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EVALUATION OF THE EFFECT OF RATE ADAPTATION TECHNIQUES ON IEEE 802.11AC AND 802.11N

NS Ravindranath[1], Inder Singh[2], Ajay Prasad[3] and V. Sambasiva Rao[4]

[1-3]*University of Petroleum and Energy Studies, Bidholi Campus, Dehradun, Uttarakhand, India. Email: [1]nethins@yahoo.co.in*
[4]*ECE Department, PES University, Banashankari 3rd Stage, Bangalore, India*

Abstract: IEEE 802.11ac is a Very High Throughput Wireless Local Area Network standard in which data rates of 7 Gbps can be realized. NS3 is an open source network simulator, the ns-3.25.1 version of which has been enhanced with functionalities such as rate adaptation algorithms meant for 802.11ac. Here, we study how 802.11ac performs with the rate adaptation algorithms and follow up with simulations in NS3. Performance is measured for both 802.11ac and 802.11n WLANs with throughput versus Signal to Noise ratio in the presence of parameters such as channel bonding and different spatial streams.

Keywords: NS3, 802.11n, 802.11ac, rate adaptation, Minstrel, Ideal, SNR.

1. INTRODUCTION

Earlier versions of 802.11 standards defined by IEEE802.11 working group used 20 MHz channels and 802.11n standard used up to 40 MHz channel bandwidth (CBW). The 802.11ac standard uses CBWs up to 80MHz and with option to increase CBW to 160 MHz or two 80 MHz blocks. The IEEE 802.11ac Wireless Local Area Networks (WLAN) standard has been developed to achieve the throughput rates on wireless networks from a minimum of around 1 Gbps and up to nearly 7 Gbps with increased bandwidth and multiple spatial streams (SS). As a result of these speeds, 802.11ac is used in numerous data hungry applications like video gaming/conferencing/High Definition streaming. To achieve this, it is required to adapt to data rates to enable larger bandwidth channels.

The aim of any communication system is to achieve maximum data rates with minimum or nil errors. Rate adaptation (RA) is a key factor that influences the performance of IEEE 802.11 WLANs. In congested networks, it is noticed that conventional RA algorithms select lower data-rates for packet transmissions and acknowledgements are used to make decisions whether the rate has to be increased or decreased. In this paper, we study the performance of 802.11ac and 802.11n WLANs with reference to the Minstrel and IdealRA algorithms.

The contents of this paper are structured as: Section 2 introduces background concepts required on RA while Section 3 brings out capability of ns-3 simulator to analyze the same. The configuration of the test bench to simulate various scenarios is listed in Section 4. The simulated results with RA and a combination of the other parameters of the protocol are illustrated graphically in Section 5 along with a discussion of the simulated results. The work proposed to be done in future in this area is in Section 6.

2. BACKGROUND CONCEPTS

A. General Concepts

Advantages gained in 802.11ac with reference to 802.11n are due to improvements in features such as multi-input mulit-output (MIMO), Spatial multiplexing, Channel bonding, Modulation and coding schemes (MCS). Explanation for these concepts is available in IEEE standards [1], [2].

An earlier study[3] was undertaken wherein 802.11ac performance was compared with 802.11n using NS3 simulator. Guard interval, channel bonding and MCS were the features of interest. The concepts mentioned above have been discussed at length. Here, we continue by studying how 802.11ac and 802.11n WLANs perform with reference to RA – specifically, the Minstrel and IdealRA algorithms.

B. Rate Adaptation

RA is an important data link layer mechanism to improve the performance of IEEE 802.11 networks. WLAN specifications use different MCS to achieve multiple transmission data rates at the physical (PHY) layer. RA algorithms estimate the optimum data rate based on wireless channel condition and decide on a data rate with best performance. Here, we list some of the existing RA schemes, while avoiding any detailed explanations, as the paper focuses on Ideal and Minstrel RA mechanisms alone.

1. *Automatic Rate Fall back (ARF) and Adaptive ARF (AARF):* ARF implements a simple history-based RA algorithm. After the successful transmission of N consecutive frames or on the expiry of a timer meant to search for the next higher PHY rate, the PHY rate is incremented by one step at the sender station. If two consecutive frames are lost, or if the very first frame sent with the enhanced PHY rate is unsuccessful, then the PHY rate is decremented by one step. The limitation with ARF is that there are too many retransmissions when the channel varies slowly. A more adaptive algorithm called AARF is proposed, where the adaptation intervals are adjusted dynamically. Unlike ARF keeping the rate increase threshold constant (N), ARRF adaptively adjusts this threshold. More specifically, a sender increases its data rate rold to a new rate rnew after N consecutive successful transmissions. If the first transmission at this new rate rnew fails, the sender falls back on the prior rate rold and doubles the threshold to 2N for the next rate increase. Otherwise, i.e., the first transmission at the new rate succeeds, the threshold is reset. With such adaptive threshold updates, AARF increases the time interval between rate increases over a stable channel and produces fewer rate fluctuations than ARF[4].
2. *Collision-Aware RA (CARA) and MiSer:* These can differentiate between the channel errors and collision errors, to allow a reduction in the PHY rate only when a channel error occurs. In CARA, after noticing a frame transmission failure, the WLAN station enables Request-to-Send (RTS) transmission. Based on the transmission results of the RTS and the frame following the RTS, the station can determine which type of error had actually caused the loss in the previous frame. MiSer attempts to adjust both the transmission rate and power in order to obtain optimized power consumption.
3. *Robust RA Algorithm (RRAA):* RRAA uses lossy data to identify channel conditions. RRAA constructs a table for each PHY rate which holds the following: (1)rate increasing/ decreasing thresholds expressed as Frame Error Rate (FER) and (2) estimation windows (ewnd) expressed in number of frames. A station sends ewnd frames with a specific PHY rate, estimates the FER and measures it against the rate thresholds in the table. If the FER is lower (higher) than the increasing (decreasing) threshold, then the station increments (decrements) the PHY rate by one step. A-RTS of RRAA is an adaptive RTS mechanism (as in CARA's adaptive usage of RTS) which is very useful in performance enhancement in the presence of hidden terminals.
4. *SampleRate and Minstrel:* SampleRate also utilizes the FER statistics to select a PHY rate. Based on these statistics, SampleRate calculates approximately the probable transmission times (including time for retransmissions) for the specific PHY rate and frame size. The PHY rate with the minimum expected transmission time is then chosen, i.e., the rate

which maximizes the expected throughput. In an open-source WLAN device driver, MadWiFi, a revised version of Sample Rate, called Minstrel, is implemented. Details of the Minstrel algorithm are explained in subsequent section.

C. Ideal RA Algorithm

Signal Strength/SNR Based Rate Adaptation Receiver Based Auto Rate (RBAR) is the first RA that takes advantage of the control frames RTS/CTS transmitted at the basic rate . In RBAR, the RA mechanism is in the receiver instead of in the sender, i.e., receiver controls senders transmission rate . Here, data transfer is initiated with a RTS broadcast. The RTS receiver calculates the possible SNR for the received RTS packet based on some SNR threshold. Then the receiver determines the suitable data rate for the upcoming data packet. It informs the sender about this determination using the modified CTS packet. Finally the data transfer is performed in the prescribed data rate. The Rate and Length field of modified RTS and CTS packet helps neighboring nodes to update Network Allocation Vector (NAV).

Ideal RA is a Closed-Loop approach similar to RBAR in spirit : every station keeps track of the SNR of every packet received and sends back this SNR to the original transmitter by an out-of-band mechanism. Each transmitter keeps track of the last SNR sent back by a receiver and uses it to pick a transmission mode based on a set of SNR thresholds built from a target BER and transmission mode-specific SNR/BER curves. The Ideal RA mechanism chooses the best mode based on SNR of the packet transmitted earlier.

Consider that node-A transmits a unicast packet to node-B. On receiving the packet successfully node-B measures and notes the received packet's SNR into a tag and adds it to an ACK sent back to node-A. Hence, node-A is aware of the SNR of the packet transmitted to node-B using the out-of-band technique (hence, called 'Ideal'). A set of SNR thresholds is tabulated from the BER desired and from the SNR vs. BER plots. Node-A utilizes this data to choose a transmission mode with the knowledge of the receive SNR at node-B.

D. Minstrel

As discussed in [5] the RA techniques are classified as Acknowledgement (ACK) packet based, SNR based, and BER based, and are built on the metric used to predict channel conditions.

Minstrel RA algorithm, an ACK packet based algorithm supports multiple rate retries. It uses four critical design concepts: (i) Retry chain mechanism (ii) Statistics of transmission (iii) Normal transmission and (iv) Sampling transmission that are discussed below.

1. *Retry chain mechanism:* A multi-rate retry chain enables the algorithm to react to short-term variations in channel quality. It comprises four rate-count pairs, ($r0$, $c0$), ($r1$, $c1$), ($r2$, $c2$) and ($r3$, $c3$). A packet is initially sent at rate r0 for c0 tries. If unsuccessful the ($r1$, $c1$) combination is attempted. This is continued until the packet is successfully sent or discarded after ($c0 + c1 + c2 + c3$) failed attempts. The values $c0$ to $c3$ are chosen to complete the retry chain in 26ms. On successful transmit at any point, the rest of retry chain is ignored. Also, as the retry time for all data rates is almost equal, more retries are achieved at a higher data rate and vice versa. The values for $r0$ to $r3$ are different for normal transmission and sampling transmission.
2. *Statistics of Transmission:* The Minstrel algorithm maintains an account of the packet transmission statistics at each rate based on an Exponentially Weighted Moving Average (EWMA) which are used to re-evaluate the retry chain per 100 mS. The steps involved to re-evaluate are measure the probability of transmissions which met with success for each data rate, calculate EWMA probability of successful transmission ratio and calculate the throughput for each data rate.
3. *Normal Transmission:* During normal transmission, the $r0$ and $r1$ rate values are

selected as the rate that obtains the largest and second largest EWMA throughput respectively while *r*2 is the rate with the largest EWMA success ratio and *r*3 is the least data rate. This method targets to provide good throughput in the wireless environment.

4. *Sampling Transmission:* The rates chosen in the retry chain are *r*0 to *r*3. During sampling transmission, rates other than *r*0 to *r*3 are chosen to enable the algorithm to modify the rates in the retry chain if the old rates *r*0 to *r*3 do not give the optimum throughput. The modification of *r*0 to *r*3 is done as below.

For each sample packet, Minstrel randomly selects a rate not present in the retry chain. Now r0 to r3 are chosen based on:

*r*0: the higher sample rate or the rate with the highest ewma throughput

*r*1: the lower sample rate

*r*2: rate yeilding highest ewma success ratio

*r*3: lowest available rate

This sampling mechanism means that Minstrel is more likely to sample higher rates, because higher rates are tried before the rate with the current highest throughput. This results in Minstrel being able to effectively increase its sending rates as the quality of the wireless channel increases, which was an area of weakness in previous algorithm such as Sample Rate. Rate algorithms for 802.11 have used the measured received Signal Strength Indication (RSSI) to choose the rate to use but do not consider the effect of multipath. The probability of success is a function of distance between devices, multipath effects, and unknown interference from other devices all with variable interdependencies. Hence system performance at different rates is not comparable and an empirical approach is followed. In the minstrel rate algorithm, the rate that works well is used and other rates are ignored, but, all rates are tried periodically.

3. NS-3 SUPPORT

Ns-3 provides an extensible network simulation platform, for study and research in the networking field. It is a free, open source project aiming to build a discrete event network simulator. Ns-3 provides models to demonstrate functioning of packet data networks, and offers a simulation engine for users to simulate and experiment. Ns-3 is written in multiple languages (C++/OTcl). The ns3-3.25version of ns-3 released in March 2016 is used for the analysis in this paper, has a Wi-Fi module with enhanced support for broader channel widths (up to 160 MHz) and multiple SS (up to 4).

Numerous RA mechanisms are present in Ns3. Some of the algorithms discussed in literature are Ideal Wifi Manager, Aarf Wifi Manager, Amrr Wifi Manager, Cara Wifi Manager, Rraa Wifi Manager, Aarfcd Wifi Manager, Parf Wifi Manager and Aparf Wifi Manager. The Algorithms used in practical devices are Arf Wifi Manager (default for Wifi Helper), Onoe Wifi Manager, Constant Rate Wifi Manager and Minstrel Wifi Manager.

The above RA algorithms are supported by NS3 for older legacy WLANs. However, the ns3.25 version of ns3 [6] used supports adaptive rate control algorithms like Ideal, and Minstrel Ht RA managers for 802.11n and 11ac protocols in addition to Constant Rate Wifi Manager included in ns3.24 version of ns3.

4. PERFORMANCE TEST

In the scenario, an adhoc WLAN is used. Operation of the WiFi Manager (Ideal or Minstrel) is tested as the SNR is varied. The output of the test case is the data rate for every HT/VHT bit rate value, which depends on the number of SS (1, 2, 3 or 4), the channel width (20 or 40 MHz for 802.11n and 20, 40, 80 or 160 MHz for 802.11ac) and the guard interval (long or short). Configuration parameters are listed below.

Ideal

- RTS threshold = 999999;
- Power between steps = 1 dBm
- Time on each step = 0.5 seconds
- Packet Size = 1024 bytes
- Broadcast or unicast; default is unicast
- nss = 1, 2, 3, 4;

- Short Guard Interval = true or false
- Channel Width = 20, 40, 80,160 MHz (as appropriate)
- Standard = 802.11n-5GHz, 802.11n-2.4GHz, 802.11ac
- Minimum SNR = 5 db
- Maximum SNR = 35 dB

Minstrel

- RTS Threshold = 65535;
- BE_Max Ampdu Size = 65535;
- Step Size = 1 dBm
- Step Time = 1 seconds
- Packet Size = 1024 bytes
- Short Guard Interval = true or false
- Channel Width = 20, 40, 80,160 MHz (as appropriate)
- Standard = 802.11n-5GHz, 802.11n-2.4GHz, 802.11ac
- Minimum SNR = 5 db
- Maximum SNR = 35 dB.

5. RESULTS AND DISCUSSION

A. Rate Adaptation in 802.11ac and 802.11n

The adapted transmit data rate in 802.11ac and 802.11n protocols with change in SNR at receiver, for various SS – 1, 2, 3, 4 when the CBW is 20 MHz and 40 MHz is plotted in Figures 1(a) and 1(b) respectively. The type of RA used is "Ideal WiFi".

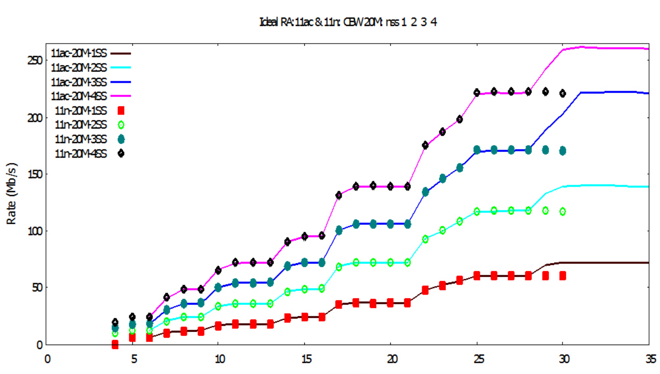

Figure 1: (a) 802.11n and 11ac response to Ideal WiFi for 1, 2, 3, 4 SS, 20 MHz CBW

As expected, 11n and 11ac do not differ in performance in the common bandwidths of 20 MHz and 40 MHz.

When Ideal Wi-Fi rate control is implemented in the 802.11ac WLAN protocol the transmit data rate adapted with variation in SNR for CBW 80 MHz and 160 MHz is as shown in Figures 1(c) to 1(d).

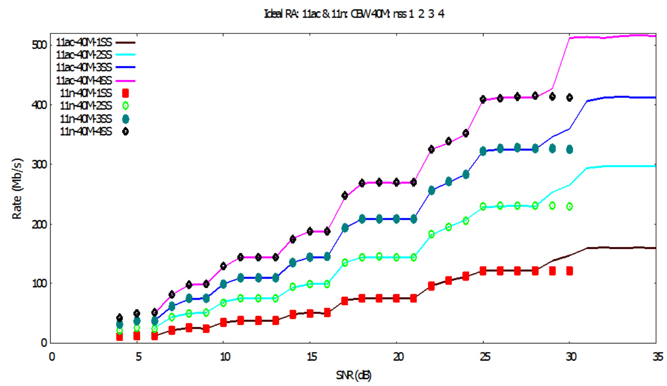

Figure 1: (b) 802.11n & 11ac response to Ideal WiFi for 1, 2, 3, 4 SS, 40 MHz CBW

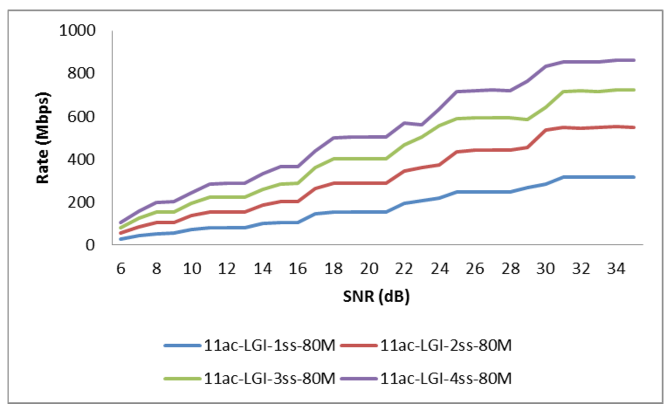

Figure 1: (c) 802.11ac response to Ideal WiFi for 1, 2, 3, 4 SS, 80 MHz CBW

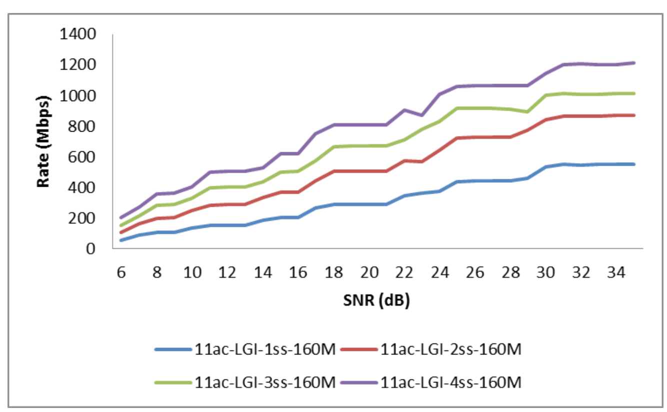

Figure 1: (d) 802.11ac response to Ideal Wi-FI for 1, 2, 3, 4 SS, 160 MHz CBW

A steady increase in transmit throughput is observed with increasing SNR, with increasing number of SS and also with increasing CBW.

It may be noted here that the theoretical data rates for different configurations in 802.11ac are as in Table-1. For all other values of bandwidth and SS (not explicitly mentioned in Table 1) the throughput may be calculated as follows with reference to the throughput at 20 MHz: 2.1 times for 40 MHz, 4.5 times for 80 MHz, 9 times for 160MHz. For every additional SS, the throughput increases correspondingly with throughput with 1SS as reference.

With Ideal Wi-FI RA, maximum throughput achieved also follows the pattern of theoretical data rates for different configurations, but the absolute values are scaled down.

Thus, the results with the "idealized" RA algorithm are consistent showing steady improvement of throughput. But, due to the constraint of adapting to SNR variations, the actual benefits of using higher BWs and SSs are not realized as expected with the theoretical values. Ideal RA introduces extra control overhead with SNR tags in ACK and the unicast data packets which increase with more SS.

Similar simulations with "Minstrel" RA are shown in Figure 2(a) and 2(b). These simulations are done with Short Guard Index (SGI).

Table 1
Minimum and Maximum Data Rates

MCS	*20MHz, 1SS, LGI*	*20MHz, 1SS, SGI*	*160MHz, 8SS, LGI*	*160MHz, 8SS, SGI*
0	6.5	7.2	468.0	520.0
1	13.0	14.4	939.0	1040.0
2	19.5	21.7	1404.0	1560.0
3	26.0	28.9	1872.0	2080.0
4	39.0	43.3	2808.0	3120.0
5	52.0	57.8	3744.0	4160.0
6	58.5	65.0	4212.0	4680.0
7	65.0	72.2	4680.0	5200.0
8	78.0	86.7	5616.0	6240.0
9	86.7	96.3	6240.0	6933.3

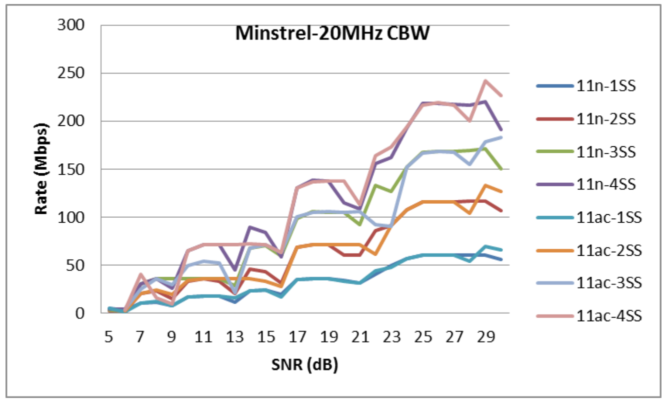

Figure 2: (a) 802.11ac and 802.11n Response to 'Minstrel' for 1, 2, 3, 4 SS, 20 MHz CBW

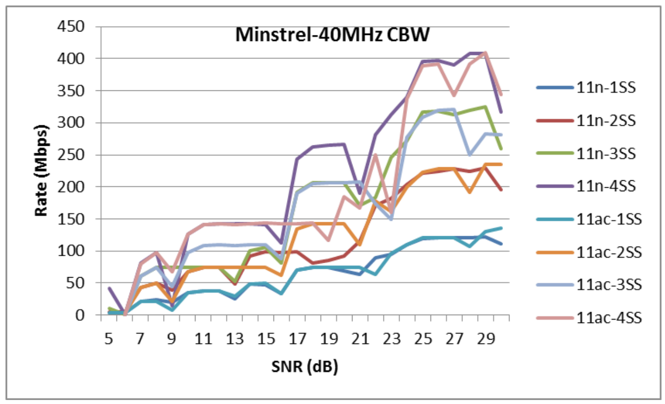

Figure 2: (b) 802.11ac & 802.11n Response to 'Minstrel' for 1, 2, 3, 4 SS; 40 MHz CBW

Observations: At 20 MHz, behavior of 11n and 11ac is similar with all combinations of SS. same is the case with 40 MHz for 1 SS and 2 SS. However, for 3 SS, 11n shows improved throughput between 12 and 22 dB SNR over 11ac whereas for 4SS, 11ac is better than 11n for the same SNR range.

With 80 and 160 MHz CBWs (Figures 2(c) and 2(d) the throughput parameters are not as expected – i.e. through put is not improving with better SNR values. Maximum throughput is the same with CBW 80 and 160 MHz i.e. about 400 Mbps. With SNR values greater than 15 dB, the throughput is the same independent of the number of SS. This irregular behavior is not seen with single SS.

With Ideal RA, both 11ac and 11n perform consistently. With Minstrel, both 11ac and 11n behave similarly at 20 MHz CBW, but for 11ac, there is inconsistency at all other BWs and number of SSs.

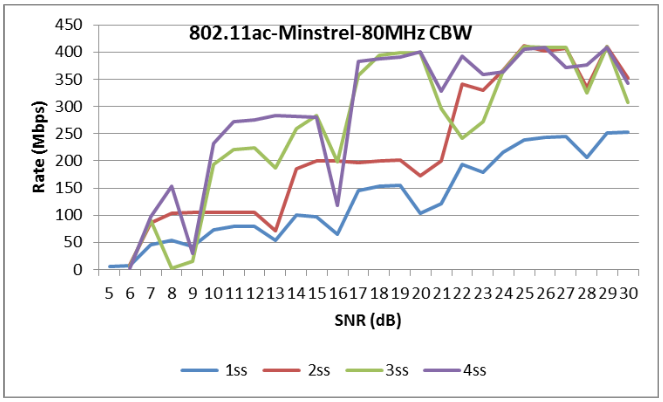

Figure 2: (c) 802.11ac Protocol Response to Minstrel; CBW = 80 MHz

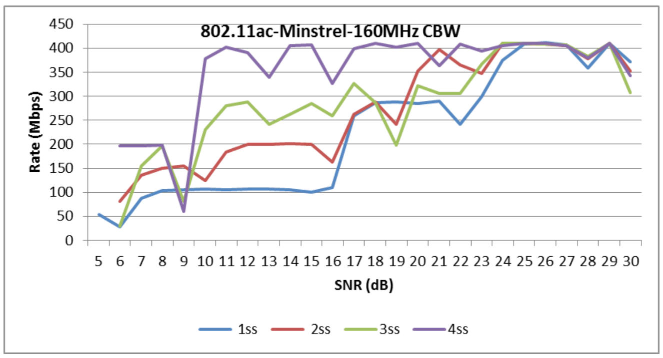

Figure 2: (d) 802.11ac Protocol Response to Minstrel; CBW = 160 MHz

B. Effect of Guard Index (GI) with Ideal and Minstrel Rate Adaptation in 802.11ac and 802.11n

With "Ideal" RA, Figure 3 shows the observed transmit data rate in 802.11ac with change in SNR, for various SS – 1, 2, 3, 4 when the CBW is 80MHz. The data is simulated for both cases when SGI is true and false to study the effect of GI on the data rates in the presence of Ideal RA.

From Figure 3 it is observed that the length of the GI does not impact the response of 802.11ac protocols with Ideal Wi-Fi RA. The results are similar for other CBWs also. With Ideal rate control, the response of 802.11n is same as 802.11ac and hence it can be inferred that the guard interval parameter does not impact the throughput of the 802.11n system with Ideal Wi-Fi RA.

When "Minstrel" RA is implemented, Figures 4(a) to 4(b) show the observed transmit data rate with change in SNR, in 802.11ac when the CBW is 20, 40, 80 and 160 MHz respectively. Similar study is done for 802.11n in Figure 5(a) and 5(b) when CBW is 20 and 40 MHz respectively. The response of the system is simulated for the cases when SGI is true and false.

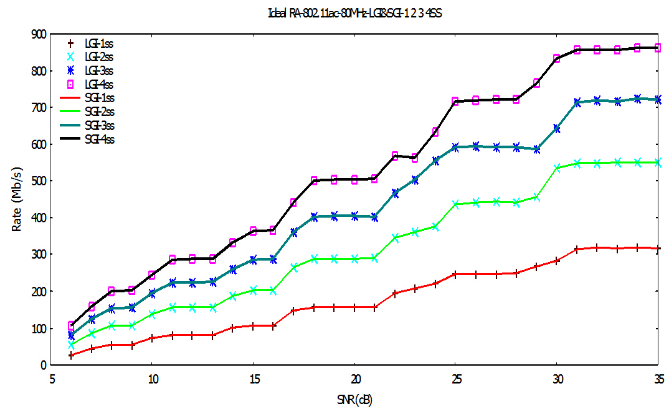

Figure 3: 802.11ac Response to Ideal Rate Control for 1, 2, 3, 4 SS; 80 MHz CBW under the influence of GI

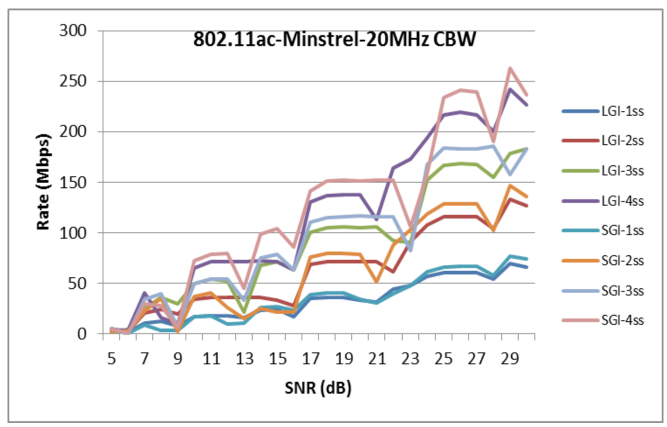

Figure 4: (a) 802.11ac Response to Minstrel for 1, 2, 3, 4 SS; CBW 20 MHz under the influence of GI

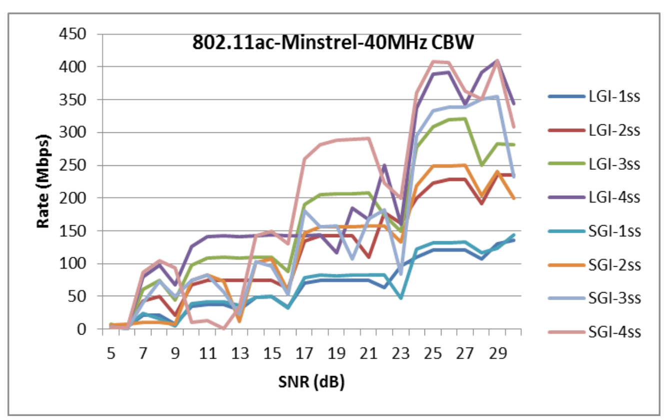

Figure 4: (b) 802.11ac Response to Minstrel for 1, 2, 3, 4 SS, CBW 40 MHz under the influence of GI

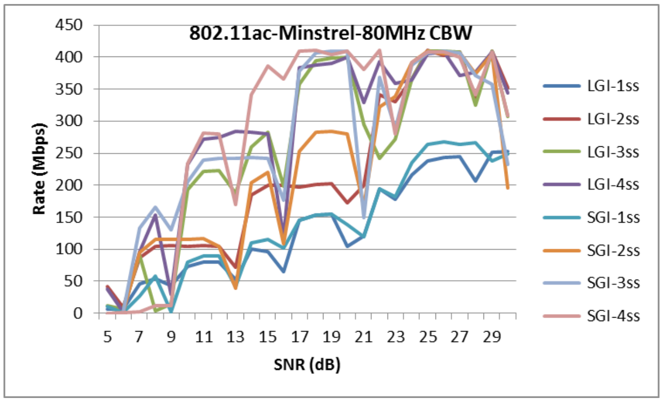

Figure 4: (c) 802.11ac Response to Minstrel for 1, 2, 3, 4 SS; CBW 80 MHz under the influence of GI

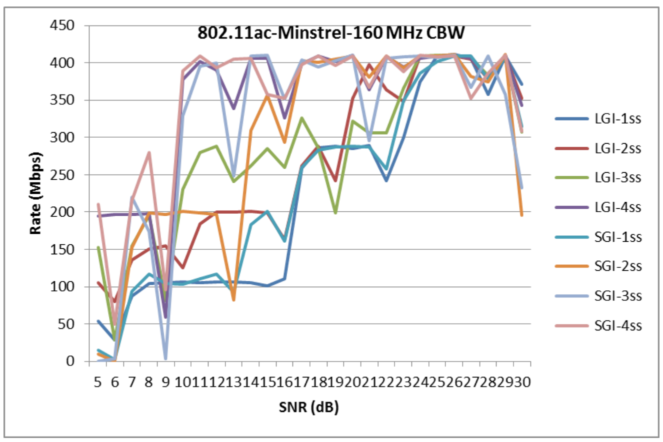

Figure 4: (d) 802.11ac Response to Minstrel for 1, 2, 3, 4 SS; CBW 160 MHz under the influence of GI

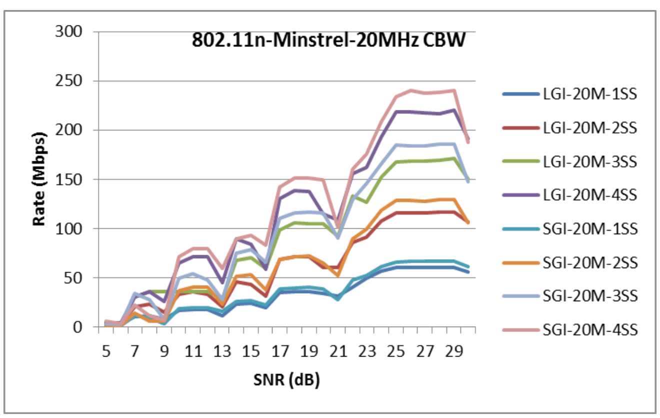

Figure 5: (a) 802.11n Response to Minstrel for 1, 2, 3, 4 SS; CBW 20 MHz under the influence of GI

Unlike Ideal Wi-Fi RA, the Minstrel algorithm results in dissimilar data rates for different values of guard interval. The response (Figures 4(a) and 5(a)) in both protocols when the CBW is 20 MHz follows a similar pattern for SGI and Long GI (LGI) for all values of SS, with a marginally better data rates for Short GI (SGI) and for 40 MHz CBW for 802.11n. This trend is repeated for 1SS only when the CBW is 40, 80 and 160 MHz in 802.11ac protocol (Figures 4(b) to 4(d)). In the other cases, the transmit data rate observed does not follow a regular pattern with reference to the SNR received.

Thus, we conclude that in Ideal RA, there is no impact of GI on both 11ac and 11n. However, with Minstrel, the results do not follow a defined pattern for GI variation.

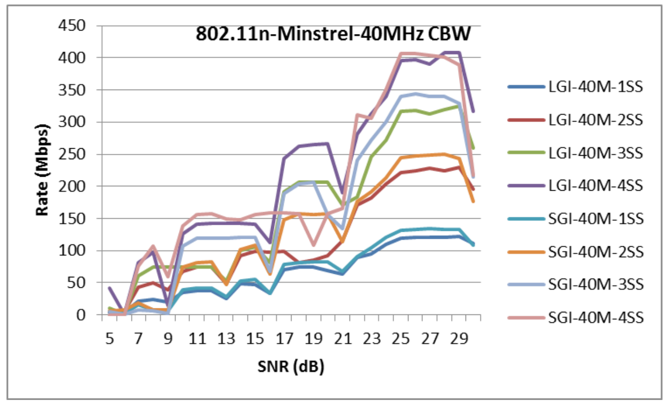

Figure 5: (b) 802.11n Response to Minstrel for 1, 2, 3, 4 SS; CBW 40 MHz under the influence of GI

C. Comparison of Ideal and Minstrel in 802.11ac

The response of 802.11ac protocol to Ideal and Minstrel rate controls is compared at different bandwidths (20, 40, 80 and 160 MHz) in Figures 6(a) to 6(d). This simulation is done for 1, 2, 3 and 4 SS.

If the data rates due to the 2 RA algorithms are compared, it is seen that the results are comparable with 20 and 40 MHz CBW. At 80 and 160 MHz CBWs performance of Minstrel is not up to the mark.

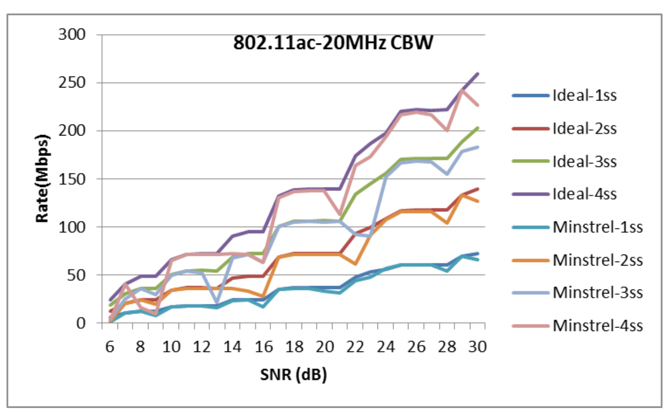

Figure 6: (a) 802.11ac Response to 'Ideal' & 'Minstrel' for 1, 2, 3, 4 SS; CBW 20 MHz

To conclude, for 11ac, both Ideal and Minstrel are suitable at 20MHz and 40 MHz, but Minstrel is not recommended for newer high CBWs.

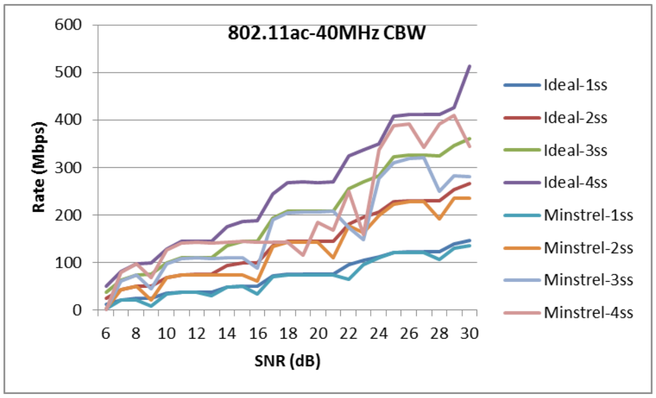

Figure 6: (b) 802.11ac Response to 'Ideal' & 'Minstrel' for 1, 2, 3, 4 SS; CBW 40MHz

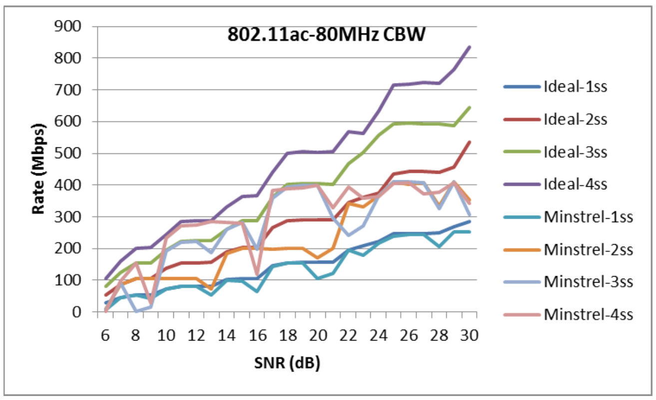

Figure 6: (c) 802.11ac Response to 'Ideal' & 'Minstrel' for 1, 2, 3, 4 SS; CBW 80 MHz

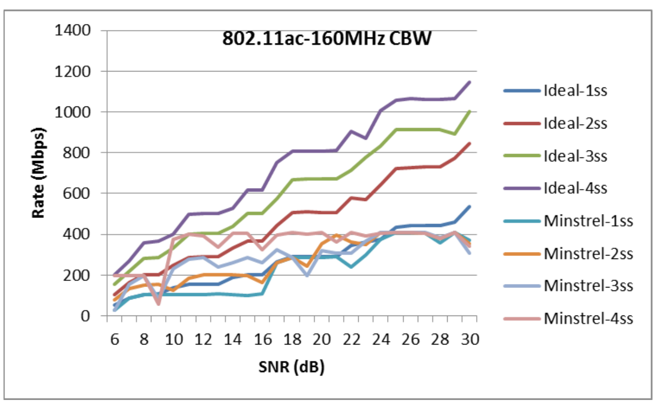

Figure 6: (d) 802.11ac Response to 'Ideal' & 'Minstrel' for 1, 2, 3, 4 SS; CBW 160 MHz

D. Evaluation of Performance of Ideal and Minstrel in 802.11ac (Between the Selected and Achieved Data Rates)

Based on the SNR values the algorithm selects the data rates for transmission based on the CBWs and the number of SS. Figures 7(a) to 7(d) compares the achieved data rates with the selected data rates for different bandwidths 20, 40, 80 and 160 MHz respectively when the Ideal RA algorithm is adopted. Simulation [7] is done for 1, 2, 3 and 4 SS.

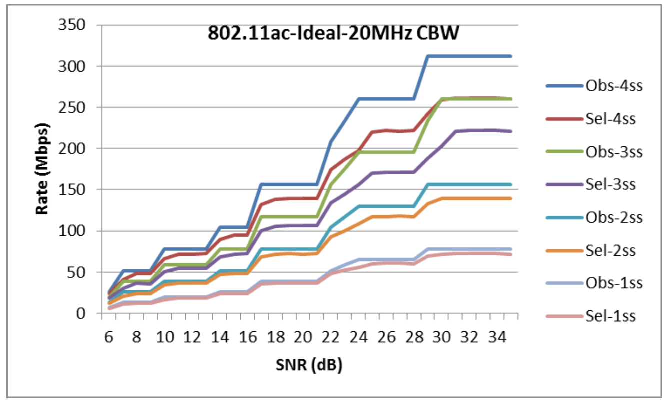

Figure 7: (a) Observed & selected rates-802.11ac-'Ideal'-1, 2, 3, 4 SS; CBW 20 MHz

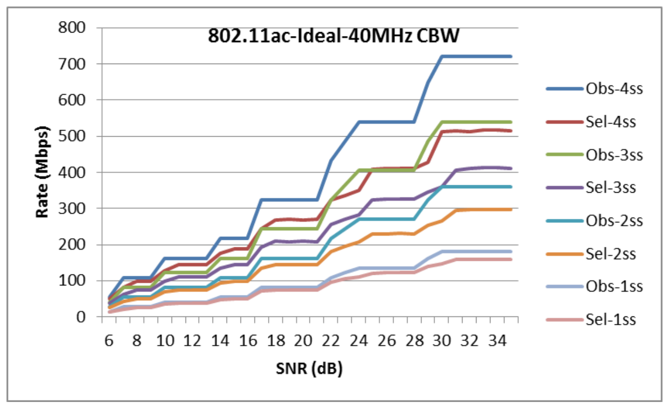

Figure 7: (b) Observed and selected rates-802.11ac-'Ideal'-1, 2, 3, 4 SS; CBW 40 MHz

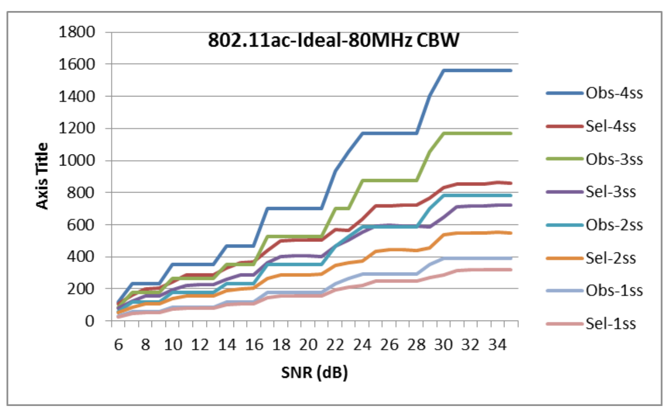

Figure 7: (c) Observed & selected rates-802.11ac-'Ideal'-1, 2, 3, 4 SS; CB 80 MHz

A similar comparison is done between the selected and observed data rates with Minstrel RA algorithm in Figures 8(a) to 8(d).

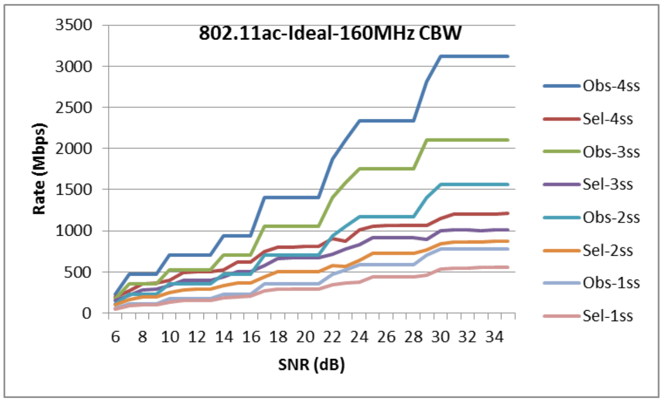

Figure 7: (d) Observed & selected rates-802.11ac-'Ideal'-1, 2, 3, 4 SS; CBW 160 MHz

With Ideal Rate control mechanism, when the CBW is 20 and 40 MHz (Figures 7(a) and 7(b)), the observed rates are closely matching with the selected rates for a single SS. Increasing deviation from the selected rate is observed in 2, 3 and 4 SS respectively.

For 80 and 160 MHz CBW (Figures 7(c) and 7(d)), RA is working well for lower SNR values, up to 20 dB for single SS and up to only 9 dB for 2 SS. For 3 and 4 SS, the adapted rate is very different from the selected data rate.

When the CBW is 20 and 40 MHz and 1 or 2 SS are utilized for transmission with Minstrel RA, for SNR values less than 21 dB the observed rates (Figures 8(a) and 8(b)) are able to meet the expectation of the algorithm. With 3 and 4 SS this is met only up to about 17 dB SNR. The Minstrel RA deviates (by about 15%) from the selected rate for moderate SNR values (up to 22 dB). In the case of 40 MHz bandwidth the achieved rates are very low compared to the selected ones at high SNRs (>22dB).

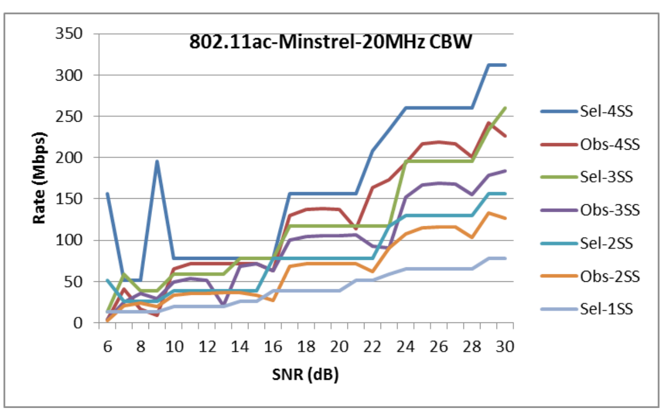

Figure 8: (a) Observed and selected rates-802.11ac-'Minstrel'-1, 2, 3, 4 SS; CBW 20 MHz

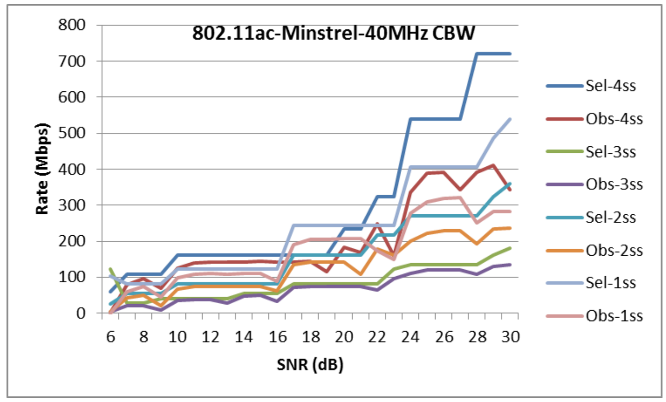

Figure 8: (b) Observed and selected rates-802.11ac-'Minstrel' 1, 2, 3, 4 SS; CBW 40 MHz

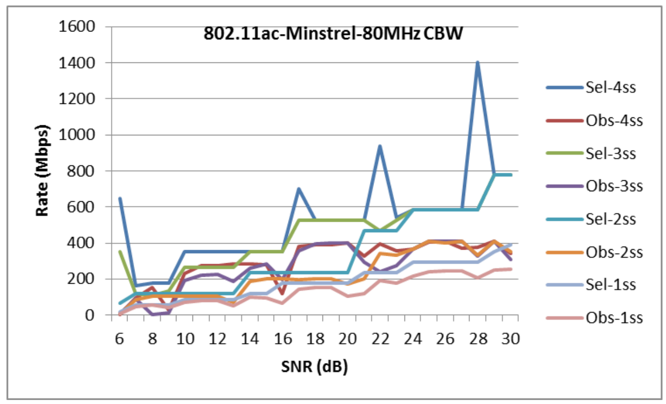

Figure 8: (c) Observed and selected rates-802.11ac-'Minstrel' 1, 2, 3, 4 SS; CBW 80 MHz

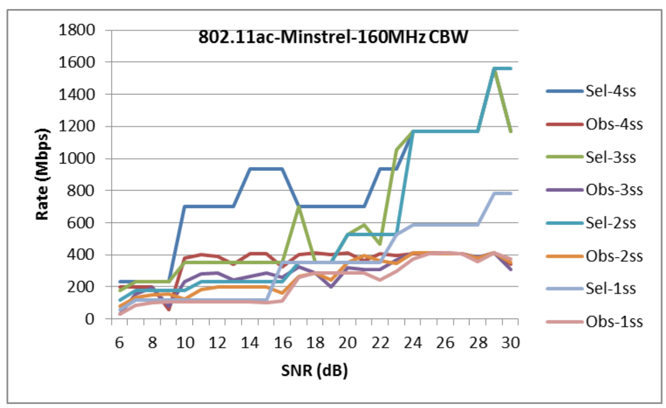

Figure 8: (d) Observed and selected rates-802.11ac-'Minstrel' 1, 2, 3, 4 SS; CBW 160 MHz

Similarly, for CBWs 80 and 160 MHz and 1 or 2 SS, observed rates are similar to the rates selected by the Minstrel algorithm, but only for SNR values less than 15 dB (Figures 8(c) and 8(d)). With 3 and 4 SS the deviation from selected rates is higher even at lower SNRs and intermediate high selected rates for 4 SS.

The difference between the selected and observed data rates in the presence of RA algorithm is plotted as standard deviation in the Figure 9, for various bandwidths and different SS for both Ideal and Minstrel algorithms.

Deviation of the data rates observed due to RA from the data rates selected by the RA algorithm is gradually increasing with number of SS and with CBW for both algorithms. The behavior of the Minstrel algorithm is marginally better than the Ideal one only in the case of 3 SS in 80 and 160 MHz CBWs and also when using 4 SS to transmit data with 160 MHz CBW. In all other conditions there is scope to improve the (*r*, *c*) combination in Minstrel RA algorithm

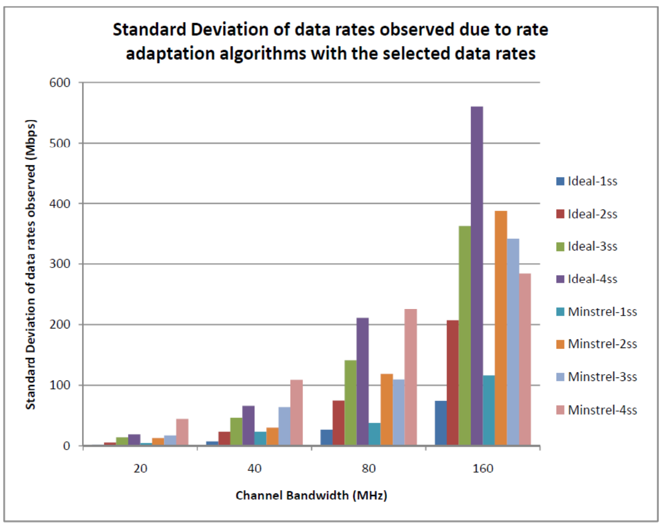

Figure 9: Standard deviation-Observed and selected data rates-Ideal and Minstrel-1, 2, 3, 4 SS

6. CONCLUSION AND FUTURE WORK

A comparison is done to study the effect of Ideal Wi-Fi and Minstrel RA algorithms in 802.11n and 802.11ac. CBWs 80 and 160 MHz in 802.11ac are not considered for 802.11n as it does not support them. With Ideal RA, both 11ac and 11n perform consistently. With Minstrel, both 11ac and 11n behave similarly at 20 MHz CBW, but for 11ac, there is inconsistency at all other BWs and number of SSs. In Ideal RA, there is no impact of GI on both 11ac and 11n. However, with Minstrel, the results do not follow a defined pattern for GI variation. For 11ac, both Ideal and Minstrel are suitable at 20MHz and 40 MHz, but Minstrel is not recommended for 80 and 160 MHz CBWs.

Minstrel is better than Ideal RA when the signal strength is enhanced from low to high due to Minstrel's property to choose high rates. Ideal RA introduces extra control overhead with SNR tags in ACK and the unicast data packets which increase with more SS. This results in throughput being lesser than the theoretical values.

The version of ns3 (ns-3.25) used in this paper, does not support simulations using transmit beam forming and MU-MIMO. Also, only "Constant Rate Wifi Manager", Ideal and Minstrel RA Managers are supported for 802.11n or 802.11ac. Future Releases of NS3 is expected to be enhanced with other RA algorithms. It is proposed to analyse in further detail other performance aspects of 11ac, using upcoming ns3 releases.

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[7] https://www.nsnam.org/src/wifi/examples/minstrel-ht-wifi-manager-example.