DOI: 10.34765/kn.0319.a03

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NEW THROUGHPUT OPTIONS IN 802.11AX STANDARD

Summary

The throughput offered in the 802.11 standard are now similar to those offered in wired solutions. The newly developed 802.11ax standard also offers new operation opportunities in an environment with high density of users. The author, using the theoretical dependencies and the ns-3.27 version of the NS simulator, compared the throughput in the 802.11n / ac / ax standards and determined the throughput for selected configurations of the radio channel parameters. The throughput of 802.11ax is usually higher then in older standards however there are some exceptions.

Key words: throughput, 802.11ax standard, signal to noise and interference ratio

JEL codes: L86

Introduction

Since the release of the 802.11 standard in 1997 its uninterrupted development continues. The goal was, above all, to increase the throughput of data transmission. A number of solutions were used for this purpose, such as: new types of modulation and coding, increasing the width of channels, packet aggregation, new technologies of signal transmission, and the use of multi-stream systems. It can be said that the 802.11n and ac standards opened new possibilities. It is expected that the new 802.11ax standard will meet HEW (High Efficiency WLAN) requirements. The first specifications have been released in 2017 and the final version of the standard is expected in 2019. It is already evident today that the number of new ideas for improving the standard is so high that next versions of that standard will be necessary in the future. The new Wi-Fi standard 802.11ax is still under development (Bellata 2016). The task group of IEEE Task Group AX (TGax) has made available the assumptions of the new standard, however, the work is still in progress, and their completion and provision of the final version of the standard is expected in 2019 (Khorov et al. 2016). Nevertheless, selected manufacturers, including Qualcom and Intel, produced the first Wi-Fi chipsets that implement part of the functionality of the 802.11ax standard (Qualcomm 2016; 2016a). The aim of the new standard is to support locations with high density of users. This time the standard is to provide support for many users using a single access point. It is allowed due to use OFDMA technology which creates a sub-channels groups. In addition, the 802.11ax standard ensures an increase in total throughput. The author presented new solutions applied in the 802.11ax standard PHY layer. The article describes the assumptions of the new standard, the structure of the PHY layer, achievable throughput versus older versions of the standard and the current status of this project.

802.11ax standard basic assumptions

The 802.11 ax standard is currently under development. The release of version 2.0 is anticipated in 2019. Version 2.0 is likely to be a stable version (Ward 2016). The current documentation includes new requirements for the physical layer Phy and modifications of the MAC layer. Documentation is available on the website (ax-spec 2017). The basic objective of the new standard is to improve the average throughput for stations at least four times in case of high density user's environment. The second basic assumption concerns the compatibility of the backward standard in relation to the previous versions using the same frequency bands. The use of the ax standard is envisaged for the service of places with high density of users and work stations such as: airports, railway stations, mobile education, public transport, multi-office buildings, and selected urban areas with high traffic. A number of changes which are to improve the efficiency of the standard are related to the limitation of transmission of management and control information, increase of maximum throughput and increase of aggregation level (Poole 2016). In relation to the version of the n and ac standard, support was introduced for the MU-MIMO solution (Multi User MIMO) and OFDMA (Orthogonal Frequency Division Multiple Access) technology. The 802.11 ax standard introduces four new PPDU (Packet Protocol Data Unit) categories, such as:

- HE SU PPDU (HE Single User PPDU) used for transmission to one user,
- HE SU EXT PPDU (HE SU Extended Range PPDU) is used when the distance between a single user and the access point increases. This type of transmission is only possible in a channel with a width of 20 MHz using low modulation and coding schemes MCS0 (BPSK ½), MCS1 (QPSK ½), MCS2 (QPSK ¾)),
- HE MU PPDU used for many transmissions to many users.

AC, N and AX versions of 802.11 standard key features comparison

The 802.11n standard introduced a number of new revolutionary solutions. The most important of them include: bonding neighboring 20 MHz channels and 40 MHz channel creation, packet aggregations, new modulation schemes when QAM 64 is the highest one. Increasing the channel width allows for a direct increase in throughput, while packet aggregation allows to limit the amount of control information sent. The 802.11ac standard has new channel widths of 80 and 160 MHz as a result of the development of channel bonding technology. Both 802.11ac and n standards have also introduced a short protection time of 400 ns, which slightly increases the bit rate.

In relation to n and ac, a number of significant changes have been introduced in the ax standard. Firstly, the subcarrier spacing was changed from 312.5 to 78.125 kHz and their number was radically increased. At the same time, the symbol length changed from 3.2 to 12.8 us. The most important change concern introducing RU (resource unit) which is subcarriers resource necessary to handle transmission of one user in the OFDMA system, which allowed increasing the number of simultaneously, supported users. The 802.11ax standard allows up to 74 users to be served at the same time. This scenario is possible when using the 160 MHz channel and each user is serving with a minimum number of subcarriers. In this configuration, each user has 0.96 Mb/s available. Selected parameters of all three basic 802.11 standards are presented in Table 1.

Table 1. Parameters of three basic 802.11 standards

Parameter	802.11n	802.11ac	82.11ax
Chanel widths [MHz]	20,40	20,40,80,160	20,40,80,160
Subcarriers spacing [kHz]	312.5	312.5	78.125
Symbol duration [us]	3.2	3.2	12.8
Guard time [us]	0.4, 0.8	0.4, 0.8	0.8, 1.6, 3.2
Transmission type	OFDM	OFDM	OFDM, OFDMA
Available MCS	0-7	0-9	0-11
Number of parallel users	1	8	72
Frequency bands [GHz]	2.4/5	5	2.4/5
Number of spatial streams in MU-MIMO technology	4	8	8

Source: own preparation.

It is possible to compare parameters of all three standards but we have some limitations. All standards could be comparing for 800ns guard time, 5 GHz band and 20 and 40 MHz channels. In case of wider channels we could compare only ac and ax standard and only in 5 GHz band.

Maximal theoretical throughput depends finally on many factors such as: channel width, guard interval, symbol time duration, number of bits per symbol and coding rate. Generally the throughput is the function of *MCS* (Modulation and Code Scheme). One can calculate this maximal theoretical throughput (Porat et al. 2015) using the following equation:

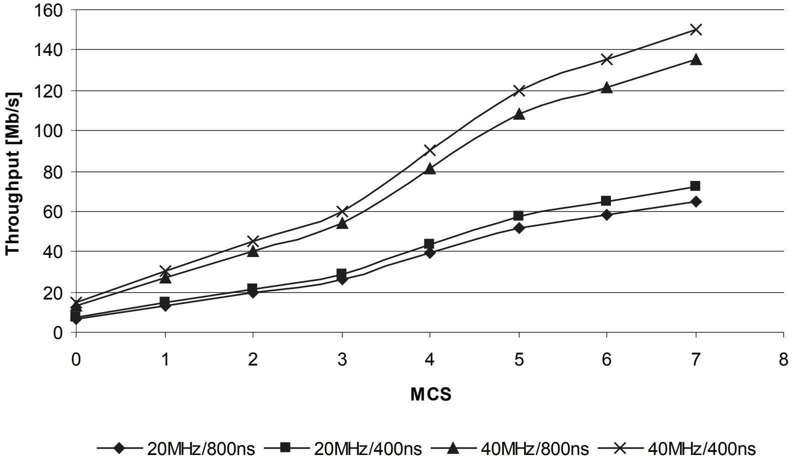
$$C_{MCS} = B_{FFT} N_{FFT} (1 - PER) \frac{T_{FFT}}{T_{FFT} + T_{GI}} \frac{bits}{symbol} CR \tag{1}$$

C_{MSC} is the maximal theoretical throughput for given *MCS*, while B_{FFT} is the subcarriers spacing. N_{FFT} is the number of subcarriers dedicated for data transmission and there are a few parameters which define the effectiveness of the spectrum usage, among them guard time duration, bits per symbol, coding rate *CR* influence and *PER* (Packet Error Rate). Generally both values, the frequency spacing and the symbol time duration are steady for the given standard and in case of 802.11 n/ac standards these values are equal 312.5 kHz/3.2 µs respectively while in 802.11ax 78.125 kHz and 12.8 µs. Both mentions above values are related by the following equation:

$$B_{FFT} = \frac{1}{T_{FFT}} \tag{2}$$

The theoretical calculation results of 802.11n throughput are shown in Figure 1. As we have 8 MCS available versus two attributes which are the channel width and the guard time, 32 values of theoretical throughput in one spatial stream scenario are available.

Figure 1. 802.11n theoretical throughput

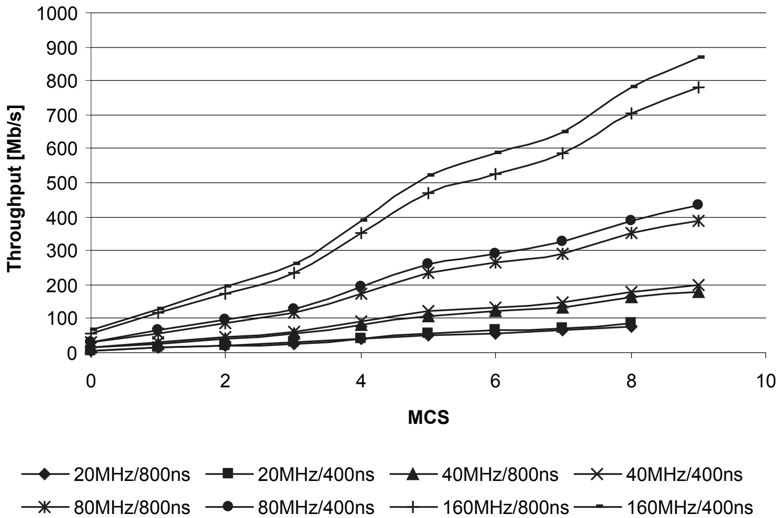


Source: own preparation.

Maximal theoretical throughput is equal 150 Mb/s for one spatial stream while the lowest is only a few Mb/s. Throughput value significantly depend on available MCS scheme which on the other hand depend on the distance between the transmitter and receiver and the received power level.

The 802.11ac standard offers more scenarios due to two additional channel widths 80 and 160 MHz. The theoretical throughput calculation results are presented in Figure 2.

Figure 2. 802.11ac theoretical throughput



Source: as in Figure 1.

The number of different throughput values for single spatial stream transmission reaches 78 as two highest MCS are not available for 20 MHz channel. Doubling the channel is not the equivalent of doubling the throughput. The issue concerns the number of subcarriers within the channel. In the MCS 0-7 range and for 20 and 40 MHz channels, the throughput is identical for both standards. In turn, the aggregate rates for 4 and 8 spatial streams, respectively, result from multiplying the throughput for one stream by the number of streams used. In the case of shortening the guard time, the throughput increases with the decrease of this period. This is usually associated with the higher SINR levels necessary for the correct receipt of packets. In the case of the 802.11ax standard, the number of possible throughput scenarios is definitely higher. We have four different channel widths, three guard intervals, twelve MCS and more over a significant number of different RU in one channel. While in 802 11n and ac standards in one channel we have one user in 802.11 ax due to the application of OFDMA, the number of user could be quite high.

It is the function of RU number. The all possible combination of RU versus subcarriers are presented in Table 2. One RU means one user. We can calculate at lest a few different types of throughput inn802.11 ax standard eg. single spatial stream throughput, single RU throughput or average throughput per given area when the different number of RU is dedicated for different users.

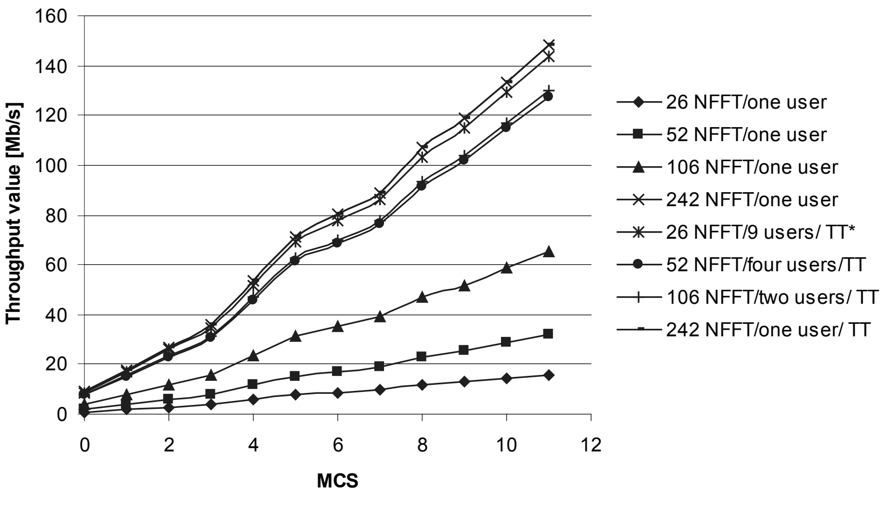
Table 2. Subcarriers versus RU/users number

Subcarriers Number	20MHz	40MHz	80MHz	160/80+80MHz
26	9	18	37	74
52	4	8	16	32
106	2	4	8	16
242	1	2	4	8
484	-	1	2	4
996	-	-	1	2
2x 996	-	-	-	1

Source: as in Table 1.

The throughput calculation results for single RU and the whole 20MHz channel are presented in Figure 3.

Figure 3. 802.11ax throughput calculation results

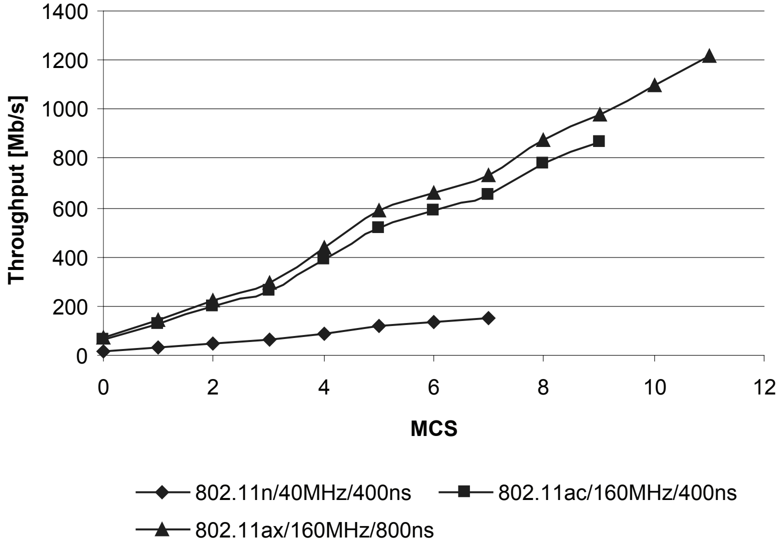


TT* total throughput

Source: as in Figure 1.

Generally 802.11ax standard outperform previous standards. The author compare throughput in two different situations. The highest possible throughput for each standard is calculated and the results are presented in Figure 4 and in Table 3.

Figure 4. Comparison of maximal theoretical throughput of three 802.11 basic standards n/ac/ax



Source: as in Figure 1.

Standard 802.11ax let us obtained higher throughput then previous standards. The ratio is respectively 8,13 for 802.11n and 1,41 for 802.11ac.

Table 3. Attributes of highest throughput in 802.11n/ac/ax

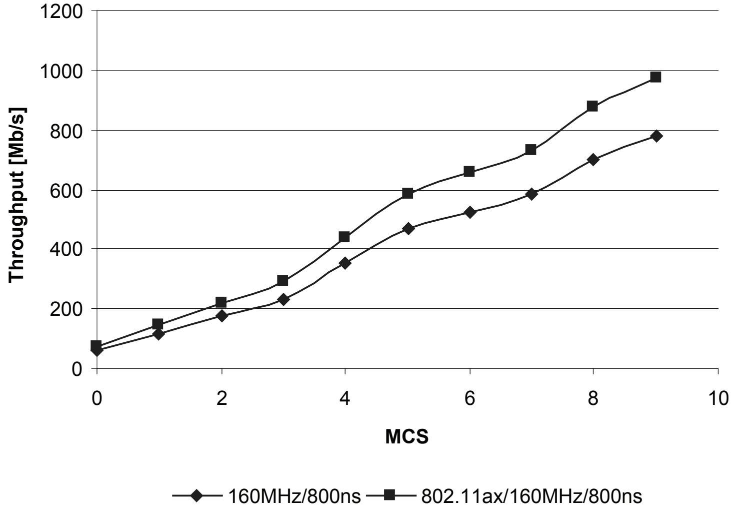
Attribute	Standard		
	802.11n	**802.11ac**	**802.11ax**
MCS	7	9	11
Channel width [MHz]	40	160	160
Guard time [ns]	400	400	800
MTT*[Mb/s]	150	866,7	1220

* Maximal Theoretical Throughput

Source: as in Table 1.

The second possible comparison is for standards 802.11ac and ax. Both standards can operate at 5 GHz band with guard time 800ns. The comparison of both standard throughput for the same band, channel width and MCS is shown in Figure 5.

Figure 5. 802.11ac and 802.11ax throughput comparison for the same attributes



Source: as in Figure 1.

This time the ratio of ax throughput to the ac throughput is the same for all MCS and is equals 125%. The theoretical throughput is normally higher then practical throughput as a lot of factors which lowered throughput are not taken into account (Dolinska et al. 2014). The most important factors concern MAC layer operation mechanism which based on different time intervals. As a result we need time not only for data transmission but also for different control and management information. The basic formula for DCF mechanism transmission time of one frame is as follows:

$$T_{transmission} = \sum_{i=1}^{10} T_i = T_{DIFS} + T_{BO} + T_{RTS} + T_{SIFS} + T_{CTs} + T_{SIFS} + T_{PH} + T_{DATA} + T_{SIFS} + T_{ACK}$$

where we have besides time for data a lot of additional time periods such as time intervals, back off time, time for control and management information. These time periods produced significant overhead to the time for data and lowered the practical throughput. In case of SU transmission using PPDU aggregation in 802.11ax standard the transmission time could be describe by the following formula (Sharon et al. 2017):

$$T_{transmission} = T_{AIFS} + T_{BO} + T_{DATA-PPDU} + T_{SIFS} + T_{BlockACK}$$

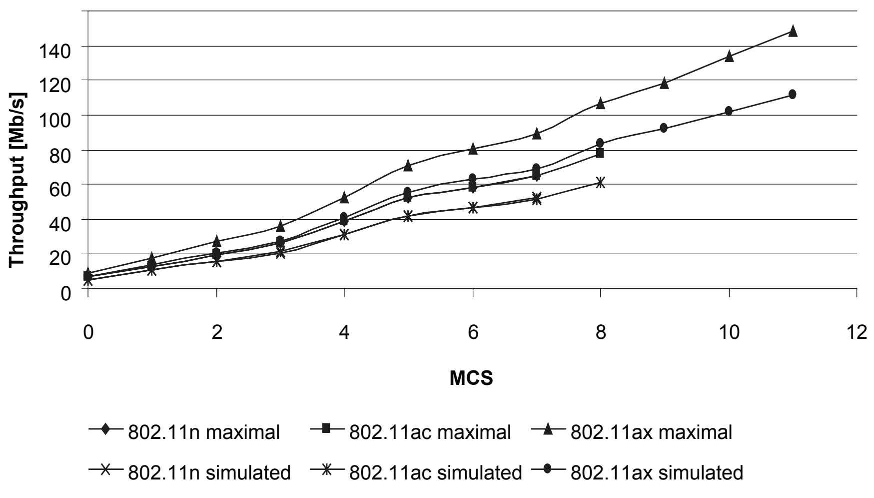
There are also other factors which lowered practical throughput. If we have more users than one the possibility of collision arise (Dolinska et al.

2014a) so the set of control information if different for TCP and UDP type of communication. Finally in practice it is difficult to calculate throughput value but one can do this using a proper simulation tool. Quite a good result could be obtained with professional NS simulator (NS-3 Network Simulator 2017).

802.11ax throughput simulation

The verification of throughput of all three 802.11 standards is possible with ns-3 simulator. Starting from version ns-3.27 which was released in Nov 2017 and with most present version ns-3.28 it is possible to calculate the more practical throughput. We can use *he-wifi-network* example to simulate throughput versus such basic attributes as: channel width, guard interval and MCS. The results are more realistic as the simulator takes into account several parameters including: different time intervals, MAC mechanism, RTS/CTS option, TCP or UDP transport layer protocols, and control and management issues. The simulated throughput is normally lower then maximal theoretical one. The same simulation could be carried out with older examples dedicated *ht-wifi-network* to the 802.11n standard and *vht-wifi-network to* the 802.11ac standard respectively. The comparison of calculated and simulated throughput value for 20MHz channel width and 800ns guard interval are presented in Figure 6.

Figure 6. Comparison of calculated and simulated throughput values



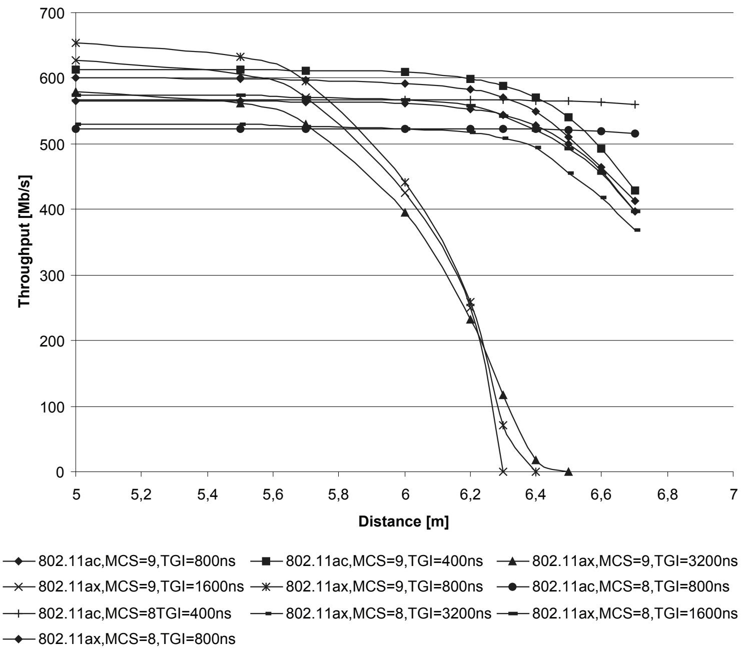
Source: as in Figure 1.

The efficiency of all standards is similar and is in the range from about 75 to 80%.

802.11ax versus ac Throughput in specific distance window

The set of throughput simulation versus distance for both standards 802.11ac and ax were carried out. (Masiukiewicz 2019).The throughput decrease significantly and quickly when the *Rx* and *SINR* drop to border values. These values are different for different *MCS* and practical values are higher then theoretical values (Masiukiewicz 2017), however in case of the 802.11ax standard there are no practical throughput measurement results with real devices so only the theoretical values could be applied. Next the author analysed the throughput available for 802.11ac and 802.11ax standards for selected attributes in the distance window from 5 to 6.7 m. All available high throughput *MCS* for channel width 160 MHz were included into simulation. The tests were carried out also for all available Guard Intervals time. One have to notice that 800 ns T_{GI} is the shortest one available for 802.11ax standard while 400 ns is still available for the 802.11ac standard and with the shorter T_{GI} time the throughput is higher. The results are presented in Figure 7. This The number of ten different solutions is available. Of course the author analysed solution with highest possible throughput. So there is no sense to analyse i.e. the throughput for narrower channel width as the throughput is respectively divided by about 2, 4 and so on. The basic *MCS* is *MCS*=9 but *MCS*=10 and *MCS*=8 are also taking into account.

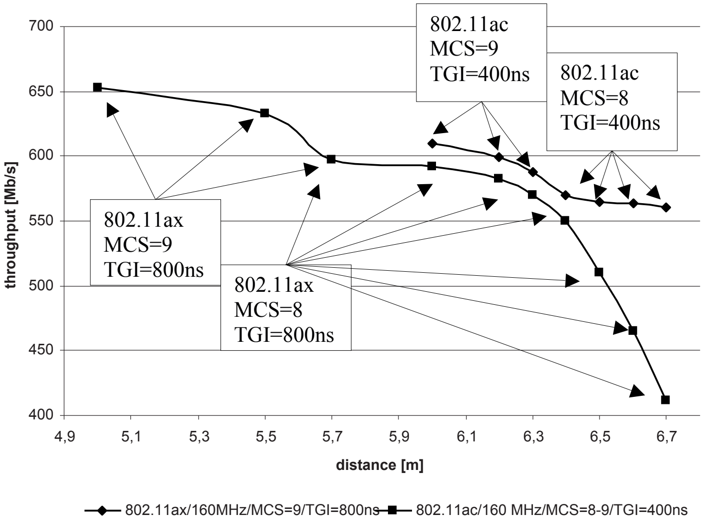
Figure 7. Throughput comparison for 160 MHz channel width



Source: as in Figure 1.

The *MCS*=10 is not available for 802.11ac because *MCS*=9 is the highest one for that standard, but it is not available also for 802.11ax because the signal drop below the critical level before the signal reach 5 m distance. In case of *MCS*=8, this *MCS* is available for both analyzed standards. The results shows that for distance range 5-5.7 m the highest possible throughput is for 802.11ax standard with following attributes: channel width equals 160 MHz, *MCS*=9, T_{GI}=800 ns, for distance range from 5.7 to 6.7 m the highest possible throughput is for 802.11ac standard with following attributes: channel width 160 MHz, *MCS*=9, T_{GI}=800 ns or *MCS*=8 and T_{GI}=400 ns. The final results are presented in Figure 8.

Figure 8. Final simulation results



Source: as in Figure 1.

The simulated throughput of the 802.11ax standard is lower then the simulated throughput of 3 to 36% depending on the distance value within the distance range from 6 to 6.7 m. This is valid in single user mode.

Present status of 802.11ax standard

The fact that availability of the final version of the standard is planned for 2019 did not prevent some producers from providing the first practical solutions. Intel declared 802.11ax chipsets availability in the near future and Qualcomm presented both the first chipset and the end user device (Qualcomm 2016). QCA6290 chipset offers the 802.11ax support as well as, possibility of two 802.11ac streams and compatibility with the 802.11n standard. The total flow rate is 1.7 Gb/s. Chipset does not realize all the possibilities of the 802.11ac and ax standards, offering only 20-80 MHz channels. In addition to that offer, Qualcomm also presented the IPQ8074 SOC end user device which supports the 802.11ax standard (Qualcomm 2016a). The first routers are also presented by D-link and Asus companies. Those routers support the new standard, and will be available for sale at the end second quarter 2018. Qualcomm presented the Atheros WCN3998 system, which is to be the first chip to offer 802.11ax and Bluetooth 5.1 connectivity, available in smart phones, tablets and laptops. The system is to offer the newest one and the most secure encryption protocol WPA3 and download about 60% less energy than other systems.

Figure 9. D-Link AX11000 Ultra Wi-Fi Router presented at CES 2018 Fairs

Source: as in Figure 1.

D-Link AX 6000 Ultra Wi-Fi, D-Link AX 11000 Ultra Wi-Fi (Figure 9) and Asus RT-AX88U are routers designed to support the latest standard. The first two are equipped with 8 antennas, WAN port, four LAN ports and USB 3.0. Asus is equipped with 4 antennas and 8 LAN ports. A document describing the framework specification and the current status of works can be found at the following addresses:

– https://mentor.ieee.org/802.11/dcn/15/11-15-0132-17-00ax-spec framework.docx,
– http://www.ieee802.org/11/Reports/tgax_update.htm.

Conclusions

The 802.11ax standard introduced several new elements in relation to the n and ac standards. The most important change is the possibility to use OFDMA and support for many users using the same resources. From the comparison of standards n, ac and ax it follows that the ax standard offers higher bit rates in a number of scenarios. Higher rates result from higher modulation schemes and from the increase in the number of sub-carriers and the increase in the length of the symbol in the timeline. The 802.11ax standard is characterized by a large number of different scenarios in the area of achieved bit rates. The range of values is huge. On the one hand, we can talk about the capacity of one RU (26 sub-carriers) with the size of about 1 Mb / s and support 74 users simultaneously within one spatial stream and 592 users under eight spatial streams, on the other, the throughput of the entire device using all resources for a single user. For one spatial stream, the bit rate is then 1220 Mb / s. You must also remember about the greater flexibility of 802.11ax and the possibility of creating different resource allocation scenarios. From the point of view of frequency resource management, the 802.11ax standard is more complex than previous versions of the standard.

However if we compare the single user mode the situation is a little bit different and throughput of the 802.11ac standard is higher for some distances than throughput for the 802.11ax standard. The main reason is the change in symbol duration time and subcarriers spacing. It is obvious that with the more dense subcarriers system it will be necessary to increase the conditions of successful transmissions. This results in higher values of necessary *Rx* and *SINR* and the distance coverage is lower for the 802.11ax standard then for the 802.11ac standard in case when the same *MCS* is used.

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Nowe opcje przepływności w standardzie 802.11ax

Streszczenie

Przepustowość oferowana w standardzie 802.11 jest obecnie podobna do przepustowości oferowanej w rozwiązaniach przewodowych. Nowo opracowany standard 802.11ax oferuje także nowe możliwości działania w środowisku o dużej gęstości użytkowników. Autor, wykorzystując teoretyczne zależności i wersję ns-3.27 symulatora NS, porównał przepustowość w standardach 802.11n / ac / ax i określił przepustowość dla wybranych konfiguracji parametrów kanału radiowego. Przepustowość 802.11ax jest zwykle wyższa niż w starszych standardach, jednak są pewne wyjątki.

Słowa kluczowe: przepustowość, standard 802.11ax, stosunek sygnał do szumu i zakłóceń.

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Artykuł zaakceptowany do druku we wrześniu 2019 roku.