Comparing the Iwl-Mvm-Rs and Minstrel-HT Rate Adaptation Algorithms Under Different Local Error Conditions

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***Abstract*—WLAN technology has grown rapidly and now provides increasingly reliable and fast wireless connectivity. A number of Rate Adaptation Algorithms (RAAs) which are designed to select the optimal line rate according to the channel conditions have been proposed. Iwl-Mvm-Rs RAA which is implemented in the Intel wireless chips and Minstrel-HT RAA which is implemented in the Linux kernels are two such well-known algorithms. Many existing papers evaluate these two algorithms with regard to device mobility and signal fading. However, the causes of frame errors can be divided into two categories: weak signal reception and collisions. Therefore, in this paper, we investigated three test scenarios in NS-3 for these two causes of error in order to analyze and compare these two algorithms. We find that the response time for Iwl-Mvm-Rs to find the optimal line rate is shorter than Minstrel-HT RAA. Minstrel-HT RAA always chooses a higher line rate than Iwl-Mvm-Rs, but Iwl-Mvm-Rs performs better in terms of reducing the Frame Error Rate (FER) when weak signal reception is the cause of the error. However, when the cause of the error is a collision, Minstrel-HT RAA performs better because it always chooses a higher line rate since lowering the line rate is not beneficial in this scenario. This approach can also be useful for analyzing the correlation between the line rate and the local channel condition.**

***Index Terms*—Wi-Fi Network, IEEE 802.11 PHY, Rate Adaptation Algorithm**

I. Introduction

With the on-going development of Wi-Fi technology, it is providing people with faster and faster wireless connections. However, wireless networks are susceptible to unpredictable wireless channel conditions. The channel conditions are time varying due to factors such as multi-path propagation, obstacles and other wireless devices operating in the same frequency band because of the possible existence of interference from other wireless devices operating on the same channel and local noise at the receiver. If the wireless signal energy is attenuated as a result of distance, obstacles or multi-path channel fading, it will reduce the Signal-to-Noise Ratio (SNR) of the received signal which may lead to reception errors. In addition, according to the Carrier Access Multiple Access with Collision Avoidance (CSMA/CA) mechanism of Wi-Fi, a device needs to select a random backoff slot time from its contention window for backoff after the channel has been idle for a specified time before sending the data. The selection of the random backoff slot time cannot completely avoid collisions. For example, when two devices choose the same backoff slot time, they will send data at the same time which will also lead to errors.

The IEEE 802.11 Physical (PHY) layer supports different line rates by supporting different Modulation and Coding Schemes (MCS), channel widths, spatial streams and guard intervals. To respond to the changing wireless channel conditions, RAAs have been developed. They use various metrics to estimate the channel conditions including SNR [1], [2], frame error rate [3] and throughput [4], [5], then select an optimal line rate that can be reliably transmitted without causing excessive errors or retransmissions.

Among these RAAs, Iwl-Mvm-Rs RAA [4] and Minstrel-HT RAA [6] are two well-known algorithms. The Linux kernel uses Minstrel-HT RAA as the default RAA [7] and Iwl-Mvm-Rs RAA is implemented in Intel wireless chips. Some work [4], [5], [8], [9] have been done to evaluate these two RAAs. The work in [4] compares and analyzes the performances of the Iwl-MvmRs, Ideal and Minstrel-HT RAAs in that scenarios include static, with mobility and with and without fast fading by using the throughput as the metric. But there is no analysis of these two algorithms based on the type of error especially concerning collisions. In addition, different RAAs use different ways to select the line rates. It will affect the analysis of the relationship between the line rate chosen by the sender and the local error condition at the receiver's device. Therefore, in this paper, we present an experimental analysis to compare the Iwl-Mvm-Rs RAA and Minstrel-HT RAA under different local error conditions. We divide the types of error causes into two main categories and build scenarios based on these error causes in NS-3. Then we analyze and compare Iwl-Mvm-Rs RAA and Minstrel-HT RAA in terms of the difference in their selection of line rates and response time to find the optimal line rate and performance when encountering the different types of error causes.

This paper is organised as follows. In Section II, the background to the Iwl-Mvm-Rs RAA and Minstrel-HT RAA is presented and we also discuss the related works that evaluate these two RAAs. In Section III, we introduce the different causes of errors and explain why we focus on these error causes. The experimental design including the NS-3 topologies and the settings of the scenarios and results are presented in

TABLE I
MULTI-RATE RETRY CHAIN

Non Probe frame	Probe frame
maxtp	max(probe, maxtp)
tp2	min(probe, maxtp)
maxp	maxp
lowest	lowest

Section IV. Finally, the summary of this paper is provided in Section V.

II. RATE ADAPTATION ALGORITHMS

A. Iwl-Mvm-Rs RAA

Iwl-Mvm-Rs RAA has two main components which are MCS scaling and Column Scaling [4]. MCS scaling tries to find the optimal MCS index and column scaling tries to find a better combination of modes.

1) MCS Scaling: Iwl-Mvm-Rs RAA calculates the success ratio after at least 8 successful transmissions or 3 failed transmissions. It decides according to the success ratio, the measured throughputs of the current MCS index, the lower MCS index and the higher MCS index and the theoretical throughputs. It only makes three decisions: decreasing the MCS index, increasing the MCS index or leaving the MCS index unchanged.

2) Column Scaling: When the MCS scaling decides not to change the MCS index, the column scaling will commence. The columns are a combination of modes like (MIMO/SISO/legacy, Antenna A/Antenna B and Long GI/Short GI). It compares the maximum theoretical throughput of each column with the current measured throughput and then selects the column that has not yet been marked for an attempt. When the measured throughput of this column is better than the measured throughput of the previously used column, it chooses to continue using that column, otherwise it marks it and reverts to using the previously used column.

B. Minstrel-HT RAA

Minstrel-HT RAA keeps a record of every transmission and successful transmission for each line rate used. For every time interval of 50 ms (set in NS-3), it calculates the success ratio for every line rate used using the Exponentially Weighted Moving Average (EWMA) based on the Equation (1).

$$p_R(t+\Delta t) = \begin{cases} (1-\omega)\times p_R(t) + \omega \times \dfrac{n_s R}{n_a R}, & if\ n_a R > 0 \\ p_R(t), & if\ n_a R = 0 \end{cases} \tag{1}$$

where $p_R(t+\Delta t)$ is the success ratio at line rate R to be updated, Δt is the time interval for every updating of the multi-rate retry chain, $n_a R$ and $n_s R$ are the number of all the transmissions and the success transmission separately at line rate R during the Δt and ω is the moving average weight for EWMA.

Minstrel-HT RAA uses the success ratio of each line rate to calculate their estimated throughput, then updates its multi-rate retry chain shown in the Tabel I. It selects the maximum throughput line rate as $maxtp$, the second highest throughput rate as $tp2$ and the line rate with the best success ratio as $maxp$.

Minstrel-HT RAA employs a mechanism named ”Probing” that uses 10% of frames as probes to estimate the success ratio for unused line rates. Its aim is to give more information of the unused line rates to select a more successful line rate. For every frame to be transmitted including non-probing frames and probing frames, the line rate is selected based on its retry times according to this multi-rate retry chain.

III. SOURCE OF ERRORS

The causes of errors can be divided into two categories based upon if a lower line rate can improve the FER: 1) errors caused by the weak signal reception at the receiver and 2) collisions due to the simultaneous transmissions of frames.

A. Errors caused by weak signal reception

The calculation of SNR is shown in Equation (2) and Equation (3)

$$SNR = 10 \times log_{10}\frac{P_{signal}}{P_{noise}} \tag{2}$$

$$P_{noise} = P_{noisefigure} + P_{noiseinterference} \tag{3}$$

where $P_{noisefigure}$ is the local noise in the receiving radio device or receiving system, $P_{noiseinterference}$ is the interference power due to noise and P_{signal} is the received signal power. There are many reasons that may cause a small SNR to lead to errors as follows:

- The path loss or fading may lead to insufficient received signal power.
- The local noise from the receiver may cause small SNR when the received signal power is small.
- The interference caused by noise from other protocols using the same channel.

With this type of error cause (i.e. small SNR), a lower line rate can reduce the bit error rate and achieve optimal throughput for the current channel condition.

B. Errors caused by collision

According to the Distributed Coordinate Function (DCF) mechanism of IEEE 802.11, when the cause of the error is collisions, even if the transmitter reduces its line rate, it will not have an impact on the probability of collision. Here the line rate will only have an impact on the propagation time of the data, but the impact of the transmission time on the collision is negligible.

Both the Iwl-Mvm-Rs RAA and the Minstrel-HT RAA do not consider whether the cause of the error is a collision or a bad channel condition. Therefore, an analysis of how they choose the line rate when the cause of the error is a collision and how this impacts on the performance is useful.

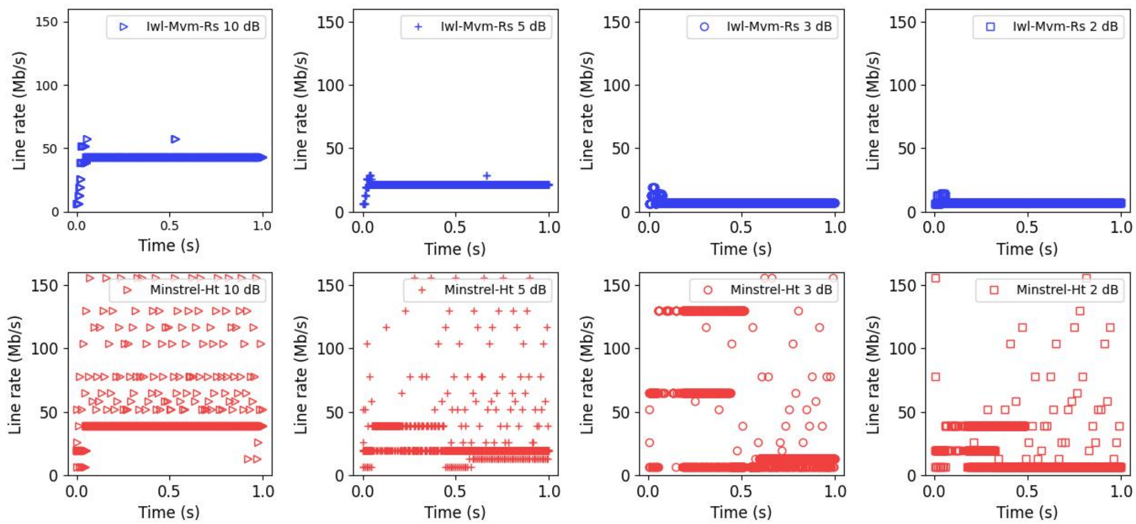

Fig. 1. Selected line rate versus time for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

IV. Experimental Methodology and Results

We use the network simulator NS-3 to evaluate the Iwl-Mvm-Rs RAA and the Minstrel-HT RAA. Under IEEE 802.11ac as both RAAs are supported for this version. Moreover, the majority of Wi-Fi networks deployed today support this version of the standard. Therefore, we analyze and compare these two RAAs in this paper based on IEEE 802.11ac

We investigated three test scenarios in NS-3. 1) static SNR, 2) dynamic SNR caused by multi-path channel fading and 3) collision. In each scenario, there is only one source of error in order to prevent interference from other factors that may cause errors. For scenario 1 and scenario 2, we used UDP down-link traffic which has a datagram of 100 bytes, 500 bytes and 1000 bytes per frame with a time interval between frames of 1 ms. For scenario 3, the size of the UDP down-link traffic was 1000 bytes. Additive White Gaussian Noise (AWGN) is used to introduce the local noise (-94 dBm) at the receiver. For every scenario, the simulation was run 50 times with a duration of 30 s. With Minstrel-HT RAA and Iwl-Mvm-Rs RAA the simulation is based upon IEEE 802.11ac operating on channel 42 (5210 MHz) with a bandwidth of 20 MHz. In Scenario 1 and Scenario 2, there are one Access Point (AP) and one client who are static at fixed positions and each is MIMO-enabled with 2 antennas supporting 2 spatial streams in transmission and reception. To reduce the influence of other factors, we disabled A-MPDU, fragmentation and RTS/CTS. All the APs are saturated. In Scenario 1, the SNR of the received signal power from the AP is set to be a constant value by setting the transmitted signal power and the loss of the signal. The SNR is set from a range of values [2 dB, 3dB, 4dB, 5dB, 10 dB, 15 dB, 20 dB, 25 dB]. In Scenario 3, the collisions are created by increasing the number of stations in the network. In this network, there is one AP associating with more than one client and all the clients are saturated.

We analyze and compare these two RAAs from the following perspectives:

- The speed of the RAA to respond to the condition.
- How does the RAA select the line rate?
- Which RAA has the better performance (i.e. the higher throughput)?
- How can the RAA reduce the FER?

The metrics to be used for analysis are described below:

- Selected line rates which are determined by MCS index, number of spatial streams, channel width and guard interval.
- FER based on MPDUs which is obtained by calculating the ratio of the number of retransmitted frames to the number of all frames.
- Throughput which is a common metric to indicate the performance of RAAs.

The details of all the experiments and results are shown in the following subsections.

A. Scenario 1: Static SNR

In this scenario, the error is only caused by a low received signal power. In this scenario, the response time of the RAAs to find the optimal line rate can be easily analyzed without the interference of uncontrollable factors such as a variable SNR.

The log-distance propagation model is described in Equation (4).

$$L(d) = l_0 + 10 \times \gamma \times log_{10}\frac{d}{d_0} \tag{4}$$

Where $L(d)$ is the path loss in dB as a function of the distance d, γ is the environment-dependent constant called the path loss distance exponent and l_0 is the path loss at the reference distance d_0. The parameter l_0, γ and d_0 used in the NS-3 model are set to be 46.6777 dB, 3 and 1 m separately.

Figure 1 shows the line rate chosen by Iwl-Mvm-Rs RAA and Minstrel-HT RAA from the first second of the example

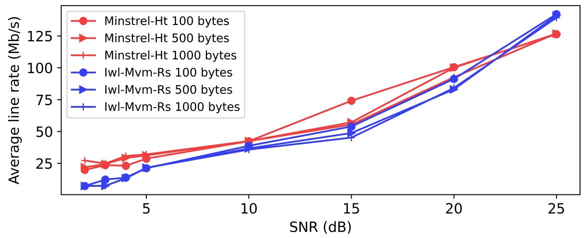

Fig. 2. Average line rate versus SNR for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

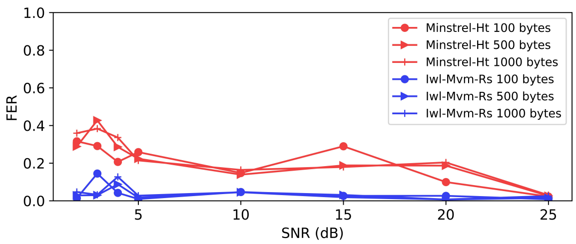

Fig. 3. FER versus SNR for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

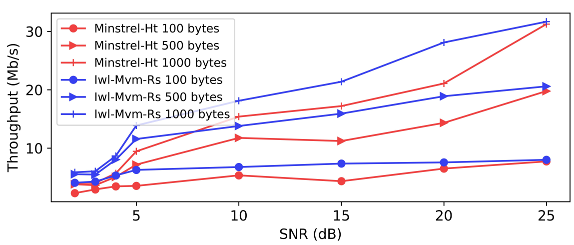

Fig. 4. Throughput versus SNR for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

simulations when the SNRs are 2 dB, 3 dB, 5 dB and 10 dB respectively. When the line rate stabilises, we consider this line rate as the optimal line rate chosen by this RAA. Therefore, from Figure 1, we can see that Minstrel-HT RAA has more than one optimal line rate when the SNR is small which shows that even with fixed SNR, the $maxtp$ changes when SNR is small. We consider that the time for a RAA to find its optimal line rates is the response time. Here we can see that Iwl-Mvm-Rs RAA can find its optimal line rate much faster than Minstrel-HT RAA especially when SNR is small. This means that Iwl-Mvm-Rs RAA has the ability to estimate the channel condition and respond faster to the changes in channel conditions than Minstrel-HT RAA.

From Figure 1, we find that Minstrel-HT RAA uses many probe frames whose line rates are much bigger than the optimal line rates. According to the retry chain, when the selected line rate of a probe frame is smaller than the current selected line rate for non-probe frames, the probe frame might not be transmitted.

To compare their performances, we also measured the line rate, FER and throughput achieved by the transmitters for both of the RAAs. The results are the mean values from 50 simulations and they are shown in Figure 2, Figure 3 and Figure 4.

From Figure 2, for both the Minstrel-HT RAA and Iwl-Mvm-Rs RAA, their line rates increase with the SNR and the frame size does not significantly influence the selection of the line rate. Minstrel-HT RAA selects the higher line rate especially when the SNR is small.

From our observation of the simulation log files, we found that when a probe frame with a higher line rate (not suitable for the current condition) was successfully transmitted and when the transmission time for that line rate was small, it resulted in a higher success ratio for that line rate. This caused Minstrel-HT to decide that the line rate should be the $maxtp$. However, Minstrel-HT updates the multi-rate retry chain only once every 50 ms. This caused Minstrel-HT to choose an inappropriate optimal line rate, resulting in a higher FER and a lower throughput.

In Figure 3, the FER from the transmitter using Minstrel-HT RAA is much higher than using Iwl-Mvm-Rs RAA. At the same time, Figure 4 shows that the throughput obtained by the transmitter using Iwl-Mvm-Rs RAA is higher than the transmitter using Minstrel-HT RAA. This shows that, although Iwl-Mvm-Rs RAA chooses a smaller line rate than Minstrel-HT RAA, its optimal line rate for the current channel condition is better than the line rate chosen by Minstrel-HT RAA because it can lead to a smaller FER and higher throughput.

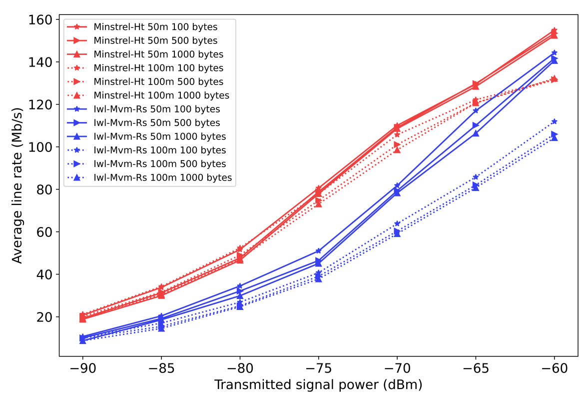

Fig. 5. Average line rate versus transmitted signal power for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

B. Scenario 2: Dynamic SNR caused by multi-path channel fading

In this scenario, the error is caused by a small received signal power with dynamic SNR. We use the Nakagami-m fading model to simulate the fading of the channel under multi-path as the loss model in NS-3. The equation of the reception power after adding propagation loss is shown below:

$$Pr(d, P) = X(m, \frac{P}{m}) \tag{5}$$

$$f(x; k, \upsilon) = \frac{x^{k-1}e^{-\frac{x}{\upsilon}}}{\upsilon^k(k-1)!} \quad for \;\; x, \upsilon \geq 0 \tag{6}$$

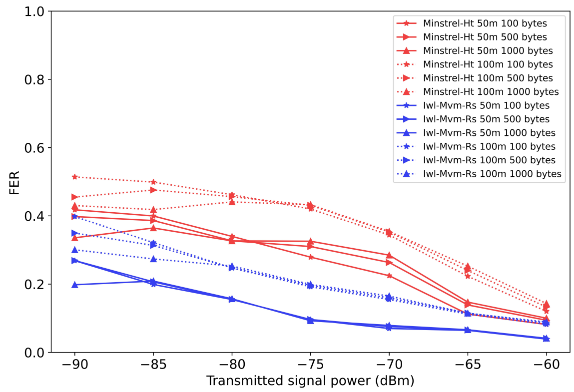

Fig. 6. FER versus transmitted signal power for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

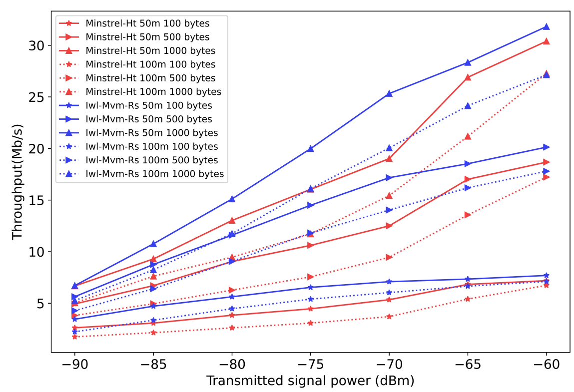

Fig. 7. Throughput versus transmitted signal power for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

where $Pr(d, p)$ is the reception power at a distance d and the transmit power is P, X is the Erlang random variable. Equation (6) shows the probability density function of this random variable. The parameter m used is the default value in the NS-3 model which is set to be 1.5 when that distance is less than 80 m and 0.75 when the distance is greater than 80 m.

The distance between the AP and the client is set to be 50 meters and 100 meters. Figure 5, Figure 6 and Figure 7 show the line rate, FER and throughput respectively. With Nakagami-m fading, without station mobility, the Iwl-Mvm-Rs RAA still performs better than Minstrel-HT RAA. It chooses smaller line rates and produces a smaller FER than Minstrel-HT RAA.

C. Scenario 3: Collision

In this scenario, the error is caused by frame collisions only. In this scenario, we are interested in how these two RAAs perform when responding to collisions.

Figure 8 shows the proportion of collisions among all the transmitted frames (i.e. the FER), throughout and the line rate with the increase in the number of clients for Iwl-Mvm-Rs RAA and Minstrel-HT RAA.

The line rate selected by the transmitters using Minstrel-HT RAA is much higher than the line rate chosen by the transmitters using Iwl-Mvm-Rs RAA. Even though the transmitters using Minstrel-HT RAA still face higher FER than the transmitters using Iwl-Mvm-Rs RAA, they perform better than Iwl-Mvm-Rs RAA in contrast to the previous two scenarios. Compared with Scenario 1 and Scenario 2, when the transmitters have the same FER, the transmitters using Minstrel-HT RAA in Scenario 3 choose higher line rates than the transmitters using this RAA in the other two scenarios.

D. Conclusion

The conclusions from the above experiments are summarised below:

- With the three scenarios we investigated, Iwl-Mvm-Rs RAA can find its optimal line rate faster than Minstrel-HT RAA. Because when there are 8 successful transmissions or 3 failed transmissions Iwl-Mvm-Rs RAA starts to make the decision to do the MCS scaling or column scaling. Minstrel-HT RAA selects its line rate from the multi-rate retry chain but it updates its retry chain every 50 ms.
- The Minstrel-HT RAA always chooses higher line rates than Iwl-Mvm-Rs RAA with these scenarios, especially in Scenario 3. The objective of Minstrel-HT RAA is to choose higher line rates based on the current local error condition and to explore the use of higher line rates by using the multi-rate retry chain and probe frames.
- With scenario 1 and scenario 2 the Iwl-Mvm-Rs RAA shows higher throughput and smaller FER which shows Iwl-Mvm-Rs RAA has selected a better optimal line rate which can lead to the smaller FER with these two scenarios.
- With scenario 3, Iwl-Mvm-Rs RAA still chooses smaller line rates. Because under this condition, smaller line rates reduce the FER slightly, Iwl-Mvm-Rs RAA has a smaller throughput than Minstrel-HT RAA. The mechanism of Minstrel-HT RAA to try higher line rates helps it to exhibit better performance than Iwl-Mvm-Rs RAA with scenario 3.

V. Conclusion

In this paper, we have analyzed and compared the Iwl-Mvm-Rs RAA and Minstrel-HT RAA from the perspective of the selection of line rate, the response time and the throughput. We investigated three scenarios based on two types of causes of errors: weak signal reception and collisions. We find that when responding to the error caused by weak signal reception, Iwl-Mvm-Rs RAA shows better performance by finding the optimal line rate faster, having higher throughput and showing a smaller FER. For Minstrel-HT RAA, the selection of line rate from the multi-rate retry chain and the use of the probing frame are the reasons why it always chooses higher line rates than Iwl-Mvm-Rs RAA. It leads to worse performance for

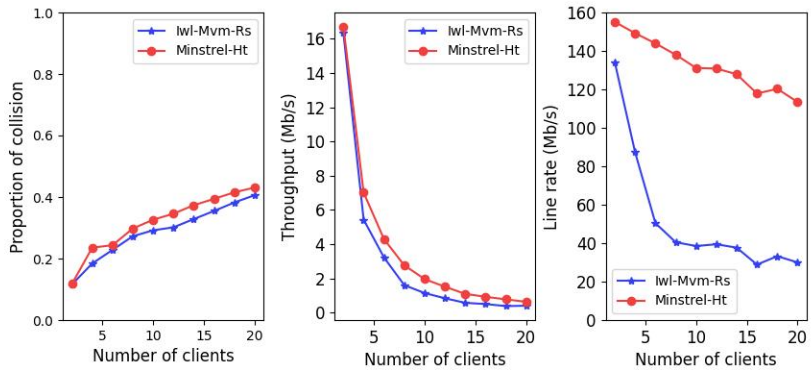

Fig. 8. Proportion of collisions, throughput and average line rate versus number of clients for Minstrel-HT RAA and Iwl-Mvm-Rs RAA

Minstrel-HT RAA compared with Iwl-Mvm-Rs RAA when responding to errors due to weak signal reception because it leads to higher FER. Moreover, Minstrel-HT RAA updates its retry chain per 50 ms, causing its response time to be much bigger than the response time of Iwl-Mvm-Rs RAA. However, when the errors are caused by collisions, Minstrel-HT RAA shows better performance than Iwl-Mvm-Rs RAA because it always tries to use a higher line rate. But in situations with high collision rates, the smaller line rate doesn't give a significant benefit.

Therefore, for Iwl-Mvm-Rs RAA, to improve the performance, when the current device is operating on the same channel with multiple other devices, it could be recognized as working in a high collision environment. Then RTS/CTS can be enabled to perform collision avoidance to improve the throughput. For Minstrel-HT RAA, it can reduce the influence of sample rate which will help it to avoid choosing inappropriate high line rates.

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