Switching to Wi-Fi 6 Technology in a SOHO Environment

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***Abstract* - The IEEE 802.11ax wireless network standard according to the new nomenclature of the Wi-Fi Alliance association is named Wi-Fi 6. It belongs to the category of High Efficient Wireless - HEW, with a maximum theoretical bandwidth of 9.6 Gbps compared to 3,5 Gbps of Wi-Fi 5standard (IEEE 802.11ac). The key advantage of the Wi-Fi 6 standard is the ability to serve a larger number of wireless clients and the use of technology that divides the wireless channel into several subchannels with improved energy efficiency. Multiple subchannels that are used by a large number of connected devices extremely well affects performance of the wireless network in everyday work. The authors have studied the key features of Wi-Fi 6 technology, then analyze the performance of the Wi-Fi 6 standard in a SOHO environment and give an overview of the need to switch to the Wi-Fi 6 wireless standard.**

Keywords* - *Wi-Fi 6 technology; SOHO; switching

I. INTRODUCTION

IEEE 802.11 wireless networks are an evolutionary phenomenon in connecting computers and network devices to a Personal Area Network (PAN) or Local Area Network (LAN). Although there are devices on the market today that support other network technologies for connecting primarily within a PAN network (eg: IEEE 802.15.1 Bluetooth or Wi-Fi Direct), the IEEE 802.11 is a widely used standard for wireless extension of local computer networks of the IEEE 802.3 wired standard. Since the appearance of the first specification in 1997, IEEE 802.11 has evolved into the currently most advanced variant and it is named IEEE 802.11ax, i.e. Wi-Fi 6 according to the new nomenclature of the world association Wi-Fi Alliance. The Wi-Fi 6 standard in the latest version delivers significant changes that primarily relate to the speed of wireless data transmission compared to previous variants. Wi-Fi 6 standard according to general specifications can be used in a corporate environment, i.e. where the emphasis is on serving a larger number of users without declining network performance, but also in Home Office - Small Office (SOHO) environment with a smaller number of users. The main topic of the paper research is analyzing the performance of the Wi-Fi 6 standard in a SOHO environment with an overview of the need to switch to the Wi-Fi 6 wireless standard. The paper will give a brief overview of Wi-Fi network standards, then highlight the comparative advantages and features of the Wi-Fi 6 standard. In the SOHO environment the data rate of the test LAN will be tested via NetMeter 1.1.3 and Iperf3.

II. ADVANCED FEATURES OF IEEE 802.11 AX STANDARD (WI-FI 6)

Since the first specification of the IEEE 802.11 wireless standard was introduced in 1997, it has become *de facto* common way to connect devices wirelessly, from mobile devices to IoT (Internet of Things). Development of versions of the IEEE 802.11 wireless standard includes several standards that enabled higher data rates and the use of specific enhancements in each new version. For example, the IEEE 802.11a standard introduces for the first time OFDM with support for speeds of 54 Mbps, the 802.11b standard enables speeds of 11 Mbps and increased signal range up to 130 meters, while the 802.11g standard achieves speeds of 54 Mbps. The IEEE 802.11n standard, with an increase in speed of 600 Mbps, offers an increased range of 250 m and introduces MIMO technology [1]. IEEE 802.11ac standard from the year 2013 uses only the operating frequency in the ISM band of 5 Ghz, 256 bit QAM and MU-MIMO with a theoretical data transfer rate of 1300 Mbps. Table 1 provides a comparative overview of popular Wi-Fi standards.

The Wi-Fi 6 standard delivers several key improvements over previous wireless network standards, namely [2]:

a) Support for MU-MIMO (Multi User - Multiple In Multiple Out);
b) More Spatial Streams;
c) Higher density of QAM (Quadrature Amplitude Modulation) modulation;
d) Advanced OFDMA (Orthogonal Frequency-Division Multiple Access) multiplexing;
e) Introduction of BSS coloring (Basic Service Set Coloring);
f) Energy saving and Target Wake Time technology page numbers.

A. *Use of MU-MIMO technology*

Significant improvement of the Wi-Fi 6 wireless standard is the use of MU-MIMO technology, i.e. the ability to communicate with multiple stations (clients) simultaneously. Communication is performed on the same

TABLE 1. WI-FI STANDARDS, SOURCE: INTEL.COM, WWW.INTEL.COM/CONTENT/US/EN/GAMING/RESOURCES/WIFI-6.HTML (26.12.2020)

Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ax
	Wi-Fi 2	**Wi-Fi 1**	**Wi-Fi 3**	**Wi-Fi 4**	**Wi-Fi 5**	**Wi-Fi 6**
Year of release	1999	1999	2003	2009	2013	2019
Operating frequency - ISM	5Ghz	2,4Ghz	2,4Ghz	2,4Ghz & 5Ghz	5Ghz	2,4Ghz & 5Ghz
Radios	SISO (Single input / Single Output	SISO	SISO	SU-MIMO	MU-MIMO (download)	MU-MIMO (upload/download)
OFDM / OFDMA	OFDM	HR-DSSS	OFDM	OFDM	OFDM / OFDMA	OFDM / OFDMA
Maximum Data rate (Mbps)	54	11	54	72 – 600	433 – 6933	600 – 9608

channel without declining network performance, i.e. routers communicate with multiple devices at the same time, instead of devices "waiting" for each other [3]. Unlike the previous Wi-Fi 5 standard (IEEE 802.11ac), which uses MU-MIMO technology exclusively in download mode, Wi-Fi 6 also uses it when downloading or uploading data. Compared to Wi-Fi 5, Wi-Fi 6 does not use a larger number of MIMO spatial signal streams and does not expand the channel, but gives 37% better performance compared to Wi-Fi 5 [3]. The increase in bandwidth per user was achieved by making more efficient use of the available frequency spectrum as shown in Fig. 1 [4].

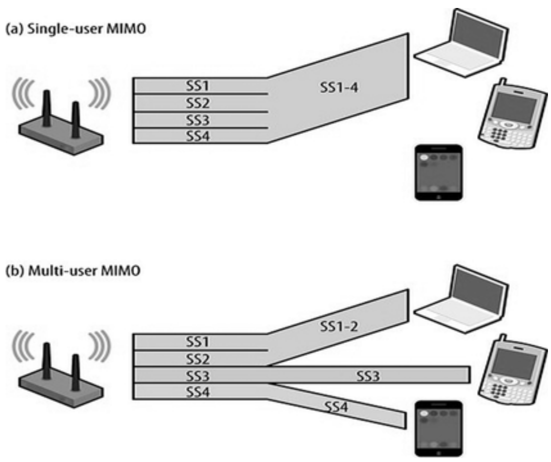

Figure 1. Comparison of SU-MIMO and MU-MIMO technology. Source: http://ontheflywifi.net/wi-fis-enigma-mu-mimo/ (20.1. 2021.)

B. Support for more spatial streams

The Wi-Fi 6 standard supports the use of spatial multiplexing which consequently leads to an increase in speed [5]. Basically, the number of spatial flows is a kind of path that will carry unique data. The visualization role of spatial flows in wireless network communication can be simply compared to the following statement: as the bandwidth can be compared to a highway to which an additional lane is added, the number of spatial flows can be compared to a bridge over an existing road. The Wi-Fi 6 standard supports up to 8 spatial streams, i.e. 8 transmitting and 8 receiving antennas and a bandwidth of 160 Mhz with 1024-QAM modulation [6].

The Wi-Fi 4 standard supports 4 spatial streams with a bandwidth of 40 Mhz, while Wi-Fi 5 (802.11ac Wave2) defines 4 spatial streams with the ability to support up to 8 streams with a maximum bandwidth of 160 Mhz and 256-QAM modulation [7].

The Wi-Fi 4 standard (IEEE 802.11n) was the first to introduce the so-called channel bonding, which enabled the expansion of the channel frequency band from 20 MHz to 40 MHz. Wi-Fi 5 has further expanded the connection to allow 80 MHz and 160 MHz channels. The 802.11n Wave2 standard allows speeds of 2.34 Gbps (802.11n Wave 1 reaches up to 1.3 Gbps) [9]

On the other hand, the number of supported antennas on the network device (adapter) determines the maximum number of available data streams, i.e. it is not possible to use a larger number of spatial streams in the configuration than the number of supported antennas on the device.

Fig.2 shows that higher spatial flows mean proportionally higher overall performance in serving multiple wireless clients.

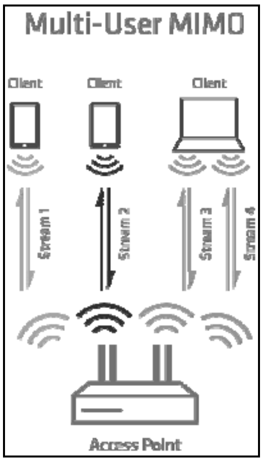

Figure 2. Higher spatial flows mean proportionally higher overall performance in serving multiple wireless clients. Source:https://lancomwire.com/wi-fi-6-as-a-traffic-control-system-for-data/ (18.1. 2021.)

C. 1024 Quadrature Amlitude modulation

As mentioned before, Wi-Fi 6 delivers 1024-QAM modulation, and is basically a modulation in the process of which amplitude and phase variations occur within which bits are transmitted. Simply put, the higher the "density" of QAM, the higher the bandwidth the wireless network will have. The Wi-Fi 5 standard (IEEE 802.11ac) uses 256-QAM modulation, i.e. each symbol transmits 8-bit data (2^8 = 256). On the other hand, Wi-Fi 6 (IEEE 802.11ax) uses 1024-QAM quadrature amplitude modulation where each symbol transmits 10-bit data (2^10 = 1024). In conclusion, the 802.11ax standard compared to 802.11ac increases the data flow of an individual spatial stream by 25%. Fig.3 shows the difference between 256-QAM and 1024-QAM modulation and it is worth to notice the higher sample density at 1024 QAM.

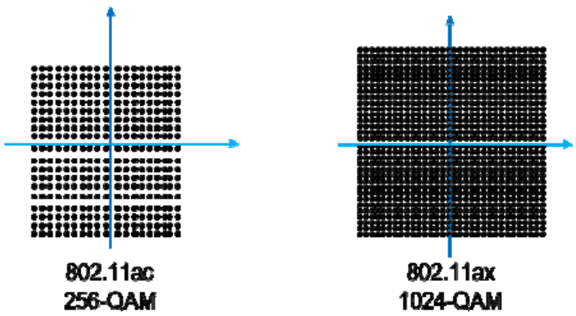

Figure 3. Difference between 256-QAM and 1024-QAM modulation. Source: https://support.huawei.com/enterprise/es/doc/EDOC1100102755?idPath=24030814|21782164|21782201|22318535|21560861 (24.1. 2021.)

D. Advanced OFDMA (Orthogonal Frequency-Division Multiple Access) multiplexing

The Wi-Fi 6 wireless standard also delivers advanced OFDMA (Orthogonal Frequency-Division Multiple Access) multiplexing. Basically, OFDMA divides a wireless channel into several smaller subchannels used by clients (multiple of them) thus ensuring simultaneous communication with the access point or router. OFDMA in the Wi-Fi 6 standard supports 9 clients using the 20-megahertz band, 18 using the 40-megahertz band, and 37 using the 80-megahertz band [10]. According to the frequency band division, the access point can then allocate to clients as much bandwidth as they need with the possibility of occupying the entire channel in case of need as shown in Fig.4. By applying OFDMA multiplexing in this way ensures continuity in wireless signal delivery to the client signal stability in locations where there are multiple connected wireless devices.

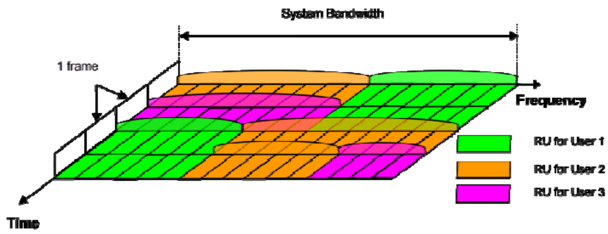

Figure 4. How OFDMA works. Source: https://support.huawei.com/enterprise/es/doc/EDOC1100102755?idPath=24030814|21782164|21782201|22318535|21560861 (24.1. 2021.)

E. Support for BSS Coloring (Basic Service Set Coloring)

The Wi-Fi 6 standard also uses BSS Coloring (Basic Service Set Coloring). Basically, BSS Coloring technology labels each piece of data traveling on a wireless network with a specific "color" that represents an affiliation to a network, as shown in Fig. 5. A wireless access point or router knows that the data belongs to them, while other data that do not belong to the same "color" are automatically rejected. That simple means that devices channels with the same color are kept far away from each other [11]. Since the access point or router thus knows which data belongs to them, it will automatically ignore data from all other surrounding wireless networks and consequently will not increase signal latency and interference.

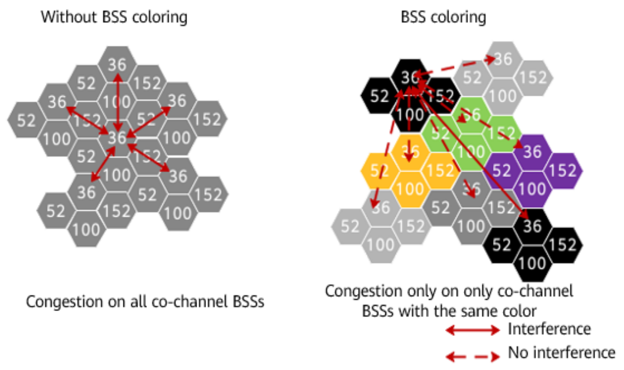

Figure 5. BSS Coloring. Source: https://forum.huawei.com/enterprise/en/wlan-from-beginner-to-expert-wi-fi-6-post-4-bss-coloring-and-spatial-reuse/thread/647487-869 (24.1.2021)

F. *Target Wake Time*

Target Wake Time technology is a novelty of the Wi-Fi 6 standard, which allows connected devices to notify the devices about the moment of sending or receiving data. This means that if there is no current activity in sending / receiving data, the network adapter of the device switches to standby mode, which consequently leads to energy savings and lower battery consumption.

III. TEST ENVIRONMENT AND TEST RESULTS

In order to see the advantages of the Wi-Fi 6 wireless standard in everyday, real operations, a simple test SOHO (Small Office - Home Office) environment was created with two computers and one router in two scenarios. The SOHO environment usually consists of a small number of people (usually up to 10) employed in an organization and relies primarily on the use of a local area network (LAN) and Internet access [12]. In addition, local area networks in a SOHO environment may also include support for Voice over IP (VoIP) as well as other network devices. For the comparative test with the Wi-Fi 6 standard, the Wi-Fi 4 standard was targeted, which is two generations older, and with the comparative test of real business operations we want to show the justification of the transition from Wi-Fi 4 to Wi-Fi 6.

The test environment in which network speed (throughput) tests were performed included a space of regular two-room layout. The two rooms (two offices) share two partition walls (locations A and B). The wireless access point is located in the middle of the space, and the whole scheme is shown in Fig.6.

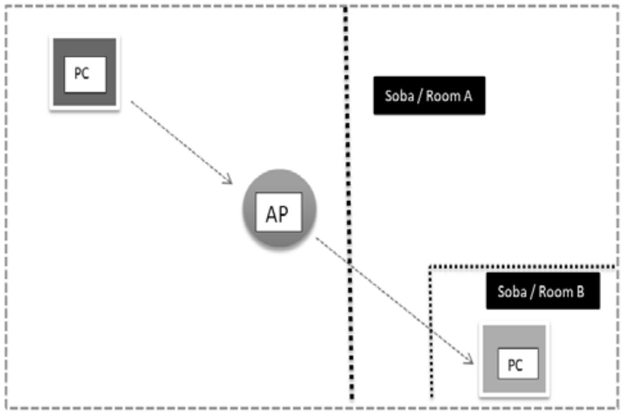

Figure 6. Test SOHO environment showing the layout of the room and the position of the test equipment. Source: authors

Testing the speed of the WiFi 6 network in a SOHO environment was performed with the application NetMeter 1.1.3 and iPerf3 using the following test samples:

- Compressed files with a total size of 23 MB;
- One 700 MB video file;
- 200 image JPEG files with a total size of 250 MB (approx. 1,2 MB per file)

Comparative tests were performed in two scenarios, namely the Wi-Fi 6 test and the Wi-Fi 4 local area network (LAN) test. The active network equipment included the following devices: Cisco AP ax-9116 for Wi-Fi 6 LAN speed test and Zyxel NBG-419n router for Wi-Fi 4 LAN speed test. The test laptops were equipped with a network adapter: Intel AX201 and Intel AX1650 for 802.11ax (Wi-Fi 6) network and Intel AC8265 and Intel AC3165 for 802.11n (Wi-Fi 4) network. The Wi-Fi 6 speed test included a channel width of 80 Mhz (4 channels), 1024 QAM modulation in a 2x2 configuration. The Wi-Fi 4 speed test included channel widths of 20 and 40 Mhz, 64 QAM modulations in a 2x2 configuration.

The test files were transferred in two cycles and the average throughput rate and time spent were measured. Thus, a simple everyday home-business scenario is simulated, i.e. a realistic operation of transferring files to a shared folder (Copy-Paste -> Share Folder). The measurement results are shown in Table 2.

TABLE 2. WI-FI 6 AND WI-FI 4 SPEED MEASUREMENT RESULTS; SOURCE: AUTHORS

	Wi-Fi 6*	Wi-Fi 4*	Wi-Fi 4*	Wi-Fi 6	Wi-Fi 4	Wi-Fi 4
Network router	Cisco AP ax-9116	Zyxel NBG-419n	Zyxel NBG-419n	Cisco AP ax-9116	Zyxel NBG-419n	Zyxel NBG-419n
1 Zip file; 23 MB file size	90 – 100 (Mbps)	8 – 9 (Mbps)	15 – 18 (Mbps)	90 – 100 (Mbps)	8 – 9 (Mbps)	15 – 18 (Mbps)
1 Video file; 700 MB file size	270 – 290 (Mbps)	14.8 – 18.9 (Mbps)	23 – 28 (Mbps)	390 – 405 (Mbps)	31.4 – 33.6 (Mbps)	44 – 59 (Mbps)
200 JPEG files; 250 MB total files size	270 – 290 (Mbps)	14.8 – 18.9 (Mbps)	23 – 28 (Mbps)	390 – 405 (Mbps)	31.4 – 33.6 (Mbps)	44 – 59 (Mbps)
Channel width (Mhz)	80	20	40	80	20	40

* speed test through obstacle obtained via NetMeter v. 1.1.3 and iPerf3

As shown in Figure 7, the average data transfer rate in the test environment in two different rooms for Wi-Fi 6 network was over 200 Mbps (218.22 Mbps), while Wi-Fi 4 achieved average speeds from 22.5 Mbps, or 14.06 Mbps. Slightly higher results of the Wi-Fi 4 standard were achieved by using a wider channel frequency spectrum of 40 Mhz, while Wi-Fi 6 used the 80 Mhz frequency band of the channel in the 2x2 configuration. Also, Wi-Fi 6 uses QAM-1024 modulation while Wi-Fi 4 uses QAM-64 which greatly affects higher network bandwidth. In the comparative test, the influence of the width of the spatial channel in data transmission (20 and 40 Mhz versus 80 Mhz) can also be noticed. Although the differences in data transfer speeds of different standards are very noticeable, the differences in data transfer speeds in favor of Wi-Fi 6 would be especially visible in situations of serving a larger number of users, i.e. in the more efficient use of MU-MIMO and OFDMA technology, i.e. a larger number of antennas and spatial flows.

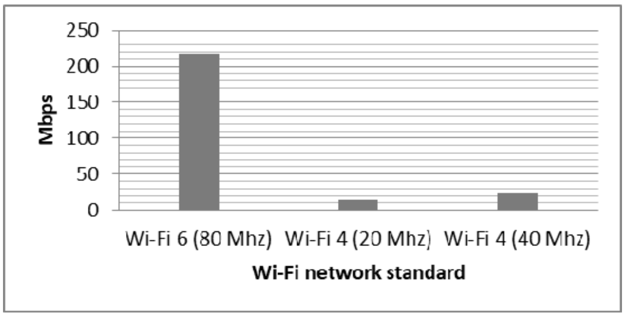

Figure 7. Average network throughput speed of tested Wi-Fi with obstacles (Two users). Source: Authors

In the measurements of network throughput speed in the simulated environment without obstacles, the achieved results of measuring the data transfer rate on Wi-Fi 6 network were 296.66 Mbps and 24.5 Mbps and 29.83 Mbps on Wi-Fi 4, as shown in Figure 8. Higher transmission speeds are also noticeable in all tests when it comes to space without obstacles (walls).

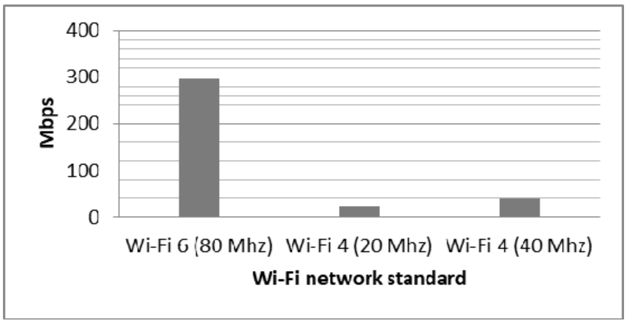

Figure 8. Average network throughput speed of tested Wi-Fi without obstacles (Two users). Source: Authors

IV. CONLUSION

Wi-Fi 6 is often associated with the term - HEW (High-Efficiency Wireless), which primarily refers to the maximum theoretical data transfer rate of 9.6 Gbps compared to the maximum of 3.5 that can give the previous standard Wi-Fi 5 [13]. However, an advanced feature of the Wi-Fi 6 standard is precisely the ability to serve a larger number of wireless clients, especially outside the SOHO environment i.e. serving a larger number of users in places such as airports, stations, stadiums, shopping malls, etc. The key technologies that bring improvements are MU-MIMO technique, then 1024-QAM modulation, OFDMA multiplexing, BSS coloring and Target Wake Time. Also, the benefit of switching to Wi-Fi 6 technology can be seen in the ability to play 4K / 8K videos for multiple users without decreasing performance (congestion) network, then in the use of augmented, virtual and mixed reality applications and significant energy savings important for the optimal functioning of IoT devices.

It should be noted that for full compatibility with the Wi-Fi 6 standard, in addition to Wi-Fi 6 supported network routers and access points, it is necessary to have the appropriate network adapters. Otherwise, users will not be able to use the advanced features that this standard carries. For average home and small office (SOHO) users, the transition from Wi-Fi 5 to Wi-Fi 6 will not bring significant improvements to make the transition necessary and cost-effective. However, if it is a transition from an older standard such as Wi-Fi 4 (802.11n), the performance gain is significant, as evidenced by comparative measurements, so the transition is justified. Although the tests involved the use of active network equipment of different classes (Cisco Vs Zyxel), the usual real operations from the example of Copy-Paste and shared content were performed significantly faster in the case of using the Wi-Fi 6 standard. The results of the conducted measurement in simulated SOHO conditions showed that there are multiple improvements in ordinary, realistic operations. For the next research, the authors recommend measuring the baud rate of the Wi-Fi 6 network in a simulated environment with a much larger number of users, and to show the impact of MU-MIMO and OFDMA technology on the baud rate of a wireless network.

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