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THE NEW FEATURES OF 802.11AC STANDARD IMPROVING THE CORPORATE WI-FI NETWORKS CAPABILITIES

Summary

IEEE 802.11ac is the newest Wi-Fi standard, which is working only in 5 GHz radio band. This standard improves and extends 802.11n functionality, i.e. it has more channel bonding, denser constellation (modulation levels) and more spatial streams. The new features, introduced in 802.11ac, like multi-user MIMO (MU-MIMO) functionality, standards-based beamforming, RTS/CTS with bandwidth indication and longer aggregated frame are making it very useful in corporate wireless networks. In the article the author analyses the new Wi-Fi features from the point of view of corporate computer network demands.

Key words: IEEE 802.11ac, MU-MIMO, multiuser MIMO, beamforming, BYOD trend, RTS/CTS transaction.

JEL Codes: O33

Introduction

The IEEE 802.11 standard network (IEEE 802.11 2012), also called Wi-Fi or WLAN (Wireless Local Area Network) uses a wireless medium for local computer communication and Internet access. This standard was introduced in 1997, but it started to be more popular after adding of first modifications, called the 802.11a and 802.11b amendments, in 1999. This wireless standard uses 2.4 GHz band in the 802.11 and 802.1b versions, and 5 GHz in the 802.11a version. So the last one is incompatible with the others. It also has a shorter range, but the band is less occupied by other wireless technologies than the 2.4 GHz band. The higher band has also more non-overlapping channels (Piwiński and Marczak 2014).

The next amendment, 802.11g defined wireless communication in the 2.4 GHz band with up to 54 Mbit/s throughput (like 802.11a) (Piwiński and Marczak 2014). The wireless networks built in the 802.11g standard have gained a great success in hotspots, enterprises, university campuses, hospitals, schools, small offices, homes, etc. But in enterprise networks Ethernet was still the basic LAN standard. The wireless networks were used as wire LAN extend and complement only (Watson 2013). This trend started to change with the 802.11n amendment (IEEE 802.11 2012) which introduced fundamental changes in WLAN networks.

The 802.11n standard, published in 2009, introduced some revolutionary changes in Wi-Fi networks (Masiukiewicz 2014, Guillory 2012). Such a network can work in the 2.4 GHz or 5 GHz band (both bands are supported). The throughput in 802.11n network can achieve 150 Mbit/s, 300 Mbit/s, 450 Mbit/s or even 600 Mbit/s (the highest is not supported in practice at this moment), depending on network configuration, the antenna number, and radio channel conditions. The most important improvements in the 802.11n standard are MIMO (multiple input multiple output) communication, new modulation schemes, short guard interval and channel bonding in the PHY layer and frame aggregation in the MAC layer (Masiukiewicz 2014; Guillory 2012).

IEEE 802.11n is fast, but still not fast enough to keep up with people's desire for higher performance, particularly in video streaming and game playing, and for handling the growing number of devices connecting to an AP. What's more, the enormous popularity and success of Wi-Fi continues to create new challenges, many of which could be attributed to the need to cope with the technology's overwhelming its success. In addition to speed, these challenges include providing greater bandwidth and better handling of channel contention. The goal for IEEE 802.11ac is for it to become the mainstream networking access point (Intel 2012).

In this paper, the author presents the IEEE 802.11ac amendment features which are key in enterprise wireless network implementations. The rest of the paper is organised as follows. The new features of 802.11ac are overviewed in the next section. The new features of MAC layer are presented in the third section. The fourth section explains beamforming, and the next one presents multi-user functionality. The conclusions summarise the article.

IEEE 802.11ac standard overview

IEEE 802.11ac is the newest standard, which is working in the 5 GHz radio band only. This avoids much of the interference at 2.4 GHz, including Bluetooth headsets and microwave ovens. This standard improves and extends 802.11n functionality (802.11ac 2014, Lendino 2015), i.e. it has more channel bonding, denser constellation (higher modulation levels) and more spatial streams (Sirko 2013). In the 802.11ac standard channel wide 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. The 160 MHz channel can be made by bonding two adjacent or not-adjacent 80 MHz channels. The denser constellation means that we have now 256 quadrature amplitude modulation (QAM) while in 802.11n is 64 QAM. The spatial stream number is increased from 4 to 8, i.e. in the future wireless routers will be able to transmit data by 8 antennas. The user will be able to communicate by 4 antennas (IEEE 802.11ac 2013, Intel 2012, Lendino 2015). The main differences between the 802.11n and 802.11ac standards are presented in Table 1 (Sirko 2013).

Table 1. The main differences between the 802.11n and 802.11ac standards

Specification	802.11n	802.11ac
Radio band	2.4 GHz and 5 GHz	5 GHz
Channel wide	20 MHz, 40 MHz	20 MHz, 40 MHz, 80 MHz, 160 MHz
Spatial streams	1 to 4	1 to 8 for AP; 1 to 4 for station
Modulation	BPSK, QPSK, 16QAM, 64QAM	BPSK, QPSK, 16QAM, 64QAM, 256QAM
MU-MIMO (Multi-user MIMO)	No	Yes
Aggregated frame length	65 535 octets	1 048 575 octets

Source: Sirko (2013).

Table 2. The comparison between 802.11n and 802.11ac theoretical throughput

Channel wide [MHz]	Spatial streams	Standard	Constellation and coding	Theoretical throughput [Mb/s]
20	1	802.11n	64 QAM 5/6	72
		802.11ac	256 QAM 3/4	86
	2	802.11n	64 QAM 5/6	144
		802.11ac	256 QAM 3/4	173
	3	802.11n	64 QAM 5/6	216
		802.11ac	256 QAM 3/4	258
40	1	802.11n	64 QAM 5/6	150
		802.11ac	256 QAM 5/6	200
	2	802.11n	64 QAM 5/6	300
		802.11ac	256 QAM 5/6	400
	3	802.11n	64 QAM 5/6	450
		802.11ac	256 QAM 5/6	600
80	1	802.11ac	256 QAM 5/6	433
	2	802.11ac	256 QAM 5/6	867
	3	802.11ac	256 QAM 5/6	1300
160	1	802.11ac	256 QAM 5/6	867
	2	802.11ac	256 QAM 5/6	1730
	3	802.11ac	256 QAM 5/6	2600

Source: like in Table 1.

The standard has some new features, making it very useful in corporate networks:

– multi-user MIMO (MU-MIMO) functionality,
– standards-based beamforming,
– RTS/CTS with bandwidth indication,
– longer aggregated frame.

The 802.11ac standard new possibilities, mentioned above, caused that the maximum throughput increases very much. The comparison between 802.11n and 802.11ac theoretical throughput is presented in Table 2.

IEEE 802.11ac is compatible with 802.11a/n standards (with 802.11n in the 5 GHz band) and is designed to coexist efficiently with these standard devices. It has strong carrier sense and a single new preamble that appears to be a valid 802.11a preamble to 802.11a/n devices. Another extension is request-to-send/clear-to-send (RTS/CTS) in bonding channels, which helps avoid collisions with users operating on slightly different channels.

The new standard supports BYOD trend (Watson 2013). The number of mobile applications has grown along with the increased use of smartphones and tablets. It has caused a huge rise of bandwidth demand. The personal mobile device has become such a part of the landscape that is called the BYOD (bring your own device) trend. This trend can be seen as increasing in enterprises. IT managers are being challenged with new network design requirements brought about this phenomenon. The new 802.11ac standard brings new possibilities of wireless communication, so is able to support the BYOD trend.

802.11ac represents a better way to deploy Wi-Fi network in the 5 GHz band (Intel 2012). It is a rich technology standard which improves a radio performance and is a better coverage for all clients operating in 5 GHz. The 802.11ac standard is delivering network with enterprise-class speeds and latencies. Wireless multimedia streaming, the speed and quality improvements will enable new possibilities of wireless communication in enterprises.

New features in the MAC layer

The 802.11ac specification defines wider channel bandwidths. It is much more likely that an 80 MHz AP will overlap with another 20- or 40 MHz AP or even several of them. To enable reliable operation in such conditions, the standard defines extension to the RTS/CTS mechanism, stronger clear-channel assessment (CCA) requirements, and new primary channel selection rules (802.11ac 2014, IEEE 802.11ac 2013).

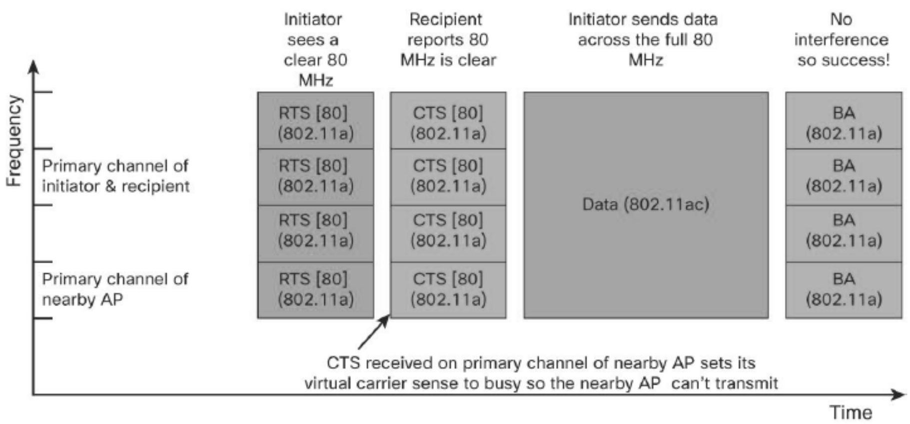
The 802.11ac standard AP, operating on 80 MHz channel, should be capable of 802.11a or 802.11n client to associate. Thus, beacon frames are sent on one 20 MHz channel, known as the primary channel within this 80 MHz channel.

So the AP and its associated clients process every transmission that overlaps this primary channel and extracts virtual carrier sense from the frames that they decode. On the other hand, the 802.11ac AP should coexist with 802.11a or 802.11n APs, which could operate on 20 MHz channel, but different than the primary channel of 80 MHz AP. The different APs and their associated clients then have virtual carrier sense on different channel (this carrier sense is not "heard" by 80 MHz device, because it is not its primary channel). What's more, they can transmit at different times on the different subchannels, including overlapping times. Taking into account the wide 802.11ac channel bandwidths, this scenario is very likely.

To protect the wireless network from such problems, the 802.11ac standard defines an enhanced RTS/CTS messages exchange. RTS/CTS transaction can be used to determine if the radio channel is clear around both the initiator and the respondent. This new functionality is presented in Fig. 1 and Fig. 2.

When an 802.11ac device wants to transmit in an 80 MHz channel, it must check if any of 20 MHz chunks is free. So this initiating device has to verify that this 80 MHz channel is clear in its vicinity. To verify the 80 MHz channel, the initiator device sends RTS frame (with the recipient address) in its primary channel and in the three another channels, so RTS frame is sending four times to fill the 80 MHz channel (or 8 times to fill the 160 MHz channel) (Perahia and Gong 2011, 802.11ac 2014). The RTS is sent as a Physical Protocol Data Unit (PPDU) in the 802.11a format for compatibility. Then every nearby device of 802.11a/n/ac type receives this RTS communicate on its primary channel (even if its primary channel is different than the initiator primary channel). The device can understand this frame and use it to set virtual carrier sense as busy (see Fig. 1).

Figure 1. RTS/CTS Enhanced method, no interference case

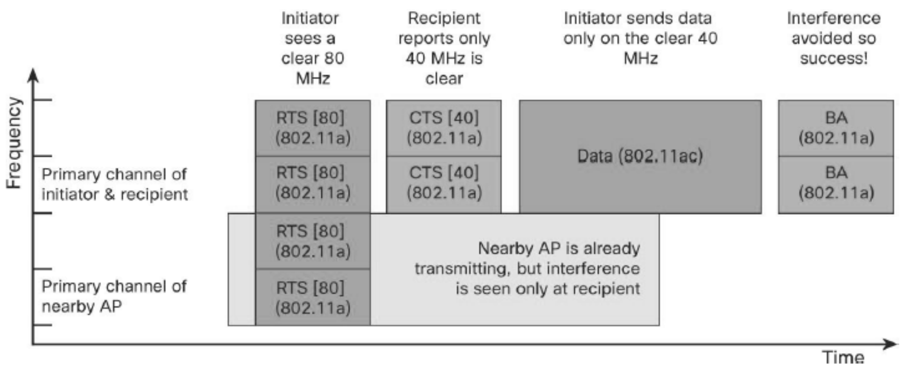


Source: 802.11ac (2014),

Before the recipient device, to which replicated RTS was addressed, responds with CTS, it must check to see if anyone is transmitting near itself, on any 20 MHz channel within the 80 MHz channel. If all parts of wider channels are free, the recipient sends four CTS frames to fill the 80 MHz channel (or 8 to fill the 160 MHz channel). This CTS is sent in the 802.11a PPDU format also, so every nearby device receives a CTS on its primary channel and they can set virtual carrier sense as busy (see Fig. 1). In this case no interference is in the whole channel and the 80 MHz channel (or 160 MHz) can be used for transmission.

If a portion of bandwidth is in use nearby the recipient, the device responds with CTS only on the available and "usable" 20 MHz subchannels. A "usable" subchannel means this, on which the initiator device can transmit, i.e. 20 MHz or 40 MHz or 80 MHz (not 60 MHz). This case, with interference on some subchannels is shown in Fig. 2. After receiving CTS frames on part of subchannels, the initiator device can transmit data in the narrower channel (for example 40 MHz, as can be seen in Fig. 2). CTS is sent again in the 802.11a PPDU format, so it can be understandable for devices in vicinity of the recipient.

Figure 2. RTS/CTS Enhanced method, interference case

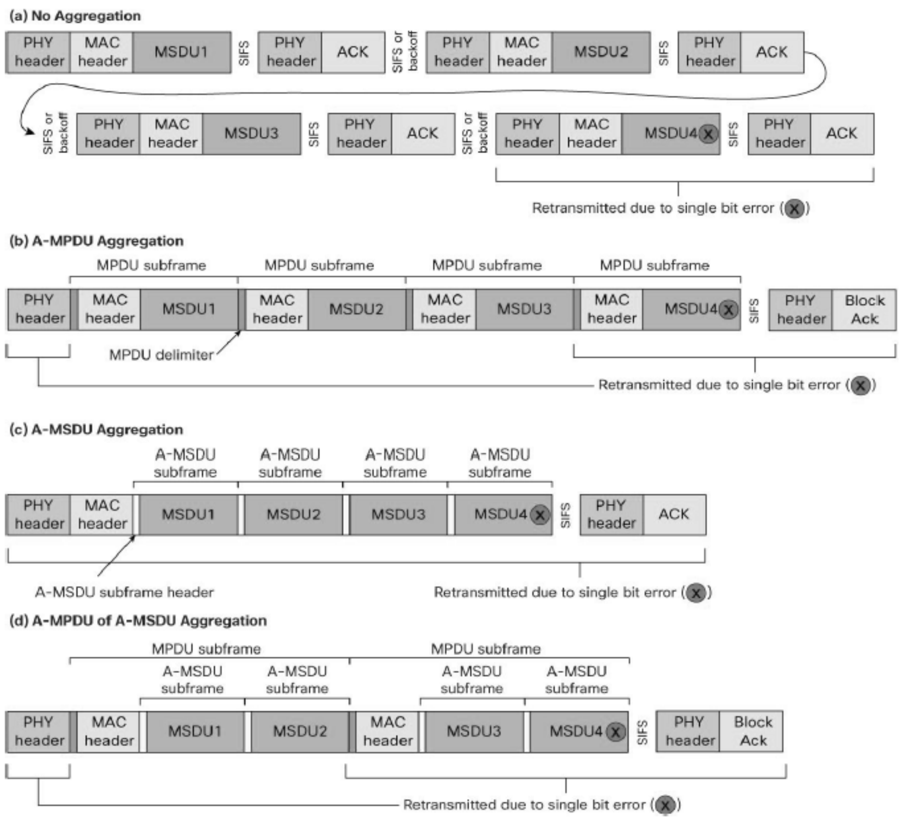


Source: like in Figure 1.

The IEEE 802.11n standard introduced frame aggregation techniques, defining two aggregation methods: A-MPDU (aggregate medium access control protocol data unit) and A-MSDU (aggregate medium access control service data unit). A-MPDU is a structure containing multiple MPDUs (MAC protocol data units), transported as a single physical layer convergence procedure (PLCP) service data unit (PSDU) by the physical layer (PHY) (IEEE 802.11ac 2013, Perahia and Gong 2011), what is presented in Fig. 3b. A-MSDU is a structure containing multiple MSDUs, transported within a single (unfragmented) data medium access control protocol data unit (MPDU) (IEEE 802.11ac 2013), what is presented in Fig. 3c. The third aggregation method is a combination of both, named “A-MPDU of A-MSDU”, as it can be seen in Fig. 3d.

With aggregation, the data is packed together in a single unit with one preamble and that acknowledged in one transmission. The A-MSDU technique aggregates MSDU units (as IP packet) at the beginning of the MAC transmission path (see Fig. 3c). An MSDU within tghe 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 (see Fig. 3b). 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 received correctly.

Figure 3. Methods of form aggregation in 802.11n and 802.11ac



Source: like in Figure 1.

The IEEE 802.11ac standard requires every 802.11ac transmission to be sent as an A-MPDU type of aggregation, even if the A-MPDU contains only single MPDU (802.11ac 2014, IEEE 802.11ac 2013). This requirement is accepted to unify transmission rules.

Beamforming

The IEEE 802.11n standard introduced a beamforming technique. Beamforming (spatial filtering) is a signal processing technique used in sensor arrays for directional signal transmission or reception (Beamforming 2014). This is achieved by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beamforming can be used at both the transmitting and receiving ends in order to achieve spatial selectivity. The improvement compared with omnidirectional reception/transmission is known as the receive/transmit gain (or loss).

The problem with 802.11n wireless communication is that beamforming is not defined in the standard, what made it hard to work effectively between different vendor products (Watson 2013). In the 802.11ac standard, the beamforming technique is defined as a part of the standard, even it is only the single way of performing channel sounding for beamforming, i.e. explicit compressed feedback. Although optional, if an implementer wants to offer the benefits of standard-based beamforming, there is no choice, but select that mechanism which can be tested for interoperability.

Two wireless 802.11n devices can beamform to each other at any time (802.11ac 2014, IEEE 802.11ac 2013, Lendino 2015). The 802.11ac adds the opportunity for the receiver to help the beamforming transmitter to transmit more effectively. This method is called "sounding" and it enables the beamformer to precisely steer its transmitter energy toward the receiver. IEEE 802.11ac defines a single, optional protocol for an 802.11ac device to sound other 802.11ac device. The protocol closely follows the 802.11n explicit compressed feedback protocol.

A device, which wants to start beamforming transmission type, typically an AP, sends a special frame, named a "Very High Throughput (VHT) Null Data Packet (NDP) Announcement". This frame contains the address of the AP and of the target recipients. The VHT NDP Announcement frame is immediately followed by a "VHT Null Data Packet" intended for those recipients. Each of them measures the RF channel from the AP to itself, using the preamble of the VHT NDP and compresses the channel. The first intended recipient responds with the compressed channel information in a VHT Compressed Beamforming frame immediately and other recipients respond, when they are polled by the AP. The VHT NDP Announcement frame, the VHT NDP, and the VHT Compressed Beamforming frame are similar to the features in 802.11n. However, because of some subtle differences, the 802.11ac sounding is not backward compatible with the 802.11n devices (802.11ac 2014, IEEE 802.11ac 2013). To support the new MU-MIMO feature, the channel feedback can contain an extra level of detail.

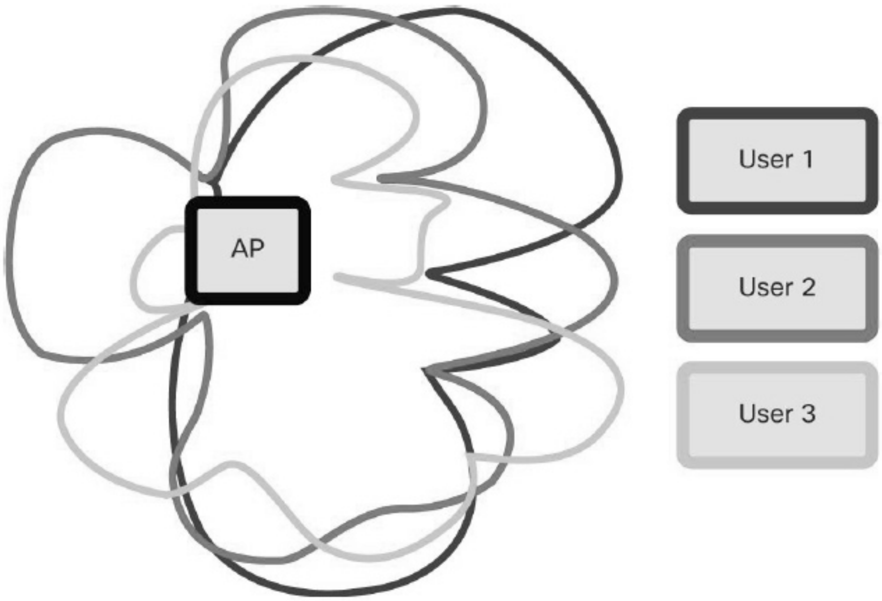
Explicit compressed feedback (ECFB) is known to provide the most precise estimate of the channel, taking into account all the imperfections at transmitter and receiver. However, ECFB comes with a lot of overhead: the VHT NDP Announcement frame, the VHT NDP itself, and the frame carrying the compressed feedback. For an AP with four antennas, the compressed feedback varies from 180 to 1800 bytes, depending on the number of client antennas and level of compression. Sounding just one single-antenna 80-MHz client takes about 250 microseconds. When devices can transmit at 433 Mbps, this is expensive, since that same time could instead have been used to send an extra 13,000 bytes (802.11ac 2014, IEEE 802.11ac 2013).

Multi-user functionality

The device of IEEE 802.11n standard can transmit multiple spatial streams at once, but only directed to a single device. It means that only single station can get data at a time, even it is a single antenna device. This technology is called single-user MIMO (SU-MIMO). With the advent of 802.11ac, a new technology is introduced, called multiuser MIMO (MU-MIMO). In this case AP is able to use its antenna resources to transmit multiple frames to different clients, all at the same time and over the same frequency spectrum (Perahia and Gong 2011).

However, MU-MIMO is challenging technology and its proper implementation is difficult (802.11ac 2014). The problem is presented in Fig. 4. When AP sends data to user 1, it forms a strong beam toward user 1, shown in Fig. 4 as the top right lobe of the blue curve. At the same time the AP minimises the energy for user 1 in the direction of user 2 and user 3. This technique is called “null steering” and is shown as blue notches in the Fig. 4. At the same time the AP is sending data to user 2, forming a beam toward user 2 (red lobe in Fig. 4). Simultaneously, the AP forms notches toward users 1 and 3. The yellow curve shows a similar beam toward user 3 and nulls toward users 1 and 2. In this way each of users 1, 2 and 3 receives a strong copy of the desired data. And this data is only slightly degraded by interference from data for the other users (802.11ac 2014). This interference makes the highest constellations, such as 256QAM, infeasible within an MU-MIMO transmission.

Figure 4. Multiuser MIMO with beamforming to handle many clients in 802.11ac standard



Source: like in Figure 1.

In this transmission technique, the AP has to know the wireless channel from itself to all of the users very accurately. And the AP has to keep measuring the channel, because it changes over the time (the transmission conditions can still change).

We can imagine that older versions of 802.11 like a/b/g/n are working like Ethernet hub, because with hub only one station in network can send its data. 802.11ac is working like Ethernet switch, where many stations in network can send its data simultaneously. Exchange hubs to switches have changed radically our traditional Ethernet networks, enlarging the network capacity and reliability. The change in wireless network will not be so radical, because the transmission limitations are much stronger. But the change will be clearly visible, especially for single antenna devices users. MU-MIMO allows the AP to deliver appreciably more data to its associated clients. Instead of one client receiving data with 433 Mb/s (one stream, channel 80 MHz and 256 AQMr5/6 constellation), three clients can receive data with 293 Mb/s (one stream, channel 80 MHz and 64 AQMr5/6 constellation). The throughput for one station will be lower, because of interference between clients, but still it will be a significant progress in wireless communication of the whole network.

Conclusions

The IEEE 802.11 standard has changed from technology that people use widely in homes, businesses, and public Wi-Fi hot spots to corporate network technology. IEEE 802.11ac is the newest standard in the Wi-Fi family, but the first one which can be considered as dedicated for the corporate computer networks. The corporate networks need very high throughput and the basic standard there is 1 Gbit/s Ethernet. But some new mechanisms, like RTS/CTS bandwidth indication, longer aggregate frame, standard based beamforming and multiuser MIMO.

Enhanced RTS/CTS messages exchange protects networks in vicinity against transmitting data at the same channels or overlapping bounded channels. It decreases the number of frame collisions and increases the communication reliability. Packet aggregation improves network throughput, because the additional load as frame headers and footers is lower than with not aggregated frame transmission. This mechanism increases network throughput. Standard based beamforming makes different vendor devices compatible, so the users are not assigned to the one wireless device producer. And last but not least the 802.11ac feature is multiuser MIMO, which is a very forward-looking mechanism, improving the whole network throughput again. All these features increased the throughput of 802.11ac standard to the level which can be accepted in corporate networks.

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Nowe cechy standardu 802.11ac zwiększającego możliwości firmowych sieci Wi-Fi

Streszczenie

IEEE 802.11ac jest najnowszym standardem Wi-Fi, który pracuje tylko w paśmie fal radiowych o częstotliwości 5 GHz. Standard ten doskonali i rozszerza funkcjonalność standardu 802.11n, tzn. ma więcej łączenia kanałów (ang. channel bonding), gęstszą konfigurację (więcej poziomów modulacji) i więcej strumieni przestrzennych. Nowe cechy, wprowadzone w 802.11ac, takie jak funkcjonalność MIMO dla wielu użytkowników naraz (MU-MIMO), tworzenie strumieni opartych na standardzie, RTS/CTS ze wskazaniem szerokości pasma i dłuższa struktura zagregowana czynią go bardzo użytecznym w firmowych sieciach bezprzewodowych. W artykule autorka analizuje nowe cechy Wi-Fi z punktu widzenia wymagań firmowych sieci komputerowych.

Słowa kluczowe: IEEE 802.11ac, MU-MIMO, MIMO dla wielu użytkowników (multiuser MIMO), tworzenie strumieni, trend BYOD, transakcja RTS/CTS.

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