This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the IEEE ICC 2011 proceedings

IEEE 802.11ac: Dynamic Bandwidth Channel Access

Minyoung Park
Intel Labs, Intel Corporation
2111 NE 25th Ave. Hillsboro, OR, 97124, USA
Email: minyoung.park@intel.com

***Abstract*—IEEE 802.11ac is enhancing throughput beyond IEEE 802.11n using an 80 MHz channel bonding technique. In this paper, we first overview the static 40 MHz and the dynamic 20/40 MHz bandwidth channel access schemes defined in 802.11n. We then extend the schemes to the IEEE 802.11ac for an 80 MHz wide channel and study the static and dynamic channel access schemes. The simulation results show that dynamically switching between 20, 40, and 80 MHz bandwidths based on the clear channel assessment (CCA) result of each 20 MHz channel outperforms the static 80 MHz scheme by 85 % in terms of throughput when the secondary channels are occupied by the 802.11a stations with moderate traffic loads. The paper also investigates the effects of the secondary channel CCA sensitivity and the primary channel selection on the 802.11ac throughput.**

***Index Terms*— 802.11ac, 802.11n, WLAN, dynamic bandwidth channel access, static bandwidth channel access**

I. Introduction

Since 2008, IEEE 802.11ac Task Group (TG) has been developing an amendment to IEEE 802.11 PHY and MAC layers to meet growing demands of new wireless applications that require higher data rates [1]. In order to increase the PHY rate, the group is considering an 80 MHz channel bonding technique that bonds two adjacent 40 MHz channels [2].

Although the 80 MHz channel bonding technique sounds very simple, efficiently utilizing the 80 MHz wide channel is challenging due to legacy 802.11a and 802.11n [3] stations operating in 20 or 40 MHz wide channels. As more and more devices are wirelessly connected to the Internet and wireless networks are deployed more densely, new 802.11ac networks are expected to have less chance to operate in its full 80 MHz bandwidth but will have to efficiently share the 80 MHz channel with the legacy 802.11a/n networks operating in the overlapping narrower channels.

The purpose of the paper is to first understand the static 40 MHz and the dynamic 20/40 MHz bandwidth channel access rules defined in 802.11n. The 802.11n 40 MHz channel consists of the primary and the secondary 20 MHz channels. The static 40 MHz bandwidth channel access scheme only transmits 40 MHz wide signals if the primary and the secondary channels are idle. If the secondary channel is busy, it will wait for the 40 MHz channel to be idle. On the other hand, the dynamic 20/40 MHz bandwidth channel access scheme may transmit 20 MHz data over the primary channel if the secondary channel is busy.

We extend 802.11n's static and the dynamic bandwidth channel access rules to the 802.11ac 80 MHz channel, which consists of one primary channel and three secondary channels [4]. We simulate and compare the throughput of the static 80 MHz and the dynamic 20/40/80 MHz bandwidth channel access schemes when there are legacy 20 MHz 802.11a stations operating in the secondary channels. The simulation results clearly show that the dynamic bandwidth channel access scheme outperforms the static bandwidth channel access scheme when the secondary channels of the 80 MHz channel are occupied by the 20 MHz 802.11a stations with a moderate level of traffic loads. We also investigate the effects of the secondary channel CCA (clear channel assessment) sensitivity and the primary channel selection schemes on the 802.11ac throughput.

The paper is organized as follows. In Section II, 802.11n's static 40 MHz and dynamic 20/40 MHz bandwidth channel access rules are described. In Section III, we extend the 802.11n's rules to the 802.11ac 80 MHz channel and discuss some of the issues. In Section IV, the simulation results are presented and finally in Section V, we draw conclusions.

II. Overview on IEEE 802.11n 40MHz Channel Access

802.11n enhanced the physical layer throughput by adopting two major techniques: i) a multiple-input-multiple-output (MIMO) technique called spatial multiplexing and ii) the 40 MHz channel bonding technique. In this section, we will focus on the 40 MHz channel bonding and describe the 40 MHz channel access rules defined in 802.11n to understand the implication of extending the rules to the 802.11ac 80 MHz channel access.

A. 40 MHz Channelization

802.11n defines the 40 MHz channelization in the 5 GHz band for US, Europe, and Japan. Currently, there are eleven 40 MHz channels defined in the UNII (Unlicensed National Information Infrastructure) bands. The 40 MHz channels are allocated in such a way that one 40 MHz channel does not overlap with its adjacent 40 MHz channels. This is to prevent the 40 MHz channels from partially overlapping with neighboring channels, which provides better coexistence with neighboring networks.

A 40 MHz channel consists of two 20 MHz channels: the primary channel and the secondary channel. The differences of the two channels are as follows:

1) CCA (Clear Channel Assessment) sensitivity: The CCA sensitivity level of the primary channel is much lower than that of the secondary channel. The CCA sensitivity level of the primary channel is -82 dBm for a valid 802.11n 20 MHz signal and -79 dBm for a valid 802.11n 40 MHz signal, whereas the CCA sensitivity level of the secondary channel is -62 dBm [3]. The CCA sensitivity level of -82 dBm requires a receiver to be able to detect the structure of the 802.11n signal such as the preamble of the signal. The CCA sensitivity level of -62 dBm can be achieved by a simple energy detection scheme and therefore extra decoding is not required in the secondary channel.

2) NAV (Network Allocation Vector) setting: The 802.11 packets received in the primary channel are decoded and the duration field of the MAC header is used to set the NAV so that a neighboring station can defer its transmission and does not cause collision to the ongoing transmissions. An 802.11n station operating in the 40 MHz mode, however, does not require its NAV to be set based on the packets received in the secondary channel [3]. This implies that when a legacy 802.11a network is operating on the secondary channel of the 802.11n network, the 802.11n network will have less information about the neighboring 802.11a network than what the 802.11a network knows about the 802.11n network.

B. 40 MHz Transmission Rules

802.11n defines a 20/40MHz station which is capable of communicating over 20 MHz and 40 MHz bandwidths. The 40 MHz transmission rules in 802.11n are as follows:

The start time of a packet transmission is solely based on the primary channel CCA result. The 802.11n station checks if the primary channel has been idle for a DIFS (DCF (distributed coordination function) inter-frame spacing) plus the backoff counter time. If the primary channel has been idle for the duration of time and if the secondary channel has also been idle for a PIFS (PCF (point coordination function) inter-frame spacing) duration of time immediately preceding the expiration of the backoff counter, the station may transmit a 40 MHz signal. However, if the secondary channel was not idle during this interval, the station has two choices:

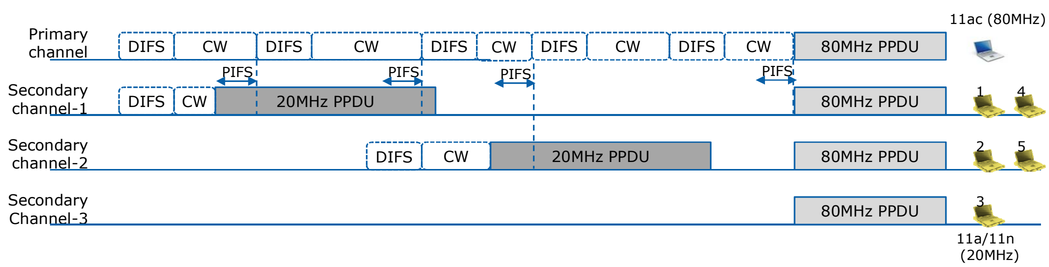
- Static 40 MHz bandwidth channel access: the station may reattempt to access the 40 MHz channel by restarting the channel access attempt with a new random number chosen from its current contention window size for the backoff counter.
- Dynamic 20/40 MHz bandwidth channel access: the station may transmit a 20 MHz signal only on the primary channel.

III. IEEE 802.11AC DYNAMIC 20/40/80 MHZ BANDWIDTH CHANNEL ACCESS

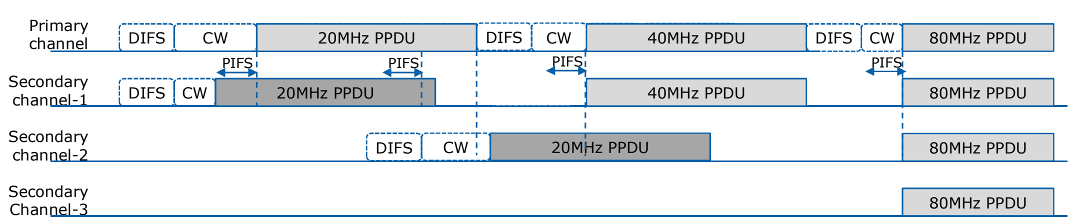
Similar approach described in the previous section can be extended and applied to the 80 MHz wide channel for 802.11ac. In this section, we describe the benefits of the dynamic 20/40/80 MHz bandwidth channel access in the 80 MHz bandwidth, the issue of the secondary channel CCA sensitivity, and the effect of the primary channel selection on the 802.11ac performance.

A. Overlapping 802.11a/n and 802.11ac Networks

As the channel bandwidth gets wider and as a networking environment gets denser due to ever increasing number of wireless devices, it gets harder for an 802.11ac AP (access point) to find a clean 80 MHz wide channel. Therefore, an 80 MHz 802.11ac network is more likely to share the frequency channels with neighboring legacy 802.11a/n networks operating on 20 or 40 MHz channels. As more and more 802.11n networks are operating in the secondary channels of



(a) Static 80 MHz bandwidth channel access



(b) Dynamic 20/40/80 MHz bandwidth channel access

Fig. 1 Illustration of 802.11ac (a) static 80 MHz and (b) dynamic 20/40/80 MHz channel access schemes (CW=contention window)

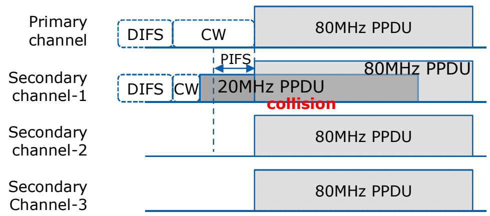


Fig. 2 Illustration of the collision problem due to the secondary channel CCA sensitivity level

the 802.11ac network, the throughput of the 802.11ac network may degrade more. Thus, it is important to use the frequency resource efficiently by dynamically changing the bandwidth amongst 20, 40, and 80 MHz.

B. Dynamic 20/40/80 MHz Bandwidth Channel Access

If we extend the 40 MHz transmission rules described in the previous section to 802.11ac, an 802.11ac station may transmit an 80 MHz PPDU (PLCP (physical layer convergence procedure) protocol data unit) when the primary channel has been idle for a DIFS plus the backoff counter and the three secondary channels have been idle for a PIFS immediately preceding the expiration of the backoff counter. This is shown in the last part of Fig. 1(a). However, if one or more secondary channels are busy, the 802.11ac station may have two choices similar to the 802.11n rules:

1) *Static 80 MHz bandwidth channel access*: the station may reattempt to access the 80 MHz channel by restarting the channel access attempt with a random number chosen from its current contention window size for the backoff counter. This is illustrated in Fig. 1(a). In the example, there are five legacy 20 MHz 802.11a/n stations on the three secondary channels of the 802.11ac station operating in the 80 MHz mode. If one of the secondary channels is busy, the 802.11ac station continues channel access attempt until all the secondary channels are idle. As more legacy stations operates in the secondary channels or as the traffic load increases, the 802.11ac gets less chance to access the medium and thus throughput degrades. This problem gets worse as the bandwidth gets wider. The simulation results are shown in Section IV.

2) *Dynamic 20/40/80 MHz bandwidth channel access*: the station may transmit data over a narrower channel with a bandwidth of 20 or 40 MHz depending on the CCA results of the secondary channels. This is illustrated in Fig. 1(b). When the secondary channels are busy, the 802.11ac station uses a narrower bandwidth (e.g. 20 MHz or 40 MHz) for data transmissions. This approach utilizes the frequency resource more efficiently than the static approach. Since the receiver has to know the channel over which the transmitter will use to transmit data, it is better to have the primary channel included in the 20 MHz or 40 MHz bandwidth transmissions.

C. Secondary Channel CCA Sensitivity

Fig. 2 illustrates the collision problem between a 20 MHz transmission from an 802.11a/n station on the first secondary

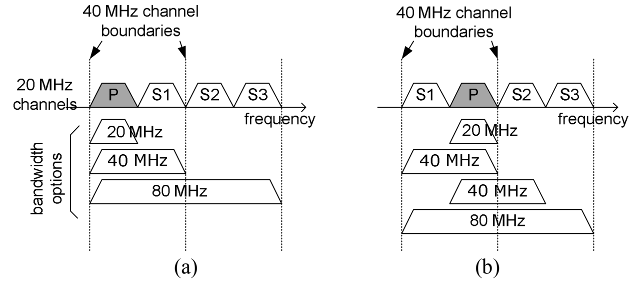


Fig. 3 Illustration of the primary channel selection for 802.11ac: (a) the primary channel at the start of an 80 MHz channel and (b) in the middle of the 80 MHz channel. (P=primary channel, S1~S3: the three secondary channels)

channel and an 80 MHz transmission from an 802.11ac station due to the secondary channel CCA sensitivity being too high. The example assumes that the 802.11ac has the primary channel CCA sensitivity level of -82 dBm and the secondary channel CCA sensitivity level of -62 dBm. Therefore, if the received signal power at the secondary channel of the 802.11ac station is higher than -82 dBm but lower than -62 dBm, the 802.11ac station will consider the secondary channel to be idle and transmit an 80 MHz wide signal, which may collide with the transmission on the secondary channel.

One way to address this problem is to have better CCA in the secondary channels so that the 802.11ac stations can better detect the signals in the secondary channels and avoid the collisions. One way to achieve lower secondary channel sensitivity is to exploit the transmission signal structure such as the preamble structure or the OFDM signal structure [5].

D. Primary Channel Selection

The position of the primary channel within the four 20 MHz channels may impact the 802.11ac throughput when the stations are using the dynamic bandwidth channel access scheme.

An 802.11ac AP may place the primary channel at the start or end of the 80 MHz channel as shown in Fig. 3(a) or in the middle of the 80 MHz channel as shown in Fig. 3(b). When the primary channel is placed at the start or end of the 80 MHz channel, 40 MHz PPDUs can be transmitted only over the primary channel P and the adjacent secondary channel S1, i.e. (P+S1). If S1 is busy, the station has to fall back to 20 MHz and use only the primary channel for 20 MHz PPDU transmissions. However, if the primary channel is placed in the middle of the 80 MHz channel, as shown in Fig. 3(b), the 802.11ac station has one more option to transmit 40 MHz PPDUs. For example, when the secondary channel S2 is busy, it can use (S1+P) for 40 MHz transmissions. When S1 is busy, it can still use (P+S2) for 40 MHz transmissions, which will help improve the throughput of the 802.11ac station when the secondary channels are busy.

There is, however, a possibility of the 40 MHz transmissions, (P+S2), across the 40 MHz channel boundary partially overlapping with another 40 MHz 802.11n BSS (basic service set) operating in (S2+S3). If S2 is also the secondary channel of the 40 MHz 802.11n BSS, the secondary channels of the 802.11ac and the 802.11n BSSs are

TABLE I
SIMULATION PARAMETERS OF 802.11A

Bandwidth	PHY rate	Packet size	Transmission Probability
20 MHz	54 Mbps	1500 bytes	0~1

TABLE II
SIMULATION PARAMETERS OF 802.11AC

Bandwidth	PHY rate	Packet size	Transmission Probability
20 MHz	130 Mbps	1500 x 2.4 bytes	1
40 MHz	270 Mbps	1500 x 5 bytes	1
80 MHz	540 Mbps	1500 x 10 bytes	1

overlapping with each other and since the 802.11n may not be able to decode the packets received from its secondary channel, S2, the 802.11ac's 40 MHz transmissions on (P+ S2) may collide with the 802.11n's 40 MHz transmissions on (S2+S3). This problem may be addressed by allowing the 802.11ac's 40 MHz transmissions across P and S2 only if S2 is the primary channel of the 40 MHz 802.11n BSS.

IV. SIMULATION RESULTS

In this section, the benefit of the dynamic bandwidth channel access over the static bandwidth channel access is quantified through MATLAB simulations. The secondary channel CCA sensitivity and the primary channel selection results are also presented.

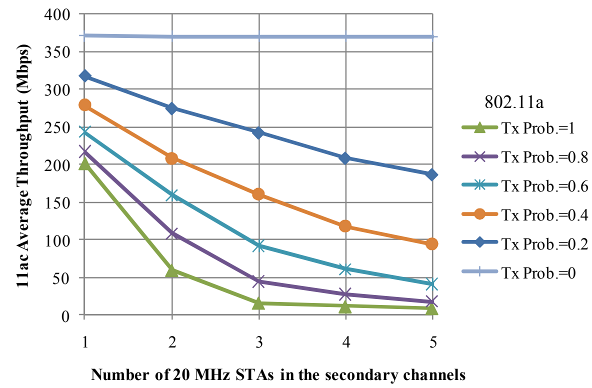
A. Simulation Setup

The wireless networking environment is configured to have one 802.11ac BSS with one 802.11ac AP and one 802.11ac station (STA), and one to three 802.11a BSSs each with one 802.11a AP and one or two 802.11a STAs. This is similar to the configuration shown in Fig. 1.

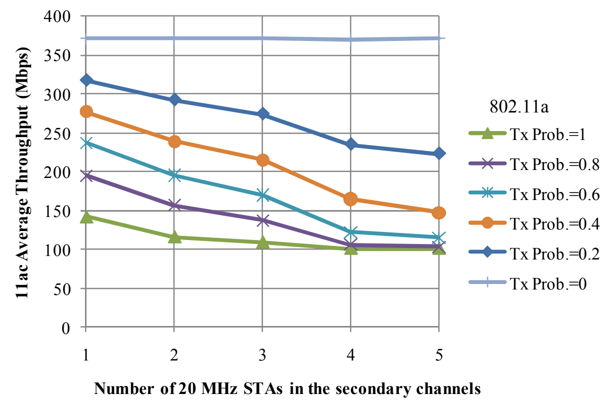
The simulation parameters for 802.11a and 802.11ac are shown in Table I and Table II. In order to have similar transmission air time between different bandwidth modes, the packet sizes are increased for the wider bandwidth modes. Two spatial streams are assumed for the 802.11ac STAs. All the PHY rates of the 802.11ac STA are derived from the 802.11n PHY rates.

B. Static versus Dynamic Bandwidth Channel Access

Fig. 4 compares the average throughput of the 802.11ac STA when (a) using the static 80 MHz bandwidth channel access scheme and (b) using the dynamic 20/40/80 MHz bandwidth channel access scheme. The received power on each 20 MHz channel is assumed to be higher than -62 dBm. The transmission probability of the 802.11a STAs is varied from 0 to 1 to show the effect of the traffic load in the secondary channels on the 802.11ac throughput, while the transmission probability of the 802.11ac STA is fixed to 1 meaning that the 802.11ac STA always has data to transmit. The number of 20 MHz 802.11a STAs are increased from 1 to 5. The first, second, and third 802.11a STAs are operating in the first, second, and third secondary channels and the fourth and the fifth 802.11a STAs are operating on the first and the second secondary channels as shown in Fig. 1(a). In the simulations, we assume that the 802.11a signals received in the secondary channels of the 802.11ac STA are above the secondary



(a) Static bandwidth channel access



(b) Dynamic bandwidth channel access

Fig. 4 802.11ac average throughput measurement results

TABLE III
DYNAMIC VERSUS STATIC BANDWIDTH CHANNEL ACCESS THROUGHPUT COMPARISON (THREE 802.11A STAS CASE)

802.11a Tx Prob.	1	0.8	0.6	0.4	0.2
Static (Mbps)	16.2	44.4	92	160	242
Dynamic (Mbps)	109	137	170	215	274
Gain	569 %	209 %	85 %	34 %	13 %

channel CCA threshold and thus the 802.11ac STA can detect the 802.11a transmissions.

The simulation results show that, when there is only one 802.11a STA occupying the first secondary channel of the 802.11ac, the throughput of the 802.11ac STA does not improve but decreases when the load of the 802.11a STA is high (i.e. the transmission probability of 0.8 and 1). This is because when the static 80 MHz bandwidth channel access scheme is used, the 802.11ac and the 802.11a have similar chance to access the medium and thus the 802.11ac STA transmits 80 MHz signals for half the time and for the rest of the time deferring. Whereas when the dynamic 20/40/80 MHz bandwidth channel access scheme is used, if the first secondary channel is heavily loaded by the 802.11a STA, the 802.11ac STA will most of the time fall back to 20 MHz, which effectively makes the 802.11ac and the 802.11a networks to use non-overlapping two 20 MHz channels.

However, as the number 802.11a STAs increases and more secondary channels are occupied by the 802.11a STAs, the dynamic bandwidth channel access scheme performs much

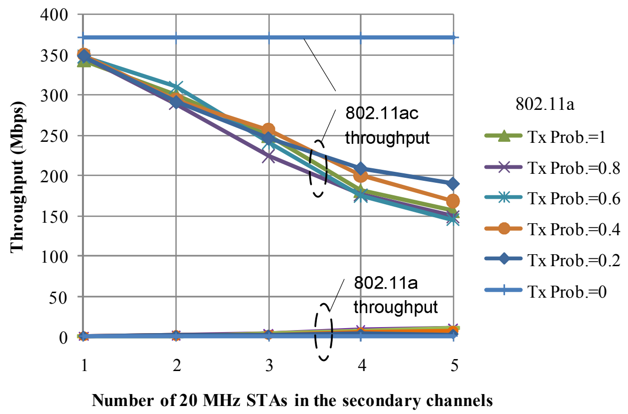


Fig. 5 Throughput comparison when the received signal power at the secondary channel is below the secondary channel CCA threshold

better than the static bandwidth channel access scheme. For example, when all three secondary channels of the 802.11ac are heavily loaded (e.g. Tx Prob.=1) by the three 802.11a STAs, the dynamic bandwidth channel access scheme performs 569 % better than the static scheme as shown in Table III. Even when the transmit probability is 0.6, which could be considered as a medium traffic load, the dynamic bandwidth channel access scheme performs 85 % better than the static bandwidth channel access scheme. This is because while the static scheme waits for all the secondary channels to be idle for it to transmit 80 MHz PPDUs using the maximum bandwidth, the dynamic scheme dynamically switches its bandwidth down to 20 MHz or 40 MHz when the secondary channels are busy, which guarantees at least the performance of the 802.11ac operating in the 20 MHz mode.

C. Secondary Channel CCA Sensitivity

We have also simulated the case where the 802.11ac STA uses the same secondary channel CCA sensitivity of 802.11n and assume that the received power at each of the 20 MHz channels of the 802.11ac STA is above the primary channel CCA threshold (i.e. -82 dBm) but below the secondary channel CCA threshold (i.e. -62 dBm). The simulation results in Fig. 5 show that in this case the aggregate throughput of the 802.11n STAs drops close to 10 Mbps. This is because while the 802.11a STAs in the secondary channels are able to detect the 802.11ac STA's transmissions and defer their transmissions when the 802.11ac STA is transmitting, the 802.11ac STA cannot detect the transmissions in the secondary channels and will not defer its transmission and may cause collisions. This makes the contention windows of the 802.11a STAs grow rapidly to a very large number, which degrades the throughput of the 802.11a STAs. Since the 802.11a STAs are deferring with very large backoff counter values, the 802.11ac STA transmits most of the time.

D. Primary Channel in the Middle of the 80 MHz Channel

Fig. 6 compares the throughput of the 802.11ac STA for two different positions of the primary channel as shown in Fig. 3. Three 802.11a STAs are occupying the three secondary channels. The results show that placing the primary channel in the middle of the 80 MHz channel improves the throughput by up to 20 % compared to the primary channel at the end of the 80 MHz channel. This gain is achieved by one more 40 MHz transmission option shown in Fig. 3(b).

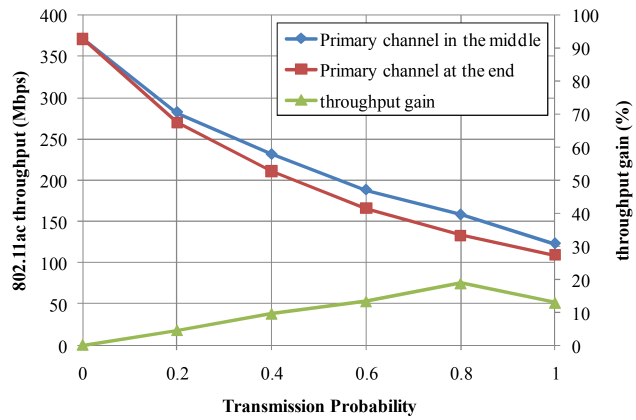


Fig. 6 Throughput comparison between the primary channel in the middle case and at the end case as shown in Fig. 3

V. CONCLUSIONS

We investigated the dynamic 20/40/80 MHz bandwidth channel access scheme for 802.11ac when there are legacy 20 MHz 802.11a/n stations operating in the secondary channels of the 80 MHz channel. The results show that in order to efficiently utilize the 80 MHz channel in a dense networking environment, the dynamic bandwidth channel access scheme is recommended for the 802.11ac stations. The study also showed that the secondary channel CCA threshold should be enhanced to mitigate collisions between the 802.11ac and the 802.11a/n stations in the secondary channels. The primary channel should be also carefully chosen to achieve better throughput.

REFERENCES

[1] Perahia, E., "VHT below 6 GHz PAR plus 5C's," IEEE 802.11-08/807r4, September 2008, https://mentor.ieee.org/802.11/dcn/08/11-08-0807-04-0vht-6-ghz-par-nescom-form-plus-5cs.doc
[2] Stacey, R. and et. al., "Specification Framework for TGac," IEEE 802.11-09/0992r13, July 2010, https://mentor.ieee.org/802.11/dcn/10/11-10-0992-13-00ac-proposed-specification-framework-for-tgac.doc
[3] IEEE 802.11n-2009, "IEEE Standard for Local and Metropolitan Area Networks – Telecommunications and Information Exchange between Systems – Local and Metropolitan Area Networks – Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput."
[4] Cariou, L. and Christin, P., "80 MHz and 160 MHz Channel Access Modes," IEEE 802.11-10/0385r1, March 2010, https://mentor.ieee.org/802.11/dcn/10/11-10-0385-01-00ac-80mhz-160mhz-channel-access-modes.ppt
[5] Kim, Y., "Enhanced CCA for Non-Primary Channels Using Guard Interval," IEEE 802.11-10/0012r0, Jan 2010, https://mentor.ieee.org/802.11/dcn/10/11-10-0012-00-00ac-cca-using-gi.ppt