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Switching between Spatial Modulation and Quadrature Spatial Modulation

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Abstract

Spatial modulation (SM) is the first proposed space modulation technique. By further utilizing the quadrature spatial dimension, quadrature spatial modulation (QSM) has been developed as an amendment to SM system to enhance the overall spectral efficiency. Both techniques are capable of entirely eliminating interchannel interference (ICI) at the receiver. In this paper, we propose a simple adaptive hybrid switching transmission scheme to obtain better system performance than SM and QSM systems under a fixed transmission date rate. The presented modulator selection criterion for switching between spatial modulator and quadrature spatial modulator is based on the larger received minimum distance of spatial modulator and quadrature spatial modulator to exploit the spatial channel freedom. It is shown through Monte Carlo simulations that the proposed hybrid SM and QSM switching system yields lower error performance than the conventional SM and QSM systems under the same fixed data rate and thus can provide signal to noise ratio (SNR) gain.

Keywords: *Spatial modulation (SM), Quadrature spatial modulation (QSM), Link adaptation, Maximum likelihood (ML) receiver, Multiple input multiple output (MIMO), Switching*

1. INTRODUCTION

Spatial modulation (SM) has been considered as a promising multiple input multiple output (MIMO) transmission technique with low-complexity [1-3]. In an SM scheme, the spatial position of each transmit antenna is exploited as a source of information. As the transmit antenna index is utilized to transmit additional information bits in addition to the conventional signal modulation, the overall spectral efficiency of the SM systems is given as $\log_2(M N_T)$ where M is the symbol constellation size and N_T is the number of transmit antennas. Moreover, the interchannel interference (ICI) existing in conventional MIMO systems can be removed in SM because a single transmit antenna is activated at one time instant. Recently, a quadrature spatial modulation (QSM) scheme has been introduced in [4]. In QSM, the in-phase signal

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constellation symbol and quadrature signal constellation symbol are transmitted by two spatial dimensions. The first and second dimensions, respectively, convey the real and imaginary parts of a signal constellation symbol. Since the real and imaginary parts of the signal constellation symbol are carried over orthogonal carriers, QSM does not avoid ICI like in SM. Compared to the SM, QSM can increase the spectral efficiency by $\log_2(N_T)$ and thus a total of $\log_2\left(MN_T^2\right)$ input bits can be mapped to each QSM symbol.

It is pointed out that the differences between channels associated with the different transmit antennas in the SM scheme can have decisive effects on the error performance of SM systems [5]-[7]. Even if the SM systems can improve their performance through receive diversity, they cannot exploit transmit diversity [8]. To improve the error performance of the SM systems, link adaptation techniques such as antenna selection, power allocation, and adaptive modulation have been employed in the SM systems [9]-[12]. However, to the best of our knowledge, there is no consideration to make use of link adaptation for QSM systems to obtain better performance than the maximum-likelihood (ML) performance bound.

In this paper, a new simple hybrid scheme of SM and QSM is proposed to enhance the error performances of both SM and QSM systems. To exploit the spatial channel freedom offered by the MIMO channels, this hybrid SM/QSM switching scheme is based on dynamic selection operation between spatial modulator and quadrature spatial modulator. It switches among two different modulation methods such as spatial modulator and quadrature spatial modulator. For switching between SM and QSM, we consider an adaptive selection criterion based on the larger received minimum distance of spatial modulator and quadrature spatial modulator. It is shown through simulations that the proposed hybrid SM/QSM switching scheme can achieve the best bit error rate (BER) performance compared to the conventional SM and QSM systems under a fixed transmission data rate.

2. SYSTEM MODEL

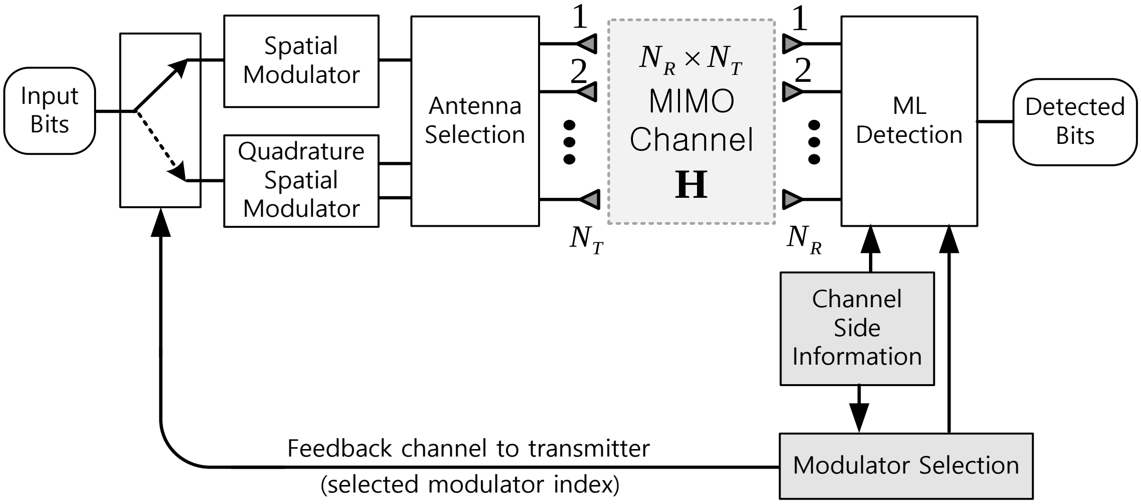

Figure 1. MIMO system where the transmitter switches between spatial modulator and quadrature spatial modulator

As shown in Fig. 1, we propose a MIMO communication system with N_T transmit antennas and N_R

receive antennas, which consists of a transmitter with a switch between spatial modulator and quadrature spatial modulator and an ML detection unit with the corresponding pair of receivers, and a low-bandwidth feedback channel. When the channel is slowly varying, the adaptive unit at the receiver computes the optimum modulator type based on the instantaneous channel state together with the used signal constellation symbol and sends this information (a single bit) of the selected modulator to the transmitter through a feedback link. The transmitter then picks the corresponding modulator for the next channel use. In this work, the channel side information of MIMO channel $\mathbf{H}$ is perfectly known at the receiver side and zero feedback delay is assumed. The $N_R \times N_T$ matrix $\mathbf{H}$ represents the propagation channel from the transmitter to the receiver, whose *m*-th column indicates the complex scalar channel coefficients from the *m*-th transmit antenna to each receive antenna and whose elements are assumed to be independent and identically distributed complex Gaussian random variables with zero mean and unit variable. Note that the number of transmit antennas can be one or two depending on the selected modulator and incoming bits. Whichever modulator is chosen, the corresponding ML detector is used for data detection.

3. SWITCHING BETWEEN SPATIAL MODULATOR AND QUADRATURE SPATIAL MODULATOR

First of all, we briefly introduce the related works such as SM and QSM. To improve the error performance of the SM and QSM systems, a simple switching approach between spatial modulator and quadrature spatial modulator is considered. The minimum Euclidean distance at the receiver is employed to derive the switching criterion. It is based on the instantaneous channel conditions and the minimum Euclidean distance of the transmitted signal constellations.

3.1 Spatial Modulator

In SM, input bits are divided into two parts as $\log_2(N_T)$ and $\log_2(M)$ bits [1]. The first bits of $\log_2(N_T)$ are used to switch on one transmit antenna for data transmission while the second bits of $\log_2(M)$ modulate a signal constellation symbol. Thus a signal symbol $x_k \in X$ with X being a signal constellation set with cardinality of $|X| = 2^Q$ is transmitted from the *m*-th transmit antenna switched on. Here $Q(=\log_2(M))$ is the number of bits transmitted by each signal symbol. Then, the $N_R \times 1$ received signal vector is given by [1]

$$\mathbf{r}_{SM} = \mathbf{H}\mathbf{s}_{SM} + \mathbf{n} \tag{1}$$

where the transmitted SM symbol vector $\mathbf{s}_{SM}$ is given as

$$\mathbf{s}_{SM} = x_k \mathbf{e}_m \tag{2}$$

Here $\mathbf{e}_m$ is the *m*-th column vector of the $N_T \times N_T$ identity matrix and determined by $\log_2(N_T)$ input bits. The elements of N_R–dimensional noise vector $\mathbf{n}$ are complex Gaussian random variables with zero mean and variance N_0.

3.2 Quadrature Spatial Modulator

In QSM, input bits are divided into three blocks as $\log_2\left(N_T\right)$, $\log_2\left(N_T\right)$, and $\log_2\left(M\right)$ bits [4]. The first and second bits of two $\log_2\left(N_T\right)$ blocks, respectively, modulate two active antenna indices used to transmit the real part and the imaginary part of a signal constellation symbol $x_k \in X$, which is modulated by the last $\log_2\left(M\right)$ bits. That is, the in-phase signal constellation symbol is transmitted on the first spatial dimension while the quadrature signal constellation one is transmitted on the second one. Then, the $N_R \times 1$ received signal vector is also represented as [4]

$$\mathbf{r}_{QSM} = \mathbf{H}\mathbf{s}_{QSM} + \mathbf{n} \tag{3}$$

where the transmitted QSM symbol vector $\mathbf{s}_{QSM}$ is given as

$$\mathbf{s}_{QSM} = \mathbf{s}_{m_R} + j\mathbf{s}_{m_I} = x_R^{m_R}\mathbf{e}_{m_R} + jx_I^{m_I}\mathbf{e}_{m_I} \tag{4}$$

Here $\mathbf{s}_{m_R}$ and $\mathbf{s}_{m_I}$, respectively, denote the in-phase and quadrature signal vectors of $\mathbf{s}_{QSM}$. m_R and m_I are the indices of transmit antennas for activation with $m_R, m_I \in \left[1, 2, \cdots, N_T\right]$. $x_R^{m_R}$ and $x_I^{m_I}$ are the real and imaginary parts of the signal constellation symbol x_k to be transmitted using the corresponding antenna index m_R and m_I. $\mathbf{e}_{m_R}$ and $\mathbf{e}_{m_I}$ are the column vectors of the $N_T \times N_T$ identity matrix corresponding to the transmit antenna index m_R and m_I, respectively, and defined by two $\log_2\left(N_T\right)$ input bits.

3.3 Switching Between Spatial Modulator and Quadrature Spatial Modulator

Given the received signal vector $\mathbf{r}$ where $\mathbf{r} = \mathbf{r}_{SM}$ for SM and $\mathbf{r} = \mathbf{r}_{QSM}$ for QSM, the joint ML search is expressed as

$$\hat{\mathbf{s}} = \arg\min_{\mathbf{s}\in\Psi}\left\{\left\|\mathbf{r} - \mathbf{H}\mathbf{s}\right\|_F^2\right\} \tag{5}$$

where $\hat{\mathbf{s}}$ is the transmit symbol vector estimated by the ML detector and Ψ is the set of all legitimate SM or QSM transmit symbol vectors. It jointly estimates the indices of the activated transmit antennas and the signal constellation symbol from them.

Since the exact BER expression of (5) does not have a simple closed form solution, the nearest neighbor approximation is employed to derive a performance metric for switching between SM and QSM. Given a MIMO channel $\mathbf{H}$, the nearest neighbor approximation of the pairwise error probability (PEP) can be given by [12]

$$\Pr\left(\mathbf{s}_i \to \mathbf{s}_j \middle| \mathbf{H}\right) \approx \eta \cdot Q\left(\sqrt{\frac{1}{2N_0} d_{\min}^2(\mathbf{H})}\right) \tag{6}$$

where η means the average number of the nearest neighbor vectors and $Q(\cdot)$ indicates the Gaussian Q-function. Here the received minimum distance $d_{\min}(\mathbf{H})$ is defined as [12],[13]

$$d_{\min}(\mathbf{H}) = \min_{\mathbf{s}_i \neq \mathbf{s}_j \in \Psi} \left\| \mathbf{H}\left(\mathbf{s}_i - \mathbf{s}_j\right) \right\|_F \tag{7}$$

where $\mathbf{s}_i, \mathbf{s}_j = \mathbf{s}_{SM}$ for SM and $\mathbf{s}_i, \mathbf{s}_j = \mathbf{s}_{QSM}$ for QSM.

The received minimum distance $d_{\min}(\mathbf{H})$ is the common performance parameter of all SM and QSM systems with ML detectors. One effective approach for offering the improved BER performance over SM and QSM systems is to select one modulator with the larger received minimum distance among two modulators such as spatial modulator and quadrature spatial modulator. Thus the selection criterion for switching between SM and QSM can be employed as

$$\mathit{Selected\ Modulator} = \arg\max\left\{ d_{\min,SM}^2,\, d_{\min,QSM}^2 \right\} \tag{8}$$

where $d_{\min,SM}$ and $d_{\min,QSM}$ are the received minimum distances of SM and QSM systems, respectively.

4. SIMULATION RESULTS

We evaluate the BER performance of the proposed hybrid SM/QSM switching scheme over the conventional SM and QSM systems. The simulation setup is based on the fixed spectral efficiencies of 4 and 6 bits per channel use over MIMO channels with frequency-flat block Rayleigh fading. In all simulation results, the BER performance curves are plotted as a function of the signal to noise ratio (SNR) in decibels, which is defined by the total transmit signal power from all active transmit antennas in all systems divided by the noise variance.

The BER performance of the proposed hybrid SM/QSM switching system with $N_T = 2$ and $N_R = 2$ is presented in Fig. 2. For a fair comparison, we consider SM with 8-PSK modulation and QSM with QPSK. That is, the spectral efficiency is a data rate of 4 bits per channel use. It is observed that the proposed SM/QSM switching scheme provides a considerable BER performance improvement over the conventional SM and QSM at the high SNR values. Specifically, the proposed switching scheme outperforms the conventional SM by about 3 dB and the conventional QSM by around 2.1 dB at BER=10^{-4}.

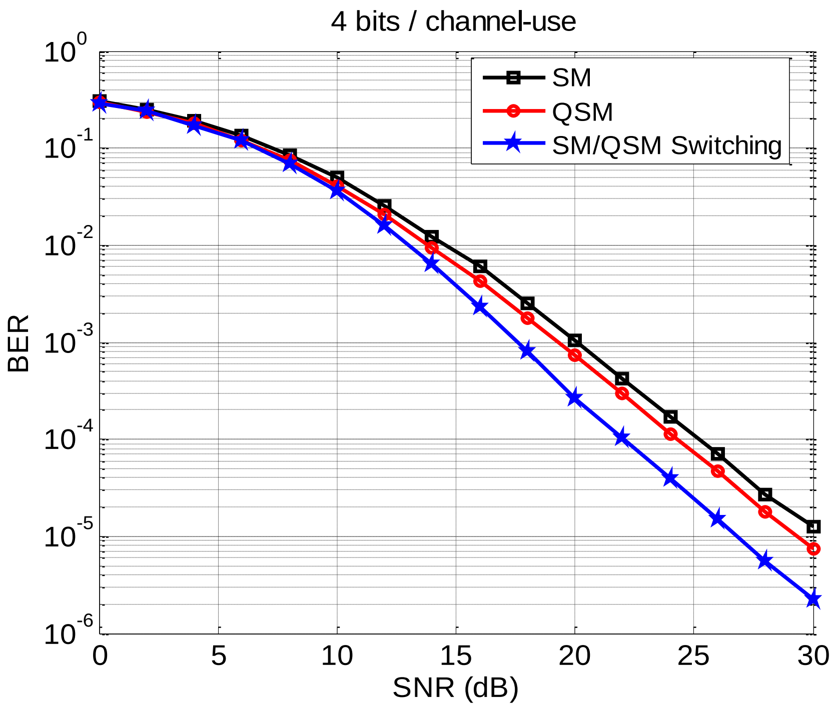

Figure 2. BER comparison for the proposed hybrid SM/QSM, the conventional SM and QSM for $N_T = 2$ and $N_R = 2$

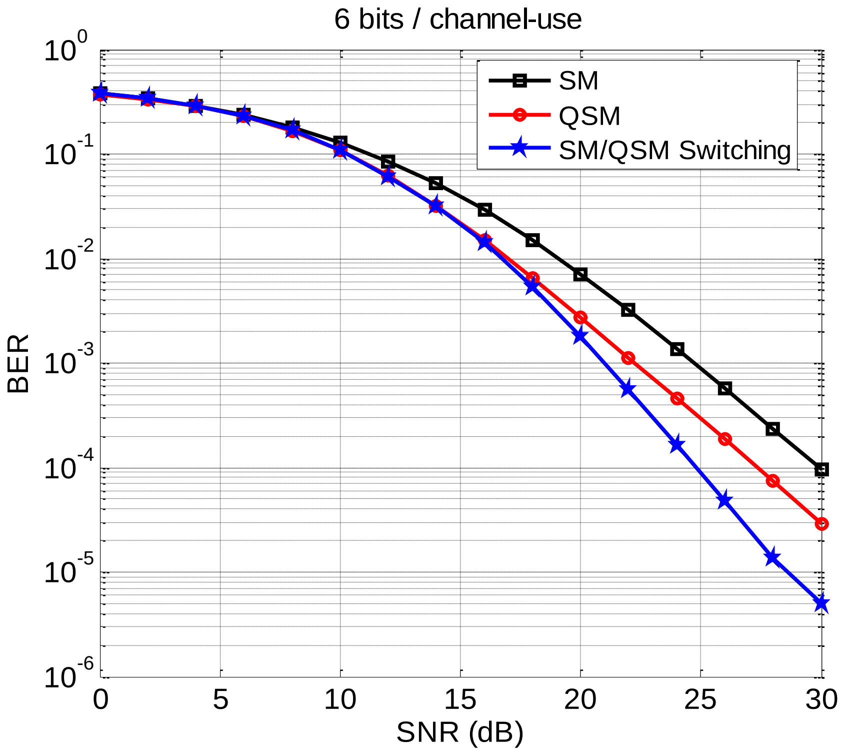

Figure 3. BER comparison for the proposed hybrid SM/QSM, the conventional SM and QSM for $N_T = 4$ and $N_R = 2$

Fig. 3 shows the comparison for BER results of the proposed SM/QSM switching scheme, the SM system and the QSM system with $N_T = 4$ and $N_R = 2$. Here 16-PSK and QPSK are assigned to the SM and QSM, respectively. Thus the spectral efficiency is given by a rate of 6 bits per channel use. Compared to the SM, the SNR gain obtained by the proposed SM/QSM switching scheme at BER=10^{-4} is approximately given by a 5.2 dB. In addition, the proposed switching scheme outperforms the conventional QSM. Here about a 2.8 dB SNR gain is obtained at BER=10^{-4}. Its performance improvement is found to get larger, compared to the gain shown in Fig. 2. Thus for the increased transmission data rate, more performance gain may be expected by the proposed SM/QSM switching scheme.

5. CONCLUSIONS

In this paper, a simple hybrid SM and QSM switching scheme has been proposed to achieve better system performance compared to conventional SM and QSM systems under a fixed transmission data rate. First, we compute the received minimum distances of SM and QSM systems. Then the adaptive switching criterion between spatial modulator and quadrature spatial modulator is based on the larger received minimum distance. Our simulation results show that the proposed switching scheme can achieve enhanced BER performance compared to the SM and QSM systems at high SNR regions. Given $N_T = 2$, $N_R = 2$, and a data rate of 4 bits per channel use, the proposed approach can achieve better performance than the conventional SM by about 3 dB and the conventional QSM by around 2.1 dB at BER=10^{-4}. Moreover, for $N_T = 4$, $N_R = 2$, and a data rate of 6 bits per channel use, our scheme at BER=10^{-4} outperforms the SM by approximately 5.2 dB and the QSM by around 2.8 dB. To further improve the proposed switching system performance, our interesting future work will be focused on the integration of some link adaptation techniques such as adaptive symbol modulation and transmit power allocation into the proposed switching scheme.

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REFERENCES

[1] R. Y. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn, and S. Yun, “Spatial modulation,” *IEEE Trans. Veh. Tech.*, vol. 57, no. 4, pp. 2228-2241, Jul. 2008.
DOI: 10.1109/TVT.2007.912136.

[2] M. D. Renzo, H. Haas, and P. M. Grant, “Spatial modulation for multiple-antenna wireless systems: a survey,” *IEEE Trans. Commun. Mag.*, vol. 49, no. 12, pp. 182-191, Dec. 2011.
DOI: 10.1109/MCOM.2011.6094024.

[3] J. Jeganathan, A. Ghrayeb, and L. Szczecinski, “Spatial modulation: optimal detection and performance analysis,” *IEEE Commun. Lett.*, vol. 12, no. 8, pp. 545-547, Aug. 2008.
DOI: 10.1109/LCOMM.2008.080739.

[4] R. Y. Mesleh, S. S. Ikki, and H. M. Aggoune, “Quadrature spatial modulation,” *IEEE Trans. Veh. Tech.*, vol. 64, no. 6, pp. 2738-2742, Jul. 2015.
DOI: 10.1109/TVT.2014.2344036.

[5] J. Wang, S. Jia, and J. Song, “Signal vector based detection scheme for spatial modulation,” *IEEE Commun. Lett.*, vol. 16, no. 1, pp. 19-21, Jun. 2012.

DOI: 10.1109/LCOMM.2011.111611.112127.

[6] M. Maleki, H. R. Bahrami, S. Beygi, M. Kafashan, and N. H. Tran, “Space modulation with CSI: Constellation design and performance evaluation,” *IEEE Tran. Veh. Techol.*, vol. 62, no. 4, pp. 1623-1634, May 2013. DOI: 10.1109/TVT.2012.2232686.

[7] M. Maleki, H. R. Bahrami, A. Alizadeh, and N. H. Tran, “On the performance of spatial modulation: Optimal constellation breakdown,” *IEEE Trans. Commun.*, vol. 62, no. 1, pp. 144-157, Jan. 2014. DOI: 10.1109/TCOMM.2013.121313.130514.

[8] E. Basar, U. Aygolu, E. Panayirci, and H. V. Poor, “Performance of spatial modulation in the presence of channel estimation errors,” *IEEE Commun. Lett.*, vol. 16, no. 2, pp. 176-179, Feb. 2012. DOI: 10.1109/LCOMM.2011.120211.112026.

[9] J. Jeganathan, “Space shift keying modulation for MIMO channels,” *M.S. Thesis*, Dept. Elect. Eng., Concordia Univ., Montreal, QC, Canada, Aug. 2008.

[10] Y. Xiao, Q. Tang, L. Gong, P. Yang, and Z. Yang, “Power scaling for spatial modulation with limited feedback,” *Int. J. Antennas Propag.*, vol. 2013, 2013, Art. ID. 718482. [Online]. Available: http://hindawi.com/journals/ijap /2013/718482/ DOI: 10.1155/2013/718482.

[11] P. Yang, Y. Xiao, B. Zhang, S. Li, M. El-Hajjar, and L. Hanzo, “Power allocation-aided spatial modulation for limited-feedback MIMO systems,” *IEEE Trans. Veh. Tech.*, vol. 64, no. 5, pp. 2198-22199, May 2015. DOI: 10.1109/TVT.2014.2339297.

[12] P. Yang, Y. Xiao, L. Li, Q. Tang, Y. Yu, and S. Li, “Link adaptation for spatial modulation with limited feedback,” *IEEE Tran. Veh. Techol.*, vol. 61, no. 8, pp. 3808-3813, Oct. 2012. DOI: 10.1109/TVT.2012.2207973.

[13] S. Kim, “Antenna selection schemes in quadrature spatial modulation systems,” *ETRI Journal*, vol. 38, no. 4, pp. 612-621, Aug. 2016. DOI: 10.4218/etrij.16.0115.0986.