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COMPARISON OF 802.11AC AND 802.11N PHY LAYERS

Summary

802.11ac, n and ad are three newest IEEE standards. 802.11n implements a lot of new proposals especially in PHY and MAC layers while in 802.11ac there aren't any new technologies but only optimization and development of ac new ideas. Both propose significant increased in throughput but only ac reaches the level which could guarantee the multimedia successful communication. Author compares the most important features of PHY layers of both standards.

Key words: 802.11ac, 802.11n , PHY layer, throughput.

JEL codes: O3

Introduction

The first 802.11 standard was released in 1997 (Hiertz et al. 2010). The physical layer of the standards (PHY) includes several parameters which describe the radio channel features. The main values are: the frequency band, the channel width, the channel number, SISO/MIMO technology and modulation features such as the modulation type, the modulation level (constellation) and the coding ratio. The PHY layer decided mainly about the throughput which is the most important parameter of the wireless transmission. Two frequency band are used in 802.11 standard almost from the beginning of the standard history. There are 2.4 GHz and 5 GHz bands. The basic radio channel width is 20 MHz however in the 802.11ac standard the widest channel reaches 160 MHz. There were a lot of changes in the modulation characteristics. Four complete standards were developed up till now together with several amendments. Basic parameters of these standards PHY are presented in Table 1.

The progress in the throughput was achieved for the first standards due to modification in the modulation area. The first significant changes in the channel structure were implemented in the 802.11n standard. Two new techniques were used. The channel bonding increases the maximal channel width to 40 MHz and the MIMO (multiple input multiple output) technology let increased the streams number up to 4. The 802.11n standard is the most popular one presently and the share of the 802.11n chipset production in the total 802.11 chipset shipment is about 90% (Aruba White Paper 2012). The market demands higher and higher throughput. The new standards such as 801.11ac and 802.11ad are in progress. The final release of the 802.11ac standard is planned in the end of 2013 while the first release of 802.11ad (60 GHz band standard) was published in 2012 (Hiertz et al. 2010; Cisco White Paper 2012). Why the high throughput is so important? The author tries to explain this in the next paragraph. Then the description of both 802.11n and ac PHY layer and they comparison are presented.

Table 1. PHY layer parameters of 802.11 standards

Standard	Band [GHz]	Maximal throughput (SISO)	Maximal channel width	Standard channel width	Antennas SISO/ MIMO
802.11a	5	1.5-54 Mbit/sec	20 MHz	20 MHz	1
802.11b	2.4	11 Mbit/sec	20 MHz	20 MHz	1
802.11g	2.4	54 Mbit/sec	20 MHz	20 MHz	1
802.11n	2.4 5	150 Mbit/sec 150 Mbit/sec	40 MHz 40 MHz	20 MHz 20 MHz	1-4 1-4

Demand for HT

The high throughput HT is required for many applications. There are others transmission parameters which describe the QoS (Dolińska et al. 2011) such as delay or jitter but we discuss them when we have satisfactory throughput. The most critical application is video. Streaming video, even when compressed, consumes orders of magnitude more bandwidth than voice communication, email and web browsing. The introduction of different type smart-phones and tablets has started enormous increases in bandwidth demand, while consumption of streaming video-over-IP in the home for TV and movies is started significant increases in Internet traffic and demands for throughput and capacity (Aruba White Paper 2012). The wireless display usage solutions are competing with the cross-room cable replacement market that at present was the objective of ultra-wide band (UWB) and that will overlap with the 802.11ad (Cisco White Paper 2012) planned for 60 GHz band. The 802.11ad standard intention is to replace the cables between set-top boxes, game consoles, PCs and TV. Most consumer electronics companies see 802.11ac and 802.11ad as the first sensible wireless technologies for video, especially uncompressed video. The throughput necessary for different type video transmission was compared in Table 2 (Cisco White Paper 2012).

Table 2. Throughput for different type video transmissions

Video type	Parameters	Throughput
uncompressed	720p, RGB, 1280x720p, 60Hz	1300 Mbit/sec
uncompressed	1080i, RGB, 1920x1080p, 60 Hz	1500 Mbit/sec

uncompressed	1080p, RGB, 1920x1080p, 60 Hz	3000 Mbit/sec
lightly compressed	Motion jpeg2000	150 Mbit/sec
lightly compressed	H.264	70-200 Mbit/sec
compressed	Blu-ray	50 Mbit/sec
compressed	HD MPEG2	20 Mbit/sec

Besides video applications the HT could be also useful in case of large file transfer.

Overwiev of improvements in 802.11n and 802.11ac standards

The 802.11n standard was quite revolutionary. There are a long list of the new solutions in both basic layers PHY and MAC. Some of the changes however are not supported in 802.11ac standard. The most important innovations in the 802.11n standard (Hiertz et al. 2010; Cisco White Paper 2012; Air Magnet White Paper 2008; IEEE 2009; Juniper Networks White Paper 2011) are as follows:

– MIMO (multiple input multiple output) implementation – this solution offer two main benefits. The SM (spatial multiplexing) splits up the data into pieces and sends each piece along parallel "spatial" channels in a fraction of the time that it would take to send the same data serially through single channel. The multipath transmissions increased uplink reliability. Due to multipath, an AP with four antennas receives four copies of a sender's signal. Each copy is distorted in four different ways, so the probability that all copies are destructively faded all at the same time is very low. Thus the MIMO equalizer within the receiver can gather all these copies, combine them, and as a result the greater reliability is achieved, delivering more predictable data rates and fewer retries,
– channels bonding – let to increased the channel width from 20 to 40 MHz. This leads to doubling the throughput. The channel bonding is available for both 802.11n frequency bands 2.4 GHz and 5 GHz,
– aggregation- two aggregation techniques are used : the "intuitively" named A--MSDU and AMPDU, which can also be combined together, as in "A-MPDU of A-MSDU." With aggregation, the data is packed together in a single unit that is sent with one preamble and acknowledged in one transmission. AMSDU aggregates MSDUs (for example, LLC+IP+TCP+data) at the top of the MAC transmission path, so an individual MSDU in an A-MSDU lacks a MAC header/footer, such as a sequence number or frame check sequence. This is good for efficiency yet makes retries at the individual MSDU level impossible. Meanwhile, A-MPDU aggregates MPDUs at the bottom of the MAC, so each MPDU in an A-MDPU contains its own MAC header,

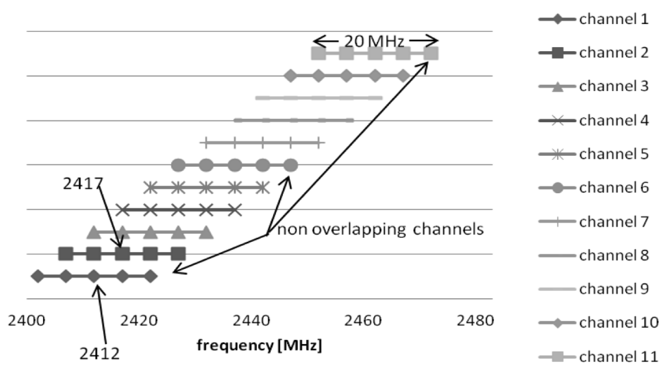
– others- new modulation schemes which include the higher modulation level and coding rate, short guard interval (400nsec), mixed modulation, block ACK, three operating modes (HT-greenfield, non HT, HT mixed).

The 802.11ac standard doesn't introduce almost anything new. One could say that this standard is the optimization of the 802.11n standard. There are some changes but there are any new technologies. The 802.1ac standard increased the number of spatial streams to eight and allow the simultaneously communication of AP with eight different stations but on the other hand reduce the aggregation modes available in the 802.11n standard. The MIMO technology used in 802.11ac standard is called MU multi user techniques while the 802.11n MIMO is called SU single user.

Structure of 802.11n PHY

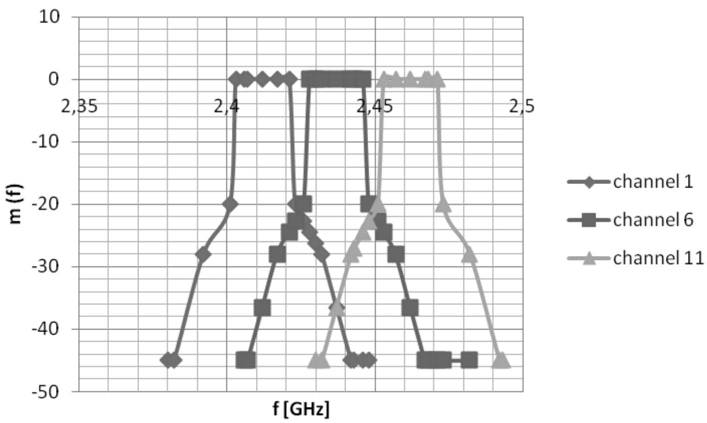
The 802.11n standard could use two frequency bands generally the same as in other 802.11 products. Basic channels are approximately 20 MHz wide. Within the 2.4 GHz ISM frequency band transmitters use one of 11, 20 MHz channels (three of them are theoretically non-overlapping: 1, 6,11). There are 12 non-overlapping 20 MHz channels in the 5 GHz UNII band. The frequency channel arrangement in the 2.4 MHz band is presented in fig. 1

Fig. 1. Channel arrangement in 2.4 GHz band (ISM – Industrial Scientific Medical)



The standard deviation between the central frequencies of these three non-overlapping channels in 2.4 GHz band is 25 MHz, while the center frequency of the adjacent channels is shifted of 5 MHz. The signal level in each channel is limited by the filter called the standard mask The filter has specially developed characteristics. The characteristics of filters for 1,6 and 11 channels in the 802.11n standard are presented in fig. 2.

Fig. 2. Mask charcteristics for channels in 2.4 GHz band



Source: Dolińska et al. (2013).

The quite large number of different MCS (modulation schemes) were implemented in the 802.11n standard. The highest throughput ia achieved with 64-QAM modulation togetrher with 5/6 coding rate and short guard interval. The maximal throughput for single spatial stream doesn't excess 150 Mbit/sec (for SGI short guard interval). Theoritecally highest throughput of 600 Mbit/sec is possible for 4 spatial streams. The set of thoughput versus modulation parameters is presented in table 3.

Table 3. Maximal throughput for different MCS of 802.11n (for 40 MHz channel and SGI)

MCS	Modulation type	Coding rate	Number of spatial streams	Data rate [Mbits/sec]
0	BPSK	1/2	1	15
1	QPSK	1/2	1	30
2	QPSK	3/4	1	45
3	16QAM	1/2	1	60
4	16QAM	3/4	1	90
5	64QAM	2/3	1	120
6	64QAM	3/4	1	135
7	64QAM	5/6	1	150
15	64QAM	5/6	2	300
23	64QAM	5/6	3	450
31	64QAM	5/6	4	600

The structure of channels in 5 GHz band is the same to some extend for 802.11 a/n and ac standards. The difference is in channel bonding. The 5GHz band is describe in the next paragraph.

The channel bonding and the use of 40 MHz channel in 2.4 GHz band is the issue of discussion concerning possible interference from such channel and disturbances which could be caused for other users of 2.4 GHz band such as older 802.11 standards, Bluetooth and ZigBee (Hiertz et al. 2010).

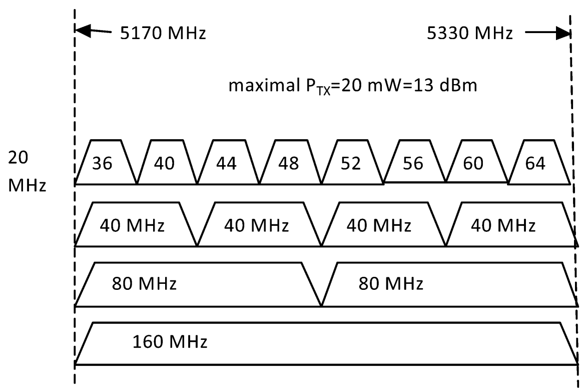
Structure of 802.11ac PHY

The 802.11ac standard is practically an improved version of 802.11n standard. 802.11ac improves 802.11n on three different dimensions:
- more channel bonding, increased from the maximum of 40 MHz in 802.11n up to 80 or 160 MHz,
- denser constellation (modulation levels), now using 256 quadrature amplitude modulation (QAM), comparing with 802.11n's 64QAM,
- more multiple input, multiple output (MIMO)b streams, the 802.11n stopped at four spatial streams, 802.11ac reaches eight.

Channel bonding in 802.11ac base on simple principles. Adjacent 20 MHz sub-channels are bonded into pairs to make 40 MHz channels, adjacent 40 MHz sub-channels are bonded into pairs to make 80 MHz channels, and adjacent 80 MHz sub-channels are bonded into pairs to make the optional 160 MHz channels.

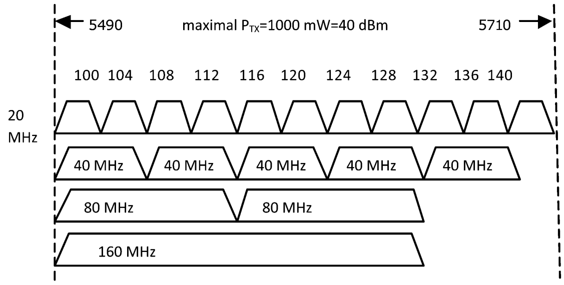
The channels configuration in bands UNII 1 and 2 (according to present European regulation) are presented in fig. 3 and 4.

Fig. 3. Channels configuration – UNII 1 band



Source: Schelstraete (2011).

Fig. 4. Channels configuration – UNII 2 band



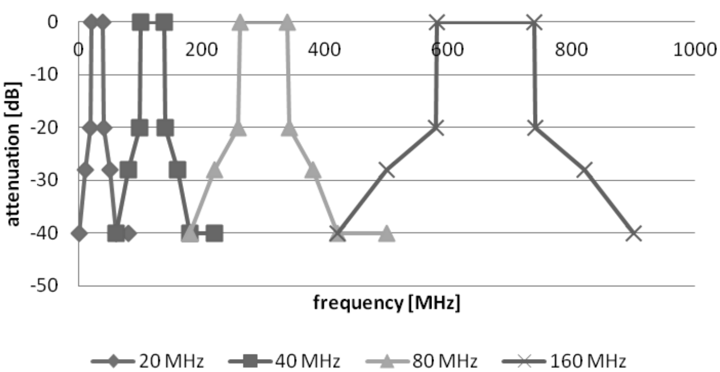
Source: Schelstraete (2011).

There are some optional resources which are allowed in some countries such as 144 channel which is the extension of UNII band and 145-161 channels within UNII-3 band and finally 165 channel in ISM 5825-5850 MHz band.

The total number of available channels could vary in different countries due to the local regulation issues and amounts 20 to 25 20 MHz channels, 8 to 12 40 MHz channels, 4 to 6 80 MHz channels, and 1 or 2 160 MHz channels.

The 802.11ac mask has to meet all regulation requirements and backwards compatibility with previous versions of the standard 802.11. The mask characteristics for different channel wide are presented in fig. 5 (Ward 2012).

Fig. 5. Mask characteristics for 20 to 160 MHz 802.11ac channels



The special construction of mask was developed for the utilization of two 80 MHz non-contiguous signals separated by 160 MHz (Ward 2012).

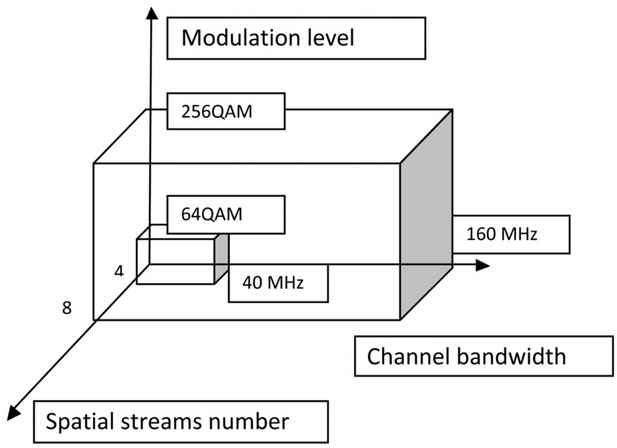
Comparison of 802.11n and ac standards

802.11ac achieves its maximal speed increase by introducing three different techniques:

- channel bonding, increased from the maximum channel width of 40 MHz in 802.11n, up to 80 or even 160 MHz,
- denser modulation, it means that distance between the symbols is used, now it is 256 quadrature amplitude modulation (QAM), comparing with 802.11n's 64QAM,
- more multiple input, multiple output (MIMO), 802.11n achieved four spatial streams while 802.11ac reaches 8.

The graphical interpretation of the difference between critical parameters of both standards is presented in fig. 6.

Fig. 6. Comparison of main parameters of 802.11 n and ac standards



Source: Cisco White Paper, 802.11ac: The Fifth Generation of Wi-Fi, Technical White Paper, Cisco, August 2012

We can estimate the benefits of 802.11ac (Cisco White Paper 2012; Hotgkinson 2007; Freeman 2007). using following formulas:

$$C = B\log_2(1 + \frac{S}{N}) \tag{1}$$

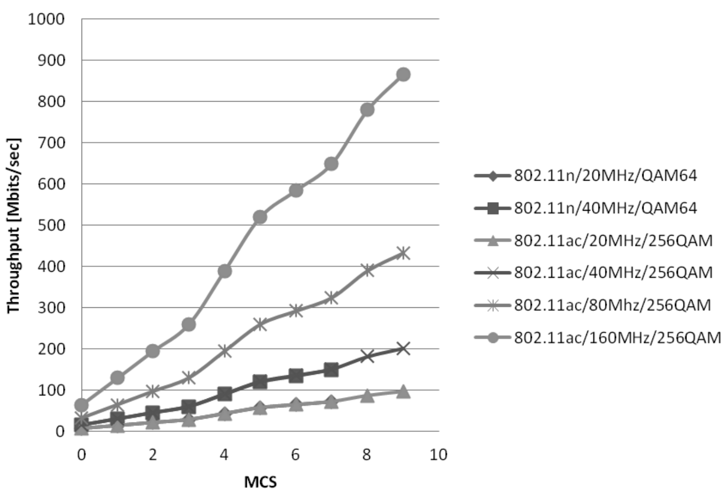
where C is the throughput while B is the channel width. This is the basic Shannon concept and if we double the B we double at the same time C. Practically there is some signal lost so if we increased the bandwidth, the received power density decrease for wider channels, however the loss is smaller than benefit. The 802.11n standard offers maximal C of 150 Mbit/sec for one stream so if we increase bandwidth from 40 MHz to 160 MHz we can achieve about 600 Mbit/sec per one stream.

The second formulae takes into account the modulation level.

$$\Delta C = \log_2 M \tag{2}$$

where M represents the modulation level (M=64 for QAM64 and so on), and ΔC represents the increased of throughput. M ratio is 6 for 64QAM (802.11n) and 8 for 256QAM (802.11ac). The increased of M let to 33% increased in throughput. The final throughput per one stream is close to 1 GHz in 802.11ac. The total system throughput is equal 8 times the single stream throughput. The comparison of both standards throughput is presented in fig. 7

Fig.7. Comparison of 802.11n and ac throughput (one spatial stream, SGI)



The total throughput of standard operating at MIMO mode is equal the single stream throughput multiply by number of streams. The ratio between channels width for 802.11ac is *1:2,1:4,5:9* for 20, 40,80 and 160 MHz channels respectively.

The correlation between long and short GI is given by the following formula:

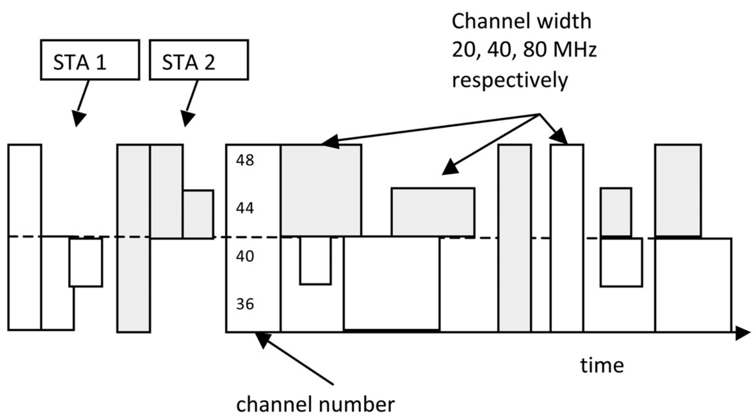
$$C_{SGI} = C_{LGI} \frac{LGI}{SGI} \tag{3}$$

The SGI is 3,6 μsec while LGI 4 μsec. The application of SGI increased the throughput of about 11%. The negative aspects could be the higher BER.

The full possibilities of 802.11n are not used up today. The most chipset support only three spatial streams. There are some reasons on both technical and economic sides. There are a lot of mobile devices on the market where application of many spatial streams is not useful because of dimension limits as well as limited power availability. This situation didn't change rapidly so the first phase 802.11ac device also will not consume all improvements. The first phase 802.11ac products will offer 80 MHz and delivering from 433 Mbps up o 1300 Mbps at the physical layer. We can expect that second generation products promise more channel bonding and spatial streams, with possible throughput up to 3.47 Gbits/sec.

A significant advantage of 802.11ac standard is the possibility of parallel transmissions in adjacent channels. The sample of such possibility is shown in fig. 8.

Fig. 8. The simultaneously transmission in 802.11ac standard



Source: Cisco White Paper (2012).

Two stations associated with one AP could use one 80 MHz with a high efficiency. Each station has its own primary 20 MHz channel. Carrier sensing enables to detect which channels are available. The six possible scenarios could be realized. The basic transmission mode is with two stations operating on 20 MHz channels. The second is the transmission on 40 MHz channel. Then we have two scenarios with one station operating at 40 MHz and one on 20 MHz channel. All mentioned solution use the non overlapping channels. The last two requires the proper sensing of 80 MHz channel availability. The stations could use the full 80 MHz but the transmissions should be separated in time domain. The multichannel parallel transmission enables very efficient cooperation with previous standards 802.11a and 802.11n which could use respectively 20 MHz channel both and 40 MHz channel only 802.11n. The station with low throughput caused by narrow channel or the poor signal level could consume a lot of time and decrease the QoS of other stations working in associated APs' or other but in close range.

Conclusions

The 802.11ac standard improved mainly three dimension of 802.11n [fig. 6]. The theoretical analysis and simulation shows that 802.11ac outperforms 802.11n if the 80 MHz channel versus 40 MHz channel is applied [11].

The full implementation of all 802.11ac options could take a long time. Full MIMO eight stream won't be available at the first implementation phase [3]. Similar situation was with 802.11n four stream. Producers because of technical and economical reason stopped at three spatial streams.

There are some question concerning details of 802.11ac such as:

- lack of permission for application of channel wider than 40 MHz in some countries,
- tests and official certification of measurement devices operating with 80 and 160 MHz channels,
- spectrum utilization of some parts in bands dedicated for 802.11ac (channel144, 5,6-5,65 GHZ- conflict with weather radar activity),
- pressure for opening new bands for 802.11ac (with possibility of usage of wide 80 and 160 MHz channels).

The open issue is the real interferences problems when very wide channels will be used. There are no practical study concerning 80 and 160 MHz channels, however there are some research results concerning 40 MHz channel [13].

The 802.11ac chipset should be available in 2013 at the beginning as not certified samples. It is obvious that 802.11ac could predominate the area of short range (home) high volume video communication [14].

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Porównanie warstw fizycznych standardów 802.11ac i n

Streszczenie

802.11ac, n i ad to trzy najnowsze standardy IEEE. W przypadku 802.11n wprowadzono szereg nowych rozwiązań, szczególnie w warstwach fizycznej i dostępu, podczas gdy 802.1ac właściwie nie zaproponował nic nowego, a jedynie zoptymalizował i rozwinął pomysły swojego poprzednika. Oba standardy znacząco zwiększyły dostępne przepustowości, ale tylko ac oferuje taki poziom przepustowości, który gwarantuje skuteczne transmisje multimedialne. W artykule porównano najważniejsze parametry warstw fizycznych obu standardów.

Słowa kluczowe: 802.11ac, 802.11n, warstwa fizyczna, przepustowość.

Kody JEL: O3

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