Performance Comparison of Linear and Non Linear Interference Cancellation Techniques for 3.466 Gbps WLAN

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Abstract— **The new WLAN standard IEEE802.11ac provides data rate up to 3.466Gbps by occupying 80MHz of bandwidth and eight spatial streams in modulation coding scheme index 9. However, these multiple streams configuration introduce dense interferences. This paper presents linear and non-linear techniques to cancel the interferences in very high data rate WLAN system. Those techniques were compared in term of performance and complexity. They are not only canceling the interference but also combining the multipath gain to obtain optimal signal to noise ratio. Zero Forcing (ZF) has the lowest complexity and performance. Minimum Mean Square Error (MMSE) considers the noise power to give better performance by low computation complexity. Maximum Likelihood Detection (MLD) gives the best performance by the cost of highest complexity, especially when deals with multiple streams. In the other side, other modern techniques, such as Sphere Detection and K-Best offer near performance to MLD by lower complexity. The comparison of those techniques was conducted under indoor channel model of IEEE802.11n Task Group.**

Keywords— Backward compatibility, Low PAPR, preamble, WLAN, IEEE802.11a/n/ac, Co-existence

I. Introduction

Healthcare Information System has been designed to improve health services to publics. It should be practical, easy, and can be accessed anywhere and anytime. A review of Electronic Health Record (EHR) execution in several places was reported in [1]. It was found that there was a lack of relationship between the physicians, the patients, and the technology which needs the support of high data rate wireless communication system.

The WLAN IEEE820.11ac is able to provide data rate up to 3.466Gbps by setting the modulation coding scheme index to 9, bandwidth 80MHz, and eight spatial streams [2]. However, these multiple streams configuration introduce dense interference signals that should be handled seriously.

To overcome this problem, one study proposed two-steps modified minimum mean square error (MMSE) interference cancelation in multi user – multiple input multiple output (MU-MIMO) system. It employed pre-filter to improve the quality of synchronization and followed by second filter to estimate the original transmitted signal. It used Gaussian posteriori symbol probability to suppress the interference and showed better BER performance. It gave 0.5 dB lower than the previous classical MMSE solution [3].

Designed structure for transceiver in single user (SU) and MU-MIMO full duplex precoding was proposed in. It was suitable for single carrier (SC) and OFDM systems which increased the dimensionality at the transmitter. It allowed the self-interference cancellation and forward beamforming to be jointly processed using precoding at the transmitter. The proposed structure implemented pre-processing schemes such as QR decomposition (QRD), Sorted QRD (SQRD), or MMSE-SQRD. [4].

In the other side, instead of using interference alignment pre-coding, another interference cancellation technique over MIMO Y channel combined space-time code and code word space alignment. It exploited the orthogonal property of Alamouti Code to eliminate the interference between code words. Here, the channel state information was not required so that number of feedback was significantly reduced [5].

K-Best detection algorithm was investigated to work with interference signal. The author has combined an estimation method and parallel sort approach to decrease the complexity. It adopted pipelined configuration in parallel and implemented the algorithm in Xilinx Virtex-6. It could attain data rate up to 2.8Gbps by four streams and 64QAM modulation. It was claimed that due to the adjustability of the proposed system, high performance interference cancellation can be achieved by low power consumption [6].

In line to cancel interferences in MIMO systems, Sphere Decoding (SD) is able to attain performance close to Maximum Likelihood Decoding (MLD) with lower complexity. A new approach to reduce the complexity was investigated in [7]. It proposed smart implementation to eliminate empty spheres. Simulation results showed that the proposed system gave significant complexity gain.

An implementation of robust SD technique to cancel interferences in MIMO systems which involved 256QAM for symbol error rate 10^{-3} was proposed in [8]. It is claimed that the proposed technique could reduce searching number to

3.6% compared to MLD with only 0.5dB performance difference.

Development of zero forcing (ZF), MMSE, and MLD equalizers for MIMO system in Xiinx Virtex 6 was presented in [9]. Several new and surprising analytical results in terms of output SNR, BER and the average detection time consuming were revealed.

Comparison of MIMO decoders based on ZF, MMSE, K-Best, Trellis, SD, and MLD methods was presented in [11]. The observation was conducted in IEEE802.11ac 40MHz for 1.266Gbps of throughput under small room channel model. It was shown that ZF and MMSE were the lightest in performance and complexity. K-Best, Trellis, and SD gave moderate performance by more complexity. MLD provided the best performance with the cost of highest computation complexity.

As the continuity research in IEEE802.11ac, this paper is addressed to compare the performance and complexity of linear and non-linear techniques in cancelling the interferences caused by MIMO channel. Those techniques are investigated in 80MHz of bandwidth, eight spatial transmission streams, and modulation coding scheme (MCS) is set to 7 and 9 to achieve 2.6 and 3.666Gbps of throughput.

The rest of this paper is organized as follow. Section II briefly presents diagram block of the proposed receiver for WLAN IEEE802.11ac with interference canceller. Section III shortly reminds the complexity of each interference cancellation techniques. IV displays simulation parameter and comparison of error performance and complexity of all interference canceller techniques. Finally, some conclusions and future works are drawn in Section V.

II. The Proposed Receiver for WLAN IEEE802.11ac

To obtain 2.6 and 3.666Gbps of throughput, the transmitter of WLAN IEEE802.11ac is set to MCS 7 and 9 with 80MHz of bandwidth and eight spatial streams. Here, we also propose a receiver side for IEEE802.11ac. The diagram block of the proposed receiver along with the interference canceller to decode the data portion of 80MHz bandwidth and eight spatial streams is drawn in Fig. 1.

Decoding process of the preambles that uses either auto or cross correlation were discussed in [12]. The output of the preambles decoding process, e.g. channel state information, noise power, frequency offset, were used to do carrier frequency synchronizing, phase tracking, and interference cancellation.

The start of packet is determined after returning the received carrier frequency and synchronizing with the generated carrier frequency.

After each guard interval (GI) is removed from data field, the payload data contained in orthogonal frequency division multiplexing (OFDM) time domain symbol is extracted. Fast Fourier Transformation (FFT) is used to convert the time domain OFDM symbol into frequency domain payload data.

The output of the channel estimator is fed into phase tracker and interference canceller. Phase tracker is used to compensate phase shift experienced by the received data due to MIMO wireless channel. Interference canceller is used to cancel all of the interferences that come along with the received signal due the use of multiple spatial streams. Here the linear and non-linear techniques of interference cancellation are implemented. For linear techniques, the ZF and MMSE are introduced, while non-linear techniques use the SD, K-Best, and MLD techniques. From Fig. 1, it can be verified that the channel estimation, phase tracking, and interference cancellation are conducted in frequency domain, due to the easiness of the process.

After interference cancellation, the signal is fed into De-Mapper to return digital symbols into bit streams. De-Interleaver is used to return the sequence of bit streams to theirs original order.

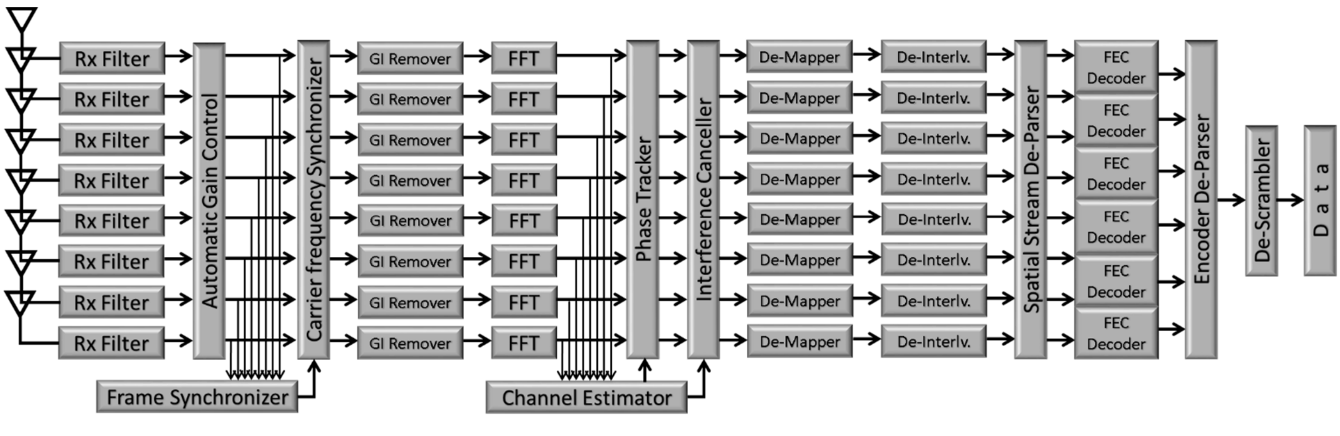

Fig. 1. The proposed receiver for IEEE 802.11ac 80MHz bandwidth and eight spatial streams completed with Interference Canceller. This proposed receiver is used to decode the received data portion.

Spatial stream De-Parser is used to divide eight streams of bits into six streams of bits by round robin rule. Here, six Forward Error Correction (FEC) decoders are needed to achieve integer number of punctured blocks for each FEC decoder per OFDM symbol. Soft Viterbi Algorithm is used in each FEC decoder to decode the received data which are coded using binary convolutional code at six FEC encoders the transmitter.

Encoder De-parser is used to de-multiplex six bit streams from six FEC decoders into one bit stream using round robin rule. Finally, De-Scrambler is used to return the data into original order of bit stream.

III. Linear and Non-Linear Interference Cancellation Techniques

Most of the WLAN IEEE802.11ac receiver device designers prefer to implement simple technique to cancel the interferences rather than the complex ones. This is because market reasons instead of technically reasons. However, simple techniques should be paid by low error performance. For the high performance communication minded, the designers offer to use the non-linear techniques. They are able to provide high performance interference cancellation by the cost of increased complexity.

A. Linear Techniques

Zero Forcing (ZF) is always the first to be observed for it is the simplest way to cancel the interferences. It needs the lowest calculation numbers among the other techniques. The easiest to be implemented in the hardware but the lowest in performance.

Minimum Mean Square Error (MMSE) is the second option in cancelling the interferences of MIMO channel by linear techniques. It can give better performance than ZF because it considers the noise that come along with the received signal. The number of calculation needed for these linear techniques is only determined by the number of transmit antennas, as expressed by equation (1) [13]:

$$C = N_{Tx}^2 + N_{Tx} \quad (1)$$

where C is the number of calculation and N_{TX} is the number of transmit antenna.

B. Non-Linear Techniques

Instead of focusing on the interferences done by linear techniques, the non-linear techniques directly pay attention to the received symbols. To filter the interferences, they compute the closest distance of received symbol to available symbol candidates.

The maximum likelihood detection (MLD) technique calculates the partial Euclidean distance (PED) of the received symbol to all available candidate symbols. From these bunch of calculations, MLD compares each PED one by one to find the smallest (minimum) value. The minimum the PED means the maximum likelihood between the received symbol and symbol candidate. The number of calculation needed by MLD is growing exponentially by the number of receive antenna. It is represented by equation (2).

$$C = B^{N_{Rx}} \quad (2)$$

where B is the number of bit in each digital symbol, i.e. for BPSK, $B = 1$; QPSK, $B = 2$; 16-QAM, B = 4; 64-QAM, $B = 6$; and 256-QAM, $B = 8$. N_{RX} is the number of receive antenna.

K-best technique computes the PED only for K chosen symbol candidates before searching for the minimum one. Deciding the value of K is kind of interesting since it determines the scale of error performance and the complexity. If K is chosen to be large then this technique gives high error performance but by the cost of high number of calculation, and vice versa. The number of computation needed by K-best technique is determined by the number of receive antenna. It is written in equation (3).

$$C = K^{N_{Rx}} \quad (3)$$

where K is the number of symbol candidates that want to be observed.

Sphere detection (SD) limits the calculation of PED and searching the minimum one, by a circle (sphere). The center of the circle is the received symbol and the size of the circle determined by the radian (distance) from the center to the targeted symbol candidate. Same as K-best technique, determining the radian of SD is a trade of between error performance and calculation number. The complexity of the SD is determined by the number of transmit antenna and the number of symbol candidates limited by the circle. It can be expressed as equation (4).

$$C = N_{Tx}^2 + \sum_{i=1}^{N} S_i + (i-1)S_{i-1} + 2 \quad (4)$$

where S_i is the number of symbol candidates within the sphere radius.

IV. Error Performance and Complexity comparison of the Interference Canceller Techniques

The transmitter used in the simulation was WLAN IEEE802.11ac model. It was set to 80MHz bandwidth, eight spatial streams, and modulation coding scheme (MCS) index 7 and 9. MCS-7 means that the digital modulation is 64-QAM (*B*=6), coding rate (*R*) is 5/6, number of channel encoder (N_{ES}) is 6, and the data rate using short guard interval is 2.6Gbps. MCS-9 means that the digital modulation is 256-QAM (*B*=8), coding rate (*R*) is 5/6, number of channel encoder (N_{ES}) is 6, and the data rate using short guard interval is 3.466Gbps. Simulation was conducted under small room MIMO channel model, e.g. channel model B of Task Group IEEE802.11n.

Two linear techniques and three non-linear techniques to cancel the interferences caused by MIMO channel are compared. Those techniques are implemented in the receiver of WLAN IEEE802.11ac 80MHz bandwidth with eight receiver antennas. Simulation parameter is listed in Table I.

TABLE I. SIMULATION PARAMETER.

Parameter	Value
Transmitter	IEEE802.11ac
Bandwidth	80MHz
Number of spatial streams	8
Modulation Coding Scheme	7 & 9 with short guard interval
PHY Throughput (Gbps)	2.6 & 3.466
Number of packet	10.000
Packet length	1KByte
Receiver	Proposed for IEEE802.11ac
Bandwidth	80MHz
Number of receive antenna	8
Interference Canceller Technique	**Linear**: ZF, MMSE **Non-Linear**: MLD, K-Best, SD

Error performance curve of the linear and non-linear interference canceller techniques for MCS-7 is shown in Fig. 2. Vertical axis is bit error rate (BER) and horizontal axis is the signal to noise ratio (SNR) in decibel (dB). To achieve observed BER 10^{-6}, the linear techniques need around 27dB while non-linear techniques, e. g. MLD needs 21dB, K-best and SD need 23dB. Better error performance around 4 dB to 6dB shown by non-linear techniques were paid by higher number of computation complexity.

Error performance curve of the linear and non-linear interference canceller techniques for MCS-9 is more detail shown in Fig. 3. Here, to attain observed BER 10^{-6}, the linear techniques ZF needs 31dB while MMSE shows better performance by 29.5dB. The non-linear techniques MLD shows superior performance by 24,5dB while K-best and SD need around 26dB. The further difference error performance shown by non-linear techniques to the linear techniques should be paid by longer time of computation.

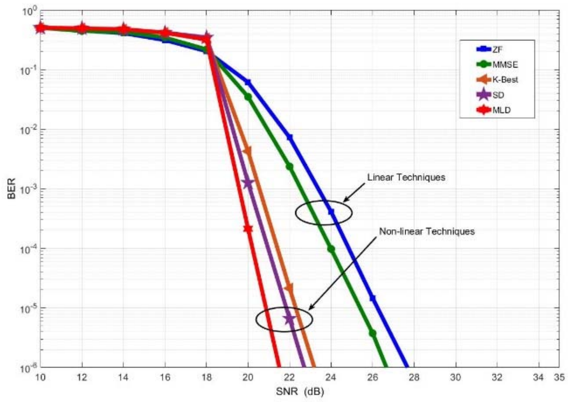

Fig. 2. Error performance comparison of linear and non-linear techniques of interference canceller in IEEE 802.11ac receiver. The transmitter is set to MCS 7, 80MHz of bandwidth, eight spatial streams, and short guard interval to give 2.6Gbps of throughput.

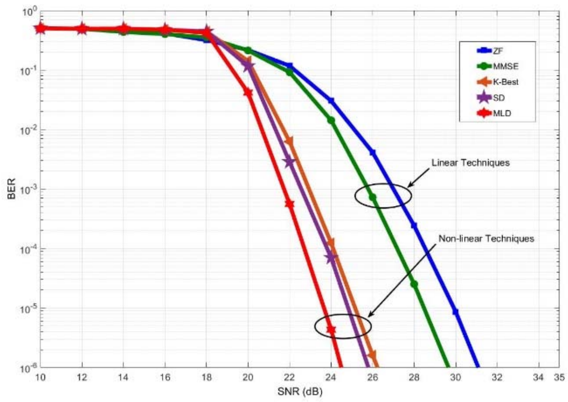

Fig. 3. Error performance comparison of linear and non-linear techniques of interference canceller in IEEE 802.11ac receiver. The transmitter is set to MCS 9, 80MHz of bandwidth, eight spatial streams, and short guard interval to give 3.466Gbps of throughput.

The number of calculation needed by linear and non-linear interference canceller techniques is displayed in Table II. The antenna configuration is set to be square. This means that the number of transmit antenna is same as the receive antenna. Table II shows the number of calculation for MCS-9 that employs 256-QAM digital modulation. It is predictable that the linear techniques only need small number of computation and logically shorter time to achieve targeted BER. In sequence MLD needs the highest number of calculation. K-best saves the number of calculation by limiting the value of K candidate symbols. In Table II, K is chosen to be 256 for the first calculation level and 8 for the second level until finish for all the receive antennas. SD saves more computation number by managing the radius of the sphere.

TABLE II. NUMBER OF CALCULATION NEEDED BY INTERFRENCE CANCELLER TECHNIQUES FOR 1 – 8 SQUARE ANTENNA FOR MCS-9

$N_{Rx} = N_{Tx}$	*C*			
	ZF & MMSE	**MLD**	**K-Best**	**SD**
1	2	256	256	256
2	6	256^2	256 x 8	2^2+4x256
4	20	256^4	256 x 8^3	4^2+10x256
8	72	256^8	256 x 8^7	8^2+18x256

Table II shows the number of calculation of each technique. The more number of calculation the more number of operational gates to build the adder, multiplier, and register. The more number of operational gates the more budget needed. Linear techniques may be implemented in low to middle performance of personal communication services such as chat, email, image transfer, video conferences, etc. Non-linear techniques may be useful for middle to high performance organizational communication services, such as high secure data transfer, confidential documents, etc.

V. CONCLUSION

Linear and Non-linear techniques to cancel the interferences for 3.466Gbps WLAN has been compared. Here the receiver for WLAN IEEE802.11ac with eight receiver antennas has also been proposed. Square MIMO configuration using eight antennas give important diversity gain. Therefore error performance difference between above techniques are not so far. In MCS-7, the linear techniques show 4dB to 6dB lower error performance than the non-linear techniques by the cost of very low complexity. In MCS-9, the non-linear techniques show 5dB to 7dB higher error performance than the linear techniques by the cost of very high complexity. The designer may choose the interference cancellation technique depend on the purpose, the available budget, and targeted market. Future works shall be investigating these interference cancellers in FPGA board of WLAN IEEE802.11ac model.

ACKNOWLEDGMENT

This work was supported by DRPM, Ministry of Research, Technology, and Higher Education of the Republic of Indonesia through the LPPM Diponegoro University under the Magister Thesis Research schema Year 2019 (Grant Number 258-18/UN7.P4.3/PP /2019).

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