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Throughput Comparison Between the New HEW 802.11ax Standard and 802.11n/ac Standards in Selected Distance Windows

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***Abstract*—The 802.11ax standard final specification is expected in 2019, however first parameters are just released. The target of the new standard is four times improvement of the average throughput within the given area. This standard is dedicated for usage in dense environment such as stadiums, means of municipal communication, conference halls and others. The main target is to support many users at the same time with the single access point. The question arises if the new standard will have higher throughput then previous ones in the single user mode. The author calculated the maximal theoretical throughput of the 802.11ax standard and compared the results with the throughput of older 802.11 standards such as 802.11n and 802.11ac. The new *he-wifi-network* example included in the ns-3.27 release of the NS-3 simulator was used to simulate the throughput between the access point and the user terminal. The results indicate that in some conditions the 802.11ac standard has higher throughput than the new 802.11ax standard.**

***Keywords*—wireless networks, throughput optimization, WLANS**

I. INTRODUCTION

HE (HighEfficienc y) or HEW (High Efficiency Wireless) acronyms are used to define the 802.11ax standard. The basic goal of the new 802.11 standard was as usual to increase the throughput. This time, the goal is to increase the average throughput four times per user working in a dense environment. Several new solutions have been introduced in the 802.11ax standard to achieve the assumed throughput value [1, 2, 3, 4, 5, 6, 7, and 8]. The crucial changes concerned the PHY layer. First, new MCS modulation and coding schemes with numbers 10 and 11 were implemented, in which QAM-1024 modulation was applied. Secondly, OFDMA broadcasting technology was used. The third significant change is an increase in the FFT number, which is followed by a four times decrease in the spacing between the subcarriers and a four times increase in the symbol length in time domain. The main difference in the 802.11ax standard in relation to 802.1n and 802.11ac is the increase of the subcarriers number what is the result of subcarriers spacing reduction. As a consequence, the duration of one FFT symbol has been lengthened. The subcarriers spacing have been reduced to 78.125 kHz and the duration of the symbol has increased to 12.8 µs. There were introduced also groups of subcarriers named RU (Resource Unit). The basic RU unit contains 26 subcarriers. The structure of the 20 MHz channel PHY layer is shown in Fig. 1. It is possible to create a series of RU's with sub-carriers number from 26 to 242 in one channel of a width of 20 MHz. This structure allows using OFDMA technology to simultaneously service for 1 to 9 users. Wider channels are multiplication of the 20 MHz channel; however, due to some differences in the number of subcarriers, the amount of RU is not directly related to the channels width ratio. The maximum number of users in a channel of 160 MHz width is 74 when system used one spatial stream, while the maximum number of subcarriers possible to allocate to one user depends on the channel width and ranges from 242 in the 20 MHz channel to 1992 in the 160 MHz channel. Using the OFDM and/or OFDMA broadcasting technology, the maximum available throughput is associated with the bandwidth dedicated to data transmission. Three important parameters were analysed within this paper. The first is maximal theoretical throughput. The author calculated the throughput and compared the results of three basic 802.11 standards. The second parameter is the efficiency of throughput what means the difference between maximal theoretical throughput and the results of simulation carried out with three NS-3 examples dedicated to the three 802.11 standards. The last analysis concerns the throughput value in selected window at the distance axis. The 802.11ac standard throughput in some distance range outperforms 802.11ax.

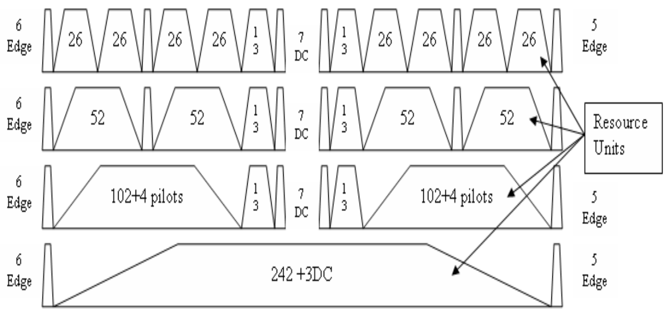

Fig. 1 Structure of the 802.11ax PHY layer in the 20MHz channel

The organization of the paper is as follows. The actual status of the 802.11ax project is presented in section 2. The basics of OFDMA throughput calculation are included in section 3, while the present information concerning newest ns-3.27 release in section 4. Simulation and calculation results are included in section 5. The conclusions are presented in section CONCLUSION.

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II. PRESENT STATUS OF THE 802.11AX PROJECT

The new 802.11ax standard is dedicated for environments with high user density. This type of environment is a challenge for the next-generation Wi-Fi standards [2]. For the proper conduct of the HEW topic in May 2013, the LMSC (LAN/MAN Standards Committee) launched the High Efficiency WLAN Study Group (HEW SG), which was later converted into a Task Group AX (TGax). The aim of the project was to create a standard dedicated to the environment of high user intensity and to provide a total bit rate of 10 GHz. In the case of 802.11ax, a unit with acronym RU (Resource Unit) was implemented. This unit includes at least 26 subcarriers and is capable to support a number of users. Such organization of the PHY layer with a simultaneous 4 times increase in the number of subcarriers significantly improves the efficiency of the system, especially the average throughput per user in an environment with a large concentration of terminals. 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 [9]. 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 [10]. Considering the 802.11ax project's status, it is necessary to notice that there are not too many studies regarding the analysis of the new standard parameters in the context of practical networks and simulators. Some authors present the current status of work on the 802.11ax project [11]. The analysis of throughput and comparison of 802.11ax and 802.11ac standards is presented by Oran Sharon and Yaron Alpert [12]. The authors calculated and simulated the throughput for both standards for the UDP protocol and MPDU frame aggregation and they used their own simulator. The authors found that the throughput obtained with the 802.11ax standard is about 29% higher then for the 802.11ac standard when the transmission is ideal, what means *PER* (Packet Error Rate) =0.

III. THE BASICS OF OFDMA THROUGHPUT CALCULATION

OFDM/OFDMA improves on the idea of FDMA technology and used several carriers, then filter them separately by using orthogonal properties of functions to increase spectral efficiency by choosing a specific $\Delta f = fi+1-fi$ interval between subcarriers [13,14]. Time signals in fact are used in a time window, and an information carrying symbol has a time interval for transmission called symbol duration. Subcarriers spacing is determined by a condition of orthogonality between the subcarriers, which allows decoding each one without interference form its neighbours.

OFDMA is a multicarrier transmission in which a user bit stream is transmitted over N_{FFT} subcarriers, each having T_{sym} symbol duration. The advantage of that parallel transmission is that the symbol time may be increased, which mitigates inter-symbol interference. Note that simply increasing the number of subcarriers in a given band of spectrum does not increase capacity but provides a useful parameter to optimize: there is an interesting trade-off between number of N_{FFT} subcarriers number and T_{sym} symbol duration time. On the other hand the throughput is the function of the subcarriers number as it is the function of total bandwidth dedicated to the channel. The more subcarriers are used, the longer is symbol duration time what is useful for multipath mitigation. T_{GI} (guard interval time) limits multipath interference from one symbol to the next.

Maximal theoretical throughput depends finally on many factors such as: channel width, guard interval time, symbol duration time, 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 [14] using the following equation:

$$C_{xMTT} = \frac{T_{sym}}{T_{sym} + T_{GI}} \frac{1}{T_{sym}} N_{FFT} \cdot bps \cdot CR \quad (1)$$

where:

C_{xMTT}	maximal theoretical throughput for *x*= *MCS* number,
T_{sym}	OFDMA symbol duration time,
T_{GI}	guard interval time,
N_{FFT}	number of subcarriers,
bps	number of bits per OFDMA symbol,
CR	coding rate.

The above formula doesn't include such factors as *PER* and efficiency ratio of the throughput. *PER* indicate how many packets have to be retransmitted and because of this, the practical throughput is lower then maximal. The PER is strongly depend on *Rx* which is received signal power level and SINR (Signal to Interference and Noise Ratio). The efficiency ratio corresponds to other elements such as: different interval frame spaces (DIFS, SIFS, PIFS, and EIFS etc.), management and control time, type of transmission protocol (UDP, TCP) and other mechanisms in MAC layer. The more practical throughput can be calculated using the following formula:

$$C_{xP} = C_{xMTT}(1 - PER)ER \quad (2)$$

where:

C_{xP}	practical throughput,
PER	packet error rate,
ER	efficiency rate.

Practical throughput could be calculated using NS-3 simulator. Examples *ht, vht, he-wifi-network* let us calculate throughput versus distance and *Rx, SINR* and *PER* are in this way taking into account.

Generally both values the frequency spacing and the symbol duration time 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 the 802.11ax are equal 78.125 kHz and 12.8 µs. The key issue is how many subcarriers could be use for data transmission and what is the total bandwidth dedicated for that purpose. The number of subcarriers for 802.11n and ac standards is shown in Table I while for the 802.11ax standard in TableII.

TABLE I
NUMBER OF SUBCARRIERS IN 802.11N/AC STANDARDS DEDICATED FOR DATA TRANSMISSION

	Channel width [MHz]			
Standard	20	40	80	160/80+80
802.11n	52	108	-	-
802.11ac	52	108	234	468

TABLE II
NUMBER OF SUBCARRIERS IN THE 802.11AX STANDARD DEDICATED FOR DATA TRANSMISSION

Subcarriers number in RU	Channel width [MHz]			
	20	40	80	160/80+80
	RU number/ total subcarriers number in the channel			
26	9/234	18/468	37/962	74/1924
52	4/208	8/416	16/936	32/1664
106	2/212	4/424	8/848	16/1696
242	1/242	2/484	4/968	8/1936
484	-	1/484	2/968	4/1936
996	-	-	1/996	2/1992
2x 996	-	-	-	1/1992

While the maximum theoretical throughput in a given channel in 802.11ac/n standards takes one value, in the 802.11ax standard it may be a lot of different scenarios depending on the amount of RU's and the amount of available subcarriers, which in turn is a function of the number of users. The practical scenarios could be even more complicated as we can use different RU's for different users [7].

IV. NS-3.27 RELEASE

The NS-3 simulator is an advanced network simulator, which is recognized as the basic tool for testing LAN, WAN and Wi-Fi networks. One of the most important NetDevice modules in NS-3 is the Wi-Fi module, which is the largest object in NS-3. WifiNetDevice implements the IEEE 802.11 standard. Simulations with different versions of MAC and PHY could be performed. The PHY IEEE 802.11 layer architecture implemented in NS-3 was designed on the base of YANS simulator developed by Mathieu Lacage and Tom Henderson [15]. The Wi-Fi model used in NS-3 is very extensive and contains 75 objects and a number of variables and functions. Work is underway to develop the new versions of the simulator. They are available practically every year. The ns-3.27 version was released at the end of 2017 [16]. The version ns-3.28 is also available at present. The new physical layer model is available from version 3.26 and in addition to the YansWifiPhy layer model it is possible to use the SpectrumWifiPhy layer model [17].

The new physical layer model enables taking into account interference from other stations or other systems by determining the *SINR* factor which is used to verify the correct receiption of the packet.

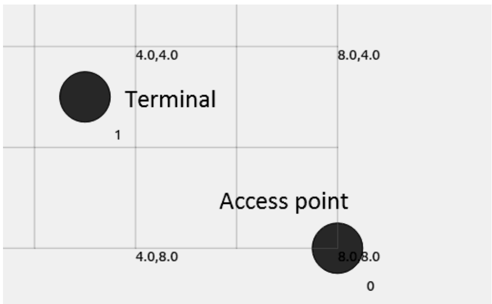

Fig. 2. Test simulated network structure

A number of examples allowing analysis of selected Wi-Fi network parameters can be found at https://www.nsnam.org/doxygen/dir_2ed9fc3d4c8eeb99a1460aa5faee4b2e.html

The author used three examples he-*wifi-network, ht-wifi-network, vht-wifi-network* dedicated respectively to the ax, n and ac versions of the 802.11 standard, to analyse the throughput. The structure of all three examples is the same. The simulation uses one access point and one station in infrastructure mode. Fig. 2 shows the network structure in the *he-wifi-network* example created in the xml file using the NetAnim application included into the NS-3 simulator.

V. THROUGHPUT ANALYSIS RESULTS

This section concerns all calculation and simulation results. The subsection *A* covers the assumptions and limitations of calculations and simulations. Then the results are presented and discussed respectively in the subsections *B-D*. Subsection *B* concerns theoretical calculations of throughput of three 802.11 standards. Subsection *C* presents results of ns-3.27 simulation and subsection *D* is devoted to the results summary.

A. Assumptions of calculation and simulation

The calculations and simulations were performed for selected *MCS*, channel width, bandwidth and the communication protocol. Some limitations result from the current possibilities of the *he-wifi-network* example. The *he-wifi-network* example allows for analysis in the 5 GHz band without the possibility of aggregating packets and using the new standard functionalities dedicated for many users. The analysis attributes are shown in Table III.

TABLE III
ANALYSIS ATTRIBUTES

Attribute	MTT* calculation	Throughput simulation with ns-3.27
Frequency band [GHz]	-	5
Channel width [MHz]	20-160	20-160
MCS	0-11	0-11
4th layer protocol	-	TCP
Distance [m]	-	4-12
Mode of operation	SU	SU
Packet length [Byte]	-	1500
TGI [ns]	400-3200	400-3200

*Maximal Theoretical Throughput

Three NS-3 examples *ht*, *vht*, *he-wifi-network* were used for throughput simulation.

B. Calculations results

Firstly, the maximum theoretical throughput for a given *MCS* as a function of the channel width for two extreme widths of 20 and 160 MHz was determined based on the formula (1) for the given number of subcarriers for each standard. Table IV shows the results of calculations. The 802.11ax standard throughput is higher than for 802.11n and 802.11ac standards for the same *MCS*. This is due to the ratio of the duration of the T_{sym} symbol to the T_{GI} time. The maximal theoretical throughput is higher for 802.11ax standard then for 802.11n/ac and outperforms older standards of 37 % in the 20 MHz channel and 25% in the 160 MHz channel.

TABLE IV
MAXIMAL THEORETICAL THROUGHPUT IN SINGLE USER MODE

				MTT [Mb/s] T_{GI}=800 [ns]				
Channel width [MHz]				20			160	
MCS	bps	CR	Modulation	802.11n$^{3/}$	802.11ac$^{3/}$	802.11ax$^{1/}$	802.11ac$^{4/}$	802.11ax$^{5/}$
0	1	1/2	BPSK	6,5	6,5	8,9	58.5	73,2
1	2	1/2	QPSK	13	13	17,8	117	146,4
2	2	3/4	QPSK	19,5	19,5	26,7	175.5	219,6
3	4	1/2	16QAM	26	26	35,6	234	292,8
4	4	3/4	16QAM	39	39	52,8	351	439,2
5	6	2/3	64QAM	52	52	70,5	468	585,6
6	6	3/4	64QAM	58,5	58,5	80,1	526.5	658,8
7	6	5/6	64QAM	65	65	89,0	585	732
8	8	3/4	256QAM	n/a	78	106,8	702	878,4
9	8	5/6	256QAM	n/a	n/a$^{2/}$	118,6	780	976
10	10	3/4	1024QAM	n/a	n/a	133,5	n/a	1098
11	10	5/6	1024QAM	n/a	n/a	148,3	n/a	1220

1/N_{FFT}=242, T_{sym}=12.8 µs, 2/ not available for 20MHz channel, 3/N_{FFT}=52, T_{sym} =3.2 us, 4/N_{FFT}=208, T_{sym}=3.2 us, 5/N_{FFT}=2x996, T_{sym} =12.8

C. *Simulation results*

The practical l throughput is obtained through the simulation with *ht/vht/he ns-3.27* examples. The comparison of the results is presented in Fig. 3.

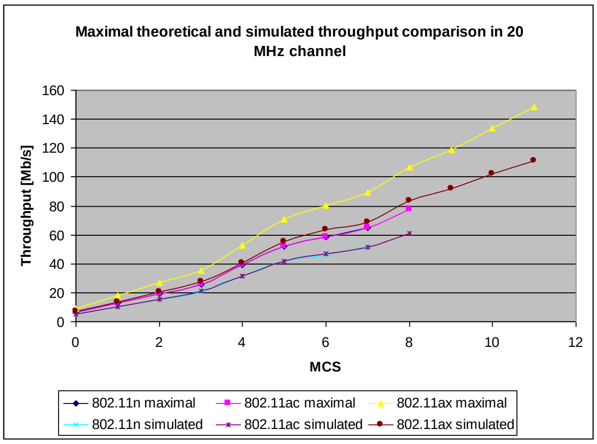

Fig. 3 Maximal theoretical and simulated throughput comparison for different attributes

These simulation were carried out for the channel width 20 MHz and T_{GI} =800 ns. The simulated throughput of the 802.11ax standard still outperforms the simulated throughput of the 802.11ac standard of 37 % and if the throughput efficiency ratio will be describing by the following formula:

$$ER = \frac{MTT - ThrS}{MTT} \cdot 100 \quad (3)$$

where *ER* is the throughput efficiency ratio, *MTT* is the maximal theoretical throughput and *ThrS* is the throughput simulation result. We can find that the simulated throughput is lower then *MTT* of about 20%. This is the results of the MAC mechanisms operating way and different dead time periods [18]. The efficiency of the throughput is presented in Fig. 4.

The efficiency values are within the range from 74,9 to 80,5 %.

The behavior of simulated throughput versus distance was next analyzed. The throughput characteristic versus distance for 802.11ax standard and for following attributes: channel width=160 MHz, T_{GI}=800 ns, *MCS*=9, *distance*=1-5 m is shown in Fig. 5.

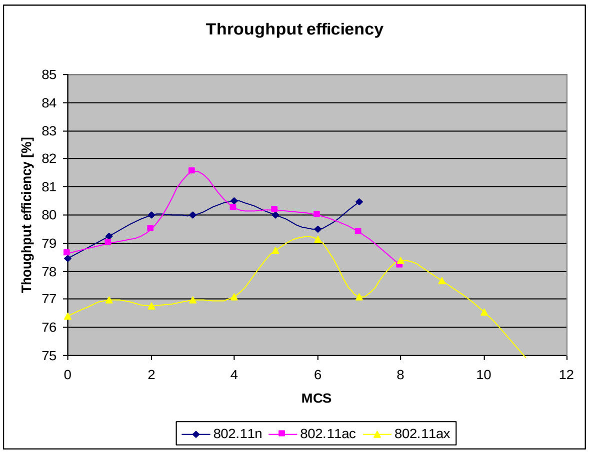

Fig. 4 Throughput efficiency

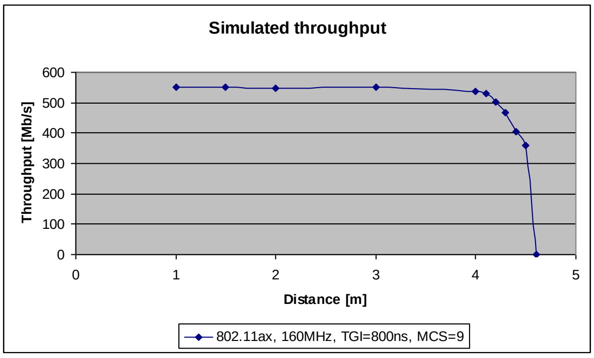

Fig. 5 Simulated throughput characteristic

The throughput was dropped to zero after reaching some distance. This shape of the characteristics is the result of wireless signal distribution characteristics within the radio channel and system requirements concerning *Rx*, which is received signal level and *SINR*, which is signal to interference and noise ratio. There are at least a few channel loss models within NS-3 simulator. All examples used by the author applied the same Friis loss channel model. The signal power loss within the channel depends on many factors and the distance [19] is one of the most important. The following equation is used to determined loss in the radio channel:

$$R_x = T_x + G_{RA} + G_{TA} - L_{fspl} - L_{corrections} \quad (5)$$

where

Rx	received signal power level,
Tx	transmitted signal power level,
G_{RA}	receiving antenna gain,
G_{TA}	transmitting antenna gain,
L_{fspl}	free space signal loss,
$L_{corrections}$	different signal loss corrections used in different radio channel models.

The signal level dependence on the distance is included in the L_{fspl} *following* formula*:*

$$L_{fspl} = 32{,}44 + 20\log f[MHz] + 20\log d[km] \quad (6)$$

Where:

32,44	fixed value depends on used units,
f	radio channel frequency in MHz,
d	distance between AP and user in km.

The frequency is steady for carried out analysis so the most important factor which deteriorated the signal level is the distance. The signal loss depending on the distance could be describe by the following formula:

$$L_{distance} = 20\log d\ [km] \quad (7)$$

where $L_{distance}$ is the signal power loss on the distance axis, d is the distance in km. The Friis model is valid for $d>3\lambda$ where λ corresponds to the system frequency. The results for very low distance values can be not trustworthy. 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 [20] 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.

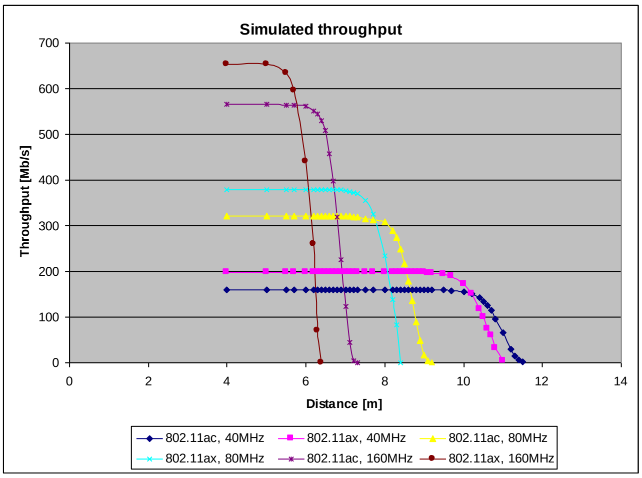

Fig. 6 Simulated throughput comparison

Next the author analysed the throughput available for 802.11ac and 802.11ax standards for selected attributes in the selected distance window. The first distance window is from 4 to 12 m and the following simulation parameters are used: *f*=5 GHz, channel width 40, 80, 160 MHz, *MCS*=9, T_{GI}=800 ns, 802.11ac/ax standards. The results are presented in Fig. 6. For each channel width one have the situation when first the throughput of 802.11ax is higher then for 802.11ac standard but later because of different *Rx* and *SINR* requirements the throughput for 802.11ax start to drop earlier then for 802.11ac and in some distance window the 802.11ac throughput is higher then for 802.11ax. However only one selected *MCS* and only one T_{GI}, which were the same for all simulation, were taking into account. To have a better look what solutions are possible in the given distance window the author include to simulation all available high throughput *MCS* for channel width 160 MHz. 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 Fig. 7. This time the author analysed the distance window from 5 to 6.7 m. 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.

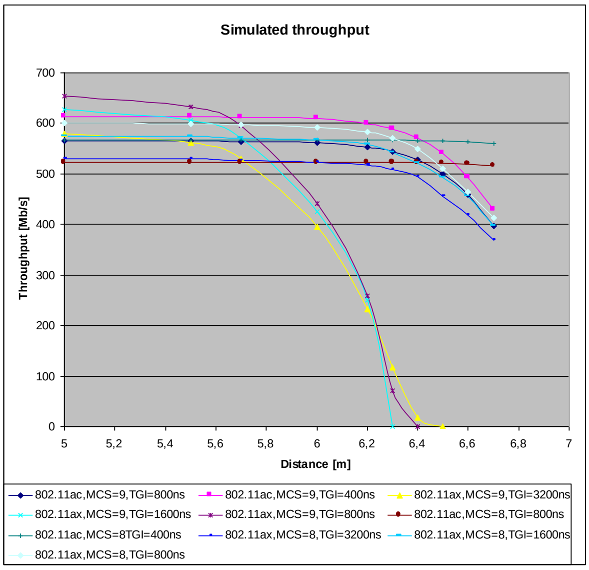

Fig. 7 Throughput comparison

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.

D. Results summary

The author analyzed and compared the throughput of 802.11ax standard with older ones. The throughput of 802.11n and ac standards is the same if we use the same channel width and the same *MCS*. The calculation and simulation results show that the new 802.11ax standard has higher maximal theoretical throughout of 37% to 25% then older 802.11n/ac standards. If one take a close look into the selected distance window it is evident that the 802.11ac standard throughput will outperform for some distances the new standard throughput. The final results are presented in Fig. 8.

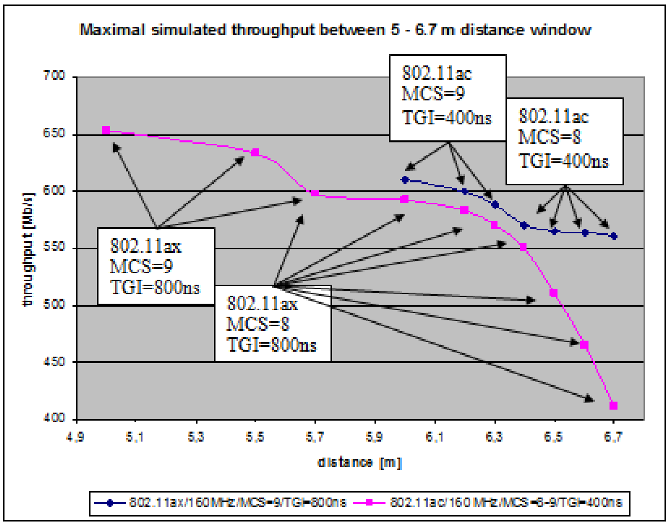

Fig. 8 Final simulation results

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.

CONCLUSION

The new 802.11ax standard is dedicated for dense environment it means that the standard is optimize from the point of view of high number of users. In this way one Access Point with full functionality of the new standard could replace some number of AP supporting older standards. The OFDMA technology enables the more efficient use of the bandwidth resources especially multi-users transmissions and the possibility to handle more users then older standards. 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. Still the 802.11ax standard will outperform other standards in a short distance, but one has to remember that the coverage is not a fixed issue at depends strongly on many factors within the radio channel. In practical conditions the loss depending on distance is described by the equation:

$$L_{distance} = \alpha 10 \log d \quad (8)$$

where α is not represent second power function but could take value in the range from 2 to 8 [21]. It means that in some radio channels the signal power level could drop very quickly. It is not possible to precisely determine the signal distribution characteristic in the radio channel on theoretical way. The final results have to be confirmed by practical measurements.

The verification of necessary *Rx* and *SINR* values for 802.11ax will be possible only after some tests with real devices.

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