Understanding the effectiveness of Spatial Reuse in dense setups for 802.11

A Dual Degree Project Report

submitted by

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under the guidance of

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THESIS CERTIFICATE

This is to certify that the thesis titled **Understanding the effectiveness of Spatial Reuse in dense setups for 802.11** , submitted by **Rohan Malik (EE16B147)**, to the Indian Institute of Technology, Madras, for the award of the degree of **Bachelors of Technology** and degree of **Masters of Technology**, is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: IEEE 802.11ax, OBSS/PD, CSMA/CD, Spatial Reuse, ns-3.

The latest standard of WiFi *802.11ax* introduces certain features targeted to increase the Spatial Reuse using techniques like BSS Color and OBSS/PD. These new features seem promising because an optimal Spatial Reuse can greatly increase the throughput of the whole network by manifolds. In this thesis, We look at the current WiFi standards and try to analyse what levels of interference are resulted by far-away nodes in a dense setup using simple ns3 simulations. In conclusion, we make remarks about what is the scope of OBSS/PD and how effective would it deem in dense setups.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

Introduction

1.1 Brief on WLAN and Spatial Resuse

WLANs are used in a diverse range of environments today; these environments are characterized by massive number of terminals clustered in small localized geographic areas. This causes more than one BSS to transmit on the same channel due to limited amount of spectrum. The ability to use the same channel by different Access Points contributes to Spatial Reuse. *The capacity of a wireless network increases with increasing spatial reuse.* [Khorov *et al.* (2019)] Up Until 802.11 ac, there were no measures in place to optimise SR (Spatial Reuse) besides the legacy CSMA/CA. 802.11 ax introduces new Spatial Reuse Capabilities that are a huge part of the whole standard.

1.2 802.11ax

The 802.11ax Spatial Reuse (SR) aims to optimise the spectrum efficiency and boost the network performance in very dense WiFi environments. The main SR technique in that amendment is the Basic Service Set (BSS) Color. With BSS color nodes can detect if a frame belongs to the same BSS or another Overlapping BSS, within the preamble decoding itself. If the preamble is a part of an OBSS, there are OBSS/PD (Overlapping Base Service Set/ Preamble Detection) measures that allow a node to drop the incoming OBSS packet if certain threshold requirements are not met and continue with it's own transmission at a lower Transmission Power levels. This promises a more optimal Spatial Reuse.[Wilhelmi *et al.* (2019)]

The thesis is an attempt to understand the effect that far away nodes and packets from OBSSs outside a certain radius have on a tagged node and how much time do these far-away nodes take up causing our tagged node to be in a busy state stopping it from Transmitting or going into Backoff stage.

The results obtained hint at a possibility of OBSS/PD not being all that effective because the amount of interference that is obtained from nodes outside (say) -65dBm is far less. The value -65dBm is a standard OBSS/PD threshold value that is used in 11ax nodes.

CHAPTER 2

Quick Brief of WiFi

2.1 Introduction to WiFi

WiFi is the name given by the WiFi Alliance to the IEEE 802.11 suite of standards. It is a family of Wireless network protocols meant for small range Wireless LAN that have come out in the last two decades. These WiFi protocols are based on the well defined and documented IEEE 802.11 family of standards. At it's most basic, WiFi is the transmission of radio signals. The current and older WiFi standards use the 2.4 GHz and the 5 GHz spectrum radio for transmission with the newer standard (802.11 ax) also looking into utilising 6GHz radios. The latest standard of WiFi *viz.* IEEE 802.11ax was first introduced in 2019, It promises a never seen before Peak rates of 10Gbps wirelessly, nearing conventional 10Gigabit wired Ethernet connections.

	802.11 (Legacy)	802.11b	802.11a	802.11g	802.11n (HT)	802.11ac (VHT)	802.11ax (HE)
Year	1997	1999	1999	2003	2009	2013	-
Band (GHz)	2.4	2.4	5	2.4	2.4/5	5	2.4/5/6
Bandwidth (MHz)	22	22	20	20	20/40	20/40/80/ 160	20/40/80/ 160
Peak PHY Rate	2 Mbps	11 Mbps	54 Mbps	54 Mbps	600 Mbps	6.8 Gbps	10 Gbps
Max SS	1	1	1	1	4	8	8
MU support	NA	NA	NA	NA	NA	4 (DL)	8 (UL, DL)
Modulation	DSSS, FHSS	DSSS	OFDM	OFDM	MIMO-OFDM	MIMO-OFDM	OFDM, OFDMA

Figure 2.1: WiFi Standards over the years
Wikipedia.com (2021)

2.2 7-Layer OSI Model

WiFI define two layers of the OSI model, The Physical Layer and The Data Link Layer.

The Data Link Layer is made of two layers, Media Access Control (MAC) and Logical Link Control (LLC). The MAC sub-layer is defined in the IEEE 802.11 specification.

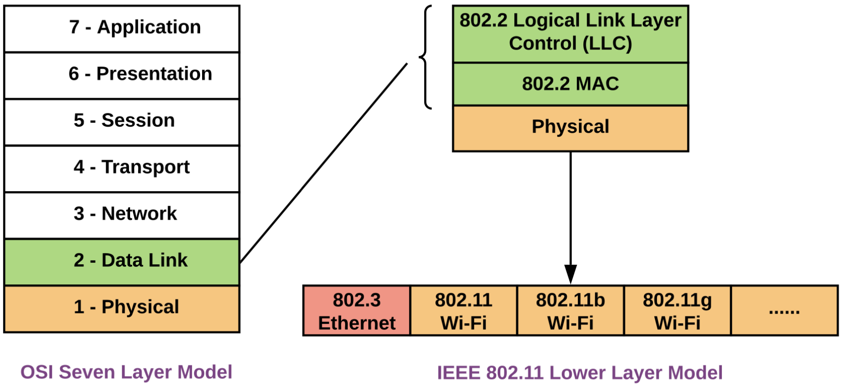


Figure 2.2: WiFi in the 7 Layered OSI Model
R (2020)

the PHY layer is defined at the Physical layer of the OSI Model.

2.2.1 MAC layer

The 802.11 MAC layer is actually a sublayer of the Data Link Layer and it deals with controlling the transmission of data into the shared Physical Channel. MAC layer passes packets to the Physical Layer based on CSMA/CA (Carrier Sense Multiple Access/ Collision Avoidance)

2.2.2 PHY layer

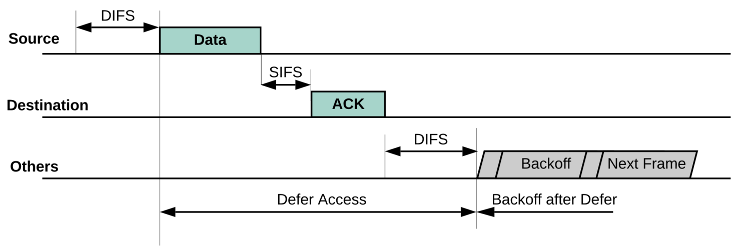
The PHY layer is mainly responsible for the encoding schemes, the modulation techniques and the actual transmission of the data packets through space. There have been greatly varying implementations of PHY in different standards of 802.11 including but not limited to DSSS (Direct Sequence Spread Spectrum), OFDM (Orthogonal Frequency-division multiplexing), MIMO (Multiple Input, Multiple Output).

2.3 Transmission of a Frame in WiFi

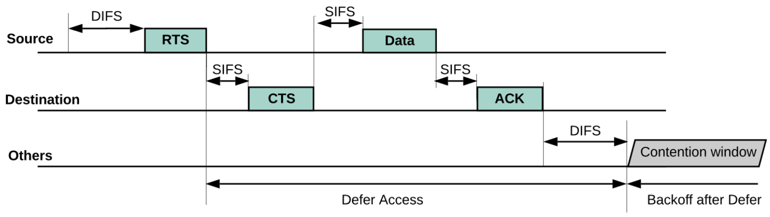
The Carrier Sense Multiple Access with Collision Avoidance protocol basically means that every node would first listen to the channel before transmitting, If the sensed energy on channel ever exceeds the Clear Channel Assement (CCA) threshold, then the node defers from transmission and identifies the channel as *BUSY*. Otherwise, the channel is supposedly *IDLE* and the node can proceed for transmission. A station with a packet monitors channel activity. If the channel is busy, a Backoff time is chosen randomly in the interval [0,CW] where CW is the the Contention Window. The station continuously monitors the channel, if the channel is idle for a duration longer than DIFS (Distributed Inter-Frame Space) time period, the Backoff Counter is decremented by one. When the Counter has reached zero, the node can transmit over the channel. To establish a successful transmission the receiver after receiving the payload goes on to transmit an Acknowledgement (ACK) packet within a SIFS (Short Inter-Frame Space) time period. This completes a succesful full packet transmission.[Manshaei *et al.* (2007)][Kumar *et al.* (2005)]

2.3.1 RTS/CTS Mechanism

In case the RTS/CTS access mechanism is used, an RTS (Request To Send) frame is first transmitted by the source and if the destination chooses to accept the sender's request, it will transmit a CTS (Clear To Send) frame prior to transmission of actual frame. The station in the sender's range can hear the RTS packet and update their NAV counter based on it while the nodes in receiver's range can hear the CTS packet and they shall update the NAV based on the CTS frame. The transmission of the data packet thus will proceed without interference from any other nodes.



(a) Basic Access Mechanism



(b) RTS/CTS Mechanism

Wang *et al.* (2004)

CHAPTER 3

States of a Node

3.1 Different States exhibited by a node

To understand the activity of each node better we must look into the different states that each Network Node goes through in a standard network setup.

1. **TX** : The duration of time when a node is transmitting.

2. **CCA_BUSY** : If the signal strength on the channel is above a specified threshold (-82dBm) and the SNR is above a certain threshold (default is 4), the node will switch to a CCA_Busy state. The radio will attempt to synchronize with the transmission and shift to RX state. In case there are more than one nodes transmitting at the same time, Since the node can't synchronise to any one of the signals, the node stays in CCA_Busy.

3. **RX** : If the SNR of a transmission is high enough to be decoded by a particular node then the node switches into RX mode and persists for the payload duration.

4. **IDLE** : If the signal characteristics are less than the above mentioned thresholds, the node interprets the channel as clear and goes in the Backoff stage of DCF. This is the Idle state.

5. **SWITCHING** : When a node is switching its channel, it changes it's state to SWITCHING.

6. **SLEEP** : When a nodes is in sleep mode.

7. **OFF** : When a node is turned off.

The first 4 states are of peak interest to us. For a normal operation, a node generally operates in only these 4 states.

3.2 State Transitions in a Node

Fig. 2.1 and Fig.2.2 explain how a node transitions from one state to other. Whenever a particular node is in IDLE state and it senses the signal on the channel with a high enough RSSI and SNR, either the node switches to CCA_Busy or RX state. This causes it to stop its back-off counter receive the current transmission on the channel even if it is from a different OBSS. This can result in network congestion and slowdown in case of dense setups.

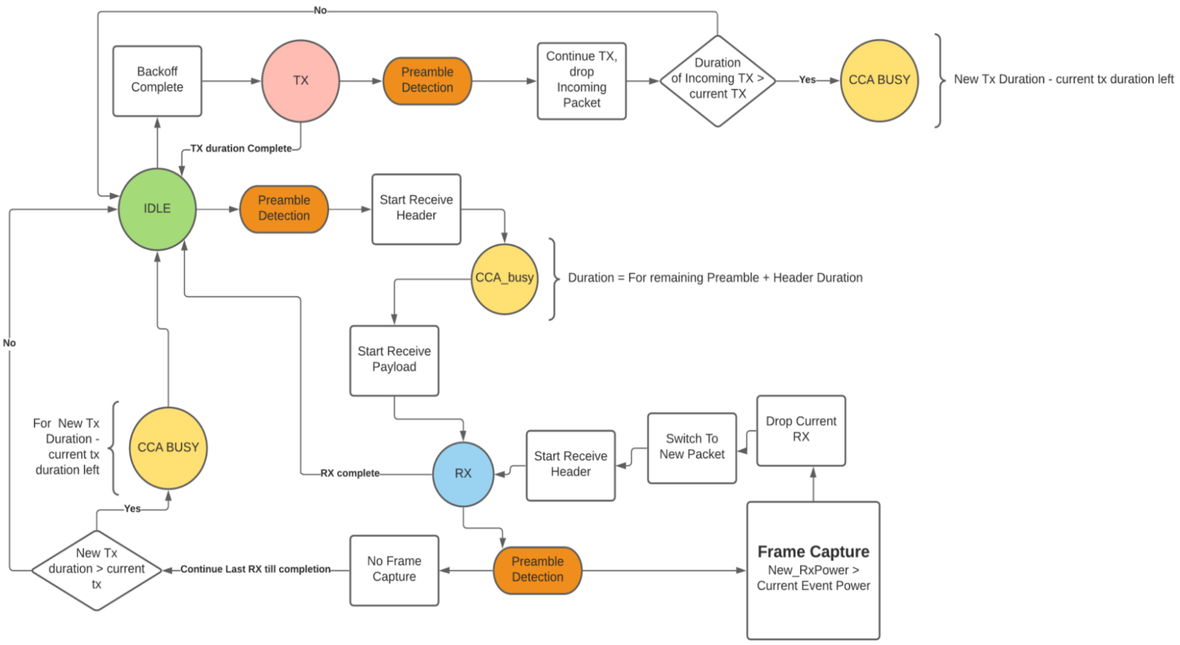


Figure 3.1: A Flow-Chart describing State Transitions in a WiFi node

CHAPTER 4

Simulation Software and Standard Parameters Used

4.1 NS3 (Network Simulator 3)

NS3 is an open-source discrete event packet simulator used to simulate internet systems. We decided to use the ns3 simulator because it provides us with models to demonstrate the functioning of packet data networks. NS3 is widely used and accepted in the Academia for Wireless system simulations and there have been many papers verifying the models used by the ns3 simulator[Baldo *et al.* (2010)][Garcia *et al.* (2018)].

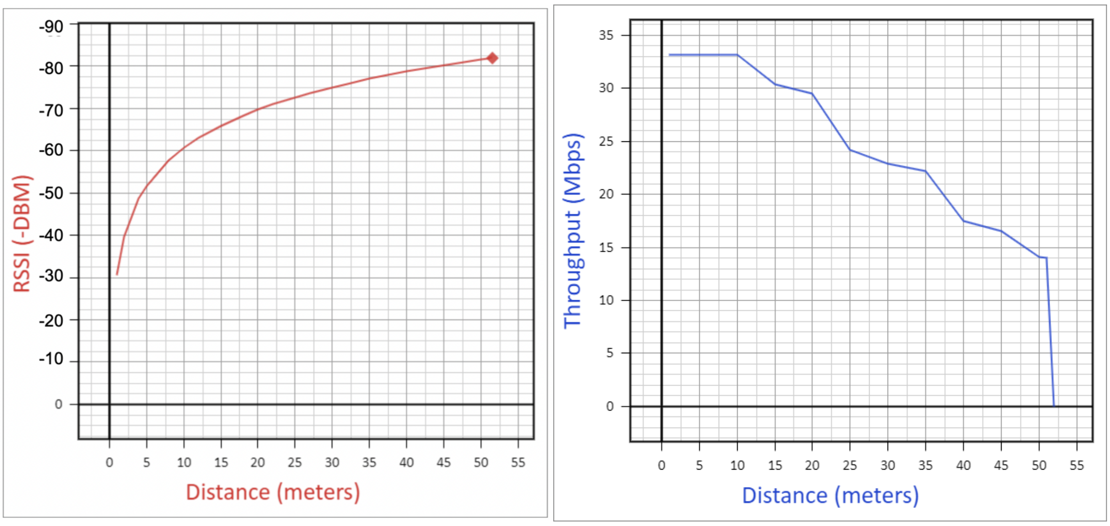
Central frequency fc (WiFi Standard)	5 Ghz (11ac)
Path Loss Model	Log Distance Propagation Loss Model
Path-loss exponent γ	3
Propagation delay model	Constant Speed Propagation Delay Model
Channel Width / Spatial Streams	20Mhz / 1
Rate Control	Ideal WiFi Manager
STA TX power	16.02dBm
AP TX power	16.02dBm.
Application Level Data Rate	180Mbps (Saturated TxOP)
AMSDU size (when on)	8Kb
AMPDU size (when on)	1Mb

Figure 4.1: ns3 parameters used in simulations across the thesis

4.2 Parameters used in ns3

We used 802.11 ac standard with a single spatial stream and a channel width of 20Mhz. For all the simulations performed, the traffic for each of the stations was unidirectional uplink traffic and all the uplink traffic had saturated TxOP queues at all times. A ns3 IdealWifiManager for rate-control was used and The propagation delay model applied was Constant Speed Propagation Delay Model; the propagation loss model was Log Distance Propagation Loss Model with a Path Loss Exponent of 3.0. The TX power of all the nodes was kept at a default of 16.02dBm. The table in figure 4.1 mentions all the values of the parameters that were used in all the experiments reported in the thesis unless stated otherwise.

Using the conditions described in the The Figure 4.1, an 1AP-1STA BSS was taken and RSSI signal strength vs. distance [Figure 4.2 (a)] and throughput vs. distance [Figure 4.2 (b)] were plotted. The plots give us a idea about how RSSI and Throughputs vary as we move away from the Node in the physical channel used in our simulations. Plot in Figure (b) tells us that the throughput for the node drops to zero at around 51.5 meters. This value is the very same obtained by interpolating -82 dBm value in Figure 4.2(a). The RSSI of -82.0 dBm is the threshold for Preamble Decoding in WiFi and it occurs at 51.455 meters for the above stated model.



(a) RSSI vs. Distance

(b) Throughput vs. Distance

Figure 4.2: Plots for (a)RSSI vs. Distance and (b)Throughput vs. Distance

CHAPTER 5

Basics Of Spatial Reuse

To understand Spatial Reuse we perform a simple simulation experiment and monitor all the different states that a node transitions in and for how long does it persist in each state.

5.1 Experimental Setup

We take a linear deployment of 3 BSS with 1 STA and 1 AP in each station. All the BSS are kept at a distance 'd' from each other and each STA is at distance 'r' from it's corresponding AP. The traffic is unidirectional uplink traffic with saturated TxOP queues and Basic Access Mechanism. All 3 BSS are operating in the same channel. We vary the inter-AP distance 'd' while keeping the distance 'r' equal to 5 meters at all times. We then go on to observe what changes were seen in RX and TX Times.

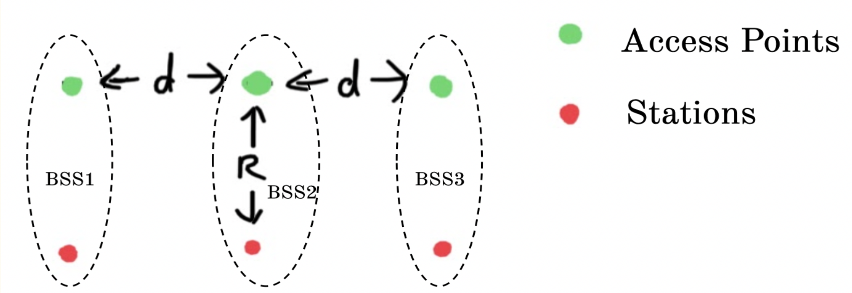


Figure 5.1: Experimental Setup for Spatial Reuse Simulation

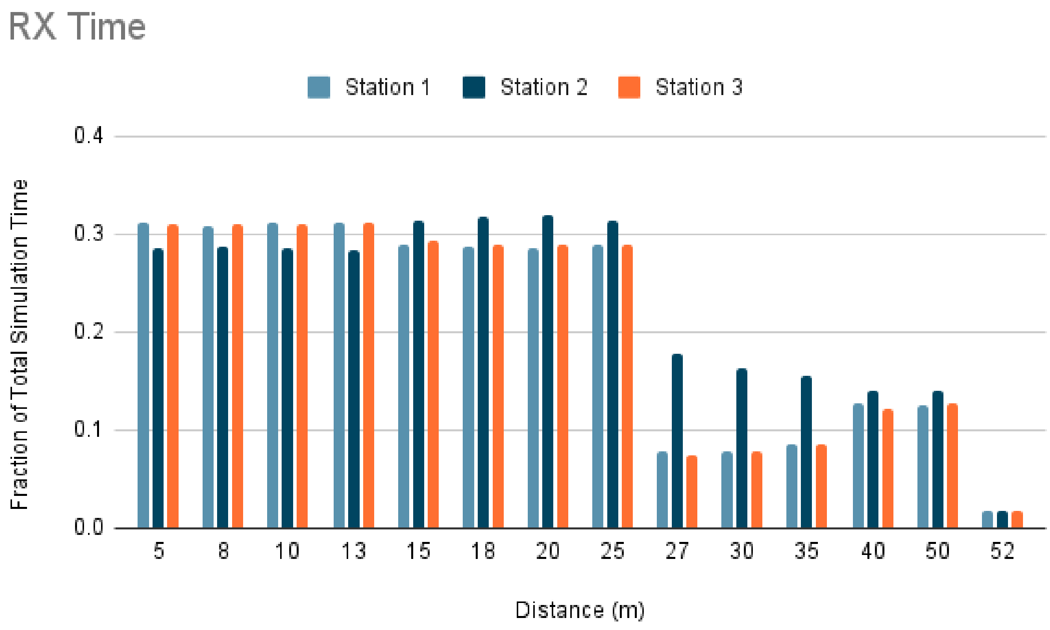


Figure 5.2: Fraction of Time STAs are in RX mode for different values of Inter-STA distance 'd'

5.2 Experimental Results

5.2.1 RX times

The figure above (Figure 5.2) reports the Fraction of time each of stations were in RX mode. As can be seen, the RX time changes drastically at about 27m. When the RSSI drops to lesser than -82dBm which is at around 51m, the Station 1 and Station 3 can not hear each other anymore (Refer RSSI vs. Distance graph in section 4.2). We can say that spatial reuse has been enabled after 27m, At 52m, the RX time fractions have dropped to almost 0, which basically terms to the fact that no station can any longer hear the transmission from other STAs and each BSS has achieved a complete spatial reuse over the same channel.

The node 2 has decreased RX timing possibly because Node 1 and Node3 no longer know about each other's presence and hence the number of simultaneous transmissions will increase (no RTS/CTS was used in the simulation) resulting in an inability to decode these Transmissions by STA2 which leads to lower RX time in node2.

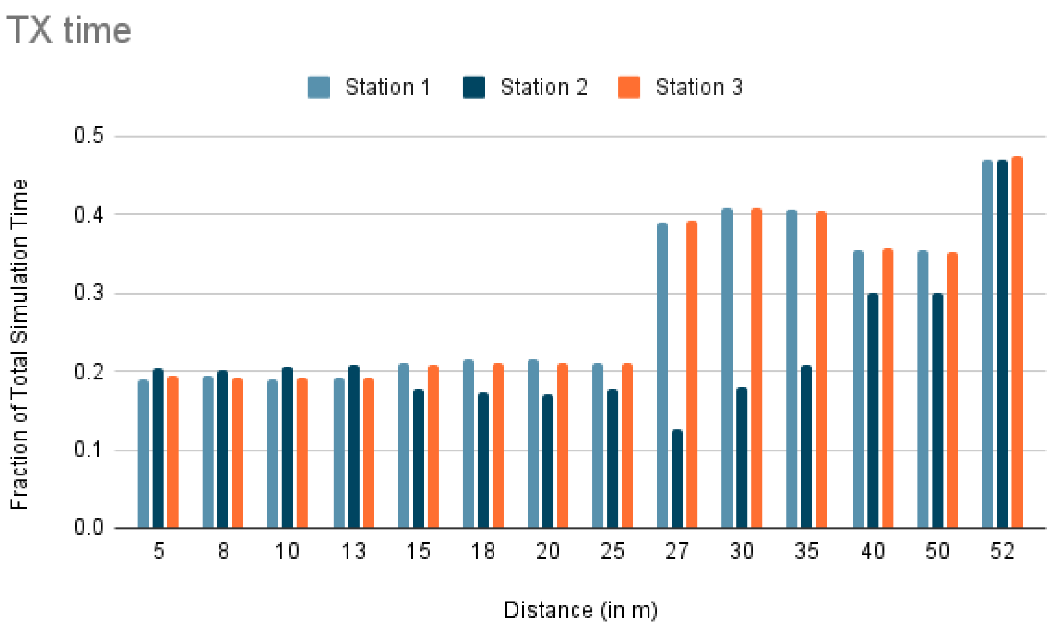


Figure 5.3: Fraction of Time STAs are in TX mode for different values of Inter-STA distance 'd'

5.2.2 TX Times

The Figure below (Figure 5.3) reports the Fraction of Time each Station was in TX state. Again, at around 27m, the RX times for Station 1 and Station 3 increase drastically. The underlying reason for this is the same as the reason for decrease in RX times. *i.e.* Since the STA1 and STA3 can not hear each other's transmissions, they have more time to Transmit their own packets. At 52m each STA has achieved complete Spatial Reuse can no longer hear other neighboring STAs.

5.2.3 Throughput

A look at the Throughput values (Figure 5.4) tells us that this sudden increase in TX times fractions has resulted in higher throughputs ('r' was constant so same MCS was being used) for STA1 and STA3 at 27m and for all the STAs at 52m. This tells us that Spatial Reuse enables less congestion and higher network throughput.

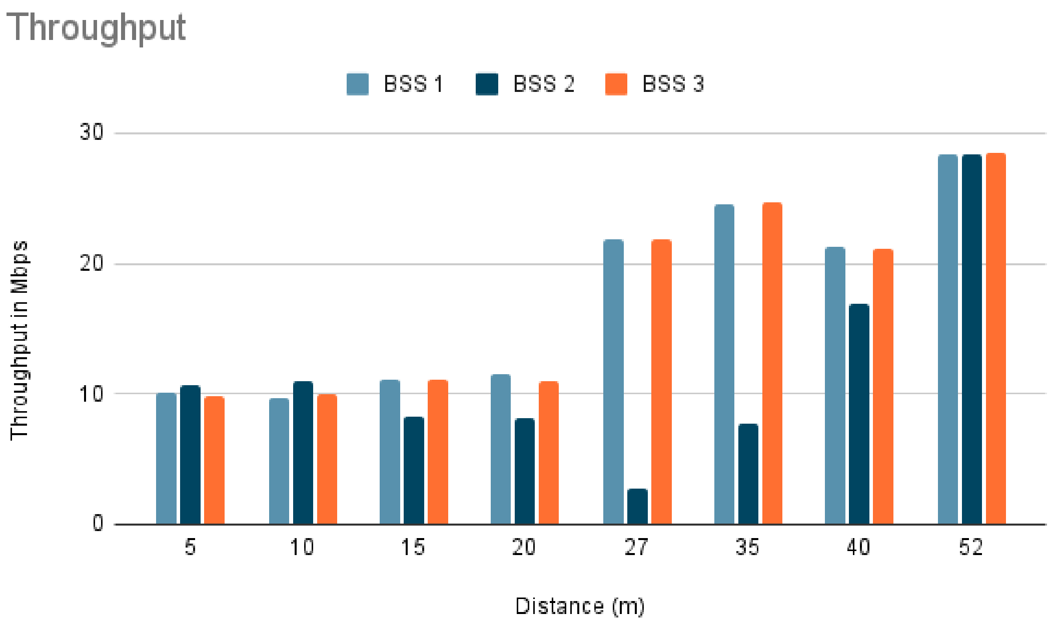


Figure 5.4: Throughput of each STA for different values of Inter-AP distance ’d’

5.3 Experiment Inferences

The above simulation essentially hints that higher spatial reuse allows for higher network throughput. *The capacity of a wireless network is thus determined by the spatial reuse that can be achieved and it increases with increasing spatial reuse*Wilhelmi *et al.* (2019)

CHAPTER 6

Spatial Reuse in 802.11ax

One of the main new features in 802.11ax was the advent of techniques to optimise Spatial Reuse by increasing number of parallel transmissions that can take place in an Overlapping Basic Service Set. [Khorov *et al.* (2019)]

6.1 BSS Color

The WiFi radios of 11ax can distinguish frames from different BSSs using BSS Color when other OBSS are transmitting on the same channel. If the BSS color is the same then it is considered an *Intra-BSS* frame transmission while if the detected frame has different color then the node recognises the frame to be an *inter-BSS* frame from an OBSS.

6.2 OBSS/PD

The Spatial Reuse Operation is based on setting an OBSS Preamble Detection threshold. This basically means that during a case of *Inter-BSS* transmission if the RSSI value is below a defined threshold, the STA can drop the frame, go to IDLE state and continue it's back-off stage without updating it's NAV. If the backoff reaches zero, the STA

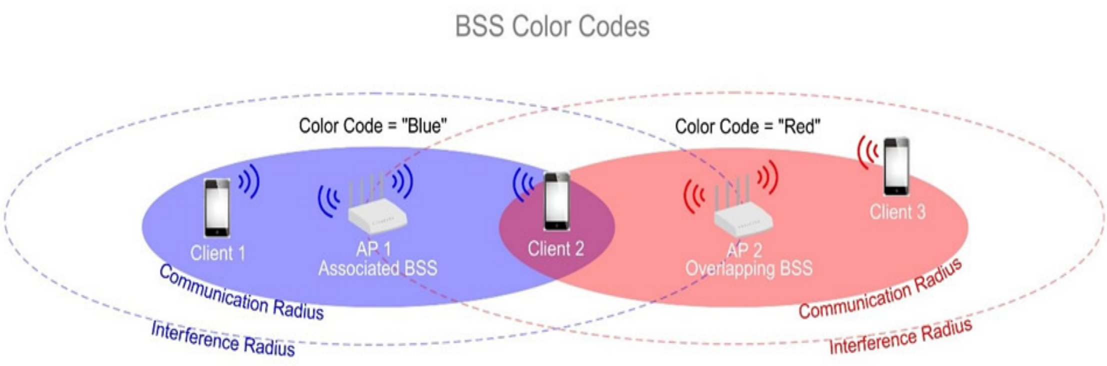


Figure 6.1: An example of two 11ax BSSs with BSS Color
accton.com (2019)

can continue to transmit it's frame even with ongoing OBSS transmissionSelinis *et al.* (2018). But in order to not affect the ongoing *inter-BSS* transmission, the STA must transmit with a lower Transmit Power. This transmit power is often a function of the OBSS/PD threshold. In most cases the OBSS/PD threshold value is around -65dBm. The figure below (Figure 6.2) is a flowchart of the OBSS/PD process cited from Khorov *et al.* (2019).

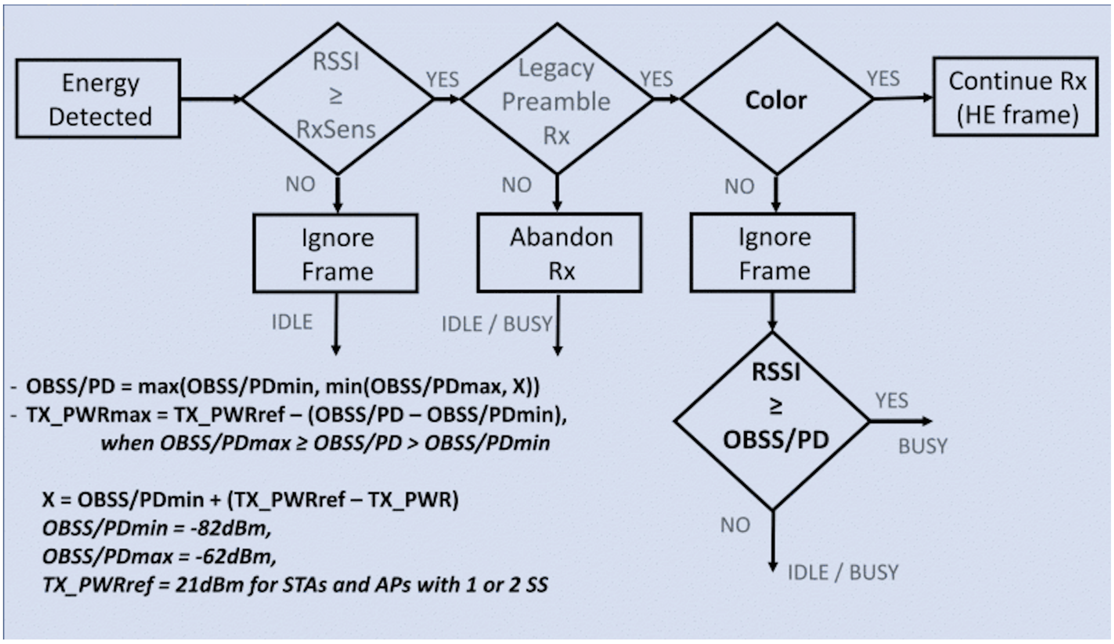


Figure 6.2: A simple flow chart of BSS color frame reception
Selinis *et al.* (2018)

CHAPTER 7

Simulations and Measurements

To see OBSS/PD's effectiveness, we need to look at how strongly does far away neighbors interfere with a tagged node and for what fraction of time is a tagged node kept in a busy (RX + CCA_Busy) state because of such transmissions from far away nodes.

7.1 Experimental Setup

We used a Linear Deployment of BSSs in a cosntant length of 100m. Each BSS had exactly 1 STA and 1 AP. The density such STA-AP pair BSS is varied while keeping the distance constant at 100m. We start from only 5 BSS in 100meters and go all the way upto 200 BSS in 100meters. To see the effects of Spatial Reuse, every single BSS was operating in the same channel. We run the experiments for two different cases.

1. Basic Access Mechanism

2. RTS/CTS with AMSDU and AMPDU aggregation methods turned on.

Below (Figure 7.1) is the figure for the experimental setup.

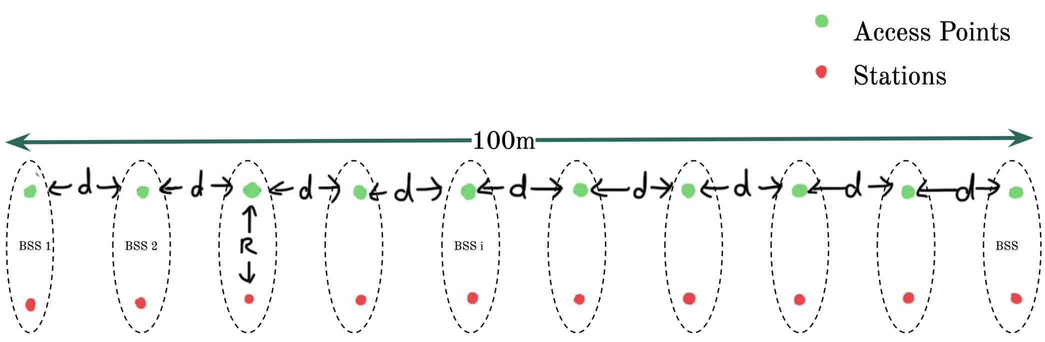


Figure 7.1: Experimental Setup

7.2 Measurements Obtained

The Following measurements were primarily obtained for the above simulation set-up.

1. Fraction of Total Simulation Time when the tagged node was in CCA_Busy or RX state when no one inside the specified RSSI radius was transmitting.

2. A Complimentary CDF; when the tagged node was in CCA_BUSY or RX state when no one inside the specified RSSI radius was transmitting.

3. Fraction of Total Preambles decoded by the STA that were outside a particular RSSI Radius.

4. Fraction of Total Cumulative Transmission time when some node inside the RSSI radius was transmitting but tagged STA wasn't busy.

CHAPTER 8

Results

8.1 Fraction of Time when the tagged node was 'Busy' when no one inside the specified RSSI radius was transmitting

To see the effect of far away nodes, we can look at the fraction of time when no node inside a specified RSSI radius was transmitting. This would essentially give us an idea of the interference produced by the nodes outside a chosen RSSI radius. We take the setup described in Section 7.1 and vary the BSS density starting from 5, all the way to 200 BSSs. Precisely put, the simulation is run for 5,25,50,100 and 200 BSSs in a constant distance of 100m. We calculate this by finding the time when all the nodes inside a chosen RSSI radius were not transmitting divided by the total simulation time.

$$y = \frac{\text{time when all the nodes inside a chosen RSSI radius } (x) \text{ were not transmitting}}{\text{total simulation time}}$$

8.1.1 Basic Access Mechanism

The plot obtained for Basic Access Mechanism for the above calculation is in Figure 8.2. We can infer a few things from this plot. Firstly, we start to observe convergence even with a 50 BSS setup. Secondly, we observe that the fraction of time my node was busy because of nodes outside -65dBm which is the general value of OBSS/PD threshold is close to only 10%-15% for dense setups which is not very high.

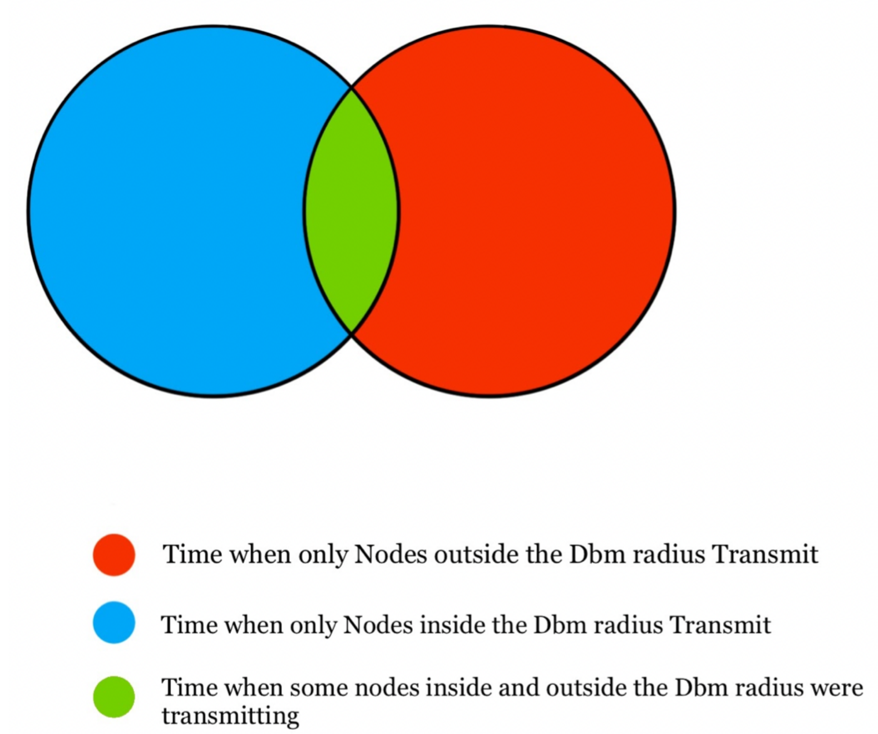


Figure 8.1: Venn Diagram of the different segments of RX + CCa BUSY time segments of the STA

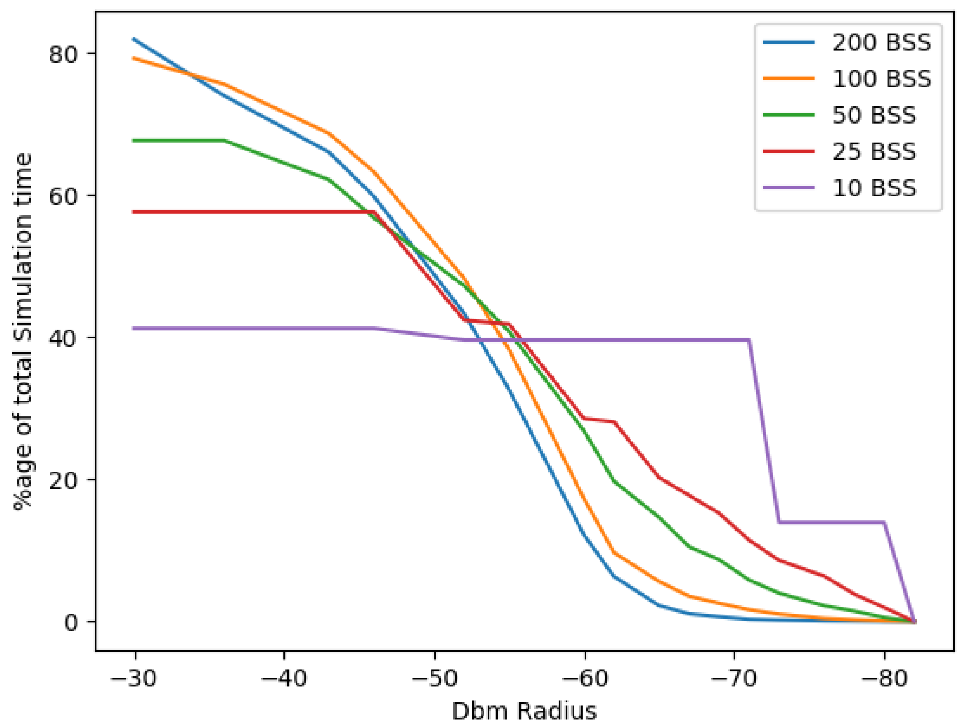


Figure 8.2: Fraction of Time a tagged node is busy when no one inside the dBm radius is transmitting for Basic Access Mechanism

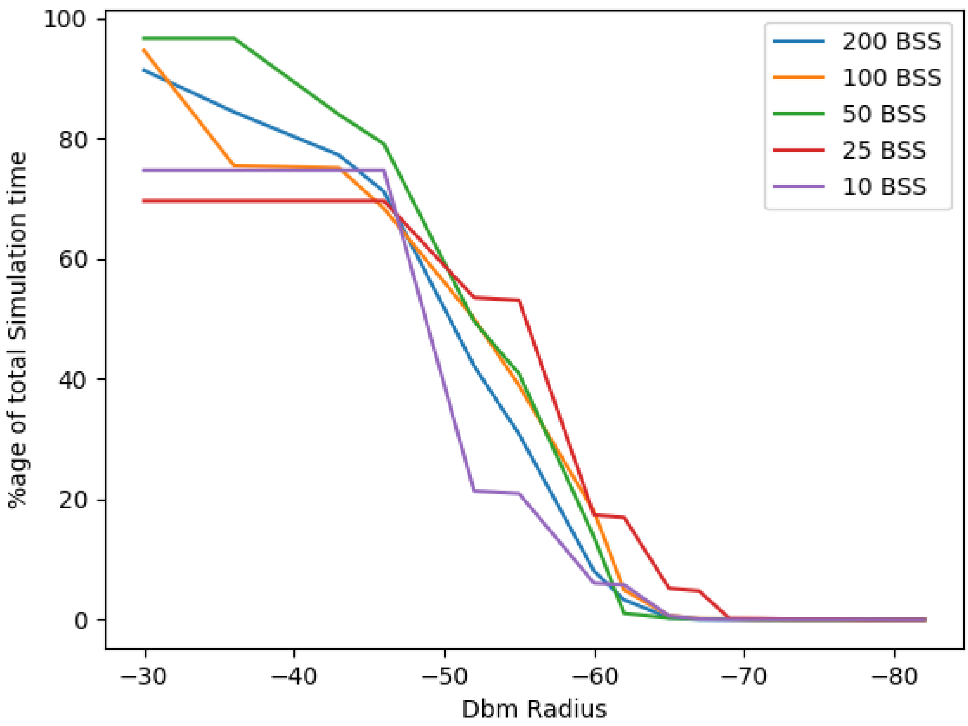


Figure 8.3: Fraction of Time a tagged node is busy when no one inside the dBm radius is transmitting for RTS/CTS Mechanism and Aggregation On

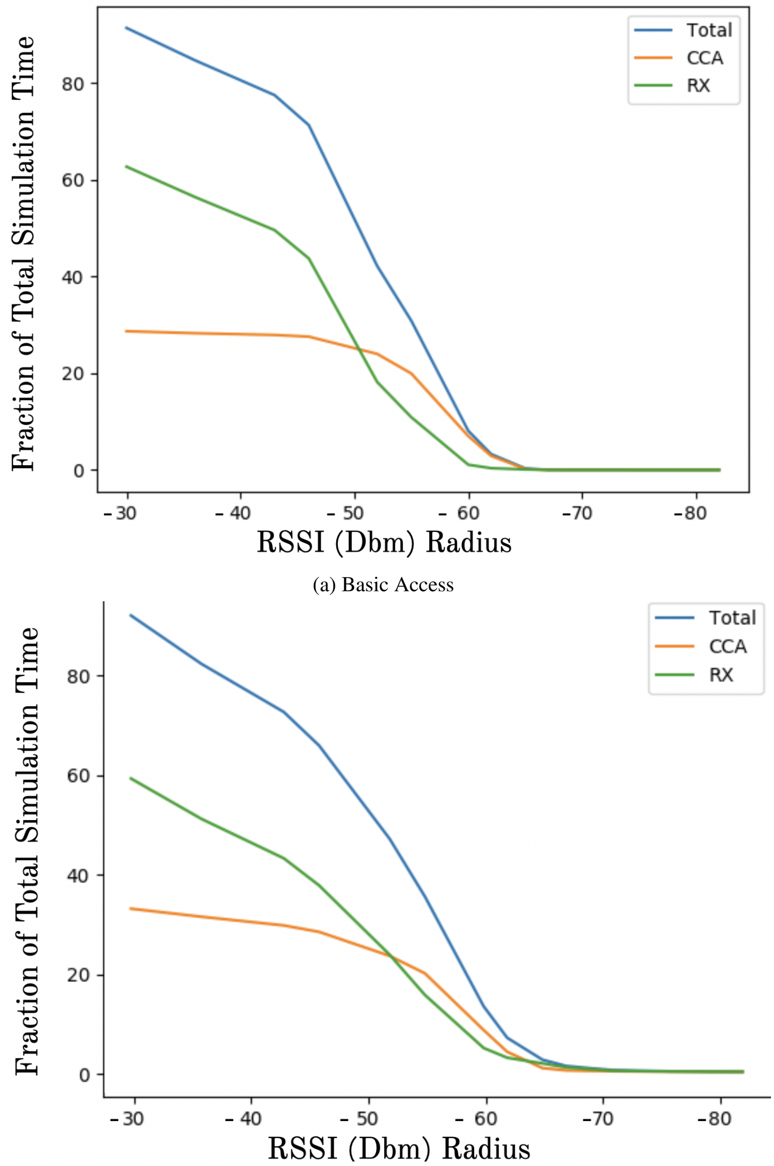
8.1.2 RTS/CTS (Aggregation On)

Figure 8.3 represents our measurements made for RTS/CTS(Aggregation on) mechanism. Most modern day devices use Aggregation for sending data along with RTS/CTS. So this graph gives a better idea of the real-life scenarios. The Convergence is observed in this plot too with around 50 BSS in the setup. Interestingly, the fraction of time my node was busy because of nodes outside -65dBm is even lower than the Basic Access Mechanism Case, around 10%.

8.1.3 Break-up of RX and CCA_Busy Times

The plots in figure 8.4 shows a clear break-up of what fraction of time was the tagged STA in RX state and what fraction of time was the tagged node in CCA_BUSY state. This plot was obtained by using the setup described in 7.1 with 100 BSSs deployed in 100m distance.

There are a few interesting things to observe. Firstly, the CCA_BUSY time is almost



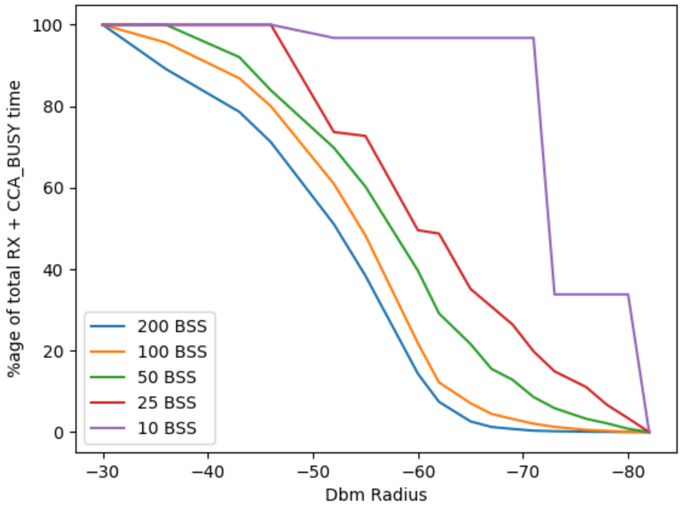
(a) Basic Access

(b) RTS/CTS Aggregation On

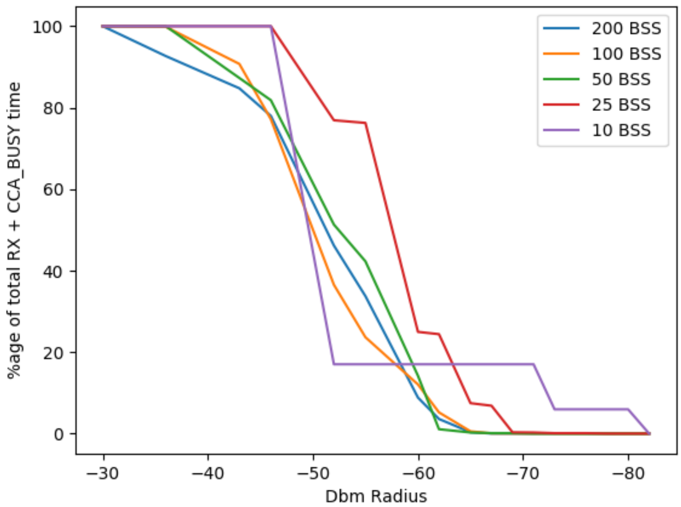
Figure 8.4: Break-Up of the Busy time obtained in Figure 8.2 and 8.3 into distinct RX and CCA_Busy States

constant and only starts to fall at around -50dBm. This maybe because after -50dBm more and more frame collisions will lead to low SNRs leading the Tagged STA to transition to IDLE state instead of CCA_BUSY state. Secondly, at around -65 dBm, the contribution of RX is significantly low and the total interference time majorly constitutes of CCA_BUSY times.

We know know that the frames sent in Aggregation are bigger in size then basic access mechanism, hence take larger amount of time, combined with the fact that the contribution to RX time is low for nodes outside -65dBm can help us explain why in RTS/CTS + Aggregation mechanism the fraction of time the tagged node was busy because of nodes outside -65dBm is even lower than the Basic Access Mechanism.



(a) Basic Access



(b) RTS/CTS Aggregation On

Figure 8.5: Complimentory CDF plots for fraction of Time a tagged node is busy when no one inside the dBm radius is transmitting)

8.1.4 Complimentary CDFs

The plots in Figure 8.5 are complimentary CDFs for the measurements that were made in section 8.1. That is we find the time a node was busy when no one inside a specified RSSI range was transmitting and we divide it with the total busy time of a node.

$$y = \frac{\text{time when all the nodes inside a chosen RSSI radius } (x) \text{ were not transmitting}}{\text{total RX + CCA\_BUSY time}}$$

The findings from these plots give a better resolution to what was seen in section 8.1. This is because these are the complimentary CDFs of plots obtained in section 8.1. We can get a better idea of how much contribution was made to the total Busy time (CCA_BUSY + RX) by nodes lying outside a particular RSSI range. It is important to observe that for the RTS/CTS mechanism we have smaller periods of involvement from nodes outside -65dBm.

8.2 Fraction of Total Decoded Preambles by the STA that belonged to nodes outside a specified RSSI Range.

Not all preambles received by the node satisfy the CSMA/CA thresholds of RSSI > -82dBm and SNR > 4. These preambles which do not pass the threshold do not affect the states, reception and transmission of the node.So, We calculated the number of decodable preambles that were sent by nodes outside the selected RSSI radius divided by total number of decodable preambles received by our tagged node.

$$y = \frac{\text{Number of Decoded Preambles from nodes outside } (x) \text{ dBm radius}}{\text{total Decoded Preambles received by tagged node}}$$

We take the setup described in Section 7.1 and vary the BSS density starting from 5, all the way to 200 BSSs. Precisely put, the simulation is run for 5,25,50,100 and 200 BSSs in a constant distance of 100m.

8.2.1 Basic Access Mechanism

The plot in Figure 8.6 presents us with information about what fraction of decoded preambles received by the STA were from outside a particular RSSI range. We again observe convergence even though at a smaller pace. On looking the fraction of pream-

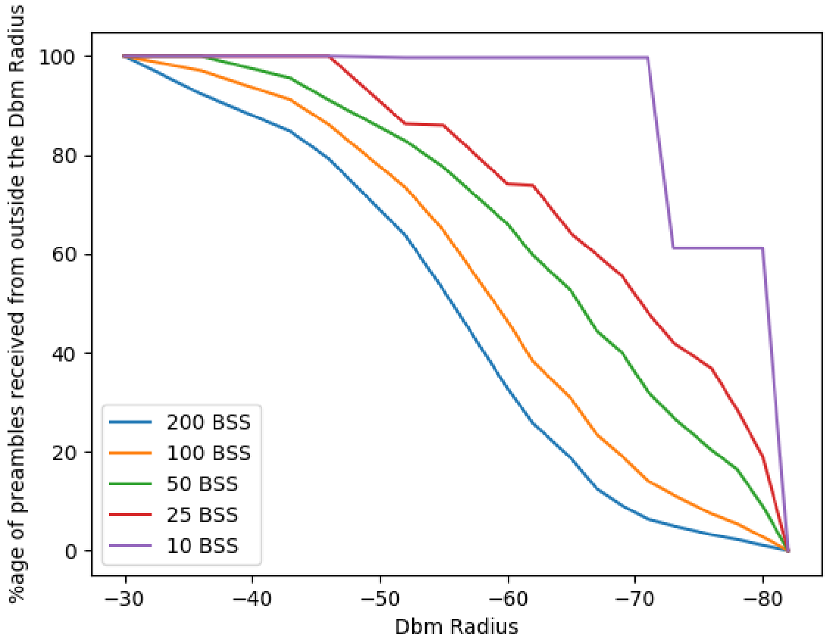


Figure 8.6: Fraction of Total Decoded Preambles by the STA that belonged to nodes outside a specified RSSI Range / Basic Access

bles received from outside -65dBm radius we see that the number is slightly larger to the fraction we obtained in section 8.1. This implies not all the frames whose Preambles were decoded were completely received by the STA. This also reflects clearly in smaller fraction of RX time compared to CCA_BUSY time that was presented in 8.1.

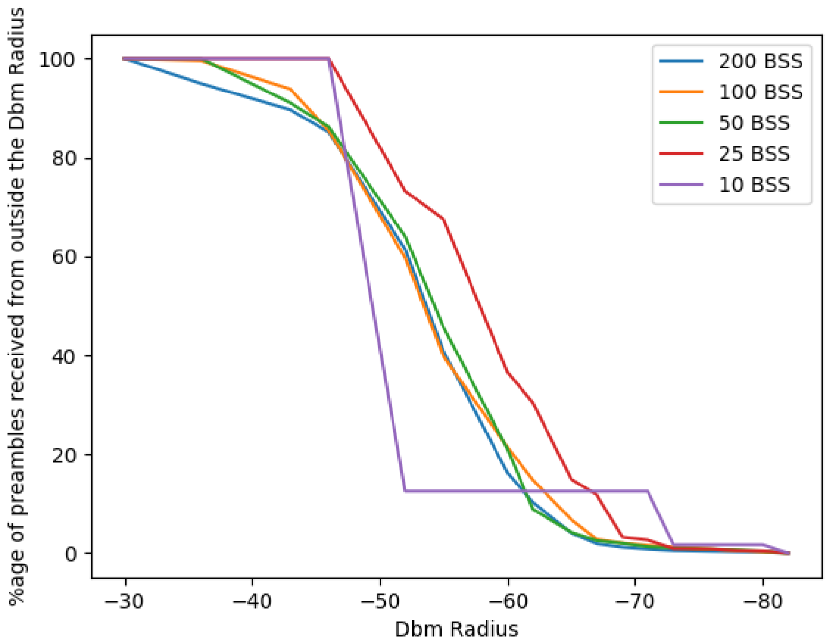


Figure 8.7: Fraction of Total Decoded Preambles by the STA that belonged to nodes outside a specified RSSI Range / RTS/CTS + aggregation

8.2.2 RTS/CTS + aggregation

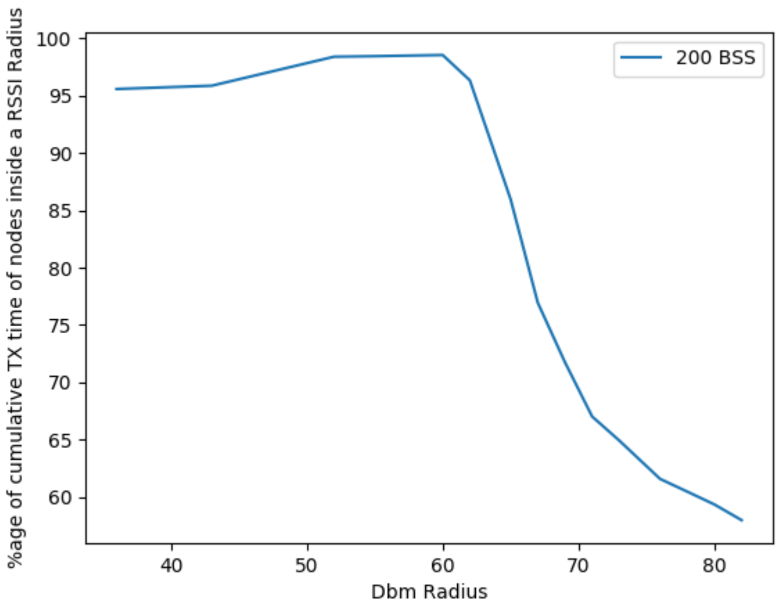
The functions of plot in Figure 8.7 seem very similiar to what we obtained in plots of Figure 8.3. This consolidates the results that were derived in section 8.1. The convergence here as well happen faster as compared to Basic Access Mechanism and the result of lower fraction of interference by far away neighbors also persists. This also implies that not all the frames with decoded preambles were fully received by the STA. The faster convergence may be attributed to RTS/CTS.

8.3 Fraction of time Tagged node is Busy while at least one of the terminals is Transmitting

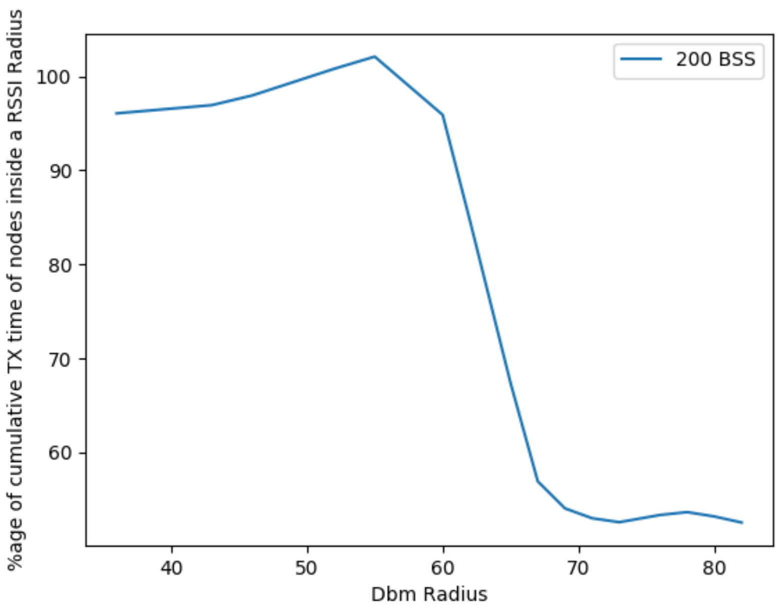
The results in Figure 8.8 describe the fraction of time the tagged node was in a CCA_BUSY or RX state while at least one of the terminals inside a selected dBm radius was in TX state. To calculate this we take the time when the tagged node was busy while at least one of the nodes inside specified RSSI range was transmitting divided by the Cumulative TX time of all the neighboring nodes inside the specified RSSI range.

$$y = \frac{\text{Time when tagged node was busy and at least one nodes inside } (x) \text{ dBm was transmitting}}{\text{Cumulative TX time of all the nodes inside the } (x) \text{ dBm radius}}$$

We take the setup described in Section 7.1 and obtain the plots for a dense setup of 200 BSSs in a constant distance of 100m. The plots for both the mechanisms are very similar and show that the tagged node was consistently in a busy state when nodes inside the radius were transmitting till the range of -60dBm, but after -60dBm there was a sharp decline and the node was no longer always receiving the frame from these far away neighbors. This is probably due to the reason that SNR for such frames from far away nodes was pretty low and the node shifted to IDLE or TX state.



(a) Basic Access



(b) RTS/CTS Aggregation On

Figure 8.8: Fraction of time the tagged node was in Busy state while at least one of the terminals inside a selected dBm radius was in TX state

CHAPTER 9

Conclusion

In these simulations that we carried out, we noticed a few important things which hinted at the fact that for dense cases, the contribution to interference by nodes outside -65 dBm radius is fairly low. For the case of RTS/CTS and Aggregation this contribution was even lower than the case of Basic Access Mechanism. This implies that there is a possibility that the OBSS/PD introduced in 11ax mayn't be that effective in optimising the SR and the gains from this mechanism wouldn't as tremendous as speculated. In addition, there is definitely a lot of scope in developing intelligent algorithms to determine a OBSS/PD threshold which can better the SR efficiency.

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