Achieving Higher Full-diversity Gain of Downlink STBC-MIMO SCMA System

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Abstract —Sparse code multiple access (SCMA) and multiple-input multiple-output (MIMO) are two important techniques that can solve high spectral efficiency problem and the massive connectivity requires of fifth generation wireless communication industry in the future. In this paper, the combination of space-time block code multiple input multiple output (STBC-MIMO) and SCMA system are suggested. However, STBC-MIMO system has diversity gain from the number of transmission and receiving antennas for flat MIMO channels. In order to make STBC-MIMO SCMA system achieve higher diversity gain, I suggest a simple method, new SCMA codeword mapping with STBC, that has diversity from the number of resolvable paths for any pairs of transmit-receive antennas. The simulation result demonstrates that the presented SCMA codeword mapping can improve bit-error rate performance.

Index Terms—5G, Sparse code multiple access, space time block code, multiple input multiple output

I. INTRODUCTION

Next generation wireless communication system can support various traffics and more requires: the higher demands of massive connectivity and throughput, less latency, and higher quality of service [1]. Sparse code multiple access (SCMA) is a codebook-base non-orthogonal access technology that can support the 5G requires, which have massive connectivity, and increase capacity [1], [2]. Moreover, multiple-input multiple-output (MIMO) is generally regarded as a very effective technology that improves spectral efficiency by using spatial multiplexing.

In order to improve the spectral efficiency, SCMA is combined with MIMO method, known as MIMO-SCMA. Most recent MIMO-SCMA focus on measuring performances, analyzing capacity, or improving detector of receiver [3], [4]. Recently massive MIMO and SCMA schemes are candidates for 5G network [5]. Massive MIMO system is developed from the original MIMO that consists of many antennas, and sometimes hundreds of antennas at the base station has very high gain for both spectral efficiency and energy efficiency [6]. However, this is system increases the complexity of hardware, energy consumption, and the complexity of processing at the transmitter and receiver.

Attempting to make each component of massive MIMO effective, accurate, less energy consumption, and low cost is very challenging. That is the reason why the original MIMO system, which is simple and less complicated, is still needed. MIMO system, which benefits from spatial diversity gain and spatial multiplexing gain, sends information to transmit antennas and different time slots that make multiple redundant and transmits through independent fading channels. This way of transmitting make receiver achieve spatial diversity gain. MIMO coding can be divided into 3 types: space-time (ST) codes, space-frequency (SF) codes, and space-time-frequency (STF) codes. These various types of coding gain have some level of space and multipath diversity. The STF-coded can achieve full rate with full diversity in space, time, and frequency.

However, the three types of coding, the ST coding is practically the simplest and has less decoding complexity [7]. Practical ST coding uses space-time block coding (STBC), which achieves diversity gain from the number of transmit antennas N_T, and receive antennas N_R, for flat MIMO channels.

I propose the combination of STBC-MIMO and SCMA system for downlink by using a new SCMA codeword mapping technique crossing space-time block coding. That technique can make codewords have independent K resolvable paths when transmitting over only flat fading channels, in order to improve the performance of message passing algorithm (MPA) detector.

This paper contents are ordered as follows. Section 2 demonstrates the whole picture of the system model of the proposed downlink STBC-MIMO SCMA. The designing of SCMA codeword mapping crossing ST block code in order to improve the performance is explained in section 3. Section 4 presents the simulation results, and section 5 is the conclusion of this paper.

II. STBC-MIMO SCMA SYSTEM MODEL

A. Downlink STBC-MIMO SCMA System

When considering downlink communication of MIMO-SCMA, we can see that the base station (BS) has communications with J user at mobile station differently. Bit information $\mathbf{b}_j \in B^{\log_2 M}$ of user j is modulated to N-dimensional constellation symbols $c_j \in C^N$. While C stands for complex field, low dimensional symbol c_j then

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are mapped to *K*-dimensional complex sparse codewords $\mathbf{x}_j \in C^{K\times 1}$ by using SCMA codebook $\chi_j \in C^{K\times M}$ size *M*, containing the constellation set *j*. $\mathbf{x}_j = (x_{1_1}^j, x_2^j, \ldots, x_K^j)$ consists of $N < K$ that has non-zeros. Spreading sparse codewords to *K* resources can be represented with factor graph as in Fig. 1, the factor graph matrix $F = (f_1, f_2, \ldots, f_J) \in B^{K\times J}$. After that, codewords $\mathbf{x}_j$ for the period *i* will be combined with other *J* users, as follows:

$$\mathbf{x}(i) = \sum_{j=1}^{J} \mathbf{x}_j(i) \tag{1}$$

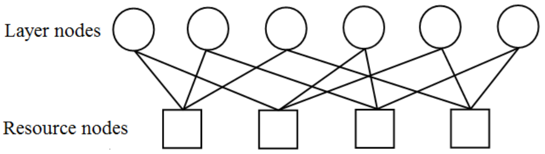

Fig. 1. Factor graph representation of SCMA system with *J*=6, *K*=4 and d_f=3.

The STBC-MIMO of base station have N_T transmit antennas that send information to user devices that have N_R receive antennas. Before the sum of codewords $\mathbf{x}$ is transmitted to antennas, $\mathbf{x}$ is coded with space-time block code to N_T - dimensional $\mathbf{X} \in C^{N_T}$ size KL, that has coding rate $1/L$. The example of complex space-time code $\mathbf{X}_{N_T,K}$ in case that $N_T = 3$, $K = 4$, and the defined coding rate $= 1/2$ can be written as:

$$(\mathbf{X}_{3,4})^T = \begin{bmatrix} x_1 & -x_2 & -x_3 & -x_4 & x_1^* & -x_2^* & -x_3^* & -x_4^* \\ x_2 & x_1 & x_4 & -x_3 & x_2^* & x_1^* & x_4^* & -x_3^* \\ x_3 & -x_4 & x_1 & x_2 & x_3^* & -x_4^* & x_1^* & x_2^* \end{bmatrix} \tag{2}$$

In equations (2), base station transmits $K = 4$ mapped codewords which are encoded over 8 symbol periods to $N_T = 3$ antennas. The row n_T of matrix in (2) is the signal that is transmitted to the antenna n_T or $(\mathbf{X}^{n_T})^T$, which $n_T = 1,2,\ldots,N_T$.

This paper focuses on flat Rayleigh fading channel, the received signal at the antenna n_R of user *j* can be represented as:

$$\mathbf{y}_j^{n_R} = \sum_{n_T=1}^{N_T} diag(\mathbf{h}_j^{n_R,n_T})\mathbf{X}^{n_T} + \mathbf{z}_j^{N_R} \tag{3}$$

while $n_R = 1,2,\ldots,N_R$, $\mathbf{h}_j^{n_R,n_T} \in C^{KL\times 1}$ is channel gain vector among the antenna n_T of BS and the antenna n_R of user *j*. These elements are according to complex Gaussian distributions $CN(0,1)$. $\mathbf{z}_j^{n_R} \in C^{KL\times 1}$ is the Gaussian noise vector over the antennas n_R of user *j*. These elements are the model in accordance with independent and identically distributed $CN(0,\sigma^2)$. We assume that the coefficients of all channels are independent.

All the received signals are in vector can be represented as $\mathbf{y}_j = [(\mathbf{y}_j^1)^T, (\mathbf{y}_j^2)^T, \ldots, (\mathbf{y}_j^{N_R})^T]^T \in C^{N_R KL\times 1}$, and user *j* can be written as:

$$\mathbf{y}_j = \mathbf{H}_j\mathbf{X} + \mathbf{z}_j \tag{4}$$

with MIMO channel matrix, $H_j \in C^{N_R KL\times N_T KL}$ can be represented as:

$$\mathbf{H}_j = \begin{bmatrix} diag(\mathbf{h}_j^{1,1}) & diag(\mathbf{h}_j^{1,2}) & \cdots, & diag(\mathbf{h}_j^{1,N_T}) \\ diag(\mathbf{h}_j^{2,1}) & diag(\mathbf{h}_j^{2,2}) & \cdots, & diag(\mathbf{h}_j^{2,N_T}) \\ \vdots & \vdots & \ddots & \vdots \\ diag(\mathbf{h}_j^{N_R,1}) & diag(\mathbf{h}_j^{N_R,2}) & \cdots & diag(\mathbf{h}_j^{N_R,N_T}) \end{bmatrix} \tag{5}$$

while $\mathbf{X} = [(\mathbf{X}^1)^T, (\mathbf{X}^2)^T, \ldots, (\mathbf{X}^{N_T})^T]^T \in C^{N_T KL\times 1}$ is spatially multiplexed signal vector, $\mathbf{z}_j = [(\mathbf{z}_j^1)^T, (\mathbf{z}_j^2)^T, \ldots, (\mathbf{z}_j^{N_R})^T] \in C^{N_R KL\times 1}$ is complex noise vector at user *j*.

B. *Space-Time Decoding*

Equation (4) can be rewritten in the form of effective channel matrix [8] according to

$$\begin{aligned} \mathbf{y}_j &= \mathbf{H}_j\mathbf{X} + \mathbf{z}_j \\ &= \mathbf{H}_{eff,j}\cdot\mathbf{x} + \mathbf{z}_j \end{aligned} \tag{6}$$

effective channel matrix, $\mathbf{H}_{eff,j} \in C^{N_R KL\times N_T K}$. In order to decode STBC, we can use orthogonality of the effective channel matrix above. The received signal will be adjusted as follows:

$$\begin{aligned} \tilde{\mathbf{y}}_j &= (\mathbf{H}_{eff,j})^H \cdot \mathbf{y}_j \\ &= (\mathbf{H}_{eff,j})^H \mathbf{H}_{eff,j}\cdot\mathbf{x} + (\mathbf{H}_{eff,j})^H \mathbf{z}_j \end{aligned} \tag{7}$$

$\tilde{y}_j$ is the received signal that has already been STBC-decoded, and $(\mathbf{H}_{eff,j})^H$ is Hermitian transpose of $\mathbf{H}_{eff,j}$.

C. *SCMA Optimal Detection*

Detecting SCMA codewords, which are transmitted by using the optimal method is maximum a posteriori (MAP) detection that is estimated as the highest value of joint a posteriori probability (APP) mass function of the transmitted codewords can be written as:

$$\hat{\mathbf{x}} = \arg\max_{\mathbf{x}\in\chi_1\times\cdots\times\chi_J} p(\mathbf{x}\,|\,\tilde{\mathbf{y}},\mathbf{H}'_j) \tag{8}$$

χ_j represents the codeword set for user *j* and $H'_j \in C^{N_R K\times N_T K}$, while APP mass function of the transmitted codewords can be represented as follows:

$$p(\mathbf{x}\,|\,\tilde{\mathbf{y}},\mathbf{H}'_j) = p(\mathbf{x})\cdot\exp\left(-\frac{1}{2\sigma^2}\left\|\tilde{\mathbf{y}}_j - \mathbf{H}'_j\mathbf{x}\right\|^2\right) \tag{9}$$

We assume that the possibility of each transmitted codewords has equal probability. The optimal maximum likelihood detection for SCMA can be simplified as:

$$\hat{\mathbf{x}} = \arg\min_{\mathbf{x}\in C^{K\times 1}} \left\|\tilde{\mathbf{y}}_j - \mathbf{H}'_j\mathbf{x}\right\|^2, \tag{10}$$

The complexity of massage passing algorithm (MPA) is $O(M^{d_f})$, while $d_f = \max_k\left(\sum_{j=1}^{J} F_{kj}\right)$. The main drawback of maximum likelihood detection is that computational complexity will exponentially increase.

III. PROPOSED SCMA CODEWORD MAPPING

From the STBC-MIMO SCMA system model that is explained in section 2 with N_T transmit antennas and N_R receive antennas. If the channel for every pair of transmit-receive antennas is independent and experiences flat fading, which the maximum diversity gain is $N_T N_R$, the bit error rate (BER) performance for wireless communication system will be improved when achieve additional diversity gain.

STBC-MIMO SCMA system for frequency-selective MIMO channels, which will have additional diversity gain if every transmit-receive link has independent multipath fading, and the channel impulse response is characterized by K resolvable paths, has the maximum diversity gain increased to $N_T N_R K$ [7]. However, in frequency-selective MIMO channel, there will be more effects from inter symbol interference (ISI).

This research focuses on flat MIMO channel that each ST block code is independent from flat fading. As in (2), ST block coding of codewords $\mathbf{x} = (x_1, x_2, \ldots, x_K)$ transmitted to antennas over flat fading channel, while the receiver has ST code decoding as in (7). We can see that all codewords transmitted to K resources $(x_{1_1}, x_2, \ldots, x_K)$ do not have resolvable paths diversity.

From the previous suggestions, I have the idea that can make codewords have channel impulse response, which is characterized by resolvable paths diversity over flat fading channel, crossing ST block coding. It uses the method of SCMA codeword mapping that distributes codewords $(x_1(i), x_2(i), \ldots, x_K(i))$ crossing ST block coding which is in period $i, i+1, i+2, \ldots, i+(K-1)$. We start by grouping K codeword blocks that are in the same matrix according to:

$$\mathbf{x}^{(K)}(i) = (\mathbf{x}(i)^T, \mathbf{x}(i+1)^T, \ldots \mathbf{x}(i+(K-1))^T)^T \tag{11}$$

$\mathbf{x}^{(K)}(i)$ is the codeword block for period $i = (i, i+1, \ldots, i+(K-1))$. The codeword mapping method crossing ST block code can be achieved by switching the position of codewords $x_k(i)$ in $\mathbf{x}^{(K)}$ block crossing the period i as follows:

$$\begin{aligned}\overleftrightarrow{\mathbf{x}}^{(K)}(i) &= (\mathbf{x}^{(K)}(i))^T \\ &= (\overleftrightarrow{\mathbf{x}}(i)^T, \overleftrightarrow{\mathbf{x}}(i+1)^T, \ldots, \overleftrightarrow{\mathbf{x}}(i+(K-1))^T)^T\end{aligned} \tag{12}$$

$\overleftrightarrow{\mathbf{x}}^{(K)}(i)$ is transpose codeword block for the period $i = (i, i+1, \ldots, i+(K-1))$. That make codewords $x_k(i)$ of each k resource switched to other periods i, and we will have new codewords which are $\overleftrightarrow{\mathbf{x}}$ that leads to ST block coding procedure. An example of $\overleftrightarrow{\mathbf{x}}^{(K)}(i)$ for $K = 4$ and $i = 0$ can be represented as:

$$\overleftrightarrow{\mathbf{x}}^{(K)}(0) = \begin{bmatrix} x_0(0) & x_1(0) & x_2(0) & x_3(0) \\ x_0(1) & x_1(1) & x_2(1) & x_3(1) \\ x_0(2) & x_1(2) & x_2(2) & x_3(2) \\ x_0(3) & x_1(3) & x_2(3) & x_3(3) \end{bmatrix} \tag{13}$$

In each column of matrix in (13), there is codeword $\overleftrightarrow{\mathbf{x}}(i)$. We can see that in each codeword $\overleftrightarrow{\mathbf{x}}(i)$ consists of codewords that include other periods, for example, the period $i = 1$, $\overleftrightarrow{\mathbf{x}}(1) = [x_1(0), x_1(1), x_1(2), x_1(3)]$ has the codewords of the period $i = 0,2,3$ included. When each $\overleftrightarrow{\mathbf{x}}(i)$ passes ST block coding, it makes codewords $(x_1(i), x_2(i), \ldots, x_K(i))$ distribute to K ST-block and transmitted to antennas. An example of downlink STBC-MIMO SCMA transmitter with codeword mapping shown in Fig. 2.

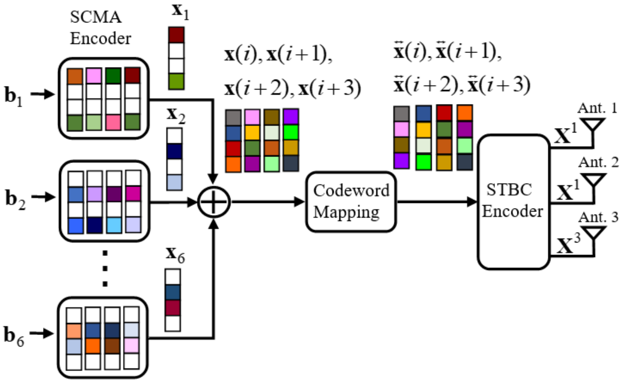

Fig. 2. Block diagram of proposed downlink STBC-MIMO SCMA transmitter with J= 6, K=4, N=2 and N_T=3.

At the STBC-MIMO SCMA receiver, the transmitted signal through flat fading channel to user j, $\mathbf{y}_j(i)$ will be ST decoded according to:

$$\begin{aligned}\tilde{\mathbf{y}}_j(i) &= (\mathbf{H}_{eff,j})^H \cdot \mathbf{y}_j(i) \\ &= (\mathbf{H}_{eff,j})^H \mathbf{H}_{eff,j} \cdot \overleftrightarrow{\mathbf{x}}(i) + (\mathbf{H}_{eff,j})^H \mathbf{z}_j(i)\end{aligned} \tag{14}$$

$\tilde{\mathbf{y}}_j(i)$ must be collected for K ST-decoding block, written as follows:

$$\tilde{\mathbf{y}}_j^{(K)} = ((\tilde{\mathbf{y}}_j(i))^T, (\tilde{\mathbf{y}}_j(i+1))^T, \ldots, (\tilde{\mathbf{y}}_j(i+(K-1)))^T)^T \tag{15}$$

Before $\tilde{\mathbf{y}}_j^{(K)}$ will be transmitted to SCMA detection, its codeword positions must be switched crossing ST decoding block to the original transmitted codeword position, by using transpose matrix $\overleftrightarrow{\tilde{\mathbf{y}}}_j^{(K)} = (\tilde{\mathbf{y}}_j^{(K)})^T$. The possibility of each codeword can be detected by MPA according to:

$$\hat{\mathbf{x}}(i) = \arg \min_{\mathbf{x} \in C^{K \times 1}} \left\| \overleftrightarrow{\tilde{\mathbf{y}}}_j(i) - \overleftrightarrow{\mathbf{H}}'_j(i) \mathbf{x}(i) \right\|^2, \tag{16}$$

$\overleftrightarrow{\mathbf{H}}'_j(i) \in C^{N_R K \times N_T K}$ is MIMO channel matrix created from $\mathbf{H}'_j$ that the values of h_j are switched crossing K channel matrix $(\mathbf{H}'_j(i), \mathbf{H}'_j(i+1), \ldots, \mathbf{H}'_j(i+(K-1)))$ according to:

$$\overleftrightarrow{\mathbf{H}}'_j = \begin{bmatrix} diag(\overleftrightarrow{\mathbf{h}}_j^{1,1}) & diag(\overleftrightarrow{\mathbf{h}}_j^{1,2}) & \cdots, & diag(\overleftrightarrow{\mathbf{h}}_j^{1,N_T}) \\ diag(\overleftrightarrow{\mathbf{h}}_j^{2,1}) & diag(\overleftrightarrow{\mathbf{h}}_j^{2,2}) & \cdots, & diag(\overleftrightarrow{\mathbf{h}}_j^{2,N_T}) \\ \vdots & \vdots & \ddots & \vdots \\ diag(\overleftrightarrow{\mathbf{h}}_j^{N_R,1}) & diag(\overleftrightarrow{\mathbf{h}}_j^{N_R,2}) & \cdots & diag(\overleftrightarrow{\mathbf{h}}_j^{N_R,N_T}) \end{bmatrix} \tag{17}$$

$\vec{\mathbf{h}}_j = (h_j(i), h_j(i+1), \ldots, h_j(i+(K-1)))$. As in (16) and (17), we can see that the SCMA codewords $(x_1(i), x_2(i), \ldots, x_K(i))$ that are transmitted have effects from independent K flat fading. This makes MPA detection more efficient. On the other hand, STBC-MIMO SCMA will have higher full diversity to $N_T M_R K$.

IV. SIMULATIONS RESULTS

In this section, the simulation result of the new codeword mapping method's potential will be presented. This codeword mapping method can achieve full diversity $N_T N_R K$. Let us assume that the downlink STBC 3x4 MIMO SCMA system transmits quasi-static Raleigh fading channels. STBC-MIMO system is defined to consist of the antennas $N_T = 3$, $N_R = 4$ and ST block coding with coding rate $= 1/2$. SCMA system parameters are set as: $N = 2, J = 6, K = 4, d_f = 3$. Factor graph mapping matrix is as follows:

$$F = \begin{bmatrix} 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{bmatrix} \tag{18}$$

bit information is encoded with convolutional code rate of 0.5.

Fig. 3 is the simulation result of STBC-MIMO SCMA system for 4 ary codebook that uses circular QAM (3, 4) [9], which $M = 4$ is minimized projection point per complex dimension from 4 to 3 points. Comparing between non-codeword mapping and the proposed SCMA codeword mapping, we can see that the new codeword mapping method can improve BER performance in the high SNR region. The reason is that the codewords have K resolvable paths over the flat fading channels and achieve higher diversity gain [7].

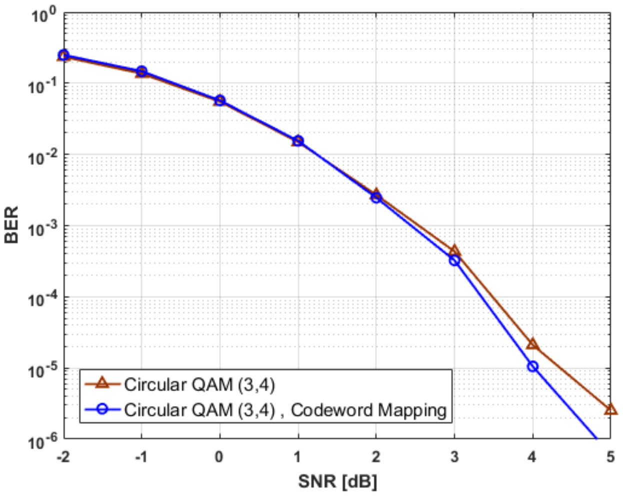

Fig. 3. BER performance comparison between non-codeword mapping and codeword mapping of 4-ary codebook STBC-MIMO SCMA system.

The simulation result of STBC-MIMO SCMA system for 16 ary codebook that uses circular QAM (8,16), which $M = 16$ is minimized projection point per complex dimension from 16 to 8 points, is presented in Fig. 4. We can see that the suggested codeword mapping method help downlink STBC-MIMO SCMA system achieve higher BER performance in high SNR region. It is noticed that the higher performance from the codeword mapping method in 16 ary codebook gives a better result than 4 ary codebook. The reason is that the additional diversity gain yields a more outstanding result, in case the Euclidean distance between points in lattice constellation is shorter.

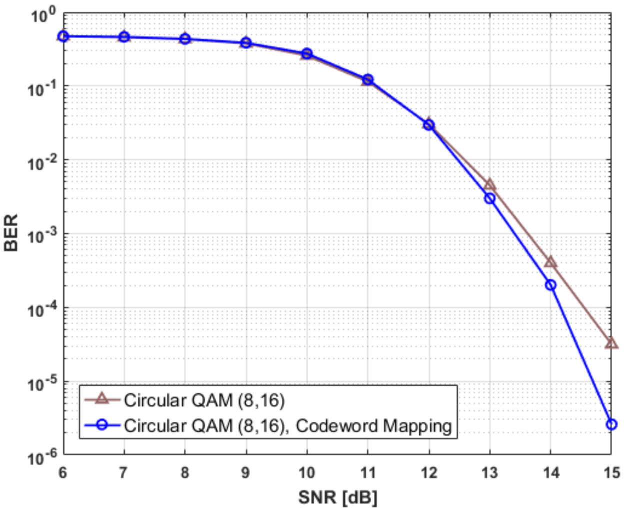

Fig. 4. BER performance comparison between non-codeword mapping and codeword mapping of 16 ary codebook STBC-MIMO SCMA system.

V. CONCLUSIONS

This paper proposes the combination of STBC-MIMO and SCMA system for the downlink. I have suggested a simple technique by adding SCMA codeword mapping, which can help codewords achieve independent K resolvable paths. This also increase MPA detector efficiency. STBC-MIMO SCMA system have additional full diversity gain from $N_T N_R$ to $N_T N_R K$. The simulation results demonstrate the better BER performance in high SNR.

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