IEEE 802.11n/ac Data Rates under Power Constraints

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***Abstract*-IEEE 802.11n/ac are two recent enhancements that increase the data rates of WLANs significantly thanks to the use of channel bonding, spatial multiplexing, an additional short guard interval, and new modulation and coding schemes. They offer a maximum transmission rate of 600 Mbps for 802.11n and 7 Gbps for 802.11ac. Due to regulatory power constraints, the sender may be obliged to divide its transmission power over different sub-channels and spatial streams. This allows the sender to respect the regulatory requirements but reduces the range of wide channels and multiple streams compared to narrow channels and single stream. Besides the use of spatial multiplexing does not allow the receiver to take a full advantage of the diversity gain. This is another factor that reduces the range of Multiple Input Multiple Output (MIMO) transmissions. So increasing the channel width and the number of spatial streams reduces the communication range significantly. Therefore, legacy 20 MHz channels with a single stream transmission may offer higher throughput than wide channels with multiple spatial streams. This affects the performance of rate adaptation algorithms. In this paper we introduce the power constraints that should be respected in WLANs and their impact on the range of 802.11n/ac data rates. We show that increasing the channel width and the number of spatial streams reduces the transmission range. Then we define a rate ordering scheme that selects the best data rates among those available. Our scheme intends to improve most rate adaptation algorithms, such as MinstrelHT. Finally we show, using simulation that our method enhances the throughput and the stability of MinstrelHT.**

I. INTRODUCTION

IEEE 802.11 [1] has experienced rapid and significant evolution since the past few years. Among recent enhancements we find 802.11n which defines High Throughput (HT) WLANs. HT networks have a maximum data rate of 600 Mbps and may operate on both 2.4 GHz and 5 GHz bands. On the other hand, 802.11ac is another amendment which defines Very High Throughput (VHT) networks and data rates up to 7 Gbps. We note that 802.11ac is defined for the 5 GHz band only. The significant increase of the data rates offered by 802.11n/ac is explained by the use of channel bonding, spatial multiplexing, an additional short Guard Interval (GI), and new Modulation and Coding Schemes (MCS). The channel bonding allows the use of channels wider than the legacy 20 MHz channel. So HT networks may use 20 MHz and 40 MHz channels, while VHT WLANs are allowed to use even wider channels of up to 160 MHz. Moreover, the spatial multiplexing enables the transmission of multiple spatial streams simultaneously. This is called Multiple Input Multiple Output (MIMO) transmission. We note that 802.11n and 802.11ac support up to 4 and 8 spatial streams, respectively. Besides, the short GI reduces the frame transmission time and improves the throughput slightly. Finally some additional MCS are defined to further increase the data rate. The supported rates are classified into different groups, where each group is identified by the channel width and the Number of spatial streams (Nss). Within each group there are up to 10 MCS. Every MCS offers two data rates corresponding to legacy and short GI. Since an MCS is repeated in every group, we note “MCS-group” as a unique identifier of an MCS within all the groups.

When a station uses a wide channel and multiple spatial streams, it should either increase its transmission power to keep a constant range, or spread its power over the different sub-channels and streams to maintain constant power consumption. **In the first case**, the transmission range does not depend on the channel width, since the sender uses the same power per 20 MHz sub-channel. But, increasing Nss limits the benefit of the receiver diversity gain [2,3] and reduces the MCS range. **In the second case**, increasing the channel width and Nss reduces the transmission range. So the same MCS offers a variable range depending on its group. We note that both 2.4 GHz and 5 GHz bands require the respect of maximum transmission powers as defined by the regulatory domains. So in most cases, a station is required to spread its power over the different sub-channels and streams. This affects many rate adaptation algorithms which operate according to the principle that a given MCS has the same range regardless of its group. Other algorithms, such as MinstrelHT [9], sample the different rates to select the best one. So they have limited performance since they have to try up to 128 data rates for 802.11n, and up to 620 for 802.11ac.

In this paper, we present the power constraints in 2.4 GHz and 5 GHz bands that should be respected by HT and VHT networks. Then we introduce the effect of the power spreading on the MCS range for different values of channel width and Nss. Our results show that reducing the channel width and the number of spatial streams, increases the coverage area and may improve the network throughput. Besides, we introduce a rate ordering scheme that selects the minimum number of MCS-groups which offer the best throughput. Our scheme intends to improve the performance of most available rate adaptation algorithms and to allow legacy algorithms [14] to work correctly in HT and VHT networks. Finally we evaluate the performance of MinstrelHT, with and without our ordering method. The simulation results show that the proposed scheme improves well the throughput of the considered algorithm.

To summarize, the contribution of this paper is threefold. First, we introduce the principle of power spreading in HT and VHT networks to satisfy the regulatory constraints. We believe that this is the first work that explains how low throughput groups (i.e. groups with narrow channel and few Nss) may outperform other groups with higher throughput (i.e. groups with wider channel and multiple Nss). Second, we define a rate ordering scheme to select the optimal set of MCS-groups. Third, we evaluate MinstrelHT, with and without our scheme, under NS3 simulator [15].

The remainder of this paper is organized as follows. The next Section introduces related work studying 802.11n/ac and the rate adaptation in HT and VHT networks. Then we present in Section III, the power constraints in 2.4 GHz and 5 GHz bands, and the transmission range. We dedicate Section IV to describe our rate ordering scheme. In Section V, we provide simulation results. Finally we conclude the paper in Section VI.

II. RELATED WORKS

Many researches focus on the recent WLAN enhancements and particularly on 802.11n and 802.11ac [4,5]. Besides, many rate adaptation algorithms are defined to support the new features of HT and VHT networks [6-12]. In [4], the authors introduce the new WLAN capabilities and provide a deep survey of significant research efforts improving the performance of 802.11n/ac. The introduced works focus on the different novelties of the standard. Another interesting survey [5] focuses on the advances in Multi-User MIMO (MU-MIMO) systems, and introduces various methodologies to maximize the overall performance of MU-MIMO transmissions. However, the discussed studies in [4,5] do not consider the effect of power constraints and spreading on the transmission range.

SampleLite [6] is a recent rate adaptation algorithm for 802.11n networks. It adapts the different features (i.e. channel width, Nss, MCS, and frame aggregation level) with the channel conditions. So the authors perform empirical measurements to find the relationship between the signal strength (RSSI) and each individual feature, and then provide a static mapping between the RSSI and the corresponding set of features to use. We believe that SampleLite is very weak as it does not consider the correlation between the different features. RAMAS [7] considers that an MCS offers the same performance regardless of its group. So the algorithm defines additional rules to select the channel width and Nss. These rules are very simple (for example, a frame loss counter is used to choose Nss) and do not take into account the correlation between the different features. In [8], the authors introduce MiRA for rate adaptation in HT networks. This algorithm adapts the rates within the same group first, and switches to other groups when reaching the best possible rate of the current group. This is called zigzag rate adaptation, and does not rely on convincing principles.

MinstrelHT [9] is another algorithm implemented in Atheros Ath9k driver, and largely used by current WLANs. It is based on Minstrel [13] which is defined for legacy networks. Like Minstrel, MinstrelHT periodically samples all the available data rates (different MCS-groups and GI) to find the best one. At the start, the algorithm puts the different data rates randomly in a table, and then probes them successively. It is clear that this algorithm does not consider the correlation between data rates and does not order them based on their relationship. However, the old Minstrel is able to provide good performance with legacy networks because there are few data rates to probe (up to 12). But in HT and VHT WLANs, MinstrelHT may need to sample up to 620 randomly ordered data rates, and may need a long time to find the best one. Therefore, it may suffer significant performance degradation. By selecting a limited number of data rates to probe, MinstrelHT may inherit the success of Minstrel.

Many other rate adaptation algorithms [10-12] are defined for 802.11n/ac but they do not consider the effect of the power spreading on the MCS-group range. Therefore they have limited efficiency in real networks.

III. POWER CONSTRAINTS AND TRANSMISSION RANGE

A. Power constraints for 2.4 GHz and 5 GHz bands

HT networks may operate on both 2.4 GHz and 5 GHz bands, while IEEE 802.11ac is defined for the 5 GHz spectrum only. This spectrum is divided into two sub-bands: A (5150 MHz – 5350 MHz) and B (5470 MHz – 5725 MHz). The use of 2.4 GHz and 5 GHz bands is subject to maximum transmission power constraints defined by the regulatory domain and depend on the countries. For example, most European countries allow up to 100 mW for the 2.4 GHz band, 200 mW for the 5 GHz (A) band and 1 W for the 5 GHz (B) band.

When a station is already using the maximum allowed power, it can either use all this power over a 20 MHz channel, or spread it over the different 20 MHz sub-channels of the selected wide channel. For example, an HT station operating in the 2.4 GHz band, can either use 100 mW over a single 20 MHz channel, or divide this power over the two sub-channels belonging to a 40 MHz channel (each 20 MHz sub-channel is allowed to use 50 mW only). We note that this power is also shared between the different spatial streams. So if the station sends 4 Nss on a 40 MHz channel, the part of each stream per sub-channel is 12.5 mW only (i.e. $100/(2\times4) = 12.5$). The same thing is true for 802.11ac stations which can either use all the 200 mW with a single stream over a 20 MHz channel, or spread the power over up to 8 streams and 8 sub-channels (i.e. 160 MHz channel). So each stream is allowed to use 3.125 mW only per sub-channel. This power spreading may limit the transmission range significantly.

B. Transmission range

Table 1 lists all MCS values and the corresponding data rates for different channel widths and GI. These rates are defined for 1 spatial stream, and it is straightforward to deduce the data rate for a given Nss by multiplying the rates of Table 1 by the corresponding Nss. Thus, the highest rate of 802.11ac is 866.7 × 8 = 6933.3 Mbps (about 7 Gbps).

Table 1. Data rates (Mbps) of 802.11n/ac (802.11n MCS are in gray) – case of 1 spatial stream (Nss = 1)

MCS	Modulation	Coding Rate	20 MHz		40 MHz		80 MHz		160 MHz	
			GI 0.8μs	GI 0.4μs	GI 0.8μs	GI 0.4μs	GI 0.8μs	GI 0.4μs	GI 0.8μs	GI 0.4μs
0	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	QPSK	1/2	13	14.4	27	30	58.5	65	117	130
2	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
8	256-QAM	3/4	78	86.7	162	180	351	390	702	780
9	256-QAM	5/6	-	-	180	200	390	433.3	780	866.7

To illustrate the effect of increasing the channel width and Nss on the transmission range, we use NS3 according to the configuration of Table 4. We consider two HT nodes (an AP and a station) capable to perform 20 MHz and 40 MHz transmissions, and to send/receive up to 2 spatial streams (i.e. both nodes have 2 antennas). So we have 4 groups (2 channel widths and 2 spatial streams) and 64 different data rates (4 groups × 8 MCS × 2 GI). The results are depicted in Fig. 1 and Fig. 2 for frame aggregation disabled and enabled, respectively. Each curve represents the maximum throughput obtained using the different MCS of the same group (no rate adaptation is used). Both figures provide 4 curves corresponding to the 4 groups. We observe that the group "20 MHz channel and 1 spatial stream" (20MHz1ss) offers the best range because all the transmission power is allocated to a single stream and a single 20 MHz channel. Besides, the receiver takes advantage of the diversity gain (offered by the 2 antennas) which enhances the signal strength. However, the group 40MHz2ss divides the transmission power over 2 spatial streams and 2 sub-channels, and has the shortest range.

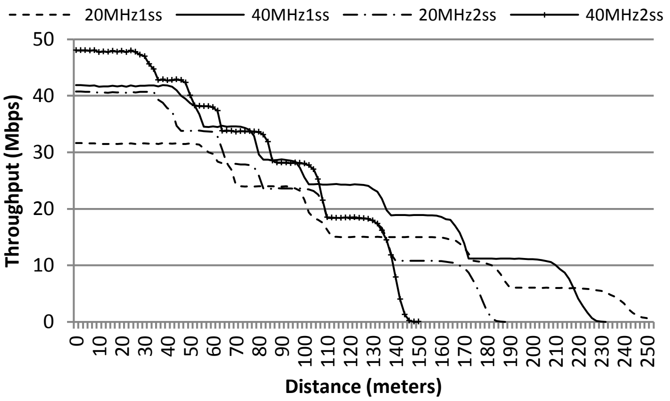

Figure 1. Throughput and range per group (no frame aggregation)

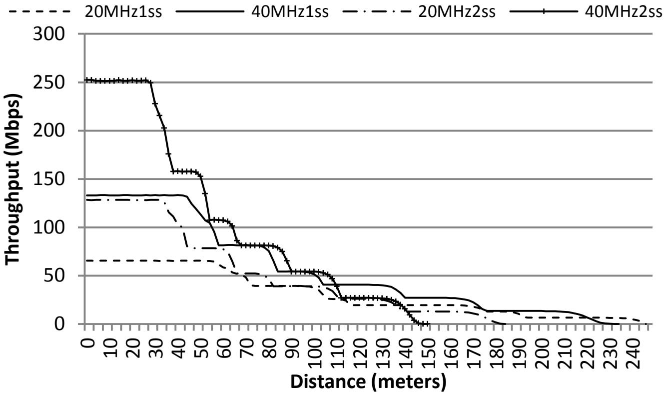

Figure 2. Throughput and range per group (using frame aggregation)

IV. RATE ORDERING SCHEME

Our objective is to define a method that selects the minimum set of MCS-groups in such a way that this set offers the highest possible throughput for all the distances. For example, an MCS-group should be removed if it offers a lower data rate and a shorter range than any other MCS-group. Our method should select an MCS-group if it offers the best throughput at any distance between the sender and the receiver. Besides, the selected set should be ordered according to the coverage area (we note that the coverage area and the received signal strength are dependent and refer to the same thing). It is worth noting that an MCS-group is identified by the MCS index, the channel width and Nss.

We define our scheme base on Table 21-25 of [1] that is illustrated in Table 2. This table provides the lowest required signal strength (as a function of the MCS and the channel width) that allows a good frame reception for the case of 1 spatial stream (Nss = 1). This table applies for 802.11ac, but cells in gray apply also for 802.11n.

Table 2. Receiver minimum input level sensitivity for Nss=1

MCS index (Modulation, Coding Rate)	**20 MHz** (dBm)	**40 MHz** (dBm)	**80 MHz** (dBm)	**160 MHz** (dBm)
0 (BPSK, 1/2)	-82	-79	-76	-73
1 (QPSK, 1/2)	-79	-76	-73	-70
2 (QPSK, 3/4)	-77	-74	-71	-68
3 (16-QAM, 1/2)	-74	-71	-68	-65
4 (16-QAM, 3/4)	-70	-67	-64	-61
5 (64-QAM, 2/3)	-66	-63	-60	-57
6 (64-QAM, 3/4)	-65	-62	-59	-56
7 (64-QAM, 5/6)	-64	-61	-58	-55
8 (256-QAM, 3/4)	-59	-56	-53	-50
9 (256-QAM, 5/6)	-57	-54	-51	-48

Table 2 shows that the minimum signal strength for a 40 MHz transmission is 3dB higher than that of a 20 MHz one. This means that a 40 MHz channel requires twice the power of a 20 MHz channel. This is obvious because the receiver of a 40 MHz transmission receives the signal from two different 20 MHz sub-channels, where each sub-channel is subject to the input levels of a 20 MHz channel. Besides, each time we double the channel width, the minimum required signal doubles (i.e. increases with 3dB). Therefore we can derive, using Eq. 1, the minimum required signal for a given MCS and a channel width (i.e. cw) from the values corresponding to a 20 MHz channel in Table 2.

$$S_{dBm}(mcs, cw) = S_{dBm}(mcs, 20MHz) + 10 \times \log_{10}(cw/20) \qquad \textbf{(1)}$$

We apply the same principle with the spatial multiplexing, and each time we increase Nss, we increase the minimum signal with $10 \times \log_{10}(Nss)$. Besides, the received signal takes advantage of a diversity gain when Nss is lower than the number of the receiving antennas. This gain is expressed in dB and corresponds to $10 \times \log_{10}(Nant/Nss)$, where Nant is the number of the receiving antennas. For example, a single stream received by 2 antennas gains 3 dB. Also, if the station has 4 antennas and receives 2 spatial streams, each stream is processed by 2 antennas and gains 3 dB (i.e. $10 \times \log_{10}(4/2)$). As the values of Table 2 apply to signals once any gain is added, we need to determine the minimum signals before adding the diversity gain. This allows us to compare the range of the different data rates. Therefore we subtract the diversity gain, and we derive the minimum signals according to Eq. 2.

$$S_{dBm}(mcs, cw, Nss) = S_{dBm}(mcs, 20MHz) + 10 \times \log_{10}(cw/20) \\ + 10 \times \log_{10}(Nss) - 10 \times \log_{10}(Nant/Nss) \qquad \textbf{(2)}$$

We note that our rate ordering scheme is used to select the transmission data rates. So the station that uses it is called the sender. Besides, the sender is always aware about the receiver characteristics (this is required by the standard).

Our scheme operates according to the following steps:

1) At the start, it selects all the MCS-groups which are supported by both the sender and the receiver. It calculates the minimum signal for each MCS-group according to Eq. 2, and saves all the MCS-groups in a list.
2) Then it sorts the list by descending value of "minimum signal". In this way, the first elements of the list are MCS-groups with the highest signal requirements (i.e. with shortest ranges), and the last elements are MCS-groups with lowest signal requirements (i.e. with largest ranges).
3) Finally, we remove any MCS-group that offers lower range and lower data rate than any other MCS-group. So we check MCS-groups having the largest ranges first. If an MCS-group offers a higher rate than all other MCS-groups having better ranges, we keep it. Else, we remove it. So we check the list from the end and we remove any MCS-group that offers a data rate lower than the previous MCS-group in the list.

The description of our scheme is presented in Algorithm 1. We execute this algorithm for various configurations of the receiver and we record the number of selected MCS-groups among the total available number. The results are illustrated in Table 3. We observe that our method selects a limited number compared to the available one. For example, the sender uses a set of 32 MCS-groups only instead of 310 (i.e. 10% only) in the case of a 160 MHz channel and 8 spatial streams.

Algorithme 1. Rate Ordering Scheme

```
structure MCS_group = {
    mcs, // the MCS index as defined in 802.11ac (from 0 to 9)
    cw, // the channel width in MHz
    nss, // the number of spatial streams
    min_signal, // signal strength in dBm according to Eq. 2
    data_rate // data rate in Mbps using legacy GI (0.8µs)
}; // the MCS for a given group
List all_MCS_groups; // stores all MCS from all groups
maxCW = Min(get_max_cw(), get_max_cw_receiver());
maxNss = Min(get_max_nss(), get_max_nss_receiver());
nRxAntennas = get_number_of_antennas_receiver();
for cw = 20 to MaxCW do
    for nss = 1 to MaxNss do
        for mcs = 0 to 9 do
            if is_mcs_group_valid(mcs, cw, nss) then
                MCS_group mcsg;
                mcsg.mcs = mcs;
                mcsg.cw = cw;
                mcsg.nss = nss;
                mcsg.min_signal =
                        get_value_from_table2_for(mcs, 20MHz)
                        + $10\times\log_{10}(cw/20)$ + $10\times\log_{10}(nss)$
                        - $10\times\log_{10}(nRxAntennas/nss)$; // Eq. 2
                mcsg.data_rate = get_data_rate_of(mcs, cw, nss);
                all_MCS_groups.add(mcsg);
            end if
        end for
    end for
end for
// Currently, all_MCS_groups contains the different MCS for
// all the groups supported by both the sender and the receiver.
// Now we need to order the MCS_groups from shortest range
// (highest min_signal) to largest one (lowest min_signal).
sort all_MCS_groups by descending min_signal;
// Actually we need to keep the best MCS_groups only. So we
// keep an MCS_group if its data_rate is higher than all other
// MCS_groups having larger ranges (i.e. lower min_signal)
data_rate = 0;
for i = count(all_MCS_groups) to 1
    if all_MCS_groups[i].data_rate > data_rate then
        // We keep this MCS_group and we record its data_rate
        data_rate = all_MCS_groups[i].data_rate;
    else
        all_MCS_groups.erase(i); // remove this MCS_group
    end if
end for
```

Table 3. Number of the selected MCS-groups among the available ones

Width	Nss	802.11n	802.11ac
40 MHz	2	15/32 (46%)	17/38 (44%)
	4	19/64 (29%)	21/77 (27%)
	8	-	27/154 (17%)
80 MHz	2	-	20/58 (34%)
	4	-	23/116 (19%)
	8	-	30/231 (12%)
160 MHz	2	-	22/78 (28%)
	4	-	26/155 (16%)
	8	-	32/310 (10%)

Although our scheme reduces significantly the number of MCS-groups to use, its principal advantage is to order the data rates and to allow the sender to know which MCS-group to use when the currently used one is not reliable any more (due to the path-loss).

V. EVALUATION RESULTS

We use NS3 [15] to evaluate the effect of increasing the channel width and Nss on the transmission range, and to measure the performance of our scheme. We consider the simulation configuration of Table 4. All the measurements are based on UDP traffic belonging to the "Best Effort" category with Ethernet frame size of 1500 Bytes. Thus the MAC frame length is 1538 Bytes. We build a network of 2 nodes: an AP and a station. We set the station in the saturation condition (i.e. it always has data to send to the AP) to measure the highest achieved throughput. Due to space limitation, and in order to provide clear results, we consider a maximum channel width of 40 MHz and a maximum Nss of 2 spatial streams. This configuration is defined by both 802.11n and 802.11ac. Besides, we consider a HT-WLAN in the 2.4 GHz band.

Table 4. Simulation parameters

Parameters	Values
Simulator version	ns3.27 (October 2017)
Error rate model	Nist
Propagation loss model	Log distance
Network type	802.11n
- Band	2.4 GHz
- Transmission Power	100mW (20 dBm)
- Maximum channel width	40 MHz
- Maximum Nss	2 spatial streams
- Number of antennas	2
- SIFS	16µs
- SlotTime	9µs
- AIFS	43µs (SIFS + 3×SlotTime)
- CWmin	15
- CWmax	1023

Our scheme selects a set of 15 MCS-groups among 32 and orders them from highest data rate with shortest range to lowest rate with largest range. We compare the maximum throughput achieved using the selected set (RO: Rate Ordering) with that of the 4 groups. The results are illustrated in Fig. 3 (no frame aggregation) and Fig. 4 (frame aggregation enabled).

Fig. 3 shows that the selected MCS-groups offer the highest throughput except in two limited regions, named zone 1 and zone 2. In zone 1, our scheme selects an MCS from group 40MHz2ss instead of 40MHz1ss because the former offers a slightly higher theoretical data rate. But due to the frame overhead which is higher in case of Nss = 2, we observe a slightly lower throughput of the selected MCS-group in zone 1. In zone 2 we observe that an MCS of group 40MHz2ss outperforms the selected MCS-group. This is explained by a slight difference in the receiver sensitivity compared to the sensitivities defined by the standard and illustrated in Table 2. However, zone 2 is very limited and does not affect the overall performance of the selected MCS-groups.

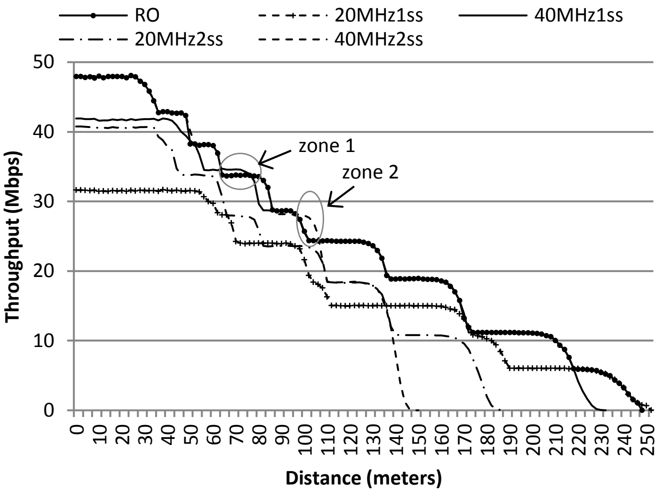

Figure 3. Throughput and range of selected MCS-groups (no frame aggregation)

In Fig. 4 we enable the use of frame aggregation which enhances the efficiency of the data rates and reduces the impact of the overhead. Therefore, the selected MCS-group in zone 1 outperforms the MCS used by group 40MHz1ss. However, the difference of zone 2 still exists.

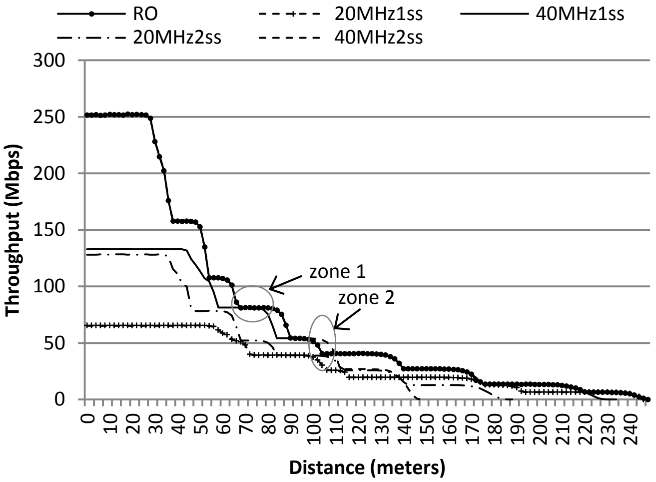

Figure 4. Throughput and range of selected MCS-groups (with frame aggregation)

To further evaluate our scheme, we use it with the well-established rate adaptation algorithm, MinstrelHT. So we compare the throughput of this algorithm with and without our scheme. We call MinstrelHTwRO the algorithm that uses our method, and we illustrate the results in Fig. 5 (no frame aggregation) and Fig. 6 (with frame aggregation). These results correspond to simulation duration of 5 seconds (largely enough compared to frame duration).

Fig. 5 shows that our scheme enhances the throughput and the stability (i.e. less fluctuation because less data rates are sampled) of MinstrelHT at almost all distances. We find that the proposed method enhances the overall throughput of MinstrelHT by 3.08% for all distances when frame aggregation (A-MPDU) is disabled.

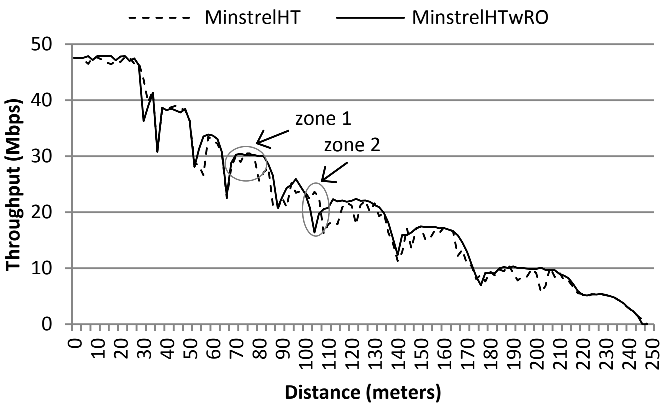

Figure 5. Evaluation of MinstrelHT with Rate Ordering (no frame aggregation)

When using frame aggregation, Fig. 6 shows that the performance of legacy MinstrelHT is significantly affected. This is because an A-MPDU has a high capacity, and choosing the wrong data rate to send an aggregated frame may reduce the WLAN throughput significantly. Besides, we notice that the fluctuation of legacy MinstrelHT is significant within the first 50 meters. This is related to the random sampling of data rates; sometimes the algorithm samples optimal data rates first, and sometimes tests them after a long time. By reducing the number of MCS-groups, MinstrelHTwRO is able to find the best rate quickly and to use it without significant throughput degradation. We note that our scheme enhances the overall throughput of MinstrelHT by 34.29% for all distances when A-MPDU is enabled.

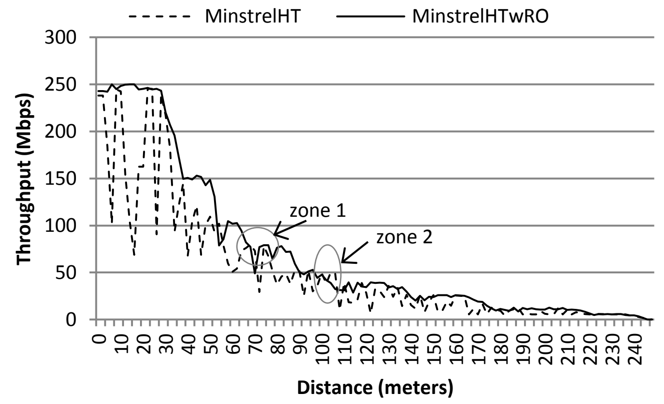

Figure 6. Evaluation of MinstrelHT with Rate Ordering (with frame aggregation)

Results in Fig. 5 and 6, show that zone 1 has no impact on MinstrelHTwRO, while zone 2 causes a very limited degradation. However, our scheme offers a significant throughput and stability enhancement for the remaining regions of the network.

VI. CONCLUSION

In this paper we introduce 802.11n/ac data rates and we show that increasing the channel width and Nss requires dividing the transmission power on the different sub-channels and spatial streams. This reduces the range of high throughput groups. Therefore, we show that groups with wide channels and high Nss do not always provide the best throughput. Then we introduce a rate ordering scheme which selects the MCS-groups that offer the best network throughput. Our scheme orders these MCS-groups from highest data rate with shortest range to lowest rate with largest range. Therefore, it allows any rate adaptation algorithm to switch easily from a rate to another. The simulation results show that the proposed scheme offers a precise selection and ordering. Besides, we show that it enhances the throughput and the stability of MinstrelHT.

Although, the proposed scheme is very interesting and practical, we believe that introducing the power spreading and the range variation of high throughput groups has a major importance for researches in the field of HT and VHT networks. This is because existing rate adaptation algorithms are not aware about the range variation, and operate according to weak and non-efficient principles. Due to space limitation, we focus on 40 MHz transmissions and 2 spatial streams. Therefore additional work should follow to provide more results for larger channels (160 MHz) and up to 8 streams. Besides, we rely on the minimum power sensitivity defined by 802.11 to define our scheme. So it can be improved in a future work by considering the real device sensitivity which may be slightly different than the minimum required by the standard.

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