinguishing short frames and long frames, aiming at maximizing the transmission efficiency of uplink data and reducing overhead. Then, considering the delay threshold and priority between different service types, this paper designs a scheduling access optimization model based on signal-to-noise ratio and considering QoS, and performs multi-frame data transmission in one TXOP time slot. Finally, for the WiFi6 access resource optimization method proposed in this paper, a heuristic-based scheduling algorithm is designed. The simulation results show that the method proposed in this paper can improve the system throughput and ensure the high quality and low delay of power services.

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