Sphere Based MIMO Decoder for High Throughput WLAN IEEE802.11n

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***Abstract*— WLAN 802.11n combines MIMO and OFDM to provide high throughput and performance wireless communications. High quality MIMO decoder is urgently required. The existing WLAN 802.11n devices implement linear method, i.e. Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) as MIMO decoder. Both methods are simple but low in performance. At the other side, non-linear but optimal method Maximum Likelihood (MLD) based MIMO decoder gives superior performance with the cost of very high complexity. This paper is addressed to present Sphere based MIMO decoder which is low in complexity but high in performance dedicated for WLAN 802.11n device. Simulation under in-door channel model shows significant improvement of performance. At BER 10^{-4}, it gives 9 to 15,5 dB better than ZF and MMSE and only 2 to 3 dB worse than MLD based MIMO decoder. The computation complexity is also dramatically reduced especially when the number of involved antenna is increased.**

***Keywords*—WLAN 802.11n, MIMO, OFDM, ML, ZF, MMSE, Sphere, Decoder.**

I. INTRODUCTION

Wireless LAN becomes the most wireless networking technology used to communicate all type of digital data. Combination of *Orthogonal Frequency Division Multiplexing* (OFDM) and *Multi Input Multi Output* (MIMO) is the key of WLAN in providing high throughput and high performance wireless communication services. Started in 1999, when OFDM is implemented in WLAN 802.11a to achieve throughput up to 54 Mbps in SISO (*Single-Input Single Output*) system. It is operated in 5 GHz industrial, scientific, and medical (ISM) frequency band [1]. Due to the exponential demand of throughput, WLAN 802.11a is then extended to WLAN 802.11n which exploits MIMO to provide throughput of 600 Mbps with four spatial streams in 40 MHz bandwidth. This WLAN 802.11n is also backward compatible to the previous WLAN 802.11g. [2, 3].

Many researches have been conducted and some techniques have been proposed and verified to enhance the performance of WLAN 802.11n system. Implementation of Low Density Parity Check (LDPC) as channel coder instead of Binary Convolutional Code (BCC) along with its Register Transfer Level (RTL) design was verified and proposed in [4]. It is shown that LDPC improves the performance of WLAN 802.11n by 6dB compared to BCC. The other smart way to improve WLAN 802.11n performance is by adjusting the space between antennas in both Tx and Rx side. The wider the space, the lower the interference. Spacing the antennas to 2 λ shows 5dB better performance than 1/2 λ. [5]. Increasing the number of receive antennas also contributes signifcant diversity gain which gives much better performance. [6].

MIMO decoder as the urgent part of WLAN 802.11n decodes the received signal to obtain the transmitted information. The existing WLAN 802.11n devices implement linear methods, i.e. Zero Forcing (ZF) and Minimum Mean Square Error (MMSE). Both methods are simple but low in performance. At the other side, non-linear but optimal method called Maximum Likelihood Detection (MLD) promises superior performance. However its complexity grows exponentially proportional to the number of receive antennas and the modulation order [7]. Performance of MLD based MIMO decoder for WLAN 802.11n in 20 MHz and 40 Mhz of bandwidth are reported in [8] and [9], respectively. Implementation of sub-optimum methods, i.e. K-best and Trellis in MIMO decoder for WLAN 802.11n system are presented in [10] and [11], respectively.

This paper is addressed to present Sphere based MIMO decoder which is low in complexity but high in performance dedicated for WLAN 802.11n device. The observation and analyzing is conducted to achieve BER 10^{-4} under in-door channel model. The rest of the paper is delivered as follows, Section II contains brief explanation of the MIMO decoder methods used in WLAN 80211n. Section III presents the proposed Sphere based MIMO decoder. Section IV shows the simulation results as performance and complexity comparison of ZF, MMSE, ML, and Sphere. Finally, some conclusion are drawn in Section V.

II. MIMO DECODER IN WLAN 802.11N

Received signal in a MIMO system with N transmit and M receive antennas is expressed as:

$$\mathbf{y} = \mathbf{Hx} + \mathbf{n} \quad (1)$$

where y=[y_1, y_2, ..., y_M]^T, **H** is MIMO channel matrix with size M x N, **x** = [x_1, x_2, ..., x_N]^T is the transmitted symbol vector, and **n** = [n_1, n_2, ..., n_M]^T is the additive white Gaussian noise.

MIMO decoder is used to get back the transmitted symbol **x** from the received signal **y.** Most of the WLAN devices implement linear methods in MIMO Decoder, such as ZF and MMSE to decode **y**.

A. Zero Forcing based MIMO decoder

ZF based MIMO decoder equalizes the received signal by multiplying it to the inverse of estimated channel matrix, **W.**

$$\mathbf{W} = \left(\mathbf{H}^{H}\mathbf{H}\right)^{-1}\mathbf{H}^{H} \quad (2)$$

where superscript ^{H} is transpose-conjugate of the matrix. Noise is assumed to be absent. The estimated information is then:

$$\begin{aligned}\hat{\mathbf{x}} &= \mathbf{W}\mathbf{y}\\ \hat{\mathbf{x}} &= \mathbf{W}(\mathbf{H}\mathbf{x}+\mathbf{n})\\ \hat{\mathbf{x}} &= \mathbf{x}+\mathbf{W}\mathbf{n}\end{aligned} \quad (3)$$

B. Minimum Mean Square Error based MIMO decoder

MMSE based MIMO decoder considers the noise into part of **W**, as:

$$\mathbf{W} = \left(\mathbf{H}^{H}\mathbf{H}+\mathbf{n}\mathbf{I}\right)^{-1}\mathbf{H}^{H} \quad (4)$$

where **I** is matrix identity. It can be easily seen that MMSE is just the same as ZF when no noise is considered. Complexity of these linear decoding methods are proportional to the number of transmit antennas, as:

$$O = N + N^2 \quad (5)$$

C. Maximum Likelihood based MIMO decoder

Instead of linear methods, MLD based MIMO decoder measures the distance of the received signal to all possible symbol candidates. It then takes the closest one to find the estimated symbol as:

$$\hat{\mathbf{x}} = \arg\min\left\|\mathbf{y}-\mathbf{H}\mathbf{x}\right\|^2 \quad (6)$$

Complexity of MLD is determined as:

$$O = L^M \quad (7)$$

where M is number of receive antenna and L is the modulation order, i.e L=1 for BPSK, L =2 for QPSK, L =4 for 16-QAM, L =6 for 64-QAM, and L=8 for 256-QAM.

III. Sphere Based Mimo Decoder

After decomposing the channel matrix **H** into **Q** and **R** matrices using QR decomposition such that **H = QR** [7, 8], equation (6) can be stated as:

$$\hat{\mathbf{x}} = \arg\min\left\|\hat{\mathbf{y}}-\mathbf{R}\mathbf{x}\right\|^2 \quad (8)$$

where $\hat{\mathbf{y}} = \mathbf{Q}^{H}\mathbf{y}$. **Q** is a unitary matrix which size is M x N and $\mathbf{QQ}^H$ = **I,** while **R** is an upper triangular matrix which size is N x N.

Involving N transmit antenna into (8), yields:

$$\hat{\mathbf{x}} = \arg\min\sum_{i=1}^{N}\left|\hat{\mathbf{y}}-\sum_{j=1}^{N}\mathbf{R}_{ij}\mathbf{x}_j\right| \quad (9)$$

To solve (8), Sphere calculates all vector of **x** that satisfies

$$\left\|\mathbf{y}-\mathbf{R}\mathbf{x}\right\|^2 < \mathbf{Z}^2 \quad (10)$$

where **Z** is the *Sphere*'s radius. Choosing value of **Z** is an important problem to determine the complexity and performance of this method. If **Z** is big, it has big number of hypothesis of symbol candidates and shows good error performance. In this case, high complexity computation is needed. Reversely, when **Z** is too small, it has no hypothesis of symbol candidates. Nothing to be compared to the received signal which leads to error. When this is happened, the searching have to be repeated by incrasing the *Sphere's* radius. Back-substitution algorithm can be used to solve the searching process to satisfy (10). Complexity of Sphere method is: [12].

$$O = N^2 + \sum_{i=1}^{N}\left((i-1)S_{i-1} + 2 + S_i\right) \quad (11)$$

where S_i is the number of symbol candidates within radius. During simulation S_i is set to 64 for initial stage and kept to 16 until the 8-th antenna stage.

IV. Simulation and Discussion

The data rate of WLAN 802.11n can be set based on demand. Modulation and Coding Scheme (MCS) is a simple representation of the setting. It determines the subcarrier modulation, coding rate, and the data rate. For instance, MCS 15 of 802.11n in two spatial streams with 40 MHz of bandwidth for each stream means the system is set to 64-QAM and coding rate 5/6. By using 800ns of guard interval length, WLAN802.11n provides 270Mbps of data rate while by 400ns, it provides 300Mbps of data rate. Run test simulations are conducted under in-door channel model or channel model B of IEEE TGn. Simulation parameters are shown in Table I.

TABLE I. SIMULATION PARAMETERS

Parameters	Value		
Antenna configuration	2 x 2		
Bandwidth	40 MHz		
Number of Data Subcarrier	108		
Subcarrier modulation	64-QAM		
Modulation Coding Scheme	13	14	15
Coding rate	2/3	3/4	5/6
Data rate (Mbps)	216	243	270
MIMO decoder method	ZF, MMSE, MLD, Sphere		
Number of packet	1000 packets		
Number of data per packet	1000 octets		
Channel Model	B of IEEE TGn		

A. BER Performance

BER performance comparison of all methods in MCS 13, 14, and 15 are shown in Fig. 1, Fig. 2, and Fig. 3, respectively.

In MCS-13 as displayed in Fig. 1, ZF and MMSE hit BER 10^{-4} at 44dB and 42dB, MLD only around 31dB, and the proposed SD at 33dB of SNR. When compared, this value is 11dB and 9dB better than ZF and MMSE and only 2dB worse than MLD.

For MCS-14 as shown in Fig. 2, ZF and MMSE achieve BER 10^{-4} at 46 dB and 44 dB while MLD at 31 dB of SNR. The proposed SD is at 33dB which improves the performance about 13dB and 11dB compared to ZF and MMSE and only 2dB different compared to MLD.

When the WLAN 802.11n is set to MCS 15, ZF and MMSE attain BER 10^{-4} at 55dB and 53dB of SNR, MLD only about 36,5dB of SNR, and the proposed SD at about 40,5dB. This is 15,5dB and 13,5dB better than ZF and MMSE. It is worse than MLD only about 3dB, as depicted in Fig. 3.

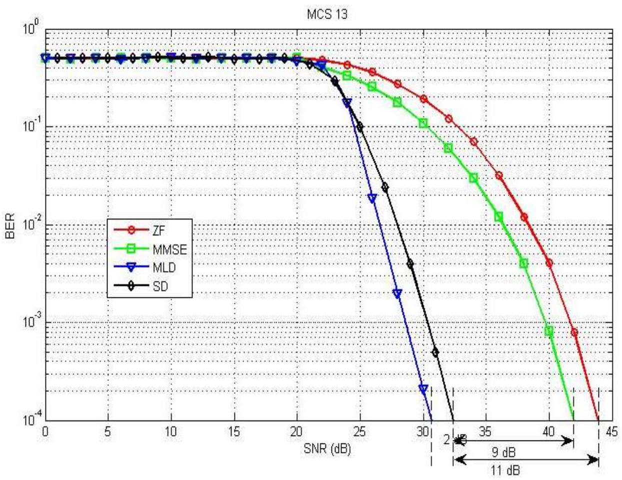

Fig. 1. Performance comparison of ZF, MMSE, MLD, and SD for MCS 13 of WLAN 802.11n 40MHz.

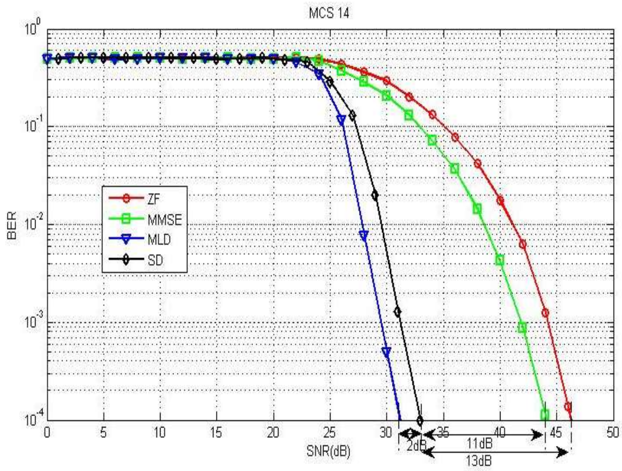

Fig. 2. Performance comparison of ZF, MMSE, MLD, and SD for MCS 14 of WLAN 802.11n 40MHz.

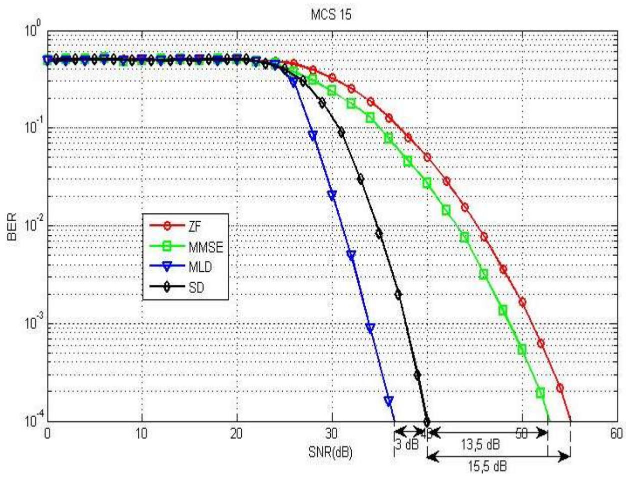

Fig. 3. Performance comparison of ZF, MMSE, MLD, and SD for MCS 15 of WLAN 802.11n 40MHz.

B. Complexity Analysis

The complexity comparison of above methods as MIMO decoder is listed in Table II.

TABLE II. COMPLEXITY COMPARISON OF MIMO DECODERS METHODS IN 40 MHZ BANDWIDTH

N	Complexity		
	ZF & MMSE	**MLD**	**Sphere**
1	2	64	67
2	6	64^2	152
3	12	64^3	191
4	20	64^4	232
8	72	64^8	416

As mentioned in the previous section, it can be verified that the linear method ZF and MMSE have the lowest complexity and MLD has the highest complexity. The proposed SD method has higher complexity compared to the linear ones but much lower than MLD. Further, its complexity computation is siginificantly reduced when the involved antennas (***N***) is increased.

V. CONCLUSION

We have presented the Sphere based MIMO decoder for WLAN802.11n system. It demonstrates 9 to 15,5dB better performance compared to the existing ZF and MMSE based MIMO decoder and only 2 to 3dB worse than MLD based MIMO decoder. Complexity of the Sphere based MIMO decoder is slighly higher than ZF and MMSE and it is much lower than MLD.

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