Precoder Index Modulation

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Abstract—Index modulation, where information bits are conveyed through antenna indices (spatial modulation) and subcarrier indices (subcarrier index modulation) in addition to information bits conveyed through conventional modulation symbols, is getting increased research attention. In this paper, we introduce precoder index modulation, where information bits are conveyed through the choice of a precoder matrix at the transmitter from a set of pre-determined pseudo-random phase precoder (PRPP) matrices. Combining precoder index modulation (PIM) and spatial modulation (SM), we introduce a PIM-SM scheme which conveys information bits through both antenna index as well as precoder index. Spectral efficiency (in bits per channel use) and bit error performance of these index modulation schemes are presented.

Keywords – Index modulation, spatial modulation, pseudo-random phase precoding.

I. INTRODUCTION

In conventional modulation schemes, information bits are conveyed in a given channel use through the transmission of a modulation symbol chosen from a pre-determined modulation alphabet (e.g., QAM, PSK) [1]. Recently, modulation techniques that convey additional information bits through antenna indices and subcarrier indices have generated increased research interest. One such index modulation scheme that is popularly researched in recent times is spatial modulation (see [2],[3] and the references therein), which is a multi-antenna modulation scheme that uses antenna indexing. Another such scheme is subcarrier index modulation, which is a multi-carrier modulation scheme that uses subcarrier indexing [4],[5].

Spatial modulation (SM) uses multiple transmit antennas but only one transmit radio frequency (RF) chain. In a given channel use, only one among all the transmit antennas will be activated and the others will remain silent. The activated antenna will carry a conventional modulation symbol. The antenna to be activated is chosen based on information bits. Therefore, the index of the activated antenna conveys additional information bits. If \( n_t \) is the number of transmit antennas and \( A \) is the modulation alphabet, the number of bits conveyed per channel use in SM is given by \( \lceil \log_2 |A| \rceil + \lceil \log_2 n_t \rceil \). Similarly, subcarrier index modulation refers to a multi-carrier modulation scheme, where information bits are conveyed through the indices of active subcarriers [4],[5]. An advantage of index modulation over conventional modulation is that, to achieve a certain spectral efficiency, index modulation can use a smaller-sized QAM/PSK alphabet compared to that needed in conventional modulation. This, in turn, can lead to SNR gains (for a given probability of error performance) in favor of index modulation [6],[7].

Pseudo-random phase precoding (PRPP): The link reliability in single-input-single-output (SISO) fading channels is poor due to lack of diversity. One way to improve the link reliability is to get diversity gains through the use of multiple antennas. Diversity gains can be achieved even in single-antenna systems using rotation coding [8] or transmit power control [9]. Transmit power control requires channel state information at the transmitter (CSIT). Whereas, rotation coding does not require CSIT. The idea in rotation coding is to use multiple channel uses and precode the transmit symbol vector using a phase precoder matrix without requiring more slots than the number of symbols precoded. A \( 2 \times 2 \) phase precoder matrix with optimized phases is shown to achieve a diversity gain of two in SISO fading channels [8]. In [10], the rotation coding idea has been exploited for large precoder sizes. Instead of using optimized phases in the precoder matrix (solving for optimum phases for large precoder sizes is difficult), pseudo-random phases are used. Also, the issue of detection complexity at the receiver for large precoder sizes has been addressed by using the low complexity likelihood ascent search (LAS) algorithm in [11]. It has been shown that with pseudo-random phase precoding (PRPP) and LAS detection, near-exponential diversity is achieved in a SISO fading channel for large precoder sizes (e.g., \( 300 \times 300 \) precoder matrix).

PRPP-SM: In [12],[13], a PRPP-SM scheme which simultaneously exploits the diversity advantage of PRPP and the SNR advantage of SM is proposed. The PRPP-SM scheme precodes both the modulation bits and the antenna index bits using pseudo-random phases. The PRPP-SM scheme has been shown to outperforms both the PRPP scheme without SM and the SM scheme without PRPP.

In this paper, we introduce the idea of index modulation applied to the choice of precoder matrix at the transmitter, which we refer to as precoder index modulation. In the precoder index modulation (PIM) scheme, additional information bits are conveyed through the choice of a precoding matrix from a set of pre-determined PRPP matrices. We also combine the PIM and PRPP-SM schemes, and propose a PIM-SM scheme which conveys bits through both antenna index as well as precoder index. The rest of the paper is organized as follows. The PRPP, SM, and PRPP-SM schemes are introduced in Section II. The PIM and PIM-SM schemes are presented in Section III. Conclusions are presented in Section IV.

II. PRPP, SM, AND PRPP-SM SCHEMES

In this section, we briefly introduce PRPP, SM, and PRPP-SM schemes.
A. PRPP scheme

Figure 1 shows the PRPP transmitter. The PRPP transmitter takes \( p \) modulated symbols and forms the symbol vector \( s \in \mathbb{A}^p \), where \( \mathbb{A} \) is the modulation alphabet. The symbol vector \( s \) is then precoded using a \( p \times p \) precoding matrix \( P \) to get the transmit vector \( Ps \). The \((r, c)\)th entry of the precoder matrix \( P \) is \( \frac{1}{\sqrt{p}}e^{j\theta_{r,c}} \), where the phases \( \{\theta_{r,c}\} \) are generated using a pseudo-random sequence generator. The seed of this random number generator is pre-shared among the transmitter and receiver. The precoded sequence \( Ps \) is transmitted through the channel, which is assumed to be frequency-flat fading. The channel fade coefficients are assumed to be i.i.d from one channel use to the other. At the receiver, after \( p \) channel uses, the received symbolic are accumulated to form the \( p \times 1 \) received vector \( y \), given by

\[
y = DPs + n = GS + n, \tag{1}
\]

where \( D = \text{diag}\{h_{(1)}, h_{(2)}, \ldots, h_{(p)}\} \), \( G = DP \), \( h_{(i)} \)s are i.i.d. complex Gaussian fade coefficients with zero mean and unit variance, and \( n \) is the \( p \times 1 \) noise vector \( [n_{(1)} n_{(2)} \cdots n_{(p)}]^T \) whose entries are distributed as \( \mathbb{C}N(0, \sigma^2) \). The entries of the matrix \( G \) are uncorrelated and \( \|D\|_F = \|G\|_F \). This creates a \( p \times p \) virtual MIMO system. It has been shown in [10] that as the precoder size becomes large (e.g., \( p = 300 \)) the performance of PRPP in SISO fading, using the likelihood ascent search (LAS) detection algorithm in [11] with MMSE initial solution, approaches exponential diversity performance (i.e., close to SISO AWGN performance). This point is illustrated in Fig. 1 which shows the performance of PRPP with BPSK modulation for \( p = 50 \) and \( 400 \) in SISO fading channels.

B. SM scheme

The SM scheme uses \( n_t \) transmit antennas but only one transmit RF chain as shown in Fig. 3. The number of transmit RF chains, \( n_f = 1 \). In a given channel use, the transmitter selects one of its \( n_t \) transmit antennas, and transmits a modulation symbol from the alphabet \( \mathbb{A} \) on the selected antenna. The number of bits transmitted per channel use through the modulation symbol is \( \lfloor \log_2 \vert \mathbb{A} \vert \rfloor \), and the number of bits conveyed per channel use through the index of the transmitting antenna is \( \lfloor \log_2 n_t \rfloor \). Therefore, a total of \( \lfloor \log_2 \vert \mathbb{A} \vert \rfloor + \lfloor \log_2 n_t \rfloor \) bits per channel use (bpcu) is conveyed. For e.g., in an SM system with \( n_t = 2 \) and 8-QAM, the spectral efficiency is 4 bpcu.

\[\text{Fig. 1. PRPP transmitter.}\]

\[\text{Fig. 2. Performance of PRPP in SISO fading with } p = 50, 400, \text{BPSK, and LAS detection.}\]

\[\text{Fig. 3. SM transmitter with } n_t \text{ antennas and one transmit RF chain.}\]

The SM alphabet set for a fixed \( n_t \) and \( \mathbb{A} \) is given by

\[
S_{n_t,\mathbb{A}} = \{x_{j,l} : j = 1, \ldots, n_t, \ l = 1, \ldots, \vert \mathbb{A} \vert \}, \tag{2}
\]

s.t. \( x_{j,l} = \lfloor 0, \ldots, 0, s_l, 0, \ldots, 0 \rfloor^T, \ x_l \in \mathbb{A}. \]

For e.g., for \( n_t = 2 \) and 4-QAM, \( S_{n_t,\mathbb{A}} \) is given by

\[
S_{2,4\text{-QAM}} = \left\{ \begin{bmatrix} +1+j \\ 0 \end{bmatrix}, \begin{bmatrix} +1-j \\ 0 \end{bmatrix}, \begin{bmatrix} -1+j \\ 0 \end{bmatrix}, \begin{bmatrix} -1-j \\ 0 \end{bmatrix}, \begin{bmatrix} 0 \\ +1+j \end{bmatrix}, \begin{bmatrix} 0 \\ +1-j \end{bmatrix}, \begin{bmatrix} 0 \\ -1+j \end{bmatrix}, \begin{bmatrix} 0 \\ -1-j \end{bmatrix} \right\}. \tag{3}
\]

Let \( x \in S_{n_t,\mathbb{A}} \) denote the transmit vector. Let \( H \in \mathbb{C}^{n_r \times n_t} \) denote the channel gain matrix, where \( H_{i,j} \) denotes the channel gain from the \( j \)th transmit antenna to the \( i \)th receive antenna, assumed to be i.i.d complex Gaussian with zero mean and unit variance. The received signal at the \( i \)th receive antenna is

\[
y_i = H_{i,j}x_l + n_i, \quad i = 1, \ldots, n_r, \tag{4}
\]

where \( n_r \) is the number of receive antennas, \( x_l \) is the \( l \)th symbol in \( \mathbb{A} \) transmitted by the \( j \)th antenna, and \( n_i \) is the noise component. The signals received at all the receive antennas can be written in vector form as

\[
y = Hx + n, \tag{5}
\]

For this system model, the maximum likelihood (ML) detection rule is given by

\[
\hat{x} = \arg\min_{x\in S_{n_t,\mathbb{A}}} \|y - Hx\|^2. \tag{6}
\]
C. PRPP-SM scheme

The PRPP-SM scheme is an SM scheme whose modulation bits as well as antenna index bits are precoded by a PRPP matrix \([12, 13]\). The PRPP-SM transmitter consists of \(n_t\) transmit antennas and \(n_{rf} = 1\) transmit RF chains as shown in Fig. 4. It takes \(p\) modulated symbols and forms the symbol vector \(x_s \in \mathbb{C}^p\), where \(\mathbb{C}\) is the modulation alphabet. A matrix \(A\) of size \(p n_t \times p\) denotes the transmit antenna activation pattern, such that \(A x_s \in \mathbb{C}^{p n_t}\). The matrix \(A\) consists of \(p\) submatrices \(A(i), i = 1, \ldots, p\), each of size \(n_t \times p\), such that \(A = [A(1) A(2) \ldots A(p)]^T\), and \(A(i) x_s \in \mathbb{C}^{n_t}\). The submatrix \(A(i)\) is constructed as

\[ A(i) = [0(1) \cdots 0(i-1) a(i) 0(i+1) \cdots 0(p)] , \tag{7} \]

where \(0(k)\) is a \(n_t \times 1\) vector of zeroes, and \(a(i)\) is a \(n_t \times 1\) vector constructed as

\[ a(i) = [0 \cdots 0 1 0 \cdots 0]^T , \tag{8} \]

where \(j_i\) is the index of the active antenna during the \(i\)th channel use. For e.g., in a system with \(n_t = 2\) and \(p = 3\), to activate antennas 1, 2 and 1 in three consecutive channel uses, respectively, the matrix \(A\) is given by

\[ A = \begin{bmatrix} A(1) \\ A(2) \\ A(3) \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} . \tag{9} \]

Note that the indices of the non-zero rows in matrix \(A\) gives the support of the spatially modulated vector \(A x_s \in \mathbb{C}^{p n_t}\). For e.g., in (9), the support given by \(A\) is \(\{1, 4, 5\}\).

The \(A x_s\) vector is then precoded as \(P A x_s\), using a rectangular precoder matrix \(P\) of size \(p \times p n_t\). The \((r,c)\)th entry of the \(P\) matrix is \(\frac{1}{\sqrt{p}} e^{j \theta_{r,c}}\), where the phases \(\{\theta_{r,c}\}\) are generated using a pseudo-random sequence generator, whose seed is pre-shared among the transmitter and receiver. The output of the precoder is transmitted on the selected antenna in each channel use.

Let \(n_r\) denote the number of receive antennas. The \(p n_r \times 1\) received signal vector at the receiver is given by

\[ y = \text{DAPA} x_s + n , \tag{10} \]

where \(D = \text{diag}(H(1), H(2), \ldots, H(p))\), \(H(i)\) is the \(n_r \times n_t\) channel matrix of the \(i\)th channel use, the elements of \(H(i)\) are i.i.d. complex Gaussian with zero mean and unit variance, \(n\) is the \(p n_r \times 1\) noise vector, whose entries are distributed as \(\mathcal{CN}(0, \sigma^2)\). The ML detection rule for the PRPP-SM system is then given by

\[ \{\hat{x}_s, \hat{A}\} = \arg \min_{x_s \in \mathbb{C}^{p n_t}, A} \| y - \text{DAPA} x_s \|^2 . \tag{11} \]

The indices of the non-zero rows in \(\hat{A}\) and the entries of \(\hat{x}_s\) are demapped to obtain the information bits.

For the same spectral efficiency, PRPP-SM scheme performs significantly better than SM scheme without PRPP and PRPP scheme without SM. This can be seen from Fig. 5 which shows the bit error performance of PRPP-SM, PRPP, and SM schemes at the same spectral efficiency of 3 bpcu. For e.g.,
at $10^{-2}$ BER, the PRPP-SM scheme outperforms SM scheme without PRPP and PRPP scheme without SM by about 7 dB and 3 dB, respectively. This performance advantage in favor of the PRPP-SM scheme is due to the diversity gain offered by the pseudo-random phase precoding.

III. Precoder index modulation

In this section, we introduce precoder index modulation (PIM) which conveys information bits through the choice of a precoding matrix among a set of pre-determined precoder matrices.

A. Precoder index modulation (PIM)

In the proposed PIM scheme, the transmitter has equal number of transmit antennas and RF chains. Consider the case of $n_t = n_{rf} = 1$. The idea here is to have a collection of precoder matrices each of size $p \times p$ and choose one among these matrices to precode $p$ modulation symbols from an alphabet $\mathcal{A}$ in $p$ channel uses. Call this collection of matrices as ‘precoder set,’ denoted by $\mathbb{P}$. Therefore, the number of bits conveyed per channel use through precoder indexing is $\frac{1}{p} \log_2 |\mathbb{P}|$. The total number of bits per channel use (including precoder index bits and modulation symbol bits) is then given by

$$1 \quad p \left( \log_2 |\mathbb{P}| + p \log_2 |\mathcal{A}| \right).$$

Construction of the precoder set: The precoder set $\mathbb{P} = \{ \mathbf{P}_1, \mathbf{P}_2, \ldots, \mathbf{P}_|\mathbb{P}| \}$ is constructed as follows. Let $n$ denote the number of precoder index bits per channel use, i.e., $n = \frac{1}{p} \log_2 |\mathbb{P}|$. Generate a PRPP matrix $\mathbf{Q}$ of size $p \times n_p$, where $n_p = 2^n$. Note that the precoder set size $|\mathbb{P}| = (n_p)^p$. The matrix $\mathbf{Q}$ can be written as

$$\mathbf{Q} = [\mathbf{Q}_1 \, \mathbf{Q}_2 \, \cdots \, \mathbf{Q}_p],$$

where $\mathbf{Q}_i$’s are sub-matrices each of size $p \times n_p$. Now, the $p$ columns of a precoder matrix $\mathbf{P}_j$ are obtained by drawing one column from each $\mathbf{Q}_i$, $i = 1, 2, \ldots, p$. Each of such draws form one precoder matrix. Since there are $n_p$ columns in each $\mathbf{Q}_i$, the number of possible draws is $(n_p)^p$, which gives us all the matrices in the precoder set. For e.g., consider $p = 2$ and $n_p = 2$, and

$$\mathbf{Q} = \begin{bmatrix} q_{11} & q_{12} & q_{13} & q_{14} \\ q_{21} & q_{22} & q_{23} & q_{24} \end{bmatrix}.$$ 

The precoder set for this example is given by

$$\mathbb{P} = \left\{ \begin{bmatrix} q_{11} & q_{13} \\ q_{21} & q_{23} \end{bmatrix}, \begin{bmatrix} q_{11} & q_{14} \\ q_{21} & q_{24} \end{bmatrix}, \begin{bmatrix} q_{12} & q_{13} \\ q_{22} & q_{23} \end{bmatrix}, \begin{bmatrix} q_{12} & q_{14} \\ q_{22} & q_{24} \end{bmatrix} \right\}.$$

System model: The PIM transmitter is shown in Fig. 6(a). It takes $\log_2 |\mathbb{P}| + p \log_2 |\mathcal{A}|$ bits and encodes them as follows. The $p \log_2 |\mathcal{A}|$ bits are used to obtain $p$ modulation symbols. Let $\mathbf{x} \in \mathcal{A}^p$ denote the vector of these modulation symbols. The vector $\mathbf{x}$ is precoded by a precoder matrix $\mathbf{P}_j$ chosen from $\mathbb{P}$ whose index is given by the $\log_2 |\mathbb{P}|$ bits. The transmitter then sends one precoded symbol in every channel use. The detection is performed after $p$ channel uses. The $p \times 1$ received signal vector $\mathbf{y}$ in this system model can be written as

$$\mathbf{y} = \mathbf{DP}_j \mathbf{x} + \mathbf{n},$$

where $\mathbf{P}_j$ is the $p \times p$ PRPP matrix chosen from $\mathbb{P}$, and $\mathbf{D}$ is the channel matrix as described in Sec. III. The ML detection rule is given by

$$\hat{\mathbf{x}}_j = \arg\min_{\mathbf{x} \in \mathcal{A}^p, j = 1, \ldots, |\mathbb{P}|} \| \mathbf{y} - \mathbf{DP}_j \mathbf{x} \|^2.$$ 

PIM with activation pattern matrix: The PIM scheme can also be described as follows. Consider an activation pattern matrix $\mathbf{B}$ generated using $\log_2 |\mathbb{P}| = p \log_2 n_p$ bits, similar to the activation pattern matrix described in Sec. II-C. Note that $\mathbf{Bx} \in \mathbb{S}_{n_p, \mathcal{A}}$. The $p n_p \times 1$ vector $\mathbf{Bx}$ is precoded with the matrix $\mathbf{Q}$ to get the $p \times 1$ transmit vector. The received signal vector in $p$ channel uses can be expressed as

$$\mathbf{y} = \mathbf{DQBx} + \mathbf{n}.$$ 

The matrix $\mathbf{QB}$ is a $p \times p$ PRPP matrix. The matrix $\mathbf{B}$ chooses one column from the $n_p$ columns of every $\mathbf{Q}_i$ to get a PRPP matrix $\mathbf{P}_j$. Thus, the choice of $p$ from $p n_p$ columns conveys $p \log_2 n_p$ information bits, where $n_p$ can be viewed as the precoder equivalent of the spatial antennas in SM, which are indexed by the information bits. The ML detection rule for this alternate system model is given by

$$\hat{\mathbf{x}}, \mathbf{B} = \arg\min_{\mathbf{x} \in \mathcal{A}^p, \mathbf{B}} \| \mathbf{y} - \mathbf{DQBx} \|^2.$$ 

The indices of the non-zero rows in $\mathbf{B}$ and the entries of $\hat{\mathbf{x}}$ are demapped to obtain the information bits. The precoder matrices convey information bits in addition to providing diversity, and we can achieve the advantages of SM-MIMO in a SISO fading channel through PIM. Also, by taking the view of (13), detection algorithms meant for SM can be effectively used for PIM detection.

Simulation results: In Fig. 7, we present the BER performance of the PIM scheme with $n_t = 1, n_{rf} = 1, n_p = 4, n_r = 1, p = 5$ and 4-QAM, using ML detection. We compare this performance with the ML detection performance of PRPP scheme without SM for $n_t = 1, n_{rf} = 1, n_r = 1, p = 5$ and 16-QAM, and SM scheme without PRPP for $n_t = 4, n_{rf} = 1, n_r = 1$ and 4-QAM. Note that the spectral efficiency in all the three schemes is 4 bpcu. We see that PIM outperforms PRPP without SM and SM without PRPP. For e.g., at $10^{-3}$ BER, PIM preforms better than PRPP without SM by about 2.5 dB and better than SM without PRPP by about 12.5 dB. The PIM scheme achieves better performance than PRPP without SM because PIM can use a smaller sized (and hence more power efficient) modulation alphabet compared to PRPP without SM. Also, the reason behind the better performance of PIM compared to SM without PRPP is that PIM provides diversity gain due to precoding. Thus, PIM provides the benefits of both diversity advantage of PRPP and SNR advantage of SM. Note that the PRPP-SM scheme in Sec. II-C also provides both these advantages,
but the possibility of using smaller-sized modulation alphabet in PRPP-SM arises due to antenna indexing, whereas in PIM it arises due to precoder indexing. Therefore, PIM avoids the need to use multiple transmit antennas compared to PRPP-SM. This observation leads us to consider exploiting the antenna indexing in SM for further reduction in modulation alphabet size in PIM. We refer to such a PIM scheme that exploits both precoder indexing as well as antenna indexing as PIM-SM scheme. The proposed PIM-SM scheme is presented in the following subsection.

**B. Precoder index modulation with SM (PIM-SM)**

The proposed PIM-SM scheme uses $n_t$ transmit antennas and one transmit RF chain, so that $\lceil \log_2 n_t \rceil$ bits are conveyed as antenna index bits. These bits are in addition to the $\lceil \log_2 n_p \rceil + \lceil \log_2 |A| \rceil$ bits conveyed in PIM. Therefore, the spectral efficiency of the PIM-SM scheme is

$$\lceil \log_2 n_p \rceil + \lceil \log_2 n_t \rceil + \lceil \log_2 |A| \rceil \text{ bpcu.}$$

For immediate reference and comparison, the spectral efficiencies achieved by the different schemes and the bits that are precoded in these schemes are tabulated in Table II

**System model:** The PIM-SM transmitter is illustrated in Fig. 6(b). The system model for the PIM-SM scheme can be written as

$$y = \text{DAPAP}_j \hat{x} + n,$$

where $A$ is the activation pattern matrix of the PRPP-SM scheme defined in Sec. II-C. The ML detection rule for PIM-SM can then be written as

$$\{\hat{x}, \hat{A}, \hat{j}\} = \arg\min_{\hat{x} \in A^p, A_j=1, \ldots, |P|} \|y - \text{DAPAP}_j \hat{x}\|^2. \quad (17)$$

The indices of the non-zero rows in $\hat{A}$, index $\hat{j}$, and the entries of $\hat{x}$ are demapped to obtain the information bits.

**Simulation results:** In Fig. 8 we present the BER performance of PIM-SM scheme with $n_t = 4, n_r = 1, n_r = 1, n_p = 2$, BPSK and $p = 5$, using ML detection. We also plot the ML detection performance of the PIM scheme (without SM) for $n_t = 1, n_r = 1, n_r = 1, n_p = 4$, 4-QAM, and $p = 5$. We have also plotted the ML detection performance of PRPP-SM scheme with $n_t = 4, n_r = 1, n_r = 1, 4$-QAM, and $p = 5$. Note that the spectral efficiency is 4 bpcu in all the three schemes. It can be seen that the PIM-SM scheme performs better than PIM scheme. This is because of the smaller-sized modulation alphabet in PIM-SM (BPSK) compared that in PIM (4-QAM). Also, PIM-SM performance is similar to that of PRPP-SM.
TABLE I
Modes of information bits conveyed and precoding done in different schemes.

| Scheme   | Number of bits conveyed through | Precoding done on          |
|----------|---------------------------------|----------------------------|
|          | Modulation symbols | Precoder index | Antenna index | Modulation symbols | Antenna index bits |
| PRPP     | \( \log_2 A \)                  | -              | yes           |
| SM       | \( \log_2 A \)                  | -              | \( \log_2 n_t \) | no               |
| PRPP-SM  | \( \log_2 A \)                  | -              | \( \log_2 n_t \) | yes              |
| PIM      | \( \log_2 A \) \( \log_2 n_p \) | yes           | -             | yes              |
| PIM-SM   | \( \log_2 A \) \( \log_2 n_p \) | \( \log_2 n_t \) | yes           |

IV. CONCLUSIONS

We introduced precoder index modulation (PIM) in this paper. We proposed a PIM scheme which conveys additional information bits through the choice of a precoding matrix from a set of pre-determined PRPP matrices. Combining the PIM and PRPP-SM schemes, we proposed a PIM-SM scheme which conveys bits through both antenna index as well as precoder index. We showed the performance of PIM and PIM-SM schemes for small precoder sizes using ML detection. Design of low complexity detection algorithms for PIM and PIM-SM for large precoder sizes is open for future extension.

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