Low-Latency Guarantee Protocol Based on Multi-links Scheduling Random Access in the Next Generation WLAN: IEEE 802.11be

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Abstract. With the advent of artificial intelligence and big data era, the demands for wireless networks require increasingly high quality of service (QoS). In the next-generation wireless local area network (WLAN), the Institute of Electrical and Electronics Engineers (IEEE) 802.11 regards low-latency guarantee as one of the main technical goals. Multi-link operation (MLO) technology can effectively guarantee network delay. Based on this, this paper proposes a low-latency guarantee protocol based on multi-link scheduling random access. The specific process of the low-latency guarantee protocol is proposed and designed, and the frame format of the protocol is designed to make it compatible with the 802.11 frame format. The simulation results show that the random access protocol based on multi-link scheduling can effectively improve the QoS of the network compared with the traditional single link. It not only increases the throughput of the network, but also effectively reduces the data transmission delay. The addition of scheduling algorithms can effectively reduce the delay of high-priority services and reduce the packet loss rate of the entire network.

Keywords: QoS · WLAN · IEEE · MLO · Low-latency guarantee

1 Introduction

With the rapid development of mobile Internet and the widespread use of smart terminals, the amount of data carried by wireless networks has continued to increase sharply, and wireless services have gradually become diversified. Wireless local area networks (WLAN) has become the main carrier of wireless services. With the advent of the internet of everything, intelligent manufacturing and big data era, lifestyle changes on network performance requirements are also increasing. The requirement for low-latency guarantee of wireless network and improvement of network throughput is also imminent.

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Based on the latest with the Institute of Electrical and Electronics Engineers (IEEE) 802.11ax specification of a new generation of more powerful Wi-Fi products Wi-Fi6 come out [1]. The Wi-Fi 6 will not only greatly improve people's lifestyle, but also bring great economic value to various industries [2]. In the next few years, video traffic will become the main traffic type (such as 4k and 8k video), and with the emergence of more advanced technologies, its throughput requirements will continue to grow to tens of gigabits per second (Gbps). At the same time, new applications requiring high throughput and low latency are also proliferating, such as augmented reality, virtual reality, giant games and remote office and so on. The IEEE 802.11 will have to further improve Wi-Fi to meet the needs of these specific scenarios with high throughput, low latency and high reliability. In order to continuously meet the rapid growth of the services and improve the user experience. The IEEE 802.11 discussed and revised the project approval of the next generation WLAN standard extremely high throughput (EHT) at the standards working group meeting held in March 2019. The next-generation WLAN standard EHT project authorization request (PAR) clearly requires that it support 30 Gbps throughput and improve the low-latency guarantee capability and jitter [3]. In order to achieve the technical goal of extremely high throughput, 802.11 be introduces a multi-band operation (MBO) mechanism, so that the device can work efficiently and coordinately on more frequency bands [4]. The multi-link operation (MLO) is one of the key MBO technologies that attracts the most attention. It runs multiple links independently or cooperatively at the same time to improve the limit throughput of the network [5].

Through the research of the literature, the author found that the previous WLAN standards mainly focused on designing the media access control (MAC) layer algorithm protocol to optimize the low-latency guarantee. In this paper, based on the introduction of multi-link operation mechanism of 802.11be, a low-delay guarantee algorithm based on multi-link scheduling random access is proposed. This algorithm mainly provides a multi-link scheduling algorithm that guarantees network delay. The access point (AP) performs effective coordinated scheduling on multiple links according to the current channel conditions. This can not only reduce network transmission delay, but also effectively improve network performance, such as throughput and packet loss rate.

In the remaining chapters of the article, the author will expand from the following aspects. In the second chapter, we mainly give an overview of the next-generation WLAN standard and introduce the MLO mechanism introduced by 802.11 be. The delay guarantee algorithm based on multi-link scheduling random access will be introduced in detail and the algorithm flow will be given in the third chapter. In the fourth chapter, the author will design the simulation scene according to the algorithm in this paper and compare it with the traditional low-delay guarantee algorithm and the scheme without scheduling algorithm. Finally, in the fifth chapter, draw conclusions.

2 Overview of the Next Generation WLAN Standards and MLO Operation

2.1 Overview of the Next Generation WLAN Standards

802.11be was formed in May 2018 to form the EHT topic interest group (TIG) [6], which is determined to enable the new MAC and physical layer (PHY) operation mode, which can support the maximum throughput of at least 30 Gbps. It also ensures backward compatibility and co-existence with older 802.11 devices in the 2.4 GHz, 5 GHz, and 6 GHz unlicensed bands. The EHT study group (EHT SG) was launched in July 2018 with the primary goal of forming an effective serialization development process. At the IEEE 802.11 standard working group meeting held in March 2019, the project document of the next-generation WLAN standard EHT working group was discussed and revised, and the project was named 802.11be [4]. In May 2019, the next-generation WLAN standard officially entered the working group stage from the study group. It is expected that the 802.11be standard will be launched around 2024.

In the 802.11be PAR approved by the IEEE standard protocol in March 2019, not only the throughput of the network is required to be improved, but also the delay guarantee capability of the network is clearly required to be improved [7]. The proposal of delay guarantee shows that the focus of the next generation WLAN will be devoted to the research and development of delay guarantee mechanisms. Low latency, low jitter, and high stability requirements have been valued by the 802.11 standardization organization, which shows that the standard development group has changed its mindset of focusing on the single characteristic of improving throughput (Fig. 1).

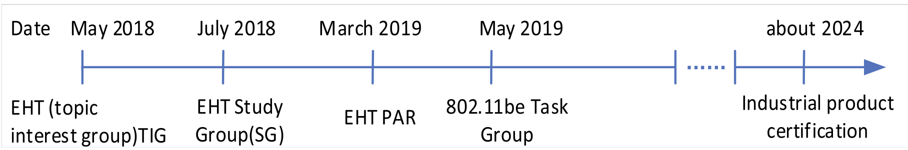


Fig. 1. 802.11be standardized timelines

2.2 Overview of MLO

In previous versions of IEEE 802.11, only one link was used between an AP and a station (STA) and worked on one frequency band, such as 2.4 GHz or 5 GHz. In order to achieve the technical goal of extremely high throughput, IEEE 802.11be introduced multi-link operation. IEEE 802.11be allows the device to have multiple sets of radios and work in multiple frequency bands such as 2.4 GHz, 5 GHz (high frequency band and low frequency band), 6 GHz at the same time. This greatly improves the limit throughput of the network [8].

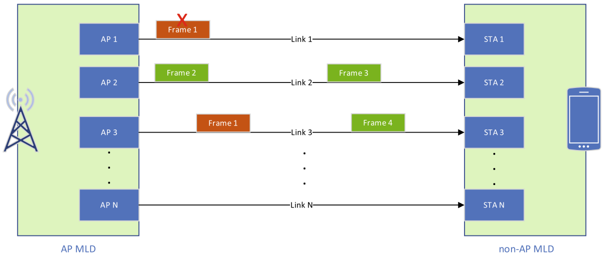


Fig. 2. Multi-link operation schematic

As shown in Fig. 2, an AP multi-link device (AP MLD) is similar to the role of the traditional AP, and the non-AP MLD (hereinafter referred to as STA MLD) is similar to the role of the traditional STA. But strictly speaking, there is a big difference in concept. An AP MLD can have multiple APs working in different frequency bands, such as AP1, AP 2, AP 3 until AP N in the figure, but these APs are located in the same device. A STA MLD can have multiple STAs working in different frequency bands, such as STA1, STA 2, STA 3 until STA N in the figure, and these STAs are located in the same device. Wherein, AP1, AP2 and AP3 work in different frequency bands, STA1, STA 2 and STA 3 work in different frequency bands, and AP1 and STA1, AP2 and STA2, AP3 and STA3 work in the same frequency band respectively. The links formed by them are called link 1, link 2, and link 3. Therefore, a link corresponds to a collection of APs and STAs working in the same frequency band. It can be seen from the figure that different links can work at the same time, such as data transmission. In addition, resources between links can be efficiently integrated. For example, the transmission of frame 1 on link 1 in the figure fails, and AP MLD chooses to retransmit the frame on link 3. It can be seen that, first of all, MLO enables APs and STAs to have more bandwidth resources, thereby laying an important foundation for achieving the goals of EHT. In addition, efficient coordination between different links can further improve the efficiency of access, transmission and retransmission.

In this paper, we design a delay guarantee protocol based on the multi-link scheduling random access design, which not only helps to reduce the network delay, but also has the advantages of increasing the network throughput rate and reducing packet loss rate.

3 The Low-Latency Guarantee Protocol Based on Multi-link Scheduling Random Access

3.1 Protocol Overview

Regarding how to ensure low-latency transmission in wireless networks, this paper proposes a low-latency guarantee protocol based on multi-link scheduling random access. When high-priority services have been transmitting data on a certain link, as the rate of generating data packets increases, because high-priority services enter the channel more aggressively, this will lead to high-priority services in the same AP Conflicts are prone to occur when accessing channels, as shown in Fig. 3(a) below. When we regularly send TSAF frames on each link, the node will access specific services to specific links according to the specific conditions of the current link. This can effectively reduce the high-priority push on a certain link, reduce the transmission delay of high-priority services and reduce the probability of conflicts between high-priority services, as shown in the following Fig. 3(b). This protocol not only improves the throughput of the network and reduces the transmission delay of the network, but also reduces the packet loss rate of the entire network.

3.2 The Process of the Low-Latency Guarantee Protocol

In order to effectively protect the low-latency data transmission in next generation WLAN. This paper proposes a scheduling random access protocol based on multiple links. The specific agreement process can be divided into the following steps:

Step 1: The AP periodically sends a traffic scheduling announcement frame (TSAF) on each link to indicate which link or links a specific service is transmitted on.

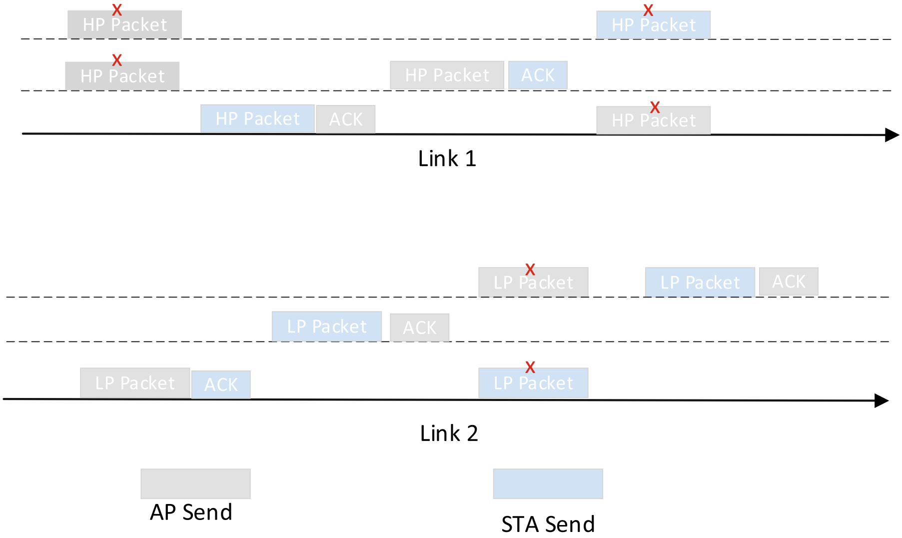
Step 2: After receiving the control frame, the STA performs data transmission on the link assigned to the specific service according to the control frame. For example, when performing downlink data transmission, the AP will put specific services into the queue of the assigned specific link to compete for current link resources. As shown in Fig. 4, the AP will assign high-priority services to the link 1 and link 2, and assign low-priority services to link 2. This greatly improves the efficiency of high-priority service access and helps reduce high-priority delay and throughput.

Step 3: When the destination node receives a packet over a link, it returns an acknowledgement (ACK) on that link.

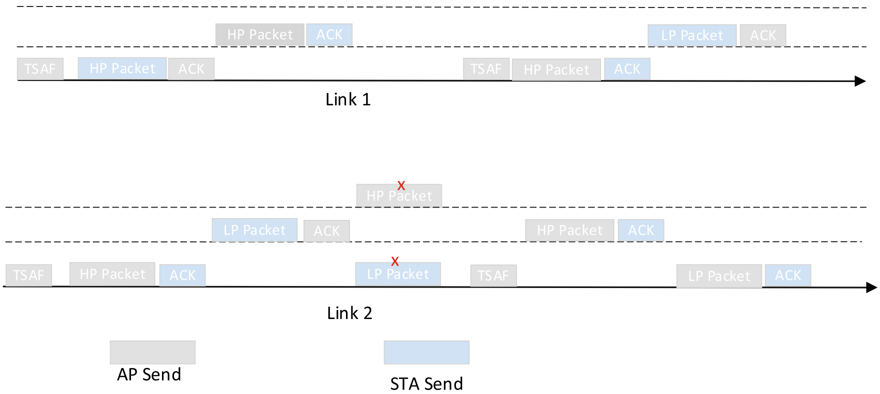
Step 4: In each TSAF cycle, each node transmits a specific service on a specific link according to the information sent by the TSAF frame. Transmission based on the information carried in the TSAF frame helps to ensure that high-priority services minimize collisions, ensure the delay of high-priority services, and improve the throughput of high-priority services.

3.3 Scheduling Algorithm Design

In order to enable the AP to effectively schedule reliable link resources to transmit high-priority services, we have designed a scheduling algorithm based on service priority differences. Through this algorithm, our goal is to enable high-priority services to be transmitted on reliable links as much as possible, so as to



(a) Traditional multi-link transmission



(b) Scheduling-based multi-link transmission

Fig. 3. Data transmission under multiple links

ensure the delay and transmission of high-priority services. Based on this idea, this paper designs an algorithm based on link utilization and TSAF's information received by AP to effectively allocate link resources. The core idea is: when the AP receives the TSAF sent by the AP of other cells, it will store the link information carried by the TSAF. When the AP competes for a certain link, it will use the stored link information, Information such as channel utilization rate allocates link resources. For link utilization, we use parametric link utilization threshold (including two thresholds, high priority threshold and low priority

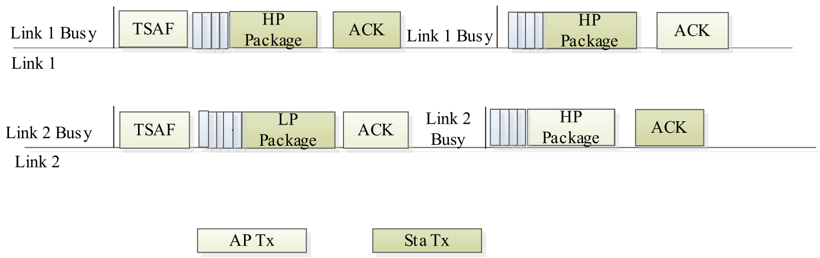


Fig. 4. The process of the low-latency guarantee protocol

threshold) to measure the current link utilization. As shown below, the basic flow of the scheduling algorithm is given:

When the high-priority service is ready to enter the queue, the queue of which link the service enters is determined according to the stored link information and the utilization rate of each link.

Step 1: Compare the utilization rate of each link and the number of high-priority services in the queue to determine which link queue the current service should enter.
Step 2: When the high-priority services in a link queue are significantly lower than the average value of the high-priority services in all link queues, we enter the high-priority services into the queue of this link.
Step 3: When high-priority services are more evenly distributed in the queue of each link, we judge which link queue the high-priority services enter according to the utilization rate of each link.
Step 4: When the channel utilization of a link is significantly lower than the utilization of other links, high-priority services will enter the link queue.
Step 5: When the channel utilization rates of all links are basically equal, high-priority services will randomly select a link and enter its queue for backoff.

3.4 Frame Structure Design

The frame structure of TSAF is extended according to the frame format of the 802.11 traditional trigger frame (TF). As shown in the figure below, the author adds a Link Info field in the TSAF to indicate the link number, service type, and transmission duration in the link. The other fields are consistent with the traditional TF structure (Fig. 5).

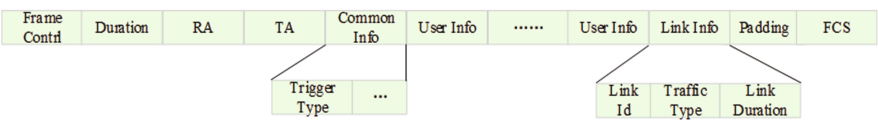


Fig. 5. Frame structure of TSAF

4 Simulation Design and Implementation

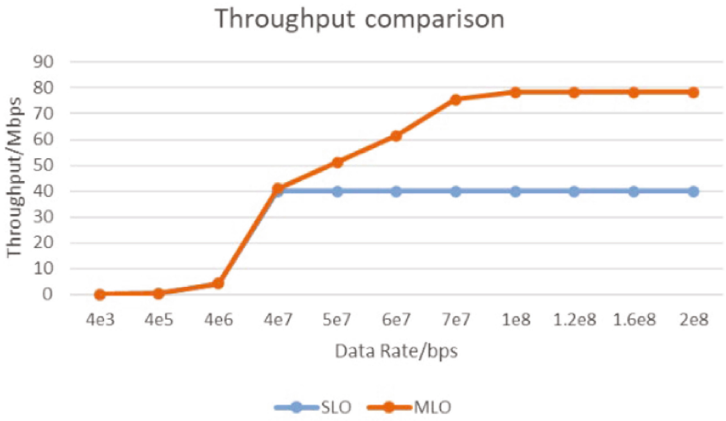
How to guarantee delay has become an important research direction in the next-generation WLAN. So what is the effect of the delay guarantee protocol based on the random access method of scheduling multi-link designed in this paper? Based on this, we designed and implemented algorithms on the NS3 simulation platform and designed specific scenarios to verify our protocol. NS3 is a discrete event simulator, which is a software dedicated to learning and researching network simulation. Based on this platform, the author has realized the test and verification of the delay guarantee of this protocol and the traditional single link. First of all, we designed a basic single cell scenario to verify the performance of this protocol and the traditional single link to compare all aspects. We adjust the node's packet production rate to compare the network performance of this protocol which is different from the traditional single link mode. The specific parameters of the scene are shown in the following Table 1:

Table 1. The parameter of simulation one

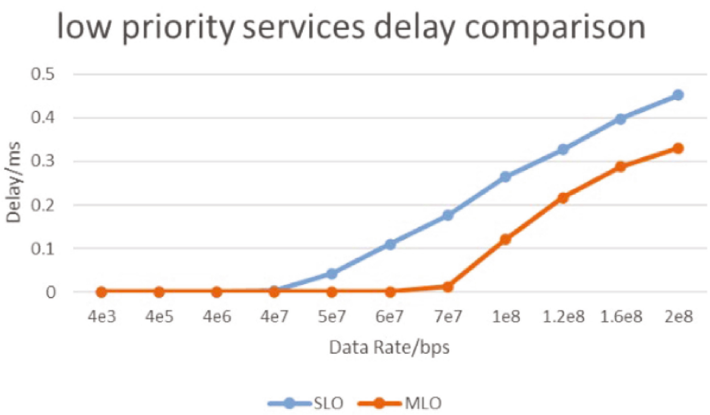
Parameter	Value	Parameter	Value
The Number of AP	1	Service Type	High/Low Priority
The Number of STA	4	The Number of Link	2
Transfer Mode	Down Link	MCS Value	4

The purpose of this simulation is to compare the basic network performance of this protocol with the traditional single link (TSL), mainly from the network throughput and service transmission delay. As shown in the figure below, we can clearly find that compared to the traditional single-link mode, the multi-link scheduling protocol not only improves the throughput of the entire network, but also significantly reduces the transmission delay of the entire network. It not only reduces the delay of high-priority services, but also reduces the transmission delay of low-priority. This shows that compared with the traditional single link, our protocol can greatly improve the performance of the entire network. And with the increase of the node's packet production rate, this protocol improves the overall network performance more obviously than the traditional single link.

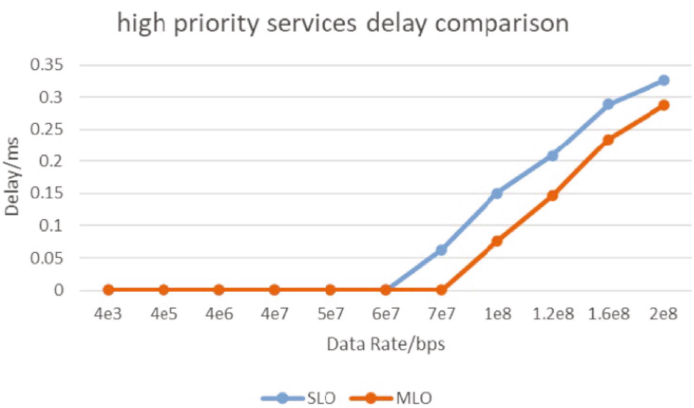
This paper designs a single-cell transmission scenario to verify whether the scheduling protocol can effectively reduce the transmission delay of high-priority services and improve network performance. The basic parameters of this scene are shown in the table below (Table 2). The simulation results are shown in the figure below. From the Fig. 6, we can see that the scheduling algorithm can effectively guarantee the high-priority transmission delay. As the data rate increases, the function of the scheduling protocol becomes more apparent (Fig. 7).



(a) Throughput comparison



(b) Low priority services delay comparison

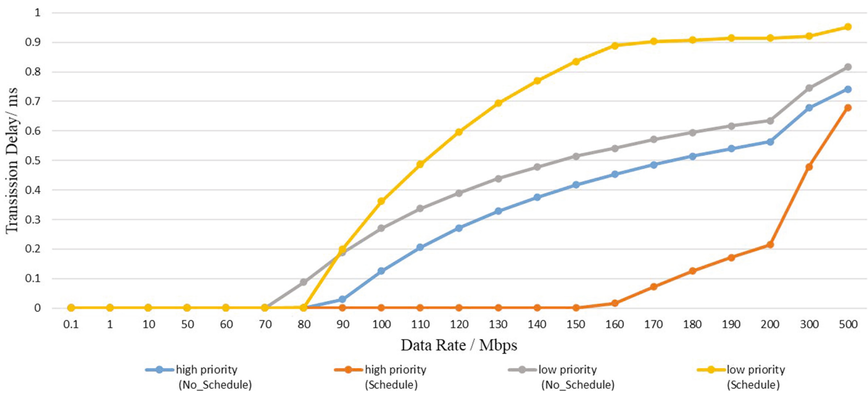


(c) High priority services delay comparison

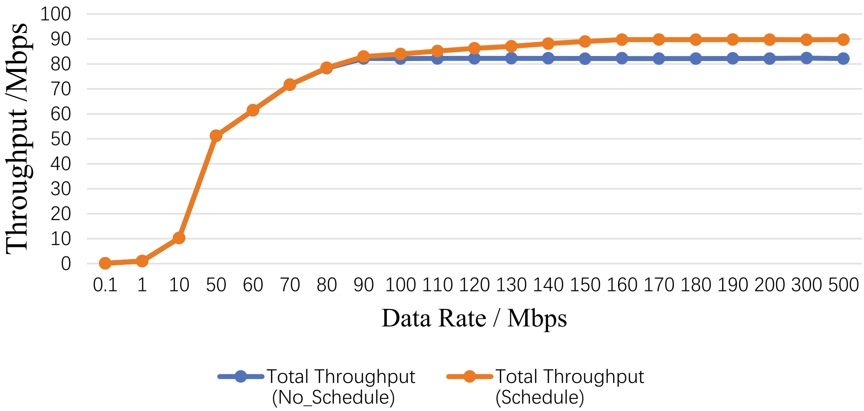
Fig. 6. Scheduling algorithm comparison

Table 2. The parameter of simulation two

Parameter	Value	Parameter	Value
The Number of AP	1	Service Type	High/Low Priority
The Number of STA	4	The Number of Link	2
Transfer Mode	Down Link	MCS Value	4
Data Rate/Mbps	0.1–500		



(a) Services delay comparison



(b) Throughput comparison

Fig. 7. Scheduling algorithm comparison

5 Conclusions and Future Works

From the simulation results, we can see that compared with the traditional single link, this protocol can not only effectively improve the throughput of the entire network, but also significantly reduce the service transmission delay. The scheduling protocol significantly improves the communication quality of the entire network in the case of multiple cells, can effectively reduce the collision of data packets, thereby improving the throughput of the network and reducing the packet loss rate and transmission delay of the network. For the research of the next-generation WLAN, how to guarantee the transmission delay of the network is a very challenging research direction. The multi-link based scheduling random access protocol proposed in this paper can effectively improve the performance in this respect. How to further ensure the research of network delay in high-density scenarios will also become one of the author's future research directions.

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