New Progress in Power Management for Current WiFi 6 Networks

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Abstract

In recent years, WiFi networks show the characteristics of dense deployment, traffic diversification and terminal miniaturization, and the existing Wi-Fi network standards (such as 802.11ac) are difficult to cope with the above changes.The IEEE 802.11ax standard introduces new mechanisms, such as Target Wake Time (TWT) and multi-channel parallel transmission, to reduce collisoin by scheduling TWT to improve network performance in dense environments.However, the new standard does not give how to schedule the wake periods, which affects the application and promotion of the new standard. At present, TWT scheduling has been slightly studied in high-level journals, but the existing work fails to effectively respond to the challenges such as high density, dynamic changes in traffic demand, and overlapping Basic Service Sets (BSS).In view of the existing work deficiencies, this paper focuses on power save technology in dense deployment environment, including the online joint optimization mechanism of unicast TWT channel resources and sleep parameters, broadcast TWT adaptive scheduling method and collaborative scheduling strategy for overlapping BSS.The research results will help the new standards to be more effectively respond to the new needs and new changes, and promote the rapid implementation and practicality of the new standards.

Keywords

WiFi; IEEE 802.11ax; Target Wake Time; Orthogonal Frequency Division Multiple Access (OFDMA).

1. Introduction

Global mobile data traffic has exploded, with an annual global data traffic of 1 ZB by 2022[1]. Facing the huge demand for data traffic, wireless access with high energy efficiency, low latency and high throughput has become an important foundation for supporting modern social and economic development and meeting people's needs for a better life. Due to its low cost, high flexibility, strong scalability and easy maintenance[2], about 60% of the mobile data traffic is diverted to the WiFi[3] and it becomes one of the main network access methods.

In the face of social, economic and lifestyle changes, the development of WiFi presents important characteristics such as high deployment density, large access scale, heterogeneous coexistence, diversified services, and miniaturization of mobile terminals. First of all, in order to facilitate large-scale users to access the wireless network anytime and anywhere, a large number of access points (APs) are deployed in many public places, such as office buildings, campuses, and large stadiums, to meet the high bandwidth demand. In typical application scenarios, such as stadiums, the AP is deployed every 5-10m apart[4]. These covered areas of adjacent APs often overlap each other, and data transmission between terminals interferes with each other, affecting the overall network throughput. On the other hand, as many as 125 terminals are associated with an individual AP[5],. The terminal distribution also presents the characteristics of dense deployment. Secondly, in the modern large community, almost every household has its own AP, and these APs use different protocol versions, power, and etc. Heterogeneous coexistence has complex effects on the efficient access. Finally, the terminals associated with a single AP in smart home have various requirements, different traffic types, channel condisitons and power consumption.In order to ensure the mobility, flexibility and portability of the terminal, the terminals become smaller and mostly battery powered. With the continuous enhancement of terminal function, how to use pwoer efficiently with limited energy equipment is of great significance. High energy efficiency has become a highly concerned research direction in the field of wireless communication[6].

However, the existing IEEE 802.11ac WiFi is difficult to cope with the above new requirements, features and challenges. Tranditional WiFi faces the problems such as declining throughput, increased terminal energy consumption and poor user experience. The ac standard now in use has a peak throughput of 1 Gbps.However, the current WiFi uses single-user uplink transmission and distributed random access mechanisms. The existing technologies in dense deployment environments have performance bottlenecks due to the use of competitive mechanisms. Faced with the limited spectrum resources and energy equipment, the network performance is even difficult to meet the existing needs of users.

To improve the performance of WiFi in dense environments, the IEEE Committee established the TGax working group to develop the sixth-generation WiFi standard for physical layer and MAC layer, namely IEEE 801.11ax[8]. It was released in the past 2021. The new version of the standard, IEEE 801.11ax, introduced Orthogonal Frequency Division Multiple Access (OFDMA) to divide channels into subchannels with each called Resource Unit (RU), and further proposed an uplink multi-user simultaneous transmission mechanism based on OFDMA technology to reduce collisions to improve the throughput for dense networks[9]. The standard also introduced Target Wake Time (TWT)[10] power saving mechanism in the IEEE 802.11h[11]. To reduce the idle listening, ax proposed the new mechanism of broadcast TWT, combined with the uplink multi-user simultaneous transmission technology, to solve the problems and challenges faced in the increasingly dense, complex and diverse environment[12]. The new technologies, mechanisms, and features introduced or proposed in IEEE 802.11ax greatly increase the peak throughput to 10 Gpbs[13]. Besides, it can effectively reduces the power consumption in the terminals.

In the introduced unicast TWT power saving mechanism, the terminals can negotiate the periodic wake-up moment with the AP through the TWT request frame. After negotiation, the terminal transfers the data during the agreed TWT Service Period (TWT SP). Off-peak dormancy is also conducive to improve performance in dense deployment environments. On the other hand, with multi-channel resources based on OFDMA, multiple terminals can tansmit simultaneously to improve channel utilization. In order to better utilize the advantages of the uplink multi-user simultaneous transmission technology, the IEEE 802.11ax standard further proposes a new and more efficient broadcast TWT negotiation mechanism[8]. During the broadcast TWT negotiation procedure, AP adds TWTinformation elements to the beacon frame to specify the start time of TWT SP. The beacon frame containing the TWT information element is known as the target beacon frame (Target Beacon). Termianls received the target beacon decide whether to participate in the data transfer during the TWT SP specified by the beacon frame or not. Compared with unicast TWT, the broadcast TWT mechanism improves the negotiation efficiency. Obviously, the target beacon received by each terminal in the TWT mechanism will affect the number of active number of terminals during the TWT SP. Therefore, different TWT scheduling schemes have a significant impact on the channel access and overall network performance during TWT SP.

However, how to schedule sleep/wake time to achieve efficient data transmission based on OFDMA multi-user simultaneous transmission technology and TWT power save mechanism is not clearly declared in the new ax standard, but is instead customized by various hardware manufacturers. In full fill the gap in TWT scheduling in IEEE 801.11ax, this paper focus on the research of adaptive high-efficiency TWT scheduling scheme to promote the rapid implementation and practicality of the new standard. Currently, several research teams have also conducted research on dormancy scheduling to improve the network performance in dense WiFi and extend the running time of small terminals. Important results are published in important international conferences and academic journals in the field of wireless communication (e. g., INFOCOM, ICC, IEEE TMC, TWC, TON). Research work mainly includes the following three aspects. First, to meet the needs of the different application, the power saving scheme on physical layer are proposed for conventional WiFi. Second, researchers discussed the channel access mechanism with low power consumption, high throughput or high energy efficiency based on the distributed access process, and designed the channel access process by combining with the new TWT mechanism and multi-user simultaneous transmission during TWT SP. Third, the scheduling of long-term TWT parameters of each terminal in one single AP scenarios.

In view of the above key deficiencies and important problems, we focuse on the TWT scheduling mechanism to improve throughput and energy efficiency in different situations. The existing power saving research on WiFi are mainly in two aspects. The first is the study on scheduling schemes for the two different TWT negotiation process, e.g. unicast and broadcast TWT, focusing on different network density, traffic requirements, and channel conditions. The joint TWT scheduling and multi-channel resources allocation will be designed. It utilize random process theory to model the throughput and energy efficiency for broadcast TWT mechanism. Second, we study the high energy efficiency TWT scheduling within overlapping BSS, focusing on the collaborative scheduling mechanism between homogeneous APs and the online distributed TWT scheduling scheme between heterogeneous APs. For homogeneous AP scenarios, the environment-based grouping process and sub-channel allocation scheme will be designed to realize efficient coexistence through AP collaboration. In heterogeneous AP scenarios, a channel bonding strategy based on game theory wil be proposed to establish the equilibrium and reasonable coexistence between different AP through adaptive online TWT scheduling.

The above research on TWT scheduling methods and corresponding channel distribution schemes in different scenarios will further improve the overall throughput and energy efficiency of WiFi and extend the operation time of mobile terminal. This plays an important role and practical significance in the research and development of IEEE 802.11ax standards, by solving the conflicts between terminal miniaturization and battery shortage, and promoting the rapid implementation and practicality of standards in China. It is expected to improve the end-user experience and achieve the goal of dense deployment.

2. Research State and Future Development Tendency

With the popularization and application of WiFi, extensive studies on dense WiFi and ax standard new technologies have been carried out at home and abroad, including channel bonding, spatial multiplexing, OFDMA and other technologies and network optimization problems under the corresponding requirements.

2.1. Research on Trajectory Pattern Mining Method

For the high power consumption of wirless network interface card, the power save mechanism has been proposed since the first generation of IEEE 802.11 standard, allowing idle terminals to turn off wireless transceivers to reduce the pwoer consumption of wirless network interface card. The task of power management scheme in IEEE 802.11 standard is to close the wireless transceiver, and let the terminal enter into the doze state to prolong the runtime, while ensure that the communication meets the service quality and user experience. Thus, it achieves the purpose of pwoer saving.

Most of the studies on power save mode focus on solving pathways that minimize the active time of the terminals and maximize the sleep cycle. The study also focuses on the high energy consumption problem caused by different channel access mechanisms. J.Snow et al[14] implemented the channel access policy by pre-scheduling, R.Palacios[15] enhanced distributed coordination function (Distribution Coordination Function, DCF) through bidirectional transmission, with modified MAC layer protocol to acheive higher performance.

In addition, the researchers have studied the methods that combine physical layer technology to improve power conservation, such as adjusting the transmission power or the adaptive sampling frequency. Without considering the channel conditions, W.Wang et al[16] improve power coservation by reducing the device sampling frequency. X.Zhang and K.G.Shi[17] presented the E-MiLi scheme to reduce the overall power consumption within one listen interal by reducing the power consumption of the idle listening state. Based on this physical layer technique, L.Both Feng and J.Yang[18] further studied the Point Coordination Function (PCF) channel access, and proposed the optimal sleep interval time under the delay constraint.

The above studies extensively discuss the power saving schemes in different application scenarios, and effectively promote the development of power management technologies for the traditional IEEE 802.11 WiFi.

2.2. New Progress of Power Save Mode in WiFi 6 Networks

The nature of power scarcity has not changed. With the trend of increasing miniaturization of mobile terminals, power saving is still one of the priorities and improvement in the process of setting the current WiFi standards. The new standard IEEE 802.11ax introduces TWT power saving meachnisam in IEEE 802.11ah standards for large-scale terminals[10]. The TWT power saving mechanism alleviates collision and interference in the time domain. During the establishment of the TWT protocol, the terminal negotiate with the AP on the wake start time and wake interval to determine the sleep cycle. The terminal wake up at the specified time to join in TWT SP for data transmission. In addition, the IEEE 802.11ax 3 prososed broadcast TWT to cope with the new feature of uplink Multi-User transmission.

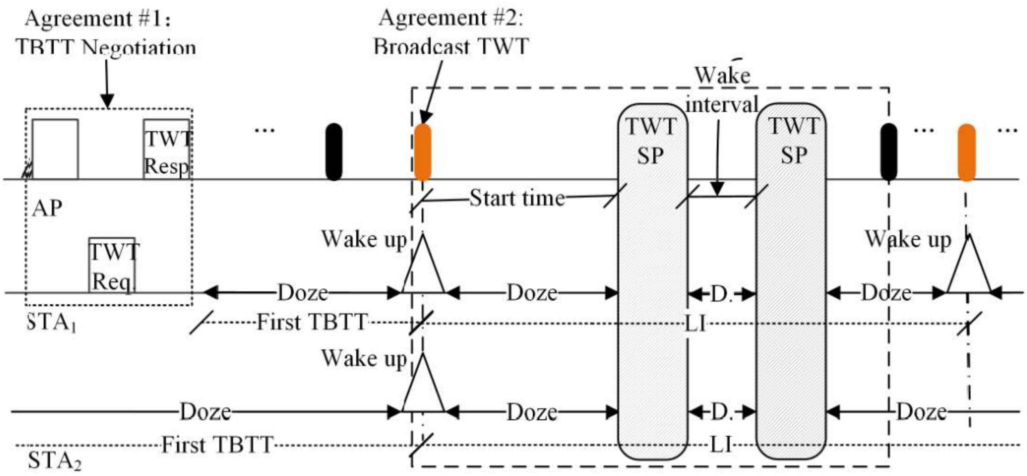

Figure 1. Broadcast TWT process in IEEE 802.11ax standard [12]

The negotiation process established by the broadcast TWT protocol is shown in Figure 1. The terminal TWT scheduling is completed in two stages. In the first stage, the terminal coordinates the first Target Beacon Transmission Time (TBTT) and listen interval, and these two parameters determine all subsequent TBTT moments; in the second stage, the terminal wakes up at the corresponding TBTT time, and receives the TWT SP parameter information contained in the beacon frame. Then the terminal wakes up at the corresponding broadcast TWT SP start time for data transmission. The broadcast TWT mechanism takes TBTT scheduling as the leader and obtains the available broadcast TWT SP service time by controlling the receiving beacon frame time of the terminal.

The power saving research and development of IEEE 802.11ax standard focuses on the global view of AP. The TWT mechanism uses the global view of AP to coordinate the sleep time of all terminals to improve the overall efficiency of the network, which is a key step for realizing deterministic access in the future WiFi[12], It is also pointed out that the TWT mechanism with multi-user simultaneous transmission has higher throughput and lower power consumption. However, the IEEE 802.11ax standard does not specify the setting of TWT parameters in the broadcast TWT mechanism. Furthermore, the problem is transferred to various wireless network interface hardware manufacturers.

Based on IEEE 802.11ax standard, Y.Hang et al[19] proposed an power saving scheme based on competition mechanism with the new features of multi-user transmission. For an ultra-high-density WiFi environment, J.Bai et al.[20] proposed an adaptive grouping algorithm based on the OFDMA multi-user transmission mechanism. D.Bankov et al[21] studied the clock shift problem of TWT uplink transmission process in IEEE 802.11ax/ah network. It shows that the transmission process based on trigger frames can effectively reduce the power consumption of random access. Besides, M. Nurchis and B.Bellalta[12] analized the broadcast TWT mechanism in the IEEE 802.11ax network which shows that the broadcast TWT can improve 10 times throughput with the multi-user transmission, while it introduces only a small communication overhead.

The research onTWT scheduling for IEEE 802.11ax has just started, and the studies on the traditional power saving mechanism[22, 23] has also been developing continuously. G.Naik et al [24] and, T.Uwai et al [25] utlized the Markov chain which was proposed by Bianchi[26] to anyalyze the performance of Uplink OFDMA Random Access (UORA) in WiFi 6 network. And the formal throughput formula is obtained. From another perspective, it confirms that the number of active terminals at the same time will greatly affect the overall throughput and energy efficiency of UORA channel access within the TWT SP. Therefore, the imbalance of the number of terminals awake at the same time inevitably leads to the excessive competition in some beacon frames and the waste of resources in part of the time slots, whichi will resulte in the overall network performance decline. For the low utilization of sub-channels, Q.Chen et al[27, 28] proposde a high-throughput TBTT scheduling scheme based on the broadcast TWT mechanism. Meanwhile, to slove the problems of serious collision and high energy consumption caused by random access of terminals in dense deployment sceanrios, a high-throughput deterministic channel access scheme combined with broadcast TWT scheduling mechanism is further proposed[29].

2.3. Summary of the Research Status

Through the in-depth investigation and targeted comparison of the existing methods at home and abroad, it is found that there are several key deficiencies.First, the energy saving scheduling scheme in traditional WiFi does not consider the new characteristics of uplink multiple users in WiFi 6 network, and the multi-channel resources cannot be fully utilized.Secondly, the existing research does not combine the different traffic requirements of each terminal site in the dense deployment environment, and the network performance needs to be further improved.Finally, most of the current energy-saving scheduling schemes consider the network application scenarios of a single AP, and the existing methods lack the analysis and research on the overlapping basic service set scenarios.In order to realize the high energy efficiency, sustainable and anti-interference operation of WiFi, T WT scheduling also faces four important

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problems and challenges: 1) The deployment density of terminal sites in different Spaces and different times is uneven, the network situation changes greatly, and T WT scheduling needs site density adaptation.2) Due to the diversification of carrying services, the terminal traffic demand varies greatly, and T WT scheduling needs traffic adaptation.3) Site data transmission in overlapping areas, and channel utilization needs to be improved, requiring multi-A P collaboration; 4) Different A P in overlapping areas may be heterogeneous, and T WT scheduling requires A P to adapt according to environmental changes.In general, the existing work still lacks an effective adaptive and high-energy-efficient T WT scheduling scheme in different scenarios by combining new technologies and new characteristics.

3. Conclusion

Currently, most existing power save schemes focus on the traditional power save mode. Hence, the sleep scheduling strategies do not consider the characteristics of multi-channel dimension, nor do they reflect the advantages of WiFi 6 network. It is obviously not appropriate to directly copy the corresponding research results of the original 802.11 standard to WiFi 6, which will lead to the waste of multi-channel resources. In addition, in dense deployment environments, the IEEE 802.11ax standard needs to consider the interconnection and connectivity between different versions and heterogeneous networks. Thus, how to design efficient and practical channel access strategies becomes more complex.

Existing work studies the channel access scheme and parameter scheduling based on TWT mechanism considered the dense deployment. However, the deployment of terminals in different space and in different time is uneven, and the network situation changes greatly. The improvement of TWT mechanism and the scheduling of sleep time did not combine the new mechanism to propose the adaptive TWT scheduling strategy under different network density, which has certain limitations. In addition, due to the diversification of traffic services, the terminal traffic demand varies greatly. At present, few literature consider the characteristics of different terminals, and TWT scheduling also requires traffic adaptation. Therefore, the TWT scheduling policy for a single BSS still needs to be strengthened.

In practice, the coverage areas of the AP often overlap irregularly. Data transmission in overlapping areas faces different degrees of complex interference. The utilization of the channel is not so effective. Most of the existing studies address the TWT scheduling problem within a single BSS and do not involve the joint effective scheduling between different BSS. To fully use the channel resources, TWT scheduling requires multi-AP collaboration; on the other hand, based on channel bonding technology, different AP may use the same bands, and the channels overlap. TWT scheduling in heterogeneous situations also requires AP to be adaptive to the environments. New technologies such as converged spatial multiplexing will provide new perspectives for achieving both efficient and energy-efficient data transmission in dense deployment scenarios. Relevant research work is still rare, and it needs to be strengthened urgently.

Therefore, how to realize high energy efficiency, sustainable and anti-interference operation for dense WiFi by effectively modeling the channel access and optimizing the parameters in the TWT mechanism is still an important research problem to be solved. In view of the above deficiencies, we will carry out research on the adaptive sleep scheduling scheme of high energy efficiency for different scenarios in combination with new technologies, which helps to promote the rapid implementation and practicality of WiFi 6 standards.

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