# Evaluation of the Minstrel-HT Rate Adaptation Algorithm in IEEE 802.11n WLANs

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***Abstract*** **- Wireless local area network (WLAN) has grown rapidly and has been used extensively as a wireless access technology. In the new WLAN standard IEEE 802.11n, there are more options data rate based on the width of the channel 20/40 MHz, guard interval 800/400 ns and the number of spatial streams 1/2/3/4. Rate adaptation (RA) algorithm is required for the selection of the data rate according to channel conditions to produce optimal throughput. Minstrel-HT algorithms specifically used in 802.11n that works based on the statistical table of the results of the sampling rate. Sampling rate that results in the highest throughput and highest probability of successful delivery of the packet is used as the data rate for the next packet delivery. In this paper we evaluate the performance of Minstrel-HT in IEEE 802.11n WLANs. We have used the network simulator NS-3.25 and Minstrel-HT performance is evaluated in a non-fading and fading channels. Our simulation results show Minstrel-HT fail to provide optimal throughput in both the non-fading channels and the channel fading. In the future work, we will optimize Minstrel-HT sampling method in order to produce optimal throughput in IEEE 802.11n WLANs.**

***Keywords - Rate Adaptation Algorithm; IEEE 802.11n; Minstrel-HT; Throughput; NS-3***

## I. INTRODUCTION

Wireless Local Area Network (WLAN) has grown rapidly and has been used extensively as a wireless access technology. WLAN developments are always characterized by the adoption of new standards such as IEEE 802.11n [1] which was developed from the old standard (802.11a and 802.11g). Development is done on 802.11n covers the development of the physical layer (PHY) and the development of the Medium Access Control layer (MAC). The development of the 802.11n PHY layer that is the number of Orthogonal Frequency Division Multiplex (OFDM) subcarrier is increased from 48 to 52 subcarriers, coding rate efficiency is improved from 3/4 into 5/6, provided Guard Interval (GI, 800 ns) and Short GI (SGI, 400 ns), the choice of channel width to 20 MHz and 40 MHz, as well as to use the transmission system Multiple Input Multiple Output (MIMO) up to 4 spatial streams. The whole development of the 802.11n PHY layer is intended to increase the throughput of the WLANs. Therefore 802.11n PHY layer also called HT-PHY layer.

In the HT-PHY layers, each of data rate is given index number of Modulation and Coding Scheme (MCS). MCS index differentiated by the modulations types, coding rate and the numbers of spatial streams are used. The type of modulation used in 802.11n is the same as that used in 802.11a/g, namely BPSK, QPSK, 16-QAM and 64-QAM.

MCS index are grouped into four major groups which are distinguished by the channel width and GI used. Each group MCS has the lowest index is MCS-0 and the highest MCS index is MCS-31. In the first group of MCS (GI and 20 MHz), the MCS-0 is used BPSK modulation, coding rate 1/2 and 1 spatial streams so that the resulting minimum data rate of 6.5 Mbps. In the fourth group of MCS (SGI and 40 MHz), the MCS-31 used 64-QAM modulation, coding rate 5/6 and 4 spatial streams. This highest MCS index produces a maximum data rate of 600 Mbps. So in 802.11n WLANs, if used HT-PHY with maximum 40 MHz bandwidth, SGI and MIMO up to four spatial streams, there will be 128 different data rate selection.

Selection of the appropriate data rate to the channel conditions is required to maintain optimum throughput. In WLAN 802.11, the selection of the data rate according to the channel conditions using the rate adaptation (RA) algorithms. Some RA algorithm that can be used is Auto Rate Fall-back (ARF) [2], Adaptive ARF (AARF) [3], Collision Aware Rate Adaptation (CARA) [4] and Minstrel [5]. ARF and AAFR try to increase the data rate if several packet transmission was successful and otherwise lower the data rate if the packet transmission failure. Rate adaptation in CARA algorithm is better than the ARF and AARF because it can distinguish packet errors caused by poor channel conditions or caused by the collision. Minstrel adapts the data rate based on the statistical table of the results of the sampling rate. Sample rate that produced the highest throughput and highest probability of successful packet transmission is used as the data rate for the next packets transmission.

Currently Minstrel has been developed to be used in 802.11n, which is referred to as the Minstrel-HT. Minstrel-HT is made for the use of data rate based on 20/40 MHz bandwidth, GI/SGI and the number of spatial streams can be adapted to channel conditions. Minstrel-HT has been implemented in wireless Linux drivers ath9k by Felix Fietkau [6] and in the network simulator NS-3 version 3.25 by Matias Richart [7]. Minstrel algorithm performance in 802.11g has been evaluated in paper [8] and [9]. In general, evaluation results showed Minstrel can produce optimal throughput in various channel conditions. Meanwhile, in [10] and [11] are made an attempt to improve the performance of the Minstrel algorithm. But from literature searching and as far as we know, is not yet known how Minstrel-HT performance in 802.11n. Therefore, this paper aims to evaluate the performance of Minstrel-HT algorithm in IEEE 802.11n WLANs using NS-3.

The remainder of this paper is organized as follows. In the second part is described the Minstrel-HT algorithm in NS-3. In section 3 is described simulation method for Minstrel-HT evaluation using NS-3.25. In section 4 is showed the results of simulation and discussion. In section 5 the conclusions is presented.

## II. THE MENSTREL-HT ALGORITHM IN NS-3

Sampling method on Minstrel-HT done differently with the Minstrel. In Minstrel-HT, sampling is done on all the existing rate in each group rate. In the Minstrel-HT, the number of group rate is determined by the number of spatial streams, the duration of the GI and the size of the bandwidth used. Implementation Minstrel-HT on NS-3 carried out starting on the version of NS-3.25. Source code implementation on NS-3 is present in the directory\ns3.25\src\wifi\models\minstrel-ht-wifi-manager.{cc, h}. In the next section we will explain how Minstrel-HT determine the data rate used for transmission of packets.

### *A. Initialize all HT Groups.*

Unlike the Minstrel, on Minstrel-HT begins with the initialization of the HT data rate group. Initialization HT data rate group performed to identify the data rate group is supported by transmitter. If there is a group rate that is not supported by the transmitter it will be marked as a group are not supported. After the identification of the group rate is done, then performed the identification group rate is supported by the receiving station.

Initialization HT group is based on the number of streams, GI and bandwidth. If the transmitter support 1 stream, GI and a bandwidth of 20 MHz, the transmitter only support one group, namely group 0: MCS0-7 [1,0,20]. This means that the group is composed of a data rate that starts from MCS0 until MCS7, which uses 1SS, GI and a bandwidth of 20 MHz. If the maximum use 2SS, SGI and a bandwidth of 20 MHz, then there are four groups of data rates which group 0: MCS0-7 [1,0,20], group 1: MCS8-15 [2,0,20], group 2: MCS0 -7 [1,1,20], group 3: MCS8-15 [2,1,20]. If the transmitter support 4 spatial streams, SGI and maximum bandwidth of 40 MHz, the transmitter supports 16 groups, namely group 0: MCS0-7 [1,0,20] up to group 15: MCS23-31 [4,1,40]. When initialization, HT group calculated the duration of packets transmission and also calculated its headers of any data rate within the group.

### *B. Initialize Sample Table*

After initiation of the entire HT group is done, then the initialization for checking the type of HT or non-HT station is performed. If HT station, then an initial sample table for the initiation of sampling rate is created. Initial sample table is created with the number of columns in accordance with the value of the initiation Minstrel-HT parameter. Then the line will be filled with a sample rate based on the index number selected randomly using uniform random variable. Filling data rate among 0 to highest sample selected is based on the generation of random numbers between 0 and highest sample number.

Initialization group rate supported by the receiver is done by checking the entire group at the transmitter if supported by the receiver. Checks are also carried out on MCS is supported in a group. This check can be used for optimization of throughput and energy consumption [12]. These checks also count the number of retransmit for each rate is supported. Retransmit calculations shall be based on Exponential Weighted Moving Average (EWMA) probability, wherein if the probability EWMA < 1 then the number of retransmit is equal to one. However, if the EWMA probability between 1 ~ 100 then the number of retransmit is calculated using an equation.

### *C. Set Next Sample*

Furthermore, the new rate is determined samples for use in the next sampling period. The sampling rate is based on the initials table that was created earlier. Based on the generation of uniform random number generator, the sample rate is then determined based on the index group and index rate in a group. Whenever required new sample rate, the sample rate is determined based on the increment index next previous sample group and the same index number. Index number will be increased after the highest group number has been reached.

### *D. Update Statistic*

Update statistic is repeated within a period of 100 ms. In the process of updating the statistics of the first, rate initialization is done by using the lowest global rate index (MCS0) as max_tp (maximum throughput), max_tp2 (maximum throughput 2) and max_prop (maximum probability). So the initial statistical table as follows: max_tp = 0, max_tp2 = 0, and max_prob = 0.

In each period update statistics, throughput and EWMA is updated for each rate in each group. After EWMA probability of rate is known, then calculated throughput slightly its estimate of the rate. Throughput is calculated with the following provisions. If the EWMA probability <

10 then the throughput assumed to be zero. If the EWMA probability > 90 (taking into account the package of errors caused by the collision) then the throughput is calculated based on the equation throughput = 90/txTime. For EWMA probability 10 ≤ ewmaProb ≤ 90 then throughput = ewmaProb/txTime. ewmaProb and throughput calculated for all sampling rate into the statistics update period. Then determined the new max_tp, max_tp2 and max_prob corresponding table update statistics. The new max_tp is the rate that has the highest throughput. The New max_tp2 is who has the second highest throughput. The new max_prob is a sample rate that has the highest EWMA probability.

### *F. Find Rate*

After the initialization process is complete statistics, the statistical information in the table has to be used for packet transmission. Each packet to be transmitted, the packet index number will be checked. If the index is equal to zero, the packet is transmitted packets using rate max_tp = 0. This means that the packet is transmitted using the data rate with the index equal to zero or use MCS0.

For the transmission of the next packet, if the packet index ≥ 1 and if it has qualified to conduct sampling, then do the next sampling using another sample rate. If the sampling process is successfully marked by the receipt of ACK, it then does an update packet counter. Update packet counters by counting the number of packets that have been received and the packet number of samples Further statistical update is done again for each count ewmaProb and throughput rate so that the update statistical sampling rate sample results can be known. The number of retries for sample rate also recalculated. Based on the statistics table updated, then determined new max_tp, new max_tp2 and new max_prop for the next packets transmission.

Rate *max_tp* that has resulted from the last update statistics table becomes the default rate for packet transmission until the next update statistics do. However, the use *max_tp* rate for the next packet transmission must meet the conditions *sampleWait* > 0. But if *sampleWait* = 0 and *sampleTries* ≠ 0 then the rate *max_tp* not be used until the sampling of the sample rate is completed. *sampleWait* is the number of transmission attempt should be awaited before the sampling process is done. In Minstrel-HT, *sampleWait* initiated *sampleWait* = 0. However, when the update package counter do, if *sampleWait* and *sampleTries* and *sampleCount* > 0 then *sampleWait* = 16 + 2 × *avgAmpduLen*. *avgAmpduLen* is the number of MPDU in an A-MPDU. *sampleTries* is the number of sample rate after *sampeWait* = 0. In Minstrel-HT determined initial value sampleTries = 4. Each time the sampling process performed on one sample of the counter sampleTries rate will be reduced. In Minstrel-HT maximum number of samples per update interval (sampleCount) is 16.

## III. SIMULATION SETUP

### *A. Simulation Topology*

To evaluate the performance Minstrel-HT on 802.11n, we use network simulator NS-3.25 [7]. In the simulator created a simulation topology as shown in Figure 1. In the network there is one Access Point (AP) and one station (STA). STA is connected with the AP using 802.11n standard WLAN. The minimum distance between the STA and the AP is 5 m and the maximum distance is 100 m. AP and STA PHY model used is YansWifiPhy. Channel model, PHY, MAC and parameter values used in the simulation are shown in Table 1. The transmit power used was 16.02 dBm. In the simulation, is used two channel model that is non-fading channel and Rayleigh fading channel. Non-fading channel using *LogDistancePropa-* gationLossModel and fading channels using JakesPro- pagationLossModel. Propagation delay is calculated using ConstantSpeedPropagationDelayModel. Based on the values of these parameters, the signal to noise ratio (SNR) characteristics in 40 MHz non-fading and fading channels are shown in Figure 2. In this simulation, the packet error rate (PER) is calculated using NistErrorRateModel.

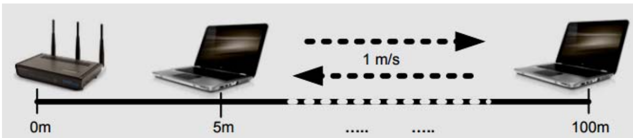


Fig. 1. Simulation topology

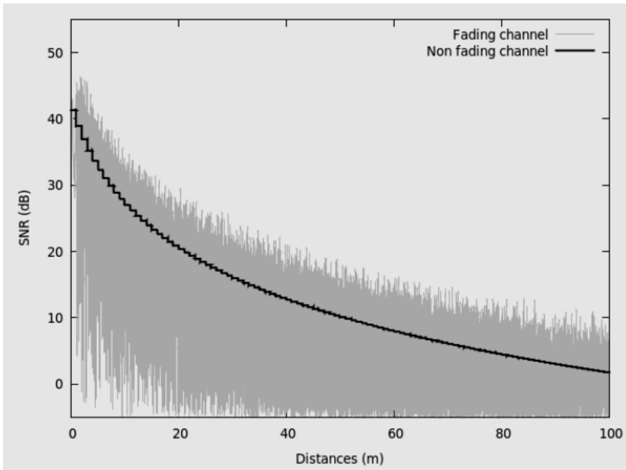


Fig. 2. 802.11n channel quality model in 40 MHz channel width

To calculate the maximum throughput Minstrel-HT, in our simulations using OnOffApplication that generates constant bit rate (CBR) traffic. OnOffApplication installed on the AP, start in 0.5 s transmits the UDP packets with a size of 1420 bytes with an infinite number of packets. Packets received by applications sink in STA. On the sending side, packets received by the HT-MAC before it is transmitted are aggregated into an aggregate MAC protocol data unit (A-MPDU) frame. A-MPDU frame then loaded into the Best Effort (BE) buffer queue. In this simulation there are no hidden terminal problems. So after getting access channels, A-MPDU frame transmitted directly without using request-to-send / clear-to-send (RTS/CTS) mode.

### *B. Experiment Design*

Minstrel-HT designed so that the packet is transmitted using MCS most suitable to channel conditions, to produce optimal throughput. In order Minstrel-HT algorithm can be evaluated in detail, in this simulation we have done some experiments. Experiments that we have to do are evaluate the performance Minstrel-HT on 802.11n using 2 spatial streams (2SS) and 3 spatial streams (3SS). In each simulation, it is assumed 802.11n uses the maximum bandwidth of 40 MHz and support short guard interval.

TABLE I. SIMULATION PARAMETER

| | |
|---|---|
| Number of AP | 1 |
| Number of STA | 1 |
| STA to AP maximum distances | 100 m |
| PHY model | `YansWifiPhy` |
| Energy detection threshold | -96.0 dBm |
| Cca mode1 threshold | -99.0 dBm |
| Tx power | 16.02 dBm |
| Tx/Rx gain | 1 dB |
| Rx noise figure | 7 dB |
| Number of Tx/Rx antenna | 2 and 3 |
| Guard interval | 800 ns (GI) or 400 ns (Short-GI) |
| Bandwidth | Up to 40 MHz |
| Frequency | 5 GHz |
| Channel loss model | LogDistancePropagationLoss |
| Fading model | JakesPropagationLossModel |
| Channel delay model | Constant speed |
| Error rate model | NistErrorRateModel |
| MAC Model | `HT-MAC` |
| Maximum A-MSDU sizes | 0 (disable) |
| Maximum A-MPDU sizes | 65535 bytes |
| RTS/CTS | Disable |
| EDCA access category | Best Effort |
| IP network / Transport | IPv4 / UDP |
| Application model | OnOffApplication |
| Data rate | 600 Mbps |
| Packet size | 1420 bytes |
| Start time | 0.5 s |
| Simulation times | 100 seconds |

Thus in 2SS, there are 8 group data rate, i.e. group 0: MCS0-7 [1,0,20] to group 7: MCS8-15 [2,1,40] with a total of 64 data rate selection. In 802.11n 3SS, there are 12 groups of data rate, which group 0: MCS0-7 [1,0,20] to group 11: MCS16-23 [3,1,40] with a total of 96 data rate selection. Because of space limitations, in this paper we do not simulate 802.11n with 1SS and 4SS.

We evaluate the performance of the 2SS and 3SS MinstrelHT on the channel non-fading and fading with SNR characteristics as shown in Figure 2. In both types of channels, Minstrel-HT evaluated on channel quality conditions changed from bad to good quality quality. The change from bad to good quality done by changing the distance between the STA from a maximum distance of 100 m to the minimum distance of 5 m. Changes within STA is done by moving closer to the AP with a speed of 1 m/s. This scenario is intended to assess whether the channel condition changed from bad to good quality, Minstrel-HT can adapt the data rate to produce optimal throughput. In the second scenario, Minstrel-HT also evaluated on changing channel quality conditions of good quality to bad quality. The change from good to bad condition is done by changing the position of STA of 5 m away from the AP with a speed of 1 m/s up to a distance of 100 m. Throughput generated by a constant rate of each MCS, made a base line optimal throughput. Throughput generated by Minstrel-HT then compared with a constant rate throughput to determine whether Minstrel-HT successfully selected data rate to produce optimal throughput corresponding channel conditions.

## IV. PERFORMANCE ANALYSIS

In this section we show the results of simulation constant throughput rate and Minstrel-HT. In the simulation using 2SS there are 64 data rate selection and in 3SS, there are 96 data rate selection. Due to limited space, the picture is only displayed eight MCS (40 MHz and SGI) for each of the number of streams.

### *A. Minstrel-HT Performance in Non Fading Channel*

Figures 3-6 show the simulation results of constant rate and Minstrel-HT throughput in non-fading channels 802.11n WLAN using the 2SS and 3SS. When the quality of non- fading channels change from bad to good condition, throughput Minstrel-HT under constant rate throughput. In 2SS, data rate to produce optimal throughput is in group 7: MCS8-15 [2,1,40]. The Group has a large selection of data rate {30, 60, 90, 120, 180, 240, 270 300} Mbps. In this 2SS, sampling rate results in all periods statistical update, Minstrel-HT has failed to get the optimum rate for max_tp. In 3SS, throughput generated by Minstrel-HT, also under constant rate throughput. But at a distance of 50 m, Minstrel- HT throughput equal to constant rate throughput. These conditions indicate the sampling rate of Minstrel-HT successfully find optimal max_tp, where max_tp = MCS18. In 3SS, to produce optimal rate throughput is in group 12: MCS16-23 [3,1,40]. Selection data rate in this group is {45, 90, 135, 180, 270, 360, 405, 450} Mbps. From Figure 3 and 5 can be concluded, in a channel change from bad to good in a non-fading channel, Minstrel-HT failed to get the optimum rate.

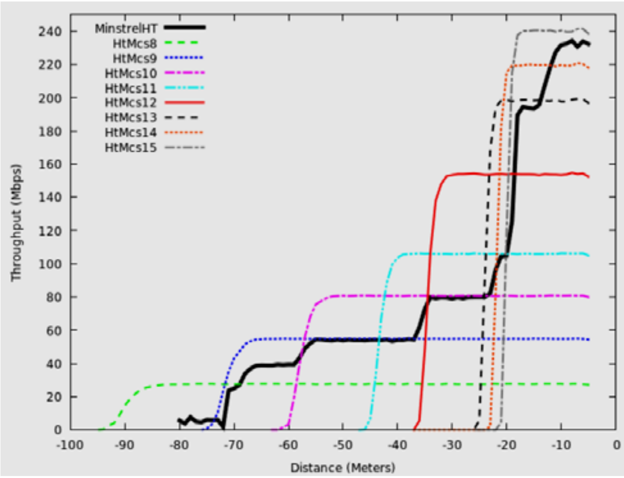


Fig. 3. Minstrel-HT performance in 802.11n WLAN with two spatial streams, the quality of non-fading channels change from bad to good.

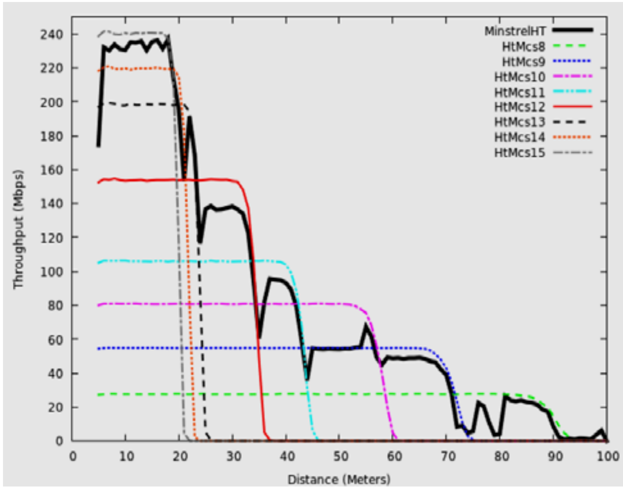


Fig. 4. Minstrel-HT performance in 802.11n WLAN with two spatial

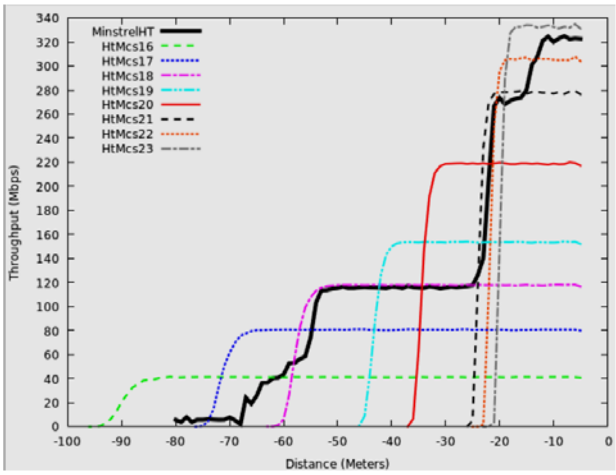


Fig. 5. Minstrel-HT performance in 802.11n WLAN with three spatial streams, the quality of non-fading channels change from bad to good.

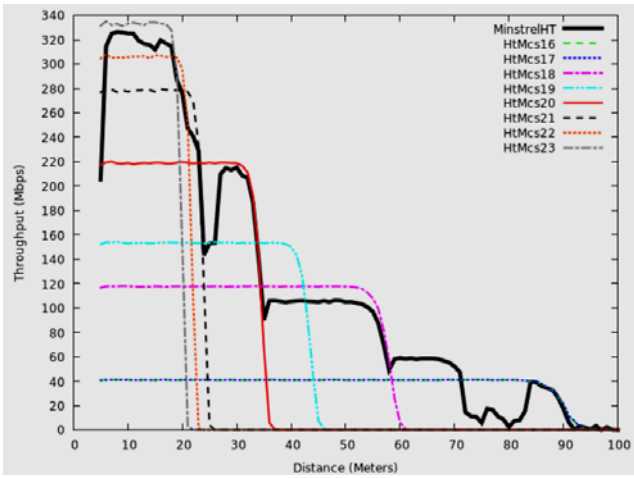


Fig. 6. Minstrel-HT performance in 802.11n WLAN with three spatial streams, the quality of non-fading channels change from good to bad.

Figures 4 and 6 show the Minstrel-HT throughput decreases when the quality of non-fading channels change from good to bad. When the quality of non-fading channels change from good condition to be bad, throughput Minstrel-HT also under constant throughput rate. But in some circumstances channels, sampling rate in Minstrel-HT can find max_tp for optimal throughput. For example in the 2SS, reduced data rate at a distance of 20 m and at a distance of 60 m, throughput Minstrel-HT approaching optimal throughput. Likewise, in 3SS, at a distance of 30 m, 50 m and 70 m, throughput generated by Minstrel-HT near optimal.

In the non-fading channels, channel quality change is linear in each period of 100 ms (in the statistics update period of Minstrel-HT). But almost all the statistics update period, Minstrel-HT failed to obtain the optimum sampling rate. This condition can be caused by too many choices sample rate (64 choices in the 2SS and 96 choices in 3SS), the provisions determining the random sampling rate and determining when sampling can be done.

*B. Minstrel-HT Performance in Fading Channel*

Figure 7-10 shows the simulation results of constant throughput rate and Minstrel-HT in fading channels 802.11n WLAN using the 2SS and 3SS. When the quality of fading channels change from bad to good condition, at a distance of -60 m to -30 m, throughput Minstrel-HT on 2SS approaching optimal throughput. While on 3SS, approaching optimal throughput at a distance of -14 m to -5 m. On the other distances, the results of the sampling rate Minstrel-HT 2SS and 3SS failed to get max_tp rate to increase throughput. Similarly, when the fading channel quality decreases, at a distance of 15 m to 40 m, sampling rate Minstrel-HT failed to get max_tp to produce optimal throughput.

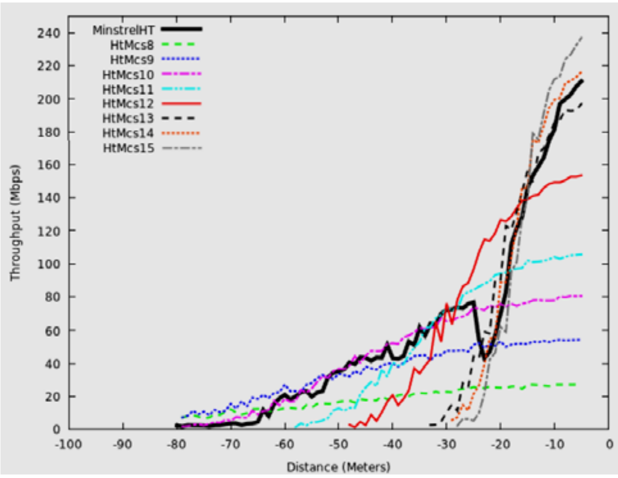


Fig. 7. Minstrel-HT performance in 802.11n WLAN with two spatial streams, the quality of fading channels change from bad to good.

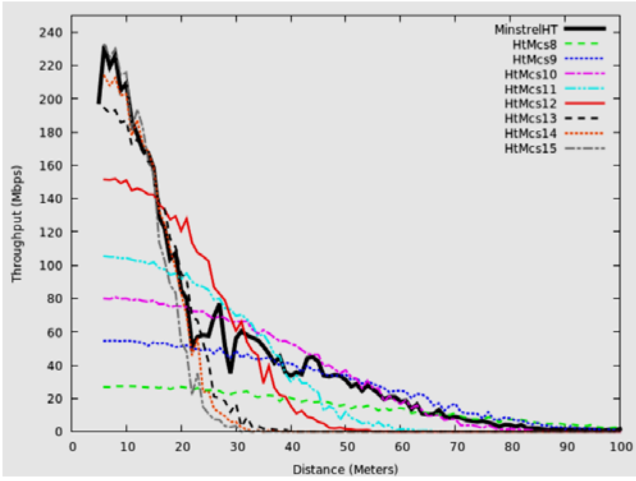


Fig. 8. Minstrel-HT performance in 802.11n WLAN with two spatial streams, the quality of fading channel change from good to bad.

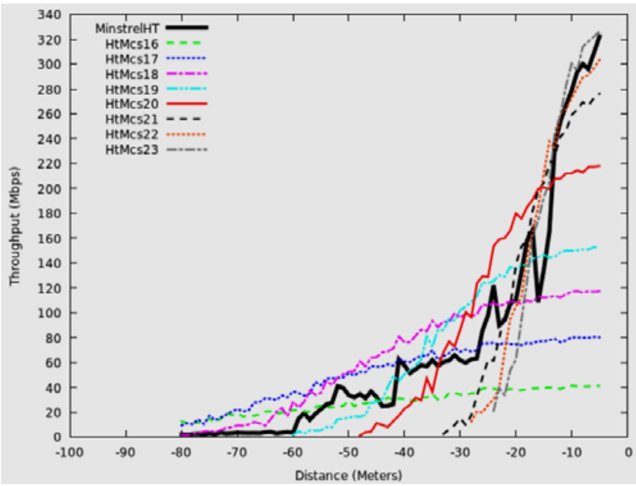


Fig. 9. Minstrel-HT performance in 802.11n WLAN with three spatial streams, the quality of fading channels change from bad to good.

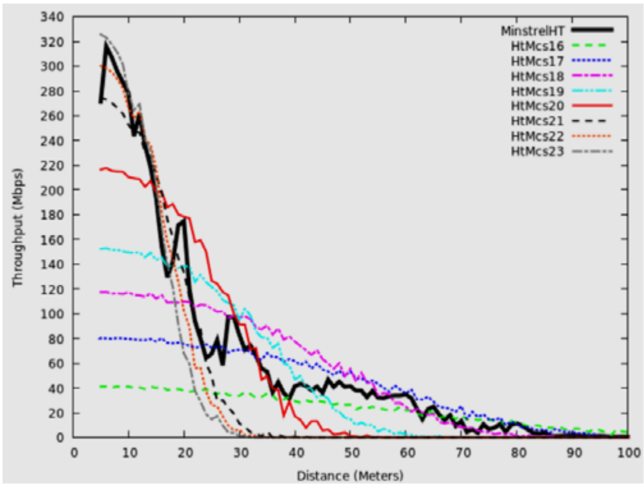


Fig. 10. Minstrel-HT performance in 802.11n WLAN with three spatial streams, the quality of fading channel change from good to bad.

At that distance, throughput Minstrel-HT on 2SS far below MCS12 and MCS10 throughput, throughput Minstrel-HT on 3SS also under throughput MCS20 and MCS18.

In fading channels, channel quality varies during the period of statistical update Minstrel-HT (100 ms). But like performance Minstrel-HT in non-fading channels, almost all the statistics update period, Minstrel-HT failed to get the optimum sampling rate in fading channels. On this condition, there should be further investigation if the number of sample rate of 64 choices on the 2SS and 96 options on 3SS have influence on the selection of the optimal rate. Similarly, the determination of random sampling rate and variable determining when sampling can be done, such as statistics update interval, sampleWait and sampleTries variable, does it also affect the determination of the optimal rate in Minstrel-HT.

## V. CONCLUSION

In this paper we have evaluated the performance of the Minstrel-HT in the transmission with 2 and 3 spatial streams in non-fading and fading channels. Simulations carried out using the NS-3 which runs four different scenarios. Our simulation results show, in a non-fading channel, when the quality of the channel changed from bad to good (STA moved closer to the AP), Minstrel-HT failed to produce optimal throughput as generated by constant rate. But when the channel quality changes from good to be bad (STA away from the AP), Minstrel-HT performance was slightly better because at a certain distance produces optimal throughput. The simulation results also showed that in fading channels, the resulting throughput approaching optimal throughput, but in some conditions Minstrel-HT still failed to produce optimal throughput. In future work, we will investigate the influence of sampling on the performance Minstrel-HT variables, such as duration of statistical update period, sampleWait and sampleTries variables.

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