

# Research on Pre-coding Codebook Selection Algorithm of LTE-A System

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## Abstract

*In this paper, on LTE-A system based MIMO pre-coding codebook selection algorithm are researched. Traditional pre-coding selection algorithm requires to complete the corresponding code to traverse, however improved traversal algorithm are optimized than traditional traversal algorithms, but it has high complexity. Based on the study of the two kinds of pre-coding selection algorithm, we propose a modified algorithm, then the algorithm in EPA5, EVA5, ETU70 on the type of channel simulation and analysis, Simulation results show that the algorithm performance with almost no loss compared with the traditional method, while significantly lower the complexity.*

**Key words:** LTE-A; PMI; Codebook selection; Pre-coding codebook selection

## 1. Introduction

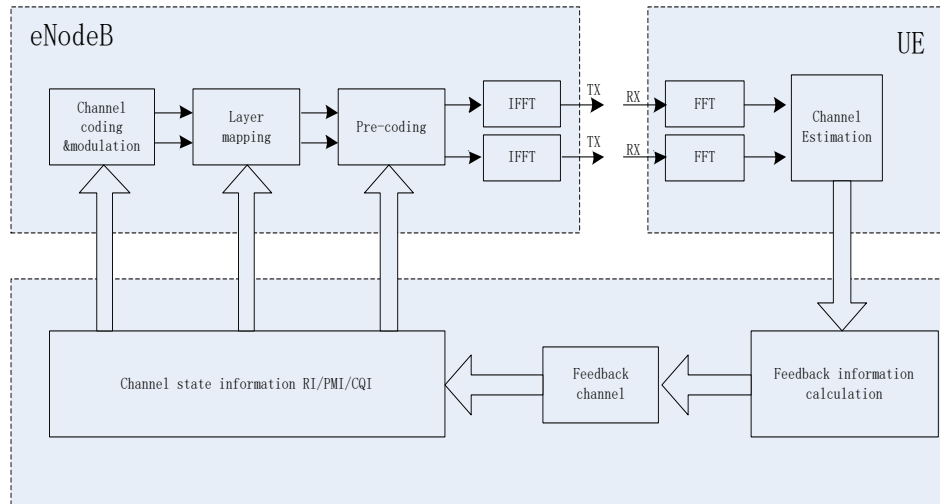
Pre-coding matrix indicates (PMI) are the base station reference information in down-link data transfer pre-coding. In order to improve spectrum efficiency and throughput, base LTE-A system of 4x4 downlink MIMO introduce 8-antenna technology. While the 8-antenna transmission can effectively increase the communication performance, but also led to a substantial increase in the number of the code, which makes the system during the PMI selection complexity and feedback overhead increases, which is not good for the system [1].

Therefore, this article gives an 8-antenna pre-coding codebook selection algorithm improvement program; it can reduce the complexity of the PMI algorithm, PMI in the loss of certain properties, and to speed up the PMI selection process.

In the closed-loop spatial multiplexing and multi-user MIMO, the terminal feedback PMI according to the downlink channel conditions and feedback mode, corresponding to each other feedback PMI and the codebook index number.

## 2. LTE-A Downlink System

Figure 1. LTE-A system downlink adaptive feedback loop system, including sending and receiving terminals. For the eNodeB, the flow of information inputs, respectively, after channel coding, interleaving and modulation, layer mapping will be processed and the resulting multi-layer data stream by pre-coding and subcarrier mapping, then the output for each transmission antenna after signals are orthogonal frequency division multiplexing (OFDM), which are sub-carrier mapping, inverse fast fourier transform (IFFT) and processing during cyclic prefix, transmitted to the transmission channel via a plurality of transmitting antennas [2].



**Figure 1. LTE-A System Downlink Adaptive Feedback Loop System**

Assuming the number of transmitting antennas LTE-A system is  $N_t$  (maximum  $N_t=8$ ), Receiving antennas  $N_r$ .

The input data stream  $X$  after a send-side processing and transmission channel matrix  $H$  is at the receiving end for the OFDM demodulated output signal  $Y$ :

$$Y = H \square W \square X + n_0 \quad (1)$$

The above formula  $n_0$  is Gaussian white noise, the number of transmitting antennas and receiving antennas are  $M$ ,  $N$ , the number of layers and the pre-coding matrix is  $L$ . Then  $M \times N$  is the matrix of  $H$ ,  $M \times L$  is the matrix of  $W$ ,  $L \times 1$  is the matrix  $X$ ,  $N \times 1$  is the matrix of  $Y$  and  $n_0$ . Channel matrix  $H$  between transmit and receive antennas may be expressed as:

$$H_{N \times M} = \begin{pmatrix} h_{11} & \cdots & h_{1M} \\ \vdots & \ddots & \vdots \\ h_{N1} & \cdots & h_{NM} \end{pmatrix} \quad (2)$$

It represents that the sender of  $j$ -th antenna to the receiving end of  $i$ -th antenna channel impulse response. Reference [3] gives the pre-coding limited feedback pre-coding matrix and codebook collection.

For the receiving side (UE), in order to achieve the reverse process and get the transmission side to send a signal, there is an important task is pre-coding matrix indicator (PMI) feedback [4]. For antenna 8 code word, the total number of 1 to 4 layers (RI-Rank Index) code words shown in Table 1:

**Table 1. Different Transmission Layers of Different Number of Codebooks**

RI	1	2	3	4
Codebook num	256	256	64	32

Seen from Table 1, when RI is 1 or 2, the code of this structure has the largest number, the use of optimal way completely traverse codebook selection, the complexity will be high, as an example, the pre-coding codebook selection algorithm from the pre-coding codebook features to transmission layers is equal to 1. This method is also can extended to the case where the number of layers 2, 3 and 4.

### 3. Pre-coding Codebook Selection Algorithm

#### 3.1 Traditional Traversal Algorithm

In the 8-antenna codebook, when the rank number is 1 the codebook to a maximum, so this article merely study for the rank of 1 codebook. Under the agreement 36.211 6<sup>th</sup> [5] contents which give codebook rank is 1, as shown in Table 2:

$$\varphi_n = e^{jn\pi/2} \quad (3)$$

$$v_m = \left[ 1 \ e^{j2\pi m/32} \ e^{j4\pi m/32} \ e^{j6\pi m/32} \right]^T \quad (4)$$

**Table 2. Rank=1 pre-coding Codebook**

$i_2$	$i_1$	0	1	2	3	4	5	6	7
0~15		$W_{2i_1,0}^{(1)}$	$W_{2i_1,1}^{(1)}$	$W_{2i_1,2}^{(1)}$	$W_{2i_1,3}^{(1)}$	$W_{2i_1+1,0}^{(1)}$	$W_{2i_1+1,1}^{(1)}$	$W_{2i_1+1,2}^{(1)}$	$W_{2i_1+1,3}^{(1)}$
$i_2$	$i_1$	8	9	10	11	12	13	14	15
0~15		$W_{2i_1+2,0}^{(1)}$	$W_{2i_1+2,1}^{(1)}$	$W_{2i_1+2,2}^{(1)}$	$W_{2i_1+2,3}^{(1)}$	$W_{2i_1+3,0}^{(1)}$	$W_{2i_1+3,1}^{(1)}$	$W_{2i_1+3,2}^{(1)}$	$W_{2i_1+3,3}^{(1)}$

$$\left( W_{m,n}^{(1)} = \frac{1}{\sqrt{8}} \begin{bmatrix} v_m \\ \varphi_n v_m \end{bmatrix} \right)$$

Traverse  $i_1, i_2$  can get 256 codebooks this can be seen in this table. There are 128 kinds of codebook are repeated, so we choose PMI selection algorithm, and we just need to select it from 128 kinds of codebooks.

Where  $N_R \times N_T$  is the channel estimation matrix  $H$ ,  $N_T \times RI$  is the pre-coding matrix  $W_{m,n}^{(1)}$  ( $RI=1$ ), corresponding to the selected maximum  $abs(H \cdot W_{m,n}^{(1)})$ ,  $m, n$  and then find the corresponding  $i_1, i_2$  to obtain the required PMI.

#### 3.2 Improved Traversal Algorithm

Assume that  $v_m = [v_m(0) \ v_m(1) \ v_m(2) \ v_m(3)]$ , Pre-coding matrix  $W$  is:

$$W = [W_1 \ W_2 \ W_3 \ W_4 \ W_5 \ W_6 \ W_7 \ W_8]^T$$

$$= [v_m(0) \ v_m(1) \ v_m(2) \ v_m(3) \ \varphi_n v_m(0) \ \varphi_n v_m(1) \ \varphi_n v_m(2) \ \varphi_n v_m(3)]^T \quad (5)$$

Assume that  $i$ -th receives antenna  $H_i$  is:

$$H_i = [H_{i1} H_{i2} H_{i3} H_{i4} H_{i5} H_{i6} H_{i7} H_{i8}] \quad (6)$$

Analysis shows that the period of  $v_m$  and  $\varphi_n$  are respectively 32 and 4, means codebook  $W_{m,n}^{(1)}$  are composed of 32  $v_m$  and 4  $\varphi_n$ , and  $\varphi_n = e^{j\pi n/2}$  can be used phase expressed as 1, j, -1 and -j, each corresponding 4 kinds of phases. Therefore, the algorithm simplified 32 matrix multiplication, then use 4 phases to adjusting. Formulas can be expressed as:

$$\begin{aligned} H \cdot W &= H_{i(1:4)} V_{(1:4),m} + \varphi_n H_{i(5:8)} V_{(5:8),m} = H_{1,m} + \varphi_n H_{2,m} \\ &= (H_{1,m} + H_{2,m}, H_{1,m} + jH_{2,m}, H_{1,m} - H_{2,m}, H_{1,m} - jH_{2,m}) \end{aligned} \quad (7)$$

To traverse  $m$  (0~31), maximum modulus of value were calculated for each  $m$  corresponding to the 4 phases  $Value_m$ ,

$$\begin{aligned} Value_m &= \max(\text{abs}(H_{1,m} + H_{2,m}), \text{abs}(H_{1,m} + jH_{2,m}), \\ &\quad \text{abs}(H_{1,m} - H_{2,m}), \text{abs}(H_{1,m} - jH_{2,m})) \end{aligned} \quad (8)$$

Select the  $\max(Value_m)$  obtained in the 32  $Value_m$  from formula, this allows get the corresponding  $m$  and  $n$ , and finally find the corresponding  $i_1$  and  $i_2$ , so that we can get the required PMI[7].

### 3.3 Lower Complexity of Improved Traversal Algorithm

Based on the foregoing, in the conventional traversal algorithm when 128 kinds of codebook opted poor traversal methods need to be 128×8 times complex multiplication and addition operations 128×7, and the improved selection and traversal algorithm can be simplified into 32 to 4 and a calculation cycle, but also need to be 32×8 times complex multiplication and addition operations 128×7.

According to the 3GPP agreement [6] given  $Rank = 1$  codebook:

$$v_m = [1 \ e^{j2m\pi/32} \ e^{j4m\pi/32} \ e^{j6m\pi/32}]^T \quad (9)$$

Make  $v_m(0) = 1$ ,  $v_m(1) = e^{j2\pi m/32}$ ,  $v_m(2) = e^{j4\pi m/32}$  and  $v_m(3) = e^{j6\pi m/32}$ ,  $v_m(1)$  can do simplification as follows:

$$\begin{aligned} e^{j2m\pi/32} &= e^{jm\pi/16} \\ &= \cos \frac{m\pi}{16} + j \sin \frac{m\pi}{16} \quad \triangleq \frac{\pi}{16} = x \\ &= \cos(mx) + j \sin(mx) \end{aligned} \quad (10)$$

By simplifying the relevant traversal  $v_m(1)$  of the  $\cos(mx)$ , show in Table 3:

**Table 3.  $v_m(1) : \cos(mx)$  Values**

$m$	$v_m(1) : \cos(mx)$	$m$	$v_m(1) : \cos(mx)$
0	1	16	-1

1	$\cos x$	17	$-\cos x$
2	$\cos 2x$	18	$-\cos 2x$
3	$\cos 3x$	19	$-\cos 3x$
4	$\frac{\sqrt{2}}{2}$	20	$-\frac{\sqrt{2}}{2}$
5	$\frac{\sqrt{2}}{2}(\cos x - \sin x)$	21	$-\frac{\sqrt{2}}{2}(\cos x - \sin x)$
6	$\frac{\sqrt{2}}{2}(\cos 2x - \sin 2x)$	22	$-\frac{\sqrt{2}}{2}(\cos 2x - \sin 2x)$
7	$\frac{\sqrt{2}}{2}(\cos 3x - \sin 3x)$	23	$-\frac{\sqrt{2}}{2}(\cos 3x - \sin 3x)$
8	0	24	0
9	$-\sin x$	25	$\sin x$
10	$-\sin 2x$	26	$\sin 2x$
11	$-\sin 3x$	27	$\sin 3x$
12	$-\frac{\sqrt{2}}{2}$	28	$\frac{\sqrt{2}}{2}$
13	$\frac{-\sqrt{2}}{2}(\cos x + \sin x)$	29	$\frac{\sqrt{2}}{2}(\cos x + \sin x)$
14	$\frac{-\sqrt{2}}{2}(\cos 2x + \sin 2x)$	30	$\frac{\sqrt{2}}{2}(\cos 2x + \sin 2x)$
15	$\frac{-\sqrt{2}}{2}(\cos 3x + \sin 3x)$	31	$\frac{\sqrt{2}}{2}(\cos 3x + \sin 3x)$

Similarly to the  $v_m(1)$  of the  $\sin(mx)$ , show in Table 4:

**Table 4.  $v_m(1) : \sin(mx)$  Values**

$m$	$v_m(1) : \sin(mx)$	$m$	$v_m(1) : \sin(mx)$
0	0	16	0
1	$\sin x$	17	$-\sin x$
2	$\sin 2x$	18	$-\sin 2x$
3	$\sin 3x$	19	$-\sin 3x$
4	$\frac{\sqrt{2}}{2}$	20	$-\frac{\sqrt{2}}{2}$

5	$\frac{\sqrt{2}}{2}(\cos x + \sin x)$	21	$-\frac{\sqrt{2}}{2}(\cos x + \sin x)$
6	$\frac{\sqrt{2}}{2}(\cos 2x + \sin 2x)$	22	$-\frac{\sqrt{2}}{2}(\cos 2x + \sin 2x)$
7	$\frac{\sqrt{2}}{2}(\cos 3x + \sin 3x)$	23	$-\frac{\sqrt{2}}{2}(\cos 3x + \sin 3x)$
8	1	24	-1
9	$\cos x$	25	$-\cos x$
10	$\cos 2x$	26	$-\cos 2x$
11	$\cos 3x$	27	$-\cos 3x$
12	$\frac{\sqrt{2}}{2}$	28	$-\frac{\sqrt{2}}{2}$
13	$\frac{\sqrt{2}}{2}(\cos x - \sin x)$	29	$-\frac{\sqrt{2}}{2}(\cos x - \sin x)$
14	$\frac{\sqrt{2}}{2}(\cos 2x - \sin 2x)$	30	$-\frac{\sqrt{2}}{2}(\cos 2x - \sin 2x)$
15	$\frac{\sqrt{2}}{2}(\cos 3x - \sin 3x)$	31	$-\frac{\sqrt{2}}{2}(\cos 3x - \sin 3x)$

Analysis of the table obtained  $v_m(1)$

$$v_{0-15}(1) = -v_{16-31}(1) \quad (11)$$

$$v_{0-7}(1) = jv_{8-15}(1) \quad (12)$$

Similarly for  $v_m(2)$  and  $v_m(3)$

$$v_{0-15}(2) = v_{16-31}(2) \quad (13)$$

$$v_{0-7}(2) = -v_{8-15}(2) \quad (14)$$

$$v_{0-3}(2) = jv_{4-7}(2) \quad (15)$$

$$v_{0-15}(3) = -v_{16-31}(3) \quad (16)$$

$$v_{0-7}(3) = jv_{8-15}(3) \quad (17)$$

Assuming  $m=31$  we can obtain:

$$\begin{aligned} & H_{i1}v_{31}(0) + H_{i2}v_{31}(1) + H_{i3}v_{31}(2) + H_{i4}v_{31}(3) + \\ & \varphi_n(H_{i1}v_{31}(0) + H_{i2}v_{31}(1) + H_{i3}v_{31}(2) + H_{i4}v_{31}(3)) \\ & = H_{i1}v_{15}(0) - H_{i2}v_{15}(1) + H_{i3}v_{15}(2) - H_{i4}v_{15}(3) + \\ & \varphi_n(H_{i1}v_{15}(0) - H_{i2}v_{15}(1) + H_{i3}v_{15}(2) - H_{i4}v_{15}(3)) \end{aligned}$$

$$\begin{aligned}
 &= H_{i1}v_7(0) + jH_{i2}v_7(1) - H_{i3}v_7(2) + jH_{i4}v_7(3) + \\
 &\quad \varphi_n(H_{i1}v_7(0) - jH_{i2}v_7(1) + H_{i3}v_7(2) + H_{i4}v_7(3)) \\
 &= H_{i1}v_3(0) + jH_{i2}v_7(1) + H_{i3}v_3(2) + jH_{i4}v_7(3) + \\
 &\quad \varphi_n(H_{i1}v_3(0) + jH_{i2}v_7(1) + H_{i3}v_3(2) + jH_{i4}v_7(3))
 \end{aligned} \tag{18}$$

Analysis of formula (10) returns: calculate  $v_m(1)$  and  $v_m(3)$ , each requires 16 times complex multiplication, calculate  $v_m(2)$  required 8 times complex multiplication. So select reduction algorithm complexity requires a total of 40 times complex multiplication.

Three kinds of pre-coding codebook selection statistics complexity of the algorithm shown in Table 5:

**Table 5. Different Pre-Coding Code Complex Multiplication Algorithm and the Complex Plus the Number of the Selection**

	Complete traversal algorithm selection	Improved selection traversal algorithm	Lowering complexity of selection algorithm
Complex multiplication	128x8	32x8	40
Complex plus	128x7	128x7	128x7

#### 4. Performance Simulation Algorithm

This section focuses on simulation LTE-A system 8x1 antennas configuration. Under different channel environments (EPA5, ETU70, EVA5) of the three pre-coding codebook selection algorithm performance and compare different pre-coding codebook selection algorithm system block error ratio and throughput.

Simulation conditions: the bandwidth of the 10MHZ, 50 resource block occupied by a user, the modulation scheme is QPSK, the number of iterations of the simulation 1000, CFI = 2, the ratio of an the uplink and downlink is 1, special sub-frame is configured 4, spatial transmission correlation is low, the transmission mode is 4, Turbo decoding the maximum number of iterations is 8, SNR = {- 5: 5: 30}, the relevant block is set to 2.

The simulation results are as follows:

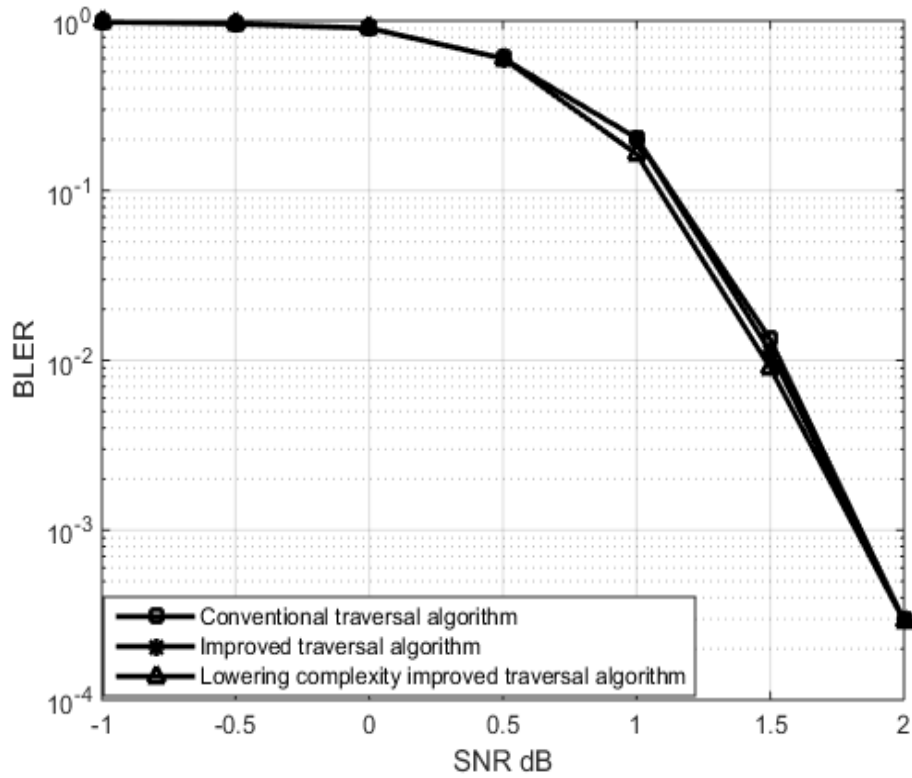


Figure 2. Different Traversal Algorithms BLER under EPA5 Channel

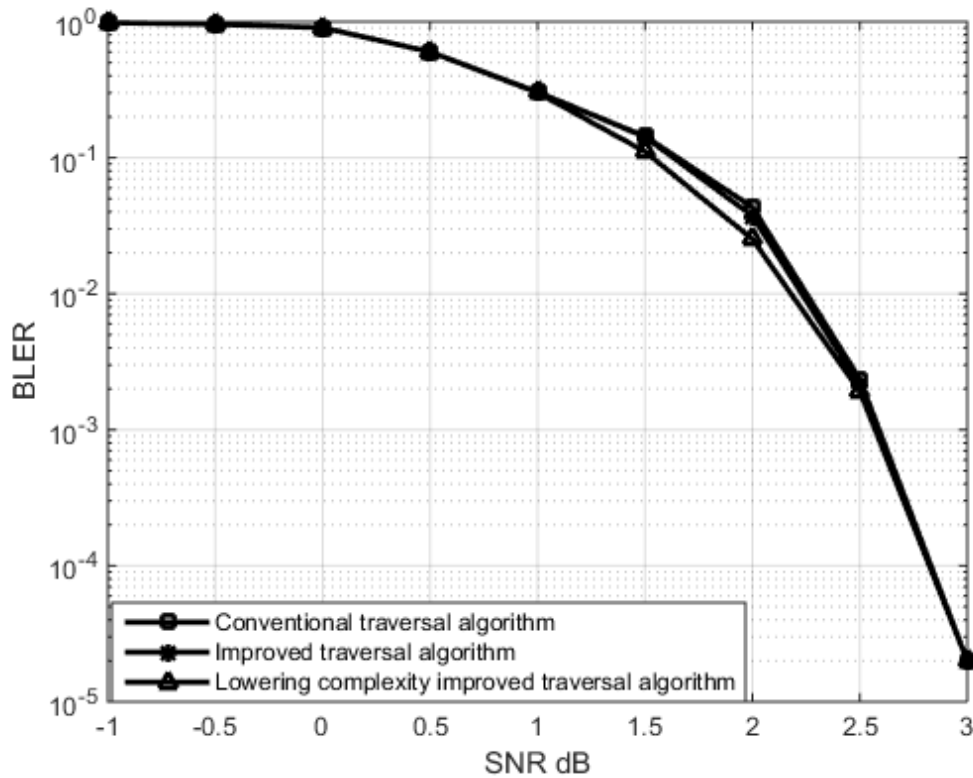
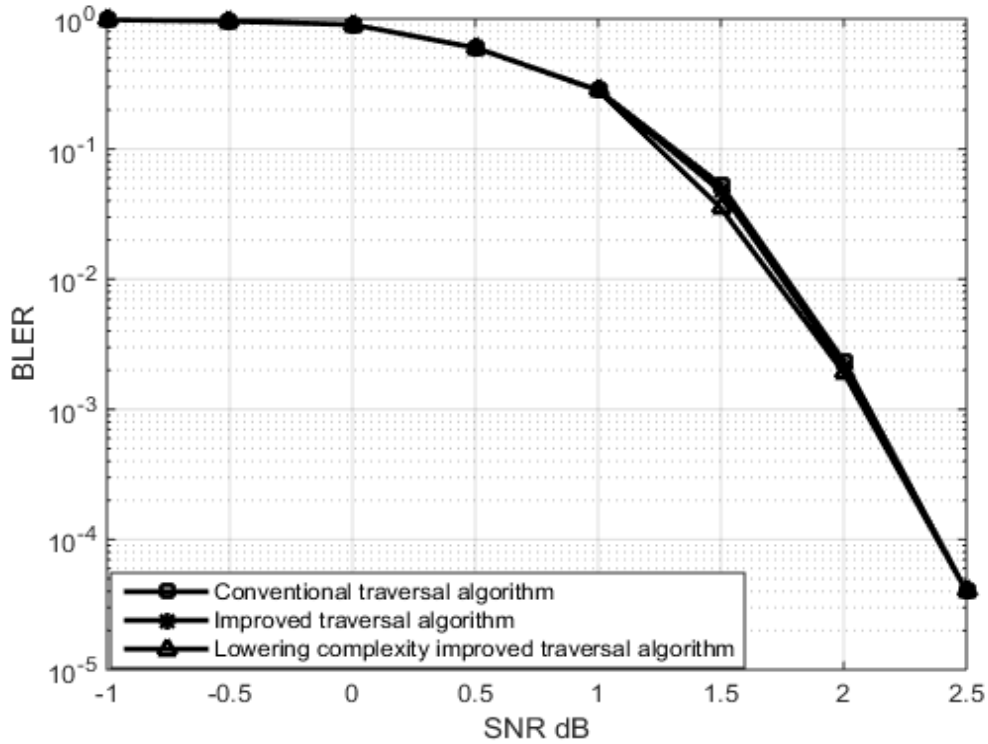


Figure 3. Different Traversal Algorithms BLER under ETU70 Channel

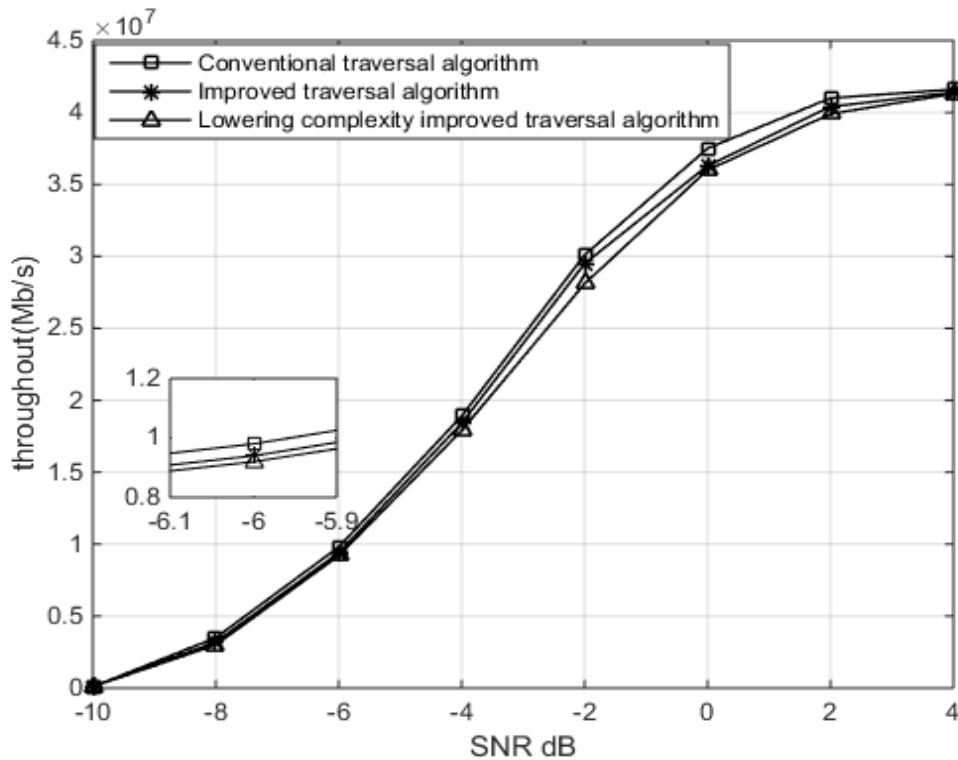




**Figure 4. Different Traversal Algorithms BLER under EVA5 Channel**

Simulation conditions: the bandwidth of 20MHz, single code word, effective sub-frame configuration is {0,1,3,4,6,9}, SNR = {- 10: 2: 4}.

The simulation results are as follows:



**Figure 5. Different Traversal Algorithm Throughput under EPA5 Channel**

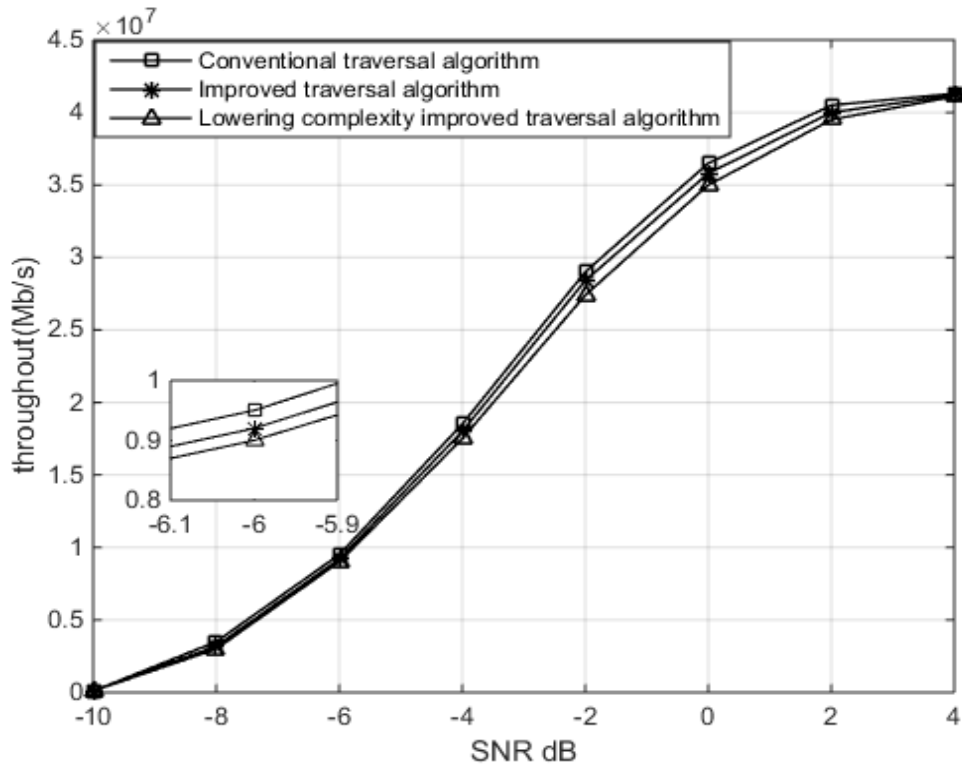


Figure 6. Different Traversal Algorithm Throughput under ETU70 Channel

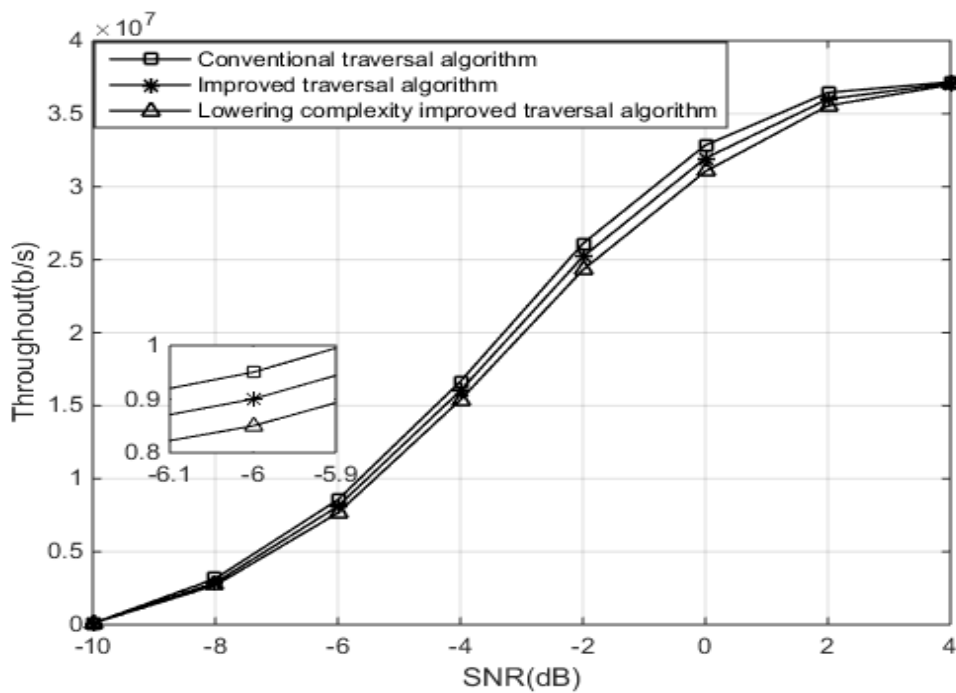


Figure 7. Different Traversal Algorithm Throughput under EVA5 Channel

## 5. Conclusions

From Section 4 we can see, by the algorithm performance simulation under different channel environments, based on 8-antenna pre-coding codebook selection lowering

complexity improved traversal algorithm and traditional traversal algorithm, the improved algorithm traversing block error rate is almost the same, moreover does not receive the basic performance to losses. Section 3.3 by the complexity of the analysis, the traversal algorithm and improved traditional traversal algorithm needs to be 128x8 times, respectively, 32x8 multiplications, compared to the two traversal algorithm, reducing the complexity of the improved traversal algorithm requires only 40 multiplications. Therefore, the lowering the complexity of the improved traversal algorithm we proposed that can ensure the system performance under the premise and also can greatly reduce the complexity.

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