An OFDMA MAC Protocol Aggregating Variable Length Data in the Next IEEE 802.11ax Standard

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***Abstract*—A new standard of the IEEE 802.11 standard is behind the scenes whose ratification is planned for the end of the current year (2019). It is the 802.11ax or HEW (High Efficiency Wireless local area network) standard dedicated to the future wireless networks. This standard promised better efficiency and throughput in more difficult use cases (dense environments) by exploiting pre-existing physical and MAC (Medium Access Control) capabilities and introducing new concepts, such as: OFDMA (Orthogonal Frequency-Division Multiple Access), 1024-QAM (1024-Quadrature Amplitude Modulation) modulation order, FD (Full-Duplex) communications and spatial reuse. The new OFDMA modulation technology divides the transmission channel into sub-carrier groups (known as: RUs for Ressources Units) to which up to 9 users can simultaneously access a 20 MHz channel. In order to improve the user data rate in dense areas, an OFDMA-based MAC access method is proposed in this paper by enabling the principle of aggregating frames of variable lengths while ensuring synchronization. Our proposal is followed by simulation results to demonstrate the improvement in throughput that it offers.**

***Keywords*—IEEE 802.11ax HEW, OFDMA, Medium Access, Variable Length Data, Aggregation, Simulation and validation.**

I. INTRODUCTION

Wireless technology has become widespread on virtually all user devices, as well as any inhabited deployment (homes, parks, airports, stadiums, etc.) since its arrival on the industrial market. However, users who are increasingly demanding, the number of connections and bandwidth intensive applications are growing. This increase will threaten the technology in its future growth to no longer serve these customers effectively. In addition to increased reliability, future networks will need to offer greater wireless capacity. This is where the sixth generation of Wi-Fi (Wireless-Fidelity) comes in. It's the IEEE 802.11ax standard.

The new 802.11ax standard, also known as HEW (High Efficiency Wireless local area network), has the ambitious goal of quadrupling average throughput per user in dense areas; it is an evolutionary improvement of the 802.11ac standard. The standard has submitted three preliminary drafts 802.11ax since its launch in May 2014, namely D1.0, D2.0 and D3.0 and provides for finalization by the end of the current year (2019) [1]. While the new 802.11ax standard is designed to maximize network efficiency, it also provides a better experience for traditional wireless LANs and more predictable performance for advanced applications, such as: 4K video, Ultra HD, wireless office, Internet of Things (IoT), etc. IEEE 802.11ax will achieve its goals taking into account the following key features: Orthogonal Frequency-Division Multiple Access (OFDMA), adoption of Full-Duplex transmissions, higher modulation rate 1024-QAM (1024-Quadrature Amplitude Modulation),Down-Link/Up-Link Multi-User Multiple-Input Multiple-Output (DL/UL MU MIMO) and spatial reuse.

The implementation of these techniques poses many new challenges to the scientists who are working to achieve. Because the old Wi-Fi standards do not support these new features. In this work, we are interested to efficiently manage the OFDMA MAC communications in the next generation of IEEE 802.11ax WLANs. In fact, various methods of access to the medium based on OFDMA have been proposed by the scientific community, each aimed at optimizing the use of subcarriers and improving the transmission rate in a dense environment.

The remainder of this paper is outlined as follows. Section II introduces the OFDMA and OFDM technologies. Section III introduces the main research works about multi-user MAC protocols based on OFDMA technology. In Section IV, we describe our OFDMA MAC protocol. Simulation results are given in Section VI, followed by Section VII which concludes this paper.

II. BACKGROUND

The main change in the 802.11ax standard is the introduction of OFDMA technology in both downlink and uplink transmissions. OFDMA makes it possible to multiplex more users in the same bandwidth. This is possible by allocating a contiguous subset of the sub-carriers (minimum 26, maximum 996) of the available spectrum for each user. This means that the existing 802.11ax channels (20, 40, 80 and 160 MHz wide) are divided into narrower subchannels with a predefined number of subcarriers. The allocated amount is referred to as the *Resource Unit* (RU) and it is allocated to users based on channel conditions and service requirements. The Figure 1 illustrates the allocation of RUs by the AP (Access Point). By using OFDM the entire channel is allocated to a single user, however using OFDMA several users can transmit simultaneously. The basic principle of OFDM and OFDMA is illustrated by Figure 2.

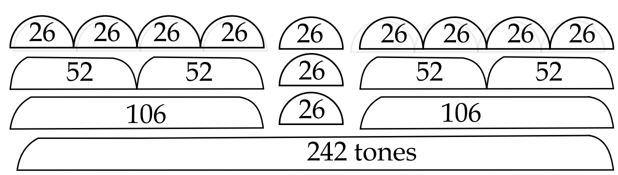

Fig. 1. Configuration of RUs on a 20 MHz band [2].

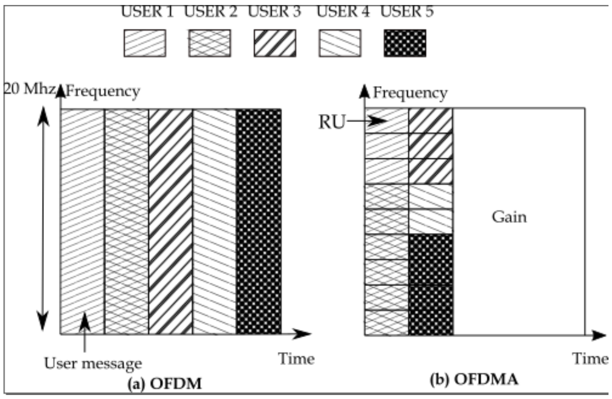

Fig. 2. Configuration of RUs on a 20 MHz band

In downlink transmissions, an AP can increase the power of some RUs while allowing weak users to maximize downlink bit rates in the Basic Service Set (BSS), by diverting power from powerful user. On the other hand, the uplink OFDMA gains are mainly due to the aggregation of multiple users. Each user transmitting on his assigned RU, which contributes to a higher signal (SNR, signal-to-noise ratio) at the level of the AP. In general, STAs (stations) have lower output power output than APs, and this power asymmetry reduces uplink throughput and may also limit the BSS range. Uplink OFDMA can be used to compensate for such power asymmetry [3].

III. Related Work

Recently, several OFDMA MAC protocols for the next generation Wi-Fi have been proposed. A summary of some research on the IEEE 802.11ax future standard, based on OFDMA technology, is presented in this section. The research studies focused above using different concepts and principles to design OFDMA-based MAC access methods by adopting the different centralized and/or randomized scheduled access controls for multi-user downlink/uplink transmissions.

P. Nasiopoulos et al. [4], [5] have proposed a hybrid MAC protocol based on OFDMA and CSMA/CA (H-OFDMA, Hybrid OFDMA) to increase the throughput of the next WLAN generation. H-OFDMA uses two frame transmission phases: the Transmission Opportunity Request(TR) phase and the Scheduled Transmission (ST) phase. The RTS packet is sent randomly by applying a CSMA/CA scheme in the TR phase. The adoption of OFDMA in the H-MAC method can cause a conflict between the users who are candidates for a transmission when the number of sub-channels is smaller than the number of users. Thus, several stations compete for each subchannel which produces a probability of collision. As a result, H-OFDMA prompts the use of CSMA/CA in the TR phase to send the RTS packet to solve the collision problem. The access point then sequentially schedules the data transmissions of the stations having sent their RTS packets correctly and responds to them by sending the CTS packet in the broadcast. The stations transmit their data sequentially according to the planning of the AP and each station occupies all the sub-channels during the transmission of its data.

G. Haile et al. [6] proposed a competing MAC protocol based on OFDMA and CSMA/CA named C-OFDMA (Concurrent OFDMA) for the new generation WLAN. The C-OFDMA method provides improvements to the H-OFDMA method of the authors [4], [5] in terms of throughput. In fact, the H-OFDMA method for a transmission of k data results in a total of k acknowledgments transmitted sequentially to the k stations, plus an overload in transmission planning. For that, the authors to [6] have opted for a method allowing simultaneous transmissions in order to reduce this overload in data and in acknowledgments. The C-OFDMA method takes place in three phases: the Sub-channel Request (SR) phase, the Sub-channel Assignment (SA) phase and the Data-Transmission (DT) phase.

T. Uwai et al. [7] highlighted on an adaptive Backoff mechanism for OFDMA random access with a finite service period in IEEE 802.11ax. Based on OFDMA random access research in the IEEE 802.11ax standard, backoff parameters should adjust to network conditions. In 802.11ax, the service period (SP) defines the operating time of the OFDMA random access and the access point is supposed to initiate random access. When SP ends, the stations should wait for the next SP to transmit their packages. In dense environments, this leads to a discontinuity, including a probability of packet loss due to high latency, and a degradation in performance. For this, the authors of [7] introduced an adaptive Backoff algorithm for OFDMA random access using an analytical performance model. They show that maximum throughput can be achieved even in dense environments by adjusting the parameters of the Backoff. The experiment is carried out on a UL-MU transmission protocol based on the OFDMA random access and divided into three phases: the transmission request phase (TR), the UL-MU frame transmission phase (UL-MU frame Transmission).

J. Lee et al. [8] suggested a new hybrid MAC protocol (H-MAC) designed to increase channel utilization in OFDMA. It is a protocol that relies mainly on a centralized approach that also allows random access in a game. Access to the medium is controlled by three types of messages defined by these authors [8] and which are: (1) Request-to-Multiple-DL (RMD), this message is sent on the channel to identify each candidate station for DL transmission,(2) Clear-to-Receive-with-UL-Request (CRU), when receiving the RMD message, the stations designated in the DL transmissions can respond by sending a CRU message in their corresponding sub-channels, they may also carry information on UL requests for transmissions, (3) Request-to-Multiple-UL (RMU), the RMU control message is only a trigger for UL transmissions sent by the access point to the stations having requests for transmissions in UL. As a result, the H-MAC protocol allows a random access portion for stations not designated by the RMD message in the network and the RMD message is sent over the entire transmission channel, stations not designated by the latter can access randomly to one of the subchannels of the transmission channel by decoding the available free sub-channel addresses defined in RMD and transmit their UL requests by sending the CRU message.

The operation of the H-MAC protocol is summarized as follows (with interframe expectations between transmissions): the access point sends the RMD message containing the requests for DL transmissions to the designated stations over the entire transmission channel, the stations designated by

RMD and the stations having requests UL (random access) send the CRU message to the access point in a first phase named Control Period, the access point transmits its data packets to the stations designated by RMD and who responded by CRU and the stations acknowledge the good reception of DL data by sending ACKs each, during a phase qualified in H-MAC by Downlink Data Transmission Period. The access point then loads the UL requests through CRU, stacks them in the RMU message and transmits them to the designated stations, all over the channel during the trigger phase (Trigger Period) so that finally the stations having UL requests trigger the transmission of their UL data and the AP responds with a BA over the entire channel to acknowledge the UL data in the last phase Uplink Data Transmission Period.

The following table summarizes the main features of the studied protocols:

TABLE I. CHARACTERISTICS OF THE STUDIED PROTOCOLS.

Articles	CTS/RTS	DL	UL	MU-OFDMA	Centralised	Distributed
[9]	✓		✓	✓	✓	
[4], [5]	✓		✓		✓	✓
[6]	✓		✓	✓	✓	✓
[7]			✓	✓	✓	✓
[10]			✓	✓	✓	✓
[8]	✓	✓	✓	✓	✓	✓

IV. Aggregated Variable Length Data for OFDMA communications

It is found that the adoption of H-MAC under variable length data is inefficient at all, given the time lost to transmit stuffing bits instead of raw data. However, an improvement in the efficiency of the H-MAC method is demonstrated by adopting our proposal called Aggregated-Variable Length DATA-MAC (A-VLD-MAC). The illustration of the A-VLD-MAC method is detailed in the next subsection.

A. A-VLD-MAC

The proposed A-VLD-MAC multiple access method makes changes in the DL data transmission phase, with the aim of improving the transmission rate by exploiting the OFDMA RUs effectively. The improvement in fact consists of introducing the aggregation mechanism of the data frames to the H-MAC method, by considering the variable length of data. The following diagram shows the different frames sent in A-VLD-MAC.

The sending of MPDU and A-MPDU frames is done by management in the access point. This management is detailed as follows:

- After receiving the CRU frames, the access point loads the first data to be sent in each queue for each station and searches for the data having the maximum length.
- The AP verifies if the data to be transmitted for the different stations are not all of the same length, one of the following two cases will be applied:
- **Case 1**: $\forall i \neq MAX, MAX - LONG1_i = 0$ where MAX is the maximum length and $LONG1_i$ is the length of the packet to send to the station i. Falling in the case where the different packets to be transmitted to the different stations are all of the same length induces us to H-MAC. Thus no aggregation can be done.
- **Case 2:** $\exists i \neq MAX, MAX - LONG1_i > 0$ for all stations there is at least one packet of length less than MAX. The occurrence of this case allows us to introduce the aggregation mechanism. To do this, the AP is looking at this point in the rest of the data of each queue, the longest packet can be inserted into X, where X is the difference between MAX and $LONG1_i$ (see the equation eqref eq1), within the limit of not exceeding the transmission time of the longest frame MAX (see the equation (2)), where ts_{MAX} is the transmission time of the data MAX, ts_{LONG1_i} is the transmission time of the first packet $LONG1_i$ and ts_{LONG2_i} is the transmission time of the second packet $LONG2_i$ that could be inserted into X for the station i.

$$MAX - LONG1_i = X. \tag{1}$$

$$ts_{MAX} \geq ts_{LONG1_i} + ts_{LONG2_i}. \tag{2}$$

- The AP encapsulates the MPDU packets, aggregated A-MPDU packets if they exist, and forwards the packets to the specified stations.
- The stations having received the frames sent by the AP, answer by ACK or BA for the MPDU and A-MPDU respectively.

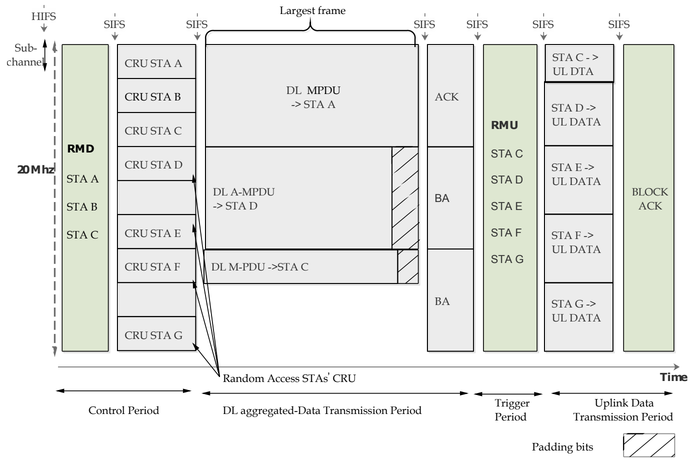

Fig. 3. Operation steps of the A-VLD-MAC protocol.

The remainder of the H-MAC method is unchanged for the remaining period (control period, trigger period, and UL data transmission period). The different conditions for the sequence of the phases are exposed in the flowchart given in the Figure 4.

V. Simulation Results and Analysis

We have used the C programming language under Linux operating system for implementing and assessing the performance of the proposed A-VLD-MAC method designed for optimizing the OFDMA MAC communications under variable length data. The choice of programming language is made in

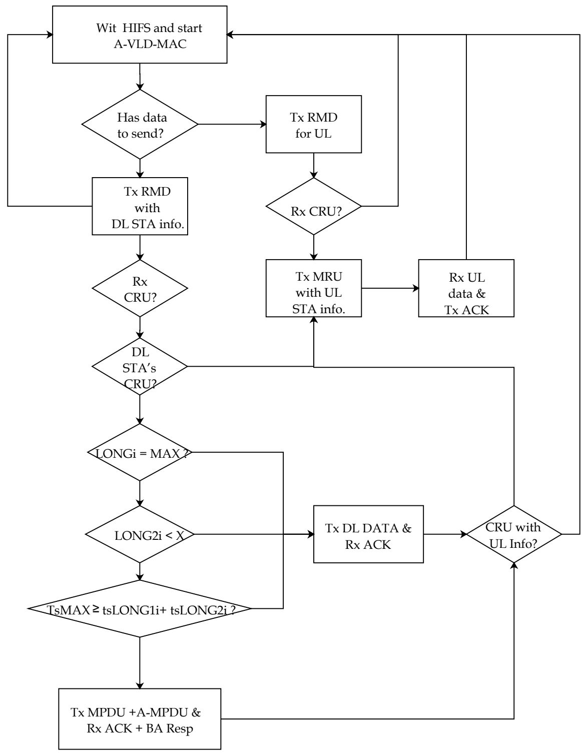

Fig. 4. Flowchart of the transitions of A-VLD-MAC.

relation to the simplicity, flexibility and speed of the language. We have used a simulation environment with a 20 MHz transmission channel, supporting 9 simultaneous users in OFDMA (RU = 26 subcarriers). The PHY and MAC parameters that we have put forward to evaluate the performance are defined in the Table II.

TABLE II. IEEE 802.11AX PHY AND MAC PARAMETERS.

Parameters	**Signification**	**Value**
Channel bandwidth	bandwidth width	20 MHz
HIFS	inter-frame time H-MAC	25 s
SIFS	inter-frame time	16 s
PHY_header	PHY header transmission time	36 s
MAC_header	length of the MAC header	320 Bits
Data_rate	Data rate transmission	65 Mbps
Basic_rate	Data rate of the overhead	6 Mbps
Del_Pad	Delimiter size and padding of A-MPDU packets	56 Bits
ACK	ACK size	112 Bits
BA	size of ACK block	320 Bits

The performance metrics that we have computed to evaluate the performance of our A-VLD-MAC proposal are: the average throughput, the average throughput per user, and the bit loss rate of the DL transmissions. Given the proposed method A-VLD-MAC is an improvement of the H-MAC method with variable packet lengths, the simulation results obtained for the A-VLD-MAC method are compared to those of the H-MAC.

A. Average throughput

The average rate determines the speed of data transmission. In order to evaluate the rate of DL transmissions in the network by varying the number of stations and the lengths of the packets in both methods, a simulation is implemented. The results of this simulation are given in Figure 5. According

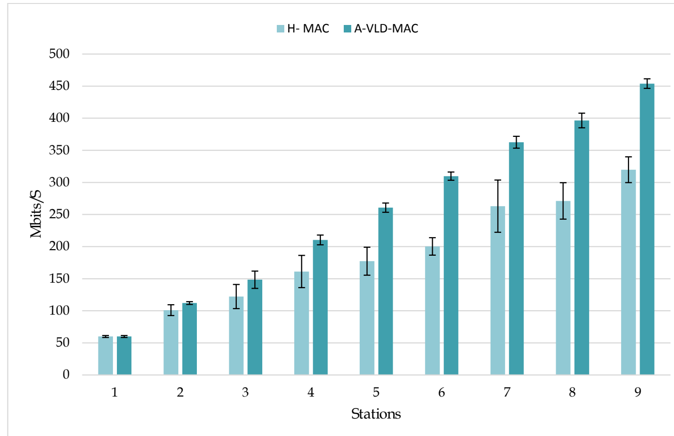

Fig. 5. Average throughput.

to the results of the simulation, the A-VLD-MAC method considerably improves the average throughput compared to the H-MAC method. The average bit rate can reach 453 Mbps in A-VLD-MAC compared to 319 Mbps in H-MAC, a difference of 134 Mbps. These results show the effectiveness of the A-VLD-MAC method in dense networks.

B. Average throughput per user

Responding to user requirements while providing better service in high density areas is one of the goals of the new IEEE 802.11ax standard, and providing better throughput is one of the important services. The Figure 6 represents the results of the simulation of the average flows per user in each of the two H-MAC and A-VLD-MAC methods.

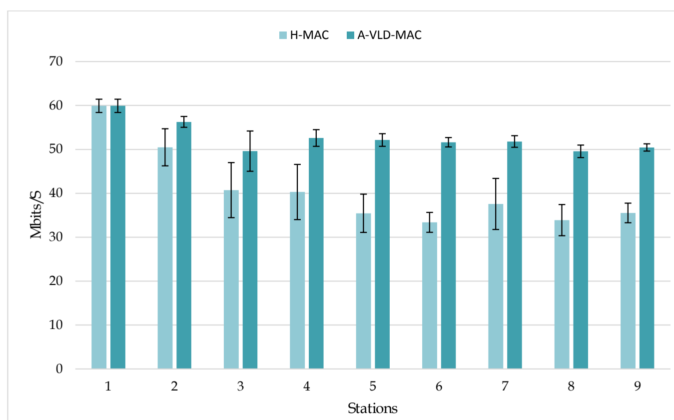

Fig. 6. Average throughput per user.

We can see clearly in the figure 6 above, that the average throughput per user in the A-VLD-MAC method is considerably improved compared to the results of the H-MAC method. Apart from the average throughput per user offered for a single station that is equal in both methods (specific case A-VLD-MAC), the average throughput per maximum user achieved and which is almost stable by increasing the number of stations in A-VLD-MAC is 56 Mbps against 50 Mbps for H-MAC and can be downgraded to 33 Mbps by increasing the number of stations.

C. Bit loss rate

A large amount of bits are sent using the H-MAC method with lengths of varying sizes to synchronize transmissions. The amount of stuffing bits sent in a DL transmission varies according to the lengths of the transmitted data for each user. The charge in stuffing bits is reduced by adopting our proposition A-VLD-MAC. The following Figure 7 shows the difference between the rate of loss in stuffing bits using the H-MAC method and the method A-VLD-MAC for the same lengths of data sent to the same number of stations in both methods.

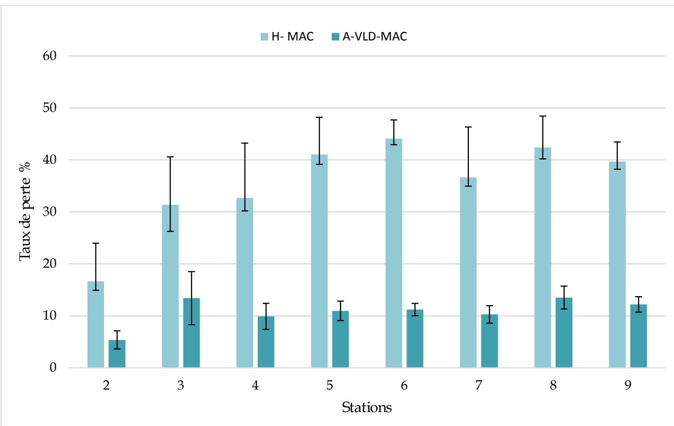

Fig. 7. Bit loss rate

We can see in Figure 7 that the loss rate varies according to the length of the packets and the number of stations in the H-MAC method, it can reach a rate of $\simeq$44% bit loss stuffing. On the other hand, the maximum loss rate in stuffing bits in A-VLD-MAC does not exceed $\simeq$ 13 %, so a gain of $\simeq$31%(44%-13%=31%) in data is offered using A-VLD-MAC. We also note, the stability of the loss rates in A-VLD-MAC, despite the variation in number of stations and lengths of the data, which guarantees the efficiency of A-VLD-MAC in the reduction of loss rates in stuffing bits.

VI. Conclusion

The efficient use of transmission channel in the IEEE 802.11ax standard allows for increased throughput. The purpose of the proposed A-VLD-MAC method is to optimize the use of OFDMA transmissions by improving the H-MAC method while introducing the data frame aggregation mechanism defined in the IEEE 802.11e standard. In this paper, we have detailed the operation steps of the proposed method A-VLD-MAC which is an improvement of the H-MAC [8] method, while underlining the differences between the two methods. A simulation part is also implemented in this work to demonstrate the effectiveness of the proposed solution. Obviously, the results given by the simulation of the two methods assert that the proposed method A-VLD-MAC is more efficient than H-MAC by increasing the transmission rate and reducing the rate of loss in stuffing bits.

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