A Quasi-Orthogonal Group Space-time Architecture for Higher Diversity Gains♣

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***Abstract*—Multiple-Input Multiple-Output (MIMO) systems can provide two kinds of gain: diversity gain and multiplexing gain. Most existing MIMO schemes, including space-time coding and layered space-time, aim at maximizing either of them. Therefore, it is desirable to design a scheme to get a better tradeoff between the multiplexing gain and diversity gain. In this paper, a novel Quasi-Orthogonal Group Space-Time (QoGST) architecture is proposed. In QoGST, the transmit stream is divided into several groups and all the groups are encoded via an inter-group space-time block encoder. Group interference suppression is adopted at the receiver. Performance is evaluated in terms of symmetric energy and it will be shown that compared to the Group Layered Space-Time (GLST) architecture, the proposed QoGST can achieve a higher symmetric energy and a better diversity-multiplexing tradeoff. Simulation results will validate our analysis and show that QoGST can achieve at least 3 dB gain over GLST at a FER of 10^{-3}, for instance.**

Keywords- *Group detection, MIMO systems, Space-time block coding, Layered space-time, Quasi-orthogonal group space-time, Symmetric energy.*

I. INTRODUCTION

MIMO (Multiple-Input Multiple-Output) systems have shown their ability in providing great performance improvements over the SISO (Single-Input Single-Output) system thanks to their higher spectral efficiency [1-3]. It has been well understood that a MIMO system can provide both diversity gain and multiplexing gain [4]. However, most existing MIMO techniques aim at achieving either maximum diversity gain or maximum multiplexing gain. For example, space-time codes (STC) [5-6] are carefully designed to achieve the full diversity order, but no multiplexing gain can be obtained. Layered space-time (LST) [7] can achieve maximum multiplexing gain but with a very low diversity gain.

In order to achieve a better tradeoff between multiplexing gain and diversity gain, [8] presented a combined array processing and space-time coding architecture, in which the transmit stream is partitioned into different groups and in each group STC is applied. At the receiver, group interference suppression is adopted, where each individual STC is decoded by suppressing the signals transmitted from other groups. This combination of STC and LST provides much better multiplexing gain than STC with lower decoding complexity, while at the same time achieving a much higher diversity gain than LST. [8] presents a good example on how to get a tradeoff between multiplexing gain and diversity gain. However, in this architecture, the substreams of each group are encoded independently. No special transmit design is adopted to suppress the interference among the groups. Besides, the mapping from the substreams to the antennas is constant over the whole time interval. As a result, no interleaving gain can be achieved. At the receiver, space-time decoding is performed for each group by assuming that the interference has been suppressed by virtue of a group detector. Therefore, the overall performance is limited by the group detection step.

In order to improve the performance of [8], this paper presents a novel group space-time architecture: Quasi-Orthogonal Group Space-time (QoGST). In this new architecture, all the groups are encoded together via an inter-group STBC. To keep the same spectral efficiency as [8], we assume that in each group no space-time coding is adopted. Particularly, at each time slot t, we regard the transmit vector of each group as one symbol and apply STBC on all the transmit vectors. It can be seen that with this inter-group STBC, the interference among groups can be effectively suppressed because of the orthogonal nature of STBC. Therefore, QoGST should have a better interference suppressing capability. Besides, interleaving gain can be achieved due to the use of the inter-group encoder. At the receiver, and in contrast to the detector used in [8], space-time block decoding is performed before group detection is applied. Specifically, for the case of m transmit and n receive antennas during T time slots, the linear nature of STBC can be exploited to obtain an equivalent $Tn\times m$ channel [9]. Group detection is then applied based on this equivalent channel. It can be seen that after decoding, the receive dimensions increase from n to Tn and thus much better performance can be achieved by group detection. In this paper, we shall always assume that this novel detector is adopted instead of the one used in [8]. For the sake of comparison, the combination of the transmission structure proposed in [8] with STBC in each group and the proposed detector is considered in this paper. This architecture, which we refer to as Group Layered Space-time (GLST), should be distinguished from the one proposed in [10] as we adopt a different detection methodology.

The performance of QoGST and GLST is evaluated in terms of symmetric energy (SE) which is an indicator of the overall performance of a multiuser detector in terms of the joint error rate defined as the probability that at least one user is detected erroneously [11]. SE was first proposed for CDMA

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systems, while in this paper we apply it to MIMO systems and analyze the SE of QoGST and GLST. It will be shown that QoGST has a higher SE than GLST, which indicates a better interference suppressing capability. Simulation results will validate our analysis and show that for m =4 and n =2, QoGST can achieve at least 3 dB gain over GLST at a FER of 10^{-3}, for example. When m =6 and n =3, this gain even increases to 7 dB! It will be also demonstrated that QoGST can obtain a higher diversity gain while keeping the same spectral efficiency as GLST. This implies that with QoGST a better diversity-multiplexing tradeoff can be achieved.

This paper is organized as follows. In Section II, we provide our channel model and briefly present the group detection scheme. In Section III, we introduce the transmitter and receiver design of GLST and QoGST. Section IV presents the performance analysis which is evaluated in terms of SE. Simulation results are given in Section V. Finally, Section VI summarizes and concludes this paper.

II. Channel Model and Group Detection

We consider in this paper a wireless link with m transmit and n receive antennas, which we refer to as (m, n). At each time slot t, the encoded and modulated signal x_t^i is transmitted through transmit antenna i, $1 \le i \le m$. We assume that the channel remains constant within a block of L symbols. Let h_{ij} denote the complex path gain from transmit antenna j to receive antenna i, which is modeled as samples of independent complex Gaussian random variables with mean zero and variance 0.5 per dimension. We also assume a perfect channel knowledge at the receiver side only, through the use of training sequences.

Let $(\cdot)'$ denote the transpose operator. The discrete received complex signal vector can now be written as

$$\mathbf{y_t} = \sqrt{\frac{SNR}{m}}\mathbf{H}\mathbf{x_t} + \mathbf{z_t} \tag{1}$$

where $\mathbf{x_t} = \left(x_t^1, x_t^2, ..., x_t^m\right)'$ and $\mathbf{y_t} = \left(y_t^1, y_t^2, ..., y_t^n\right)'$. The additive noise $\mathbf{z_t}$ has i.i.d. entries z_t^i, $i = 1,...,n$, which are all Gaussian random variables with mean zero and unit variance. Also SNR is the average signal-noise ratio at each receive antenna.

Assume that the transmit signals are divided into G groups, $\mathcal{G}_1, \mathcal{G}_2, ..., \mathcal{G}_G$, with group size $|\mathcal{G}_i|$, i=1,…,G. Then, (1) can be written as

$$\mathbf{y_t} = \sqrt{\frac{SNR}{m}}\left[\mathbf{H}_{\mathcal{G}_1}, \mathbf{H}_{\mathcal{G}_2}, ..., \mathbf{H}_{\mathcal{G}_G}\right] \cdot \begin{bmatrix} \mathbf{s_t^1} \\ \mathbf{s_t^2} \\ \vdots \\ \mathbf{s_t^G} \end{bmatrix} + \mathbf{z_t} \tag{2}$$

where $\mathbf{s_t^i}$ is the transmit vector of group $\mathcal{G}_i$ at time slot t, t=1,…,L and i=1,…,G. $\mathbf{H}_{\mathcal{G}_i}$ is the $n \times |\mathcal{G}_i|$ channel matrix of group $\mathcal{G}_i$, i=1,…,G.

Throughout this paper, we assume that a Group Zero-Forcing (GZF) receiver is adopted. In particular, at time slot t, group $\mathcal{G}_i$ is assumed to be detected. Then, the interference from the other groups $\mathcal{G}_1, ..., \mathcal{G}_{i-1}, \mathcal{G}_{i+1}, ..., \mathcal{G}_G$ should be nulled out using an orthogonal projection. To obtain the projection matrix, we partition $\mathbf{H}$ into $\mathbf{H} = \left[\mathbf{H}_{\mathcal{G}_i}, \mathbf{H}_{\bar{\mathcal{G}}_i}\right]$, where $\mathbf{H}_{\bar{\mathcal{G}}_i}$ includes the columns of $\mathbf{H}$ corresponding to the groups except $\mathcal{G}_i$. The projection matrix $\mathbf{P}_{\mathcal{G}_i}$ is then defined as [12]: $\mathbf{P}_{\mathcal{G}_i} = \mathbf{I_n} - \mathbf{H}_{\bar{\mathcal{G}}_i}(\mathbf{H}_{\bar{\mathcal{G}}_i}^+ \mathbf{H}_{\bar{\mathcal{G}}_i})^{-1}\mathbf{H}_{\bar{\mathcal{G}}_i}^+$, where $(\cdot)^+$ denote the complex conjugate transpose. Therefore, using the transformation $\mathbf{W_i} = \mathbf{H}_{\mathcal{G}_i}^+ \mathbf{P}_{\mathcal{G}_i}$ on $\mathbf{y_t}$, we have

$$\tilde{\mathbf{y}}_\mathbf{t}^\mathbf{i} = \mathbf{W_i}\mathbf{y_t} = \sqrt{\frac{SNR}{m}}\mathbf{H}_{\mathcal{G}_i}^+ \mathbf{P}_{\mathcal{G}_i}\mathbf{H}_{\mathcal{G}_i}\mathbf{s_t^i} + \tilde{\mathbf{z}}_\mathbf{t} = \sqrt{\frac{SNR}{m}}\mathbf{Q}_{\mathcal{G}_i}^{-1}\mathbf{s}_\mathbf{t}^i + \tilde{\mathbf{z}}_\mathbf{t} \tag{3}$$

where $\mathbf{Q}_{\mathcal{G}_i}^{-1} = \mathbf{H}_{\mathcal{G}_i}^+ \mathbf{P}_{\mathcal{G}_i}\mathbf{H}_{\mathcal{G}_i}$. Actually we know that $\mathbf{Q}_{\mathcal{G}_i}$ is the $|\mathcal{G}_i| \times |\mathcal{G}_i|$ diagonal submatrix of $\left(\mathbf{H}^+\mathbf{H}\right)^{-1}$ and the noise $\tilde{\mathbf{z}}_\mathbf{t}$ has covariance $\mathbf{Q}_{\mathcal{G}_i}^{-1}$.

The transmit symbols of group $\mathcal{G}_i$ at time slot t can then be decoded using MLD based on $\tilde{\mathbf{y}}_\mathbf{t}^\mathbf{i}$:

$$\hat{\mathbf{s}}_\mathbf{t}^\mathbf{i} = \arg\min_{\mathbf{s_t^i}}\left(\mathbf{r_t^i}\right)^+ \mathbf{Q}_{\mathcal{G}_i}\mathbf{r_t^i} \tag{4}$$

where

$$\mathbf{r_t^i} = \tilde{\mathbf{y}}_\mathbf{t}^\mathbf{i} - \sqrt{\frac{SNR}{m}}\mathbf{Q}_{\mathcal{G}_i}^{-1}\mathbf{s_t^i} \tag{5}$$

Throughout this paper, we denote by $(\cdot)^*$ and $\det(\cdot)$ the conjugate and the determinant operators, respectively. $\mathbf{I_m}$ represents an $m \times m$ identity matrix. $\bar{\mathbf{S}}$ represents the complement of a set $\mathbf{S}$ with the length $|\mathbf{S}|$.

III. Combined STBC and LST

We begin by presenting GLST, and then present the details of our proposed QoGST architecture.

A. GLST

A.1 Transmitter

As shown in Fig. 1, all the m transmit antennas are partitioned into G groups, respectively, comprising $m_1, m_2, ..., m_G$ antennas. A block of input bits $\{b_i\}_{i=1...m}$ is divided into G groups, $\mathcal{G}_1, \mathcal{G}_2, ..., \mathcal{G}_G$, and in each group, $\mathbf{b_i} = [b_{i,1}, b_{i,2}, ..., b_{i,|\mathcal{G}_i|}]'$, i=1,…,G, is then encoded by a component space-time block code $STBC_i$ associated with m_i transmit antennas. Assume that all the component codes $STBC_i$, i=1,…,G, have the same code length T and we have $m_i = |\mathcal{G}_i| = g$, i=1,…,G. Then, the output $m \times T$ codeword matrix $\mathbf{X}$ over a block of T symbol intervals can be written as

$$\mathbf{X} = \begin{bmatrix} x_1^1 & \cdots & x_T^1 \\ \vdots & \ddots & \vdots \\ x_1^m & \cdots & x_T^m \end{bmatrix} = \begin{bmatrix} \mathbf{s_1^1} & \cdots & \mathbf{s_T^1} \\ \vdots & \ddots & \vdots \\ \mathbf{s_1^G} & \cdots & \mathbf{s_T^G} \end{bmatrix} = \begin{bmatrix} \mathbf{S_1} \\ \vdots \\ \mathbf{S_G} \end{bmatrix} \tag{6}$$

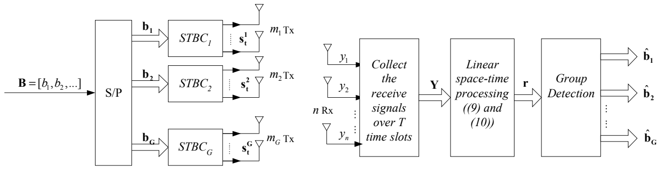

Fig. 1: Block diagram of GLST

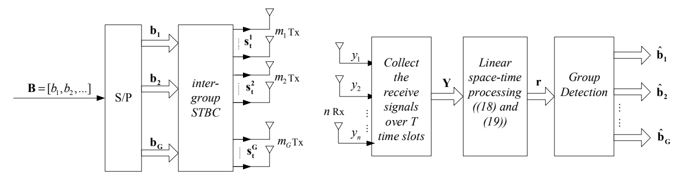

Fig. 2: Block diagram of QoGST

where $\mathbf{S_i}=[\mathbf{s_1^i},\cdots,\mathbf{s_T^i}]$ is the $g\times T$ codeword matrix of group $\mathcal{G}_i$, i=1,…,G.

As we know, an m-antenna-T-time-slot-k-symbol STBC $\mathcal{O}_x$ can be represented as $\mathcal{O}_x=\left[\mathbf{A_1x}+\mathbf{B_1x}^*,\mathbf{A_2x}+\mathbf{B_2x}^*,...,\mathbf{A_Tx}+\mathbf{B_Tx}^*\right]$, where $\mathbf{x}$ is an $k\times 1$ complex variable vector and $\mathbf{A_i},\mathbf{B_i}$ are constant coefficient matrices in $\mathcal{R}^{m\times k}$. The matrix $\mathcal{O}_x$ is called [m, T, k] STBC for short in the following. Therefore, $\mathbf{S_i}$ can be written as

$$\mathbf{S_i}=\left[\mathbf{A_{i1}b_i},...,\mathbf{A_{iT}b_i}\right]+\left[\mathbf{B_{i1}b_i^*},...,\mathbf{B_{iT}b_i^*}\right], \tag{7}$$

for i=1,…,G, where $\mathbf{A}_{ij},\mathbf{B}_{ij}$ are constant coefficient matrices in $\mathcal{R}^{g\times g}$, j=1,…,T.

It can be seen that in this transmit architecture, the bit streams of each group are space-time coded. Therefore, a higher diversity gain can be achieved compared to the conventional LST. Besides, the multiplexing gain is higher than the conventional STBC due to the use of multiple group transmission. We can thus conclude that this transmit scheme offers a good tradeoff between the diversity gain and multiplexing gain.

A.2 Receiver

The detector presented in [8] is to suppress signals transmitted from other groups of antennas by virtue of a group detector first, and then perform space-time decoding for the desired group. In this paper, we adopt a new detector, in which space-time decoding is performed first and then do group detection. To do so, an equivalent channel is obtained by virtue of the linear nature of STBC. GZF is then performed. Particularly, by combining (6) and (7), the received signal vector can be written as

$$\mathbf{Y}=\sqrt{\frac{SNR}{m}}\left[[\mathbf{H}_1\mathbf{A}_{11},...,\mathbf{H}_G\mathbf{A}_{G1}]\cdot\begin{bmatrix}\mathbf{b}_1\\ \vdots\\ \mathbf{b}_G\end{bmatrix},\quad\cdots,\quad[\mathbf{H}_1\mathbf{A}_{1T},...,\mathbf{H}_G\mathbf{A}_{GT}]\cdot\begin{bmatrix}\mathbf{b}_1\\ \vdots\\ \mathbf{b}_G\end{bmatrix}\right]+ \tag{8}$$

$$\sqrt{\frac{SNR}{m}}\left[[\mathbf{H}_1\mathbf{B}_{11},...,\mathbf{H}_G\mathbf{B}_{G1}]\cdot\begin{bmatrix}\mathbf{b}_1^*\\ \vdots\\ \mathbf{b}_G^*\end{bmatrix},\quad\cdots,\quad[\mathbf{H}_1\mathbf{B}_{1T},...,\mathbf{H}_G\mathbf{B}_{GT}]\cdot\begin{bmatrix}\mathbf{b}_1^*\\ \vdots\\ \mathbf{b}_G^*\end{bmatrix}\right]+\mathbf{Z}.$$

After a series of linear transformation, finally we can get

$$\mathbf{r}=\sqrt{\frac{SNR}{m}}\left[\mathbf{H}_{\mathcal{G}_1},...,\mathbf{H}_{\mathcal{G}_G}\right]\cdot\begin{bmatrix}\mathbf{b}_1\\ \vdots\\ \mathbf{b}_G\end{bmatrix}+\tilde{\mathbf{z}} \tag{9}$$

where $\mathbf{r}=[\tilde{\mathbf{y}}_1^{'},...,\tilde{\mathbf{y}}_T^{'}]^{'}$ and $\tilde{\mathbf{y}}_j=\begin{cases}\mathbf{y}_j, & \mathbf{B}_{ij}=\mathbf{0}_{g\times g}\\ \mathbf{y}_j^*, & \mathbf{A}_{ij}=\mathbf{0}_{g\times g}\end{cases}$, $\mathbf{y}_j$ represents the j-th column vector of $\mathbf{Y}$, j=1,…,T. For any group $\mathcal{G}_i$, i=1,…,G, the corresponding sub-channel matrix is given by

$$\mathbf{H}_{\mathcal{G}_i}=\begin{bmatrix}\mathbf{H}_i\mathbf{A}_{i1}+\mathbf{H}_i^*\mathbf{B}_{i1}^*\\ \vdots\\ \mathbf{H}_i\mathbf{A}_{iT}+\mathbf{H}_i^*\mathbf{B}_{iT}^*\end{bmatrix}. \tag{10}$$

From (9) and (10) it is clear that after obtaining this $Tn\times m$ equivalent channel of GLST, the decoding process is done. Group detection can then be applied so as to get the original transmit symbols.

B. QoGST

B.1 Transmitter

In GLST, the bit streams of each group are encoded separately so that the output streams $\mathbf{S_1}$, $\mathbf{S_2}$, …, $\mathbf{S_G}$ are independent of each other. No special transmit design is adopted to suppress the interference among the groups. Besides, the mapping from different groups to the transmit antennas is always fixed over all the time slots. Therefore, no interleaving gain can be achieved. In this section, we present a new space-time architecture, in which all the groups are encoded together via an "inter-group STBC" encoder. As Fig. 2 shows, instead of being encoded separately, all the groups are encoded together. The design of the inter-group STBC is given by

$$\mathbf{X}=\left[\tilde{\mathbf{A}}_1\mathbf{b},...,\tilde{\mathbf{A}}_T\mathbf{b}\right]+\left[\tilde{\mathbf{B}}_1\mathbf{b}^*,...,\tilde{\mathbf{B}}_T\mathbf{b}^*\right] \tag{11}$$

where

$$\tilde{\mathbf{A}}_j=\left[\tilde{\mathbf{A}}_{1j},...,\tilde{\mathbf{A}}_{Gj}\right],\ \tilde{\mathbf{B}}_j=\left[\tilde{\mathbf{B}}_{1j},...,\tilde{\mathbf{B}}_{Gj}\right], \tag{12}$$

and

$$\tilde{\mathbf{A}}_{ij}=\mathbf{A}_j^i\otimes\mathbf{I}_g,\ \tilde{\mathbf{B}}_{ij}=\mathbf{B}_j^i\otimes\mathbf{I}_g, \tag{13}$$

for i=1,…,G and j=1,…,T. $\mathbf{A}_j^i$ and $\mathbf{B}_j^i$ are the i^{th} column vector of $\mathbf{A}_j$ and $\mathbf{B}_j$, respectively. $\mathbf{A}_j$ and $\mathbf{B}_j$, j =1,…T, are the coefficient matrices of a [G,T,G] STBC.

To further illustrate this encoding process, we consider the following example. Assume that the bit streams are divided into G=2 groups and transmitted by m=4 transmit antennas over T=2 time slots. For a 2-symbol-2-time-slot STBC, the coefficients $\mathbf{A}_1,\mathbf{A}_2,\mathbf{B}_1,\mathbf{B}_2$ are given by

$$\mathbf{A}_1=\begin{bmatrix}1&0\\0&1\end{bmatrix},\ \mathbf{B}_2=\begin{bmatrix}0&-1\\1&0\end{bmatrix},\ \mathbf{A}_2=\mathbf{B}_1=\mathbf{0}_{2\times 2}. \tag{14}$$

Then, $\tilde{\mathbf{A}}_1,\tilde{\mathbf{A}}_2,\tilde{\mathbf{B}}_1,\tilde{\mathbf{B}}_2$ can be computed via (12-14) and the output codeword matrix of QoGST is given by

$$\mathbf{X}_{QoGST}=\begin{bmatrix}b_{1,1}&b_{1,2}&b_{2,1}&b_{2,2}\\-b_{2,1}^*&-b_{2,2}^*&b_{1,1}^*&b_{1,2}^*\end{bmatrix}^{'} \tag{15}$$

Compared to the codeword matrix of GLST:

$$\mathbf{X}_{GLST} = \begin{bmatrix} b_{1,1} & b_{1,2} & b_{2,1} & b_{2,2} \\ -b_{1,2}^* & b_{1,1}^* & -b_{2,2}^* & b_{2,1}^* \end{bmatrix}' \quad (16)$$

it is obvious that in QoGST the mapping from the bit streams of different groups to the transmit antennas is not constant any more. Therefore, a higher diversity gain can be achieved thanks to the interleaving gain. Besides, here STBC is applied to the transmit vectors. The interference among the groups is not independent any more and thus can be better suppressed.

B.2 Receiver

From (11), the received signal vector can be written as

$$\mathbf{Y} = \sqrt{\frac{SNR}{m}} \left[\left[\mathbf{H}\tilde{\mathbf{A}}_{11}, ..., \mathbf{H}\tilde{\mathbf{A}}_{G1} \right] \cdot \begin{bmatrix} \mathbf{b}_1 \\ \vdots \\ \mathbf{b}_G \end{bmatrix}, \ \cdots, \ \left[\mathbf{H}\tilde{\mathbf{A}}_{1T}, ..., \mathbf{H}\tilde{\mathbf{A}}_{GT} \right] \cdot \begin{bmatrix} \mathbf{b}_1 \\ \vdots \\ \mathbf{b}_G \end{bmatrix} \right] + \quad (17)$$

$$\sqrt{\frac{SNR}{m}} \left[\left[\mathbf{H}\tilde{\mathbf{B}}_{11}, ..., \mathbf{H}\tilde{\mathbf{B}}_{G1} \right] \cdot \begin{bmatrix} \mathbf{b}_1^* \\ \vdots \\ \mathbf{b}_G^* \end{bmatrix}, \ \cdots, \ \left[\mathbf{H}\tilde{\mathbf{B}}_{1T}, ..., \mathbf{H}\tilde{\mathbf{B}}_{GT} \right] \cdot \begin{bmatrix} \mathbf{b}_1^* \\ \vdots \\ \mathbf{b}_G^* \end{bmatrix} \right] + \mathbf{Z}.$$

Similarly, we can get

$$\mathbf{r} = \sqrt{\frac{SNR}{m}} \left[\mathbf{H}_{\mathcal{G}_1}, ..., \mathbf{H}_{\mathcal{G}_G} \right] \cdot \begin{bmatrix} \mathbf{b}_1 \\ \vdots \\ \mathbf{b}_G \end{bmatrix} + \tilde{\mathbf{z}} \quad (18)$$

where for i=1,…,G,

$$\mathbf{H}_{\mathcal{G}_i} = \begin{bmatrix} \mathbf{H}\tilde{\mathbf{A}}_{i1} + \mathbf{H}^*\tilde{\mathbf{B}}_{i1}^* \\ \vdots \\ \mathbf{H}\tilde{\mathbf{A}}_{iT} + \mathbf{H}^*\tilde{\mathbf{B}}_{iT}^* \end{bmatrix}. \quad (19)$$

Given $\mathbf{r}$, group detection can then be applied.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of QoGST and GLST in terms of Symmetric Energy (SE). Since the full rate design exists only when the transmit antennas are two, we consider Alamouti's scheme in the following analysis. Besides, QPSK is assumed to be adopted.

SE is proposed in [11] as an indicator of the overall performance of a multiuser detector in terms of the joint error rate defined as the probability that at least one user is detected erroneously. It reflects the interference suppressing capability of a multiuser detector. SE is defined by:

$$E(\phi) = \min\left(D_1^2, ..., D_G^2\right) \quad (20)$$

where D_i is the minimum distance of the matrix $\mathbf{Q}_{\mathcal{G}_i}^{-1}$. That is, $D_i^2 = \min_{\mathbf{e}=\left|\hat{\mathbf{b}}_{\mathcal{G}_i} - \mathbf{b}_{\mathcal{G}_i}\right|/2} \mathbf{e}'\left(\mathbf{Q}_{\mathcal{G}_i}^{-1}\right)\mathbf{e}$, where $\mathbf{Q}_{\mathcal{G}_i}$ is the $|\mathcal{G}_i| \times |\mathcal{G}_i|$ diagonal submatrix of $\left(\mathbf{H}^+\mathbf{H}\right)^{-1}$ as shown in Section II. Obviously, a higher SE indicates better interference suppressing capability.

According to (10) and (19), we can get $\mathbf{Q}_{\mathcal{G}_i}^{GLST}$ and $\mathbf{Q}_{\mathcal{G}_i}^{QoGST}$, respectively. Then, from (20) the SE of GLST and QoGST can be computed. Figs. 3 and 4 present the SE averaged over 1000 frames. Since the equivalent channel matrice of QoGST and GLST with the element given by (10) and (19), respectively, both have $Tn \times m$ dimensions, for comparison, we also draw the SE curve of an (m, 2n) system over Rayleigh quasi-static channels with GZF (we refer it to as (m, 2n) GZF in the following text). As Fig. 3 shows, when m =4, QoGST always has the highest SE, which indicates that QoGST has the best interference suppressing capability. GLST has a lower SE than QoGST, but a higher SE than (m, 2n) GZF. Both QoGST and GLST have better SE than (m, 2n) GZF thanks to the coding gain. QoGST can achieve even better performance than GLST since it further suppresses the interference with STBC among groups. Moreover, it can be also seen that the slopes of these 3 curves are equal. This is because they have the same group size g_Q=g_L=g=2.

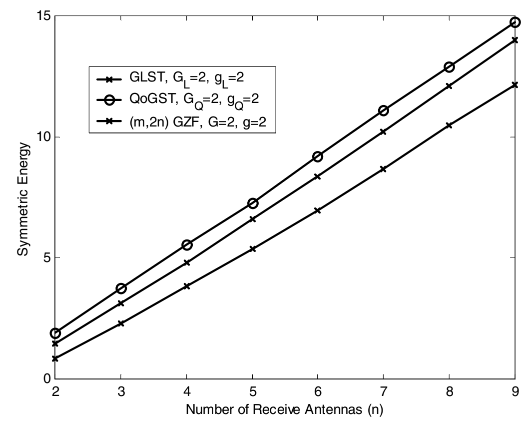

Fig. 3: Symmetric Energy vs. n for QoGST and GLST when m =4.

Fig. 4 shows the SE comparison when m =6. In this case, QoGST and GLST have different group sizes. In GLST, STBC is adopted inside each group. Therefore, the group size g_L has to be 2 and there are totally G_L=3 groups. However, for QoGST, STBC is applied among the groups. Therefore, G_Q=g_L=2 and g_Q=3. From Fig. 4, it can be seen that QoGST not only has a much higher SE than GLST but also the gain will increase as n increases. This is because QoGST has a larger group size (g_Q=3) than GLST (g_L =2). The comparison of GLST and (m, 2n) GZF shows that, when they have an equal group size (g_L=g=2), GLST always has a higher SE than (m, 2n) GZF but with the same slope. The same conclusion can be also obtained for QoGST and (m, 2n) GZF with g_Q =g=3.

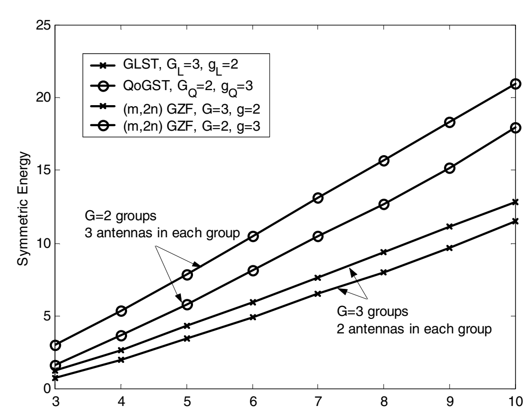

Fig. 4: Symmetric Energy vs. n for QoGST and GLST when m =6.

V. FER Results and Discussions

We have shown that our new scheme QoGST has a better SE than GLST. In this section, we further compare their FER performance. QPSK is assumed to be adopted and the FER is averaged over 10,000 frames. As Fig. 5 shows, when m =4 and n =2, QoGST can achieve a gain of 3 dB over GLST at a FER of 10^{-3}. This observation validates our analysis: QoGST has a higher SE than GLST. Besides, in high-SNR regime, the FER curve of QoGST has a larger slope than that of GLST, which implies that QoGST has a better diversity gain. Notice that these two schemes have the same spectral efficiency. As a result, we can conclude that QoGST achieves a better diversity-multiplexing tradeoff.

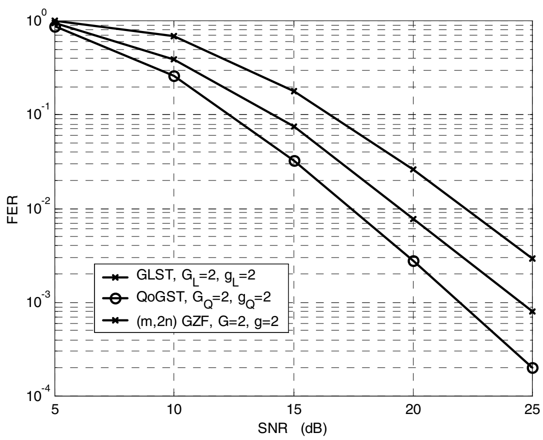

Fig. 5: FER vs. SNR curves of QoGST and GLST when m =4 and n =2.

When m =6 and n =3, the performance gap between QoGST and GLST becomes even larger. From Fig. 6 it can be seen that in this case QoGST can achieve at least 7 dB gain at a FER of 10^{-3}, and the FER curve of QoGST is much steeper than that of GLST, which implies a much better diversity gain. As shown in Section IV, in this case QoGST has a larger group size, i.e., g_Q=3> g_L=2. Therefore, the performance gain is even more significant. Besides, both QoGST and GLST can achieve better FER performance over the corresponding (m, 2n) GZF with g=g_Q or g= g_L, thanks to their coding gain.

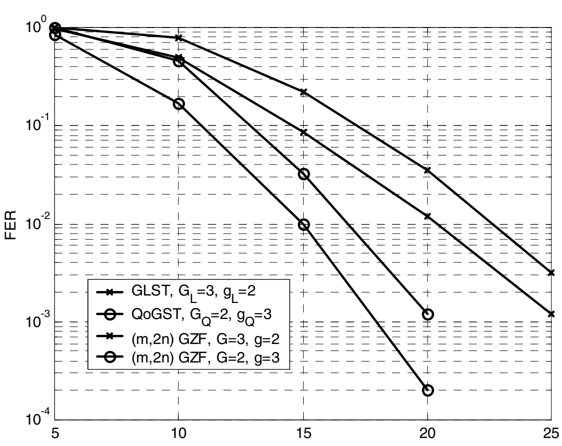

Fig. 6: FER vs. SNR curves of QoGST and GLST when m =6 and n =3

VI. Conclusions

In this paper, we proposed a novel space-time architecture, Quasi-Orthogonal Group Space-time (QoGST), in which the transmit stream is partitioned into several groups and all the groups are encoded together via a Quasi-orthogonal inter-group STBC coder. This inter-group encoder effectively suppresses the interference among the groups and the interleaving gain can be also achieved. We analyzed its SE and found that compared with GLST, QoGST has a higher SE and a better diversity-multiplexing tradeoff. The simulation results validate our analysis and demonstrated that QoGST can achieve at least 3 dB gain over GLST at a FER of 10^{-3}.

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