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THE ANALYSIS OF THE NEW OPPORTUNITIES AND THE RESULTING CHALLENGES OF IEEE 802.11AX WIRELESS NETWORK STANDARD

Summary

The evolution of Wi-Fi was focused primarily on achieving successively higher theoretical speeds in the past. However, in the real world, with lots of users with diverse needs, a network needs to be designed to deliver all users an efficient communication. IEEE 802.11ax standard is an upcoming wireless network standard, which is still at the design stage. It defines new features and possibilities in Wi-Fi transmission. The article presents the description in details PHY layer and the MAC layer of this amendment. Then an analysis of challenges is carried out, which is mainly focused on the hardware design and testing.

Key words: IEEE 802.11ax, High-Efficiency Wireless, MU-MIMO, OFDMA.

JEL codes: L86

Introduction

IEEE (Institute of Electrical and Electronics Engineers) 802.11 standard, called also Wi-Fi, is a basis of wireless communication in current computer networks. In the past, the evolution of Wi-Fi was focused primarily on achieving successively higher peak (theoretical) speeds. However, in the real world, with lots of users with diverse needs, a network needs to be designed to deliver all users an excellent experience. The problem isn't how fast Wi-Fi can go, but if the Wi-Fi network has enough capacity to handle the growing demand for many different connected devices and services (Mailheau 2018; Masiukiewicz 2018). Previsions show a clear increase of wireless traffic on mobile devices (Bellalta 2015). The average household had about 8 wireless devices in 2012. In 2018, their number is 3 times bigger (18 per household). And for 2020 the average wireless devices number is forecasted for 50. And this is the forecast for private houses only. In every public place this numbers are as big as hundreds or thousands (Bellalta 2017; Mailheau 2018). High-definition video traffic will become dominant. The network must offer high and constant transmission rates. The standard needs effectiveness improvements very much. That's why the communication efficiency is one of the basic assumptions for the developed amendment.

IEEE 802.11ax standard is an upcoming wireless network standard, which is still at the design stage. A draft standard is available now, but the Wi-Fi Alliance has prepared hardware requirements and first devices compatible with IEEE 802.11ax draft are appearing on the market now. The new amendment defines important changes in wireless communication, especially regarding efficiency. The wireless network efficiency is lacking in previous versions. This problem is particularly annoying in the environments where many users use the wireless network, like stadium, shopping center, airport or even multi-family building (Bellalta 2017).

IEEE 802.11ax standard is known also as High-Efficiency Wireless (HEW). It has the challenging goal of improving the average throughput per user by a factor of at least 4X in dense user environments. This new standard focuses on implementing mechanisms to serve more users a consistent and reliable stream of data (average throughput) in the presence of many other users.

In this paper the author presents the physical and MAC layer changes, introduced by IEEE 802.11ax amendment. The rest of the paper is organized as follows. The next section contains most important IEEE 802.11ac amendment features, to give the reader some background information. The improvements introduced in physical layer are described in detail in the third section and the MAC layer in the fourth. The fifth section is devoted to the analysis of the IEEE 802.11ax amendment. The conclusions summarize the article.

Most important features of IEEE 802.11ac

IEEE 802.11ac standard improves and extends IEEE 802.11n functionality (802.11ac 2014, Dolińska 2016). It works in 5 GHz radio band only to avoid much of the interference at 2.4 GHz, including Bluetooth headsets and microwave ovens. Channel bonding is increased from 40 MHz (for 802.11n) to 80 MHz (obligatory in the standard) and 160 MHz (optional). Adjacent 20 MHz channels are bonded to make 40 MHz channel, then adjacent 40 MHz channels are bonded to make 80 MHz channel. 160 MHz channel can be made by bonding two adjacent or not-adjacent 80 MHz channels. The denser constellation means that 256 quadrature amplitude modulation (256-QAM) can be used. The data spatial stream number is increased from 4 to 8. It means, that the AP can transmit data by 8 antennas and user can transmit data by 4 antennas. IEEE 802.11ac is compatible with IEEE 802.11a/n standards (with IEEE 802.11n in 5 GHz band) and is designed to coexists efficiently with this standard device. It has strong carrier sense and a single new preamble, that appears to be a valid IEEE 802.11a preamble to IEEE 802.11a/n devices (802.11ac 2014; Dolińska 2016).

IEEE 802.11ac uses an aggregation, like IEEE 802.11n, but aggregated frame can le longer. With aggregation, the data is packed together in a single unit with one preamble and that acknowledged in one transmission. The aggregation types are the same. A-MSDU technique aggregates MSDU units (as IP packet) at the beginning of the MAC transmission path. An MSDU within an A-MSDU lacks a MAC header/footer, such as sequence number or frame check sequence. This method improves efficiency but making retries at the individual MSDU level is impossible. The second aggregation method, A-MPDU, works at the end of the MAC transmission path. Each MPDU in an A-MPDU contains its own MAC header. Efficiency is not quite as good, especially for short MPDUs, but if the packet transmission caused an error, the other MPDUs can be still receive correctly.

The new features, introduced by IEEE 802.11ac are multi-user MIMO (MU-MIMO) functionality, standards-based beamforming, RTS/CTS with bandwidth indication (IEEE 802.11ac 2013). Multi-user transmissions can be carried out by AP only. MU-MIMO is challenging technology and its proper implementation is difficult (802.11ac 2014). When AP sends data to the user, it forms a strong beam toward this user. At the same time the AP minimizes the energy for the first user in the direction of another users. So, the signal to every user can be slightly degraded by interference from data for the other users. This interference makes the highest constellations, such as 256-QAM, infeasible within a MU-MIMO transmission. But for the first time more than one user can occupy the radio channel in Wi-Fi network.

IEEE 802.11ac standard AP, operating on 80 MHz channel should be capable of IEEE 802.11a or IEEE 802.11n client to associate. Thus, beacon frames are sent on one 20 MHz channel, known as primary channel within this 80 MHz channel. On the other hand, the 802.11ac AP should coexists with 802.11a or 802.11n APs, which could operate on 20 MHz channel, but different than primary channel of 80 MHz AP. The different APs and their associated clients than have virtual carrier sense on different channel (this carrier sense is not “heard” by 80 MHz device, because it is not its primary channel). To protect the wireless network from such problems, IEEE 802.11ac standard defines an enhanced RTS/CTS messages exchange (802.11ac 2014; Dolińska 2016). RTS frame is sending four times to fill 80 MHz channel (or 8 times to fill 160 MHz channel). If all parts of wider channels are free, recipient sends four CTS frames to fill 80 MHz channel (or 8 to fill 160 MHz channel). If a portion of bandwidth is in use nearby the recipient, the device responds with a CTS only on the available and “usable” 20 MHz subchannels.

The beamforming defined by standard allows to improve multi-antenna communication by supporting of more precise control of data spatial stream. The more data streams are used the more important is such precision. Beamforming (spatial filtering) is a signal processing technique used in sensor arrays for directional signal transmission or reception. In IEEE 802.11ac beamforming technique is defined as a part of standard, even it is only the single way of performing channel sounding for beamforming, i.e. explicit compressed feedback.

But despite all these improvements, when many users try to use wireless network, especially video applications, nobody has good throughput. It means transmission speed is not very high (Masiukiewicz 2018).

The physical layer improvements in IEEE 802.11ax

IEEE 802.11ax amendment is focused on wireless network efficiency improvements and to achieve this goal many new techniques are developed (Bellalta 2015, Bellalta 2017). The Table 1 presents the most important differences between new revision and current IEEE 802.11ac standard. HE (High Efficiency) device will be required to comply with mandatory requirements of the legacy WLAN PHY layers. That is, HE device operating in 2.4 GHz will need to comply with the IEEE 802.11n PHY requirements and the HE device operating in the 5 GHz band will be required to be compliant with IEEE 802.11n and IEEE 802.11ac PHY specifications (Ward 2016).

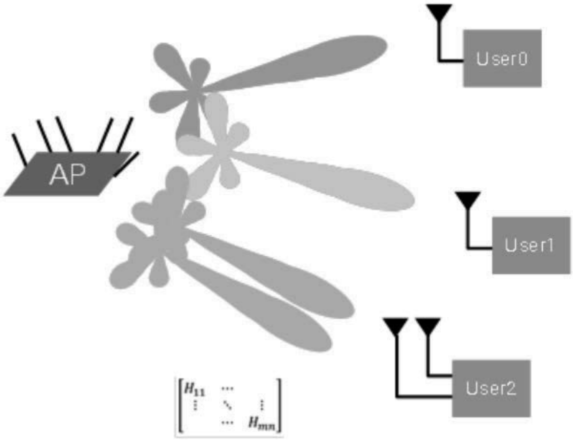
Table 1. The differences between IEEE 802.11ac and IEEE 802.11ax

PHY feature	802.1ac	802.11ax
Bands [GHz]	5	2.4 and 5
Channel bandwidth [MHz]	20, 40, 80, 80+80 and 160	20, 40, 80, 80+80 and 160
FFT sizes	64, 128, 256, 512	256, 512, 1024, 2048
Subcarrier spacing [kHz]	312.5	78.125
OFDM symbol duration [µs]	3.2	12.8
Guard interval duration [µs]	0.8, 0.4	0.8, 1.6, 3.2
MU-MIMO	Downlink	Uplink and downlink
Data subcarrier modulation	BPSK, QPSK, 16-QAM, 64QAM, 256QAM	BPSK, QPSK, 16-QAM, 64QAM, 256QAM, 1024QAM
Data rates	433 Mbps (80 MHz, 1 SS) 6933 Mbps (160 MHz, 8 SS)	600.4 Mbps (80 MHz, 1 SS) 9607.8 Mbps (160 MHz, 8 SS)

Source: based on: Introduction (2017); Ward (2016).

One of the most important changes is the addition of MU-MIMO (Multi User-MIMO) in the uplink as well as downlink (Ward 2016). IEEE 802.11ax standard has two modes of operation: Single User and Multi-user. Single user mode is a sequential mode, in which every wireless station sends and receives data one at a time, when it wins access to the radio channel. Multi-user mode allows for simultaneous operation of multiple non-AP STAs. The standard divides this mode further into Downlink and Uplink Multi-user (Naik at al. 2018). The downlink multi-user refers to data that the AP transmits to multiple associated wireless STAs at the same time, as presented in Figure 1. The existing IEEE 802.11ac standard already specifies this feature. Uplink multi-user involves simultaneous transmission of data from multiple STAs to the AP. This is new functionality of IEEE 802.11ax standard, which did not exist in any of the previous versions of the Wi-Fi standard.

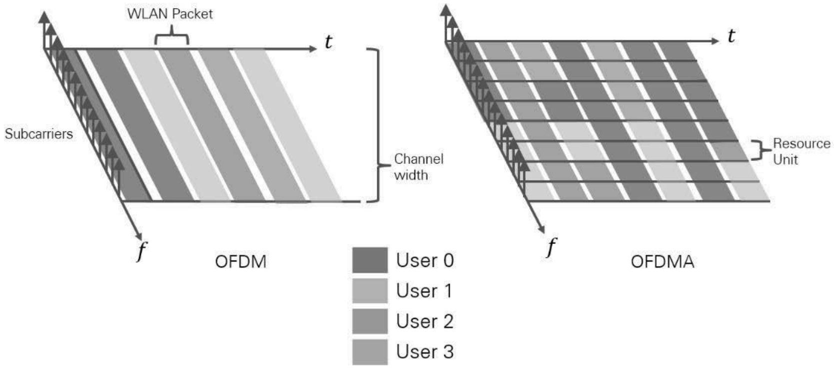
Figure 1. Downlink multi-user MIMO transmission from AP to users



Source: Introduction (2017).

The AP acts as a central transmission controller in multi-user mode. The AP uses beamforming to direct packets simultaneously to many users. So, the AP can calculate a channel matrix for each user and steer simultaneous beams to different users, each beam containing specific packets for its target user (see Figure 1). IEEE 802.11ax supports sending up to eight multi-user MIMO transmissions at a time, up from four for IEEE 802.11ac. Also, each MU-MIMO transmission may have its own Modulation and Coding Set (MCS) and a different number of spatial streams (Introduction 2017).

Figure 2. The differences of channel occupation between OFDM and OFDMA transmission

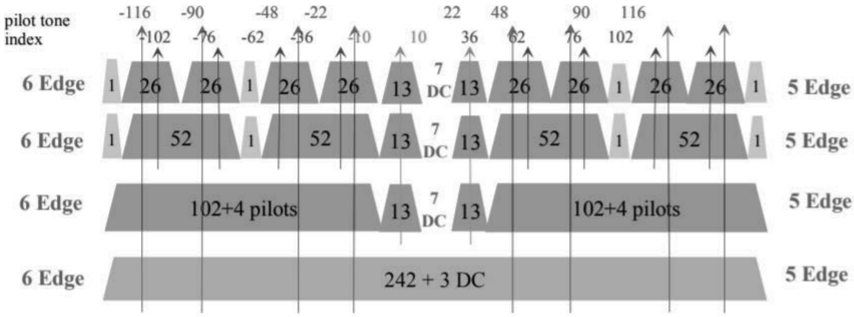


Source: as in Figure 1.

The using of OFDMA (Orthogonal Frequency Division Multiple Access) is the second important new feature of IEEE 802.11ax amendment (Naik at al. 2018). This technique, borrowed from LTE, allows to multiplex more users in the same channel bandwidth. The differences between the both methods are presented in Figure 2. The OFDM technique, used in IEEE 802.11n and IEEE 802.11ac, allows to send only one data packet at a time. This packet occupied all subcarriers of data channel, because transmissions are intended for a single user. In OFDMA technique (see Figure 2), the resources are allocated in two dimensional regions over time and frequency, referred to as a resource unit (RA). Resource Unit (RU) is a unit in OFDMA terminology used in IEEE 802.11ax to denote a group of subcarriers (tones) used in both Downlink (DL) and Uplink (UL) transmissions. RA is a specified number of subcarriers and time, which can be allocated to user. Based on client traffic needs, the AP can allocate the whole channel to only one user or may partition it to serve multiple users simultaneously. With OFDMA, different transmit powers may be applied to different RUs. Thus, different sets of subcarriers of the OFDMA signal are allocated to different users as shown in Figure 2 (Ward 2016). A central coordinating entity (the AP in IEEE 802.11ax) assigns RUs for reception or transmission to associated stations. Through the central scheduling of the RUs contention overhead can be avoided, which increases efficiency in scenarios of dense deployments.

Note that all users in IEEE 802.11ax OFDMA will have the same time allocations and will end at the same time. In the downlink, this will be achieved by adding padding bits to the shorter packets and requiring that the extra bits are transmitted at the same power level as the data portion of the packet. While this decreases the efficiency, it makes the requirement for backwards compatibility with legacy IEEE 802.11 networks easier to achieve (Ward 2016). In the MU uplink case, the AP will not know how much data the individual users have to transmit. Therefore, the AP uses a control frame called a trigger frame to provide information to the user to know how long it would like the uplink packet to be.

Figure 3. Resource Units and Tone Allocation in 20 MHz channel



Source: Ward (2016).

For uplink and downlink OFDMA frequency allocation, the resource units (RU) may contain 26, 52, 106, 242, 484 or 996 tones (aka subcarriers) and are in fixed locations (Introduction 2017; Ward 2016). Each tone consists of a single subcarrier of 78.125 kHz bandwidth. Therefore, bandwidth occupied by a single OFDMA transmission is between 2.03125 MHz and ca. 80 MHz bandwidth. The tones (subcarriers) in the resource units are adjacent and contiguous except in the middle of the channel where DC null carriers are present. The locations of resource units for 20 MHz channel is presented in Figure 3. Three types of subcarriers are presented in Figure 3: data subcarriers, pilot subcarriers and unused subcarriers. The unused subcarriers are marked as DC, the guard band subcarriers, and the null subcarriers. They help protect against interference from adjacent channels. The data subcarriers are used for user data transmission. Pilots are subcarriers that transmit a known signal that are used by the OFDM demodulator to compensate for frequency errors, etc., and are critical to proper demodulation of the received signal. They are an important part of the transmission (Introduction 2017; Ward 2016).

IEEE 802.11ax can operate on the same bands as IEEE 802.11n, but 802.11ax is able operate in both bands at the same time. It means that it can use 12 channels of 20 MHz: 4 in 2.4 GHz and 8 at 5 GHz band. So, it is easier to operate on wide channels and to offer better throughput.

Another important change is the four-time longer symbol time (12.8 μs). The Guard interval duration is extended also to values 0.8 μs, 1.6 μs, 3.2 μs. These features should improve the robustness in outdoor channel, give the greater tolerance to timing jitter across users in uplink MU-MIMO/OFDMA and higher indoor efficiency (Introduction 2017, Ward 2016). New specification defines four times larger FFT (fast Fourier transforms) sizes: 256, 512, 1024, 2048 instead of 64, 128, 256, 512. The subcarrier spacing has been reduced to one fourth the subcarriers spacing in previous IEEE 802.11 revisions (312.5 KHz to 78.125 KHz), preserving the existing channel bandwidths. A narrow subcarrier spacing allows better equalization and thus a higher channel robustness.

IEEE 802.11ax will use beamforming procedure, similar to that of IEEE 802.11ac. Under this procedure, the beamformer initiates a channel sounding procedure with a Null Data Packet. The sounded station measures the channel and responds with a beamforming feedback frame, containing a compressed feedback matrix. The beamformer uses this information to compute the channel matrix, H. The beamformer can then use this channel matrix to focus the RF energy toward each user (Introduction 2017). The channel width of IEEE 802.11ax is the same as in IEEE 802.11ac.

Target wait time (TWT), also known as sleep times, allows a device to stay in a sleep state longer before transmitting data. This resource scheduling improves battery life and means a better experience for a consumer. An IEEE

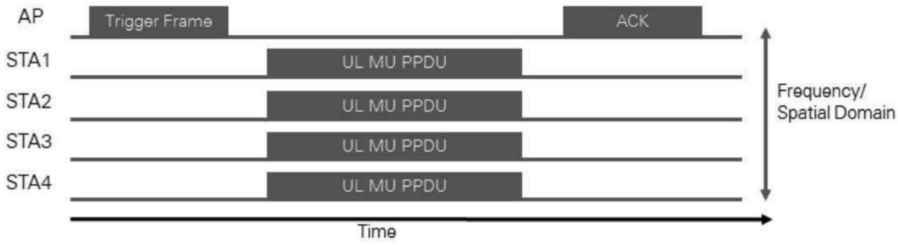
802.11ax AP can negotiate with the participating STAs the use of the TWT function to define a specific time or set of times for individual stations to access the medium. The STAs and the AP exchange information that includes an expected activity duration. This way the AP controls the level of contention and overlap among STAs needing access to the medium. IEEE 802.11ax STAs may use TWT to reduce energy consumption, entering a sleep state until their TWT arrives.

The MAC layer new features in IEEE 802.11ax

IEEE 802.11ax introduces four new PPDU (Packet Protocol Data Unit) formats: High Efficiency Single User PPDU, High Efficiency Extended Range PPDU, High Efficiency Multi-User PPDU and High Efficiency Trigger-Based PPDU (Ward 2016). High Efficiency Single User PPDU (HE_SU) is used when data are transmitted to a single user. High Efficiency Extended Range PPDU (HE_EXT_SU) is also intended transmitting to a single user, but the user may be further away from the AP such as in outdoor scenarios. The HE_EXT_SU will only be transmitted in 20 MHz channel bandwidths. Further, the HE_EXT_SU will use only 1 spatial stream and either MCS0 (BPSK ½), MCS1 (QPSK ½) or MCS2 (QPSK ¾). High Efficiency Multi-User PPDU (HE-MU) carries one or more transmissions to one or more users (see Figure 1). High Efficiency Trigger-Based PPDU (HE_Trig) carries a single transmission and is sent in response to a trigger frame. This frame format is sent in an OFDMA and/or MU MIMO uplink transmission. MU UL transmissions typically require devices that are carefully calibrated and can meet strict requirements in power and measurement accuracy. However, IEEE 802.11 specification allows for device implementations with a wide range of capabilities. In order to accommodate both high and low-end devices, devices that support HE_Trig will also be required to declare whether they are a class A device that is carefully calibrated and can meet stricter power and measurement accuracy requirements or a class B device that is a low-cost device with limited capabilities and looser requirements (Ward 2016). IEEE 802.11ax device has to transmit and receive also IEEE 802.11a, IEEE 802.11n and IEEE 802.11ac frame formats.

The AP initiates a simultaneous uplink transmission from each of the STAs by means of a trigger frame in multi-user uplink mode, as is presented in Figure 4. When the multiple users respond in unison with their own packets, the AP applies the channel matrix to the received beams and separates the information that each uplink beam contains. The AP may also initiate Uplink multi-user transmissions to receive beamforming feedback information from all participating STAs (Introduction 2017).

Figure 4. AP coordinatates UL MU transmission with trigger frame



Source: as in Figure 1.

A Trigger-based random-access mode allows performing UL OFDMA transmissions by stations which are not allocated RUs directly. The AP specifies scheduling information about subsequent UL MU transmission in Trigger frame. However, several RUs can be assigned for random access. Stations which are not assigned RUs directly can perform transmissions within RUs assigned for random access. To reduce collision probability (i.e. situation when two or more stations select the same RU for transmission), the IEEE 802.11ax amendment specifies special OFDMA back-off procedure. Random access is favorable for transmitting buffer status reports when the AP has no information about pending UL traffic at a station.

Every IEEE 802.11ax station should have two NAVs (network allocation vectors). In dense deployment scenarios, NAV value set by a frame originated from one network may be easily reset by a frame originated from another network, which leads to misbehavior and collisions. To avoid this, each 802.11ax station will maintain two separate NAVs — one NAV is modified by frames originated from a network the station is associated with, the other NAV is modified by frames originated from overlapped networks.

Another important improvement in IEEE 802.11ax is BSS coloring (Gates 2018, Introduction 2017). BSS Coloring was a mechanism originally introduced in IEEE 802.11ah to assign a different “color” per BSS. The main idea was that to increase capacity in dense environments the frequency reuse between BSS’s must be increased also. However, with existing medium access rules, devices from one BSS will defer to another co-channel BSS, with no increase in network capacity. BSS Coloring is a method for addressing this medium contention overhead due to overlapping basic service set (OBSS) and spatial reuse. The HE devices can differentiate between BSS’s by adding a number (color) to the PHY header and new channel access behavior will be assigned based on the color detected. The same color bit indicates an intra-BSS while different color bits indicate inter-BSS. Inter-BSS detection means that a listening device treats the medium as busy and must defer. However, adaptive CCA implementation could raise the signal detect (SD) threshold for inter-BSS frames while maintaining a lower threshold for intra-BSS traffic (Gates2018). BSS Coloring could potentially decrease the channel contention problem that is a result of existing 4 dB signal detect (SD) thresholds. The goal of BSS Coloring is to increase reuse, while not causing a significant reduction in selected MCS due to interference.

The last of described IEEE 802.11ax new features is the ability of power saving with Target Wake Time (TWT). An 802.11ax AP can negotiate with the participating STAs the use of the TWT function to define a specific time or set of times for individual stations to access the medium (Introduction 2017, Gates 2018). HE devices can negotiate when and how often they will wake up to send or receive data. TWT increases device sleep time and, in turn, substantially improves battery life. In IEEE 802.11ax, IEEE 802.11ah TWT mechanism has been modified to support triggered-based uplink transmission, meaning it supports non-AP stations that have not negotiated any implicit agreement with the AP. Target Wake Time (TWT) will be very useful for both mobile devices and IoT devices. TWT uses negotiated policies based on expected traffic activity between IEEE 802.11ax clients and an IEEE 802.11ax AP to specify a scheduled wake time for each client. 802.1ax IoT clients could potentially sleep for hours or days at a time to conserve battery life (Gates 2018).

The IEEE 802.11ax standard challenges analysis

IEEE 802.11ax standard introduces more new extensions to wireless communication, then the previous one. The implications of these changes include increase in IEEE 802.11ax access point test intensity than previous generations.

IEEE 802.11ax standard borrows OFDMA technology from LTE networks to deliver a significant breakthrough in user capacity. While this technology has long been in use in 4G/LTE networks, it is the first time it is being applied to the crowded and chaotic unlicensed bands in which Wi-Fi operates. This presents some unique testing challenges (Smith 2018). OFDMA system require all users (STAs) to transmit at the same time (< 400 ns difference) and at the same carrier frequency (<350 Hz difference). It means, that OFDMA systems have very high susceptibility to frequency and clock offsets. Consequently, IEEE 802.11ax multi-user OFDMA performance demands extremely tight frequency synchronization and clock offset correction. This ensures that all STAs operate exactly within their allocated subchannels with minimal spectral leakage. Additionally, the strict timing requirements guarantee that all STAs will transmit simultaneously in response to the AP's MU trigger frames (Introduction 20017). OFDMA uses RUs, which are segments of time and frequency. Many use cases of RU's using must be developed and tested to provide comprehensive testing of the increased user scenarios. It increased test time and makes the tests much more complicated (Smith 2018).

The IEEE 802.11ax standard now mandates support for 1024-QAM. Additionally, the subcarriers are only 78.125 KHz away from each other. This means that 802.11ax devices need to have oscillators with improved phase noise performance and RF front ends with better linearity. The test instruments that measure device under test (DUT) behavior in turn require their error vector magnitude (EVM) noise floor to be significantly lower than the DUT's. Similar to the requirement of reduced frequency and clock errors, the power that an AP receives during uplink multi-user transmissions should not have large variations across all users (Introduction 2017). This requires that the AP controls the transmit power of each individual STA. The AP may use a trigger frame that contains transmit power information for each STA. Developers can test this functionality in two steps, in a way similar to the frequency error test.

TWT technique also brings some new challenges. Unlike LTE base station technologies, IEEE 802.11ax doesn't have a synchronized clock signal. As a result, devices will rely on the access point to keep all the devices on the network synchronized. Additionally, IEEE 802.11ax uses longer OFDM symbols than IEEE 802.11ac, which means more data comes through. AP must do much more work than in previous version.

Summarizing, in IEEE 802.11ax, design validation is more crucial than ever because 802.11ax leverages new technology to change the nature of Wi-Fi and the testing it requires to ensure quality products. Testing different configurations with network simulator, like ns-3 (ns-3 Tutorial 2017, Dolińska, Jakubowski, Masiukiewicz 2017), will also be very important issue. Such simulations allow to check new standard possibilities without real devices and better adjust network configuration to real needs.

Conclusions

As it was mentioned above, the previsions show a high increase of wireless traffic on mobile devices. The wireless network efficiency is lacking in previous versions. This problem is particularly annoying in the environments where many users use the wireless network, like stadium, shopping center, airport or even multi-family building.

IEEE 802.11ax, also called High-Efficiency Wireless (HEW), has the challenging goal of improving the average throughput per user by a factor of at least 4X in dense user environments. This new standard focuses on implementing mechanisms to serve more users a consistent and reliable stream of data (average throughput) in the presence of many other users. The new standard features, presented in the article improve communication efficiency in crowded environments. But the hardware design and testing are more crucial, than in previous generations, because the IEEE 802.11ax AP and STA are much more complicated

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Analiza nowych możliwości i wynikających stąd wyzwań dla standardu technologii sieci bezprzewodowej IEEE 802.11ax

Streszczenie

W przeszłości ewolucja Wi-Fi koncentrowała się przede wszystkim na osiąganiu sukcesywnie wyższych teoretycznych prędkości. Natomiast w świecie realnym, przy mnóstwie użytkowników i odmiennych potrzebach, sieć musi być zaprojektowana tak, by zapewniała wszystkim użytkownikom skuteczną komunikację. Standard IEEE 802.11ax jest standardem przyszłej sieci bezprzewodowej, która nadal pozostaje w stadium projektu. Określa on nowe cechy i możliwości w transmisji Wi-Fi. Artykuł przedstawia szczegółowy opis warstwy PHY i warstwy MAC tej modyfikacji. Następnie przeprowadzono analizę wyzwań, skoncentrowaną głównie na projekcie sprzętu komputerowego i testowaniu.

Słowa kluczowe: technologia IEEE 802.11ax, wysoko wydajna technologia bezprzewodowa (High-Efficiency Wireless), MU-MIMO, OFDMA.

Kody JEL: L86

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