Space-Polarization Division Multiple Access System with Limited Feedback

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Abstract

This paper proposes a space-polarization division multiple access (SPDMA) system that has limited feedback channels. The system simultaneously serves data streams to multiple mobile users through dual-polarized antenna arrays, by using pre-determined sets of precoding vectors that are orthogonal in both space and polarization domains. To this end, a codebook whose elements are sets of the precoding vectors is systematically designed based on the discrete Fourier transform (DFT) matrix and considering the power imbalance of polarized channels. Throughput of the SPDMA system is evaluated and compared to that of space division multiple access (SDMA) system, according to the various parameters including cross polarization discrimination (XPD). The results show that the throughput of SPDMA system outperforms that of SDMA in the environments of high XPD with many mobile users.

Keywords: Space-polarization division multiple access (SPDMA), codebook design, discrete Fourier transform (DFT) codebook, dual polarized antenna arrays

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1. Introduction

Since 1957, the capacity of wireless communications systems has been increased approximately a million times. About 25 times has been achieved by sophisticated modulation schemes, another 25 times by wider bandwidth, and a surprising 1600 times by decreasing cell sizes [1]. Continuing to decrease the cell sizes, now we have pico- and femto-cells and observe channel characteristics different from that of macro-cells. Most small cells have a few strong propagation paths and relatively less scatterers, which consequently reduce the number of effective propagation paths and increase the probability to encounter line-of-sight(LOS). When a mobile user equipped with single-polarized antennas receives a signal coming through few propagation paths, a critical problem occurs: the polarization state of antennas does not match to that of the signal and this results in considerable power loss.

Dual-polarized antenna arrays may be the solution to the problem of polarization mismatch. They can receive the signals polarized to any direction (in vertical-horizontal plane) and distinguish vertically/horizontally polarized components as well. Besides, the dual-polarized antenna reduces the size of the arrays by half. Various studies have been done about channel modeling, channel measurement, and transmit schemes for the dual-polarized antenna arrays: [2] modeled dual-polarized multiple-input and multiple-output (MIMO) channels in a matrix form whose elements represent the Rician fading effect. [3] modeled three dimensional dual-polarized MIMO channels. [4] and [5] derived the spatial correlation between dual-polarized antennas. [6] measured the channel in rural environment. [7] proposed a bimodal Rayleigh distribution as the angle probability of polarization rotation, which is based on channel measurement. [8] proposed precoding method which obtains polarization diversity. [9] and [10] evaluated channel capacity by using spatial channel model (SCM) of the 3rd generation project partnership (3GPP). [11] introduced polarization division multiple access (PDMA) in LOS environment by modulating symbols on the Poincaré sphere. [12] introduced a codebook for single user transmission. [13] derived precoding vectors based on various criteria for single user transmission. But none of them has introduced space-polarization division multiple access (SPDMA) system with limited feedback channels.

SPDMA is an extension of space division multiple access (SDMA) that creates orthogonal beams not only in space domain but also in polarization domain. Each beam is formed towards a certain user and conveys data dedicated to the user. The orthogonal beams are created based on channel information of users. In practice, channel information is almost perfectly measurable at each user but is fed back to the transmitter through limited feedback channels. Thus, quantizing the channel information to the size of the feedback channels is an important issue to realize the SPDMA. The quantization depends on the channel characteristics. Thus, understanding of dual-polarized MIMO channel is another important issue to realize the SPDMA.

In this paper, we propose an SPDMA system whose feedback channels have limited capacity. Section 2 describes the channel model of the SPDMA system and the block diagram is depicted in **Fig. 1**. Section 3.1 provides a systematic codebook design that is suitable to the SPDMA system. Each element of the codebook consists of precoding vectors orthogonal each other. We manifest the discrete Fourier transform (DFT) matrix to get the orthogonal basis of precoding vectors in space domain. We further manifest the power imbalance between vertically/horizontally polarized components to get the orthogonal basis of precoding vectors in polarization domain. Section 3.2 gives details of the procedure on how mobile users measure the channel state information and which information is fed back to the bases station. Also user and codebook selection methods are presented. Section 4 shows simulation results according to various parameters, mainly to cross polarization discrimination (XPD). The comparison between SPDMA and SDMA is conducted on the same configuration of antenna arrays, where SPDMA uses the dual-polarized antenna arrays for multiple accessing both in space and polarization domains but SDMA uses the dual-polarized arrays for multiple accessing in space domain only (polarization domain is used for diversity). Section 5 concludes this paper.

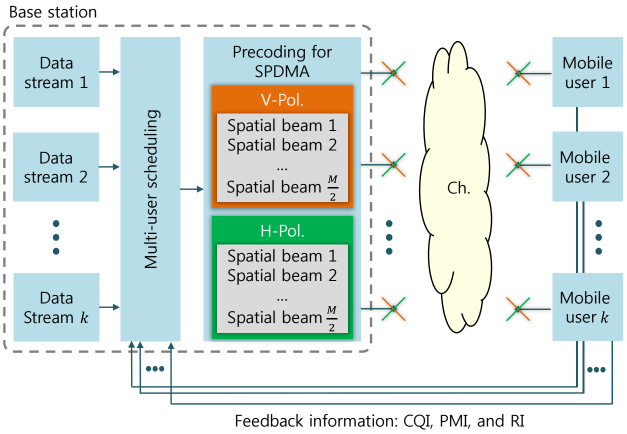

Fig. 1. SPDMA system block diagram

2. System Model

We consider a dual-polarized MIMO broadcast channel where a base station with $M \in 2\mathbb{N}$ transmit antennas (or $M/2 \in \mathbb{N}$ of dual-poalrzed transmit antennas) serves $K \in \mathbb{N}$ mobile users. Each mobile user has $N \in 2\mathbb{N}$ receive antennas (or $N/2 \in \mathbb{N}$ of dual-poalrzed receive antennas). We assume that mobile users experience the identical path loss and frequency-flat block Rayleigh fading. The received signal vector $\mathbf{y}_k \in \mathbb{C}^{N\times 1}$ of the k th mobile user is given by

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{x} + \mathbf{z}_k, \tag{1}$$

where $\mathbf{H}_k \in \mathbb{C}^{N\times M}$ denotes the dual-polarized MIMO channel matrix of the k th mobile user, $\mathbf{x} \in \mathbb{C}^{M\times 1}$ is the transmit signal vector with the power constraint $\mathrm{E}\{\mathbf{x}^{\mathrm{H}}\mathbf{x}\} \leq P$, where $\mathrm{E}\{a\}$ denotes the ensemble average and $\mathbf{A}^{\mathrm{H}}$ denotes the complex conjugate transpose matrix of the matrix $\mathbf{A}$, and $\mathbf{z}_k \in \mathbb{C}^{N\times 1}$ is the additive noise vector whose elements are independently and identically distributed (i.i.d) zero mean-unit variance-circularly symmetric complex Gaussian (ZM-UV-CSCG) random variables. The channel matrix is decomposed as follows [14].

$$\mathbf{H}_k = \left(\mathbf{1}_{N/2\times M/2} \otimes \mathbf{\Sigma}\right) \odot \left(\mathbf{C}_{\text{rx}}^{1/2}\mathbf{W}_k\mathbf{C}_{\text{tx}}^{1/2}\right), \tag{2}$$

where $\otimes$ denotes the Kronecker product and $\odot$ denotes the Hadamard product. $\mathbf{H}_k$ breaks down into two parts; the power imbalance part $\left(\mathbf{1}_{N/2\times M/2} \otimes \mathbf{\Sigma}\right)$ and the correlation part $\left(\mathbf{C}_{\text{rx}}^{1/2}\mathbf{W}_k\mathbf{C}_{\text{tx}}^{1/2}\right)$. The power imbalance part introduces the effects of XPD (please refer to [14] for the definition of XPD) to the channel by using the power imbalance matrix

$$\mathbf{\Sigma} = \begin{bmatrix} \sqrt{\dfrac{\text{XPD}}{\text{XPD+1}}} & \sqrt{\dfrac{1}{\text{XPD+1}}} \\ \sqrt{\dfrac{1}{\text{XPD+1}}} & \sqrt{\dfrac{\text{XPD}}{\text{XPD+1}}} \end{bmatrix} \tag{3}$$

which is repteated by using the $(N/2)\times(M/2)$ matrix of ones. The correlation part has the form of the well-known space-correlated MIMO channel matrix with $\mathbf{W}_k \in \mathbb{C}^{N\times M}$ of white channel matrix whose elements are ZM-UV-CSCG random variables. However, it includes not only spatial correlation but also polarization correlation between vertically and horizontally polarized antennas. The correlation matrix at the receiver $\mathbf{C}_{\text{rx}} \in \mathbb{C}^{N\times N}$ is given by

$$C_{\text{rx}} = \begin{bmatrix} 1 & r_s & r_s^2 & \cdots \\ r_s^* & 1 & r_s & \cdots \\ \left(r_s^*\right)^2 & r_s^* & 1 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \otimes \begin{bmatrix} 1 & r_p \\ r_p^* & 1 \end{bmatrix}, \tag{4}$$

where r_s and r_p represent the space and polarization correlation coefficients at the receiver, respectively, and a^* denotes the conjugate of the complex number a. Similarly, the correlation matrix at the transmitter $\mathbf{C}_{\text{tx}} \in \mathbb{C}^{M\times M}$ is given by

$$C_{\text{tx}} = \begin{bmatrix} 1 & t_s & t_s^2 & \cdots \\ t_s^* & 1 & r_s & \cdots \\ \left(t_s^*\right)^2 & t_s^* & 1 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \otimes \begin{bmatrix} 1 & t_p \\ t_p^* & 1 \end{bmatrix}, \tag{5}$$

where t_s and t_p represent the space and polarization correlation coefficients at the transmitter, respectively. The base station simultaneously transmits data to M mobile users chosen from total K mobile users. Data symbols for the selected M mobile users are linearly precoded and they construct the transmit signal vector which is given by

$$\mathbf{x} = \mathbf{F}\mathbf{s} = \sum_{k=1}^{M} \mathbf{f}_k s_k, \tag{6}$$

where $\mathbf{F} \in \mathbb{C}^{M\times M}$, $\mathbf{F} = \left[\mathbf{f}_1 \mathbf{f}_2 \cdots \mathbf{f}_M\right]$ is the precoding matrix, $\mathbf{f}_k \in \mathbb{C}^{M\times 1}$ is the precoding vector for the k th mobile user among the selected M mobile users, $\mathbf{s} \in \mathbb{C}^{M\times 1}$, $\mathbf{s} = \left[s_1\, s_2 \cdots s_M\right]^{\mathrm{T}}$ is the transmit symbol vector, where $\mathbf{A}^{\mathrm{T}}$ denotes the transpose matrix of the matrix $\mathbf{A}$, and s_k is the transmit symbol for the k th mobile user among the selected M mobile users. The precoding matrix is chosen from the pre-determined matrix set that is designed in Chapter 3.1 and the procedure is provided in Chapter 3.2.

Signal-to-interference-and-noise ratio (SINR) of the k th mobile user is calculated by [15]

$$\gamma_k = s_k^* \mathbf{f}_k^{\mathrm{H}} \mathbf{H}_k^{\mathrm{H}} \left(\mathbf{I} + \sum_{l=1, l\neq k}^{M} \mathbf{H}_k \mathbf{f}_l s_l s_l^* \mathbf{f}_l^{\mathrm{H}} \mathbf{H}_k^{\mathrm{H}} \right)^{-1} \mathbf{H}_k \mathbf{f}_k s_k, \tag{7}$$

where the minimum mean square error (MMSE) receiver is used. The throughput of the system is obtained by

$$R = \sum_{k=1}^{M} \log_2\left(1+\gamma_k\right). \tag{8}$$

The precoding matrix is selected within SPDMA codebook $\mathcal{F}$ by using the scheduling algorithm described in the following section.

3. Space-Polarization Division Multiple Access

To provide reliable communications, the base station needs to know the information on $\mathbf{H}_k$ in most scenarios. The information is generally available through feedback channels. When the system has a limited feedback channel, however, the information should be compressed so that it can be fed back without delay. Codebook is one of the most effective concepts to provide channel information through the limited feedback channel. Codebook consists of a number of pre-determined precoding matrices, each of which has orthogonal column vectors that are known to both the base station and mobile uses. Mobile users feed back the index of the most preferred precoding matrix (and some other information that is needed for the reliable communications) that effectively represents the channel state. The design criterion of codebook differs from channel to channel, thus, a new design criterion should be provided for the dual-polarized MIMO channel. For the SPDMA with limited feedback channel, we propose the design criterion whose codebook maximizes the minimum angular spacing between orthonormal bases in both space and polarization domain. Further, we give descriptions about what information mobile users should send back to the base station and how the base station schedules the transmission according to the information in the following subsections.

3.1 Systematic Codebook Design

The proposed codebook satisfies the following criterion.

Design criterion: Precoding matrices in codebook $\mathcal{F}$ maximize the minimum angular spacing between orthonormal bases in both space and polarization domains.

$\mathcal{F}$ can be obtained by combining two sub-codebooks, each of which maximized the minimum angular spacing between orthonormal bases in space domain and polarization domain, respectively. First, let us consider the sub-codebook $\mathcal{S}$ which consists of O_{spa} precoding matrices for the space domain. The beam steering vector of $M/2$ antenna arrays towards an angle ϕ, $0 \le \phi \le \pi$, is given by

$$\mathbf{e}_{\mathsf{spa}}(\Omega) = \frac{1}{\sqrt{M/2}} \begin{bmatrix} 1 & e^{-j\pi\Omega} & \cdots & e^{-j\pi\left(\frac{M}{2}-1\right)\Omega} \end{bmatrix}^{\mathsf{T}}, \tag{9}$$

where $\Omega = \cos\phi$ and we assumed that the antenna arrays are linearly placed with half the wavelength. The orthonormal basis $\mathbf{S} \in \mathbb{C}^{M/2 \times M/2}$ in space domain is then defined as a matrix whose column vectors are $M/2$ of steering vectors orthogonal each other, i.e., $\left|\mathbf{e}_{\mathsf{spa}}(\Omega_1)^{\mathsf{H}} \mathbf{e}_{\mathsf{spa}}(\Omega_2)\right| = 0$ and is given by [16, eq.(7.62)]

$$\mathbf{S} = \begin{bmatrix} \mathbf{e}_{\mathsf{spa}}(0) & \mathbf{e}_{\mathsf{spa}}\left(\frac{1}{M/4}\right) & \cdots & \mathbf{e}_{\mathsf{spa}}\left(\frac{M/2-1}{M/4}\right) \end{bmatrix}. \tag{10}$$

Then, a set of $\mathbf{S}$ shifted by $\mathbf{\Theta}(o_{\mathsf{spa}})$, $o_{\mathsf{spa}} = 1, \cdots, O_{\mathsf{spa}}$ maximize the minimum angular spacing and they are given by [17, eq.(9)]

$$\mathbf{S}^{(o_{\mathsf{spa}})} = \mathbf{\Theta}(o_{\mathsf{spa}})\mathbf{S} = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & e^{-j2\pi\left(\frac{1}{M/2}\right)\left(\frac{o_{\mathsf{spa}}-1}{O_{\mathsf{spa}}}\right)} & & \\ \vdots & & \ddots & \\ 0 & & & e^{-j2\pi\left(\frac{M/2-1}{M/2}\right)\left(\frac{o_{\mathsf{spa}}-1}{O_{\mathsf{spa}}}\right)} \end{bmatrix} \mathbf{S}. \tag{11}$$

$\boldsymbol{\Theta}\left(o_{\text{spa}}\right)$ shifts each initial vectors in S through o_{spa} dimensional complex space using the o_{spa} th root of unity [18, eq(17)]. In short, each element in $\mathbf{S}^{\left(o_{\text{spa}}\right)}$ is calculated by using

$$S^{\left(o_{\text{spa}}\right)}_{(u,v)} = \frac{1}{\sqrt{M}} e^{j2\pi\frac{(u-1)}{M/2}\left(v-1+\frac{\left(o_{\text{spa}}-1\right)}{O_{\text{spa}}}\right)}, \tag{12}$$

where $\mathbf{A}_{(i,j)}$ denotes the i th row and j th column element of a matrix $\mathbf{A}$. The sub-codebook S is then given by

$$\mathsf{S} = \left\{\mathbf{S}^{(1)}, \mathbf{S}^{(2)}, \cdots, \mathbf{S}^{\left(O_{\text{spa}}\right)}\right\}. \tag{13}$$

Next, let us consider the sub-codebook P which consists of O_{pol} precoding matrices for the polarization domain. In $\mathbf{H}_k$, the effect of polarization is represented by the power imbalance part $\left(\mathbf{1}_{N/2\times M/2} \otimes \boldsymbol{\Sigma}\right)$. Thus, it is sufficient to determine the amplitude of precoding matrices for the polarization domain. Let $\mathbf{e}_{\text{pol}}(\theta)$ be the beam vector in the polarization domain that rotates the polarization state to a certain angle θ, $0 \le \theta \le \pi/2$, which is given by

$$\mathbf{e}_{\text{pol}}(\theta) = \begin{bmatrix} \cos\theta \\ \sin\theta \end{bmatrix}. \tag{14}$$

Note that in optics $\mathbf{e}_{\text{pol}}(\theta)$ is called Jones vector that represents linearly polarized light [19, ch.3.3.1]. The polarization domain has only two basis vectors, i.e., the vector that represents the vertically polarized channel state and the vector that represents the horizontally polarized channels state. Therefore, it is obvious that the orthonormal basis $\mathbf{P} \in \mathsf{R}^{2\times 2}$ is simply given by

$$\mathbf{P} = \left[\mathbf{e}_{\text{pol}}(0) \quad \mathbf{e}_{\text{pol}}\left(\frac{\pi}{2}\right)\right] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \tag{15}$$

and the corresponding O_{pol} precoding matrices are given by

$$\mathbf{P}^{(o_{\text{pol}})} = \begin{bmatrix} \cos\left(\frac{\pi}{2}\left(\frac{o_{\text{pol}}-1}{O_{\text{pol}}}\right)\right) & -\sin\left(\frac{\pi}{2}\left(\frac{o_{\text{pol}}-1}{O_{\text{pol}}}\right)\right) \\ \sin\left(\frac{\pi}{2}\left(\frac{o_{\text{pol}}-1}{O_{\text{pol}}}\right)\right) & \cos\left(\frac{\pi}{2}\left(\frac{o_{\text{pol}}-1}{O_{\text{pol}}}\right)\right) \end{bmatrix} \tag{16}$$

for $o_{\text{pol}} = 1, \cdots, O_{\text{pol}}$, where $\mathbf{P}^{(o_{\text{pol}})}$ is only the rotation matrix that rotates $\mathbf{P}$ by equal intervals within $0 \le \theta \le \pi / 2$. The sub-codebook P is then given by

$$\mathsf{P} = \left\{\mathbf{P}^{(1)}, \mathbf{P}^{(2)}, \cdots, \mathbf{P}^{(O_{\text{pol}})}\right\}. \tag{17}$$

Now, the SPDMA codebook F is given by

$$\mathsf{F} = \left\{\mathbf{F}^{(1)}, \mathbf{F}^{(2)}, \cdots, \mathbf{F}^{(O)}\right\}, \tag{18}$$

where $\mathbf{F}^{(o)} \in \mathbb{C}^{M \times M}$ for $o = O_{\text{pol}}\left(O_{\text{spa}} - 1\right) + o_{\text{pol}}$ and

$$\mathbf{F}^{(o)} = \mathbf{S}^{(o_{\text{spa}})} \otimes \mathbf{P}^{(o_{\text{pol}})}. \tag{19}$$

Each precoding matrix creates M beams, each of which conveys data signals through space and polarization domain. The total of MO beams result in the minimum angular spacing of

$$\delta_{\Omega} := \left|\Omega_1 - \Omega_2\right| = \frac{1}{O_{\text{spa}}} \frac{\pi}{M / 2} \tag{20}$$

in the space domain and

$$\delta_{\theta} := \left|\theta_1 - \theta_2\right| = \frac{1}{O_{\text{pol}}} \frac{\pi / 2}{2} \tag{21}$$

in the polarization domain, respectively. One of the main advantages of the proposed codebook is that one can adaptively modify the size of precoding matrix according to the structure of the transmit antenna arrays and the number of bits available in the feedback channels.

3.2 Multiuser Scheduling with Limited Feedback

After the base station and mobile users share the codebook F , they need to agree on what information will be fed back from mobile users to the base station. Here we recall three kinds of information that are key feedback data defined in 3GPP [20]; precoding matrix indicator (PMI), rank indicator (RI), and channel quality indicator (CQI). PMI is equivalent to the index of a precoding matrix in F , i.e., o . RI denotes a column index of the precoding matrix $\mathbf{F}^{(o)}$, say r , $r = 1,\cdots,M$ here. For given o and r , CQI is the possible data rate that the k th mobile user can receives a symbol through the r th precoding vector of $\mathbf{F}^{(o)}$, which is calculated by

$$c_{k,o,r} = \log_2\left(1+\left(\mathbf{F}_r^{(o)}\right)^{\mathsf{H}} \mathbf{H}_k^{\mathsf{H}} \left(\mathbf{I} + \sum_{j=1,\, j\neq r}^{M} \mathbf{H}_k \mathbf{F}_j^{(o)} \left(\mathbf{F}_j^{(o)}\right)^{\mathsf{H}} \mathbf{H}_k^{\mathsf{H}}\right)^{-1} \mathbf{H}_k \mathbf{F}_r^{(o)}\right), \tag{22}$$

where $\mathbf{A}_r$ denotes the r th column vector of the matrix $\mathbf{A}$. The unit feedback information consists of a PMI, a RI, and a CQI. Let B be the total amount of feedback information. Then, B allows that the system adaptively control the amount of feedback information according to the available feedback channel that has limited capacity. Multiuser scheduling is conducted by the following procedure.

1) Channel estimation: we assume that each mobile user perfectly estimates $\mathbf{H}_k$.
2) Feedback information gathering: each mobile user calculates $c_{k,o,r}$ for all o and r by using (22).
3) Feedback information transmission: each mobile user transmits B of feedback information through the limited feedback channel to the bases station.
4) User sorting: the base station has $O \times M$ empty bins, where O for PMI and M for RI. The base station fills the bins up with mobile user indices according to PMI and RI that are fed back from the mobile users. When a bin overlaps, the mobile user index whose CQI is larger is left.
5) Precoding matrix selection: $O \times M$ bins correspond to O precoding matrices, each of which has M precoding vectors. Furthermore, each precoding vector is dedicated to the mobile user with the index in the bin. The base station now calculates the possible throughput for given o by

$$C(\mathbf{F}^{(o)}) = \sum_{r=1}^{M} c_{\left(k_r^*\right),o,r}, \tag{23}$$

where k_r^* denotes the mobile user index in the (o,r) bin. Finally, the precoding matrix for transmission is selected by

$$\mathbf{F}^* = \underset{\{\mathbf{F}^{(o)}\}_{o=1,\cdots,O}}{\arg\max}\ C(\mathbf{F}^{(o)}) \tag{24}$$

that maximizes (23) subject to o.

4. Simulation Results and Discussions

Performance of the proposed SPDMA system is evaluated and compared to that of the SDMA system. Both systems have the same configuration of antenna arrays for fairness. SPDMA fully exploits the dual polarized antenna arrays to get multiple accessing by using F. Whereas, SDMA employs the dual polarized antenna arrays to get only polarization diversity. Thus, SDMA has the half of the degrees of freedom that SPDMA does. The codebook for SDMA $\mathsf{S}' = \left\{S'^{(1)},\cdots,S'^{(O)}\right\}$, $S'^{(o)} \in \mathsf{C}^{M\times M/2}$ is given by

$$S'^{(o)}_{(u,v)} = \frac{1}{\sqrt{M}} e^{j2\pi\frac{(M/2-1)}{M/2}\left(v-1+\frac{(o-1)}{O}\right)}. \tag{25}$$

The numbers of antennas are $M = 4$ and $N = 2$. The sizes of codebooks are $O = 4$, $O_{\text{spa}} = 2$, and $O_{\text{pol}} = 2$. The amount of feedback information is $B = 1$ or $B = 4$. We considered the polarization correlation coefficients as $r_p = t_p = 0.6$, which is the average value for XPD from 0 to 15dB [4]. While, we considered the spatial correlation coefficients as $r_s = t_s = 0.3$ or $r_s = t_s = 0.7$.

Fig. 2 through **4** show the throughput of SPDMA and SDMA with respect to K, varying XPD from 0 to 10dB (the transmit power is fixed to $P = 4$ Watts). When small K, it can be seen that SDMA performs better than SPDMA. This is because there are not enough mobile usres to exploit multilexing. In this regime of K, it is better to use polarization diversity to increase received SNR, consequently the throughput of the system. When large K, however, SPDMA outperforms SDMA owing to the large candidate for multiple accessing. Further, it can be seen that larger XPD provides higher throughput, because high values XPD reliefs the interference between data symbols that are of multiple accessing in the polarization domain. The throughput gap of SPDMA between the case of $B = 1$ and $B = 4$ is large than that of SDMA. This can be understood that a large value of B increases the effective number of mobile users and the throughput of SPDMA is more sensitive to the number of mobile users than that of SDMA. One minor observation is that, both SPDMA and SDMA shows better performance when the channel is much corrrelated in the spatial domain, which is inherited from the DFT-based codebook.

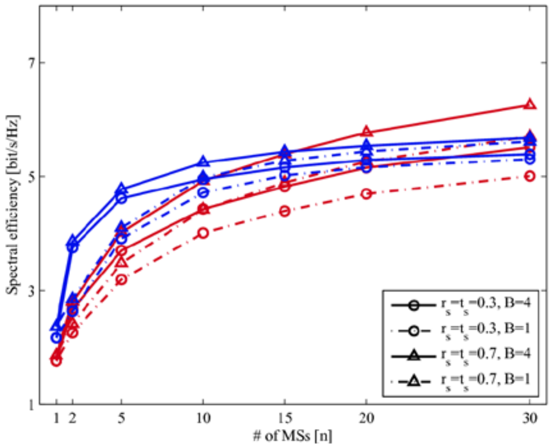

Fig. 2. Throughput comparison between SPDMA (in red) and SDMA (in blue) for XPD = 0dB.

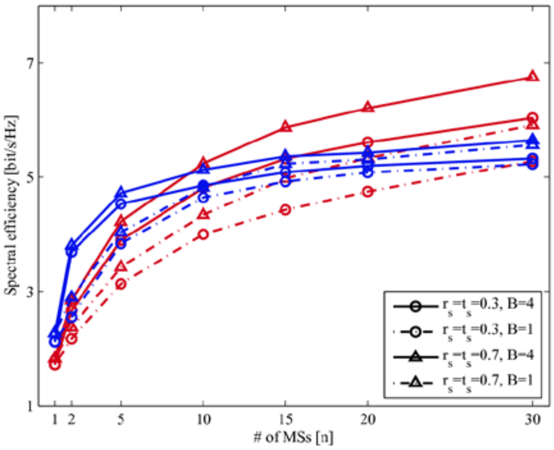

Fig. 3. Throughput comparison between SPDMA (in red) and SDMA (in blue) for XPD = 5dB.

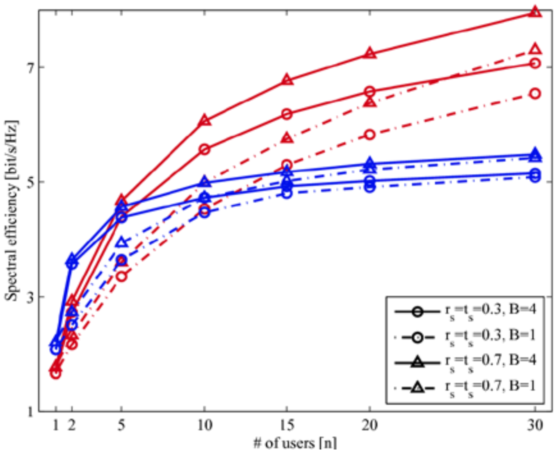

Fig. 4. Throughput comparison between SPDMA (in red) and SDMA (in blue) for XPD = 10dB.

Figs. 5 and **6** show the throughput of SPDMA and SDMA with respect to average SNR or P, in the case of $K=5$ and $K=20$. The spatial correlation coefficients are fixed to $r_s = t_s = 0.3$ and XPD is fixed to 10dB. When $K=5$, high values of SNR do not show a noticable amount of throughput growth of SPDMA compared to that of SDMA. When $K=20$, it can be seen that the cross point of the throughputs is appread at relatively low SNR (about 0dB). SPDMA can extract much more multiuser diversity gain from the network than SDMA even with low values of SNR.

In general, the crossing points between SPDMA and SDMA shown in **Figs. 2** through **6** suggest us that we exploit the dual polarized antenna arrays as polarization diversity when there are a few users with low SNR. Or it is better to use the dual polarized antenna arrays as multiple access when there are many users with high SNR.

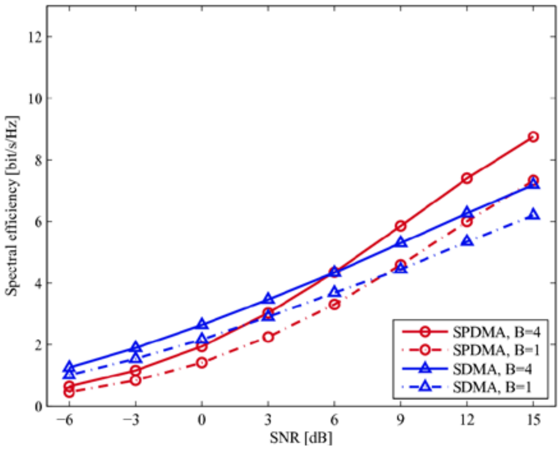

Fig. 5. Throughput comparison between SPDMA and SDMA for $K=5$.

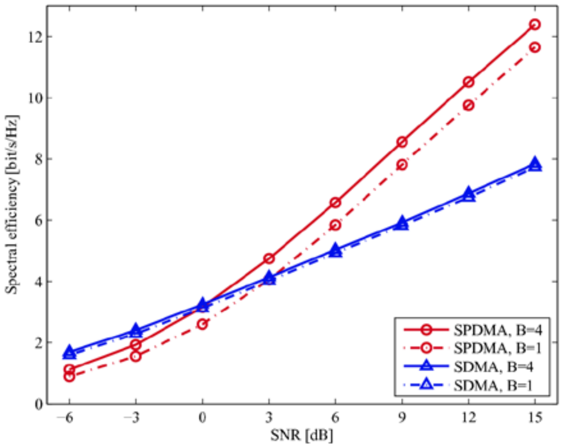

Fig. 6. Throughput comparison between SPDMA and SDMA for $K=20$.

5. Conclusion

The SPDMA system is proposed that operates with limited feedback channel. Channel state information is quantized bases on the codebook that is systemically design for dual polarized MIMO channels. Simulation results show that the SPDMA outperforms the convential SDMA when there are many mobile users by fully exploting multiple accessing in both the space and polarization domains. Furthermore, high values of XPD accelarates the throughput growth of SPDMA with respect to the number of mobile users by mitigating the interference in the polarization domain. For future study, we plan to analyze the SPDMA with limited feedback channels.

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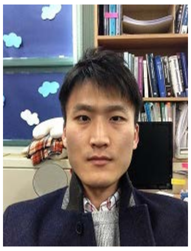

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