Survey on OFDMA based MAC Protocols for the Next Generation WLAN

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***Abstract*—The physical (PHY) layer peak rate of the wireless local area network (WLAN) has been almost exponentially improved over the past 15 years since 1999. However, it is proved that the throughput is very low comparing to the PHY peak rate, and the media access control (MAC) efficiency is very low in the current WLANs specification, especially in dense deployment scenarios. Therefore, to achieve high MAC efficiency the IEEE Standards Association Standards Board (IEEE-SA) approves IEEE 802.11ax in March 2014, to draw up a brand new amendment for the next generation WLAN. One of the promising technologies to improve MAC efficiency is Orthogonal Frequency Division Multiple Access (OFDMA). In this paper, we firstly investigate the existing OFDMA based MAC protocols in the literature. Then, a framework of OFDMA based MAC protocol for the next generation WLAN is proposed. Finally, all of the existing OFDMA based MAC protocols listed in this paper are compared according to the proposed design issues. To the best of our knowledge this paper is the first survey focusing on OFDMA based MAC protocols for the next generation WLAN.**

***Keywords*—Survey; Next Generation WLANs; IEEE 802.11ax; MAC; OFDMA**

I. Introduction

Wireless local area networks (WLANs) have been significantly developed for 15 years. We use WLANs to communicate with each other and to know the world in our daily lives. World has changed, so as WLANs. Take 5GHz bandwidth as an example, IEEE 802.11a published in 1999 uses Orthogonal Frequency Division Multiplexing (OFDM) technology and achieves 54Mbps in one 20MHz channel [1], while IEEE 802.11n published in 2009 adopts OFDM and 4X4 multiple input multiple output (MIMO) and achieves 600Mbps in two 20MHz channels (total 40MHz) [1], and recently IEEE 802.11ac published in 2013 leverages OFDM and 8X8 MIMO and achieves 6.9Gbps in eight 20MHz channels (total 160MHz) [2]. Despite the almost exponentially increase of the PHY peak rate, in the dense deployment scenarios which is regarded as one of the unique characteristics of the next generation WLAN, the current WLAN specification can hardly be directly used due to the deteriorated low MAC efficiency.

To improve the efficiency of the WLAN, the IEEE-SA approved IEEE 802.11ax in March 2014, to draw up a brand new amendment to define standardized modifications both in MAC layer and PHY layer for the next generation WLAN. It requires four times throughput improvement per station (STA) in dense deployment scenarios comparing to the current WLAN, higher quality of service (QoS) of all kind of services especially video service, and efficient backward compatibility and coexistence with legacy WLANs.

In current WLANs, the nodes contend to access the wireless channel with the carrier sense multiple access with collision avoidance (CSMA/CA) method. Once one node successes to access the channel, it has to immediately use the whole channel resource for a time duration. Other nodes, located in the interference range of the receiver node, have to keep silent to avoid collision during the transmission period. In other words, current WLAN MAC protocol is a typical single user channel access and single user data transmission protocol. However, in the dense deployment scenarios of the next generation WLAN, the MAC efficiency of this single access single transmission protocol will deteriorate [4] to almost 33%-40%, as illustrated in Fig. 1. Thus the current MAC protocol will be no longer suitable.

One of the promising technologies to improve MAC efficiency is orthogonal frequency division multiple access (OFDMA). For instance, in order to achieve high MAC efficiency the OFDMA based centralized MAC protocol is adopted for channel access and data transmission in LTE [6] and WiMax [7]. With OFDMA technology, the whole channel is divided into several sub-channels, and several subcarriers comprise one sub-channel. Thus, OFDMA enable multiuser channel access and multiuser data transmission since different nodes could use different sub-channels simultaneously.

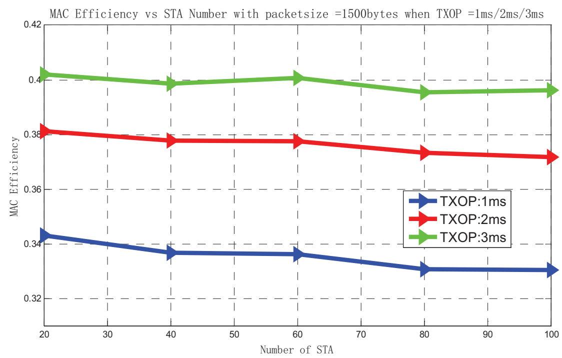

Fig. 1. MAC efficiency in dense deployment [5].

Many researchers have proved that the introduction of OFDMA into WLANs could make remarkable improvement on MAC efficiency. Hence, OFDMA is considered as one of the most promising technologies for the next generation WLAN. From the authors' viewpoint, there are total four advantages of introducing OFDMA into the next generation WLAN MAC protocol, i.e., multiuser access and transmission, QoS guaranteed scheduling, multiuser diversity and low signaling overhead.

*1) **Multiuser access and transmission:*** Multiuser could access channel and transmit data simultaneously. Due to the orthogonal feature of OFDM, the multiuser interference can be eliminated and thus multiple nodes can access channel simutaneously and transmit data concurrently.

*2) **QoS guaranteed scheduling:*** The QoS of the different categories of traffic can be guaranteed. The time-frequency resource block (RB) could be fine-grained using OFDMA, hence various scheduling algorithm may be employed in access point (AP) to guarantee the QoS of the traffics.

*3) **Multiuser diversity:*** The throughput of WLANs can be further improved by taking advantage of multiuser diversity in frequency domain. Since multiple users can access the channel simutaneously and the RBs can be scheduled, each user can be allocated with only high channel gain RBs.

*4) **Low signaling overhead:*** The signaling overhead of the OFDMA can be largely decreased. Since some control signaling could be aggregated into one frame using OFDMA, the same frame space time can be shared by many nodes.

The rest of the paper is organized as follows. The existing OFDMA based MAC protocols are presented in Section II. In Section III, the framework of the OFDMA based MAC protocols for the next generation WLAN is proposed, based on which ten MAC design issues are concluded, and the existing MAC protocols listed in this paper are compared according to the design issues. Section IV concludes this paper.

II. SURVEY ON OFDMA BASED MAC PROTOCOL

Recently, there is a great number of paper focusing on implementing OFDMA in WLANs, including MAC protocol design, new PHY technologies, resource allocation and so on. This paper pays great attention to survey and investigate OFDMA based MAC protocols for WLANs, especially to uplink MAC protocol design. The research on OFDMA based MAC protocols design is classified into total four categories based on two domains, i.e., sponsor node (AP or STAs) and channel access type (OFDM or OFDMA), shown in Fig. 2. These four categories are introduced respectively.

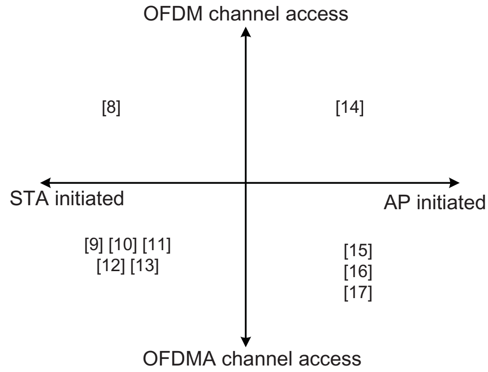

Fig. 2. Four categories of OFDMA based MAC protocol.

A. STAs Initiated Channel Access with OFDM

Based on Request to Send (RTS) and Clear to Send (CTS) mechanism in IEEE 802.11, [8] proposed an OFDMA MAC protocol using channel state information (CSI) measurement. STAs contend for the channel resource as in current WLANs, and once AP receives a RTS frame from STAs, AP sends ask for request (AFR) to allocate resource to the STA sending the RTS frame based on the CSI capturing from RTS frame and to ask for new channel access request from other STAs. When all resource is allocated, collision happens in channel access or AP does not receive RTS frame for a given time, AP could allocate the rest resource to the last STA sending RTS frame by sending AFR' frame, and then send CTS frame to start data transmission as shown in Fig 3.

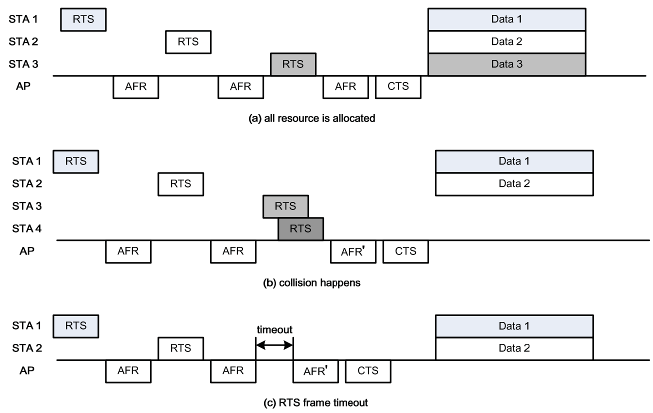

Fig. 3. Multiuser CSMA/CA protocol based on OFDMA transmission.

B. STAs Initiated Channel Access with OFDMA

In [9], time-frequency two domain backoff procedure is proposed to implement random channel access based on CSMA/CA in IEEE 802.11. The basic idea of time-frequency two domain backoff procedure is that STAs could monitor all the sub-channels in WLAN, and adjust the backoff rate according to idle sub-channel number. In Fig. 4, there are total two STAs and two sub-channels in WLAN. At the beginning of backoff, STAs chose a random number independently (STA1 chooses 4 and STA2 chooses 6), and the backoff rate is 2 since there are two idle sub-channels. STA1 finishes backoff procedure after 2 time slot and randomly selects one sub-channel to transmit DATA frame. STA2, on the other hand, continues backoff procedure and the backoff rate is 1 since the idle sub-channel number is one. After another 2 time slot STA2 also completes backoff procedure and selects other sub-channel to transmit DATA frame. Based on the work in [9], some improvement is introduced in [10] and [11]. In [10] CSI is considered to take good advantage of multiuser diversity, while in [11] the process of both uplink and downlink transmission is described, and it is approved that there should be one backoff timer for each sub-channel to decrease access delay.

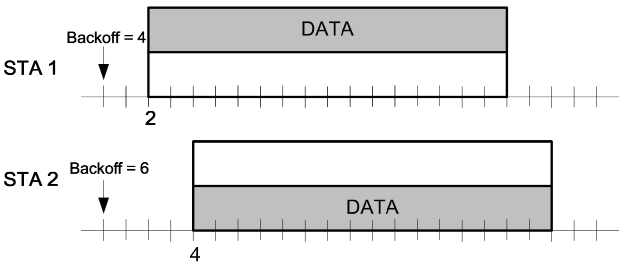

Fig. 4. Time-frequency two domain backoff process.

An hybrid OFDMA based MAC protocol is proposed in [12]. The total process of MAC protocol consists of transmission opportunity request (TR) phase and scheduled data transmission (ST) phase. In TR phase, each STA runs one CSMA/CA procedure on every sub-channel, thus STAs should monitor all the sub-channels in WLAN. The backoff counters decrease one when corresponding sub-channel has been idle for a minimum time slot. Once any backoff counter reaches zero in TR phase, STAs could send channel access request frame. In the ST phase, AP sends scheduling frame to schedule channel resource allocation, and all the sub-channels are assigned to just one STA at the same time like OFDM operation. [13] designs the same type MAC protocol as [12], and the main difference of [13] is that OFDMA is employed in data transmission phase.

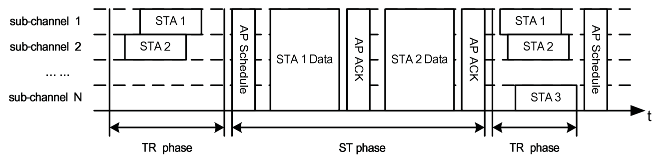

Fig. 5. An hybrid OFDMA based MAC protocol.

C. AP Initiated Channel Access with OFDM

In [14], it is proposed that only AP could occupy the channel resource and shares the channel resources with other STAs in the transmission opportunity (TXOP). The detail of this protocol is illustrated in Fig. 6. At first, AP occupies the channel resource for TXOP duration following CSMA/CA in IEEE 802.11. AP asks the STAs to reply CTS frames to provide service information in the RTS frame. After receiving all the CTS frames of STAs, AP sends DL-ARBI (downlink assigned resource block information) and UL-ARBI (uplink assigned resource block information) to announce scheduling information, and STAs send or receive data frame according to the scheduling information. At the end of downlink or uplink data transmission, STAs send ACK frames one by one, while AP sends just one UL-ACK frame. In addition, the whole channel is divided into RB like in LTE network.

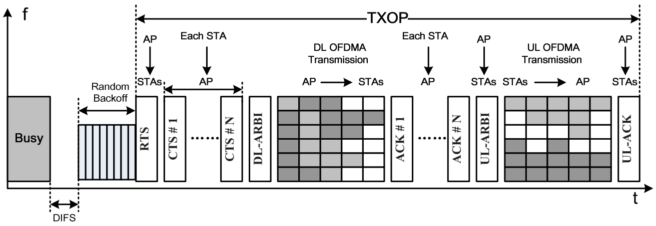

Fig. 6. AP contend for channel resource and allocate to STAs.

D. AP Initiated Channel Access with OFDMA

In [15], the uplink transmission and downlink transmission are all controlled by AP. When AP has data packets for STAs, AP sends downlink data transmission scheduling information to STAs on different sub-channels. Once STAs receive the downlink scheduling information, STAs replay ACK frame on the corresponding sub-channel. After receiving ACK frame of STAs, AP transmit downlink data and wait for STAs' ACK frames. For the uplink data transmission, AP send uplink polling frame to ask for uplink request frame (ULR) of STAs. Then STAs send ULR in their own sub-channel according to the information in uplink poll frame. After collecting the uplink request of STAs, AP sends scheduling frame to allocate channel resource to STAs. Once receive the scheduling frame, STAs send data frames on the allocated sub-channel.

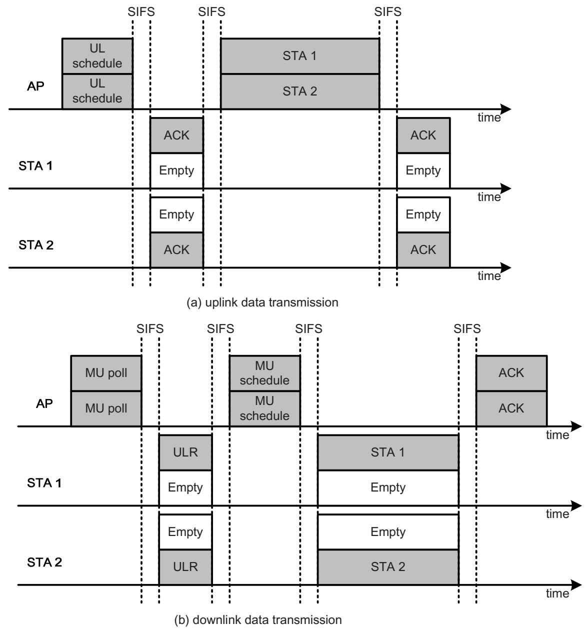

Fig. 7. Pure AP scheduling MAC protocol.

STAs in a BSS is grouped based on the propagation delay before channel access and data transmission by AP in [16]. After grouping process, the STAs with similar propagation delay are in one group, and AP can schedule each group of STAs in order. In the transmission time of each group, the AP only receives RTS frames sent in q symbols duration, and then sends one CTS frame to announce scheduling information. In order to utilize all the channel resource AP could schedule the channel resource both in time and in frequency as long as that different data frames satisfy symbol synchronization.

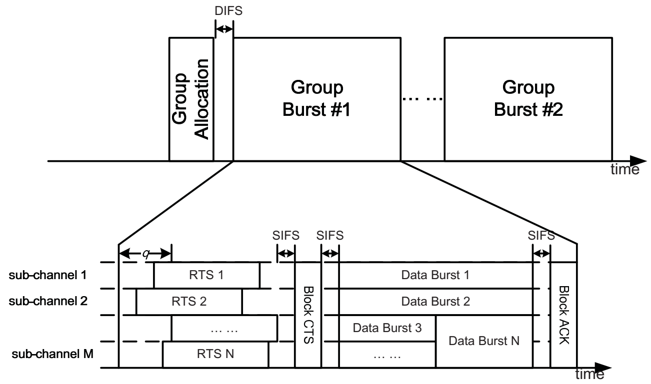

Fig. 8. Group based OFDMA MAC protocol.

In [17], an MAC protocol based on point coordination function (PCF) is proposed. As shown in Fig. 9, after AP senses the channel is idle for a PCF inter-frame space (PIFS), it sends a beacon frame to inform the 802.11ax STAs to submit their access request in the following request period, and to make legacy 802.11 STAs avoid sending their packets in the specified time duration. In request period, STAs submit their access request through OFDMA operation, and AP listens all the subcarriers to collect request information. In contention free period, AP divides channel resource into small resource block both in time and frequency domain, and sends CF-poll frame to schedule the resource blocks to the STAs successfully transmitting access request. After all the STAs transmit their packets to AP on the allocated resource blocks, AP broadcasts an ACK frame and releases the channel resource.

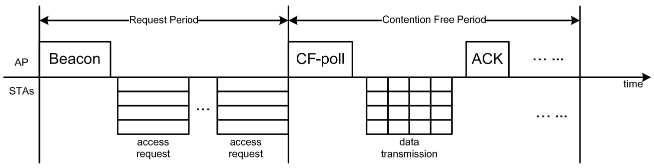

Fig. 9. OFDMA MAC protocol based on PCF.

III. FRAMEWORK FOR PROTOCAL DESIGN

To satisfy the requirements of the next generation WLAN, a framework of OFDMA based multiuser MAC protocol is proposed, as shown in Fig. 10, which consists of 3parts.

*1) **Multiuser channel access:*** A number of STAs could access channel simultaneously by using OFDMA to decrease collision probability and thus improve the channel access efficiency. The spirit of simple and flexibility in IEEE 802.11 distributed coordination function (DCF) should be keeped in multiuser channel access procedure, and it is not necessary to add overmuch signaling. It is better for STAs to carry service information and channel state information during channel access which could be helpful for AP to allocate channel resource.

*2) **Multiuser resource scheduling:*** After the collection of channel access requests, service information and channel state information, AP need to schedule the channel resource to all the STAs which access channel successfully. The two main goals of resource scheduling are satisfying QoS of different services and achieving multiuser diversity. Since the node mobility in WLANs is slight, the coherence bandwidth in WLANs is wider than in LTE and WiMax systems. Thus, the scheduling resource size in the next generation WLAN should be relatively large.

*3) **Multiuser data transmission:*** all the scheduled STAs can transmit data several times within a TXOP, and for each data transmission there could be a group of STAs share the transmission time simultaneously. A group of STAs could transmit data at the same time by using OFDMA and/or multiuser multi-input and multi-output (MU-MIMO). In IEEE 802.11ac, downlink MU-MIMO is already implemented, and in the next generation WLANs uplink MU-MIMO is also a proposed technology which is out of scope of this paper. In addition, it is proposed that OFDMA is employed for the acknowledgement transmission to reduce the signaling overhead.

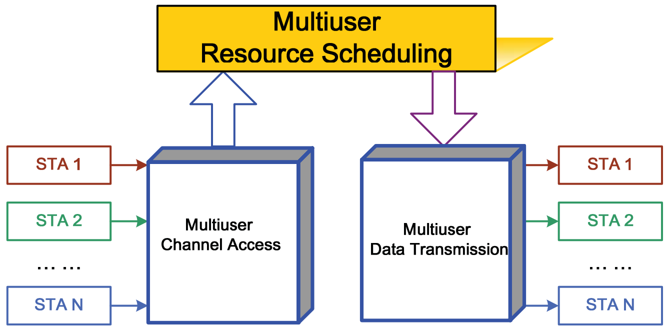

Fig. 10. Framework of OFDMA based multiuser MAC protocol.

With the frame work in mind, the surveyed OFDMA based MAC protocol is compared in total ten design issues as shown in TABLE I and II.

TABLE I. COMPARISON OF OFDMA BASED MAC PROTOCOL-PART I

item	[8]	[9]	[10]	[11]	[12]
Multiuser Access		√	√	√	√
Multiuser Transmisson	√	√	√	√	
Multiuser Diversity	√		√		
Non sub-channel monitor	√				
CSI Measurement	√				
AP Scheduling	√		√	√	√
Downlink Transmission		√	√	√	
QoS Guaranteeing					
Simple Signaling Exchange	√	√	√	√	√
Compatibility	√				

TABLE II. COMPARISON OF OFDMA BASED MAC PROTOCOL-PART II

item	[13]	[14]	[15]	[16]	[17]
Multiuser Access	√		√	√	√
Multiuser Transmisson	√	√	√	√	√
Multiuser Diversity		√			
Non sub-channel monitor		√	√		√
CSI Measurement		√			
AP Scheduling	√	√	√	√	√
Downlink Transmission		√	√		
QoS Guaranteeing		√			
Simple Signaling Exchange	√		√		
Compatibility		√			√

IV. CONCLUSION AND FUTURE WORK

The dense deployment scenario is one of the main characteristics of the next generation WLAN. However, the current MAC protocol in IEEE 802.11 is not suitable in the dense deployment scenario due to its low MAC efficiency. This is mainly resulted from its feature of single-user channel access and single-user data transmission. Therefore, how to design a high efficiency MAC protocol becomes one of the key problems in IEEE 802.11ax. OFDMA is one of promising technologies in the next generation WLAN, since it enables multiuser channel access and multiuser data transmission.

In this paper, the existing OFDMA based multiuser MAC protocols are surveyed and categorized into four categories. Moreover, the framework of OFDMA based MAC protocol for the next generation WLANs including multiuser channel access, multiuser resource scheduling and multiuser data transmission is proposed. Based on this framework, the MAC protocols surveyed in this paper are compared according to ten design issues. In the future, we will dedicate ourselves to propose an suitable OFDMA based multiuser MAC protocol for the next generation WLAN according to the requirements of IEEE 802.11ax and the framework proposed in this paper.

V. ACKNOWLEDGEMENT

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REFERENCES

[1] IEEE 802.11, *Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications*, IEEE 802.11 Std., Mar. 2012.

[2] IEEE 802.11, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Enhancements for Higher Throughput Amendment 4: Enhancements for Very High Throughput for Operation in Bands below 6 GHz*, IEEE 802.11 Std., Dec. 2013.

[3] IEEE 802.11, *Proposed 802.11ax Functional Requirements*, IEEE 802.11-14/0567r7, Jul. 2014.

[4] IEEE 802.11, *HEW MAC Efficiecy Analysis for HEW SG*, IEEE 802.11-13/0505r0, May 2013.

[5] IEEE 802.11, *Performance Evaluation for 11ac*, IEEE 802.11-13/0576r0, May 2013.

[6] IEEE 802.16, *Part 16: Air Interface for Fixed Broadband Wireless Access Systems*, IEEE 802.16 Std., 2004.

[7] 3GPP, TS 36.201-820, *Evolved Universal Terrestrial Radio Access (E-UTRA); Long Term Evolution (LTE) physical layer; general description*, 3GPP Std., Dec. 2008.

[8] M. Kamoun, L. Mazet, and S. Gault, "Efficient backward compatible allocation mechanism for multi-user CSMA/CA schemes," *First International Conference on Communications and Networking(ComNet 2009)*, pp. 1-6, 2009.

[9] Hojoong Kwon and Hanbyul Seo and Seonwook Kim and Byeong Gi Lee, "Generalized CSMA/CA for OFDMA systems: protocol design, throughput analysis, and implementation issues," *IEEE Transactions on Wireless Communications*, vol. 8, no. 8, pp. 4176–4187, Aug. 2009.

[10] Hojoong Kwon, Seonwook Kim and Byeong Gi Lee, "Opportunistic multi-channel CSMA protocol for OFDMA systems," *IEEE Transactions on Wireless Communications*, vol. 9, num. 5, pp. 1552-1557, May 2010.

[11] Xudong Wang and Hao Wang, "A Novel Random Access Mechanism for OFDMA Wireless Networks," *2010 IEEE Global Telecommunications Conference (GLOBECOM 2010)*, pp. 1-5, 2010.

[12] Y. P. Fallah, S. Khan, P. Nasiopoulos, H. and Alnuweiri, "Hybrid OFDMA/CSMA Based Medium Access Control for Next-Generation Wireless LANs,"*, 2008 IEEE International Conference on Communications (ICC)*, pp. 2762-2768, 2008.

[13] G. Haile, and Lim Jaesung, "C-OFDMA: Improved Throughput for Next Generation WLAN Systems Based on OFDMA and CSMA/CA," *2013 4th International Conference on Intelligent Systems Modelling Simulation (ISMS)*, pp. 497-502, 2013.

[14] T. Mishima, S. Miyamoto, S. Sampei, and Wenjie Jiang, "Novel DCF-based multi-user MAC protocol and dynamic resource allocation for OFDMA WLAN systems," *2013 International Conference on Computing, Networking and Communications (ICNC)*, pp. 616-620, 2013.

[15] Hanqing Lou, Xiaofei Wang, Juan Fang, M. Ghosh, Guodong Zhang and R. Olesen, "Multi-user Parallel Channel Access for high efficiency carrier grade wireless LANs,"*, 2014 IEEE International Conference on Communications (ICC)*, pp. 3868-3870, 2014.

[16] Junwoo Jung and Jaesung Lim, "Group Contention-Based OFDMA MAC Protocol for Multiple Access Interference-Free in WLAN Systems," *IEEE Transactions on Wireless Communications*, vol. 11, num. 2, pp. 648-658, Feb. 2012.

[17] Der-Jiunn Deng， Kwang-Cheng Chen and Rung-Shiang Cheng, "IEEE 802.11ax: Next generation wireless local area networks," *2014 10th International Conference on Heterogeneous Networking for Quality, Reliability, Security and Robustness (QShine)*, pp. 77-82, 2014.