The Design of Receiver with Low Complexity for PDMA System

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Abstract. As one of promising non-orthogonal multiple access scheme, pattern division multiple access (PDMA) scheme is considered to be one competitive multiple access technology for the fifth generation (5G) communications. The detection algorithm is the key technology to improve the system performance. Due to the PDMA patterns sparse nature, belief propagation (BP) become one effective receiver algorithm to achieve close to maximum likelihood (ML) detection performance with lower complexity. However, the complexity order is still exponential with the row weight of the PDMA pattern and the modulation index. A novel receiver based on expectation propagation (EP) algorithm is proposed in this paper to reduce the complexity order from exponential to linear. This paper makes a comparison on the two algorithms above in terms of system performance and complexity. Link-level simulation results show that the proposed EP receiver achieves nearly the same performance as the BP receiver with orders less complexity.

Keywords: Pattern division multiple access; 5G; Receiver algorithm.

1. Introduction
The fifth generation (5G) wireless networks have higher performance indicators such as supporting massive connectivity, low latency and better coverage [1]. As one kind of non-orthogonal multiple access (NOMA) technique, pattern division multiple access (PDMA) [2, 3] has excellent performance and is considered as a promising candidate for 5G multiple access technology. Based on former research about successive interference cancellation amenable multiple access (SAMA) [4, 5], PDMA was proposed to face the higher performance index of 5G. The performance analysis on PDMA is performed in [6], where the analysis and simulation results show that PDMA outperforms the conventional OMA in terms of outage probability performance and sum data rate. In [7], the relevant researches on PDMA pattern design are carried out, where the authors proposed the pattern design methods and rules for 5G for application scenarios such as the massive Machine Type Communication (mMTC) and enhanced Mobile Broad Band (eMBB). Cooperative PDMA (Co-PDMA) proposed in [8] also showed the superiority of PDMA over OMA in the system throughput when considering cooperative networks.
Despite PDMA shows the excellent performance, there is one of the major obstacles at the receiver to choose a proper detection algorithm for pattern recognition. Minimum mean squared error successive interference cancellation (MMSE-SIC) [9] is first proposed to detect the multiple user’s data in PDMA with its simple structure. However, when the number of users that need to be detected is very large, MMSE-SIC is impractical for its long time latency and the error propagation. Belief propagation (BP) [10] can detect a group of users at the same time, the time latency of signal processing can be shortened greatly. However, BP algorithm brings higher computational expense. The authors in [11] proposed an iterative multiuser detection based on expectation propagation (EP) for MIMO-IDMA Systems, which can significantly reduce the computation complexity, however, in the process of iteration, the refinement may sometimes fail due to a negative value for factor variance. And some details such as approximate computation with probability distribution function (PDF) and normalization in the process of iteration are not revealed clearly. Inspired and motivated by this, we make further information disclosure of EP as the detection algorithm in PDMA. In the analysis, The detailed algorithm derivation is given and some methods of unusual cases are given out. The following papers are arranged as follows, the system model of PDMA receiver is first elaborated in section II, and then introduce the EP algorithm and the analysis of the complexity in section III. In section IV, we compare the performance of the two algorithms. Finally, section V makes the summary to the full text.

2. System Model
In this section, an uplink PDMA system is considered, where there are $K$ independent single-antenna users and one base station (BS) with multiple receive antennas, as shown in Fig.1.

![Figure 1. Block diagram of uplink PDMA system transceiver](image)

At the transmitter side, the users input bits set $b_k$ are encoded by channel encoder, then the PDMA encoding modulation modulates the channel encoding bits $c_k$ into the modulation symbols $x_k$ and map them onto the PDMA resource element (RE). At the receiver side, PDMA multi-user detector is used to detect multiplexing users on the same PDMA resource.

The PDMA encoding process can be simply stated as follows. $K$ users data are mapped onto $N$ REs in the domain of time, frequency, or space. Each user has a distinguished PDMA pattern, $g_k$ is an $N \times 1$ binary vector with binary elements “0” or “1”, where the element “1” means that the user’s data are mapped onto the corresponding RE, otherwise not. A PDMA pattern matrix $G_{PDMA}^{[N,K]}$ with dimension of $N \times K$ is denoted by
The received signal \( y = [y_1, y_2, \ldots, y_N]^T \) is given by:

\[
y = \sum_{k=1}^{K} \text{diag}(h_k) g_k x_k + n
\]

where \( h_k \) is the uplink channel response vector of the \( k \)-th user; \( \text{diag}(h_k) \) represents a diagonal matrix with elements from \( h_k \); \( n \) denotes noise vector at the receiver and \( E[nn^H] = \sigma^2 I \) (\( \sigma^2 \) is the noise power and \( I \) is the identity matrix); both \( n \) and \( h_k \) are vectors of length \( N \). In case of simplification, (2) can be further denoted as

\[
y = H_{\text{PDMA}} x + n
\]

where \( x = [x_1, x_2, \ldots, x_K]^T \) is the vector consisted of \( K \) users’ signals and \( H_{\text{PDMA}} \) denotes the PDMA equivalent channel with dimension of \( N \times K \) which can be further expressed as

\[
H_{\text{PDMA}} = H_{\text{CH}} e^{G_{\text{PDMA}}^{K,K}}
\]

(4)

\[
H_{\text{CH}} = [h_1, h_2, L, h_K],
\]

(5)

where "e" indicates element-wise dot product of two matrices.

Define \( C_{k,m}^+ \) and \( C_{k,m}^- \) as the set of coded bits with \( c_{k,m} = 1 \) and \( c_{k,m} = 0 \) respectively:

\[
C_{k,m}^+ \triangleq \{c_{k,1}, \ldots, c_{k,m-1}, 1, c_{k,m+1}, \ldots, c_{k,D}: c_{k,j} \in \{0,1\}, j \neq m\}
\]

\[
C_{k,m}^- \triangleq \{c_{k,1}, \ldots, c_{k,m-1}, 0, c_{k,m+1}, \ldots, c_{k,D}: c_{k,j} \in \{0,1\}, j \neq m\}
\]

(6)

where \( D = \log_2(M) \) is the modulation order with \( M \) constellations. For the \( m^{th} \) bit in a modulation symbol of user \( k \), its posterior LLR is given by

\[
L_{\text{pos}}(c_{k,m}) = \ln \left( \frac{p(c_{k,m} = 1 | y)}{p(c_{k,m} = 0 | y)} \right) = \ln \left( \frac{P(c_{k,m} = 1 | \hat{x})}{P(c_{k,m} = 0 | \hat{x})} \right) = \ln \left( \frac{P(\hat{x} | c_{k,m} = 1)}{P(\hat{x} | c_{k,m} = 0)} \right) + \ln \left( \frac{P(c_{k,m} = 1)}{P(c_{k,m} = 0)} \right)
\]

(7)

where \( \hat{x} \) denotes the estimated value of the transmission symbol \( x \), \( L_{\text{est}}(c_{k,m}) = \ln \left( \frac{p(c_{k,m} = 1 | y)}{p(c_{k,m} = 0 | y)} \right) \) and \( L_{\text{pos}}(c_{k,m}) = \ln \left( \frac{p(c_{k,m} = 1)}{p(c_{k,m} = 0)} \right) \) denote extrinsic information and priori information, respectively. Define \( S_k^+ \) and \( S_k^- \) as the set of modulation symbols mapped from the coded bits in \( C_{k,m}^+ \) and \( C_{k,m}^- \) then we have

\[
L_{\text{pos}}(c_{k,m}) = \ln \left( \frac{p(c_{k,m} = 1 | y)}{p(c_{k,m} = 0 | y)} \right) = \ln \left( \sum_{s \in S_k^+} p(x_k = s | y) \right) = \ln \left( \sum_{s \in S_k^-} p(x_k = s | y) \right)
\]

(8)
It should be noted that in equation (8), we used the max-log algorithm \( \log (\exp(a) + \exp(b)) \approx \max(a, b) \) and we define the posterior LLR of \( x_k \) as follows:

\[
L_{pos}(x_k = s) = \ln \frac{p(x_k = s \mid y)}{p(x_k = s_0 \mid y)}
\]

where \( s_0 \) denotes specific constellation point with all-zero bit sequence.

3. Receiver Algorithm

3.1. BP Algorithm

BP is effective parallel detection algorithm compared with MMSE-SIC. When the received signal \( y \) and PDMA equivalent channel response matrix \( H_{PDM} \) are given, the optimum detection for the transmitting modulation symbols \( x \) is

\[
\hat{x} = \arg \max_x p(x \mid y, H_{PDM})
\]

the joint optimum solution in (10) for \( x \) can be get by the approximation of partial solution. By using Bayesian theory to further deduce equation (10), we can get

\[
\hat{x}_k = \arg \max \sum_{x \in \mathcal{X}_k} \mathcal{X} \prod_{n \in N_k} p(y \mid x) \]

where, \( \mathcal{X}_k \) is the set consisted by all the constellations of user \( k \); \( N_k(j) = \{ j \mid G_{\text{PDM}}^j, k \neq 0, j \leq N \} \) is the time & frequency resource index set corresponding to the PDMA mapping pattern of user \( k \). The problem in (11) can be resolved by BP detection algorithm. A multiple-user detection receiver based on the BP algorithm can be represented by a factor graph in Fig. 2. Where, VN, UN and CN denote the variable node, user node and channel node, respectively. In Fig. 2, there four types of information propagation, i.e., from the VN to UN, UN to VN, UN to CN and from CN to UN, which are denoted by \( I_{VU}^{2C} = L_{\text{in}}(c_{k,m}) \), \( I_{U2V} = L_{\text{pos}}(c_{k,m}) \), \( I_{U2C} \) and \( I_{C2U} \), respectively.

**Figure 2. Factor graph**

The propagation information is iterated between \( CN \) and \( UN \). In the process of the outer \( W^\text{th} \) iteration and inner \( t^\text{th} \) iteration, the information from \( UN \) to \( CN \) is given by
\[ I_{U2C} @ I^{'w}_{V2U} (x_k) = I^{'w}_{V2U} \prod_{j \in \mathcal{N}(k) \setminus \{j\}} I^{ -1,w}_{c_k \leftarrow x_j} (x_k) = I^{'w}_{c_k \leftarrow x_k} \prod_{j \in \mathcal{N}(k) \setminus \{j\}} I^{ -1,w}_{c_j \leftarrow x_j} (x_k) \]  

(12)

where,

\[ I^{'w}_{V2U} = \prod_{c_l \leftarrow x_k}^{q=1} p(c_{l,q}) = \prod_{q=1}^{Q} \frac{e^{c_{l,q} L_{\text{pr}}(c_{l,q})}}{1 + e^{c_{l,q} L_{\text{pr}}(c_{l,q})}} \]  

(13)

is the information from channel decoder to user node. When log function and iteration are considered, (7) can further impressed by

\[ L_{\text{pos}}^w (x_k = s) = \sum_{f \in \mathcal{N}(k) \setminus \{j\}} L_{\text{pos}}^{ -1,w} (x_k = s) + L_{\text{pos}}^{ -1,w} (x_k = s) = \sum_{f \in \mathcal{N}(k) \setminus \{j\}} L_{\text{pos}}^{ -1,w} (x_k = s) + \sum_{m=1}^{Q} L_{\text{pr}}^m (c_{k,m}) \]  

(14)

where, \( N_c(k) \setminus j \) denotes the set comprising of all elements of \( N_c(k) \) excluding \( j \).

Similarly, the propagation information from \( CN \) to \( UN \) in the process of the outer \( w \)th iteration and inner \( t \)th iteration is given by

\[ I^{'t,w}_{x_k \leftarrow y_j} (x_k) = L_{\text{pos}}^t (x_k = s) \approx \max_{k \in N_c(j) \setminus k \setminus x_k = s} \left\{ -\frac{1}{2 \sigma^2} \left| y_j - H_{\text{PDMA},j} x_k \right|^2 + \sum_{k' \in N_c(j) \setminus k \setminus x_k = s} L_{\text{pos}}^t (x_{k'}) \right\} \]

(15)

where \( N_c(j) = \{k | G_{\text{PDMA}}(k, j) \neq 0, 1 \leq k \leq K\} \) is the time & frequency resource index set corresponding to the PDMA mapping pattern of RE \( j \). \( N_c(j) \setminus k \) is the set comprising of all elements of \( N_c(j) \) excluding \( k \).

Summarizing the above process, the BP detection algorithm for PDMA is shown in the following Algorithm 1.

**Algorithm 1: PDMA BP detection**

- **Initialization**
  \[ L_{\text{pos}}^{0,0} (x_k = s) = 0, \quad L_{\text{pos}}^{w,0} (x_k = s) = 0, \quad L_{\text{pr}} (c_{k,m}) = 0 \]

- **Iteration Process**
  - **For** \( w = 1: W_{\text{max}} \) **do**
    - **For** \( t = 1: T_{\text{max}} \) **do**
      1) Compute \( I^{'t,w}_{x_k \leftarrow y_j} (x_k) \) via (12)
      2) Compute \( I^{t,w}_{x_k \leftarrow y_j} (x_k) \) via (15)
  - **End for**
  - **End for**

- **LLR Calculation**
  Compute \( L_{\text{pos}} (c_{k,m}) \) via (7)
Although using the sparsity of PDMA codewords can reduce the complexity, BP algorithm still has exponential complexity which is too high to accept in practice, especially for the scenarios with large codebook size and high overload.

3.2. EP Algorithm
The essential difference between EP and BP is that EP imposes an exponential family constraint on the messages. The main core idea of EP is to approximate a complex distribution \( p \) with another simple distribution \( q \) [9], which is constrained to lie in a family of “simple” distribution set \( \Phi \). Mathematically, the projection is expressed as

\[
q = \text{proj}_\Phi(p) \triangleq \arg \min_{q \in \Phi} D(q \parallel p)
\]

where

\[
D(q \parallel p) = \int q(x) \log \frac{q(x)}{p(x)} \, dx
\]

is the Kullback-Leibler (KL) divergence. If \( p \in \Phi \), the projection is simplified to identity mapping. However, in general, \( p \notin \Phi \) and hence the operation is a nonlinear projection. We make

\[
p^{t,\omega}(x_k) = \frac{I^{t,\omega}(x_k)}{x_k \rightarrow y_j} f_j \prod_{j' \in N_j(k)} I^{t-1,\omega}(x_{k'})
\]

and

\[
q^{t,\omega}(x_k) = \frac{I^{t,\omega}(x_k)}{x_k \leftarrow y_j} = \sum_{k \in N_j(j) \setminus k} f(x) \prod_{j' \in N_j(k)} I^{t-1,\omega}(x_{k'})
\]

Let \( \Phi \) be the set of complex Gaussian distribution, which is given by

\[
\Phi = \{ \rho : \rho(x_i) = N(\mu_i, \sigma_i) \}
\]

where \( \mu_i = \sum_{x \in \Omega} p(x = s) \bullet s \) is the mean, \( \sigma_i = \sum_{x \in \Omega} p(x = s) \bullet s^2 - \mu_i^2 \) is the variance, and \( \lambda \triangleq CN(\mu; \mu, \sigma) \) indicates that the random variable \( \lambda \) follows the complex Gaussian distribution with \( \mu \) and \( \sigma \).

With EP algorithm, the projection is written as:

\[
I^{t,\omega}(x_k) = \frac{\text{proj}_\Phi \left[ I^{t,\omega}(x_k) p^{t,\omega}(x_k) \right]}{I^{t,\omega}(x_k)}
\]

and

\[
I^{t,\omega}(x_k) = \frac{\text{proj}_\Phi \left[ I^{t-1,\omega}(x_k) q^{t,\omega}(x_k) \right]}{I^{t-1,\omega}(x_k)}
\]

Both \( I^{t,\omega}(x_k) \) and \( I^{t,\omega}(x_k) \) can be approximated with Gaussian distribution, which are denoted as \( CN(x_i; \mu_{x_i \rightarrow y_j}, \sigma_{x_i \rightarrow y_j}) \) and \( CN(x_i; \mu_{x_i \leftarrow y_j}, \sigma_{x_i \leftarrow y_j}) \), respectively. Then (21) is further denoted as
\begin{equation}
I_{x_k \to y_j}^{t,w}(x_k) = \frac{N_k(x_k; \mu_k, \sigma_k)}{CN(x_k; \mu_k^{t-1,w}, \sigma_k^{t-1,w})} \propto CN(x_k; \mu_k^{t,w}, \sigma_k^{t,w})
\end{equation}

\begin{equation}
= \frac{1}{\sqrt{2\pi}\sigma_{x_k \to y_j}^{t,w}} \exp\left(-\frac{(x_k - \mu_{x_k \to y_j}^{t,w})^2}{\sigma_{x_k \to y_j}^{t,w}}\right)
\end{equation}

where

\begin{equation}
\sigma_{x_k \to y_j}^{t,w} = \left(\frac{1}{\sigma_i} - \frac{1}{\sigma_{x_k \to y_j}^{t-1,w}}\right)^{-1}
\end{equation}

and

\begin{equation}
\mu_{x_k \to y_j}^{t,w} = \sigma_{x_k \to y_j}^{t,w} \left(\frac{\mu_i}{\sigma_i} - \frac{\mu_{x_k \to y_j}^{t-1,w}}{\sigma_{x_k \to y_j}^{t-1,w}}\right)
\end{equation}

The equation (22) is further denoted as

\begin{equation}
I_{x_k \to y_j}^{t,w}(x_k) = \frac{1}{\sqrt{2\pi}\sigma_{x_k \to y_j}^{t,w}} \exp\left(-\frac{(x_k - \mu_{x_k \to y_j}^{t,w})^2}{\sigma_{x_k \to y_j}^{t,w}}\right)
\end{equation}

where

\begin{equation}
\mu_{x_k \to y_j}^{t,w} = \frac{1}{h_{j,k}} \left(y_j - \sum_{j \in N_k} h_{j,k} \mu_{x_j \to y_j}^{t,w}\right)
\end{equation}

and

\begin{equation}
\sigma_{x_k \to y_j}^{t,w} = \frac{1}{h_{j,k}^2} \left(\sigma_i^2 + \sum_{j \in N_k} h_{j,k}^2 \sigma_{x_j \to y_j}^{t,w}\right)
\end{equation}

In the \(w\)th outer iteration and \(t\)th inner iteration, the updated symbol posterior belief value is given by

\begin{equation}
p(x_k | y) = I_{x_k \to y_j}^{t,w}(x_k) \prod_{j \in N_k} I_{x_j \to y_j}^{t-1,w}(x_j) = I_{x_k \to y_j}^{t,w}(x_k) \prod_{j \in N_k} N(x_k; \mu_{x_j \to y_j}^{t,w}, \sigma_{x_j \to y_j}^{t,w})
\end{equation}

\begin{equation}
= I_{x_k \to y_j}^{t,w}(x_k) N(x_k; \mu_{x_k \to y_j}^{t,w}, \sigma_{x_k \to y_j}^{t,w})
\end{equation}

\begin{equation}
= \frac{1}{\sqrt{2\pi}\sigma_{x_k \to y_j}^{t,w}} \exp\left(-\frac{(x_k - \mu_{x_k \to y_j}^{t,w})^2}{\sigma_{x_k \to y_j}^{t,w}}\right)
\end{equation}

where

\[7\]
\[ t_{x_k \leftarrow y_j}^{t,w} = \left( \sum_j \frac{1}{\sigma_{x_k \leftarrow y_j}^{t,w}} \right)^{-1} \]  

(30)

and

\[ z_{x_k \leftarrow y_j}^{t,w} = t_{x_k \leftarrow y_j}^{t,w} \cdot \left( \sum_j \frac{\mu_{x_k \leftarrow y_j}^{t,w}}{\sigma_{x_k \leftarrow y_j}^{t,w}} \right) \]  

(31)

Summarizing the above process, the EP based multiuser detection algorithm for PDMA systems can be synthesized as Algorithm 2, where \( MAX \) is a large positive constant value (e.g., \( 10^6 \)) and the other symbols’ meanings are the same as Algorithm 2.

Algorithm 2: EP PDMA detection

- **Initialization**
  \[ \mu_{x_k \leftarrow y_j}^{0,0} = 0, \sigma_{x_k \leftarrow y_j}^{0,0} = MAX, k = 1, \cdots K, j = 1, \cdots N. \]

- **Iteration Process**
  For \( w=1: W_{\text{max}} \) do
    For \( t=1: T_{\text{max}} \) do
      1) Compute \( p(x_k \mid y) \) via (29)
      2) Compute \( I_{x_k \leftarrow y_j}^{t,w} \) via (23)
      3) Compute \( I_{x_k \leftarrow y_j}^{t,w} \) via (26)
    End for
  End for

- **LLR Calculation**
  Compute \( L_{\text{pos}}(c_{k,m}) \) via (7)

It should be noted that when the variance \( \sigma_{x_k \leftarrow y_j}^{t,w} \) is a negative, the EPA refinement fails. This happens in the subtraction step (24), we subtract a positive value from variance renewed and are left with something negative. As we all known, the variance must be a positive, so the algorithm fails. In this case we need set a bigger value (e.g., \( 10^6 \)) to the variance to make sure the EP algorithm continues to work.

4. Two Algorithms' Complexity Analysis

In this Section, the complexity analysis for the receiver algorithms above is conducted. For EP algorithm, The detector computes the statistical information of the information symbols approximated by the Gaussian distribution rather than the decoding information returned by the decoder. thus, the matrix inversion operation is avoided, (matrix inversion operation make the complexity exponential growth with the number of users, the number of receive antennas and transmit antennas.)

The comparison of computation complexity per modulation symbol on BP and EP are summarized in Table 1, where \( N \) is the number of RE, \( Q_m = \log_2(M) \) is the modulation index, \( T_{in} \) is the inner iteration number, \( T_{out} \) is the outer iteration number and \( d_f \) is the maximum row weight of PDMA pattern matrix.

It should also be noted that the computation of Turbo decoder is not accounted in the following comparison.

| Algorithm | Number of multiplications | Number of additions |
|-----------|---------------------------|---------------------|
| BP        | \( O(d_f NM^{d_f}) \)     | \( O(T_{out} T_{in} d_f NQ_m M^{d_f}) \) |
| EP        | \( O(d_f NM) \)          | \( O(T_{out} T_{in} d_f NQ_m M) \) |
Form the table above, we can see that the complexity of all the equations for EP is linear to the modulation size and the number of UEs, thus the complexity is much reduced compared with BP.

5. Simulation Results
The uplink PDMA link-level simulation with EP algorithm is performed in this Section. The simulation parameters assumption is shown in Table 2.

| **Table 2. Simulation parameters** |
|-----------------------------------|
| **Parameters**                  | **Values or assumptions** |
| Carrier Frequency               | 2 GHz                     |
| Waveform                        | OFDM                      |
| Channel coding                  | LTE Turbo                 |
| System Bandwidth                | 10 MHz                    |
| Total allocated bandwidth for transmission | 4RB (0.72MHz) |
| BS antenna configuration        | 2Rx                       |
| UE antenna configuration        | 1Tx                       |
| Receiver type                   | BP/EP                     |
| Propagation channel             | TDL-C (300ns) in TR38.900 [12] |
| UE velocity                     | 3km/h                     |
| PDMA pattern                    | \( G_{PDMA}^{[4,6]} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix} \) |
| Channel estimation              | Ideal                     |

5.1. Convergence Evaluation
In the convergence evaluation simulations, we adopt the antenna configuration with 1 transmitting (1Tx) antenna at the user and 2 receiving (2Rx) antenna at the BS. Firstly, the convergence evaluation of the BP algorithm receiver is evaluated in Fig. 3. From the BLER curves in Fig. 3, we can see that the BLER curve with 4 inner iterations superpose with that with 5 inner iterations, which indicates without no outer iteration and when the inner iteration is up to 4, the BP algorithm converges.

![Figure 3. Convergence performance of BP algorithm without outer iteration](image)

When adding the outer iteration information from channel decoder, the detection performance can further be improved. The relevant results are exhibited in Fig. 4, where we fix the inner iteration as 4 and increase the times of outer iteration. The results show that the BP algorithm converges when the outer iteration is up to 3.
Secondly, the convergence of the EP algorithm is investigated. Fig. 5 shows the convergence performance of EP algorithm when inner iteration is 2, 3, 4 and 5 times without outer iteration, where the BLER curves with 4 iterations nearly superpose with that with 5 iterations. So we can get the conclusion under the conditions given in Table I, EP algorithm converges when the outer iteration is up to 4.

Keeping the number of inner iterations to be 4 and increasing the number of outer iterations, we get the corresponding convergence performance as Fig. 6 shown. It is revealed that when the times of outer iteration is 3, the performance of EP algorithm tends to convergence.

In this subsection, we make a comparison among two algorithms with the number of inner and outer iterations to be 4 and 3. We evaluate the BLER performance between EP algorithm and BP algorithm with different spectrum efficiencies (SEs). Fig. 7 shows the BLER versus SNR under different SEs with parameter value set of 6 active users and 4 receive antennas. It is can be seen from Fig. 7 that the
proposed EP receiver has a similar performance with BP receiver for $SE=0.0625$–$0.375$, while there is a slight performance loss for $SE=0.4$ (about 0.3 dB loss at BLER= 0.01).

Figure 7. Performance comparison between BP algorithm and EP algorithm with different SE

6. Conclusion
In this paper, two detection algorithms for PDMA are introduced. From the analysis and simulation results, we can see that BP receiver is an effective style to make multiple user’s data detection, however, it has higher complexity, while EP receiver has a good performance with acceptable complexity. Uplink link-level simulation results in this paper demonstrate that the proposed EP receiver with computation complexity significant reduction has nearly the same performance as the BP receiver, which implies its potential use in future 5G practical system implementations.

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References
[1] Linglong Dai, Bichai Wang, Yifei Yuan, et al., “Non-Orthogonal Multiple Access for 5G: Solutions, Challenges, Opportunities, and Future Research Trends,” IEEE Commun. Magazine, vol. 53, no. 9, Sep. 2015, pp. 74-81.
[2] Y. Wang, B. Ren, S. Sun, et al., “Analysis of Non-orthogonal Multiple Access for 5G,” China Commun., (Suppl.), vol. 13, no.2, pp. 52-66, Jan., 2017.
[3] S. Chen, B. Ren, Q. Gao, et al., “Pattern Division Multiple Access-A Novel Nonorthogonal Multiple Access for Fifth-Generation Radio Networks,” IEEE Transactions on Vehicular Technology, vol. 66, no. 4, Apr. 2017, pp. 3185-3196.
[4] X. Dai, S. ShaoHui, W. Yingming and R. Zou, “Successive interference cancellation amiable space-time codes with good multiplexing-diversity tradeoff,” Proc. 2009 15th Asia-Pacific Conference on Communications, Shanghai, 2009, pp. 237-240.
[5] X. Dai, R. Zou, J. An, X. Li, S. Sun and Y. Wang, “Reducing the Complexity of Quasi-Maximum-Likelihood Detectors Through Companding for Coded MIMO Systems,” in IEEE Transactions on Vehicular Technology, vol. 61, no. 3, 2012, pp. 1109-1123.
[6] W. Tang, S. Kang, B. Ren, X. Yue and X. Zhang, “Uplink Pattern Division Multiple Access (PDMA) in 5G Systems,” in IET Communications, 2018, vol.12, no. 9, pp. 1029-1034.
[7] B. Ren, Y. Wang, X. Dai, K. Niu and W. Tang, “Pattern matrix design of PDMA for 5G UL applications,” in China Communications, vol. 13, no. Supplement2, 2016, pp. 159-173.
[8] W. Tang, S. Kang and B. Ren, "Performance Analysis of Cooperative Pattern Division Multiple Access (Co-PDMA) in Uplink Network," in IEEE Access, 2017, vol. 5, pp. 3860-3868.
[9] A. Krebs, M. Joham and W. Utschick, “Comparative performance evaluation of error regularized Turbo-MIMO MMSE-SIC detectors in Gaussian channels,” 2015 IEEE International Conference
on Acoustics, Speech and Signal Processing (ICASSP), South Brisbane, QLD, 2015, pp. 2984-2988.

[10] B. Ren et al., “Advanced IDD receiver for PDMA uplink system,” Proc. 2016 IEEE/CIC International Conference on Communications in China (ICCC), Chengdu, 2016, pp. 1-6.

[11] X. Meng, S. Wu, L. Kuang, Z. Ni and J. Lu, “Expectation Propagation Based Iterative Multi-User Detection for MIMO-IDMA Systems,” IEEE 79th Vehicular Technology Conference (Spring), Seoul, 2014, pp. 1-5.

[12] 3GPP TR 38.900, v14.1.0, “Study on channel model for frequency spectrum above 6 GHz.” http://www.tech-invite.com/3m38/tinv-3gpp-38-900.html