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Optimal Peak Power Ordering (OPPO) in MMSE-SIC for IEEE802.11ac Industrial Standard

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Abstract

IEEE 802.11ac is the fifth generation in Wi-Fi networking standard which will be a boom to the next generation wireless networks. It will bring fast, high quality video streaming and nearly instantaneous data syncing and backup to notebooks, tablets and mobile phones that have become our everyday companions co-existing with the other legacy 802.11 standards. The most important features proposed in the IEEE 802.11ac amendment include larger channel bandwidth of 160 MHz, a denser modulation scheme 256 quadrature amplitude modulation(QAM) and a MU-MIMO (multiuser MIMO) supporting up to eight spatial streams . In this paper we have proposed to detect the spatial streams in 802.11ac device using (2×2), (4×4), (8×8) MU-MIMO systems using some of the MIMO detection algorithms. Hence, the main aim of this paper is to evaluate the effect of Detectors/Interference Canceller (IC) like Zero-forcing (ZF), Minimum Mean Squared Error (MMSE), and the proposed ZF-Successive IC(SIC)- OPPO , MMSE -SIC-OPPO for WLAN on the performance of 802.11ac standard in a Rayleigh fading channel.

1. Introduction

Mobile data traffic is projected to experience an 18-fold increase between the years 2011 and 2016 due to the growth of mobile subscribers and bandwidth demands to support data hungry applications Consequently, there is a need for devices and standards capable of coping with the next generation mobile networks that require very high data rates to sustain video, voice, live gaming, and augmented reality applications, To this end, IEEE 802.11ac is the latest Wi-Fi standard that builds upon 802.11n by improving data rates, network robustness, reliability, and RF bandwidth utilization efficiency. Hence more measures are being taken to enhance the performance of the same in both the PHY and MAC layer. Limited to the scope of this paper we are considering only the PHY layer to evaluate the detection of the 802.11ac signals.

When the data is transmitted at high bit rates, over mobile radio channels, the channel impulse response can extend over many symbol periods, which leads to Inter symbol interference (ISI) which is a critical factor. The operation of 802.11ac in the dual-band (2.4 GHz and 5 G Hz) creates many sources of interference and noise over the various channel bandwidths in accordance with the spatial streams which will be considered further in the Section 3. In order to cancel out the interference completely, general MIMO detection techniques such as ZF, MMSE, ML, ZF-SIC and MMSE-SIC is used. More and more detection schemes is being proposed to enhance the performance with a complexity trade-off. Jaime Adeane et. al, [1] proposed Lattice reduction detection, Partial reduction and BLAST techniques which performed well but at the expense of increased complexity when the number of antennas or spreading sequences increases. Bindu et. al, [2] showed the performance of detectors but with an increased complexity in MIMO (2×2). ZF-SIC outperformed MMSE-SIC in the case of complexity with a low performance . G. J. Foschini et.al [3,4] and Chien-Jen Huang et. al [5], evaluated the performance of detectors in multi-antenna systems. ML outperforms all other systems with an increased complexity of the order $O(C^N)$. C is the constellation size and N is the number of antennas.

Kumar K.R et.al., [6] proved that both ZF, MMSE achieved the same Diversity Multiplexing trade-off (DMT) in WLAN(802.11n). Moreover the linear receivers had a loss of diversity gain compared to non-linear receivers. Roger Pierre Fabris Hoefel [7] proposed lattice reduction techniques for MMSE, ZF in 802.11ac and concluded that LR-MMSE outperformed LR-ZF .Raw BER and PER are taken for result comparison. Xu Qiang et. al [8] proposed QRM-MLD-LLR detection of signals in coded 802.11 ac MIMO system. Reduced constellation search was performed with MMSE-SIC which gave improved throughput results for the variation in SNR.

The paper is organized as follows. Section 2 gives the system model. In Section 3, brief introduction to IEEE 802.11ac is listed comparing with the legacy standards 802.11n. Various detection techniques with the proposed MMSE-SIC(OPPO) for 802.11 ac is given in Section 4. Plotted Results along with simulation parameters for various antennas are discussed in Section 5. Finally conclusion is discussed in 6.

2. System Model

WLAN system model consisting of a single AP with N antennas and multiple STA's with M antennas is shown in Fig 1. Here N=M=8 is considered since we use 8 spatial streams for detection. In MU-MIMO only one antenna is considered for each STA.

However we can also extend our model to MU-MIMO where multiple antennas are considered for each STA. For MU-MIMO, considered in our model the transmitted signal from the AP with beam forming at any time instant is given by [9],

$$X = bS \tag{1}$$

where X is the transmitted signal, b is the beam forming vector and S is the transmit data symbol of AP with unit power. Here since we are not considering beam forming, substitute b = 1 in Equn (1). Therefore $X = S$ is considered in our proposed model for proper detection of signals at the STA. Hence the signal without beam forming at any time instant received by any STA is given by

$$Y = HS + n \tag{2}$$

where H is the channel matrix given by

$$H = \begin{bmatrix} h_{11} & \cdots & h_{1n} \\ \vdots & \ddots & \vdots \\ h_{m1} & \cdots & h_{mn} \end{bmatrix} \tag{3}$$

and n is the noise vector added at the STA

2.1 IEEE 802.11ac Standard:

IEEE 802.11ac is a revolutionary standard [10], which aims at providing Very High Throughput (VHT) to the end users without compromising for the other degrading factors such as SNR, delay, etc. It will be able to supply the wireless data rates and client capacity that are demanded by the increasingly mobile business community as it is theoretically able to exceed the 1 Gigabit-per-second (Gbps) border . This standard will be able to achieve throughputs of up to 6.93 Gbps in the extreme settings case; using 160 MHz channel bandwidth, 8 spatial streams, 256-Quadrature Amplitude Modulation (QAM) and Short Guard Intervals (GIs). Till now the product development phase of 802.11ac has given a maximum throughput in two sections: Wave 1 (1.3 Gbps) and Wave 2 (2.6 Gbps) [11,12].

In this paper we have taken 802.11ac standard for the study of detection as well as interference cancelation algorithms used in MIMO detection. So this section deals with some insights in to the 802.11ac standard. 802.11 ac has evolved out from 802.11n. The major improvement made to 802.11n in terms of data rate and throughput are listed in Table 1 [12, 13]. The modifications made at the physical layer gave data rate improvement where as the enhancements made at the MAC layer improved the throughput. Hence the feature, VHT (Very High Throughput) is a special form of characteristics for 802.11ac devices compared with HT of the 802.11n devices.

The data rate calculation for a typical 802.11n/ac device is shown in below [13]. In general the data rate for a 802.11n/ac device is given as

$$Data\ Rate = \frac{BW(interms\ of\ Data\ Carrier) \times SS \times Data\ bits\ per\ SC}{Guard\ Interval} \tag{4}$$

where BW is the Channel bandwidth, SS is the number of spatial streams, SC represents sub carrier.

3. Detectors

3.1 Zero Forcing (ZF) Detector

A ZF detector uses an inverse filter to compensate for the channel response function, this results in the removal of the interference from all other symbols in the absence of the noise. Zero forcing is a linear detector method that does not consider the effects of noise, thus noise may be enhanced in the process of eliminating the interference [14]. From Equn (2 and 3), we get the representation of H, the channel matrix for 802.11ac. In this case, we consider the channel state information is known to the receiver and so we multiply inverse of H on both sides of the above equation

$$yH^{-1} = S + nH^{-1} \quad (5)$$

To solve for x, We need to find a matrix W_{ZF} which satisfies the condition below

$$W_{ZF}H = 1 \quad (6)$$

The Zero forcing linear detector for meeting the above constraint is given by:

$$W_{ZF} = (H^H H)^{-1} H^H \quad (7)$$

The covariance matrix of the effected noise may be calculated as:

$$E[(nH^{-1})^H . nH^{-1}] = (H^{-1})^H . E[n^H . n] . H^{-1} = N(H . H^H)^{-1} \quad (8)$$

It is clear from the above equation that noise power increases because of the factor $(H . H^H)^{-1}$. If the number of transmitter and receiver antennas is not same, we multiply by Moore–Penrose generalized inverse, pseudo-inverse of H to achieve a similar zero-forcing result. In other words, it inverts the effect of channel as

$$\hat{s}_{ZF} = W_{ZF}y = x + (H^H H)^{-1} n \quad (9)$$

3.2 Minimum Mean Square Error (MMSE) Detector

The MMSE detector is a optimal detection technique that seeks to balance between cancelation of the interference and reduction of noise enhancement [14]. Let us denote MMSE detector as W_{MMSE} and detection operation by

$$\hat{s}_K = sgn[W_{MMSE} y] \quad (10)$$

The W_{MMSE} that maximizes the SNR and minimizes the mean square error which is given by:

$$E[\{\hat{s}_K - W\_MMSE\ y)^T (\hat{s}_K - W_{MMSE} y)] \quad (11)$$

To solve for x , We need to find a matrix W_{MMSE} which satisfies the condition $W_{MMSE}\, H = 1$, MMSE linear detector for meeting above constraint is given by:

$$W_{MMSE} = (H^H H + \sigma_n^2 I)^{-1} H^H \quad (12)$$

$$W_{MMSE} = (H^* H + \frac{1}{SNR} I)^{-1} H^* \quad (13)$$

MMSE at a high SNR :

$$W_{MMSE} = (H^{*}H + \frac{1}{SNR}I)^{-1}H^{*} \approx (H^{H}H)^{-1}H^{H} \quad (14)$$

At a high SNR, MMSE becomes Zero Forcing.

3.3 Detection And Interference Cancellation Techniques

In high SNR regime, we follow the hybrid approach of combining the linear receiver schemes (ZF, MMSE) with a non- linear approach such as the SIC, which has the less complexity compared to the optimal ML approach. Inspite of the complexity , it gives better results at high SNR. Ordering a SIC holds good performance in the literatures [15]. Ordering such as Post- Signal-to-interference-plus-noise-ratio (SINR) based ordering , Post-Signal-to-noise-ratio (SNR) based ordering, Column -max norm-based ordering are followed which have a high BER in the high SNR-MIMO regime. In this paper ORPO is used as the ordering method and it gives better results compared to the existing methods .

3.3.1 Proposed OPPO method for SIC:

In SIC, the receiver takes one of the estimated symbol, and subtracts its effect from the other received symbols. However, we can have more intelligence in choosing which symbol should be subtracted from the effect of other received symbol. To make that decision, we have adopted our proposed OPPO to find out the transmit symbol (after multiplication with the channel) which came at higher power at the receiver. Fig 2. below gives the outline of SIC used both for ZF and MMSE detection procedure in the case of three streams/antennas.

Fig 3. lists the flow of SIC detection and cancellation using ZF/MMSE for a 2×2 MIMO channel. The received output power at both the antennas corresponding to the transmitted symbol s_1 is,

$$P_{o_{x_1}} = |h_{1,1}|^2 + |h_{2,1}|^2 \quad (15)$$

The received output power at both the antennas corresponding to the transmitted symbol s_2 is,

$$P_{o_{x_2}} = |h_{1,2}|^2 + |h_{2,2}|^2 \quad (16)$$

Doing successive interference cancellation with optimal ordering ensures that the reliability of the symbol which is decoded first is guaranteed to have a lower error probability than the other symbol. This results in lowering the chances of incorrect decisions. Hence gives lower error rate than simple successive interference cancellation.

4. Simulation and Results

The simulation parameters for the detection of 802.11ac which gives a throughput of 62.2Mb/s is given below:

The proposed OPPO for ZF/MMMSE-SIC gave an improvement in performance when the number of antennas/streams is increased. For an SNR of 20dB we get a minimum BER of 5.95×10^{-4}, 1.5×10^{-5} and 6.25×10^{-6} for MMSE-SIC-OPPO in 2, 4 and 8 spatial streams respectively. Moreover the percentage improvement in SNR and BER compared to other detections schemes are tabulated in Table 3 and 4:

5. Conclusion

The Detection and IC techniques like ZF,MMSE,ZF-SIC-OPPO and MMSE-SIC-OPPO were simulated using different antenna in the Rayleigh fading environment for the IEEE 802.11ac standard. The results of all four techniques were compared to the existing method. The Proposed OPPO method for both ZF-SIC and MMSE-SIC gave an improvement in both the SNR and BER. MMSE-SIC-OPPO detector out performs the other three detection techniques with the lowest SNR and BER for a MIMO (8×8) 802.11ac system but at the expense of complexity compared to ZF-SIC-OPPO.

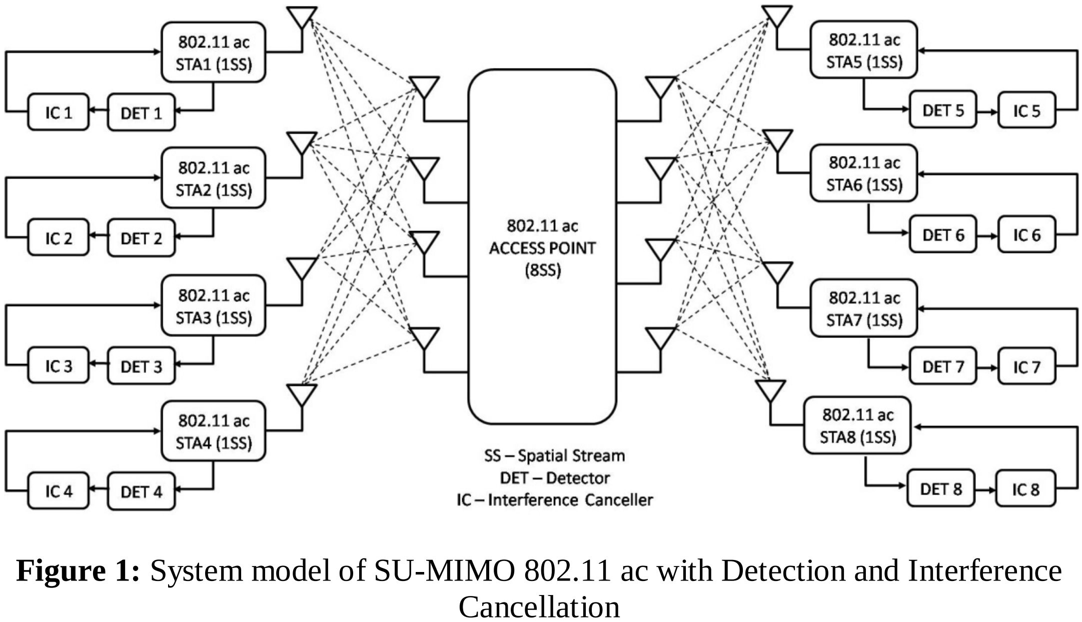

Figure 1: System model of SU-MIMO 802.11 ac with Detection and Interference Cancellation

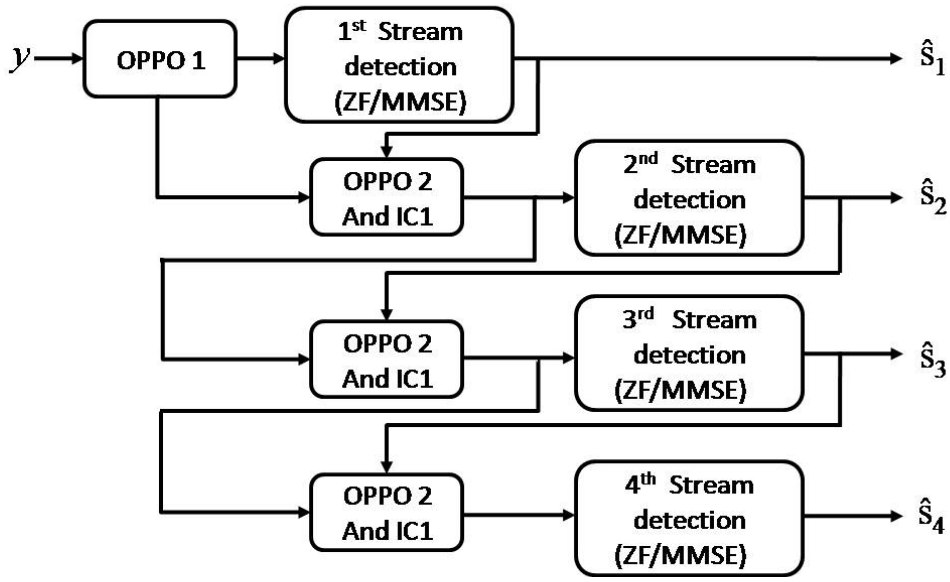

Figure 2: OPPO for ZF/MMSE in 802.11ac with four spatial streams (*N*=4)

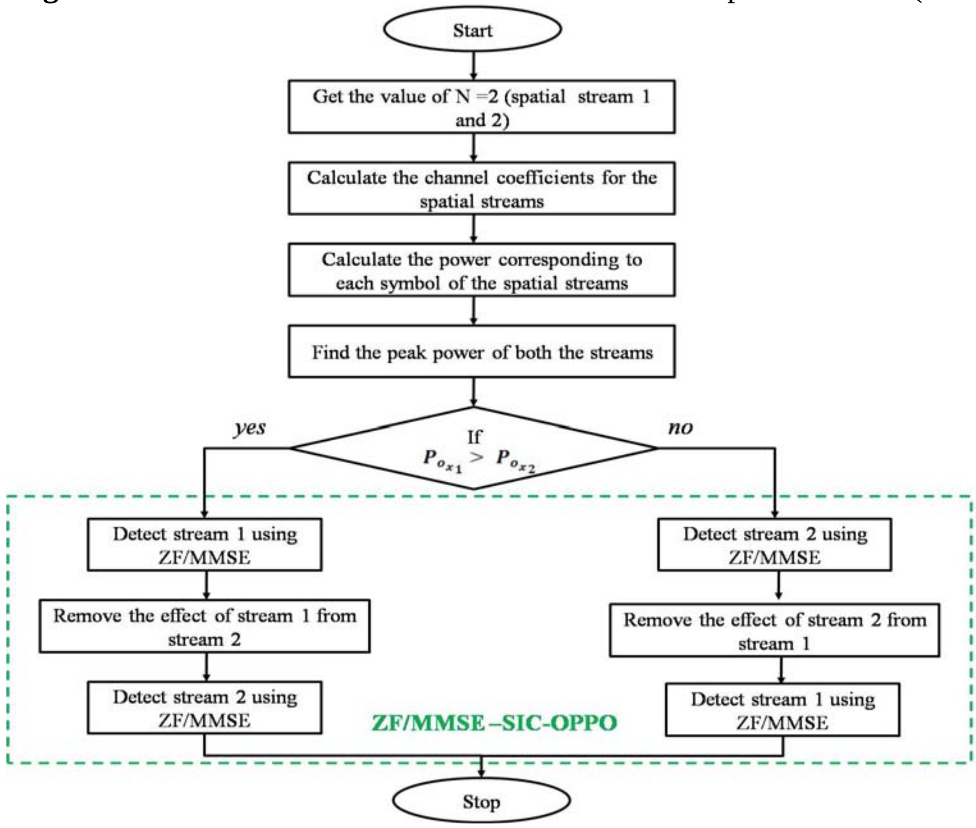

Figure 3: Flowchart for OPPO with two spatial streams (*N*=2)

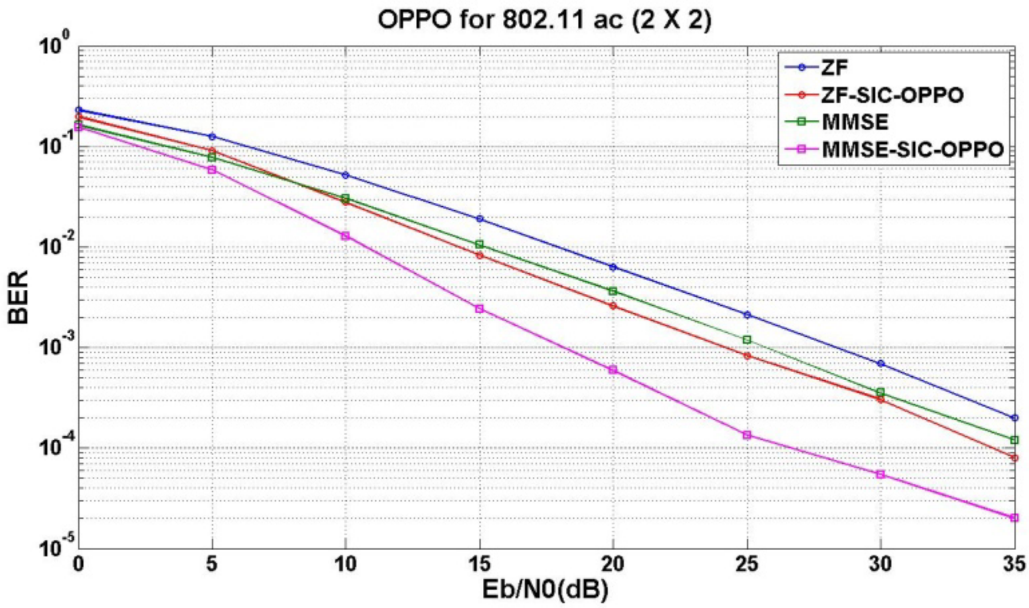

Figure 4: OPPO For 2 Spatial Streams

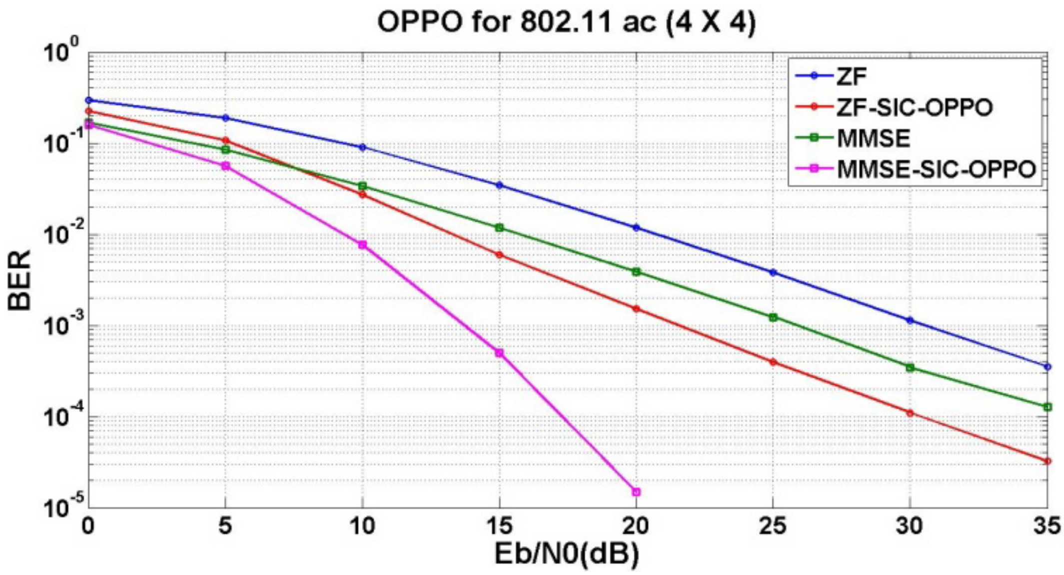

Figure 5: OPPO For 4 Spatial Streams

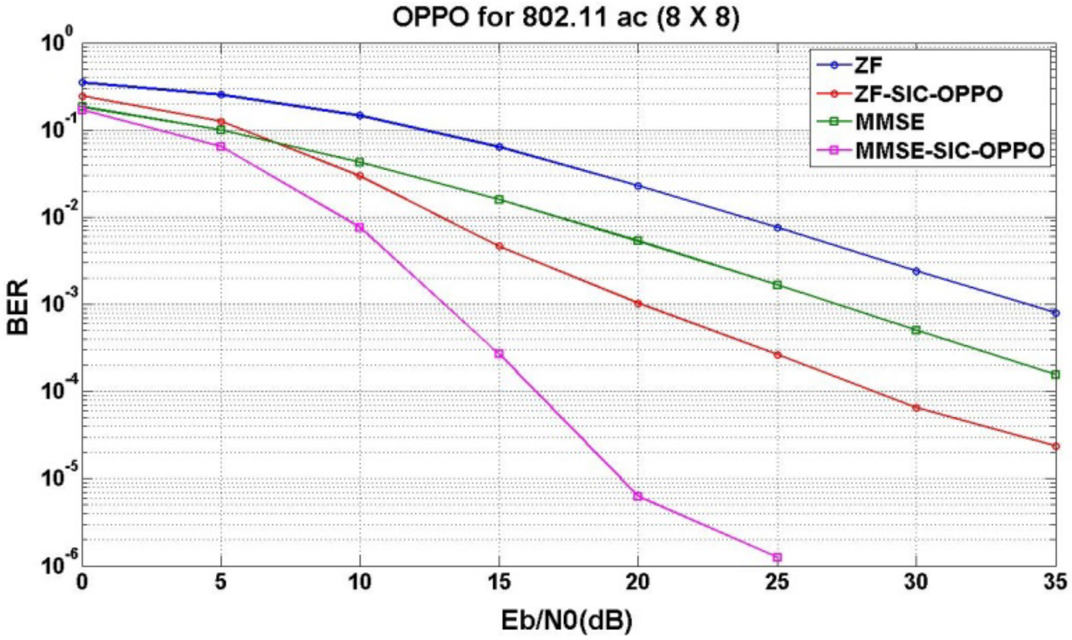

Figure 6: OPPO For 8 Spatial Streams

Table 1: Difference between 802.11n and 802.11ac

Parameter/Technique	**802.11n**	**802.11ac**
Channel BW	20 and 40 MHz	80 and 160 MHz in addition
Frequency bands	Supports 2.4 GHz and 5 GHz	Supports 5 GHz only
Modulation	BPSK, QPSK, 16-QAM, and 64-QAM	256-QAM
Beam forming	Supports many types of explicit beam forming	Supports only null data packet (NDP) explicit beam forming
Spatial Streams	Supports up to four spatial streams	Supports up to eight spatial streams (AP);
SU/MU transmission	SU transmission only	Adds MU transmission
MAC Enhancements	Includes significant MAC enhancements (A-MSDU, A-MPDU)	Supports similar MAC enhancements, with extensions to accommodate high throughput

Table 2: Simulation parameters

Parameter	Value	Parameter	Value
Modualtion	BPSK	Guard Interval	3.6µs (Short GI)
Channel BW	20 MHz	Coding	Uncoded
Beam-forming	1	SU/MU-MIMO	MU-MIMO

Table 3: SNR Improvement

Number of spatial streams	BER	SNR Improvement (%)		
		ZF with ZF-SIC-OPPO	MMSE with MMSE-SIC-OPPO	ZF-SIC-OPPO with MMSE-SIC-OPPO
2	10^{-3}	16	30	25
4		32	46	33
8		41	51	35

Table 4: BER Improvement

Number of spatial streams	SNR (dB)	BER Improvement (%)		
		ZF with ZF-SIC-OPPO	MMSE with MMSE-SIC-OPPO	ZF-SIC-OPPO with MMSE-SIC-OPPO
2	20	60.57	83.61	76.40
4		87.39	99.96	99.90
8		95.63	99.98	99.93

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