Implementation of K-Best Method for MIMO Decoder in WLAN 802.11n

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***Abstract*—WLAN IEEE 802.11n is recent wireless data communication technology which provides high throughput and high performance. These features are definitely determined by the strength of MIMO decoder. The existing MIMO decoder of WLAN 802.11n is based on linear method, i.e Zero Forcing (ZF) and Minimum Mean Square Error (MMSE). Both of them are low in complexity but poor in performance. In the other hand Maximum Likelihood Detection method demonstrates optimal performace but with very high in complexity. This paper presents our research in developing a high performance low complexity MIMO decoder for WLAN 802.11n by implementing K-Best method. Simulation of WLAN 802.11n 2x2 with QPSK, 16QAM, and 64QAM modulation order is conducted under channel model B of TGn. By target BER of 10^{-4}, the performance and complexity of each decoder are analyzed. The results show that K-Best detector achieves near-MLD performance, only degrade 1 dB, and has much better performance compared to ZF and MMSE with average 12 dB to 8 dB. The complexity ratio of the K-Best to MLD will significantly decrease as the increasement of transmitter antenna (N_{Tx}) and modulation order, i.e 46,9 % for QPSK to 5,27 % for 64QAM in N_{Tx}=2.**

***Keywords*—IEEE WLAN 802.11n, MIMO, OFDM, K-Best method**

I. INTRODUCTION

Wireless LAN is a wireless technology which mainly used for voice and data communication. There are two techniques used in WLAN Development. The first one is Orthogonal Frequency Division Multiplexing (OFDM). OFDM is a multi carrier transmission technique, where the subcarrier used are orthogonal each other, thus overlapping would not result in interference. Applying this technique yields *multipath fading channel* become *flat fading channel.* The second technique is MIMO (*Multi Input Multi Output*) which is used to maximize spectral efficiency. MIMO employs multiple antennas at both ends to take advantages of multipath environment without additional bandwidth.

OFDM technique has been applied in 802.11a with SISO antenna configuration. It operates in 5GHz Frequency [1]. Further development is applying MIMO-OFDM in 802.11n [2]. As an extension of WLAN 802.11a/g with MIMO technique, WLAN 802.11n promises more robust and higher throughput. Within the same 20 MHz of bandwidth, WLAN 802.11n offers five folds in throughput, i.e. 270 Mbps and by doubling the bandwidth into 40MHz it rises ten times of throughput, i.e. 540 Mbps compared to WLAN 802.11a/g. Therefore WLAN 802.11n is called high throughput (HT-WLAN). [3].

The use of same channel to transmit multiple independent data requires a special technique to get back the sent information. This job is handled by MIMO decoder. Linear methods used by the existing MIMO decoder of WLAN 802.11n are Zero Forcing (ZF) and Minimum Mean Square Error (MMSE). Both of them are low in complexity but poor in performance. In the other hand, one theoritical technique known for its optimal performance is Maximum Likelihood Detection (MLD). It has highest performance but the complexity would grows exponentially as the increasement of number of transmit antennas and modulation order [4]. The previous researches concerning the development of high performance low complexity MIMO decoder have taken non linear method as a derivation of MLD such as Sphere Decoding and Trellis Algorithm. [5,6].

This paper focuses on performance improvement of WLAN 802.11n by implementing K-Best method as MIMO decoder. The performance and complexity of each method, i.e. ZF, MMSE, MLD, and K-Best are compared within the same parameters of MIMO Spatial Division Multiplexing (SDM) at 2 x 2 MIMO configuration with order modulation QPSK, 16 QAM, and 64QAM. Simulations are conducted under channel model B of IEEE 802.11TGn representing the coverage area of a small office.

The rest of this paper is organized as follows. In Section II MIMO system in WLAN IEEE802.11n is briefly reviewed. Section III contains the stages and the parameters of simulation with the analysis of simulation's resultan and finally conclusion is drawn in Section IV.

II. MIMO SYSTEM

A. MIMO Channel Model

MIMO is one of diversity technique which is used to suppress fading and interference from other user, and to raise data rate without additional bandwidth. There are two MIMO scheme which are widely used, they are *Space Time Block Code* (STBC) and *Spatial Division Multiplexing (SDM).*

SDM means several independent data streams transmitted over different transmit antennas in the same bandwidth. On SDM system, the minimum number of transmit antennas equals to the number of receive antennas. MIMO configuration with 4 transmit antennas and 4 receive antennas is shown in fig. 1.

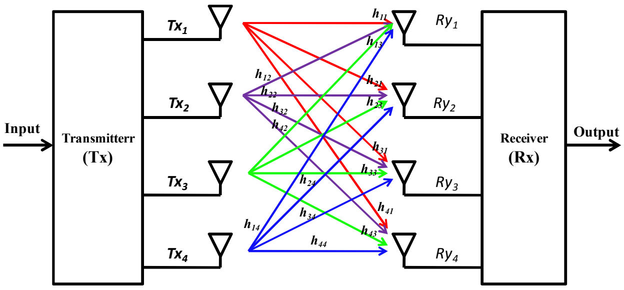

Fig. 1. 4 x 4 MIMO system

In a MIMO system with N_{Tx} transmitter and N_{Rx} receiver antennas , the channel model can be described as:

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

where **y** is received symbol, **H** is channel matrix, **s** is transmitted symbol, and **n** is noise.

B. MIIMO Decoding

The task of MIMO detector is to recover **s** from **y** by soliving (1). Conventional WLAN 802.11n has 2 linear decoding method, such as ZF and MMSE which discussed briefly bellow.

i. Zero Forcing (ZF)

ZF method eliminates channel's effect by simply multiply the receive signal by the inverse of estimated channel matrix, symboled by matrix **W,** without considering the additive noise. where the weight of **W** is set so that **WH** = **I**, which would be satisfied by :

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

The information is obtained by:

$$\hat{s} = \mathbf{Wy}$$
$$\hat{s} = \mathbf{W}(\mathbf{Hs} + \mathbf{n}) \quad (3)$$
$$\hat{s} = \mathbf{s} + \mathbf{Wn}$$

ii. Minimum Mean Square Error (MMSE)

Differs from ZF, MMSE method considers the additive noise when defining the coefficient weight W, as :

$$\mathbf{W} = [\mathbf{H}^H\mathbf{H} + \mathbf{nI}]^{-1}\mathbf{H}^H \quad (4)$$

Where **I** is matrix identity. When the noise factor is zero, MMSE equation is same as ZF equation.

The complexity computation of linear decoding method is calculated by following formula [5]:

$$K = N_{Tx}^2 + N_{Tx} \quad (5)$$

iii. Maximum Likelihood Detection (MLD)

MLD compares the euclidean distance of the received signal to all possible transmitted symbol or symbol candidate to find symbol with the minimum euclidean distance. The Maximum Likelihood Detector solve the following equation :

$$\hat{s} = arg\min\|\mathbf{y} - \mathbf{Hs}\|^2 \quad (6)$$

The complexity of MLD can be calculated by :

$$K = M^{N_{Tx}} . N_{T_x}^2 \quad (7)$$

where M is modulation order used. The example of MLD detection depicted in fig. 2

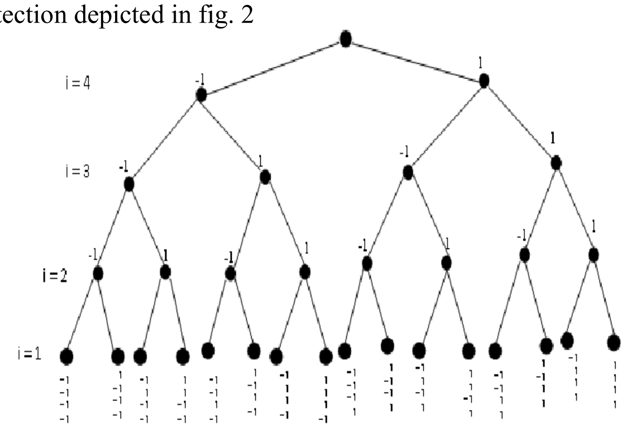

Fig. 2. MLD algorithm represented in tree diagram for BPSK modulation and 4 transmit antennas (i=1,2,,,N_{Tx})

iv. K-Best Detector

Following standard simplification by aplying QR decomposition on channel matrix H [6] [7], the MLD detection rule (6) can be written as (8) :

$$\hat{s} = argmin\ \|\hat{y} - Rs\|^2 \quad (8)$$

such that

$$H = QR$$

and

$$\hat{y} = Q^H y$$

where Q is a unitary matrix of size N_{Rx} x N_{Tx} and R an upper triangular matrix of size N_{Tx} x N_{Tx}.

Expanding vector norm in (8) yields

$$\hat{s} = argmin \sum_{i=1}^{N_{Tx}} \left| \hat{y} - \sum_{j=i}^{N_{Tx}} R_{ij}\, s_j \right|^2 \quad (9)$$

Starting from i = N_{Tx}, (9) can be solved recursively as follows :

$$T_i\,(P_i) = T_{i+1}\,(P_{i+1}) + |e_i\,(P_i)| \quad (10)$$
$$T_{N_{t+1}}(P_{N_{t+1}}) = 0$$

where

$$T_i(P_i) > T_{i+1}(P_{i+1}) \quad (11)$$

and

$$e_i\,(P_i) = \hat{y} - \sum_{j=i}^{N_T} R_{ij}\, s_j \quad (12)$$

In (10)-(12), $P_i = [s_i, s_{i+1}, \ldots s_{N_T}]^T$ is known as *partial symbol vector*. Fig. 3 associate (10) with a tree diagram.

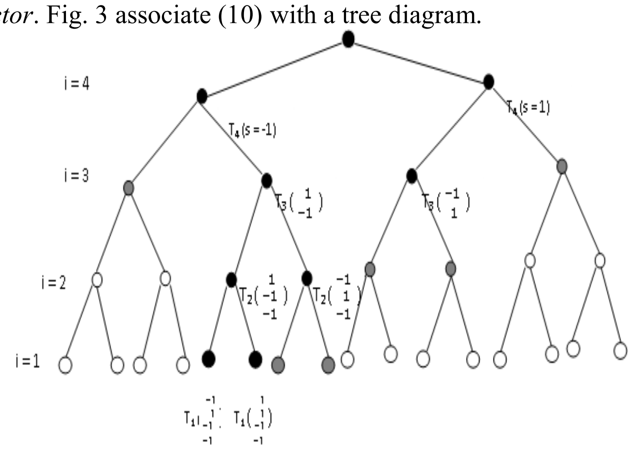

Fig. 3. K-Best algorithm represented in tree diagram for BPSK modulation, , *K* = 2 and 4 transmit antennas (i=1,2,,,N_{Tx})

Each node in the tree corresponds to a so-called *partial Euclidean distance* (PED) $T_i(s^{(i)})$. In K-Best algorithm a breadth-first tree is conducted to search for solution of (9) i.e. the detector visits all siblings of a node before it proceeds to the next level. Instead of expanding every node at each layer of the tree, we only keep the best *K* node that have the smallest accumulated PEDs. Each path in the tree corresponds to a signal vector s. The path with smallest PED is the detection result. The choice of *K* is a trade-off between BER performance and computational complexity.

Fig.3 illustrates K-Best detection on MIMO system with BPSK modulation, 4 transmit antennas and *K* = 2. The black nodes denote the *K* best nodes that stored at each level, and the grey nodes are the pruned ones, which did not succed in the selection. Nodes that have not been visited at all, are shown as white nodes. It should be noted that the impact of tree pruning becomes more significant when the number of transmit antenna increases and a higher modulation order is used.

The complexity of K-Best is calculated by each of i-th stage, by decipher matrix operation on equations (8), (10), and (12). Equation (8) shows that there are 1 operation addition / subtraction and 1 matrix multiplication operations. In the initialisation the amount of addition and multiplication for all nodes passed through will be calculated. For example, in fig. 3for i-1every combination of symbol is multiplied by the received signals, so that there are 2 combinations according to BPSK constellation points. The considered nodes are the black and the grey ones, therefore for *K* = 2, there are 4 considered nodes for i = 3 to i = 1. So the number of addition operations is equal to the multiplication operations that is 14. From (10), we can see that there are addition and multiplication operations on each node. The example of (10) calculation in 4 x 4 MIMO system are as follows :

$$T_4(P_4) = T_5(P_5) + \left|\hat{y} - \sum_{j=4}^{N_4} R_{44} s_4\right|^2$$
$$T_3(P_3) = T_4(P_4) + \left|\hat{y} - \sum_{j=3}^{N_4} R_{33} s_3 + R_{44} s_4\right|^2 \quad (13)$$
$$T_2(P_2) = T_3(P_3) + \left|\hat{y} - \sum_{j=2}^{N_4} R_{22} s_2 + R_{33} s_3 + R_{44} s_4\right|^2$$
$$T_1(P_1) = T_2(P_2) + \left|\hat{y} - \sum_{j=1}^{N_4} R_{11} s_1 + R_{22} s_2 + R_{33} s_3 + R_{44} s_4\right|$$

the QR decomposed channel matrix are :

$$R = \begin{bmatrix} R_{00} & R_{01} & R_{02} & R_{03} \\ 0 & R_{11} & R_{12} & R_{13} \\ 0 & 0 & R_{22} & R_{23} \\ 0 & 0 & 0 & R_{33} \end{bmatrix} \quad (14)$$

From (14) we konow that

- For i = 4 (line 4), there is 1 matrix (R_{33}) which value $\neq 0$. There is only 1 addition.
- For i = 3 (line 3), there are 2 matrices (R_{22}, R_{23}) which value $\neq 0$. There are 2 additions and 1 multiplication.
- For i = 2 (line 2), there are 3 matrices (R_{11}, R_{12}, R_{13}) which value $\neq 0$. There are 3 additions and 2 multiplications.
- For i = 1 (line 1), there are 4 matrices (R_{00}, R_{01}, R_{02}, R_{03}) which value $\neq 0$. There are 4 additions and 3 multiplication operations.

There is also addition operation when accumulating PED for each node succeeded in i-th stage. So there are M^2 addition operations for i = N_{Tx-1} , and K-numbered x M for i = (N_{Tx-2}) to i = 1.

III. SYSTEM DESIGN AND RESULT

Block diagram of WLAN 802.11n receiver with two antennas is shown in fig. 4. The MIMO decoder is put after phase tracker.

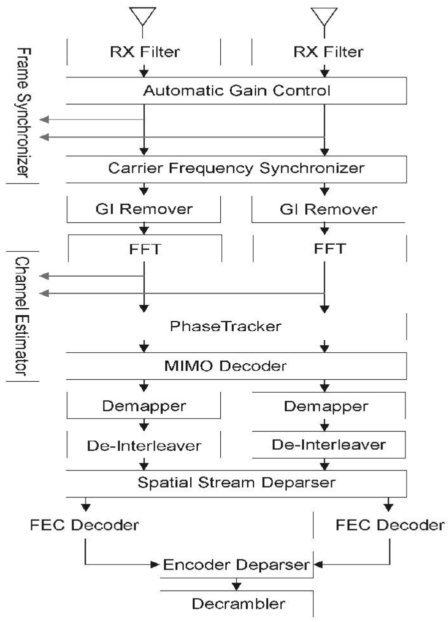

Fig. 4. Receiver diagram of the WLAN802.11n with two antennas

The flowchart of K-Best detection method shown in fig. 5. In this test, we will conduct research of MIMO decoder performance in 2 x 2 antenna configuration, coding rate 3/4, with QPSK, 16 QAM, 64QAM modulation order. The choice of *K* is 2.

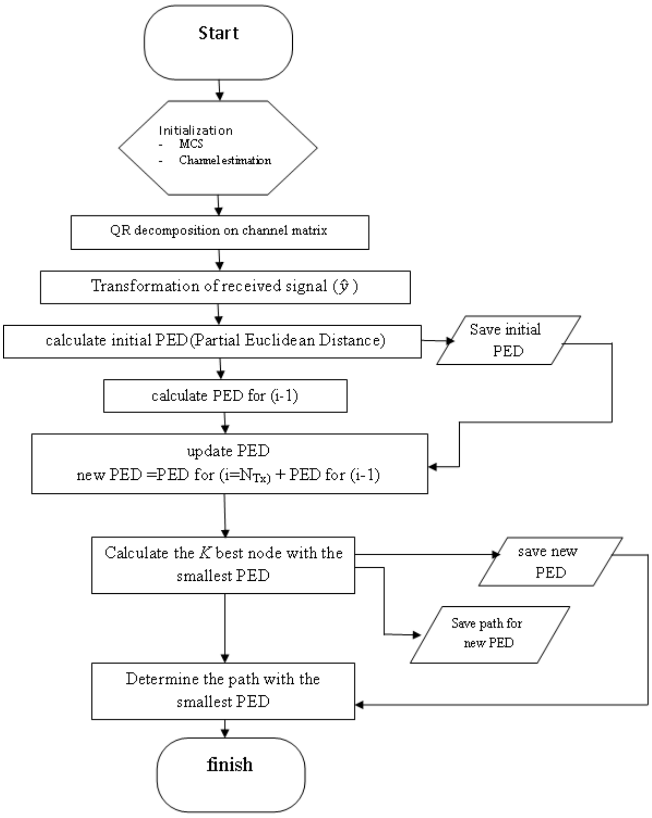

Fig. 5. Flowchart of K-Best detection method

In IEEE 802.11n standard, this configuration is represented in Modulation and Coding Scheme (MCS) 10, 12, and 14. This is a simple representation of WLAN 802.11n setting which defines the modulation type, coding rate, number of spatial stream, and the throughput. As an example, when the WLAN 802.11n is set to MCS 14 with 40 MHz of bandwidth, it defines the modulation is 64-QAM, coding rate is 3/4, number of spatial stream is two, with the throughput up to 243 Mbps. The simulation is done under TGn channel model B. The full simulation parameter is shown in table 1. Performance comparison of three methods interference canceller which conducted based on the same MCS setting are shown in fig. 6, 7, and 8.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Iteration	1000
Subcarrier modulation	QPSK,16QAM,64QAM
Antenna configuration	2 x 2
Coding rate	3/4
Bandwidth	40 MHz
MIMO decoder	ZF, MMSE, MLD, K-best
Number of data per packet	1000 *octet*
Channel Model	B of IEEE TGn
Forward Error Correction	BCC with Viterbi
Throughput (Mbps)	81,162,243

A. Test Results

Simulation result on MCS 10 is shown in fig 6. MLD achieves the target BER at 16,5 dB, ZF at 29,5 dB, MMSE at 24 dB and K-Best at 18 dB. This means that the performance of the K-Best decoder is better than ZF and MMSE about 11.5 dB and 6.5 dB, respectively. The difference in the performance of K-Best method to MLD is only 1,5 dB.

Simulation result on MCS 12 is shown in fig 7. MLD achieves the target BER at 22 dB, ZF at 34,5 dB, MMSE at 31 dB and K-Best at 23 dB. This means that the performance of the K-Best decoder is better than ZF and MMSE about 8,5 dB and 8 dB while the difference to MLD is only 1 dB.

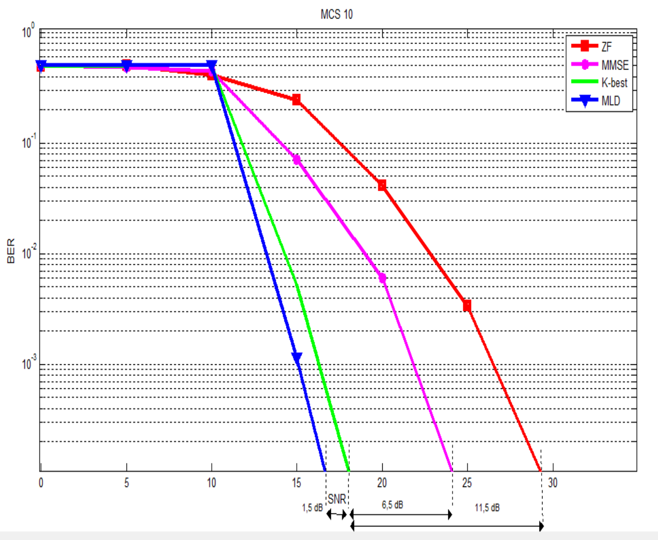

Fig. 6. Performance comparison of WLAN 802.11n MCS-10 with MIMO decoder based on ZF, MMSE, MLD, and K-Best method.

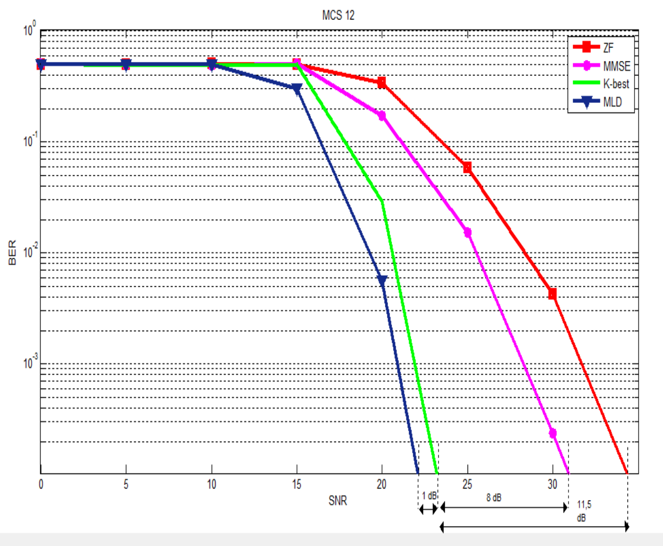

Fig. 7. Performance comparison of WLAN 802.11n MCS-12 with MIMO decoder based on ZF, MMSE, MLD, and K-Best method.

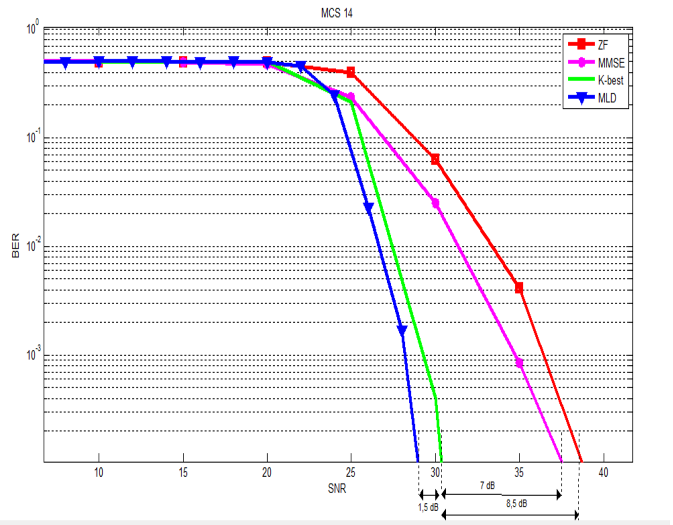

Fig. 8. Performance comparison of WLAN 802.11n MCS-14 with MIMO decoder based on ZF, MMSE, MLD, and K-Best method.

Test result on MCS 14 is shown in fig 8. MLD achieves the target BER at 29 dB, ZF at 39 dB, MMSE at 37,5 dB and K-Best at 30,5 dB. This means that the performance of the K-Best decoder is better than ZF and MMSE about 8,5 dB and 7 dB while the difference to MLD is 1,5 dB.

B. Complexity Analysis

The complexity comparison of each decoder is shown in table 2. It can be verified that as the number of spatial streams and modulation order are increased, the complexity of MLD getting very high. However, the complexity ratio of K-Best to MLD decreases significantly. These results show low complexity of K-Best method as a MIMO decoder.

TABLE II. COMPLEXITY COMPARISON

NTx	Modulation	complexity (Σ = addition + multiplication)			Complexity ratio K-Best : MLD
		Linear Receiver	MLD	K-Best	
2	QPSK	6	128	60	46,9%
	16QAM	6	1048	400	38,2%
	64QAM	6	32768	1728	5,27%
3	QPSK	12	1152	244	21,2%
	16QAM	12	36864	2096	5,69%
	64QAM	12	2359296	26816	1,14%
4	QPSK	20	2048	392	19,14%
	16QAM	20	2097152	2736	0,13%
	64QAM	20	536870912	29376	0,0055%

IV. CONCLUSION

We have succeded implementing K-Best method on MIMO decoder for IEEE WLAN 802.11n. Run test under small office channel model shows that K-Best demonstrates much better performance than the existing method, i.e. ZF and MMSE. It achieves a near-MLD performance with average difference only 1 dB.

From complexity comparison point of view, the ratio of K-Best to MLD will decrease significantly with increasing number of transmit antennas and modulation order used. As a future research, it is expected to determine the algorithm to find the optimal *K* value. The choice of *K* is a trade-off between BER performance and computational complexity

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