

**Low Complexity Iterative Detection for a Large-scale Distributed MIMO Prototyping System**

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**Abstract**—In this paper, we study the low-complexity iterative soft-input soft-output (SISO) detection algorithm in a large-scale distributed multiple-input multiple-output (MIMO) system. The uplink interference suppression matrix is designed to decompose the received multi-user signal into independent single-user receptions. An improved minimum-mean-square-error iterative soft decision interference cancellation (MMSE-ISDIC) based on eigenvalue decomposition (EVD-MMSE-ISDIC) is given to perform low-complexity detection of the decomposed signals. Furthermore, two iteration schemes are given to improve receiving performance, which are iterative detection and decoding (IDD) scheme and iterative detection (ID) scheme. While IDD utilizes the external information generated by the decoder for iterative detection, the output information of the detector is directly exploited with ID. In particular, the performance of the schemes is evaluated in a 128×128 (16 remote antenna units (RAUs) and 16 users, each equipped with 8 antennas) large-scale distributed MIMO prototyping system, which is also a cell-free massive MIMO. The experimental results show that the proposed iterative receiver greatly outperforms the linear MMSE receiver, since it reduces the average number of error blocks of the system significantly.

**Index Terms**—Iterative detection, interference suppression, distributed MIMO prototyping system, cell-free massive MIMO

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**I. INTRODUCTION**

Recently, cell-free massive multiple-input multiple-output (MIMO) has attracted much attention due to its great potential to improve the spectral efficiency and the energy efficiency of wireless communication systems [1]. By using coherent processing across large number of geographically distributed MIMO [2], cell-free massive MIMO can provide uniformly good service for all users in the network without cells or cell boundaries. From this aspect, it is also called large-scale distributed MIMO (D-MIMO) [3]–[5]. Compared with the conventional point-to-point MIMO system, large-scale D-MIMO system takes the advantages of both spatial multiplexing and macro-diversity [6]–[9]. Meanwhile, there are challenges in large-scale D-MIMO systems posed by several design aspects, such as channel estimation, hardware implementation, and detection complexity. In particular, a critical design challenge in such system is to design a reliable and computationally efficient detector even if the number of antennas grows very large and the complexity of joint processing is rather high [10], [11].

The performance and complexity of several detection algorithms in the reverse link for single-cell massive MIMO systems are compared in [12], such as linear minimum-mean-square-error (LMMSE), tabu search (TS) and fixed complexity sphere decoder (FCSD). It was revealed that LMMSE receiver can operate very close to the optimal maximum-likelihood (ML) detector while saving an order of magnitude or more in the number of antennas. In order to further improve the performance of the receiver, MMSE-based iterative soft decision interference cancellation (MMSE-ISDIC) was proposed in [13], [14], which is an iterative soft-input soft-output (SISO) detector and can be implemented in both uncoded and coded systems. However, it becomes noncompetitive when used to serve large-scale systems since it suffers from impractically high computational complexity.

We consider large-scale D-MIMO systems and our purpose is to develop efficient low-complexity iterative receivers for these systems. Firstly, the uplink interference suppression matrix is designed to decompose the received multi-user signal into independent single-user receptions. Then, referring to [15], an improved low-complexity solution named as MMSE-ISDIC based on eigenvalue decomposition (EVD-MMSE-ISDIC) is given to process the decomposed signals, which can reduce the complexity of the inversions of large-scale matrices via EVD. Two iteration schemes are given based on the low-complexity EVD-MMSE-ISDIC to improve the receiving performance of large-scale D-MIMO systems. While iterative detection and decoding (IDD) scheme utilizes the external information generated by the decoder as the a priori information for iteration, the output information of the detector is directly exploited with iterative detection (ID) scheme to form iterative detector. In addition, the method of using the external information as the a priori information to calculate the symbol mean and variance for iterations is discussed. Finally, a 128×128 large-scale D-MIMO prototyping system based on cell-free architecture is introduced to validate the proposed iterative receiver.

The following notation is used in the sequel. Vectors and matrices are denoted by lowercase and uppercase boldface letters, such as \( \mathbf{x} \) and \( \mathbf{A} \), respectively. \( | \cdot | \) denotes the absolute value of a scalar. \( \cdot^T \) and \( \cdot^H \) represent transpose and Hermitian transpose, respectively. \( \text{diag}(\mathbf{x}) \) represents a diagonal matrix with \( \mathbf{x} \) along its diagonal. We use \( \mathcal{CN}(0, \sigma^2) \) to denote a circularly symmetric complex Gaussian variable with zero mean and covariance \( \sigma^2 \).

**II. SYSTEM MODEL**

Consider a large-scale D-MIMO system with \( M \) remote antenna units (RAUs) and \( K \) users. \( N_R \) and \( N_U \) denote the number of antennas employed by RAU and user, respectively. All transmitted symbols are mapped from a QAM constellation \( \Theta \). We assume that the number of data streams currently
supported by the $k$th user is $N_{R1,k}$. For the $k$th user, the $N_{R1,k}$-length information sequence $s_k = \left[ s_{k,1}, s_{k,2}, \ldots, s_{k,N_{R1,k}} \right]^T$ is fed to the precoder, where $s_k$ is mapped to an $N_U$-length sequence $s_k'$ by a precoding matrix $P_k \in \mathbb{C}^{N_U \times N_{R1,k}}$. The precoded sequence $s_k'$ is given as

$$s_k' = P_k s_k = \left[ s_{k,1}', s_{k,2}', \ldots, s_{k,N_U}' \right]^T.$$  

(1)

The received signal of RAUs is matched filtered, sampled and formed into $y = \left[ y_1, y_2, \ldots, y_{M_N} \right]^T$. Assuming adequate spatial separation and rich scattering between the RAU antenna elements, the received signal $y$ can be expressed as

$$y = G s' + n,$$

(2)

where $s' = \left[ s_1', s_2', \ldots, s_K' \right]^T$ represents the signals sent by all users. We define $G = [G_1, \ldots, G_K]$ where $G_k = \left[ G_{k,1}, \ldots, G_{m,k} \right]^T$ with $G_{m,k} \in \mathbb{C}^{N_R \times N_U}$ represents the channel gain matrix from the $k$th user to the $m$th RAU. $n$ is the complex additive white Gaussian noise (AWGN) with i.i.d. entries $\sim \mathcal{C}\mathcal{N}(0, \sigma^2)$.

### III. UPLINK INTERFERENCE SUPPRESSION

Since the RAUs receive signals from $K$ users simultaneously, it is necessary to perform interference suppression to eliminate inter-user interference. The interference suppression matrix $W_{IS}$ should satisfy

$$W_{IS} G = \begin{bmatrix} R_1^T \\ \vdots \\ R_K^T \end{bmatrix},$$

i.e., the product of the interference suppression matrix and the uplink channel is a block-diagonal matrix. Therefore, in order to obtain the desired $W_{IS}$, singular value decomposition (SVD) on the channel matrix should be performed. For the $k$th user, we define $G_{[k]} = [G_{1,k}, \ldots, G_{K,k}]$, and it can be decomposed as

$$G_{[k]} = U_k A_k D_k^H = \left[ U_k^{(1)} U_k^{(0)} \right] \left[ \Lambda_k^{(1)} \Lambda_k^{(0)} \right] D_k^H,$$

where $A_k$ is diagonal matrix, in which the diagonal elements are singular values of $G_{[k]}$ arranged in descending order. $\Lambda_k^{(1)}$ represents all non-zero singular values of $G_{[k]}$. Assuming the rank of $G_{[k]}$ is $r_k$, $U_k^{(1)}$ contains the first $r_k$ left-singular vectors and $U_k^{(0)}$ contains the remaining $(M N_R - r_k)$ left-singular vectors of $G_{[k]}$. Therefore, $U_k^{(0)}$ satisfies

$$G_{[k]}^H U_k^{(0)} = D_k \left[ \Lambda_k^{(1)} \right] H \left( \Lambda_k^{(1)} \right) H U_k^{(0)} = 0.$$

We choose $N_R$ rows of $\left( U_k^{(0)} \right)^H$ randomly and denote it as $W_{IS,k}$. Thus, the uplink interference suppression matrix is derived as $W_{IS} = \left[ W_{IS,1}^T, \ldots, W_{IS,K}^T \right]^T$.

With interference suppression, the received multi-user signal is decomposed into $K$ independent single-user receptions, which can be expressed as

$$\tilde{y}_k = \hat{H}_k s_k + \tilde{n}_k,$$

(3)

where $\tilde{n}_k = W_{IS,k} \sum_{l \neq k} H_l s_l + W_{IS,k} n_k = W_{IS,k} n_k$ and $\hat{H}_k = W_{IS,k} H_k$. $H_k = G_k P_k$ is the equivalent channel matrix between all RAUs and the $k$th user, which can be estimated by demodulation reference signal (DM-RS). $n_k$ is the additive noise with i.i.d. entries $\sim \mathcal{C}\mathcal{N}(0, \sigma^2)$.

### IV. ITERATIVE RECEIVER BASED ON EVD-MMSE-ISDIC

In this section, we review the MMSE-ISDIC algorithm and propose the low complexity solution. In IV-A, the improved algorithm named as EVD-MMSE-ISDIC is described. Then, we give two specific block-wise implementation, which are IDD scheme and ID scheme, based on EVD-MMSE-ISDIC to improve the receiving performance of large-scale D-MIMO systems. In IV-B, the method of calculating the mean and variance of the a priori information is discussed. Throughout the paper, the extrinsic messages and the a priori information are in log-likelihood ratio (LLR) form [16], [17].

#### A. EVD-MMSE-ISDIC

Consider the concatenation of detector and decoder. Utilizing the received signal $\tilde{y}_k$, mean of received signal $\hat{s}_k$ and variance of received signal $v_k$, the traditional ISDIC output of the SISO detector is written as

$$\hat{s}_k = s_k + V_k \tilde{H}_k^H \left( \tilde{H}_k V_k \tilde{H}_k^H + \Sigma_k \right)^{-1} \tilde{y}_k - \tilde{H}_k s_k,$$

(4)

where $V_k = \text{diag} \left( v_k \right)$ and

$$\Sigma_k = \text{Cov} \left( \tilde{n}_k, \hat{s}_k \right) = W_{IS,k} \left( \sum_{l \neq k} H_l H_l^H \right) W_{IS,k}^H + \sigma^2 I_{N_U}$$

(5)

denotes the covariance matrix of $\tilde{n}_k$. Then, soft demodulation is performed on $\hat{s}_k$ to generate extrinsic messages, which can be used as the a priori information to calculate the mean and variance of $\hat{s}_k$. It will be discussed in detail in section IV-B.

The updated $\hat{s}_k$ and $v_k$ are returned to the detector, which constructs the iterative receiver. It should be noted that the iteration is implemented in form of blocks, i.e., the vectors $\hat{s}_k$, $v_k$, $\tilde{y}_k$ and $\hat{s}_k$ are reconstructed into $\tilde{S}_k = [\tilde{s}_k, i, j] \in \mathbb{C}^{N_{R1,k} \times N_L}$, $V_k = [v_k, i, j] \in \mathbb{C}^{N_{R1,k} \times N_L}$, $\tilde{y}_k = [\tilde{y}_k, i, j] \in \mathbb{C}^{N_{R1,k} \times N_L}$, and $\tilde{S}_k = [\tilde{s}_k, i, j] \in \mathbb{C}^{N_{R1,k} \times N_L}$, respectively, where $N_{R1,k} \cdot N_L$ is the block length. The values of $\tilde{S}_k$ and $V_k$ are updated simultaneously when the detection or decoding of $y_k$ in one block is finished. Therefore, the soft output of the SISO detector can be estimated according to Bayesian Gauss-Markov theory as [18], [19].

$$\hat{s}_{k,l} = \Omega_k^{-1} \left( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k V_{k,l} + I_{N_{R1,k}} \right)^{-1} \left( \tilde{y}_{k,l} - \tilde{H}_k s_{k,l} \right) + \hat{s}_{k,l},$$

(6)

where $l = 1, 2, \ldots, N_l$, $V_{k,l} = \text{diag} \left( v_{k,l} \right)$, $\tilde{s}_{k,l}$, $v_{k,l}$, $\tilde{y}_{k,l}$ and $\hat{s}_{k,l}$ represent the $l$th column of $\tilde{S}_k$, $V_k$, $\tilde{y}_k$ and $\hat{s}_k$, respectively. The unbiased estimation coefficient $\Omega_k$ is defined
as \( \Omega_k \widehat{=} \text{diag} (\rho_k) \) where \( \rho_k = [\rho_{k,1}, \ldots, \rho_{k,j}, \ldots, \rho_{k,N_R,l,k}]^T \) and it can be calculated by

\[
\rho_{k,j} = e_j^H \left( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k V_{k,l} + I_{N_R,l,k} \right)^{-1} \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k e_j. \quad (7)
\]

When the detector performs iterative detection as expressed in (6), the inverse operation of \( N_{R,l,k} \times N_{R,l,k} \) matrix need to be performed \( N_L \) times within a block. In this case, the computation complexity is \( O \left( N^3 \right) \cdot N_L \), which is extremely high.

In order to reduce the complexity, we propose the EVD-MMSE-ISDIC algorithm. Firstly, \( \nu_{k,l} \) is denoted as the mean of the diagonal elements of \( V_{k,l} \). Thus, \( V_{k,l} \) can be approximated as \( V_{k,l} = \nu_{k,l} I_{N_R,l,k} \). It has been proved in [20] that such an approximation does not result in much performance degradation while simplifying the calculation. Then, applying EVD, \( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k \) can be factorized as \( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k = Q_k A_k Q_k^{-1} \). Therefore, we obtain

\[
\left( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k V_{k,l} + I_{N_R,l,k} \right)^{-1} = Q_k \left( \nu_{k,l} A_k + I_{N_R,l,k} \right)^{-1} Q_k^{-1}. \quad (8)
\]

In this way, the inverse operation of \( N_{R,l,k} \times N_{R,l,k} \) matrix can only be performed for one time. The simplified computation complexity is reduced to \( O \left( N^3 \right) \cdot N_L \). Based on (8), (6) can be rewritten as

\[
\bar{s}_{k,:,:l} = \Omega_k^{-1} Q_k \left( \nu_{k,l} A_k + I_{N_R,l,k} \right)^{-1} Q_k^{-1} \tilde{H}_k^H \Sigma_k^{-1} \left( \tilde{y}_{k,:,:l} - \tilde{H}_k \bar{s}_{k,:,:l} \right) + \bar{s}_{k,:,:l}. \quad (9)
\]

Two iteration schemes named as IDD and ID are given based on the low-complexity EVD-MMSE-ISDIC to improve the receiving performance of large-scale D-MIMO systems. The receiver structures of IDD scheme and ID scheme are shown in Fig. 1 and Fig. 2, respectively. In the IDD scheme, interleaving/deinterleaving is first performed. Then, the low-density parity-check (LDPC) decoder generates extrinsic LLRs by using the correlation between different code structures introduced by the encoder. The extrinsic LLRs are used as the \textit{a priori} information to calculate \( \bar{s}_k \) and \( v_k \) and returned to the detector afterwards. The main difference between IDD scheme and ID scheme is that in the ID scheme, the extrinsic LLRs calculated by the output of the detector is directly used as the \textit{a priori} information to calculate \( \bar{s}_k \) and \( v_k \). Then, they are returned to the detector directly.

In the first iteration, we set \( \bar{s}_{k,:,:l} = 0 \) and \( V_{k,l} = I_{N_R,l,k} \). According to matrix inversion lemma

\[
(A + BCD)^{-1} = A^{-1} - A^{-1}B(DA^{-1}B + C^{-1})^{-1}DA^{-1},
\]

(9) is simplified to

\[
\bar{s}_{k,:,:l} = \left( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k + I_{N_R,l,k} \right)^{-1} \tilde{H}_k^H \Sigma_k^{-1} \tilde{y}_{k,:,:l}, \quad (10)
\]

which is the expression of the usual linear MMSE (LMMSE) detection algorithm. In the last iteration, the decoders produce hard decisions on information bits. The proposed EVD-MMSE-ISDIC detection algorithm is described in Algorithm 1.

**Algorithm 1 EVD-MMSE-ISDIC Detection Algorithm**

1. **Require** Iterative Scheme (IS), \( \nu_k \), \( \tilde{H}_k \), Number of Iterations \( (N_I) \).
2. **Set** \( \bar{s}_k = \text{zeros} (N_{R,l,k} N_I, 1) \), \( v_k = \text{ones} (N_{R,l,k} N_I, 1) \).
3. **Calculate** \( \Sigma_k \) with equation (5) and calculate \( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k = H_k^H W_{IS,k}=\Sigma_k^{-1} W_{IS,k} H_k \).
4. **Detection Algorithm—EVD-MMSE-ISDIC**
5. **EVD** \( \left( \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k \right) : \tilde{H}_k^H \Sigma_k^{-1} \tilde{H}_k = Q_k A_k Q_k^{-1} \).
6. **for** \( i = 1 \rightarrow N_I \) **do**
7. **for** \( l = 1 \rightarrow N_L \) **do**
8. **Calculate** \( \nu_{k,l} A_k + I \), \( Q_k \left( \nu_{k,l} A_k + I \right)^{-1} Q_k^{-1} \).
9. **Calculate** \( \Omega_k \) with equations (7).
10. **Calculate** \( \bar{s}_k \) with equations (9).
11. **end for**
12. **Soft demodulation and obtain the extrinsic LLRs \( I_k \).**
13. **if** \( IS = \text{IDD} \) **then**
14. **LDPC Decoding**
15. **Obtain the output \( r_k \) and the extrinsic LLRs \( \tilde{I}_k \).**
16. **end if**
17. **Calculate** \( \tilde{s}_k \) and \( v_k \) with equations from (11) up to (14).
18. **end for**
19. **if** \( IS = \text{ID} \) **then**
20. **LDPC Decoding**
21. **Obtain the output \( r_k \).**
22. **end if**

**Remark 1:** It should be noted that the proposed EVD-MMSE-ISDIC detection algorithm is also applicable to the downlink receiver. The detection expression in the downlink transmission is the same as (9) without \( W_{IS,k} \) and \( W_{IS,k}^H \).
B. Calculation of Symbol Mean and Variance

In this subsection, we discuss the method of calculating the mean and variance of $s_k$ from the \textit{a priori} LLRs. The LLR of $s_{k,j}$ is denoted as $1_{k,j} = [L_{k,j,1}, \ldots, L_{k,j,M}]^T$. Thus, the probability of the symbol $s_{k,j}$ can be calculated as

$$P[s_{k,j} = \alpha(d)] = \prod_{i=1}^{M_c} \left[ \frac{1}{1 + \exp\left(-\tilde{d}_i L_{k,j,i}\right)} \right],$$

where $M_c$ is the bit numbers contained in a constellation symbol, $d$ is a $M_c \times 1$ vector of bits, $\alpha(d)$ represents the constellation symbol of $d$ and the elements in $M_c \times 1$ vector $d$ are defined as

$$\tilde{d}_i = \begin{cases} +1, & d_i = 1 \\ -1, & d_i = 0 \end{cases}.$$

The mean and variance of $s_k$ can be calculated by [14], [21]

$$\bar{s}_{k,j} = \sum_{d \in \Theta} \alpha(d) P[s_{k,j} = \alpha(d)],$$

$$v_{k,j} = \sum_{d \in \Theta} |\alpha(d)|^2 P[s_{k,j} = \alpha(d)] - |\bar{s}_{k,j}|^2.$$

\textbf{Remark 2:} In practical situations, in order to further reduce the computational complexity, the values of $1 + \exp(\tilde{d}_i L_{k,j,i})$ are mapped to a hash table, where $x$ ranges from $-\max(L_{k,j,i})$ to $\max(L_{k,j,i})$. Therefore, we can obtain the values directly according to index $L_{k,j,i}$ when calculating (11).

V. LARGE-SCALE D-MIMO PROTOTYPING SYSTEM

The large-scale D-MIMO prototyping system consists of $M$ RAUs and $K$ users (up to 16 RAUs and 16 users), each RAU and user is equipped with 8 antennas to support real-time wireless transmission testing of D-MIMO systems with an antenna size of $128 \times 128$. The layout of the system is shown in Fig. 3 and the system is based on cell-free architecture. The carrier frequency of the system is 3.5 GHz and the bandwidth is 96 MHz. We consider a time-division-duplex (TDD) system with a 1:1 ratio between uplink and downlink. The baseband processing is performed by base station-baseband processing units (BS-BPUs) and user equipment-BPUs (UE-BPUs). Each BPU has an Intel Xeon E5 72 core general-purpose processor (GPP) based on Sandy Bridge architecture. Since the demand for computing capability of the RAU side is much larger than that of the user side, the RAUs are connected to the cloud processing center composed of large-scale high-performance processors. That is also in line with the practical scenario where the RAUs have powerful computing capability while the computing performance of the terminal device is limited. Tab. I lists the main parameters of the system.

System architecture of the large-scale D-MIMO prototyping system is shown in Fig. 4. There are $P_B$ BS-BPUs on the RAU side and the 96 MHz bandwidth of each RAU is divided into $P_B$ parts. Specific sub-band is transmitted to specific BS-BPU in the cloud computing center through switches. On the user side, each user is equipped with $P_U$ UE-BPUs.

According to the channel quality indication (CQI), the users obtain the number of data streams $N_D$, the modulation order $Q_m$, and the coding rate $R_c$. For each user, the data generated by UE-BPUs is transmitted to the radio frequency (RF) electrical control panel after encoding, interleaving, modulating, subcarrier mapping, antenna mapping and OFDMA [22]–[25]. On the RAU side, the receiver performs interference suppression, MIMO detecting, demodulating, deinterleaving and decoding orderly to obtain the transmitted data.

To improve system performance, we use Intel’s math kernel library (MKL) to perform baseband processing at BPUs, which provides a number of highly optimized routines that support vector-vector, matrix-vector and matrix-matrix operations for real and complex, single and double precision data. In addition, through multi-core parallel programming, the computational

\textbf{TABLE I}

\textbf{PARAMETERS OF LARGE-SCALE D-MIMO PROTOTYPING SYSTEM}

| Parameter            | Value     |
|----------------------|-----------|
| Subcarrier space $\Delta_f$ | 30 KHz    |
| Total number of subcarriers, IFFT/FFT size $N_{FFT}$ | 4096 |
| Sampling rate $f_s$ | 122.88 MHz |
| Number of used subcarriers $N_D$ | 3208 |
| Bandwidth $W$ | 96 MHz |
| IFFT/FFT cycle $T_{FFT} = \frac{1}{f_s}$ | 33.333 $\mu$s |
| Cyclic prefix length $T_{CP}$ | 4.167 $\mu$s, 512 |
| OFDM symbol duration $T_{SYM} = T_{CP} + T_{FFT}$ | 37.5 $\mu$s |

Fig. 4. System architecture of the large-scale D-MIMO prototyping with $P_B = 8$ and $P_U = 4$. Specific signals are transmitted to specific BS-BPU for processing, e.g., all red sub-band signals received by all RAUs are transmitted to the rightmost BS-BPU.
efficiency of the processor is greatly improved. For example, in multi-user scenarios, one core of a BS-BPU processes one sub-band of a user, including signal receiving and transmitting. After the interference suppression matrix is multiplied by the received signal, the multi-user receiver is decomposed into $K$ independent single-user receivers which are implemented in $K$ independent core sets.

The real-time throughput of the system is measured by Optixia XM2 instrument and IXNetwork software. Test results of rooms 1-4 are shown in Fig. 6. It can be seen that when 12 RAUs and 12 users are activated, the total system throughput reaches 10.185 Gbps, and the overall spectral efficiency of the system exceeds 100 bps/Hz with CQI7. It is worth noting that the overall spectral efficiency of the system can be higher when further increasing the layout density of RAUs and users.

**VI. EXPERIMENTAL RESULTS**

Since the complexity of the proposed EVD-MMSE-ISDIC algorithm is reduced dramatically, both IDD and ID schemes can be implemented in prototyping systems. Therefore, experimental validation of EVD-MMSE-ISDIC is performed in the large-scale D-MIMO prototyping system. Furthermore, we compare the performance of the proposed iterative algorithm with non-iterative LMMSE to demonstrate that both IDD scheme and ID scheme offer a higher-performance solution. We perform the experimental verification in Room 1 in Fig. 3, where the system layout in Room 1 is shown in Fig. 5. Each user is equipped with 4 UE-BPUs while all RAUs share 8 BS-BPUs. With CQI1-CQI5, error-free transmission can be achieved in the uplink generally. Therefore, we focus on the condition with CQI6 ($N_{RI} = 4, Q_m = 4, R_c = 3/4$) and CQI7 ($N_{RI} = 4, Q_m = 6, R_c = 2/3$).

The statistical averaging on the number of error blocks within a time period is performed. The average number of error blocks of all BS-BPUs with different iteration schemes and different number of iterations are recorded in Fig. 7 and Fig. 8. Considering the limitations of computing resources and system delay, the maximum number of iteration is set to be three. The experimental results demonstrate that the proposed EVD-MMSE-ISDIC algorithm can greatly reduce the average number of error blocks compared with the conventional non-iterative LMMSE receiver.

Compared with the LMMSE receiver, in the ID scheme, the average number of error blocks can be reduced by 20% and 40% with two iterations and three iterations, respectively. Besides, in the IDD scheme, a approximately 48% and 68% decrease for the average number of blocks in comparison with LMMSE can be achieved with two iterations and three iterations, respectively. Furthermore, the IDD algorithm converges faster and has better receiving performance compared with ID. However, the decoding operation need to be performed for multiple times in IDD and higher calculation capability of the system is required. In the case of limited computing resources of the practical system, ID scheme with three iterations or IDD scheme with two iterations are preferred since they are cost-effective.

**VII. CONCLUSION**

In this paper, we have presented a low-complexity iterative SISO detection algorithm in a large-scale distributed MIMO system. The uplink interference suppression matrix was designed to decompose the received multi-user signal into
Fig. 7. The average number of error blocks in the uplink with different iteration schemes and different iteration numbers with CQI6.

Fig. 8. The average number of error blocks in the uplink with different iteration schemes and different iteration numbers with CQI7.

independent single-user receptions. Then, EVD-MMSE-ISDIC algorithm was proposed to perform low-complexity detection of the decomposed signals. Based on EVD-MMSE-ISDIC, two different schemes, named as ID scheme and ID scheme, have been given and the proper detection scheme can be chosen according to the computing capability of the practical system. A large-scale distributed MIMO prototyping system has been introduced to perform experimental validation of the proposed detection schemes. Experimental results demonstrate that the proposed iterative receiver can greatly reduce the average number of error blocks of the system. Compared with the non-iterative LMMSE receiver, the average number of error blocks can be reduced by 68% and 40% with three iterations in IDD and ID scheme, respectively.

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