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A Review on OFDMA and MU-MIMO MAC Protocols for upcoming IEEE Standard 802.11ax

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Abstract-IEEE introduced a new standard IEEE 802.11ax for the next generation WLANs.As we know,the current throughput is very low because of the current Media Access Control(MAC) in present wireless area networks.So,the concept of Orthogonal Frequency Multiple Access(OFDMA) to facilitate multi user access is introduced.The main challenges of adopting OFDMA areoverhead reduction and synchronization.To meet these challenges this paper revised an OFDMA based OMAX protocol.And due to various various bandwidth consuming applications and devices today's WLANs have become stressed and low at throughput.To handle this problem MU MIMO is used to improve the performance of WLANs.This paper surveys uplink/downlink mutli user MAC protocols for MIMO enabled devices.It also identifies the key requirements of MAC protocol design.

Keywords- *OFDMA, MU MIMO, MAC protocol*

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1. Introduction

Wireless Local Networks(WLANs) based on IEEE 802.11 is predominant in our life to deliver high speed wireless connectivity at home, at offices and public places [1].This paper will focus on the IEEE 802.11ax in which OFDMA MAC protocols and MU MIMO MAC protocols that are used to improve spectrum efficiency and throughput.In any case, the fast development of wirelessdevices has made WLANs low at throughput.The most recent IEEE WLAN revision IEEE 802.11ac respond to these difficulties by characterizing an arrangement of PHY and Medium access control (MAC) features[2].A key test of IEEE 802.11ac is to accomplish a productive reuse of the range when a few transfer speeds are utilized as a part of situation with numerous covering WLANs.Increase in the channel width hypothetically permits singular WLANs to accomplish higher throughput.To take care of the issue of recurrence covering IEEE 802.11 hatchet correction in Wireless neighborhood systems (WLANs) framework is presented. The IEEE 802.11ax alteration will be dispatched in 2019 and it will be the IEEE 802.11 gives answer for the difficulties of thick situations and high-data transmission requesting WLAN scenarios [3].We need to enhance general throughput and range proficiency of Wireless Local Area Networks (WLANs) as the requirement for quick correspondence is expanding day by day.Wireless Communication innovation gives exceptionally proficient framework execution that prompts quick correspondence services.High Efficiency Wireless Area Network[WLANs] study bunch known as IEEE 802.11 has characterized an arrangement of new specialized elements i.e.,IEEE 802.11ax-2019 standard [4][24][25][27].

2. OFDMA (Orthogonal Frequency Division Multiple Access)

The MAC layer of WLANshardly changed for years.WLANs adopted Distributed Coordination Function (DCF) as the Medium Access Control (MAC) protocol since starting. In DCF protocol, any station (STA) can send data to access point (AP) at anytime and at the same time only one STA could use thechannel resource and transmit data.However,DCF used currently is applicable to only low density WLANs [6].On the other hand; in high density deployment cases the MACefficiency of DCF is very low due to the single useraccess and single user transmission.Clearly, multiuserMAC is needed to solve the problem above.Thereby,OFDMA is considered[20][21][22][23].Using OFDMA,the channel is divided into several sub-channels and subcarriers.Thus,it allow multiuser channel access and multiuser data transmission as many nodes can use different sub-channels simultaneously.

However, there are two challenges of adopting OFDMA.

This paper will concentrate on the IEEE 802.11ax in which OFDMA MAC protocols and MU MIMO MAC protocols that are utilized to enhance range effectiveness and throughput.

1. Synchronization
2. Overhead Reduction

Protocol Design

To design a promising MAC protocol for next generationWLANs, the synchronization issue, and overhead reductionshould be considered vigilantly.[1]Theframework of an OFDMA based multiuser access for IEEE802.11ax (OMAX) protocol is proposed for next generationWLANs in this paper. In OMAX protocol, fast backoff process and whole channelphysical channel sensing are adopted to solve synchronization problem, also enhanced RTS/CTS mechanism and new frame structure are depicted to reduceoverhead.

To outline a promising MAC protocol for next generationWLANs, the synchronization issue, and overhead lessening ought to be viewed as vigilantly [1]. The system of an OFDMA based multiuser access for IEEE802.11ax (OMAX) protocol is proposed for cutting edge WLANs in this paper. In OMAX protocol, quick backoff procedure and entire channel physical channel detecting are embraced to take care of synchronization issue, additionally upgraded RTS/CTS system and new edge structure are delineated to decrease overhead.

Procedure of OMAX protocol :-

1) STAs distinguish the entire channel as indicated by the physical transporter detecting in DCF until the channel is unmoving for circulated between casing space (DIFS).
2) STAs take out the step back procedure utilizing the backoff rules as utilized as a part of IEEE 802.11 DCF expect the backoff counter in STAs short 4 for every unmoving opening subsequent to there are four sub-diverts in Fig 1.
3) After finishing backoff, STAs arbitrarily select one sub-channel to transmit solicitation to send (RTS), and AP transmit assemble clear to send (G-CTS) to show the sub-channels allotment data as per the administrations necessity of various STAs.
4) STAs transmit DATA as indicated by the data inG-CTS, and AP answers the gathering affirmation (G-ACK).

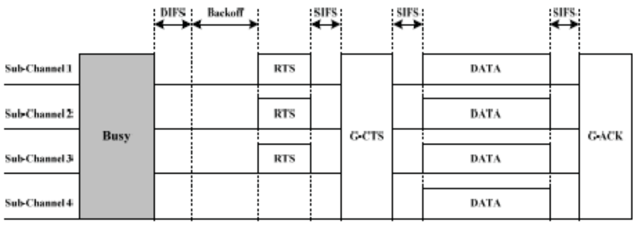

Fig 1.Procedure of OMAX Protocol

Fast Backoff Process

In OMAX protocol, each STA keeps up one backoff clock for all the sub-channels. The backoff counter is picked in the extent [0, CW] (CW implies conflict window size). CW worth is chosen by the parallel exponential backoff calculation: CW is set as the base quality at the primary backoff stage for each transmission and it is multiplied after each fizzled transmission until the maximum estimation of CW is come to. Each STA transmit RTS after the backoff counter is zero.

Whole Channel Physical Channel Sensing

In DCF protocol,concurrent transmission happens just on various sub channels.There is a cyclic prefix (CP) time in OFDM symbol [5].The time bungle ought to be not exactly CP time.But it is troublesome for numerous STAs to begin transmission in CP time when sub-channel physical detecting is used.To fathom this entire channel physical divert detecting is utilized as a part of OMAX.All STAs sense entire channel as opposed to detecting sub channels.If all sub directs are out of gear state then it is considered as unmoving else it is considered as busy.So, when one STA begins transmission the various STAs will consider it as busy. And those STAs whose backoff procedure is finished in the same opening could at the same time begin their transmission.

Enhanced RTS/CTS Mechanism

In customary WLAN, if two STAs transmit RTS in the meantime, their RTS bundles will slam into each other and AP couldn't get both of them. Be that as it may, in OMAX protocol, when a few STAs transmit RTS at the same time AP still gets some RTS packets.Though some are impacted and some are gotten effectively. As represented in Fig 2.(RTS 1, RTS 2) and (RTS 3, RTS 4) are crashed in sub-channel 1 and sub-channel 2, RTS 5 in sub-channel 3, RTS 6 in sub-channel 4 and RTS 7 in sub-channel 5 are effectively gotten by AP. By and large, there are all out 7 STAs transmitting RTS, and AP got 3 RTS taking all things together.

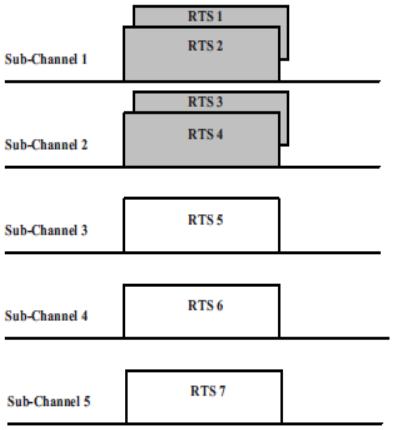

Fig. 2 RTS Transmission in OMAX Protocol

At the point when AP gets RTS from each sub-channel, it ascertains the subcarrier task utilizing any booking calculation i.e., Round Robin planning calculation. For example, the channel is separated into 4 sub channel at to begin with, and AP needs to apportion 4 sub-channels to the STAs effectively transmitting RTS. In the event that there

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are 4 STAs effectively transmitting RTS, each STA acquire 1 sub-channel; if there are 3 STAs effectively transmitting RTS, one STAobtain 2 sub-channels while each of the other 2 STAs get 1sub-channel, et cetera. After the figuring, AP includes the scheduling result in G-CTS in OMAX protocol.

In the wake of getting G-CTS from AP, STAs finishing RTS transmission hold up short between casing space (SIFS) time in any case, and after that transmit DATA all the while through their allotted sub-channels. At last, when all DATA is gotten from every sub-channel, it transmit G-ACK.G-ACK is utilized to suggest that there are affirmation data for some STAs.

New Frame Structure

[1]In OMAX protocol, the frame structure of RTS andDATA is similar to DCF, and the only difference between RTS and DATA in OMAX and DCF is that RTS andDATA in OMAX is transmitted in sub-channel not in thewhole channel.

In Fig. 3. There are morethan one Revive Address (RA) field in G-CTS, and there is ascheduling information (SI) field follows each RA field toindicate the sub-channel allocation. There are total 16 bits inSI field to present allocation information of at most 16 subchannels,in which 0 indicates that corresponding sub-channelis not allocated to the STA. In G-ACK frame 1 indicates the corresponding sub-channelis allocated to the STA, and thereis an additional ACK info field to acknowledge all the DATApacket AP has received. Since there are most 16 sub-channelsin WLAN, ACK info field is also 16 bits as the same in SIfield. Moreover, the receiver of G-ACK is a group of STAs,the RA field in G-ACK is the address of AP rather than anySTA address.

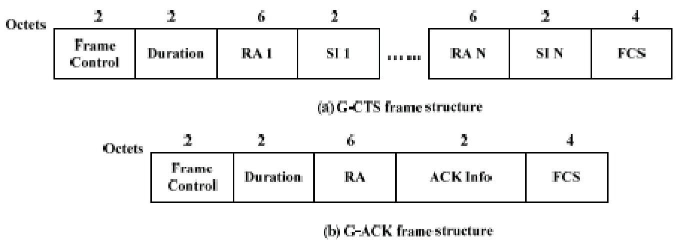

Fig. 3 G-CTS and G-ACK frame structures

3. MUMIMO (Multi-User Multiple In Multiple Out)

Another key attribute that is proposed for improving the efficiency is MU MIMO. To meet the demand of higher performance the next generation WLANs will employ promising Muti-user Multiple Input and Multiple Output technology in the PHY to improve the reliability and capacity of channel.Thus,it is important to study the impacts of MIMO on the Medium Access Control (MAC) of WLANs.

Multiple-input multiple-output (MIMO) is asmart antenna technology.It uses multiple antennas at bothsender and receiver side to improve performance.MIMO communications have been studied in detail for wireless local area networks (WLANs) as specified in the IEEE 802.11n standard.A MIMO system uses two types of gains: spatial diversity gain and spatial multiplexing gain.Spatial diversity can tackle severe fading and improves the reliability of the wireless link.It duplicates information among multiple antennas. Spatial multiplexing uses multiple physical paths between the antennas at transmitter and receiver end to carry multiple data streams [11].

IEEE 802.11ax-2019 will continue implementing SU-MIMO and Downlink MU-MIMO both, as in IEEE 802.11ac-2013. However,it may also support Uplink MU-MIMO, Massive MIMO and NetworkMIMO.Multi-user MIMO enables multiple transmissions at the same time to different STAs(stations) from the AP(Access Point) in downlink and from multiple STAs to the AP in the uplink[2].

REQUIREMENTS TO DESIGN MU-MIMO MAC PROTOCOLS

MU-MIMO transmissions in WLANs have two communicationpaths: Uplink (i.e., STAs continuouslysend frames to the AP, which is also referred as the MIMO-MACchannel) and the Downlink.The MU-MIMO uplink and downlink transmissions have different problems and different requirements in designing MAC protocols.

A. De/Pre-Coding Schemes for Receptions/Transmissions

[2]In the uplink, the AP needs to perceive the transmitted signals from STAs that is Multi-user Detection (MUD) problem. In the downlink, firstthe AP makes a group of STAs based on a criterionsuch asthe queue occupancy. It is necessary that the selected STAs are spatially non-correlated,it is scheduling problem. The next is preceding the outgoing frames. It is to nullify the interferenceamong concurrent spatial streams, which is called as Multi-user InterferenceCancellation (MUIC) problem. An illustrationis given in Fig. 4 about MUMIMOuplink and downlink transmissions.

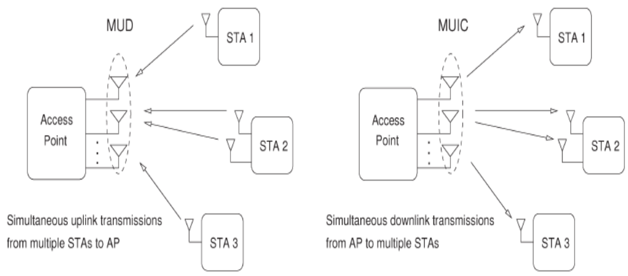

Fig 4. Up/Down-link multi-user transmissions

MUD Schemes for Uplink Receptions:

a)Minimum mean square error (MMSE):Signals received at each antenna of the AP are multiplied by a complexweight and then added up. The weight is adjusted by minimizing the difference between the sum of the outputsignal and a reference that is known by both the AP and STAs.The performance improves with the number of AP's antennas increment anddegrades with the network scales up[7].

b)Sphere decoding (SD):SD based MUD algorithms have been introduced to ease the complexity of the pureML MUD to attainthe performance of ML MUD. The wholeidea is to gerthe radius of the search scope minimized by focusing on the area of the ML solution.

c)Maximum likelihood (ML)*:* The ML MUD consists adeep search to extract the transmitted signals. It providesbetter performance,but has highestcomplexity. Complexity increases as the number ofSTAs increases and that makes it impossible in practical.

d)Successive interference cancellation (SIC):The SICis an enhancement to MMSE MUD.A detection algorithm isused to estimate the received power at the AP. Thesignal which is having highest power and is the least interfered, get detected. This signal is then subtracted frommixed signals.Next highest signal is singled usingthe same process until the lowest STA signal is found.

MUIC Schemes for Downlink Transmissions:

a)Block diagonalization (BD):Block Diagonalization is a very famous channel inversion technique, especially in the case where receivers have multipleantennas.Singular value decomposition (SVD) isemployed to discard unitary matrices, which makes the computationalcomplexity of BD higher than MMSE.

b)Zero forcing (ZF):In the Zero Forcing scheme, the originalsignal is multiplied with the pseudo-inverse of the channel matrixto completely nullify the MUI. The conditions are (1) the AP hasthe full CSI, and (2) the channel is invertible.The ZF scheme causes an increase in theerror rate (because the noise vector is amplified) when multiplied with the pseudo-inverse weight. The amplifiednoise vector shows that ZF can only work well for the highSignal-to-Noise Ratio (SNR) region.The ZF schemerequires that the number of total receiving antennas should not be lessthan that of transmitting antennas[16].

In comparison, [8] and [16] shows that the MMSE scheme can reduce the overallerror rate without amplifying the noise and show thatthe MMSE scheme performs better than ZF in the low SNRregion, and attains the performance of ZF in the high SNRregion.

c)Dirty paper coding (DPC):DPC is a non-linear precodingscheme introduced by Costa[15], which canachieve the optimum performance at the cost of significantcomputing complexity.The process is to add an offset to thetransmitted signal, which tells that the AP has to know theinterference in advance and the AP always has codewords, i.e., the infinite length of codewords make DPCinappropriate for practical use.

B. Channel State Information Acquisition

The acquisition of CSI(Channel State Information Acquisition) isassumed at the AP.There are two types of CSI:the statistical CSI and the instantaneous one.The Statistical CSI works onthe statistical characteristics of the channel todecide the CSI, which performs well where thechannel has a large mean component or strong correlation(either in space, time, or frequency).Where theinstantaneous CSI means thecurrent channel state is known and that enables the sender to adapt its outgoing signal. Because wireless channel varieswith time, the instantaneous CSI has to be calculated repeatedly on short-term basis[2].

The acquisition of CSI is done byestimating a training sequence that is known by both sender andreceiver.In the uplink, the AP can easily derive the uplinkCSI from the PHY preambles of received frames. While,in the downlink, the acquisition of the CSI isnot that easy.

There are two CSI feedback schemes:

1) Implicit feedback,where the AP computes the CSI by calculating training sequences sent from STAs

2) Explicit feedback,where STAs calculate the CSI by calculating the training sequences sent from the AP, and then STAs feedback the CSI to the AP.

Note: No matter which CSI feedback scheme is applied,theCSI feedback affects the network performance.It is because ofthe frequent CSI feedback increases overheads,while the infrequent results in the outdated CSI that causes interference among parallel streams.

C. The Scheduling Scheme

Scheduling scheme is another way to design MU MIMO MAC protocols. It selects a group of STAs orframes for transmissions which can optimize some aspects ofthe system performance. The design of the scheduling scheme can be divided intotwo types: the scheduling in the uplink and downlink.

1)Scheduling in the Uplink:In the uplink, it is very difficult to make a joint scheduling decision among spatially distributed STAs(Stations).Uplink transmissions are categorized into the coordinated and the uncoordinated depending on whether the RTS/CTS(Request To Send/Clear To Send) exchanging process is employed or not.In the un-coordinated one, STAs utilize a random MAC mechanism to decide which STA will be allowed for transmissions, which have two cases: Synchronous[12] and Asynchronous[13] data transmissions, as shown in Fig. 5.The synchronous scheme allows multiple STAs that automatically choose the same BO(Backoff Process) to transmit data frames continuously,while the asynchronous one allows STAs to transmit frames along with other transmissions.In the coordinated, STAs utilize the MAC random mechanism to struggle for the channel, while let the AP(Access Point) to decide who will be involved in the followed parallel transmissions.[14]The coordinated uplink access scheme implies the implication of the AP (as a coordinator) and the employment of RTS/CTS exchanges. The AP extracts the interested information fromRTSs sent by the contending STAs, and then it makes scheduling decisions for all the frame transmissions (i.e., the scheduled transmissions), or the AP just responds to the received RTSs to inform who have won the channel contention (i.e., the un-scheduled transmissions). A general example of the coordinated uplink access is shown in Fig. 6

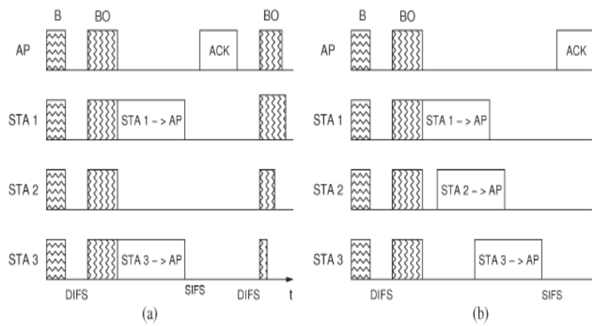

Fig.5Un-coordinated uplink channel access (a) Synchronous data transmissions (b)Asynchronous data transmissions

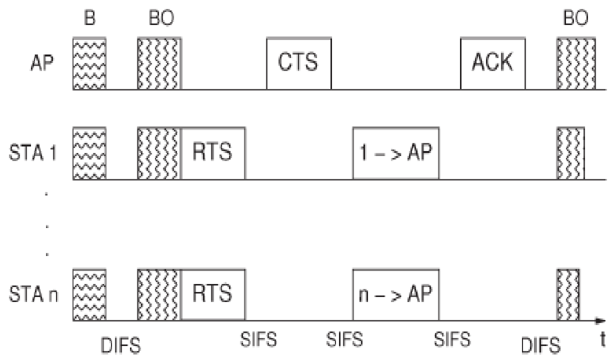

Fig.6Coordinated uplink channel access

2) Scheduling in the Downlink:As compared to the uplink, the AP plays direct role in the downlink scheduling, which can be categorized in the packet based scheduling and theSTA based one.The packet based scheduling algorithmuses a unique metrics,the packetqueuing status of the AP.The STA based scheduling have a criteria to identify set of STAs for simultaneous downlink transmissions.This criteria includes the channel state,spatial compatibility[18],fairness,etc.A combination of the previously mentioned scheduling schemes is considered most of the time.However,the mostcommonly used scheduling schemes are Fist In First Out and Opportunistic followed by greedy and WFQ.

3) Cross-Layer Scheduling:The combination of parametersfrom different layers should be jointly considered [19], which isthe concept of cross-layer scheduling.The cross-layer scheduling promises to achieve the optimal system performance with parameters from different layers, such asthe channel information at the physical layer, queuing state atthemedia access layer and routing information at the network layer.But the cross-layer scheduling is far morecomplex than combining these parameters.The reasonis that the interaction between the layers breaks the OSI layered structures andcreates problems between the performance and the stability ofsystems,which can lead to unexpected results as thewireless network scales up[17].

In general,with the CSI acquisition and other layers'key parameters, the following points should be considered for Cross-layer design.

• **System Complexity**: As we know, the cross-layer design has shattered theprotocol layered structure; the new wireless systemsmight become incompatible with protocolsystems. Since the maintenance or upgrade of the cross-layer protocolis no longer isolated within each layer, and any parameterchanges must be carefully traced and coordinated [17].

•**Design Constraints**: Different data rates are mostly appliedto distributed STAs,which might causeinterferences from stronger signals to weaker signals in thedownlink or the near-far effect in the uplink. Therefore, control or data rate selection scheme needs tobe taken account with the MAC design. In addition, someQoS(Quality of Services) metrics such as the average delay and the jitter are also needed(i.e.,decreasing collisions and increasing throughput).And sometimes,maximizing throughput means sacrificing transmissionopportunities of some low-rate STAs.

4. Conclusion

An OFDMA based multiuser access for IEEE 802.11axnamed OMAX protocol is revised for upcoming WLANs in this paper. The framework of OMAX is explained in detail. In OMAX, whole channel physical channel sensingand fast backoff process is proposed to solve synchronizationproblem and enhanced RTS/CTS mechanism and framestructure is designed to reduce overhead.The theoreticalanalysis of the OMAX protocol is discussed. The uplink and downlink MU-MIMO MAC protocols forWLANs are investigated and categorized in the paper.The requirements for designing MU-MIMO MAC protocols are identified such as Channel Acquisition Information and Scheduling Schemes and sometypical MUD and MUIC techniques for de/pre-coding are described.

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