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Multi-AP Coordination Technology in The Next Generation WiFi 7 Networks

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Abstract

A number of important challenges of Wi-Fi are becoming more and more evident, such as highly dense deployment, miniaturization of mobile terminals, coexistence of multiple APs, and large traffic. The existing Wi-Fi standards, such as 802.11ac, are not competent to cope with the changes. The next generation Wi-Fi standard named IEEE 802.11be, which designed for multiple AP deployment scenarios, introduces new mechanisms such as multiple resource unit operation, multi-AP coordination so as to improve the network performance in the interference environment through cooperation. At present, the Wi-Fi 7 standard is still in progress, and many new functions need to be improved and verified. The existing research work also fails to make full use of the new features to effectively deal with the challenges of high density, large bandwidth and overlapping coverage. In order to achieve higher energy efficiency and sustainable operation of dense Wi-Fi, researches focuses on the AP deployment and resource scheduling scheme, including the joint optimization strategy of AP deployment and power control, the adaptive dynamic channel bonding mechanism for large bandwidth, and the collaborative optimization scheme of channel access and resource allocation with multi-AP coordination. The output would fill the blanks in the new 802.11be standard, making future Wi-Fi to meet new needs and changes more effectively. It would benefit quicker adoption of the new standard in the real world.

Keywords

WiFi 7; IEEE 802.11be; Multi-AP Coordination; Orthogonal Frequency Division Multiple Access(OFDMA).

1. Introduction

In recent years, telecommuting, distance education, e-commerce, non-contact distribution and online entertainment have become important ways for people to maintain production, life and interaction amid the epidemic. The vitality and resilience of the digital economy have become prominent[1]. In the construction of a new generation of information, communication technologies and new infrastructure, wireless access with high energy efficiency, low latency and high throughput has become an important basis for supporting modern society and economic development. Wireless Local Area Network (WLAN) is one of the main wireless network access modes due to its low cost, high flexibility, strong scalability, and easy maintenance features[2].

The existing WLAN standards and technologies are in the intensive deployment environment, and the problems such as high terminal energy consumption, low throughput and low user experience occur. In fact, the IEEE 802.11 standards have been evolving in response to the changes. From the first generation WLAN standard IEEE 802.11a in 1997 to the sixth generation 802.11ax standard, the IEEE 802.11 LAN / Man Area Network Standard Committee has increased performance by using new technologies. The ax standard now in use has a peak throughput of 10 Gbps. However, the current protocol used by WLAN is designed for single-AP transmission, and existing technologies in densely deployed multi-AP environments experience performance bottlenecks because of using competitive mechanisms. In the face of limited spectrum resources and energy allocation, network energy efficiency and delay indicator need to be further improved.

To meet new challenges, especially to improve the performance of WLAN in dense environments, the IEEE Committee established the TGbe Working Group in 2019 to develop the 7th-generation WLAN physical layer and MAC layer standards, namely IEEE 801.11be[3], which will be released in May 2024. The 7th generation of WLAN scenarios will effectively change from a single access point (Access Point, AP) to a multi-AP situation, forming a multi-AP system. How to use multi-AP coordination and power saving mechanism to achieve high energy efficiency data transmission with extremely high throughput and low delay in the system has become one of the key concerns [4].

The next generation of Wi-Fi 7 will also realize the interconnection and sharing between regions, without interfering with each other, and achieve full regional coverage. This will lead to more new changes, including connectivity between vehicles and mobility detection in homes. IEEE Chairman Paul Nikolich said, " We want to detect people moving in different rooms without any sensors, and even to detect the breathing of users. Because the user's breathing changes the RF characteristics and the channel characteristics." This also means that the Wi-Fi 7 use scenario will effectively shift from a single AP to a multi-AP situation, forming a multi-AP system. In order to cope with the changes, how to use multi-AP coordination to achieve extremely high throughput and low delay of efficient data transmission in the system has become one of the key technologies of Wi-Fi 7[5].

In multi-AP systems, AP needs to interact and coordinate information transmission with the neighboring AP, resulting in additional signal overhead and higher information processing complexity. Therefore, centralized network structures such as cloud-based network architecture [6] and software-defined networks [7] are potential solutions for the next generation of Wi-Fi 7 that can be used to reduce inter-alone AP synchronization and collaboration complexity. A typical multi-AP system consists of one Master AP (M-AP) and multiple Slave AP (S-AP). Among them, the master AP is responsible for AP management and resource scheduling, while the slave AP will participate in the multi-AP collaborative transmission process. In order to realize the collaborative information interaction between AP in more real time, wired networks with high capacity and low delay can be used between APs, such as optical fiber.

Facing the above future scenario of Wi-Fi 7, the existing Wi-Fi network still has many problems and deficiencies. We found that in large public situations, a large number of APs are often configured to cope with peak demand due to the uneven number and traffic imbalance of Wi-Fi devices in different regions and at different time periods. This will waste a lot of resources during the trough times. In addition, the AP interference with overlapping coverage has also become one of the important factors affecting the efficiency and reliability of site communication. Reasonable AP configuration is conducive to giving full play to the overall effectiveness of the system. Based on the multi-AP system framework of Wi-Fi 7, how to design the AP configuration scheme is put on the agenda again, and it has become a research hot spot. We need to reasonably deploy and configure the number, location, wake-up mechanism and power control of each AP according to the requirements of the multi-AP collaboration technology framework and application scenarios, so as to facilitate users to access and transmit data without interference.

At present, nearly 9 billion terminals are connected to Wi-Fi networks, including smartphones, sensors, etc. Many new applications also require Wi-Fi should be of high throughput [5], low latency [8], and high reliability. We focuses on the academic frontier of the next generation of

Wi-Fi 7, and connects with the common key problems of spectrum resource shortage in the wireless communication network. Aiming at the gaps and deficiencies of the existing work at home and abroad, it focuses on the AP deployment and multi-AP collaborative resource allocation optimization scheme based on 802.11be standard. The power control strategy and adaptive channel allocation scheme will effectively improve the spectrum resource utilization rate and system throughput, further reduce the data delay, and the overall network energy consumption. This is of an important role and practical significance to the development of IEEE 802.11be standards to promote the rapid implementation and practicality of the next-generation Wi-Fi 7 network in China, and is expected to improve the end-user experience to achieve a high energy-efficient Wi-Fi network with extremely high throughput and low latency. The successful development of the research will make a positive contribution to the channel access scheduling of multi-AP system from theory to practice, promote the research and development of Wi-Fi technology, and facilitate people's life.

2. Research State and Future Development Tendency

With the continuous popularization of Wi-Fi technology, various levels of research work have been conducted to improve the throughput of dense Wi-Fi network in recent years, and many excellent research results have been achieved. At present, the Wi-Fi standard for extremely high throughput, namely IEEE 802.11be, is still being exploring, and there are many meaningful exploratory studies and targeted suggestions for its formulation. In this part, we will focus on the development of the next generation of Wi-Fi 7 standard, including the AP deployment, channel binding, resource allocation and multi-AP collaboration mechanism for multi-AP systems.

2.1. AP Deployment Issues in Dense Wi-Fi Network

With the wide application and dense deployment of AP, there exists serious and complex interference between adjacent APs. If the AP is not properly configured, it results in a significant decrease in network performance[9]. There are two main factors affecting its performance, one is the deployment scheme of AP, the other is the resource allocation between APs and stations, including power, channel and RU. In addition, users can maintain a continuous Wi-Fi service[10], even when the AP fails. Therefore, it is crucial to study how to optimize AP deployment.

The fault-tolerance deployment of multi-AP has been extensively investigated and studied . Ling et al. [11] investigated two AP deployment issues to provide better web services. Zheng et al. [12] investigated the positional placement of AP aimed to minimize the number of AP used. The AP deployment problem is also studied in [13], helping to optimize the deployment of AP. Zhang et al. [9] focused on finding the optimal AP location to minimize the total cost. An optimization framework for AP deployment is proposed in the literature [14], which aims to maximize signal coverage. In terms of the AP configuration optimization problem, Kiran et al. [15] maximizes the coverage by optimizing the AP power allocation. Audhya et al. [16] conducted a study of the ultra-high density 5G network and proposed an scheme about optimal placement of AP.

2.2. Channel Bonding Technology in Overlapping WiFi Networks

How to alleviate the competition and interference between overlapping basic service sets, and improve throughput and energy efficiency has become an important research topic. Many papers have been published to alleviate the problem of interference between overlapping basic service sets. Kang[17] used neighbor discovery and spectrum information to reduce interference, while Wu Jiang [18] and Yin Jiang [19] alleviate the interference problem between overlapping basic service sets based on access control. Kang et al [20] proposed a channel selection mechanism to inhibit interference in a overlapped BSS environment. Han et al. [21]

focused on optimal power distribution in heterogeneous downlink networks. Abinader et al. [22] addressed the use of uncompetitive channel access mechanisms for overlapping basic service sets. The Ropitault[23] combined the adjustment of power transmission and carrier detection thresholds to increase the number of concurrent transmissions in dense environments. Kanda[24] focused on hybrid channel access mechanisms to alleviate the problem of overlapping basic service sets, and proposed two methods to improve the coexistence ability of distributed access networks using the capture effect. The above solutions mainly focus on the interference suppression problem or channel access control mechanism under the same bandwidth. However, with the development of 802.11ac networks and the coexistence of 802.11a and IEEE 802.11n networks, the overlapped BSS for different channel bandwidths (such as 20 MHz, 40 MHz, 80 MHz, and 160 MHz) will become more common. This results in partial band overlap between BSS. Guo et al. [25] proposed two complementary competition-based MAC layer schemes to solve the spectrum problem by establishing competing virtual master channels. More optimized channel bonding technology [26,27] is also one of the ways that researchers focus on.

The 802.11n amendment originally introduced a 40 MHz frame format for transmission when continuous 40 MHz blocks were determined to be idle. As a proof of the validity of the channel bonding, the 802.11ac and 802.11ax amendments further extend the channel bonding bandwidth to 80 MHz and 160 MHz. The upcoming 802.11be amendment to be released in 2024 further extends the bonding channel to 320 MHz [5]. However, data transfers with more bandwidth are more vulnerable to interference from partially overlapping (same-channel) networks. Unreasonable channel bonding scheme may lead to reduced data rates. Second, the transmission power control can reduce the user's received signal intensity and the data rate. This means that AP with high traffic load may be under capacity, resulting in queue overflow and long latency. On the other hand, the higher power produces more interference at the nearby AP. Third, since the load of the AP is a time-varying [28], the AP needs to carefully adjust its transmit power and the usage of its bonding channels. Otherwise, the AP capacity may be inadequate or over-configured. To this end, optimizing the transmit power of AP combined with channel bonding will bring more beneficial effects. In addition, many researches applied new methods like reinforcement learning (RL) [29-31] in wireless local area networks, to seek to meet the user experience or maximum throughput.

2.3. Research on Channel Access and Resource Scheduling

In order to reduce collisions, an extensive study of the channel access mechanism in the new standard is developed, and a variety of random access improvement schemes suitable for multi-user simultaneous transmission are proposed. Based on the non-cooperative game, Yang Fan et al.[32] enabled AP to estimate the conditional conflict probability of the allocation channel, and the proposed resource allocation strategy reaches the compromise of fairness and data transmission rate. Lanante et al. [33] equipped UORA with carrier-sensing capabilities, resulting in a new uplink hybrid UORA (H-UORA) access mechanism to improve throughput.

The above studies mainly involved an individual AP. However, multiple APs with overlapping coverage regions often exist in current dense networks. Competition and interference between different basic service sets can seriously affect the performance of their respective systems. Soleimani et al. [34] proposed a clustering scheme based on the strongest received signals to manage interference between AP. Qin et al. [35] studied the important issue of AP association and resource allocation, comprehensively considering to maximize user throughput in the case of AP allocation and transmission scheduling. Qiu et al. [36] combined the 802.11ax throughput and interference model with the AP deployment problems, to achieve the joint optimization of RU resource allocation and AP configuration. Athanasiou et al. [37] investigated the problem of user association by minimizing the maximum load across all AP by matching each user to the

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AP. On the other hand, the existing distributed Wi-Fi architectures work in different frequency bands do not support AP coordination, which makes efficient network management and improved quality of service (QoS) difficult. To overcome these challenges, we can use a Wi-Fi centralized control architecture with decoupled control and data planes to coordinate wireless resource allocation across the network, while improving communication performance. Therefore, Zhou et al. [38] designed a new Wi-Fi architecture of control/data decoupling plane for efficient network management and optimized wireless resource allocation by dividing the control planes and data planes into sub-6GHz and millimeter waves, respectively.

2.4. Multi-AP System in Wi-Fi 7

In order to meet the goal of ultra high definition video service and achieve extremely high throughput (EHT), the multi-AP coordination technology [39] will be introduced in the new IEEE 802.11be standard. In the future, a set of APs will be allowed to form a distributed or centralized multi-AP system. At present, the research group mainly considers two types of multi-AP systems: collaborative system and joint system. The collaborative system sends and receives data through a single AP, while the joint system sends and receives data through multiple APs.

The collaborative multi-AP system involve: collaborative spatial reuse, collaborative OFDMA and collaborative joint transmission. The AP can broadcast important information with beacon frame or a management frame. The AP that has acquired transmission opportunities shares information with other AP to perform simultaneous transmission with appropriate power control and link adaptation. Inter-AP coordination will create more spatial multiplexing opportunities and reduce channel conflict [40] than the spatial multiplexing schemes available in IEEE 802.11ax. Yang et al [41] proposed a MAC framework for AP coordination and full-duplex support. In literature [40], the authors demonstrated the effect of efficient spatial multiplexing using multi-AP collaborative beamforming, demonstrating the importance of collaborative beamforming. Collaborative spatial multiplexing and collaborative OFDMA is relatively simple, flexible, and has many feasible solutions. Besides, it is also the most easily to be implemented in the IEEE 802.11be standard. For the collaborative joint transmission, Titus et al. [42] studied the best possible rate under the multi-AP joint transmission mechanism, and used these findings to solve the joint scheduling problem in common practical deployment scenarios.

2.5. Analysis of Current Status

To sum up, after an in-depth analysis of the current research situation at home and abroad, it is found that the existing work still has the following key deficiencies:

(1) For large-scale equipment access, people have conducted research on multi-AP deployment. This paper discusses the number of AP or self-repair schemes. However, most schemes do not reflect the time variation of user location, and AP deployment schemes (including power control, etc.) are prone to obsolete. The stochastic optimization approach is more feasible. In addition, with the practical transformation of the 7th-generation Wi-Fi standard application scenarios, reliable deployment solutions suitable for the intensive deployment of APs need to be further explored.

(2) In order to improve the peak data rate of the Wi-Fi network, people use the channel bonding technology to create larger bandwidth channels to improve the throughput, and build multiple effective interference analysis models. However, AP wireless communication accounts for a high proportion. How to improve the energy efficiency of multi-AP systems has become more prominent. AP can reduce its power to minimize its energy expenditure or interference with its adjacent APs. At present, the new standard introduces higher frequency, greater bandwidth and multi-AP coordination mechanism. And the AP power control and channel bonding scheme

produces new problems and new solutions. Therefore, the construction of energy efficiency optimization problems based on AP dynamic channel bonding and power control need to be deeply explored.

(3) In order to realize the next generation of extremely high throughput expectation, researches on the transmission access and resource allocation scheme combined with the new transmission protocol is put on the agenda. The existing related research work is mainly based on the sixth generation Wi-Fi standard. With the development of the new standard formulation work, a variety of improvement functions are gradually improved, such as multi-link operation, multi-RU operation and multi-AP coordination, which have also ushered in new problems and new challenges. Currently, no agreement on resource allocation schemes is made in the new standards. The original scheme obviously can not effectively use the new features in the new standard. Therefore, we need to pay more attention to the resource allocation scheme that suitable for multi-AP coordination.

3. Conclusion

Facing the future situation of dense AP deployment, how to optimize AP deployment, power allocation and resource allocation by effectively modeling channel allocation, channel bonding and transmission protocol is still an important research problem to be solved urgently. In the future, we need to combine the new technologies and mechanisms to be introduced in the Wi-Fi 7 standards to carry out the adaptive and high energy-efficient multi-AP collaborative strategy research under different demand scenarios, to promote the rapid implementation and practicality of the next generation of IEEE 802.11be standards in China.

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