Impact of Imperfect Channel Estimation on the Performance of Signed Quadrature Spatial Modulation in Massive MIMO Systems

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Abstract. *Signed quadrature spatial modulation (SQSM) is invented to enhance the spectral efficiency of spatial modulation (SM), which is a promising candidate to be used as the energy-efficient modulation technique for the 6G-MIMO network. It is shown in the pioneering work that, for the case of the not-so-large number of antennas, SQSM is very robust to the effect of imperfect channel estimation. This motivates us to investigate further the impact of imperfect channel estimation on the performance of SQSM for the case of a large number of antennas. Our results demonstrate that the performance of SQSM is quite robust to the channel estimation error when the number of antennas is increased.*

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1. Introduction

For the next decade, the sixth-generation (6G) wireless communication network is expected to meet more demanding communication requirements, i.e., higher data rate, more reliable, and can support a large number of users with ultra-low latency [1-3]. Ultra-massive multiple-input multiple-output (UM-MIMO) is one of most important technological domains for 6G wireless communications in which multiple antennas are used to achieve higher data rates and reliability [4],[5]. However, the advantage of UM-MIMO is obtained at the expense of power consumption and loss energy efficiency. Therefore, there are many solutions to solve this problem [6]-[9].

A new MIMO transmission technique called signed quadrature spatial modulation (SQSM) has been proposed in [10]. This technique can achieve the spectral efficiency of quadrature spatial modulation (QSM) system. Furthermore, the bit error rate (BER) performance of SQSM is superior that of QSM and SM with a marginal increase in computational complexity. The SQSM technique utilizes a single RF chain which can reduce the power consumption. With all the advantages of SQSM, it can possibly candidate as a promising candidate MIMO technique for the 6G system [3].

Channel estimation error is one of the challenges in large MIMO systems [11]. From literature review, the impact of imperfect channel estimation on SQSM has been few studied in some aspects. For example, Ammar is proposed in [10] that the impact of imperfect channel of SQSM has stronger than QSM in the case of the not-so-large number of antennas. Therefore, we deep investigate the impact of imperfect channel of SQSM in the case of large number of antennas in this paper.

2. Signed Quadrature Spatial Modulation

Before going to explain the transmission of SQSM, we would like to elaborate on the definition of important parameters. The number of transmitted and received antennas are denoted by N_t and N_r, respectively. M-ary QAM is the modulation order for the quadrature amplitude modulation. For simplicity, these parameters are presented by $N_t \times N_r$ MIMO M-QAM. The number of bits per one SQSM transmission, i.e., the spectral efficiency, is denoted by η. The spectral efficiency of SQSM is given by

$$\eta_{\text{SQSM}} = \log_2\left(\frac{M}{4}\right) + \log_2(N_t^4) \text{ bps/Hz} \qquad (1)$$

Note that this parameter is the length of information bits or message vector $\boldsymbol{b}$ for SQSM. This message vector will split into two parts, i.e., modulation vector $\boldsymbol{m}$ and antenna vector $\boldsymbol{a}$. The first subpart of the message vector, called modulation vector, can be expressed as follows:

$$\boldsymbol{m} = \begin{bmatrix} m_1 & m_2 & \cdots & m_{\log_2\left(\frac{M}{4}\right)} \end{bmatrix}^{\mathbf{T}}. \qquad (2)$$

The modulation vector will be mapped by a M-QAM to obtain a signal symbol s_{SQSM}. Whereas, the M-QAM is considered only the first quadrant of the underlying constellation modulation with order M. For instance, the case of 8-QAM is illustrated in Fig. 1.

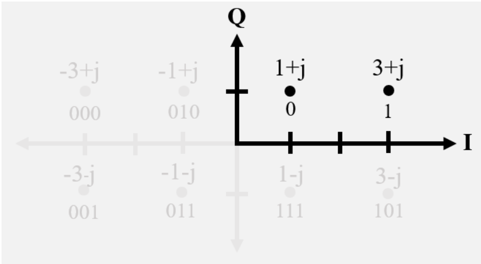

Fig. 1 Block diagram of polar coding scheme.

After that, the signal symbol is copied into the inverse of s_{SQSM}, denoted by $-s_{\text{SQSM}}$. Both symbols consist of four related components are constructed as follows:

$$\begin{aligned} s_{r^+} &= \mathcal{Re}(s_{\text{SQSM}}), \\ s_{i^+} &= j \times \mathcal{Im}(s_{\text{SQSM}}), \\ s_{r^-} &= \mathcal{Re}(-s_{\text{SQSM}}), \\ s_{i^-} &= j \times \mathcal{Im}(-s_{\text{SQSM}}). \end{aligned} \tag{3}$$

Where $\mathcal{Re}(\cdot)$ and $\mathcal{Im}(\cdot)$ are the real and imaginary part of signal symbol, respectively. Like modulation vector, the antenna vector of length $\log_2(N_t^4)$ bits must be equally divided into four subparts in order to respond for s_{r^+}, s_{i^+}, s_{r^-}, and s_{i^-}, respectively. The antenna vector can be expressed as follows:

$$\mathbf{a} = [\, a_1 \quad a_2 \quad \cdots \quad a_{\log_2(N_t^4)} \,]^{\mathbf{T}}. \tag{4}$$

To create the index of transmitted antenna, the antenna vector must be split to four subparts with $\log_2(N_t)$ bits. Then, each subpart is matched with the binary representation of transmitted antennas and finally obtained the index of transmitted antenna. Next, the four signal components, which are s_{r^+}, s_{i^+}, s_{r^-}, and s_{i^-}, will be transmitted at $\mathfrak{a}_1$-th, $\mathfrak{a}_2$-th, $\mathfrak{a}_3$-th, and $\mathfrak{a}_4$-th transmitted antennas, respectively. After completing this mapping, the index set for SQSM can be defined as $A = \{\mathfrak{a}_1, \mathfrak{a}_2, \mathfrak{a}_3, \mathfrak{a}_4\}$. The $\mathfrak{a}$-th transmitted antenna deals with the position of transmitted SQSM vector. So, the transmitted SQSM vector is given by

$$\mathbf{z} = [\, z_1 \quad z_2 \quad \cdots \quad z_{N_t} \,]^{\mathbf{T}}. \tag{5}$$

To clearly, the transmitter of SQSM illustrate in Fig. 2. After getting $\mathbf{z}_{\text{SQSM}}$, the received SQSM vector $\mathbf{y}$ can be expressed as

$$\mathbf{y} = \mathbf{Hz} + \mathbf{n}, \tag{6}$$

where $\mathbf{H}$ is the matrix channel $N_t \times N_r$. $\mathbf{n}$ is the noise vector $N_r \times 1$. For this paper, the entries of $\mathbf{H}$ are distributed with unit variance.

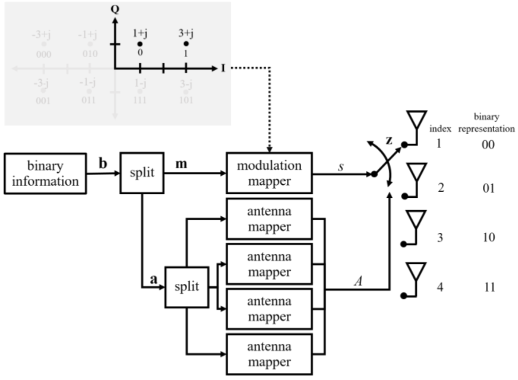

Fig. 2 The block diagram of SQSM transmitter with 4 × 4 MIMO 8-QAM.

3. Channel Model

The channel estimation is a major problem for large MIMO systems. The estimated channel matrix, adopted in [12], can be expressed by

$$\bar{\mathbf{H}} = \mathbf{H} + \Delta\mathbf{H}, \tag{7}$$

where $\Delta\mathbf{H}$ is the estimation error matrix in which the entries are assumed to be the complex Gaussian with zero mean and variance σ_e^2. From (6), the matrix channel in the general MIMO channel model is substituted with (7), can be expressed as

$$\mathbf{y} = \bar{\mathbf{H}}\mathbf{z} + \mathbf{n}. \tag{8}$$

This means that although it has no the noise vector, the estimation error matrix affects the transmitted vector. Ammar has proposed in [10] that the impact of imperfect channel of SQSM has stronger than QSM in the case of the not-so-large number of antennas. Therefore, we deep investigate the impact of imperfect channel of SQSM in the case of large number of antennas in this paper. The effect of imperfect channel estimation on SQSM will be discussed in the next section.

4. Results and Discussions

The impact of channel estimation error to the performance of SQSM is elaborated in this section. The performance of SQSM is expressed in terms of the BER, plotted against SNR per received antenna. For all the results, uncorrelated Rayleigh fading channel is assumed and rectangular QAM is employed as the modulation scheme. The optimal ML detection, described in the pioneer work [10], is utilized at SQSM receiver. So, the impact of channel estimation error is considered under optimal detection assumption.

Firstly, the effect of channel estimation error to performance of SQSM is evaluated over 16×16 MIMO QPSK. Figure 3 shows the performance of SQSM with various σ_e^2. As we expected, the performance of SQSM gets worse when the effect of channel estimation error increases. The channel estimation error $\sigma_e^2 = 0.1$, $\sigma_e^2 =$

0.2, and $\sigma_e^2 = 0.3$ incur performance loss about 0 dB, 2 dB, and 6 dB, respectively. It can be observed that the performance loss due to the channel estimation error up to, $\sigma_e^2 = 0.2$ is still small. So, it can be primarily stated that SQSM is quite robust to the effect of channel estimation error.

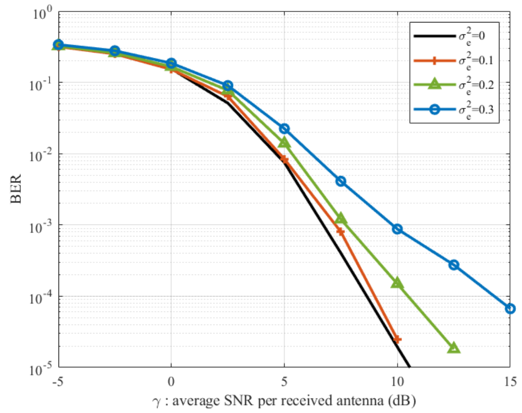

Fig. 3 The BER performance of SQSM with impact of imperfect channel estimation at 16 × 16 MIMO 4-QAM.

Comparing with the previous result, the number of modulation order for SQSM is increased from 4 to 64, in order to further investigate the effect of channel estimation error. For 16×16 MIMO 64-QAM, the performance of SQSM with imperfect channel estimation is demonstrated in Fig. 4. Similar to 16×16 MIMO 4-QAM case, SQSM can tolerate to the channel estimation error up to $\sigma_e^2 = 0.2$. Therefore, under imperfect channel estimation, the increase of modulation order may not affect the performance of SQSM and, for the case of higher order modulation, SQSM is still robust to the effect of channel estimation error.

Next, the effect of channel estimation error number with 32×32 MIMO 4-QAM is illustrated in Fig. 5. With fix $\sigma_e^2 = 01, 0.2,$ and $0.3,$ the impact of fixed σ_e^2 values on the performance of SQSM can robust to the various imperfect channel estimation. The channel estimation errors degrade the performance of SQSM system by about 0.5 dB, 1.2 dB, and 2 dB at 10^2. Therefore, SQSM in the case of increase number of antennas is tolerated under imperfect channel estimation.

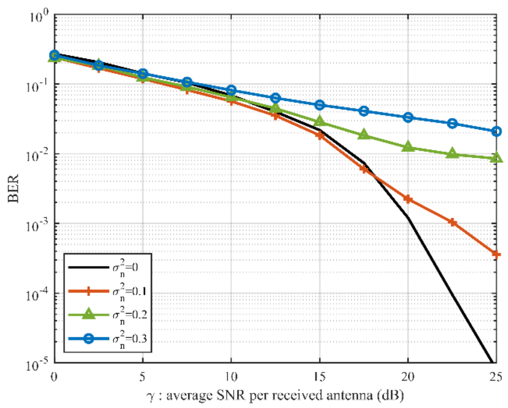

Fig. 4 The BER performance of SQSM with impact of imperfect channel estimation at 16 × 16 MIMO 64-QAM.

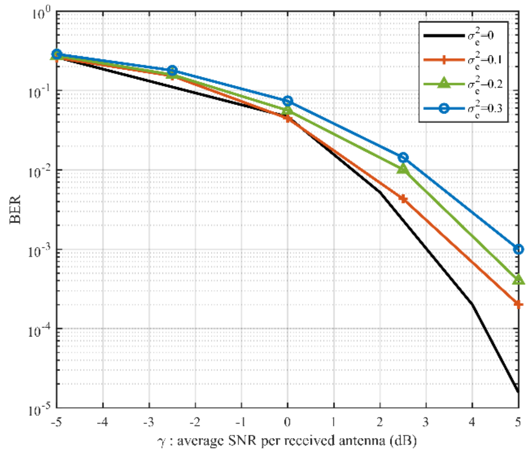

Fig. 5 The BER performance of SQSM with impact of imperfect channel estimation at 32 × 32 MIMO 4-QAM.

5. Conclusions

Spatial modulation technique is believed to be the energy efficient modulation scheme for 6G network technology. Due to the great spectral efficiency, a special kind of SM technique called SQSM is very attractive for 6G-MIMO systems. This work reveals that, in the presence of channel estimation error, SQSM is very robust to be used in massive MIMO system. The investigation of SQSM for more realistic scenarios, e.g., spatial correlated channel or THz channel model, is our future work.

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Biographies

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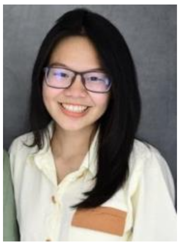

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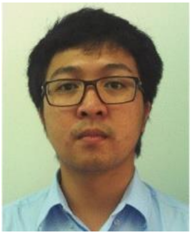

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