Performance Comparison of Spatial Channel Modulation with Two/Three-Dimensional Constellations

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Abstract. In this paper, in view of merit of both the index modulation (IM) and the spatial channel modulation (CM), a new scheme, named as spatial channel modulation with multidimensional constellation (SCM-MDC), is designed to enhance the throughput and the reliability of communication systems. In the SCM-MDC, according to the employment of the signal constellations, it has two cases: Firstly, if modulating the QAM constellation, the antenna index (AI) vector set A and B are constructed by one active transmit antenna. Secondly, if modulating the 3D signal constellation, the AI vector set A and B are constructed by two and one active transmit antenna, respectively. Then, in order to be capable of enhancing the additional information, each transmit antenna is equipped with several radio frequency mirrors for carrying channel index information. Furthermore, the spectral efficiency and the bit error probability are provided. In the comparisons of the simulation results with the bit error rate (BER) performance, it can be seen that, the SCM-MDC achieves the better BER performance than the SM-MBM and QSM-MBM schemes.

Keywords: Spatial channel modulation, 3D constellation, AI vector set A, BER performance.

1. Introduction

In the MIMO systems with the index modulation (MIMO-IM) technique, the deeply exploitation of additional information bits is to not only improve the spectral efficiency (SE) but also enhance the bit error rate (BER) performance, such as quadrature spatial modulation (QSM) [1] that exploits the in-phase and quadrature index domain for the additional information bits, enhanced SM (ESM) [2] that exploits the additional information by extending the size of the signal spaces with the combination of both multiple constellations with the number of active transmit antennas. Then, with the exploiting of the dimension for the signal constellation, quadrature index modulation (QIM) [3] is proposed to design three dimension (3D) constellation for improving the squared minimum Euclidean distance (MED) between the transmit symbols. Recently, extended space index modulation (ESIM) [4] is proposed to expand the size of the signal spaces with the same detection complexity as the QSM system for improving the SE. However, to meet the requirement of higher transmit rate, the above-mentioned MIMO-IM schemes are much inferior.

In the past few years, the media-based modulation (MBM) [5] system, which employs radio frequency (RF) mirrors placed in each transmit antenna to create different channel fade realizations based on two states of ON/OFF, is designed to greatly improve the SE and reliability of wireless communications. In order to further improve the SE, the MBM is developed into multiple types of the MBM with IM schemes such as generalized spatial modulation-MBM (GSM-MBM) [6] that utilizes both the achieved multiplex gain and the specified channel states to improve the BER performance, and quadrature SM aided MBM (QSM-MBM) [7] that utilizes the in-phase and quadrature domains for further develop the dimension of the MBM system. Then, with the aid of one reserved transmit antenna, as compared with SM-MBM, quadrature channel modulation (QCM) [8] is proposed to greatly improve the BER performance with the condition that it utilizes the reserved antenna to avoid the overlapping of the active antennas when the real and imaginary parts of the mapped symbol are modulated. However, no work regarding the amalgamation of the MBM system with the multi-dimension signal constellation is available in the above-mentioned literatures.

Against this background, in order to improve the BER performance, a new scheme of spatial channel modulation with multidimensional constellation (SCM-MDC) is investigated to develop the spatial domain in the MBM system by extending the dimension of the signal constellation. Firstly, the transmitter of the SCM-MDC system is designed to modulate the QAM or 3D constellation symbol. According to the employed signal constellations, the AI vector set **A** and **B** are designed. Specifically, with employing the QAM constellation, all vectors in the set **A** and **B** are constructed by one active transmit antenna; with employing the 3D constellation, all vectors in the set **A** and that of the set **B** are constructed by two and one active transmit antenna, respectively. Then, due to each transmit antenna is equipped with multiple radio frequency (RF) mirrors, with the aid of the channel index bits, the components of the mapped symbol at the activated transmit antennas with the antenna index (AI) bits are transmitted over the specified channel states. Furthermore, the spectral efficiency and the bit error probability (BEP) for the SCM-MDC are provided. Finally, simulation results are provided for the BER performance comparisons between the SCM-MDC and the SM-MBM, QSM-MBM and QCM-III schemes at the same spectral efficiency.

The organization of this paper is as below. The SCM-MDC is introduced in Section II. The spectral efficiency and the BEP are provided in Section III. Simulation results are provided in Section IV and the conclusion is provided in Section V.

2. the Proposed QIM-MBM

As is shown in Fig. 1, the transmitter diagram of the SCM-MDC system with N_t transmit antennas is introduced. The information **b** bits are modulated into a MBM vector symbol to be transmitted through $2\times N_t$ RF Mirrors Control Switch, two AI Vector Selectors and Signal Mapper after being mapped.

According to the design of Fig.1, each transmit antenna is equipped with a MBM unit having m_{rf} RF mirrors.

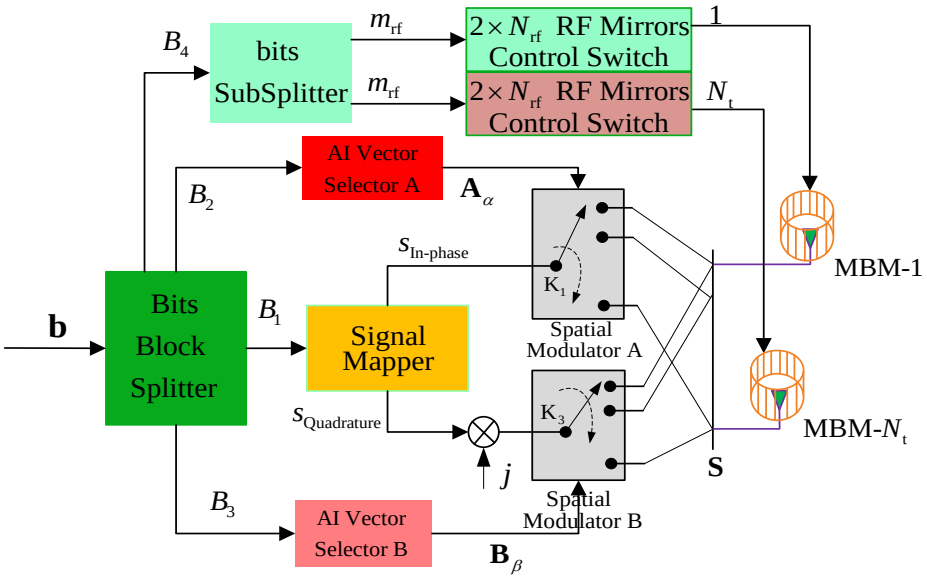


Fig. 1 Transmitter of the proposed SCM-MDC

Specifically, the bits stream of $\mathbf{b}=\left[b_1,\mathrm{L}\ ,b_{B_1+B_2+B_3+B_4}\right]$ is fed into the bits splitter and divided into four blocks: B_1 with $\log_2 N$ bits, B_2 with $\left\lfloor \log_2 C_{N_t}^{n_a} \right\rfloor$ bits, B_3 with $\log_2 N_t$ bits, B_4 with $2\log_2 M_{rf}$ bits, where N is the modulation order of the signal constellation such as QAM/PSK or 3D constellation, $n_a \in \{1,\ 2\}$ is the number of active transmit antenna(s) in the in-phase spatial dimension,

$M_{\mathrm{rf}}=2^{m_{\mathrm{rf}}}$ is the number of the channel states generated by the m_{rf} RF mirrors. For the block of B_1, it is fed into the Signal Mapper and mapped into one signal constellation point $s=(s_{\text{In-phase}},s_{\text{Quadrature}})$ from *N*-ary QAM symbol $s^{2\mathrm{D}}(s_{\Re}^{2\mathrm{D}},s_{\Im}^{2\mathrm{D}})$ or 3D signal symbol $s^{3\mathrm{D}}(s_x^{3\mathrm{D}},s_y^{3\mathrm{D}},s_{\mathrm{z}}^{3\mathrm{D}})$, note that $s_{\text{In-phase}}\in\left\{s_{\Re}^{2\mathrm{D}},(s_x^{3\mathrm{D}},s_y^{3\mathrm{D}})\right\}$, $s_{\text{Quadrature}}\in\{s_{\Im}^{2\mathrm{D}},s_{\mathrm{z}}^{3\mathrm{D}}\}$. For instance, 16-ary QAM: $s^{2\mathrm{D}}\in\left\{\pm1\pm j,\pm3\pm j,\pm1\pm3j,\pm3\pm3j\right\}$, 16-ary 3D signal constellation [3]: $s^{3\mathrm{D}}\in\left\{(\pm2,\pm1,\pm1),(\pm1,\pm2,\pm1)\right\}$.

In other words, when employing the QAM constellation, $s_{\text{In-phase}}=s_{\Re}^{2\mathrm{D}}$, $s_{\text{Quadrature}}=s_{\Im}^{2\mathrm{D}}$. When employing the QAM constellation, $s_{\text{In-phase}}=(s_x^{3\mathrm{D}},s_y^{3\mathrm{D}})$, $s_{\text{Quadrature}}=s_{\mathrm{z}}^{3\mathrm{D}}$.

For the block of B_2, it is fed into AI Vector Selector A and then mapped into an antenna index (AI) vector $\mathbf{A}_\alpha$ from the AI vector set $\mathbf{A}=\left\{\mathbf{A}_1,\mathrm{L}\ ,\mathbf{A}_\alpha,\mathrm{L}\ \mathbf{A}_\lambda\right\}$, where α is the decimal number of the block of B_2, $\lambda=2^{\left\lfloor\log_2 C_{N_{\mathrm{t}}}^{n_{\mathrm{a}}}\right\rfloor}$. Note that, when $n_{\mathrm{a}}=1$, $\lambda=N_{\mathrm{t}}$, the vector $\mathbf{A}_\alpha$ is from the α-th column vector of the unit matrix $\mathbf{I}_{N_{\mathrm{t}}}$ with $N_{\mathrm{t}}\times N_{\mathrm{t}}$ dimensions, and when $n_{\mathrm{a}}=2$, $\lambda=2^{\left\lfloor\log_2 C_{N_{\mathrm{t}}}^{2}\right\rfloor}$, λ number of AI vectors in the set $\mathbf{A}$ are selected out from $C_{N_{\mathrm{t}}}^{n_{\mathrm{a}}}$ number of AI vectors that are constructed by n_{a} active transmit antennas. For instance, in this case of both $n_{\mathrm{a}}=2$ and $N_{\mathrm{t}}=4$, it has $C_4^2=6$ number of AI vectors respectively corresponding to each column vector of the following matrix, and then results in the set $\bar{\mathbf{A}}'$.

$$\begin{bmatrix}1&1&0&0&1&0\\0&0&1&1&1&0\\1&0&0&1&0&1\\0&1&1&0&0&1\end{bmatrix}\rightarrow\bar{\mathbf{A}}'=\begin{bmatrix}1&1&0&0\\0&0&1&1\\1&0&1&0\\0&1&0&1\end{bmatrix}. \tag{1}$$

For the block of B_3, it is fed into AI Vector Selector B and then mapped into an AI vector $\mathbf{B}_\beta$ from from the AI vector set $\mathbf{B}=\left\{\mathbf{B}_1,\mathrm{L}\ ,\mathbf{B}_\beta,\mathrm{L}\ \mathbf{B}_{N_{\mathrm{t}}}\right\}$, where β is the decimal number of the block of B_3. Meanwhile, $\mathbf{B}_\beta$ is from the β-th column vector of the unit matrix $\mathbf{I}_{N_{\mathrm{t}}}$ with $N_{\mathrm{t}}\times N_{\mathrm{t}}$ dimensions.

In the Spatial Modulator A, according to the design of the AI vector set $\mathbf{A}$, if $n_{\mathrm{a}}=1$, the selected AI vector $\mathbf{A}_\alpha$ is used to modulate the in-phase part $s_{\text{In-phase}}(\mathrm{i.e.},s_{\Re}^{2\mathrm{D}})$ of the mapped symbol $s^{2\mathrm{D}}$ is modulated on the specified one active transmit antenna. If $n_{\mathrm{a}}=2$, the selected AI vector $\mathbf{A}_\alpha$ is used to modulate the in-phase part $s_{\text{In-phase}}(\mathrm{i.e.},\ (s_x^{3\mathrm{D}},s_y^{3\mathrm{D}}))$ of the mapped symbol $s^{3\mathrm{D}}$ is modulated on the specified two active transmit antennas. Thus, the in-phase spatial vector $\mathbf{S}_{\Re}$ can be expressed and has two cases:

$$\mathbf{S}_{\Re}=\begin{cases}s_{\Re}\cdot\mathbf{A}_\alpha, & n_{\mathrm{a}}=1, s=s^{2\mathrm{D}}\\ s_x\cdot\mathbf{A}_{\alpha,\tau1}+s_y\cdot\mathbf{A}_{\alpha,\tau2}, & n_{\mathrm{a}}=2, s=s^{3\mathrm{D}}\end{cases}, \tag{2}$$

where $\mathbf{A}_{\alpha,\tau1}$ and $\mathbf{A}_{\alpha,\tau2}$ are the unit vectors with the $\tau1$-, $\tau2$-th row non-zero elements equaling to "1" in the AI vector $\mathbf{A}_\alpha$.

Then, in the Spatial Modulator B, with the aid of the AI vector $\mathbf{B}_\beta$, the quadrature part $s_{\text{Quadrature}}$ of the mapped symbol s is modulated on the specified one active transmit antenna, resulting in the in-phase spatial vector $\mathbf{S}_{\Im}$, which is as follows:

$$\begin{aligned}\mathbf{S}_{\Im} &= s_{\text{Quadrature}} \cdot \mathbf{B}_{\beta} \\ &= \begin{cases} s_{\Im}^{2\text{D}} \cdot \mathbf{B}_{\beta}, & \text{when } s = s^{2\text{D}} \\ s_{\text{z}}^{3\text{D}} \cdot \mathbf{B}_{\beta}, & \text{when } s = s^{3\text{D}} \end{cases}. \end{aligned} \tag{3}$$

Thus, the spatial vector symbol is obtained as

$$\begin{aligned}&\mathbf{S} \\ &= \begin{cases} s_{\Re}^{2\text{D}} \cdot \mathbf{A}_{\alpha} + j s_{\Im}^{2\text{D}} \cdot \mathbf{B}_{\beta}, & \text{if } s = s^{2\text{D}} \\ (s_x \cdot \mathbf{A}_{\alpha,\tau 1} + s_y \cdot \mathbf{A}_{\alpha,\tau 2}) + j s_{\text{z}}^{3\text{D}} \cdot \mathbf{B}_{\beta}, & \text{if } s = s^{3\text{D}} \end{cases}. \end{aligned} \tag{4}$$

After obtaining the spatial vector symbol $\mathbf{S}$, in order to not only improve the spectral efficiency but also the BER performance, the non-zero components of the spatial vector $\mathbf{S}$ are transmitted over the specified channels with the block of B_4 information bits to the destination. Specifically, the block of B_4 bits is divided into two subblocks of both m_{rf} and m_{rf}. Then, through the $2 \times N_{\text{t}}$ RF Mirrors Control Switch, one subblock of m_{rf} bits is used to modulate the non-zero element(s) of the in-phase spatial vector $\mathbf{S}_{\Re}$ to be transmitted over the γ-th channel state $\mathbf{h}_{\gamma}^{n_{\text{t}}}$ at the n_{t}-th active transmit antenna, where $\mathbf{h}_{\gamma}^{n_{\text{t}}} \in \mathbf{H}_{n_{\text{t}}}$, $\mathbf{H}_{n_{\text{t}}} \in C^{N_{\text{r}} \times M_{\text{rf}}}$ is denoted by $\mathbf{H}_{n_{\text{t}}} = \left[\mathbf{h}_1^{n_{\text{t}}}, \text{L}\ , \mathbf{h}_{\gamma}^{n_{\text{t}}}, \text{L}\ , \mathbf{h}_{M_{\text{rf}}}^{n_{\text{t}}}\right]$. Thus, the in-phase part of the transmit vector $\mathbf{X}$ can be obtained as

$$\mathbf{X}_{\Re} = \left[\mathbf{S}_{\Re}(1) \cdot \mathbf{e}_{\gamma}, \text{L}\ , \mathbf{S}_{\Re}(N_{\text{t}}) \cdot \mathbf{e}_{\gamma}\right]^{T}, \tag{5}$$

where $\mathbf{e}_{\gamma}$ denotes an unit vector with the γ-th row non-zero element equaling to "1". Similarly, through another $2 \times N_{\text{t}}$ RF Mirrors Control Switch, the remaining subblock of m_{rf} bits is used to modulate the non-zero element of the quadrature spatial vector $\mathbf{S}_{\Im}$ to be transmitted over the ϑ-th channel state $\mathbf{h}_{\vartheta}^{n_{\text{t}}}$ at the n_{t}-th active transmit antenna. Thus, the quadrature part $\mathbf{S}_{\Im}$ of the transmit vector $\mathbf{X}$ can be expressed as

$$\mathbf{X}_{\Im} = \left[\mathbf{S}_{\Im}(1) \cdot \mathbf{e}_{\vartheta}, \text{L}\ , \mathbf{S}_{\Im}(N_{\text{t}}) \cdot \mathbf{e}_{\vartheta}\right]^{T}. \tag{6}$$

On the basis of the above design, the transmit vector $\mathbf{X}$ can be expressed as

$$\begin{aligned}\mathbf{X} &= \mathbf{X}_{\Re} + j\mathbf{X}_{\Im} \\ &= \begin{bmatrix} \mathbf{S}_{\Re}(1) \cdot \mathbf{e}_{\gamma} + j\mathbf{S}_{\Im}(1) \cdot \mathbf{e}_{\vartheta} \\ \text{M} \\ \mathbf{S}_{\Re}(N_{\text{t}}) \cdot \mathbf{e}_{\gamma} + j\mathbf{S}_{\Im}(N_{\text{t}}) \cdot \mathbf{e}_{\vartheta} \end{bmatrix}. \end{aligned} \tag{7}$$

Finally, the transmit vector $\mathbf{X}$ is transmitted over the Rayleigh fading channel matrix $\mathbf{H} = \left[\mathbf{H}_1, \text{L}\ , \mathbf{H}_{n_{\text{t}}}, \text{L}\ , \mathbf{H}_{N_{\text{t}}}\right]$, the receive signal $\mathbf{y}$ at the receiver is given by

$$\begin{aligned}\mathbf{Y} &= \mathbf{H} \cdot \mathbf{X} + \mathbf{N} \\ &= \begin{cases} s_{\Re}^{2\text{D}} \cdot \mathbf{h}_{\gamma}^{\alpha} + j s_{\Im} \cdot \mathbf{h}_{\vartheta}^{\beta} \\ (s_x^{3\text{D}} \cdot \mathbf{h}_{\vartheta}^{\alpha,\tau 1} + s_y^{3\text{D}} \cdot \mathbf{h}_{\vartheta}^{\alpha,\tau 2}) + j s_{\text{z}} \cdot \mathbf{h}_{\vartheta}^{\beta} \end{cases} + \mathbf{N} \end{aligned} \tag{8}$$

where $\mathbf{Y} \in C^{N_{\text{r}} \times 1}$, $\mathbf{H} \in C^{N_{\text{r}} \times N_{\text{rf}} N_{\text{t}}}$ is the channel matrix, whose each element is the Gaussian Rayleigh fading coefficient with the independent and identically distribution with $CN(0,1)$, $\mathbf{N} \in C^{N_{\text{r}} \times 1}$ is the Gaussian white noise vector, whose each element is with $CN(0, \sigma^2)$.

At the receiver, with the employment of the maximum likelihood (ML) detector and assumption of the channel state information, the incoming bits $\mathbf{b}=\left[b_1,\mathrm{L}\ ,b_{B_1+B_2+B_3+B_4}\right]$ are detected and retrieved. On the basis of Eq. (8), by the ML detector, the retrieved information bits for the proposed SCM-MDC are given by

$$\left[\hat{B}_1,\hat{B}_2,\hat{B}_3,\hat{B}_4\right]=\arg\min_{B_1,B_2,B_3,B_4}\left\|\mathbf{Y}-\mathbf{H}\cdot\mathbf{X}\right\|^2, \tag{9}$$

where $\hat{B}_1$ is the block of information bits for the detected signal constellation point s, $\hat{B}_2$ is the block of information bits for the detected in-phase AI vector index α, $\hat{B}_3$ is the block of information bits for the detected quadrature AI vector index β, $\hat{B}_4$ is the block of information bits for two detected channel indexes: γ and ϑ. $\|\cdot\|^2$ denotes the operation of Frobenius norm.

3. Performance Analysis

In this section, the spectral efficiency and the average bit error probability (BEP) are provided.

3.1. Spectral Efficiency

Based on the above design, the incoming bits are divided into four blocks: B_1, B_2, B_3, B_4, which are respectively modulated into one signal constellation point s, the in-phase and quadrautre AI vectors: $\mathbf{A}_\alpha$ and $\mathbf{B}_\beta$ and the two specified channel states: $\mathbf{h}_\gamma^{n_\mathrm{t}}$ and $\mathbf{h}_\vartheta^{n_\mathrm{t}}$, to be formed one transmit vector. Thus, the spectral efficiency can be calculated by

$$\begin{aligned}R&=B_1+B_2+B_3+B_4\\&=\log_2 N+\left\lfloor\log_2 C_{N_\mathrm{t}}^{n_\mathrm{a}}\right\rfloor+\log_2 N_\mathrm{t}+2m_\mathrm{rf}\end{aligned} \tag{10}$$

3.2. The Bit Error Probability

In this subsection, the BEP is analyzed.

With the assumption of the channel state information and its constraint, and on the basis of the Eq. (9) and reference [9], the conditional pairwise error probability (PEP) is obtained as

$$\begin{aligned}&P(\mathbf{X}\to\hat{\mathbf{X}}\,|\,\mathbf{H})\\&=P(\left\|\mathbf{Y}-\mathbf{H}\cdot\mathbf{X}\right\|_F^2>\left\|\mathbf{Y}-\mathbf{H}\cdot\hat{\mathbf{X}}\right\|_F^2\,|\,\mathbf{H})\\&=Q\left(\sqrt{\frac{\left\|\mathbf{H}\cdot\mathbf{X}-\mathbf{H}\cdot\hat{\mathbf{X}}\right\|^2}{2\sigma^2}}\right)\end{aligned} \tag{11}$$

where $\mathrm{Q}(x)$ is the Q function denoted by $\mathrm{Q}(x)=\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\exp\left(\frac{-x^2}{2\sin^2\theta}\right)d_\theta$.

Then, in order to obtain the average PEP (i.e., unconditional PEP), the expectation of Eq. (11) on the channel matrix $\mathbf{H}$ is taken. Consequently, the average PEP can be obtained by

$$
\begin{aligned}
&P\left(\mathbf{X}\to\hat{\mathbf{X}}\right)\\
&=E_{\mathbf{H}}\left\{\left(\mathbf{X}\to\hat{\mathbf{X}}\,|\,\mathbf{H}\right)\right\}\\
&=\frac{1}{\pi}E_{\mathbf{H}}\left\{\int_0^{\frac{\pi}{2}}\exp\left(\frac{\left\|\mathbf{H}\cdot\mathbf{X}-\mathbf{H}\cdot\hat{\mathbf{X}}\right\|^2}{2\sigma^2\sin^2\theta}\right)d_\theta\right\}\\
&=\left(\frac{1-\eta}{2}\right)^{N_\mathrm{r}}\sum_{\mathrm{l}=0}^{N_\mathrm{r}-1}\binom{N_\mathrm{r}-1+\mathrm{l}}{\mathrm{l}}\left(\frac{1+\eta}{2}\right)^{\mathrm{l}}
\end{aligned}
\tag{12}
$$

Where $\eta=\sqrt{\dfrac{d_{\mathbf{X}}^2}{4\sigma_0^2+d_{\mathbf{X}}^2}}$.

Finally, based on the upper bound technique [9], the average BEP is obtained as

$$
P_{\mathrm{e}}=\frac{1}{|\mathbf{b}|\cdot 2^{|\mathbf{b}|}}\sum_{\mathbf{X}}\sum_{\mathbf{X}\neq\hat{\mathbf{X}}}P\left(\mathbf{X}\to\hat{\mathbf{X}}\right)\cdot e\left(\mathbf{X}\to\hat{\mathbf{X}}\right)
\tag{13}
$$

Where $|\mathbf{b}|$ is the number of the total incoming bits $\mathbf{b}$. e($\mathbf{X}\to\hat{\mathbf{X}}$) is the number of erroneous bits with the case of $\mathbf{X}\neq\hat{\mathbf{X}}$.

3.3. Simulation Results and Discussions

In this section, simulation results with MATLAB is provided on the basis of the perfect assumption of channel state information at the receiver and $m_{\mathrm{rf}}=2$ (i.e., each transmit antenna with four RF mirrors).

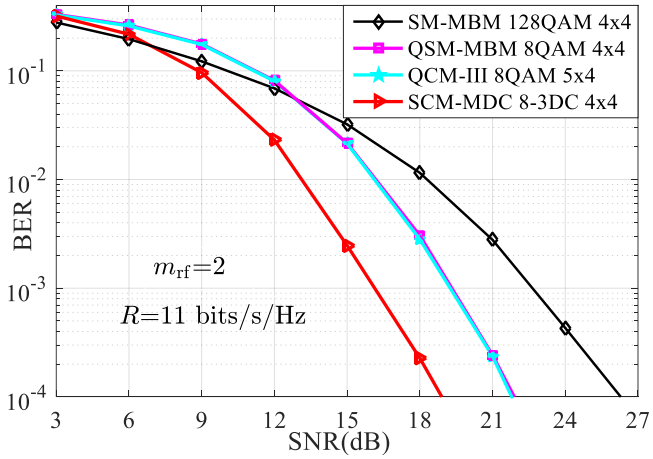


Fig. 2 BER curves comparisons between the SCM-MDC and the SM-MBM, QSM-MBM and QCM-III schemes at R=11 bits/s/Hz.

In Fig.2, the BER vs SNR curves are depicted for the SCM-MDC with the 8-ary 3D constellation (i.e., $s^{3\mathrm{D}}\in\{(\pm1,\pm1,\pm1)\}$), the QCM-III with 8QAM, the QSM-MBM with 8QAM and the SM-MBM with 128QAM at the spectral efficiency of 11 bits/s/Hz. It can be seen that the SCM-MDC has the significant BER performance in comparisons with other schemes. For instance, compared with the SM-MBM, approximately 6 dB SNR gain is achieved for the proposed SCM-MDC at the BER value of 10^{-3}.

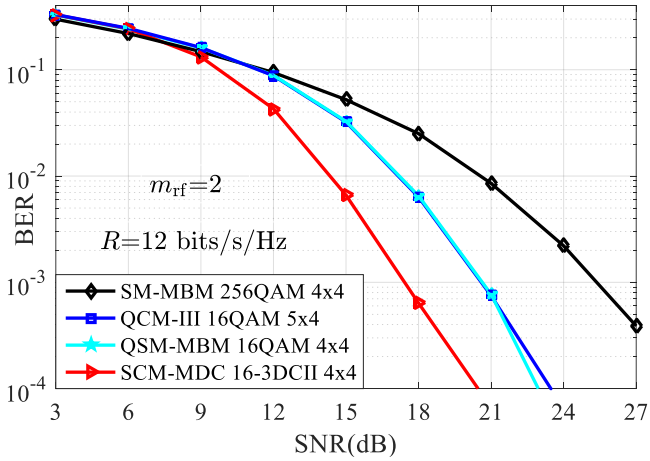


Fig. 3 BER curves comparisons between the SCM-MDC and the SM-MBM, QSM-MBM and QCM-III schemes at R=12 bits/s/Hz.

Then, in order to verify that it also has the same advantage when using higher modulation order of the 3D signal constellation, Fig.3 depicts the BER vs SNR curves with 12 bits/s/Hz for the SCM-MDC with the 16-ary 3D constellation (i.e., $s^{3D} \in \{(\pm 2, \pm 1, \pm 1), (\pm 1, \pm 2, \pm 1)\}$), the QCM-III with 16QAM, the QSM-MBM with 16QAM and the SM-MBM with 256QAM. Also, it can be seen that, the SCM-MDC has the significant advantage in terms of the BER performance in comparisons with other schemes. Specifically, about 7.5 dB SNR gain over the SM-MBM, about 3 dB SNR gain over both the QCM-III and QSM-MBM are achieved for the proposed SCM-MDC at the BER value of 10^{-3}.

In addition, in order to verify the advantage of the proposed SCM-MDC in different number of transmit antennas, Fig.4 depicts the BER vs SNR curves with (Nt, Nr)=(8, 8) and 14, 15 bits/s/Hz. In Fig.4, the solid lines are depicted for the SCM-MDC with the 8-ary 3D constellation (i.e., $s^{3D} \in \{(\pm 1, \pm 1, \pm 1)\}$), the QSM-MBM with 16QAM and the SM-MBM with 512QAM at the spectral efficiency of 14 bits/s/Hz, and the dot lines are depicted for the SCM-MDC with the 16-ary 3D constellation (i.e., $s^{3D} \in \{(\pm 2, \pm 1, \pm 1), (\pm 1, \pm 2, \pm 1)\}$), the QSM-MBM with 32QAM and the SM-MBM with 1024QAM at the spectral efficiency of 15 bits/s/Hz. It can be observed from Fig.4 that,

the BER performance achieved by the SCM-MDC are more significant than other schemes. From the Fig.4, at the spectral efficiency of 14 bits/s/Hz, approximately 5 dB SNR gain over the QSM-MBM, about 12 dB SNR gain over the SM-MBM are achieved for the proposed SCM-MDC at the BER value of 10^{-3}. Similarly, At the 15 bits/s/Hz, the proposed SCM-MDC achieves approximately 5.5 dB SNR gain over the QSM-MBM, about 13.5 dB SNR gain over the SM-MBM at the BER value of 10^{-3}.

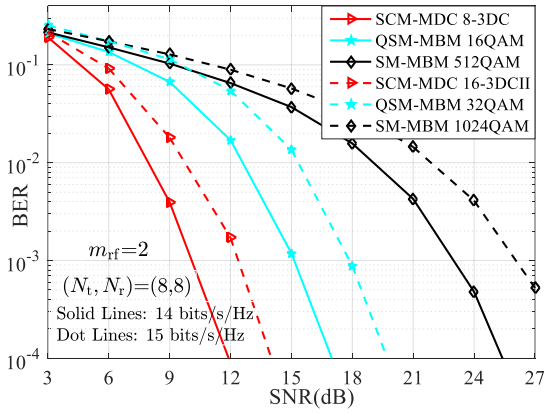


Fig. 4 BER curves comparisons between the SCM-MDC and the SM-MBM and QSM-MBM schemes at R=14, 15 bits/s/Hz and Nt=Nr=8.

4. Conclusions

In this paper, in order to improve the throughput and BER performance in MIMO systems, the SCM-MDC is proposed. Firstly, the transmitter of the SCM-MDC is designed. Furthermore, the spectral efficiency and the average BEP are provided. Finally, simulation results are provided to discuss the advantage of the proposed SCM-MDC in comparisons with other schemes such as the SM-MBM, QSM-MBM and QCM-III at the same spectral efficiency.

Acknowledgments

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