ON THE ENERGY EFFICIENCY OF IEEE 802.11AX HIGH DENSITY WLANS

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ABSTRACT

Wireless communications evolved in a remarkable way during the last decade and is well on its way to surpass wired internet. The demand shifted towards higher transmission speed for more users and heavier traffics. In this paper, we present an IEEE 802.11ax scenario, in which we study the energy efficiency for the key metrics of the MAC layer. In this latest edition, called High Efficiency WLAN (HEW) energy is a main concern in order to satisfy scenarios of internet of things and wireless sensor networks. we prove that some of the new features such as the higher order modulation and coding schemes enhance remarkably the energy efficiency. We also show the impact of an increase in the number of users on the system and prove the payoff of using IEEE 802.11ax. We evaluate the contention window size performance as one of the most important metrics, on which throughput highly depends.

KEYWORDS

802.11ax, Contention Window, Energy Efficiency, Throughput, Wireless Networks.

1. INTRODUCTION

Since appearing in the late 90’s, IEEE 802.11 standard has had subsequent amendments. The latest version, IEEE 802.11ax offers a new approach with the focus shifting towards enhancing the overall efficiency instead of the throughput. The aim is to accommodate real time applications, 4K/8K videos, virtual reality, as well as coexist with 4G, 5G, and LTE. Internet of Things (IoT) can also benefit from this amendment and its new features [1], with efficient allocation of low data rate connections over an extended range, which will remarkably improve battery life for IoT sensors.

For these reasons, energy consumption in Wireless Local Area Networks (WLANs) is a key consideration in the design and the implementation of physical layer (PHY) or medium access layer (MAC). In every scenario, it depends highly on the system throughput, the reliability and the achievable lifetime. The stations consume energy during transmission, reception, and in idle states due to collisions, transmission errors, channel sensing, listening, and the use of wider bandwidths. Remedying these energy-consuming problems has been the subject of several studies.

In [2], the authors show the importance of the contention window size. They investigate the energy efficiency in an IEEE 802.11 network with an analytical model and prove that the maximum energy efficiency is a function of optimal packet size and contention window size. The work in [3] uses a configuration for IEEE 802.11, which aims to optimize the energy efficiency. The authors show that although we can have an energy-optimized configuration, it does not necessarily mean that throughput and energy efficiency can have a joint maximization. The

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backoff window effect on the throughput is a very important aspect in saturation conditions. Paper [4] presents an energy consumption model for different numbers of users and its impact on the system throughput.

The number of users affects resource allocation, which in turn influences the throughput and energy efficiency. In [5], a bi-directional distributed coordination protocol improves the energy efficiency remarkably. The authors use an optimal configuration to reduce overhead and channel contention and balance throughput and energy efficiency. A closely related matter; power efficiency is examined in [6]. The authors present a tradeoff between power efficiency and bandwidth efficiency. They prove that a joint maximization is not possible and that only suboptimal maximization is possible. [7], presents a throughput performance for IEEE 802.11ax which is crucial in determining the energy efficiency.

The rest of our paper presents an overview of the IEEE 802.11ax amendments in section 2, then we layout the system model in section 3, we present our results and their interpretations in section 4, and section 5 concludes the paper with summary and perspectives.

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2. OVERVIEW OF IEEE 802.11AX

While IEEE 802.11ax conserves most of the features provided by previous amendments and enhances them, it also adds features specific for highly dense networks. Among the new additions, we mention the following. Enhancements for MU-MIMO include both the Downlink and the Uplink with eight possible streams, while the SU transmission benefit from up to four streams. The 1024 QAM with 3/4 and 5/6 rates, joins the Modulation and Coding Schemes (MCS) as a new addition. The increase in the number of subcarriers to 256 enables longer Guard Interval (GI) and a longer symbol duration. While the GI helps decrease the Inter Symbol Interference (ISI), longer symbol duration allows connectivity in larger coverage areas and makes the system a robust one against propagation delays.

802.11ax introduces the concept of Resource Units (RU), which allows several users the use of the same frequency domain. Thus, providing multiplexing in the frequency domain. A modification in the frame format includes trigger frame, which contains information about the stations involved in a transmission. This information contains a list of users, their RU, resource allocation, bandwidth and MCS. The stations start to transmit only after receiving this frame from the Access Point (AP). A variant of trigger frame is MU Request-To-Send (MU-RTS) frame; it includes information about the stations and the channel widths. Each station replies with a Clear-To-Send (CTS) frame and the AP transmits only to the station that have replied.

For more details about the technical features of IEEE 802.11ax, refer to [8] and [9].

3. SYSTEM MODEL

The Distributed Coordination Function (DCF) The Distributed Coordination Function (DCF) is the default access mechanism for MAC layer in IEEE 802.11 standards. It is similar in principle to the Carrier Sense Multiple Access mechanism with Collision Avoidance (CSMA/CA). In order to transmit, a station must listen to the medium until it encounters an idle state. When a period equal to Distributed Inter-Frame Space (DIFS) passes, the station can transmit. To avoid collisions, the station waits a random backoff time, which is also used between two consecutive transmissions. If the channel is busy, the station continues listening for a DIFS in order to transmit.

DCF employs either the basic access scheme or the four-way handshaking RTS/CTS. In the latter, the station sends a RTS frame and waits for the CTS before transmitting the packet. RTS/CTS is very useful against the hidden nodes problem. When the transmission is successful, the receiver sends the ACK. During this period, the other stations can update their Network Allocation Vector (NAV). For more details about DCF see [10]. Since IEEE 802.11ax offers MU transmissions in both the Downlink and the Uplink directions, the same can be said about both directions. When the AP is transmitting to several stations or when it is receiving from several stations.

In our paper, we use the well-known Markov Chain Model of [11] to represent the system throughput and the expression of the energy efficiency. The Markov Chain analytical model is very accurate in evaluating thethroughput of both IEEE 802.11ac such in [12] and IEEE 802.11ax.

We note the number of stations as n, in saturation conditions, every station has a packet ready for transmission. The Markov Chain model allows us to deduce the transmission probability (1) that a station transmits in a randomly chosen slot time τ and the collision probability p in (2).

$$\tau = \frac{2(1-2p)}{(1-2p)(CW_{min}+1)+pCW_{min}(1-(2p)^m)} \quad (1)$$

$$p = 1-(1-\tau)^{n-1} \quad (2)$$

To compute the system throughput S we define P_{tr} as the probability that there is a transmission, and P_S the probability that said transmission is successful. Therefore, we express the system throughput as the ratio of successfully transmitted bits in a slot time $E[P]$ against said slot time (5).

$$P_{tr} = 1-(1-\tau)^n \quad (3)$$

$$P_S = \frac{n\tau(1-\tau)^{n-1}}{1-(1-\tau)^n} \quad (4)$$

$$S = \frac{P_{tr}P_S E[P]}{(1-P_{tr})\sigma + P_{tr}P_S T_S + (1-P_S)P_{tr}T_C} \quad (5)$$

The expressions σ, T_S, and T_C represent respectively an empty slot time, the time spent for a successful transmission, and the time spent during a collision. The expressions of both T_S and T_C are detailed respectively in (6) and (7). Certain expressions extensions encompass the new modifications added by 802.11ax and allow calculating the throughput [7].

$$T_S = T_{MU-RTS} + 3 * SIFS + CTS + T_{DATA} + BA + AIFS + \sigma \quad (6)$$

$$T_C = T_{MU-RTS} + SIFS + CTS + DIFS + \sigma \quad (7)$$

$$T_{MU-RTS} = PHY + [\frac{L_{SF} + L_{MU-RTS} + L_{TB}}{R}]\sigma \quad (8)$$

$$T_{DATA} = PHY + [\frac{L_{SF} + N_a(L_{MD} + L_{MH} + L_{DATA}) + L_{TB}}{R}]\sigma \quad (9)$$

With the transmission rate R expressed as:

$$R = \frac{N_{DBPS}}{T_{SYM}} \quad (10)$$

N_{DBPS} is the number of bits per OFDM symbol. It can be calculated as in [13] using the number of data subcarriers, the number of information bits in a modulation, and the coding rate. The symbol duration T_{SYM} is equal to the number of subcarriers divided by the used bandwidth plus the Guard Interval (GI).

$$P_{success} = \tau(1-\tau)^{n-1} \quad (11)$$

$$E = (1-\tau)^n p_i + \tau p_t T_S + (1-\tau)(1-(1-\tau)^{n-1})p_r T_S \quad (12)$$

We can finally express the energy efficiency EE, which is the ratio between transmitted bits and the energy consumed in a slot time as:

$$EE = \frac{P_S E[P]}{E} \quad (13)$$

E is the energy per slot. In Table 1, details the parameters with constant numerical values (see more in [14]).

Table 1. Simulation Values

Parameter	**Value**
L_{SF}	16 bits
L_{TB}	18 bits
L_{MD}	32 bits
L_{MH}	360 bits
L_{DATA}	1500 Bytes
N_a	64
CW_{min}	32
CW_{max}	1024
L_{RTS}	160 bits
L_{CTS}	128 bits
$SIFS$	16 µs
$DIFS$	34 µs
$AIFS$	34 µs
m	5
σ	16 µs
PHY	164 µs
p_e	1.15 W
p_t	1.65 W
p_r	1.5 W

4. RESULTS AND DISCUSSION

We consider a Basic Service Set (BSS) with IEEE 802.11ax capable devices, in which we have a single AP and n stations. All stations are within hearing distance from the AP, as well as from each other. These stations possess the same capabilities and are able to operate in MU-MIMO for both transmission and reception (Uplink and Downlink). In addition, we assume that every station has a packet ready for transmission every time. We consider all the bandwidths available for IEEE 802.11ax amendment, and the full capabilities of spatial streams and diversity. N_a packets are transmitted using Aggregated MAC Protocol Data Unit (A-MPDU) packet aggregation scheme. We present the energy efficiency for different number of users, varying contention window sizes and different MCS.

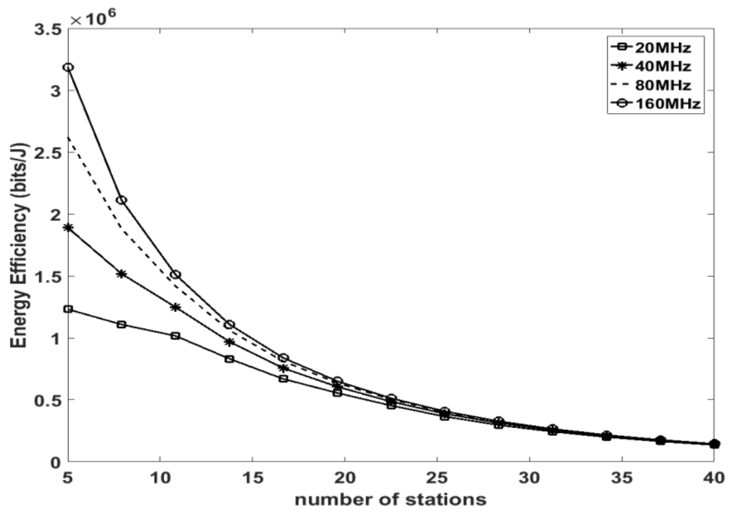

Figure 1. Energy Efficiency against the number of STAa

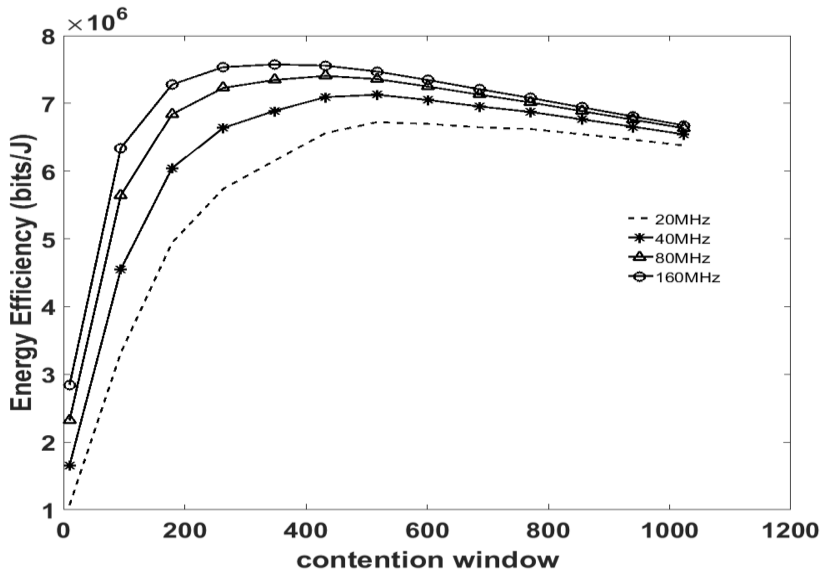

Figure 2. Energy Efficiency against Contention Window

We start with the energy efficiency against the number of stations depicted in figure 1, the energy efficiency obviously decreases as the number of users increase. This is due to the energy consumed during retransmissions and overhearing besides the collisions, which present the most wasteful condition for energy.

For another important metric, the contention window size in figure 2, for small values of CW a lot of energy is wasted in collisions. Choosing an optimal minimal CW can enhance the energy efficiency regardless of the channel bandwidth. This is mainly because CW affects the collisions in the system. Finding the best value for every case scenario can remarkably minimize contentions and provide a better energy efficiency. There is a CW value, which maximizes EE devoted to successful transmission.

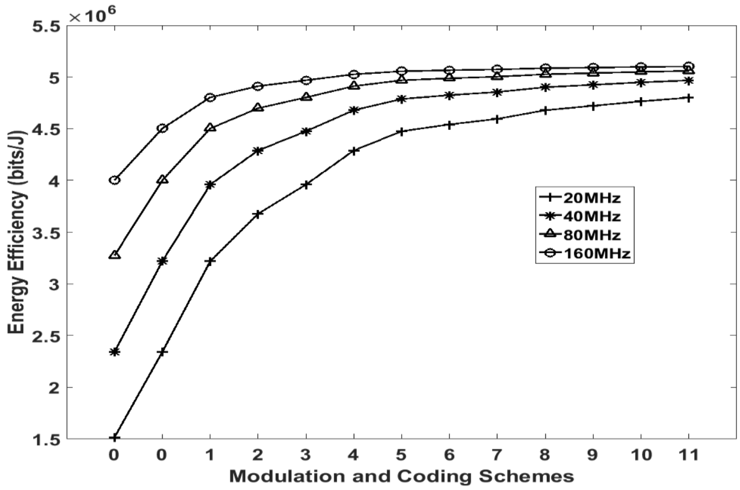

Figure 3. Energy Efficiency for MCS

Finally, as to a very important metric in the IEEE 802.11ax, the modulation and coding schemes. With the newly added 1024QAM or MCS11, the energy efficiency provides remarkable results. Despite reaching saturation faster the higher the MCS gets, we found that low MCS offer low energy efficiency, this is due to the fact that the throughput is lower and the transmission is longer (see figure 3). We obtain the maximum EE, by combining both the optimal packet size and CW optimal value.

5. SUMMARY

In this paper, we presented an overview of the new amendment IEEE 802.11ax; we showed in our analysis the performance of the energy efficiency of the norm as a function of several key parameters in every WLAN with a PHY and MAC layer based on IEEE 802.11ax. We compared the results for various bandwidths and proved the impact of the CW size on the optimization of the energy efficiency. We also proved that the newly added features of aggregation and throughput remarkably improve the performance for higher MCS schemes. Finally, we show the impact of a high number of users (i.e. dense networks) on the energy efficiency.

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