New Block-Based Spatial Modulation

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***Abstract*—Spatial modulation (SM) conveys additional information using antenna patterns in MIMO system. The existing SM schemes limit the active antennas to a fixed number in each transmit vector to avoid detection ambiguity. Motivated by this, we introduce a new block-based SM (BSM) scheme wherein transmit vectors can have different number of active antennas, with the constraint that the total number of active antennas over a transmission block is fixed. This enables us to not only avoid detection ambiguity but also achieve low bit error rate than an existing SM scheme.**

***Index Terms*—Block pattern, spatial modulation (SM).**

I. Introduction

Schemes to transmit information by exploiting the indices of multiple-input multiple-output (MIMO) spatial dimensions have gained significant interest. For example, the spatial modulation (SM) [1]–[3] uses active antennas patterns in addition to standard constellations to transmit information. It has a key advantage that it does not suffer from inter-carrier interference, thus leading to an improved BER performance [4], [5]. The one popular scheme [2] which generalizes SM to transmit different data symbols from the multiple active antennas, strikes a trade-off between the multiplexing gain and the BER gain [6]. The number of active transmit antennas, however, is fixed for the entire communication interval, and does not change arbitrarily.

The variable number of active transmit antennas i) increases the number of antenna patterns, which can either be used to increase the data rate or reduce the bit error rate (BER); and ii) makes detection ambiguous due to lack of this information at the receiver [3], [7], which severely impacts the SM systems performance. The SM systems with variable number of active antennas are studied in [8] and [9]. The SM scheme in [8], however, uses variable number of active antennas to transmit the same symbol. The enhanced SM scheme in [9] varies the number of active antennas but uses $M/2$ constellation size for $2N_A$ active antennas.

We propose a novel *block-based* SM (BSM) scheme which transmits different M-ary symbols from *arbitrary* number of active antennas in each transmit vector, keeping the total number of active antennas over a block constant. We use this idea to generate multiple active antenna patterns over a block of K transmit vectors, referred to as the "block-patterns." These block-patterns exploit the benefits of using arbitrary number of active antennas per transmit vector to avoid detection ambiguity. Further, we design the block to have *different* number of active antennas in each transmit vector, thus an error occurs only when position of active antennas in multiple transmit vectors in the block are in error, which is less likely to happen. This is unlike the existing *generalized* SM (GSM) scheme [3], wherein an error in detecting the position of even a single active antenna would lead to an error. Also, increasing the block-length K will further reduce the BER, a fact explained later in the letter.

The proposed BSM scheme, similar to [10], extends SM to downlink of massive MIMO systems, with few active transmit antennas out of large number of available ones. We use these few active antennas to design the proposed block-patterns, and numerically show that this results in lower BER of the proposed BSM than the GSM. Further, motivated by [11], we also propose a two-step detector which uses the likelihood of active antennas to detect the block-pattern followed by MMSE detection for symbols. We also show that the BSM outperforms GSM with the proposed low-complexity detector.

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II. System Overview

We consider a MIMO system with all-active N_r receive antennas, and N_t transmit antennas wherein at most $K(\leq N_t)$ are active in any transmit vector. We consider a block of K transmit vectors, and the input-output relation for the kth transmit vector '$\mathbf{x}_k$' is

$$\mathbf{y}_k = \frac{1}{\sqrt{d_k}}\mathbf{H}_k\mathbf{x}_k + \mathbf{n}_k \quad k = 1, \ldots, K. \tag{1}$$

Here $\mathbf{y}_k \in \mathbb{C}^{N_r \times 1}$, $\mathbf{H}_k \in \mathbb{C}^{N_r \times N_t}$, and $\mathbf{n}_k \in \mathbb{C}^{N_r \times 1}$ respectively denote the kth receive-vector, the kth channel matrix, and the kth additive white Gaussian noise vector, with its elements distributed as $\mathcal{CN}(0, \sigma^2)$. The transmit vector $\mathbf{x}_k \in \mathbb{C}^{N_t \times 1}$ has d_k and $N_t - d_k$ non-zero and zero elements respectively, where $1 \leq d_k \leq K$. The d_k non-zero elements are symbols from a standard unit-energy M-ary constellation transmitted using d_k active antennas. We use the factor $\sqrt{d_k}$ to scale the power of $\mathbf{x}_k$ to unity. We assume the receiver has perfect channel state information (CSI).

III. Proposed Block-Based SM Scheme

The proposed scheme generates active antenna patterns in a block of K transmit vectors and uses these block-patterns to encode the information bits, along with the bits encoded using M-ary constellations. Let us denote the set of possible block-patterns as $\mathcal{P} = \{\mathbf{P}_1, \ldots, \mathbf{P}_{N_p}\}$, where N_p is the cardinality of set $\mathcal{P}$. The block-pattern $\mathbf{P}_i$ is an $N_t \times K$

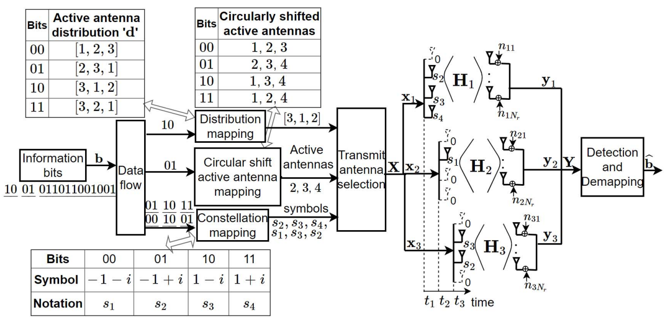


Fig. 1. Block diagram of BSM-MIMO transceiver with $N_t = 4$ and $K = 3$.

matrix containing 0's and 1's representing inactive and active antennas, respectively. Each $\mathbf{P}_i$ is used to form a block of transmit vectors $\mathbf{X} = [\mathbf{x}_1, \ldots, \mathbf{x}_K]$ by replacing the 1's in $\mathbf{P}_i$ with scaled unit-energy M-ary constellation. We denote the number of active antennas distributed over the block-pattern $\mathbf{P}_i = [\mathbf{p}_{i1}, \ldots, \mathbf{p}_{iK}]$ as $\mathbf{d} = [d_1, \ldots, d_K]$, where the vector $\mathbf{p}_{ik}$ denotes the antenna pattern of the kth transmit vector and $d_k (1 \leq d_k \leq K)$ is the number of active antennas in $\mathbf{p}_{ik}$.

A. Design of Block-Pattern $\mathbf{P}_i$

As the proposed design encodes information using block-patterns, which are active antenna patterns in a block of K transmit vectors, we can construct block-patterns (spatial codes) with a larger minimum Euclidean/Hamming distance than the GSM scheme which encodes information over antenna patterns in a single transmit vector [3]. We create such block-patterns $\mathbf{P}_i$ by imposing the constraints such that in each block, no two $\mathbf{p}_{ik}$'s have same d_k values. This constraint results in $K!$ possible active antenna distributions '$\mathbf{d}$,' and also fixes the total number of active antennas over a block to $N_{total} = \frac{K \times (K+1)}{2}$. Hence, we use the first $\lfloor \log_2(K!) \rfloor$ bits to decide the distribution $\mathbf{d}$. For a particular $\mathbf{d}$, we form the block-patterns as follows:

1) Take an initial block-pattern where each $\mathbf{p}_{ik}$ has d_k "consecutive" active antennas and the position of lowest-indexed active antenna is '1' for all $\mathbf{p}_{ik}$ vectors.

2) Generate other block-patterns for the same distribution '$\mathbf{d}$' by *circularly* shifting the position of active antennas.

This achieves N_t circular shifts leading to N_t different block-patterns. Hence, the next $\lfloor \log_2(N_t) \rfloor$ bits fix a particular block-pattern $\mathbf{P}_i$. The total number of possible block-patterns are therefore $N_p = 2^\ell$ with $\ell = \lfloor \log_2(K!) \rfloor + \lfloor \log_2(N_t) \rfloor$. After deciding $\mathbf{P}_i$, the subsequent $N_{total} \times \log_2 M$ bits are mapped to the symbols from an M-ary constellation, and we form a block of transmit vectors $\mathbf{X}$ by replacing the 1's in $\mathbf{P}_i$ with M-ary symbols. The data rate for the proposed BSM scheme in bits per channel use (bpcu) is

$$\frac{\ell}{K} + \frac{N_{total} \times \log_2(M)}{K} = \frac{\ell}{K} + \frac{(K+1) \times \log_2(M)}{2}. \quad (2)$$

B. Example of the Proposed Scheme

We explain the proposed BSM scheme using an example system shown in Fig. 1 that employs QPSK modulation with $N_t = 4$ transmit antennas. We consider block length of $K = 3$, and hence, $K! = 6$ active antenna distributions $\mathbf{d}$, out of which we choose 4 distributions to transmit $\lfloor \log_2(K!) \rfloor = 2$ bits. Let the 4 distributions be [1, 2, 3], [2, 3, 1], [3, 1, 2], and [3, 2, 1], where 1, 2, and 3 denote the number of active transmit antennas. Assuming a stream of 16 bits, we observe from Fig. 1 that the first $\lfloor \log_2(K!) \rfloor = 2$ information bits select one of the four distributions. The next $\lfloor \log_2(N_t) \rfloor = 2$ bits select from the block-patterns corresponding to different shift in positions of active antennas.

The subsequent $N_{total} \times \log_2 M = 12$ bits are transmitted using 6 QPSK symbols from the $N_{total} = 6$ active antennas.

C. ML Detection and the BER of the Proposed Scheme

The ML detection rule is defined as the block of solution vectors which minimizes the sum of euclidean distances between the block of receive vectors $\mathbf{Y} = [\mathbf{y}_1, \ldots, \mathbf{y}_K]$ and the possible block of transmit vectors, say Φ. This can be mathematically expressed as $\hat{\mathbf{X}}_{ML} = \underset{\mathbf{X} \in \Phi}{\operatorname{argmin}} \sum_{k=1}^{K} \|\mathbf{y}_k - \frac{1}{\sqrt{d_k}} \mathbf{H}_k \mathbf{x}_k\|^2$, where $\| \cdot \|$ denotes the l_2 norm.

The pairwise error probability (PEP) in GSM of deciding on $\mathbf{x}_j$ given that $\mathbf{x}_i$ is transmitted conditioned on $\mathbf{H}$ is [12]:

$$P(\mathbf{x}_i \to \mathbf{x}_j | \mathbf{H}) = P(\|\mathbf{y} - \mathbf{H}\mathbf{x}_i\|^2 > \|\mathbf{y} - \mathbf{H}\mathbf{x}_j\|^2)$$
$$= Q\left(\sqrt{\frac{\|\mathbf{H}(\mathbf{x}_i - \mathbf{x}_j)\|^2}{2\sigma^2}}\right) \leq \frac{1}{2} \cdot \exp\left(-\frac{1}{2} \frac{\|\mathbf{H}(\mathbf{x}_i - \mathbf{x}_j)\|^2}{2\sigma^2}\right), \quad (3)$$

where each $\mathbf{x}_i$ is the unit-power transmit vector. For the proposed BSM scheme, let $\mathcal{X}$ be the set of possible block vectors. For a given block length of $K = 3$, the PEP of deciding on a block $\mathbf{X}_j$ given that $\mathbf{X}_i$ is transmitted conditioned on $\mathbf{H}_1, \mathbf{H}_2$ and $\mathbf{H}_3$ is given, using (1), as

$$\begin{aligned} &P(\mathbf{X}_i \to \mathbf{X}_j | \mathbf{H}_1, \mathbf{H}_2, \mathbf{H}_3) \\ &= P(\|[\mathbf{y}_1 \ \mathbf{y}_2 \ \mathbf{y}_3] - [\mathbf{H}_1 \mathbf{x}_{1i} \ \mathbf{H}_2 \mathbf{x}_{2i} \ \mathbf{H}_3 \mathbf{x}_{3i}]\|_F^2 \\ &\quad > \|[\mathbf{y}_1 \ \mathbf{y}_2 \ \mathbf{y}_3] - [\mathbf{H}_1 \mathbf{x}_{1j} \ \mathbf{H}_2 \mathbf{x}_{2j} \ \mathbf{H}_3 \mathbf{x}_{3j}]\|_F^2) \\ &= Q\left(\sqrt{\frac{\|[\mathbf{H}_1(\mathbf{x}_{1i} - \mathbf{x}_{1j}) \mathbf{H}_2(\mathbf{x}_{2i} - \mathbf{x}_{2j}) \, \mathbf{H}_3(\mathbf{x}_{3i} - \mathbf{x}_{3j})]\|_F^2}{2\sigma^2}}\right), \end{aligned} \quad (4)$$

where $\| \cdot \|_F$ denotes the Frobenius norm. This PEP is upper bounded by the Chernoff bound $Q(x) \leq \frac{1}{2} e^{-x^2/2}$ as (5), as shown at the bottom of this page.

We observe that the the PEP between any two possible block vectors, similar to (3), is the product of exponential terms of the corresponding transmit-vectors. Now, for the block vectors corresponding to the same block-pattern, the PEP will correspond to error in detection of symbols and it will be the same as in case of GSM. However, when block vectors have different block-patterns, our design of block-patterns, as shown in Fig. 2, is such that the error will occur only when i) the position of multiple active antennas in all the transmit vectors in a block is shifted by same index and/or ii) the distribution '$\mathbf{d}$' is changed such that it leads to another valid distribution. This will happen only when at least two transmit vectors are detected incorrectly. Consequently, the PEP for BSM will be less than or equal to the PEP for GSM. We also note that (5) can be generalized for any block length K, and thus the PEP for BSM will decrease as the block length increases.

$$\begin{bmatrix} 0&0&0\\1&1&1\\1&0&1\\1&0&0 \end{bmatrix} \quad \begin{bmatrix} 1&1&1\\1&0&1\\1&0&0\\0&0&0 \end{bmatrix} \quad \begin{bmatrix} 0&0&0\\1&1&1\\1&1&0\\0&1&0 \end{bmatrix} \quad \begin{bmatrix} 1&1&1\\1&1&0\\0&1&0\\0&0&0 \end{bmatrix}$$

(a) (b) (c) (d)

Fig. 2. Error scenarios for the proposed scheme: (a) Pattern transmitted. (b) Shift in index. (c) Change in distribution. (d) Both (b) and (c) changed.

D. Data Rate Discussion

The data rate for the existing GSM scheme for fixed number of active antennas, say N_{fix} is [3]: $\lfloor \log_2 \binom{N_t}{N_{fix}} \rfloor + (N_{fix} \times \log_2(M))$. The numerical comparison of data rates for two schemes, however, is subject to the choices of K and N_{fix}. For example, the system considered in Fig. 1 has a data rate of 5.33 bpcu (ref Eq. (2)). The data rates of the GSM scheme for $N_{fix} = 1$ and $N_{fix} = 2$ are 4 and 6 bpcu, respectively. We also note that by varying the block length 'K,' we can vary the achievable data rate.

IV. Low-Complexity Detection

There are N_p possible block-patterns – the ML search has computational complexity of the order $\mathcal{O}(\frac{N_r N_P}{K} \sum_{i=1}^{K} iM^i)$. Motivated by [11], we reduce the detection complexity by implementing a two-stage detector. Firstly to detect the active antennas by identifying the transmit block-patterns from the set $\mathcal{P} = \{\mathbf{P}_1, \ldots, \mathbf{P}_{N_p}\}$, and secondly to use MMSE receiver to detect symbols transmitted using the active antennas.

We now modify the MMSE detector in [11] to take into account the block of K vectors in the proposed BSM design. To address the first sub-problem, we modify the weighted-correlation-based metric defined in [11] to identify the active antennas in a block of K vectors. We first determine the likelihoods of the active antennas as $\mathbf{W}(k,j) = |\mathbf{h}_{kj}^H \mathbf{y}_k / (\mathbf{h}_{kj}^H \mathbf{h}_{kj})|^2$, where $\mathbf{W}(k,j)$ denotes the likelihood for the jth antenna to be active in the kth transmit vector and $\mathbf{h}_{kj}$ is the jth column of the channel matrix $\mathbf{H}_k$. Given the likelihoods for all the antennas, we then compute the sum considering only those antennas which are active in a particular block-pattern. We do this for all possible N_p block-patterns. Let us denote these sum values as v_i's defined as $v_i = \sum_{k,j} \mathbf{P}_i(k,j) \mathbf{W}(k,j), \quad \forall\, i = 1, \ldots, N_p$, where $\mathbf{P}_i(k,j)$ denotes the active '1' or inactive '0' state of the jth transmit antenna in the kth transmit vector of ith block-pattern. The pattern corresponding to largest v_i value is the most likely candidate. Thus, we sort these sum values v_i in descending order to obtain the likelihoods of candidate block-patterns '$\bar{\mathcal{P}} = \{\bar{\mathbf{P}}_1, \bar{\mathbf{P}}_2, \ldots, \bar{\mathbf{P}}_{N_p}\}$'.

We then estimate the transmit symbols corresponding to a given block-pattern $\bar{\mathbf{P}}_i = [\bar{\mathbf{p}}_{i1}, \bar{\mathbf{p}}_{i2}, \ldots, \bar{\mathbf{p}}_{iK}]$. For this, we use the linear MMSE detector given as

$$\hat{\mathbf{s}}_k = Q\left(\left((\mathbf{H}_k(\bar{\mathbf{p}}_{ik}))^H \mathbf{H}_k(\bar{\mathbf{p}}_{ik}) + \sigma^2 \mathbf{I}\right)^{-1} \mathbf{H}_k(\bar{\mathbf{p}}_{ik})^H \mathbf{y}_k\right) \quad (6)$$

Algorithm 1 Ordered Block-Pattern Based MMSE Detection (OBP-MMSE)

Input: $\mathbf{Y}, \mathbf{H}_1, \mathbf{H}_2, \ldots, \mathbf{H}_K, \alpha, \sigma^2, \mathcal{P}$. **Output:** $\hat{\mathbf{b}}$. *Initialize*
$V_{th} = \alpha N_r \sigma^2, minvalue = \infty$;
$\mathbf{W}(k,j) = |\mathbf{h}_{kj}^H \mathbf{y}_k / (\mathbf{h}_{kj}^H \mathbf{h}_{kj})|^2 \ \forall\ k \& j$;
$v_i = \sum_{k,j} \mathbf{P}_i(k,j) \mathbf{W}(k,j), \quad \forall\, i = 1, 2, \ldots, N_p$;
$\bar{\mathcal{P}} \leftarrow$ 'N_p' block-patterns in descending order of v_i's;
while $i \le N_p$ & $minvalue \le V_{th}$ **do**
  $\tilde{\mathbf{s}} = Q\left(\left(\left(\tilde{\mathbf{H}}(\bar{\mathbf{P}}_i)\right)^H \tilde{\mathbf{H}}(\bar{\mathbf{P}}_i) + \sigma^2 \mathbf{I}\right)^{-1} \tilde{\mathbf{H}}(\bar{\mathbf{P}}_i)^H \tilde{\mathbf{y}}\right)$;
  $temp = \sum_{k=1}^{K} \|\mathbf{y}_k - \frac{1}{\sqrt{d_k}} \mathbf{H}_k(\bar{\mathbf{p}}_{ik}) \hat{\mathbf{s}}_k\|^2$;
  if $temp < minvalue$ **then**
    $minvalue = temp$;
    $\mathbf{X}^{min} \leftarrow$ detected block using $\hat{\mathbf{s}}_1, \ldots, \hat{\mathbf{s}}_K$;
  end
  $i = i + 1$
end
$\mathbf{X}^{min} \leftarrow$ detected block using $\hat{\mathbf{s}}_1, \ldots, \hat{\mathbf{s}}_K$;
$\hat{b} \leftarrow$ detected bits from X^{min} **return** $\hat{\mathbf{b}}$.

for $k = 1, \ldots, K$. The term $\bar{\mathbf{p}}_{ik}$ represents the kth column of $\bar{\mathbf{P}}_i$, and $\mathbf{H}_k(\bar{\mathbf{p}}_{ik})$ denotes the columns of $\mathbf{H}_k$ corresponding to the non-zero indices in $\bar{\mathbf{p}}_{ik}$.

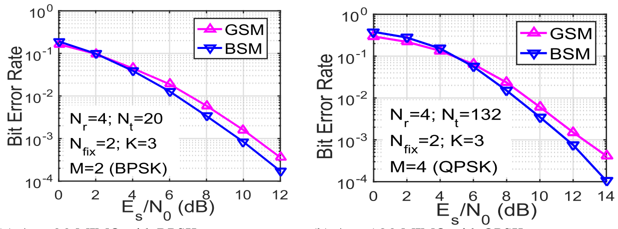
Let $\tilde{\mathbf{y}} = [\mathbf{y}_1^T \ \mathbf{y}_2^T, \ldots, \mathbf{y}_K^T]^T$, $\tilde{\mathbf{x}} = [\mathbf{x}_1^T \ \mathbf{x}_2^T, \ldots, \mathbf{x}_K^T]^T$ and $\tilde{\mathbf{H}} = \mathbf{diag}(\mathbf{H}_1, \mathbf{H}_2, \ldots, \mathbf{H}_K) \in \mathbb{C}^{KN_r \times KN_t}$. Then (6) can be re-expressed as following

$$\tilde{\mathbf{s}} = Q\left(\left(\left(\tilde{\mathbf{H}}(\bar{\mathbf{P}}_i)\right)^H \tilde{\mathbf{H}}(\bar{\mathbf{P}}_i) + \sigma^2 \mathbf{I}\right)^{-1} \tilde{\mathbf{H}}(\bar{\mathbf{P}}_i)^H \tilde{\mathbf{y}}\right) \quad (7)$$

Here $\tilde{\mathbf{H}}(\bar{\mathbf{P}}_i) = \mathbf{diag}\left(\mathbf{H}_1(\bar{\mathbf{p}}_{i1}), \mathbf{H}_2(\bar{\mathbf{p}}_{i2}), \ldots, \mathbf{H}_K(\bar{\mathbf{p}}_{iK})\right)$, and $\tilde{\mathbf{s}} \in \mathbb{C}^{N_{total} \times 1}$ is the vector containing all the detected symbols of the block. The symbol $Q(\cdot)$ is the digital demodulator function. This operation is performed for all block-patterns starting from $\bar{\mathbf{P}}_1$. We update the block of solution vectors if the MMSE estimates corresponding to the next likely block-pattern has a lower ML cost. This process continues until the corresponding ML cost is lower than a fixed threshold V_{th}. The value of the threshold can be determined as $V_{th} = \alpha\, N_r\, \sigma^2$, where the parameter α is used to customize the algorithm performance [11]. The proposed detection process, referred to as Ordered Block-pattern based MMSE detection (OBP-MMSE), is summarized in Algorithm 1.

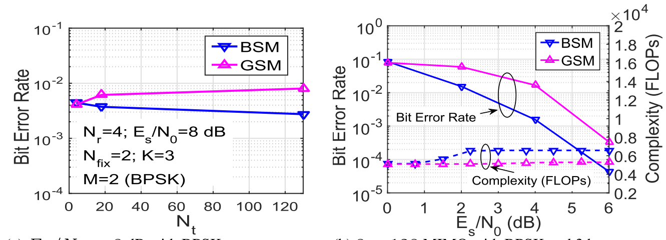
Computational Complexity: The complexity of Algorithm 1 is determined by the three crucial steps, i.e. $i)$ computing $\mathbf{W}$, $ii)$ determining v_i's, and $iii)$ the MMSE detection in (6). The respective order of complexity (in FLOPs) per block for these steps are $14\, N_r\, N_t\, K + 3\, N_t\, K$, $N_p\, N_{total}$, and $\sum_{N_a=1}^{K} (12\, N_a^2\, N_r + 11\, N_a\, N_r)\, \rho_{avg}$, where ρ_{avg} denotes the average number of block MMSE detections required. So the overall computational complexity per transmit vector will be $14\, N_r\, N_t + 3\, N_t + N_p\, \frac{K+1}{2} + (4K + 2 + \frac{11}{2})(K+1)\, N_r\, \rho_{avg}$.

$$\begin{aligned} P(\mathbf{X}_i \to \mathbf{X}_j | \mathbf{H}_1, \mathbf{H}_2, \mathbf{H}_3) &\le \frac{1}{2} \cdot \exp\left(-\frac{1}{2} \frac{\|\mathbf{H}_1(\mathbf{x}_{1i} - \mathbf{x}_{1j}) \ \mathbf{H}_2(\mathbf{x}_{2i} - \mathbf{x}_{2j}) \ \mathbf{H}_3(\mathbf{x}_{3i} - \mathbf{x}_{3j})\|_F^2}{2\sigma^2}\right) \\ &= \frac{1}{2} \cdot \exp\left(-\frac{1}{2} \frac{\|\mathbf{H}_1(\mathbf{x}_{1i} - \mathbf{x}_{1j})\|^2 + \|\mathbf{H}_2(\mathbf{x}_{2i} - \mathbf{x}_{2j})\|^2 + \|\mathbf{H}_3(\mathbf{x}_{3i} - \mathbf{x}_{3j})\|^2}{2\sigma^2}\right). \end{aligned} \quad (5)$$



(a) 4 × 20 MIMO with BPSK. (b) 4 × 132 MIMO with QPSK.

Fig. 3. BER performance of the proposed BSM and the GSM schemes.



(a) $E_s/N_0 = 8$ dB with BPSK (b) 8 × 128 MIMO with BPSK and 3 bpcu.

Fig. 4. BER and complexity comparison.

V. Simulation Results

We now compare the performance of the proposed BSM and the existing GSM scheme. For a fair comparison, we ensure that the average number of active antennas per transmit vector for both the BSM scheme (N_{total}/K) and the GSM scheme (N_{fix}) are equal. Also the data rate is same for both schemes. This is ensured by taking the number of BSM block-patterns as the Kth power of the number of GSM patterns.

We first compare the two schemes for i) a BPSK system with 4 bpcu; and ii) a QPSK system with 7 bpcu. We fix $K = 3$ and $N_{fix} = 2$ to ensure same number of average active antennas for both BSM and GSM, leading to the same number of transmit symbols per channel use. To achieve 4 bpcu in the first configuration, the total number of bits encoded over a block-pattern, i.e., ℓ in (2) should be 6. Substituting $l = 6$ and $K = 3$ in the expression of ℓ in Sec. III, the value of N_t should at least be 16. For the first configuration we consider a 4×20 (i.e., $N_r \times N_t$) MIMO system. For a fair comparison with the GSM scheme, for a data-rate of 4 bpcu, we randomly select the required number of active antenna patterns from the available ones in both the BSM and GSM schemes. Similarly for the second configuration with QPSK, the value of N_t comes out to be 128. Here, we consider a 4×132 MIMO system.

The optimal/ML BER for the BPSK and QPSK is shown in Fig. 3(a) and Fig. 3(b), respectively. We observe from Fig. 3(b) that at a BER of 10^{-3}, the BSM has a gain of at least 1.5 dB over GSM. Next, in Fig. 4(a) the BER of both BSM and GSM are plotted by varying N_t for a fixed $N_r = 4$, fixed $E_s/N_0 = 8$ dB and the BPSK. The data rates of both the schemes for different values of N_t are kept equal. We see that the proposed BSM outperforms GSM for $N_t \geq 18$. The lower BER is because, as discussed in Section III, the block-patterns are designed such that the error occurs only when the position of active antennas in multiple vectors are detected incorrectly, which is less likely to occur than in the GSM scheme.

For the systems in Fig. 3 and Fig. 4, $K = 3$ for BSM implies that 3 RF chains are required. For the GSM, $N_{fix} = 2$, which implies that 2 RF chains are required. Thus the BSM scheme uses 1 extra RF chain. However, we note that the BSM scheme,similar to GSM, requires on an average 2 active RF chains per transmission. Also, the ML complexity for the BSM and the GSM [11] scheme is $\mathcal{O}(\frac{N_r N_P}{K} \sum_{i=1}^{K} iM^i)$ and $(6\ MN_tN_r + 2N_{fix}N_rn_p + 6N_rn_p)$ FLOPs per transmit vector respectively, where N_P is the number of possible block-patterns in BSM and n_p is the number of possible transmit vectors in GSM. As the decoding complexity of BSM increases exponentially with the constellation size (M), we propose OBP-MMSE detector, whose complexity (as given in Sec. IV) does not increase with the constellation size.

We next compare in Fig. 4(b) the BER and the complexities of the BSM and the GSM schemes with the proposed OBP-MMSE detector and the OBMMSE detector [11], respectively. For this study, we consider an 8×128 MIMO system with BPSK modulation for a target transmission of 3 bpcu and $\alpha = 1$. We see that the proposed BSM scheme outperforms GSM by a margin of 1.8 dB at 10^{-2} BER. We also note that the BSM has a slightly higher complexity of 6500 FLOPs per bit when compared with 5300 FLOPs per bit of the GSM. The proposed BSM scheme, therefore, provides a graceful trade off between the performance and the complexity. A direction for future research is to further reduce the BSM receiver complexity.

VI. Conclusion

We proposed a novel BSM scheme which uses arbitrary number of active antennas in each transmit vector, but fixed over a block. We showed that the proposed scheme has lower BER than the existing GSM scheme.

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