Performance and Throughput Analysis of IEEE 802.11ah for Multiband Multimode Operation

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***Abstract*- Recent advancements in wireless technology has led to the development of large number of Machine-to-Machine (M2M) and Internet of Things (IOT) applications, with the fastest foreseen growth rate in coming years. The key functional requirements include long range, energy efficiency and suitable data rates. To provide a better solution compared to existing wireless technologies, IEEE 802.11ah HaLow was standardized by making amendments to IEEE 802.11 in 2016. It is a sub 1 GHz IOT Brand WiFi Technology with the capability of multiple band multimode of operation , improved physical and link layer, longer transmission range, energy conserving mechanisms and operability of up to 4 spatial streams. However, an in-depth performance analysis of this standard needs to be further investigated. This work provides BER and Effective throughput analysis of IEEE 802.11ah for various modes of operation. The presented analysis is helpful for the development of adaptive modulation & coding to include link adaptation in this standard.**

Keyword: IOT brand WiFi technology, IEEE, 802.11ah, Sub 1 GHz, AWGN, BER and Effective Throughput.

I. INTRODUCTION

Recently, Wireless networks have achieved a huge audience due to variety of applications in areas such as surveillance, wildlife monitoring, data communication, etc.[1, 2]. New wireless standards are being developed and implemented after amendments to the original IEEE 802.11 or subsequent protocols [3]. Many countries in America, Europe and South East Asia have been using a wireless protocol drafted in 2016 named “IEEE 802.11ah HaLow”. It is an Internet of Things (IOT) brand Wifi technology. Improvement to the original Wifi Protocol IEEE 802.11 allows it to have a long Range, enhanced power saving mechanisms, multi band multimode operation capability ranging from 1 MHz to 16 MHz up to 10 modes in each band respectively, and suitable data rates[4, 5]. The physical layer uses the concept of Orthogonal Frequency Division Multiplexing (OFDM) [6] conferring system resilience to selective fading and signal Inter-Symbol Interference (ISI). Such characteristics give it an edge over single carrier systems. OFDM being a multiplexing technique allows multiple signals to be sent simultaneously with better bandwidth utilization as compared to single carrier signal. In order to reduce the complexity of the equalizers at the receiver, Inverse Fast Fourier Transform (IFFT) is used to add subcarriers in OFDM [7]. This helps solve the problem of making series of narrowband channels from a single wideband channel.

Different authors have evaluated IEEE 802.11ah since the standard was drafted. They found it to have Long range, bandwidth flexibility and suitable data rates. This gives it a huge advantage over other standards allowing it to be used in many applications especially related to IOT. [8-10] are based on TGn channel model and 3GPP cellular simulation channel model in indoor and outdoor environments, respectively.

Technical summary provided by [8] is based on PHY and MAC layer IEEE 802.11ah with SISO for TGn channel model and 3GPP cellular simulation channel model in indoor and outdoor environments, respectively. Their work also presented Throughput versus MCS at 200mW transmission power and transmission range vs Transmission power analysis. A concept of enhanced coverage range extension of IEEE 802.11ah through repetition was discussed in [2]. The coverage range of MCS 0 – Repetition 2 for 1 MHz is higher than MCS 0 for 2 MHz bandwidth.

Differentiation between IEEE 802.11ah and 802.11a/n/ac in terms of throughput and transmission range has been presented in [9]. The scenario considered was of one radio link made up of two stations, Transmitter and Receiver, exchanging data frames with different payload sizes. It is concluded that on the basis of lower frequency band, narrow bandwidth, less propagation loss, improved power spectral density and robust coding scheme, IEEE 802.11ah has much wider use compared to others. IEEE 802.11ah has five times improved version of the second best range of IEEE 802.11a and 10 times improved range as compared to IEEE 802.11n (at 2.4 GHz band) having the lowest performance. However IEEE 802.11ah has lower throughput compared to others, a restriction that should be kept in mind when it is used for applications requiring higher data transmission rate.

Analysis of [10] are based on micro and pico deployment. Bit rate versus range for uplink and downlink scenario. Concluding that as the range increases the bit rate decreases. Details of the parameters selected are also provided in it. A detailed survey [11] of the challenges and implications of WLAN deployments mentioned in scientific literature from 2002 to 2014 has been performed. IEEE 802.11ah throughput analysis of different MCS, outdoor path loss models for Micro and Pico/Hot zone deployments respectively, detailed over of different long range Networks, common and proposed path loss models with problems during transmission.

Comparison between IEEE 802.15.4 and IEEE 802.11ah shows that IEEE 802.11ah has better performance with regards to Association time, Throughput, End-to-End delay and Coverage range [12]. Technologies that are considered notable contenders for IOT on the basis of frequency band, Data rate, throughput for different spatial streams, Coverage range, Power consumption, Number of stations and their MAC features is presented by [5, 13]. Comparisons among such technologies provide a better view as to which among them is most suitable for a certain application.

Fig. 1 represents the channelization of IEEE 802.11ah in different parts of the World. Each Country or Continent has their specific frequency band in which they utilize this protocol.

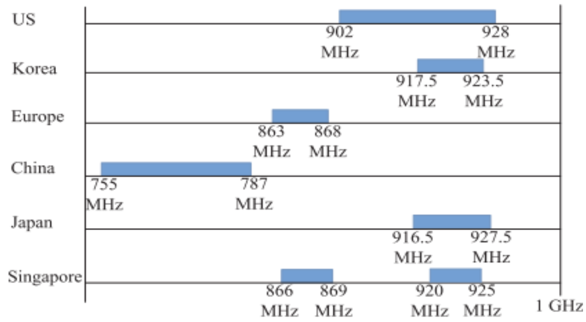

Fig. 1. Channelization of 802.11ah [2, 5, 8].

There is no such work that has provided detailed BER and effective throughput analysis on multimode multiband. This paper provides such comparison in AWGN. In the above given literature and in [8, 9], there is no such work of this dept regarding IEEE 802.11ah multimode comparison in multiband. In 4 bands, a collective 22 modes are implemented in the paper. This paper is organized as follows. Section I dealt with general introduction, Section II is divided into 2 parts. System model of IEEE 802.11ah is presented first which contains PHY layer Block diagram and Parameters. Secondly, modes/bands are described for which simulations are performed. Section III gives details about the performance analysis of IEEE 802.11ah in AWGN. Section IV concludes the findings of the paper.

II. SYSTEM MODEL

A. Block diagram of PHY layer of standard

OFDM is being implemented in the PHY layer of IEEE 802.11ah. Block diagram and PHY layer properties are shown in Fig. 2 and Table I respectively.

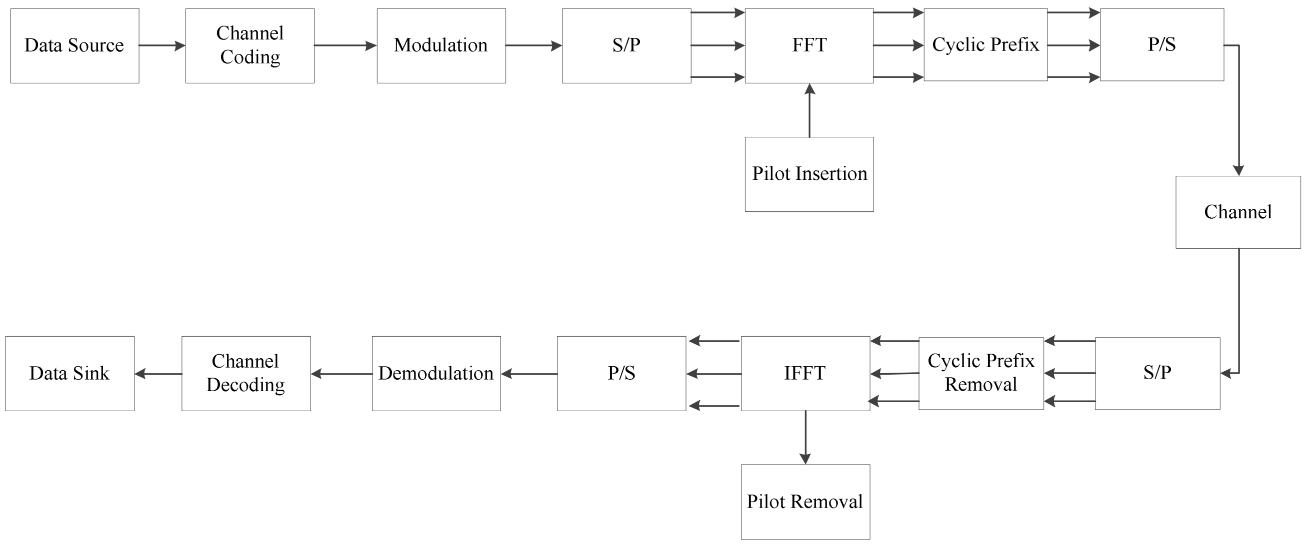

Fig. 2. PHY layer block diagram of IEEE 802.11ah

Table I. provides detailed PHY layer parameters of IEEE 802.11ah. Some of the properties are flexible for different bandwidths.

Table I. PHY layer characteristics of 802.11ah [8, 9, 11, 14-17]

Parameter	Values
Modulation	BPSK,QPSK,16 QAM, 64 QAM and 256 QAM
Multiplexing	OFDM and MIMO for downlink Multi-User MIMO (DL MU – MIMO)
Code Rate	1/2 with 2 times repetition using MCS 10 for 1 MHz only, 1/2 ,2/3, 3/4 and 5/6
Modulation and Coding Scheme (MCS)	MCS 0 up to MCS 10 are available. MCS 10 only for 1MHz channel with code rate 1/2 2x repetition.
Multiband	1 MHz, 2MHz, 4MHz, 8MHz and 16 MHz The best utilized channel bandwidth is of 1 MHz but with channel bonding it can create 16 MHz wide channel.
Range	Flexible around 1000m
Max. STAs	Up to around 8000
Data rate	150 kbps (1MHz channel bandwidth, 1 spatial stream, BPSK, 1/2 coding rate, repetition coding) to 347 Mbps (16 MHz channel bandwidth, 256-QAM, 5/6 coding rate)
Number of data/total subcarriers per OFDM symbol	24/32 (1MHz) 52/64 (2MHz) 108/124 (4MHz) 234/256 (8MHz) 468/512 (16MHz)
No of pilots per Channel	2 pilot (1 MHz) 4 pilot (2MHz) 6 pilot (4MHz) 8 pilot (8MHz) 16 pilot (16MHz)
Spatial stream	Minimum 1, up to maximum 4
MIMO	4x4 multi-User MIMO (MU-MIMO)
Preamble	For 1MHz is Short 2,4,8 and 16 has Long
Subcarrier spacing	31.25 kHz
Fast Fourier Transform (FFT)	32 for 1 MHz channel, 64 for 2MHz channel. Also supports 128, 256 and 512
Transmission Power	10 mW < Ptx < 1 W (depending of country's regulations)
Cyclic Prefix	25 % of the OFDM symbol length

B. *Multimode Operation*

Multiple bandwidths give the ability to implement IEEE 802.11ah in multiple scenarios. Multiple bandwidths supporting variety of data rates make it much more flexible as compare to WiFi protocols which are implemented in a specific band. With multiple bands (1 MHz, 2 MHz, 4 MHz, 8 MHz and 16 MHz) mentioned in Table I, along with PHY properties of IEEE 802.11ah, it is important to mention multi mode operations as well. The official 2016 Draft to IEEE 802.11ah provides the PHY and MAC layer Specifications as detailed in [18].

Multiband, multimode (for all spatial streams) parameters are mentioned in it. Due to the variety modes offered by IEEE 802.11ah standard, it be applied to many multiuser scenarios having differential Quality of Service (QoS) requirements. One of them is video surveillance using swarm of Unmanned Airborne Vehicles (UAVs). With a maximum throughput requirement set to 5Mbps with minimal bandwidth, some suitable modes are selected. General parameters for simulations are 1 spatial stream, AWGN, Modulation (Mod) schemes, MCS index, Code rates (R), Number of subcarriers per OFDM symbol (N_{sd}), Number of pilot symbols per OFDM symbol (N_{sp}), Guard interval (GI) , Number of BCC encoders (N_{es}) and selected modes of operations are given in tables II, III, IV & V.
For all the MCS indices in all the Bandwidths, the common design parameters are $N_{es} = 1, GI = 8\,\mu sec$ and $N_{ss} = 1$ respectively.

Parameters that are similar only for all MCS indices in 1 MHz are $N_{sd} = 24$ *and* $N_{sp} = 2$ respectively.

Table II. Design Parameters for 1 MHz

Bandwidth of 1 MHz					
MCS Idx	**Mod**	**R**	N_{cbps}	N_{dbps}	**Data rate (Kbps)**
0	BPSK	1/2	24	12	300.0
1	QPSK	1/2	48	24	600.0
2	QPSK	3/4	48	36	900.0
3	16-QAM	1/2	96	48	1200.0
4	16-QAM	3/4	96	72	1800.0
5	64-QAM	2/3	144	96	2400.0
6	64-QAM	3/4	144	108	2700.0
7	64-QAM	5/6	144	120	3000.0
8	256-QAM	3/4	192	144	3600.0
9	256-QAM	5/6	192	160	4000.0

Parameters that are similar only for all MCS indices in 2 MHz are $N_{sd} = 52$ and $N_{sp} = 4$ respectively.

Table III. Design Parameters for2 MHz

Bandwidth of 2 MHz					
MCS Idx	**Mod**	**R**	N_{cbps}	N_{dbps}	**Data rate (Kbps)**
0	BPSK	1/2	52	26	650.0
1	QPSK	1/2	104	52	1300.0
2	QPSK	3/4	104	78	1950.0
3	16-QAM	1/2	208	104	2600.0
4	16-QAM	3/4	208	156	3900.0

Parameters that are similar only for all MCS indices in 4 MHz are $N_{sd} = 108$ and $N_{sp} = 6$ respectively.

Table IV. Design Parameters for 4 MHz

Bandwidth of 4 MHz					
MCS Idx	**Mod**	**R**	N_{cbps}	N_{dbps}	**Data rate (Kbps)**
0	BPSK	1/2	108	54	1350.0
1	QPSK	1/2	216	108	2700.0
2	QPSK	3/4	216	162	4050.0
3	16-QAM	1/2	432	216	5400.0

Parameters that are similar only for all MCS indices in 8 MHz are $N_{sd} = 234$ and $N_{sp} = 8$ respectively.

Table V. Design Parameters for 8 MHz

Bandwidth of 8 MHz					
MCS Idx	Mod	R	N_{cbps}	N_{dbps}	Data rate (Kbps)
0	BPSK	1/2	234	117	650.0
1	QPSK	1/2	468	234	1300.0
2	QPSK	3/4	468	351	1950.0

Table VI. Packet size for different bandwidths

Bandwidth (MHz)	Packet size
1	QAM and PSK with 216 and 72 packets respectively. Each with 100 bit per packet
2	QAM and PSK both with 312 packets with 100 bit per packet
4	QAM and PSK with 216 and 162 Packets respectively. Each with 100 bit per packet
8	QAM and PSK both with 351 packets with 100 bit per packet

III. PERFORMANCE ANALYSIS

A. BER performance

In this section, we present detailed BER analysis of the selected modes of operation listed in Table II through V. Fig. 3 shows the BER performance of 10 modes utilizing 1 MHz bandwidth. In which MCS 0 gives the best performance with BPSK but MCS 9 has the worst performance with modulation scheme of 256 QAM. Higher modulation schemes provide higher data rates but results in poor performance. The analysis of effective throughput for selected modes of operation is discussed in the next section.

From Fig. 3-6, it can be shown that BER performance is degraded as we move to higher MCS indices. Fig. 3 portrays BER curves of 1 MHz bandwidth with selected MCS indices. MCS 0 gives the best performance among all the indices selected. It is clear that MCS 0 shows almost 17dB performance improvement as compared to MCS 9. An interesting observation is that MCS 2 and MCS 3 having different modulation schemes, show almost similar performance especially at higher SNRs. The reason is the difference of code rates associated with these modes. A similar observation about MCS 2 and MCS 3 can also be observed in Fig. 4-5.

It can be concluded that as the modulation scheme or the bandwidth increases the data rate increases. The higher MCS indexes will result in poorer performance as compared to smaller MCS indexes as the SNR increases. Although, same MCS indices across different bandwidths result in similar BER performance, the increase in bandwidth directly affects the transmission range of that particular mode.

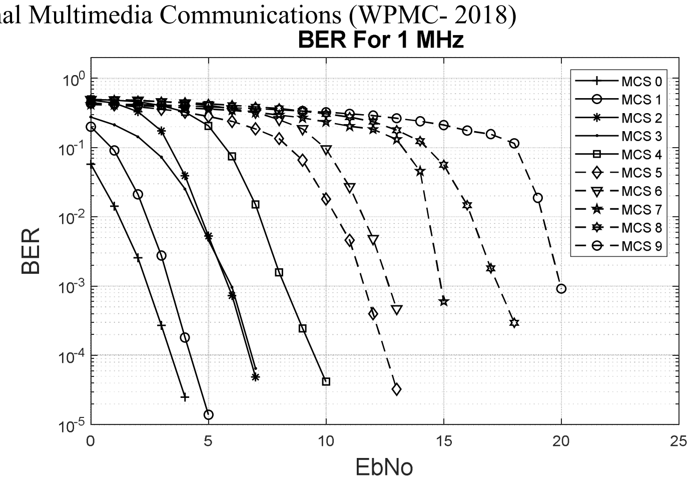

Fig. 3. BER plot of 1 MHz

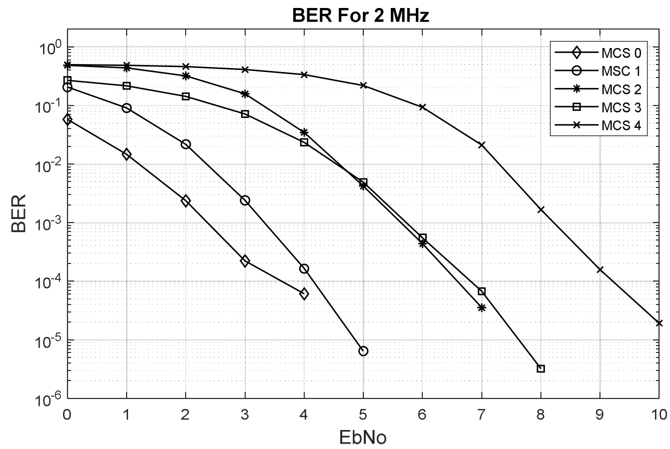

Fig. 4. BER plot of 2 MHz

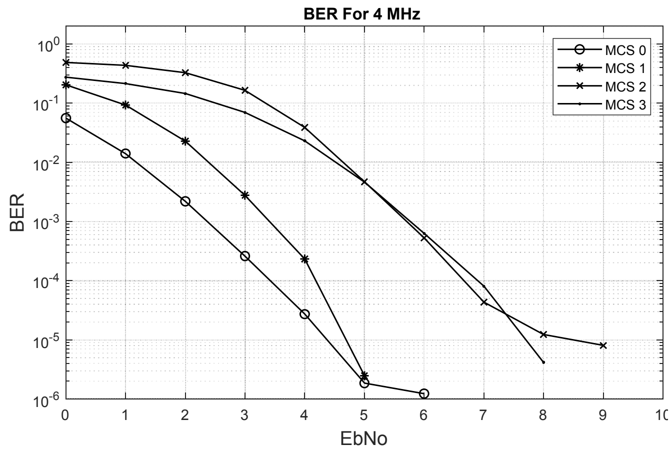

Fig. 5. BER plot of 4 MHz

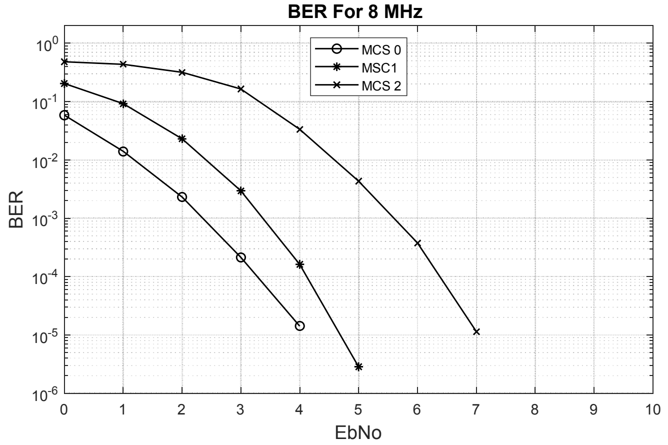

Fig. 6. BER plot of 8 MHz

B. *Effective Throughput*

In this section, we present detailed effective throughput analysis of the selected modes of operation listed in Table II through V. Fig. 7 shows the effective throughput of 10 modes utilizing 1 MHz bandwidth. MCS 9 gives the highest throughput due to the fact that it uses 256 QAM and MCS 0 giving the lowest throughput with BPSK. Equation (1) represents formula for calculation of Effective Throughput.

$$R_E = R_T\left(\frac{N}{N+N_R}\right) \quad (1)$$

R_E = Effective Throughput
R_T = Theoretical Throughput
N = Total Number of Packets Send.
N_R = Total Number of Retransmissions.

Fig 7-10 shows the effective throughput is showing steady increase as the SNR values increases before reaching a theoretical throughput. This increase is attributable to the fact that at smaller SNR values signal strength is weak and larger numbers of errors are present. This high number of errors results in an inability to achieve the desired theoretical throughput. As the signal strength increases leading to a decrease in errors, the effective throughput starts to steadily increase and reaches the theoretical throughput. Beyond that SNR, effective throughput becomes steady for rest of the SNR values. In some of the modulation indexes the steady increase of effective throughput is achieved quickly as compared to other modulation indexes. In similar or different bands MCS 0 achieves theoretical throughput faster than others MCS indexes. Before going into the details of each figure, it is important to discuss selection of multimode in multiband for a system. As discussed above higher MCS indexes does provide higher data rates but at cost of higher SNR and retransmissions. So for a simpler and with less number of retransmissions in a system, it is suggested to select smaller MCS indexes but data rates will be low as compared to higher indexes.

In Fig. 7, 1 MHz bandwidth with MCS 9 shows no increase in effective throughput till 14dB. When compared with other indexes they are all either showing steady increase or have already reached their theoretical throughput. The effective throughput remains the same because of high percentage of errors, till the point Signal strength increases to the value at which the errors start to reduce. Theoretical throughput is achieved for different modulation indices at different SNR values. Also the 1 MHz with MCS 9 achieving throughput of 4000 kbps but in Fig. 8 with BER curves for 2 MHz giving 3900 kbps at MCS 4. Smaller MCS index, consider table II-III for comparison of MCS 4 and MCS 9 of different Bandwidths, giving approximately similar effective throughput due to the fact that different bandwidth are considered Even through MCS 9 of 1 MHz has 256 QAM compared to MCS 4 of 2 MHz with 16 QAM.

Similar reasoning can be done for Fig. 9-10. It is concluded that at higher bandwidths and smaller MCS indexes will result in higher throughput or data rates. Higher MCS indexes at higher bandwidths provides much higher effective throughputs but there BER performance will be considerably poorer.

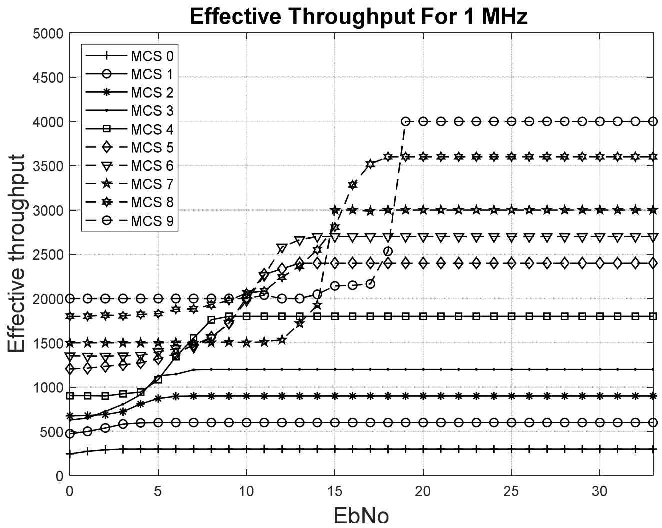

Fig. 7. Effective throughput plot of 1 MHz

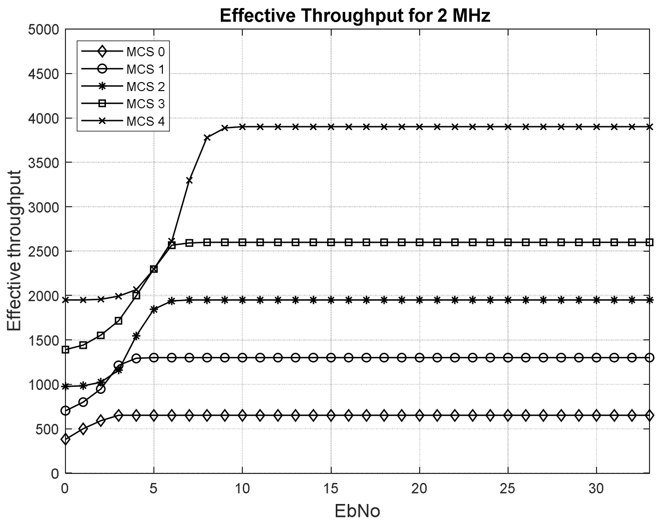

Fig. 8. Effective throughput plot of 2 MHz

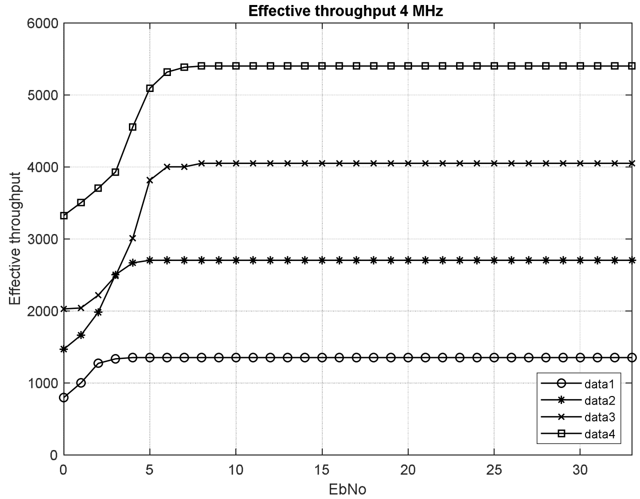

Fig. 9. Effective throughput plot of 4 MHz

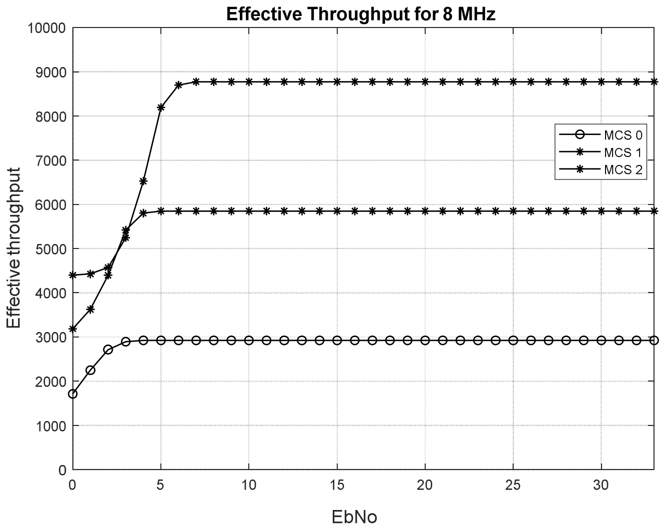

Fig. 10. Effective throughput plot of 8 MHz

IV. CONCLUSION

In this paper, multimode multiband analysis of IEEE 802.11ah has been performed. The BER performance of MCS indexes improves with increase in SNR showing a decrease in errors. However the error probability also increases at larger bandwidths with increased data transmission rate. The analysis provides an overview of the properties of various modulation indices, making it easier to select a particular index based on specific QoS requirements (higher data rate or better performance). MCS 0 shows better performance and the lowest effective throughput compared to other MCS indexes in each of the bandwidths. Such analysis provides a better point of view in decision making regarding link adaptation in a radio link. In future work, we intend to extend our work by analyzing IEEE 802.11ah in different fading channels.

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