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doi:10.15199/48.2018.02.21

Experimental analysis of susceptibility of IEEE 802.11ac Wave 1 networks to adjacent and co-channel interference

***Abstract**. The goal of this paper is to present and discuss the results of practical experiments performed to determine the impact of adjacent and co-channel interference on the throughput of the IEEE 802.11ac Wave 1 radio links. Measurements were done in two scenarios: the first only in presence of a foreign link and the second with transmission in a foreign link and with different combinations of radio channel width in observed and foreign 802.11ac Wave 1 links. The obtained results can be used to design new Wi-Fi networks as well as to expand the existing ones.*

***Streszczenie.** Artykuł omawia wyniki praktycznych eksperymentów mających na celu określenie wpływu zakłóceń sąsiedniokanałowych i wspólnokanałowych na przepustowość sieci IEEE 802.11ac Wave 1. Pomiary zostały wykonane zarówno w warunkach jedynie obecności obcej sieci, jak i przy transmisji odbywającej się w tej sieci. W przeprowadzonych badaniach uwzględniono różne kombinacje szerokości kanału radiowego w obu sieciach. (**Eksperymentalna analiza podatności sieci IEEE 802.11ac Wave 1 na zakłócenia wspólnokanałowe i sąsiedniokanałowe**).*

Keywords: 802.11ac Wave1, Wi-Fi network throughput, adjacent channel interference, co-channel interference.
Słowa kluczowe: 802.11ac Wave 1, przepustowość sieci Wi-Fi, zakłócenia sąsiedniokanałowe, zakłócenia wspólnokanałowe.

Introduction

Wireless local area networks (WLAN) are usually operating using the family of IEEE 802.11 standards and are widely known under the Wi-Fi trademark. The newest IEEE 802.11 standard is 802.11ac and it was finally approved in December 2013. 802.11ac introduces many new techniques that allow to increase the data rate even up to a few Gb/s [1, 2]. In comparison with older 802.11n standard, 802.11ac devices can operate only in 5GHz U-NII (Unlicensed National Information Infrastructure) band that is divided into radio channels with frequency spacing of 5 MHz. Due to the current regulations, different parts of the U-NII band are allowed to use in particular countries or regions (also called as a regulatory domains).

In table 1 the center frequencies (fc) of the 20 MHz radio channels in the U-NII band are listed for selected regulatory domains.

Table 1. Radio channels in the 5GHz U-NII band.

U-NII band	Channel	fc [GHz]	Regulatory domain			
			Europe	USA	Japan	China
1	36	5.180	√	√	√	-
	40	5.200	√	√	√	-
	44	5.220	√	√	√	-
	48	5.240	√	√	√	-
2	52	5.260	√	√	√	-
	56	5.280	√	√	√	-
	60	5.300	√	√	√	-
	64	5.320	√	√	√	-
2e	100	5.500	√	√	√	-
	104	5.520	√	√	√	-
	108	5.540	√	√	√	-
	112	5.560	√	√	√	-
	116	5.580	√	√	√	-
	120	5.600	√	√	√	-
	124	5.620	√	√	√	-
	128	5.640	√	√	√	-
	132	5.660	√	√	√	-
	136	5.680	√	√	√	-
	140	5.700	√	√	√	-
3	149	5.745	-	√	-	√
	153	5.765	-	√	-	√
	157	5.785	-	√	-	√
	161	5.805	-	√	-	√
	165	5.825	-	√	-	√

For each 20 MHz channel its main lobe is not overlapped with adjacent channels. In Europe channels in bands 1 and 2 (36 - 64) can be used only in indoor applications, whereas channels in band 2e can be used indoor or outdoor as well.

Using U-NII bands in Europe subjects to additional limitations, which prevent WLAN devices from interfering with other systems such as military and meteorological radars. To comply with European regulations regarding 5 GHz band IEEE worked out a standard called 802.11h, which incorporates mechanisms that allow 802.11 devices to comply with the ITU-R Recommendations M.1652 on interference avoidance. These mechanisms are based on two radio techniques for reducing interference: Dynamic Frequency Selection (DFS) and Transmit Power Control (TPC). DFS detects other devices using the same radio channel and switches WLAN operation to another channel if necessary. TPC reduces interference by decreasing the radio transmit power used by WLAN devices.

The 802.11ac standard defines the new format of physical layer called VHT PHY (Very High Throughput PHY). In addition to the modes compatible with the previous versions of the 802.11 standard, VHT PHY specification introduces the new high speed transmission modes based on the OFDM (Orthogonal Frequency Division Multiplexing). These modes utilize such techniques as:

- up to eight MIMO (multiple-input multiple-output) spatial streams,
- up to four clients downlink MU-MIMO (Multi-User MIMO) with Transmission Opportunity (TXOP) sharing [3],
- high-density QAM modulation (up to 256-QAM),
- possibility of using 160, 80, 40 and 20 MHz channels.

All these features are implemented subsequently in the particular generations of 802.11ac devices called Waves. Currently there are available Wave 1 and Wave 2 devices. Wave 1 devices implement 256-QAM modulation, 80 MHz channels and up to 3x3 MIMO (there is no MU-MIMO in Wave 1 generation). Theoretical performance of 802.11ac Wave 1 devices is up to 1.3 Gb/s (about 433 Mb/s in each MIMO stream). Wave 2 devices can use 160 MHz radio channels, up to four MIMO spatial streams and downlink MU-MIMO with up to four single-stream clients. Theoretical the maximum data rate of 802.11ac Wave 2 devices is 3.47 Gb/s.

Each 802.11ac transmission mode is indicated by MCS (Modulation and Coding Scheme) index and number of MIMO spatial streams. MCS index determines modulation type and Forward Error Correction (FEC) coding rate. Every MCS can be used in 20 MHz, 40 MHz, 80 MHz and 160 MHz radio channels and with 800 ns or 400 ns Guard Interval (GI). It results in many possible data rates that are listed in table 2 (for 20 MHz and 40 MHz channels) and in table 3 (for 80 MHz and 160 MHz channels).

Table 2. 802.11ac data rates for 20 and 40 MHz channels

MCS Index	Modulation type	Coding rate	Transmission rate [Mb/s]			
			20 MHz channel		40 MHz channel	
			800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	BPSK	1/2	6.50	7.20	13.50	15.00
1	QPSK	1/2	13.00	14.40	27.00	30.00
2	QPSK	3/4	19.50	21.70	40.50	45.00
3	16-QAM	1/2	26.00	28.90	54.00	60.00
4	16-QAM	3/4	39.00	43.30	81.00	90.00
5	64-QAM	2/3	52.00	57.80	108.00	120.00
6	64-QAM	3/4	58.50	65.00	121.50	135.00
7	64-QAM	5/6	65.00	72.20	135.00	150.00
8	256-QAM	3/4	78.00	86.70	162.00	180.00
9	256QAM	5/6	N/A	N/A	180.00	200.00

Table 3. 802.11ac data rates for 80 and 160 MHz channels

MCS Index	Modulation type	Coding rate	Transmission rate [Mb/s]			
			80 MHz channel		160 MHz channel	
			800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	BPSK	1/2	29.30	32.50	58,50	65.00
1	QPSK	1/2	58.50	65.00	117.00	130.00
2	QPSK	3/4	87.80	97.50	175.50	195.00
3	16-QAM	1/2	117.00	130.00	234.00	260.00
4	16-QAM	3/4	175.50	195.00	351.00	390.00
5	64-QAM	2/3	234.00	260.00	468.00	520.00
6	64-QAM	3/4	263.30	292.50	526.00	585.00
7	64-QAM	5/6	292.50	325.00	585.00	650.00
8	256-QAM	3/4	351.00	390.00	702.00	780.00
9	256QAM	5/6	390.00	433.30	780.00	866.70

Data rates included in tables 2 and 3 are valid for one spatial stream. For more MIMO streams they must be multiplied by the number of streams. IEEE 802.11ac Wave 1 devices use only 20, 40 and 80 MHz radio channels. Because the number of the non-overlapped 40 MHz and 80 MHz channels in 5GHz U-NII band is limited, in practice 802.11ac networks have to operate in the partially overlapped frequency channels that can result in adjacent and co-channel interference. The main goal of this paper is to determine how such interference influence the network throughput. The problem is presented from the practical point of view, but mathematically interference can be modelled using state equations [4]. Such practical approach is also presented in [5] for many links with constant channel configurations. The results presented here were determined for all combinations of radio channels in two links environment. This paper is the continuation and extension of the previous ones [6, 7, 8] and completes them with the newest WLAN standard.

The test environment

The configuration of the test environment, which was used in the experiments, is presented in Fig. 1. It consists of two user stations (PC1 and PC2) and two access points (AP1 and AP2) connected to the test servers (S1 and S2). The first access point (AP1) was Cisco AIR-AP2702 and the second (AP2) was Ruckus ZoneFlex R700.

During experiments two radio links were set: one between PC1 and AP1 and the second between PC2 and AP2. The link PC2-AP2 was acting as a foreign link and was set on the constant radio channel (112 or 108+112 or 100+104+108+112). The link PC1-AP1 was acting as a observed link and its channel was changed through the whole 2e U-NII band (channels from 100 to 140). The measured values were the average throughputs determined on PC1 AP1 link for TCP transmission. Measurements were done using iPerf software and the results were averaged over about 1 minute transmission.

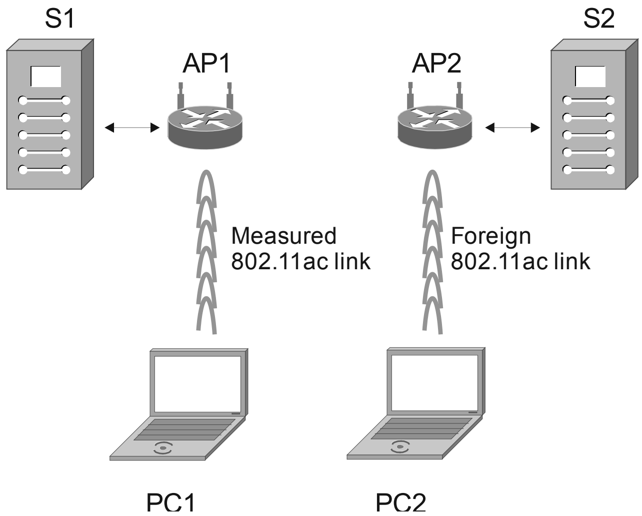

Fig.1. Diagram of the test environment

The measurements were done in two scenarios presented in the following sections. Both of them used the same test environment with two wireless 802.11ac links presented in Fig. 1.

Scenario I – influence of presence of a foreign AP

The goal of this scenario was to determine a real throughput of the IEEE 802.11ac Wave 1 radio link in presence of a foreign access point. The experiments were done in the following configurations:

a. The AP1 was operating on channel 112 (20 MHz) and the AP2 (acted as a foreign AP) was operating on 20 MHz channel changed from 100 to 140.
b. The AP1 was operating on channel (108+112) (40 MHz) and the AP2 (acted as a foreign AP) was operating on 20 MHz channel changed from 100 to 140.
c. The AP1 was operating on channel (108+112) (40 MHz) and the AP2 (acted as a foreign AP) was operating on 40 MHz channel changed from (100+104) to (140+144).
d. The AP1 was operating on channel (100+104+108+112) (80 MHz) and the AP2 (acted as a foreign AP) was operating on 20 MHz channel changed from 100 to 140.
e. The AP1 was operating on channel (100+104+108+112) (80 MHz) and the AP2 (acted as a foreign AP) was operating on 40 MHz channel changed from (100+104) to (140+144).
f. The AP1 was operating on channel (100+104+108+112) (80 MHz) and the AP2 (acted as a foreign AP) was operating on 80 MHz channel changed from (100+104+108+112) to (134+136+140+144).

In scenario I the server S2 and station PC2 were not used. Because the results obtained in the configurations listed above are very similar, only the outcomes for configurations “a”, “c” and “f” are presented in figures 2, 3 and 4 respectively.

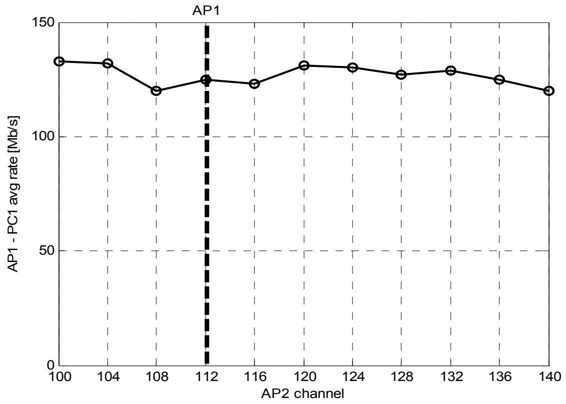

Fig.2. Average throughput of the PC1-AP1 link operating on channel 112 in presence of a foreign access point (AP2) operating using 20 MHz channel

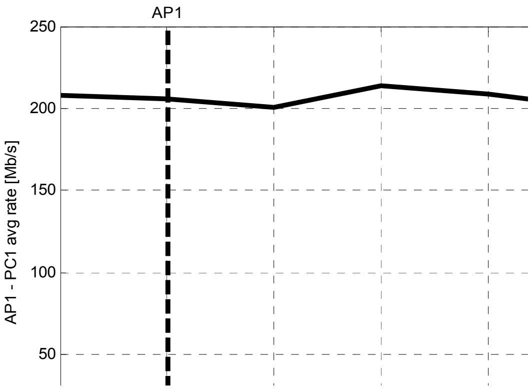

Fig.3. Average throughput of the PC1-AP1 link operating on 40 MHz channel (108+112) in presence of a foreign access point (AP2) operating using 40 MHz channel

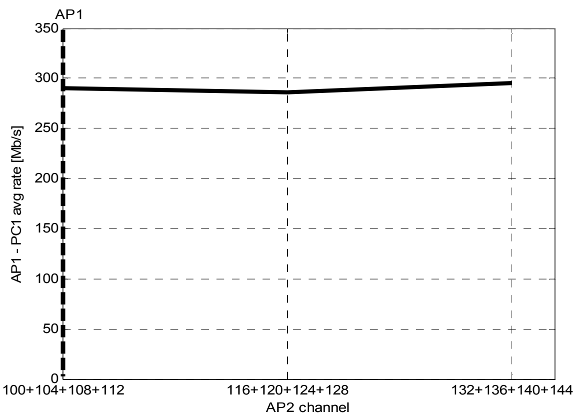

Fig.4. Average throughput of the PC1-AP1 link operating on 80 MHz channel (100+104+108+112) in presence of a foreign access point (AP2) operating using 80 MHz channel

As it can be seen from figures 2, 3 and 4, presence of a foreign access point practically does not affect the throughput of the observed link. The slight changes of the throughput that were noticed are on the level of fluctuations from measurement errors.

Scenario II – influence of the other transmission

The aim of this scenario was to determine a real throughput of the IEEE 802.11ac Wave 1 radio link in presence of a foreign transmission belonged to the other radio link operating in the same area. The experiments were done using the same 6 configurations as in scenario I but in this case AP2 was also transmitting data.

Fig. 5 presents frequency spectrum recorded during experiments (configuration "e"). There are clearly visible 80 MHz channel used by AP1 (100+104+108+112) and 40 MHz channel used by AP2 (136+140).

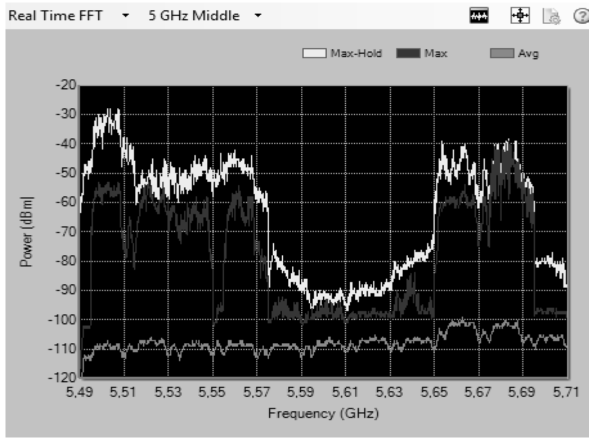

Fig.5 Frequncy spectrum for AP1 operating on 80 MHz channel and AP2 operating on 40 MHz channel

The obtained results of the average throughputs in tested configurations "a", "b", "c", "d" and "e" for foreign transmission in radio channel of width 20 MHz, 40 MHz and 80 MHz are presented in Fig. 6, 7 and 8 respectively.

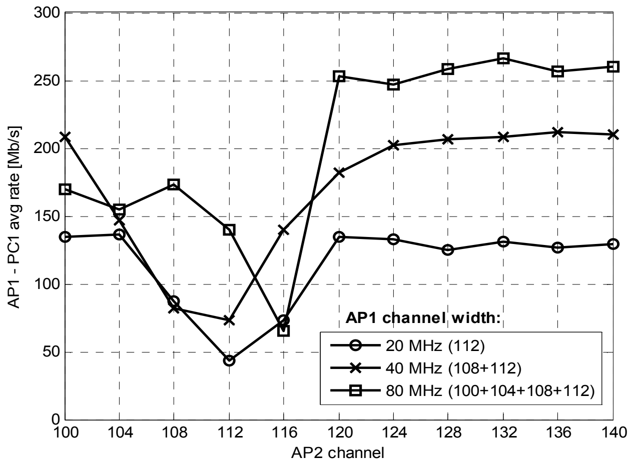

Fig.6 Average throughput of the PC1-AP1 link operating on 20, 40 and 80 MHz channels in presence of a foreign transmission in 20 MHz channel

As it can be seen in Fig. 6, foreign transmission causes a significant deterioration of throughput of the observed link. It happens not only when foreign transmission is on the channel that directly overlaps the channel of the observed link but also when the foreign link operates on the adjacent channel (in this case it is channel number 116). It can be explained by analysis of the signal spectral mask [1]. Adjacent channels have overlapped 10 MHz sidelobe with level between -20 dB and -28 dB and then the next 10 MHz sidelobe with level from -28 dB to -40 dB. OFDM technology, that is used in contemporary Wi-Fi networks, intensively explore these sidelobes what substantially limits efficiency of Wi-Fi links operating in adjacent channels.

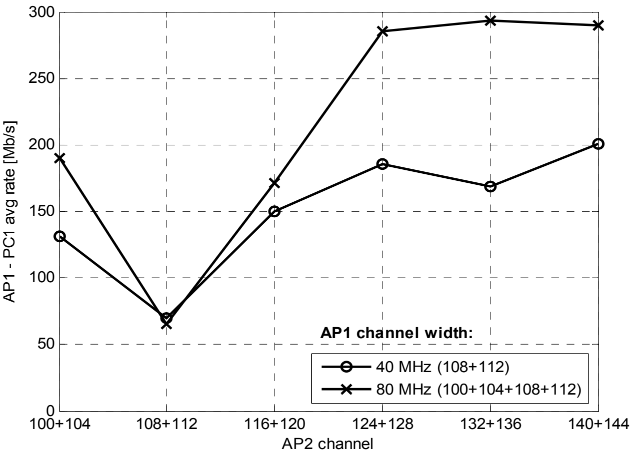

Fig.7 Average throughput of the PC1-AP1 link operating on 40 and 80 MHz channels in presence of a foreign transmission in 40 MHz channel

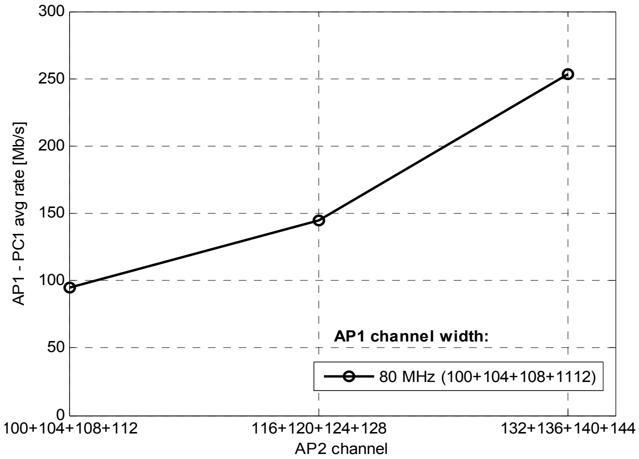

Fig.8 Average throughput of the PC1-AP1 link operating on 80 MHz channel in presence of a foreign transmission in 80 MHz channel

The results showed in Fig. 7 and Fig. 8 obtained for foreign link operating in 40 MHz and 80 MHz channels confirm presented and discussed above outcomes for the foreign transmission in 20 MHz channel.

Conclusions

This paper discusses a problem of coexistence of different wireless local area networks operating in the same area using IEEE 802.11ac Wave 1 standard. These networks operate in unlicensed 5 GHz U-NII radio band that offers much more non-overlapped channels in comparison with 2.4 GHz ISM band. However, in order to provide high data rate, 802.11ac Wave 1 networks utilize wide 40 MHz and 80 MHz radio channels that results in limitation of available non-overlapped channel. Moreover, due to spectral characteristic of OFDM transmission, using directly adjacent channels also deteriorates data throughput.

On the other hand, 802.11ac devices use different techniques that make overall transmission more reliable. One of them is dividing the whole transmission in the 40 MHz or 80 MHz channel into 20 MHz channels that can be switched dynamically to avoid interference with other networks [9]. It temporally reduces transmission rate but prevents from transmission breaks that were noticed in experiments with older 802.11 standards [7, 8].

The general conclusion from performed experiments is that 802.11ac Wave 1 networks are quite sensitive to other transmission on overlapped or adjacent channels and using such channels leads to a significant deterioration of the throughput of the links. However, due to additional mechanisms 802.11ac networks practically do not experience breaks in communication.

The research was conducted within the project S/WE/1/2015, financially supported by Polish Ministry of Science and Higher Education.

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