On the Coexistence of Overlapping BSSs in WLANs

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Abstract— **In this paper, we investigate the issue of 20/40 MHz coexistence in next generation wireless local area networks (WLAN). To that end, we present simulation results of overlapping basic service sets (BSSs) an 802.11n BSS operating in 20/40 MHz mode and a legacy BSS operating in 20 MHz channel. Our results show that if clear channel assessment (CCA) is not used in the overlapping channel; i.e., the 20 MHz channel used by both BSSs, the throughput in legacy BSS falls to zero, while the throughput of 802.11n BSS decreases dramatically. If CCA is used in the overlapping channel, the throughput of both, legacy and 802.11n BSS increases compared to the earlier case. When devices operating in 20/40 MHz BSS are able to dynamically switch between 20 and 40 MHz transmissions and in addition, CCA is used in the overlapping channel, the throughput of both BSSs further increases. Reducing transmission opportunity (TXOP) interval for 40 MHz transmissions also improves fairness and throughput for legacy BSSs.**

I. Introduction

Tomorrow's wireless LAN networks will provide high data rates and multimedia services to end users [1]-[8]. Currently, IEEE 802.11n working group is pursuing a multiple-input-multiple-output (MIMO) orthogonal-frequency-division-multiplexing (OFDM) solution for next generation wireless local area network (WLAN) standard, which is expected to be standardized in middle of 2008. The presence of MIMO-OFDM physical (PHY) layer in 802.11n will yield higher data rate in the network. To further increase the data rate, the working group has proposed an optional 40 MHz operation, where stations (STAs) and/or the access point (AP) can transmit/receive in two adjacent 20 MHz channels simultaneously. These two channels consists of control and extension channels. To distinguish between the control and the extension channel one should refer to the fact that a 20/40 MHz capable basic service set (BSS) will use the control channel for 20 MHz operation.

While the use of 40 MHz channels in WLANs increases the data rate in the network, it will also introduce fairness issues in the network, since 40 MHz channels will increase the number of overlapping BSSs. In this paper, we investigate the problems with 20/40 MHz coexistence and discuss the impact of various overlapping BSSs scenarios on the overall network performance. We assume that the extension channel is the overlapping channel; i.e., the channel used by both 20/40 MHz BSS and 20 MHz legacy BSS. In our investigation, we assume that the legacy BSS uses either of the IEEE 802.11a/b/g technologies. The argument for this is that most of WLANs today use IEEE 802.11a/b/g technology and we are interested on investigating the impact of 20/40 MHz operation on these particular networks. The terms 802.11a/b/g/n and IEEE 802.11a/b/g/n are used interchangeably throughout the paper.

Our results show that if clear channel assessment (CCA) is not used in the overlapping channel, the throughput in legacy BSS is almost zero, while the throughput of the 20/40 MHz BSS decreases dramatically. If CCA is used in the overlapping channel, the throughput of legacy and 20/40 MHz BSSs increase compared to the case when no CCA is used. In addition, when STAs/AP that operate in 20/40 MHz BSS are able to dynamically switch between 20 MHz and 40 MHz transmit/receive mode and CCA is used in the overlapping channel, the throughput of both BSSs further increases. Reducing transmission opportunity (TXOP) interval for 40 MHz transmissions also improves fairness and throughput for legacy BSSs. Thus, this paper answers the fundamental question of whether CCA should be used in the extension channel, it quantifies its impact on the network performance, and proposes solutions to improve the network performance.

The remainder of the paper is organized as follows. In Section II we describe existing problems with 20/40 MHz coexistence. Simulation setup is described in Section III, while results follow in Section IV. Finally, we briefly discuss the impact of these results in Section V and we conclude our findings in Section VI.

II. Problems with 20/40 MHz Coexistence

Figure 1 illustrates two overlapping BSSs. The first AP is capable of operating in 20 MHz and 40 MHz channels, while the second AP is capable of operating in 20 MHz channel only. The 20/40 MHz capable AP can serve 20 MHz or 20/40 MHz transmit/receive capable STAs, while the 20 MHz only capable AP can serve only 20 MHz transmit/receive capable STAs. The STAs that are 20 MHz transmit/receive capable can be legacy STAs, i.e., devices that use IEEE 802.11 a/b/g technology; or 20 MHz IEEE 802.11n technology. The STAs that are 20/40 MHz capable can transmit/receive either in 20 MHz or 40 MHz channels. The 40 MHz channel consists of 20 MHz control channel and 20 MHz extension channel. Note that 20/40 MHz BSS uses the control channel for 20 MHz operation. Also note that in Figure 1, the 20 MHz extension channel is given as

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the overlapping channel. The scenario where the overlapping channel is the 20 MHz control channel is of little interest, because this scenario is similar to two 20 MHz legacy BSSs using the same channel. Therefore, in this paper, we investigate the scenario where the overlapping channel is the 20 MHz extension channel.

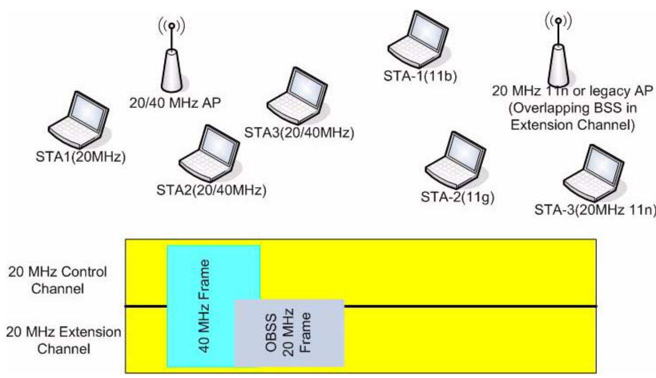

Fig. 1. Two overlapping BSSs.

In the initial draft of IEEE 802.11n [1], a STA/AP transmitting in 40 MHz channel shall sense CCA on the 20 MHz control channel and *may* sense CCA on the 20 MHz extension channel and may combine the result with that from the control channel. However, different WLAN chip vendors may choose not to implement CCA in the extension channel. Under this scenario, 20 MHz transmissions in the extension channel in the 20 MHz BSS shown in Figure 1 will not be detected. Hence, 20/40 MHz capable STAs will start transmitting in 40 MHz mode, causing a collision in the extension channel if the medium is already in use by the STAs/AP in the 20 MHz BSS. This collision in the extension channel will result in bad packets reception in both BSSs. As a result, the overall throughput in the network will decrease. Hence, the use of CCA in the extension channel is the first step to avoid collisions in the aforementioned scenario.

However, even if CCA is used in the 20 MHz extension channel before a STA/AP transmit a 40 MHz frame, it may not always avoid collisions in the network. Figure 2 illustrates the case when collisions occur in the extension channel even if CCA senses that the medium is idle in the extension channel. The reason is that the transmission in the 20 MHz extension channel is in the short interframe spacing (SIFS) time interval when CCA in the extension channel senses the channel idle. Hence, the 20/40 MHz STA/AP starts transmitting assuming that the extension channel is idle, thus a collision occurs less than SIFS interval later. To avoid collisions, the 20/40 MHz STA/AP will need to sense the channel in the extension channel and also ensure that the channel has been idle for at least a point coordination function interframe space (PIFS) time interval. The reason for using PIFS time interval is that PIFS is greater than SIFS and the STA/AP would have sensed the transmission in the extension channel by this time. Thus, to avoid collisions in the extension channel, 40 MHz transmissions should not start if the time interval for which CCA senses the medium in the extension channel to be idle is not at least PIFS.

It is important to mention here that collisions could still occur in the aforementioned overlapping BSSs. For example, the presence of hidden nodes could still create collisions in the network. However, in this paper, we do not investigate the impact of the hidden nodes in the overall network throughput.

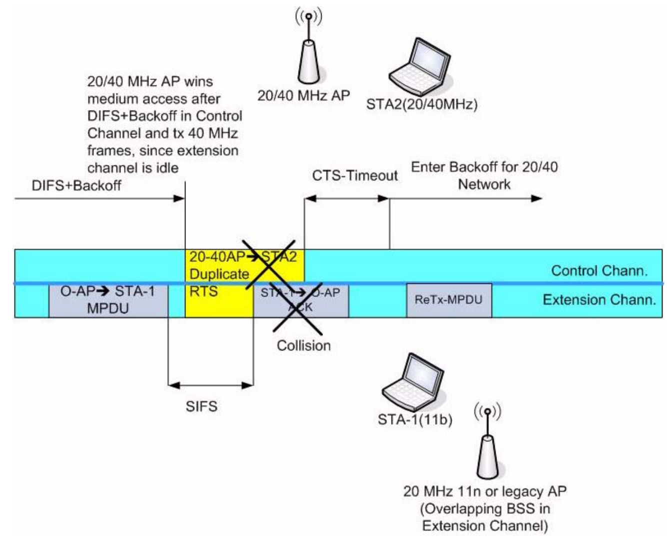

Fig. 2. Collisions in overlapping BSSs.

III. Simulation Setup

To investigate the performance of overlapping BSSs for different scenarios, we consider the network depicted in Figure 2, where each BSS consists of one STA and the AP. In addition, we assume the following:

- For the 20/40 MHz BSS:
  - Both STA and the AP can operate in 20/40 MHz mode and use 802.11n
  - PHY rate is 162 Mbps for 40 MHz operation and 78 Mbps for 20 MHz operation
  - Traffic load is 300 Mbps
  - Up to 5 frames aggregation (i.e., multiple frames are sent as a single frame) and
  - Best effort traffic only
- For 20 MHz BSS:
  - Both STA and the AP use 802.11g
  - PHY rate of 54 Mbps
  - Traffic load is 60 Mbps
  - No aggregation and
  - Best effort traffic only

To evaluate the performance of the network, we use OPNET™ simulations. We extended and modified the code to accomodate some of the 802.11n features, such as aggregation, block ACK, PHY level protection, as well as 20/40 MHz coexistence. We modified the code to implement CCA in the extension channel, enable 20/40 MHz transmissions, as well as the ability to switch transmission from 40 MHz to 20 MHz when the extension channel is not idle for at least PIFS duration. Note that in our simulations PHY layer is abstracted such that only collisions cause packet errors.

Although the 20 MHz BSS is assumed to be a legacy BSS, one could possibly consider other scenarios where the overlapping BSS uses 802.11n technology, which could be a 20 MHz mode only BSS or a 20/40 MHz mode BSS. In this paper, however, we consider legacy BSS since most of the WLANs today use 802.11a/b/g technology and we are interested on investigating the impact on the existing WLAN networks.

Next we report simulation results obtained for different scenarios.

IV. Simulation Results

Before proceeding with simulation results for the overlapping BSSs, we first report throughput performance results of individual BSSs when there is no overlap.

Figure 3 shows the maximum achievable throughput when there is no overlap and under the following assumptions i) 20/40 MHz BSS operates in 40 MHz channel only and PHY rate of 162 Mbps ii) 20/40 MHz BSS operates in 20 MHz channel only and PHY rate is 78 Mbps iii) 20 MHz legacy BSS operates at 54 Mbps. As one would expect, higher PHY rate implies higher throughput.

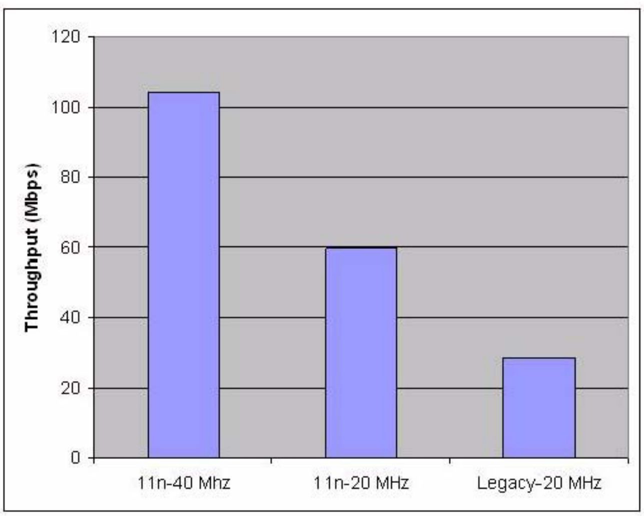

Fig. 3. Maximum throughput of 20/40 MHz BSS and 20 MHz legacy BSS.

Figure 4 shows the throughput for both BSS in presence of i) no overlap, ii) overlap and CCA is used in the extension channel, and iii) overlap and CCA is not used in the extension channel. The 20/40 MHz BSS is assumed to operate in 40 MHz transmit/receive mode only. It can be seen that if the STA/AP in the 20/40 MHz BSS do not use CCA in the extension channel, the throughput of legacy BSS is reduced to 2kbps, while that of 20/40 MHz BSS is reduced to approximately 14 Mbps. On the other hand, the use of CCA in the extension channel increases the throughput in both BSS, to 59.6 Mbps and 12 Mbps, for 20/40 MHz BSS and legacy BSS, respectively. These translate into a five time increase in the overall throughput. While for the 20/40 MHz BSS the increase is approximately four times, the increase for 20 MHz legacy BSS is more than three orders of magnitude. Note that when CCA is used in the extension channel, the medium has to be sensed idle for at least PIFS interval duration before a 40 MHz transmission takes place.

Figure 5 shows the throughput for both BSS in the presence of i) overlap and CCA is used in the extension channel,

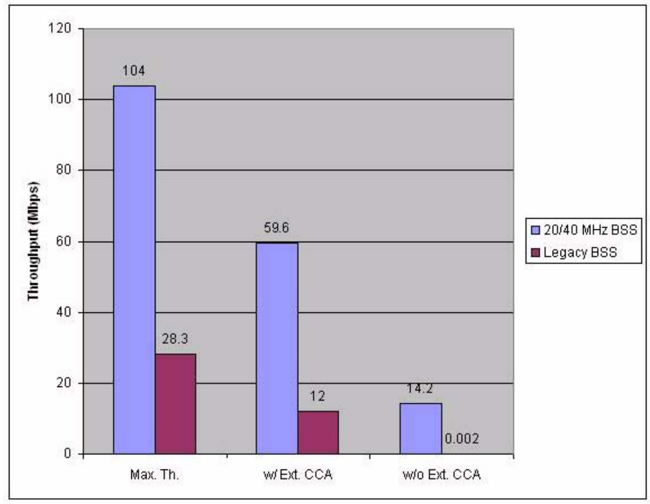

Fig. 4. Throughput of overlapping BSSs.

however 20/40 MHz BSS operates in 40 MHz mode only, and ii) overlap and CCA is used in the extension channel with the additional feature that if a 40 MHz transmission is not possible because the extension channel has not been idle for at least PIFS time interval, the STA/AP switches to 20 MHz transmission mode, and iii) overlap and no CCA is used in the extension channel. It is clear that if 20/40 MHz capable STA use CCA in the extension channel and switch between 20 MHz and 40 MHz transmission modes, the throughput of both BSSs increases drastically, especially the one for legacy BSS.

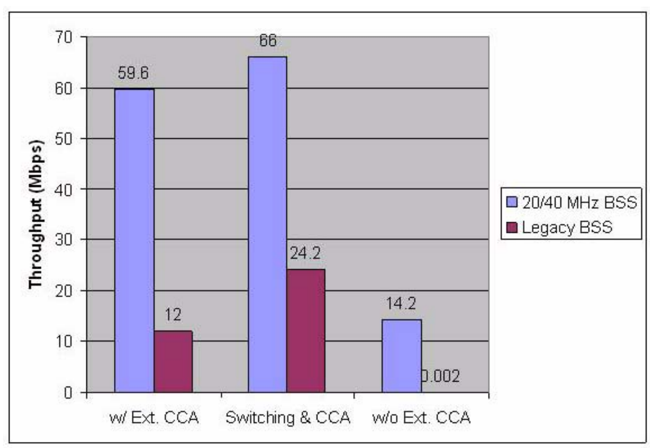

Fig. 5. Throughput of overlapping BSSs when channel switching is used.

Figure 6 shows the utilization of 20 and 40 MHz channels for the 20/40 MHz BSS. The utilization for 20 MHz channel is 77.1% of the time, while for the 40 MHz channel is 22.9% of the time. This also implies that 20 MHz legacy BSS is using the medium; i.e., the extension channel, at least 77.1% of the time. In addition, it also shows that the usage of 20 MHz channel is at least 3 times that of the 40 MHz channel for the simple scenario considered in this paper. If the network consists of more STAs, these being legacy or

802.11n capable STAs, one would expect that 40 MHz channel utilization further decreases. Note that the overhead associated with switching between 20 MHz and 40 MHz transmissions has not been taken into account. This overhead will further reduce the throughput associated with the 20/40 MHz BSS.

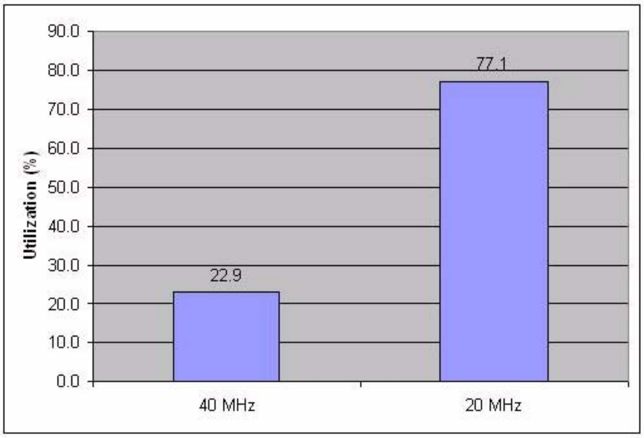

Fig. 6. Utilization of 20/40 MHz BSS when channel switching is used.

Another way to improve the fairness in the network is to reduce the transmission opportunity (TXOP) time interval limit during 40 MHz transmissions. TXOP is a time interval that a transmitting STA/AP reserves for communication with a receiving STA/AP. The TXOP value is included in the MAC header and after the devices in the network read this value, they set their network allocation vector (NAV) to this value. The devices will start counting down from this value and they will not contend for the channel till the NAV value is reset to zero. IEEE 802.11e specifies the TXOP values assuming transmission occurs in 20 MHz [6]. However, 40 MHz transmission will require less time since the PHY rate is higher, and therefore, the TXOP values should be smaller than those for 20 MHz transmissions. Figure 7 shows the throughput for 20/40 MHz BSS and 20 MHz legacy BSS if reduced TXOP is used during 40 MHz transmissions, while normal TXOP (as defined in 802.11e standard [6]) is used during 20 MHz transmissions. If the TXOP transmissions for 40 MHz is reduced from 1.5 msec to single PHY protocol data unit (PPDU) TXOP (i.e., single packet transmission), the throughput of 20 MHz legacy BSS increases from 19.4 Mbps to 24.2 Mbps, while that of 20/40 MHz BSS decreases from 77.6 Mbps to 66 Mbps, as one would expect.

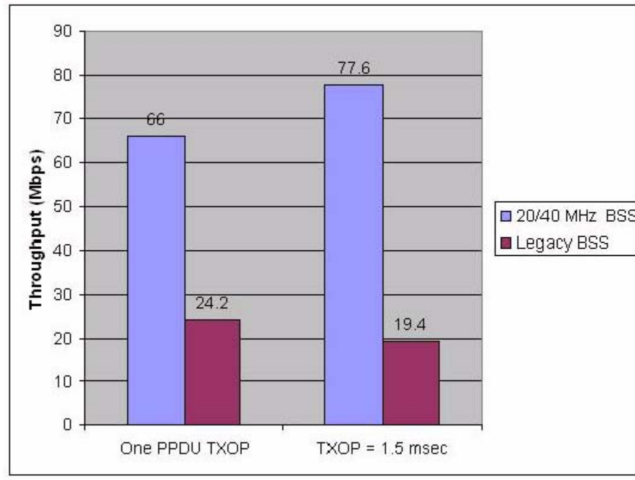

Fig. 7. Throughput of overlapping BSSs when TXOP is reduced.

V. Discussion

In this paper, we investigated and quantified throughput performance of two overlapping BSSs, one being a 20/40 MHz BSS with 20/40 MHz capable STA/AP and the other being a legacy BSS that operates in the 20 MHz extension channel. Our results clearly show that if CCA is not used in the extension channel, the throughput of the network and that of individual BSSs will reduce drastically. The reason for this is that the absence of the CCA in the extension channel implies more collisions during 40 MHz transmissions.

The reported results show that implementation of CCA in the extension channel is the first step toward a solution for 20/40 MHz coexistence. It is clear that the throughput increases because there are less collisions in the network. In addition, if the 20/40 MHz capable STAs/AP are able to transmit in 20 MHz control channel if the 20 MHz extension channel is busy, then the throughput increases further. This can be explained with the fact that 20/40 MHz capable STAs transmit in 20 MHz control channel when the 20 MHz extension channel is busy and hence, freeing the extension channel which, in turn, can be used by the legacy BSS. The utilization results support our conclusions.

Another way to improve fairness for 20 MHz legacy BSS is to reduce the TXOP values for 40 MHz transmissions. This will ensure that 40 MHz transmitting STAs/AP are using the extension channel for a shorter period of time; which implies that STAs/AP in the 20 MHz legacy BSS will have more opportunities and time to use the channel they operate on.

The presence of hidden nodes is also an issue that needs attention. Let us consider the following scenario. A packet is transmitted by a STA in the legacy BSS and it can not be detected (i.e., the received signal strength is below the CCA detection threshold) by a 20/40 MHz STA in the 20/40 MHz BSS that has just gained access to the medium and starts 40 MHz transmission. Collision will occur if the receiving STA of the 40 MHz transmission in the 20/40 MHz BSS or the the receiving STA of the 20 MHz legacy transmission in the legacy BSS can hear both transmissions. However, regardless of whether the receiving STAs in their respective BSSs can hear both transmissions, there could be other STAs in the 20/40 MHz BSS or legacy BSS that would be able to hear both transmissions. Hence, these STAs will not be able to set their correct value of NAVs if the medium access control (MAC) headers are corrupted due to collision. Therefore, these STAs can become potential hidden nodes, which will result in a decrease in the network performance.

This scenario clearly suggests that if the collisions are to be avoided, then the BSSs have to operate in non-overlapping channels. Further studies are needed to quantify the impact of hidden node problems on 20/40 MHz coexistence.

VI. Conclusion

In this paper, we presented and discussed issues related to overlapping BSSs when 20/40 MHz BSSs are present and

20 MHz legacy BSS is operating in the extension channel. Our results show that the use of CCA in the extension channel is a necessary step to achieve high throughput in next generation WLANs. Switching to 20 MHz transmission when the extension channel is not available, as well as reducing TXOP for 40 MHz transmissions are two of the solutions proposed to improve fairness for 20 MHz legacy BSS.

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