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Iterative Clipping Noise Elimination of Clipped and Filtered SCMA-OFDM System

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ABSTRACT Similar to conventional orthogonal frequency division multiplexing (OFDM) signal, the signals of sparse code multiple access combine with orthogonal frequency division multiplexing (SCMA-OFDM) existing the problem that its peak-to-average power ratio (PAPR) is unbearable high. In this paper, the clipping method is adopted to reduce the PAPR of the SCMA-OFDM signal. However, the clipping process brings extra noise to the SCMA-OFDM signal while the clipping noise is not taken into account in the message passing algorithm (MPA), which makes the MPA detection inaccurate and leads to a phenomenon that the decoding performance declines sharply with the increasing of $\mathbf{E_b/N_0}$. Moreover, due to the distortion of SCMA-OFDM signals caused by clipping process, the system bit error rate (BER) performance degrades obviously. To tackle the issues above, we analyze the random characteristics of the clipping noise for the MPA detection scheme. Then, an iterative clipping noise elimination scheme is proposed to restore the BER performance of clipped SCMA-OFDM system. Simulation results show that our method can remove the phenomenon that the BER performance declines sharply at the high $\mathbf{E_b/N_0}$ region and the proposed iterative clipping noise elimination scheme restores the BER performance significantly.

INDEX TERMS Clipping noise, message passing algorithm (MPA), orthogonal frequency division multiplexing (OFDM), peak-to-average power ratio (PAPR), sparse code multiple access (SCMA).

I. INTRODUCTION

To support the massive connectivity, low latency and high spectrum efficiency requirements of the coming age of fifth generation (5G) wireless communications [1], some non-orthogonal multiple access (NOMA) schemes have been proposed since the orthogonal multiple access (OMA) schemes are hard to support massive user equipments (UEs) simultaneously. Among these NOMA schemes, sparse code multiple access (SCMA) [2] is a competitive one which can address the requirements mentioned above.

The SCMA is evolved from low-density signature (LDS) [3] which supports more UEs than the OMA schemes. Different from the simple repetition procedure of bits to quadrature amplitude modulation (QAM) symbols in LDS, SCMA merges the mapping and spreading together and the binary data bits are directly mapped into complex multi-dimensional codewords selected from predefined codebook sets [4], which makes SCMA system obtain better performance improvement. Due to the sparsity of SCMA codewords, the massage passing algorithm (MPA), which achieves nearly optimal BER performance but has much lower decoding complexity compared with optimal maximum a posterior (MAP), is leveraged in the multiuser detection scheme.

The existing researches about SCMA are mainly concentrated on low complexity decoding, codebook design, and channel estimation. Based on lattice constellation design principles, the codebooks designed in [4], [5] enable layer to own its dedicated codebook and thus improve the BER performance obviously. In [6], shuffled MPA (SMPA) detector has been proposed to greatly reduce decoding complexity by updating the massage in a serial strategy. In [7], by utilizing the characteristic of Gaussian noise, the sphere decoding based MPA (SD-MPA) selects the superposed constellation points (SCPs) inside circle region with predefined radius and thus reduces the complexity commendably.

Considering that SCMA is a multi-carrier scheme, it is a general trend to combine SCMA with OFDM (named SCMA-OFDM) to further exploit the advantages of SCMA and OFDM. However, the SCMA-OFDM signal possesses the same shortcomings as OFDM signal that its peak-to-average power ratio (PAPR) is unbearable high, which will make the high-power amplifier (HPA) of the transmitter work at saturation, produce in-band distortion that degrades the BER performance and engender out-of-band distortion that interfering the other channels. Since it is impractical to equip mobile terminal with a large linear dynamic range HPA, measures should be taken to reduce the PAPR of SCMA-OFDM signal.

Until now, there are a few methods about PAPR reduction for SCMA system in the direction of codebook design. In [8], the authors proposed spherical codes to build multidimensional mother constellations for SCMA codebooks. For making full use of lattice theory and mapping principle, a top-down SCMA codebook design scheme was proposed in [9].

In [10], the authors presented three classes of PAPR reduction techniques for OFDM systems: signal distortion techniques, signal distortion-less techniques and coding techniques. Among these techniques, clipping is the simplest method to reduce the PAPR. For reducing the PAPR efficiently, the clipping should be performed on oversampled signals [11], [12].

Unlike AWGN, clipping noise produced at the transmitter can be reconstructed at the receiver. Based on this characteristic, a number of effective schemes [13], [14] have been proposed to mitigate the effect caused by the clipping noise. In [15], a novel iterative high performance receiver was put forward to estimate and eliminate the signal distortion. To reconstruct the clipping noise Based on compressed sensing (CS) theory, some reconstruction algorithms for different clipping models were introduced in [16]–[19].

In this paper, the clipping method is used to reduce the PAPR of SCMA-OFDM signals. The clipping process can be seen as an operation that brings extra noise to the original SCMA-OFDM signals. However, at the receiver side, the MPA detector demands the overall noise for achieving accurate detection while it does not take the extra clipping noise into account, which makes MPA perform inaccurately and the SCMA-OFDM system suffers the BER performance deterioration with the increasing of E_b/N_0. The contributions of this paper are as follows

1) Since the clipping process brings extra noise to the SCMA-OFDM signal, an analytic method is employed to analyze the random characteristics of the clipping noise and takes the extra noise into account for decoding accurately. Simulation results show that our proposed analytic of the clipping noise is precise and the overall noise utilized in MPA can solve the phenomenon that the BER performance declines sharply at high E_b/N_0 range.
2) Since the clipping process is available in advance at both side, we propose an iterative clipping noise elimination scheme to reconstruct the clipping noise and then remove it from the original receive signals to restore the BER performance. Simulation results show that the proposed iterative clipping noise elimination scheme can restore the BER performance of the clipped SCMA-OFDM system within small gap compared with the non-clipped SCMA-OFDM system case.

The rest of this paper is organized as follows. In Section II, the SCMA-OFDM system model is introduced briefly. Section III discusses the clipping process and gives the analytical expression of the clipping noise. Then the proposed iterative clipping noise elimination scheme is given in detail. Simulation results and conclusion are presented in Section IV and Section V, respectively.

II. SYSTEM MODEL

A. SCMA SYSTEM

For a SCMA signal block, I user nodes (UNs) share the same K resource nodes (RNs) while each UN only occupies d_u of K RNs and each RN only allocates to d_r of I UNs. At the transmitter, the incoming $\log_2 M$ data bits are mapped into a complex K-dimensional codeword which is selected from a SCMA codebook of size M, where K can be regarded as spreading factor. Then the codewords of I user nodes are multiplexing in frequency domain and transmit by the transmitter. The SCMA encoding and frequency domain multiplexing is shown in Fig. 1.

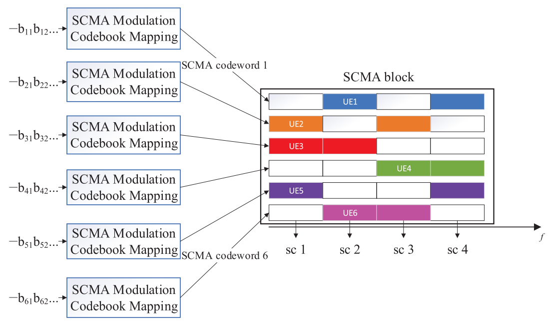

FIGURE 1. SCMA encoding and frequency domain multiplexing.

At the receiver side, the received signal can be written as

$$\mathbf{y} = \sum_{i=1}^{I} diag(\mathbf{h}_i)\mathbf{x}_i + \mathbf{n} \tag{1}$$

where $\mathbf{x}_i = (x_{1,i}, \ldots, x_{K,i})^T$ is the SCMA codeword of user i, $\mathbf{h}_i = (h_{1,i}, \ldots, h_{K,i})^T$ is Rayleigh fading channel vector of user i, and $\mathbf{n} \sim CN(0, \sigma^2\mathbf{I})$ denotes the Gaussian noise.

B. FACTOR GRAPH REPRESENTATION AND CONVENTIONAL MPA

The factor graph [3] can be used to represent the interrelation between user nodes (UNs) and resource nodes (RNs) in SCMA. An example of SCMA factor graph is shown in Fig. 2, in which each UN occupies two RNs and each RN is connected to three UNs. For each resource node at the receiver side, the local channel observation is obtained by multiplexing the 6 users over the 4 orthogonal resources.

Compared with optimal MAP scheme, MPA scheme is implemented base on the message propagation between RNs

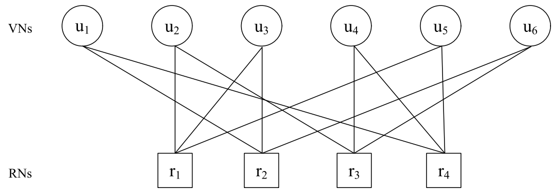

FIGURE 2. An example of factor graph for SCMA with $I = 6$, $K = 4$.

and UNs to achieve nearly optimal BER performance and owns much lower decoding complexity. Therefore, MPA scheme is widely used for uplink SCMA multiuser detection. Let $Q^{(t)}_{u_i\to r_k}(x_m)$ and $Q^{(t)}_{r_k\to u_i}(x_m)$ represent the massage from the ith UN to the kth RN and from the kth RN to the ith UN at the tth iteration, respectively. The MPA procedure can be shown as follows

1) **Initialization:**
The probability of the codewords are supposed equally as

$$Q^{(0)}_{u_i\to r_k}(x_m) = 1/M \tag{2}$$

2) **RN update:**
Each RN computes the probability distribution of the UNs based on the local channel observation by

$$Q^{(t)}_{r_k\to u_i}(x_m) = \sum_{\{x_i\}}\left\{\frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{1}{2\sigma^2}\left\|y_k-\sum_{m\in V_k}h_{k,m}x_{k,m}\right\|^2\right)\times\prod_{n\in V_k\backslash i}Q^{(t-1)}_{u_n\to r_k}(x_n)\right\} \tag{3}$$

3) **UN update:**
At each UN, the probability distribution is computed by multiplying the messages from adjacent RNs together

$$Q^{(t)}_{u_i\to r_k}(x_m) = \prod_{m\in R_i\backslash k} Q^{(t)}_{r_m\to u_i}(x_m) \tag{4}$$

where t, $\{x_i\}$ denote the number of iterations and the marginal function for x_i, respectively. V_k and R_i represent the set of UNs connect to kth RN and the set of RNs connect to ith UN, respectively.

4) **Soft Output of MPA:**
When it reaches the max iteration number $t_{\max}$, the decoding output is defined as

$$Output(x_m) = \prod_{k\in R_i} Q^{(t_{\max})}_{r_k\to u_i}(x_m) \tag{5}$$

C. SCMA-OFDM AND PAPR

Fig. 3 shows a simplified uplink SCMA-OFDM system in which I users spread over K orthogonal frequency resources in a SCMA signal block and N/K serial SCMA signal blocks make up a N-subcarriers SCMA-OFDM signal.

Let $X_i = [X_{i,0}, X_{i,1}, \ldots, X_{i,N-1}]^T, (i = 1, \ldots, I)$ denote a SCMA-OFDM frequency domain symbol of user i. Unlike the traditional OFDM signal that data is transmitted on each subcarrier, it is worth noting that there are total $(K-d_u)N/K$ zero elements in X_i and the position of zero elements are related to different users. As for an example of SCMA block, the factor graph is shown in Fig.2, in which user 1 occupies $2th$ and $4th$ resource elements in the SCMA block, and its SCMA-OFDM frequency domain symbol can be given as $X_1 = [0, X_{1,1}, 0, X_{1,2}, \ldots, 0, X_{1,N/2-1}, 0, X_{1,N/2}]^T$. Thus, the time domain SCMA-OFDM signal can be expressed as

$$x(t) = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_{i,k}e^{j2\pi kt/T}, \quad 0 \le t < T \tag{6}$$

where T is the symbol period of SCMA-OFDM signal.

The oversampled version of (6) can be used to approximate the PAPR accurately. Hence, the discrete-time SCMA-OFDM signal $x_{i,n}$ corresponding to $X_{i,n}$ with L times oversampling can be represented as

$$\mathrm{x}_{i,n} = \frac{1}{\sqrt{N}}\sum_{k=0}^{LN-1}\widetilde{X}_{i,n}e^{j\frac{2\pi kn}{LN}}, \quad n = 1, 2, \cdots, LN-1 \tag{7}$$

where L is the oversampling factor and has been proved that $L \ge 4$ can get the PAPR precisely. $\widetilde{X}_{i,n} = [X_{i,n}, 0, 0, \cdots, 0]$ is obtained by adding $L(N-1)$ zeros in the tail of $X_{i,n}$.

Then the PAPR of the oversampled SCMA-OFDM signal sequence $x_{i,n}$ is defined as

$$PAPR = \frac{\max_{0\le n\le LN-1}\left|x_{i,n}\right|^2}{E\left[\left|x_{i,n}\right|^2\right]} \tag{8}$$

where $E[\bullet]$ represents the expectation operator.

III. PROPOSED ITERATIVE CLIPPING NOISE ELIMINATION SCHEME

A. ANALYZATION OF CLIPPING NOISE

The details of clipping and filtering procedure at the transmitter is described in [20]. There are many clipping models and the Soft Envelope Limiter clipping model is adopted in this paper, in which the clipped signal $\bar{x}_{i,n}$ of user i can be written as

$$\bar{x}_{i,n} = \begin{cases} x_{i,n}, & \left|x_{i,n}\right| \le A \\ A\cdot e^{j\angle x_{i,n}}, & \left|x_{i,n}\right| \ge A \end{cases} \tag{9}$$

where A is the clipping level. Then the clipping ratio γ is defined as

$$\gamma = \frac{A^2}{E\left[\left|x_{i,n}\right|^2\right]} \tag{10}$$

The clipped signal $\bar{x}_{i,n}$ can be composed of the original SCMA-OFDM signals $x_{i,n}$ and the clipping distortion $c_{i,n}$. Thus, we can get the following expression as

$$\bar{x}_{i,n} = x_{i.n} + c_{i,n}, \quad 0 \le n \le LN-1 \tag{11}$$

Since $x_{i,n}$ can be seen as a complex Gaussian process when the number of subcarriers N is large enough according to

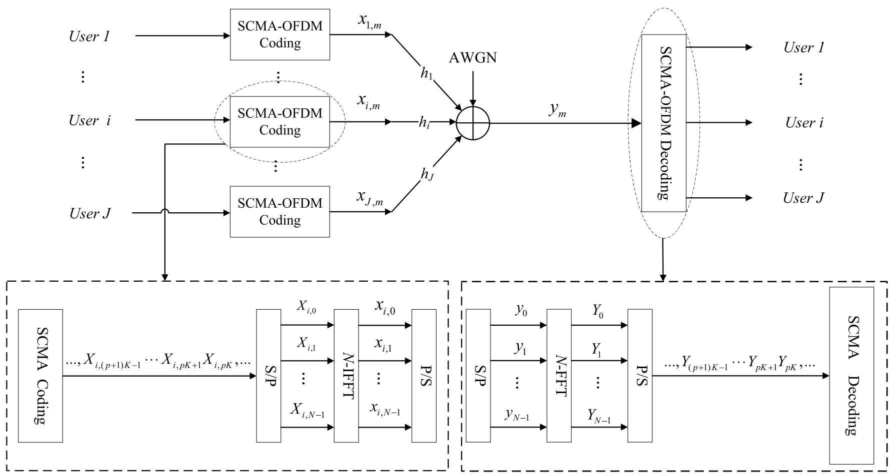

FIGURE 3. **A simplified uplink SCMA-OFDM system.**

the central limit theorem, the clipped signal $\bar{x}_{i,n}$ applying the Bussgang theorem [20] can be decomposed into two uncorrelated parts as

$$\bar{x}_{i,n} = \alpha x_{i,n} + d_{i,n}, \quad 0 \leq n \leq LN-1 \tag{12}$$

where $\alpha \in (0, 1]$ denotes an attenuation factor and $d_{i,n}$ is zero-mean clipping noise uncorrelated with $x_{i.n}$ ($E\left[d_{i,n}\right] = 0$ and $E\left[d_{i,n}x_{i,n}{}^*\right] = 0$). The attenuation factor α is defined as

$$\alpha = \frac{E\left[x_{i,n}\bar{x}^*_{i,n}\right]}{E\left[\left|x_{i,n}\right|^2\right]} = 1 - e^{-\gamma} + \frac{\sqrt{\pi\gamma}}{2} erfc(\sqrt{\gamma}) \tag{13}$$

It is noteworthy that α just depends on γ and α can be known at both side when γ is fixed.

Due to the oversampled operation on SCMA-OFDM signal, the clipping noise diffuses outside of the signal bandwidth after clipping process. Therefore, filtering operation is required to remove the diffused clipping noise. Thus, the frequency domain representation of the clipped SCMA-OFDM signal can be expressed as

$$\bar{X}_i = X_i + C_i = \alpha X_i + D_i, \quad 1 \leq i \leq I \tag{14}$$

where C_i is the clipping distortion in frequency domain and D_i is the FFT and out-of-band filtered version of the clipping noise $\mathbf{d}_i = \left(d_{i,1}, d_{i,2}, \cdots, d_{i,n}\right)$

Each user transmits the clipped signal $\bar{X}_i$ separately and the clipped signal from different users are multiplexed on the same frequency domain resource, then the received signal in the frequency domain at the base station side can be given as

$$\begin{aligned} Y &= \sum_{i=1}^{I} diag(H_i)\bar{X}_i + W \\ &= \alpha \sum_{i=1}^{I} diag(H_i)X_i + \sum_{i=1}^{I} diag(H_i)D_i + W \end{aligned} \tag{15}$$

where W is the AWGN with variance σ_W^2 and $H_i = \left(h_{1,i}, h_{2,i}, \ldots, h_{N-1,i}\right), 1 \leq i \leq I$ is the Rayleigh fading channel vector of user i. Noting that the attenuation factor α should be removed before MPA detection, we can get the observation vector $\widehat{Y}$ from equation (15) as

$$\begin{aligned} \widehat{Y} &= \alpha^-1Y \\ &= \sum_{i=1}^{I} diag(\bar{H}_i)X_i + \alpha^{-1}(\sum_{i=1}^{I} diag(\bar{H}_i)D_i + W) \end{aligned} \tag{16}$$

It can be seen in equation (16) that $\widehat{Y}$ in clipped SCMA-OFDM system has extra noise element D_i compared with the received non-clipped SCMA-OFDM signal in (1). Thus, the clipping noise should be attracted attention for decoding correctly. Since the clipping and filtering is just employed once in this paper, the variance of the clipping noise D_i can be obtained by making use of the power spectral density (PSD) of the clipping noise term as follow

$$\sigma_{D_i}^2 = E\left[|D_i|^2\right] = N \times S_{D_i}, \quad i = 1, \ldots, I \tag{17}$$

where S_{D_i} is the PSD of clipping noise term d_i and can be obtained through computing the DFT of the correlation function of the clipping noise term d_i

$$R_{d_i}(m) = E\left[d_{i,n+m}d^*_{i,n}\right] = \sum_{n=1}^{\infty} c_n \left[\frac{R_{x_i}(m)}{R_{x_i}(0)}\right]^{2n+1} \tag{18}$$

where the coefficient c_n can be seen in [21], which depends on the clipping ratio γ only. Due to the signal format difference between different users, the correlation function $R_{x_i}(m)$ of the signal $x_{i,n}$ can be given as

$$R_{x_i}(m) = \sigma_{x_i}^2 \frac{\text{sinc}(\frac{m}{L})}{\text{sinc}(\frac{m}{N})} e^{\frac{j\pi(2r_1+2r_2+N-K)m}{LN}} \tag{19}$$

where $\sigma_{x_i}^2$ is the power of the input signal $\sigma_{x_i}^2$ and $\text{sinc}(x) = \frac{\sin(\pi x)}{\pi x}$. The parameters of r_1 and r_2 depend on the position of RNs that the ith user occupies. Then the overall noise variance of the clipped SCMA-OFDM system can be given as

$$\sigma_{\text{All}}^2 = \alpha^{-2}(\sum_{i=1}^{I} \sigma_{D_i}^2 + \sigma_W^2) \tag{20}$$

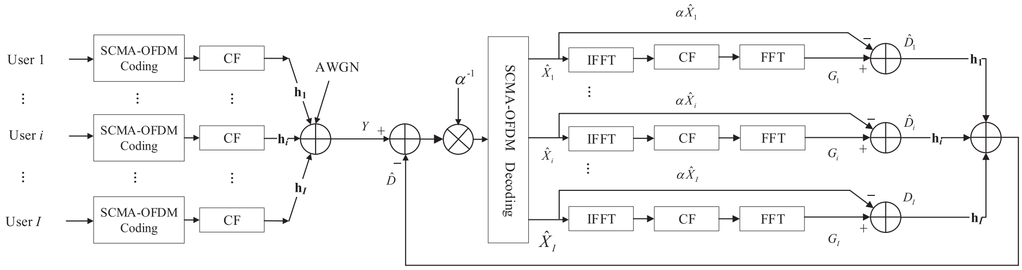

FIGURE 4. Structure of the proposed clipping noise elimination of clipped and filtered SCMA-OFDM system.

B. PROPOSED ITERATIVE CLIPPING NOISE ELIMINATION SCHEME OF CLIPPED AND FILTERED SCMA-OFDM SYSTEM

For estimating and eliminating the clipping noise, the proposed iterative clipping noise elimination scheme needs to reproduce the same clipping process at the receiver via exploiting the detected sequences. In this paper, it is assumed that the channel state information (CSI) and the synchronization are perfectly known at the receiver.

Fig. 4 shows the structure of the proposed iterative clipping noise elimination scheme. Note that the process of "CF" in Fig.4 represent the clipping and filtering operation. At the receiver side, it works in an iterative way as follows

1) The observation vector $\widehat{Y}$ is obtained by multiplying the channel observation Y with attenuation factor α. Once $\widehat{Y}$ is detected by utilizing MPA detection, the decision outputs of the I transmitted sequences can be expressed as $\hat{X}_i\ (i = 1, \ldots, I)$.
2) The decision output sequence $\hat{X}_i$ will experience two different types of processing parts: the first processing part indicates that the output sequence $\hat{X}_i$ participates in the same clipping and filtering process just as in the transmitter to regenerate the clipped signals which is expressed as $G_i(i = 1, \ldots, I)$. The second processing part is to obtain the attenuated non-clipping signals $\alpha\hat{X}_i$ by combining the sequence $\hat{X}_i$ with attenuation factor α together. On the basis of the analysis in the former subsection, the clipped signals G_i at the receiver can be decomposed into the sum of the attenuated non-clipping signal $\alpha\hat{X}_i$ and the clipping noise $\hat{D}_i$ as
$$G_i = \alpha\hat{X}_i + \hat{D}_i, \quad i = 1, \ldots, I \tag{21}$$
Noting that G_i and $\alpha\hat{X}_i$ are available at the receiver side, the clipping noise $\hat{D}_i$ can be estimated as
$$\hat{D}_i = G_i - \alpha\hat{X}_i, \quad i = 1, \ldots, I \tag{22}$$
Then the overall clipping noise $\hat{D}$ of the I users combined with the Rayleigh fading channel can be given as
$$\hat{D} = \sum_{i=1}^{I} diag(H_i)\hat{D}_i \tag{23}$$
3) With regard to the next iteration, the estimated overall clipping noise $\hat{D}$ is removed from the current channel observation Y to get the modified channel observation $\tilde{Y}$ as
$$\begin{aligned}\tilde{Y} &= Y - \hat{D}\\ &= \alpha\sum_{i=1}^{I} diag(H_i)X_i + \sum_{i=1}^{I} diag(H_i)(D_i - \hat{D}_i) + W\end{aligned} \tag{24}$$
where $(D_i - \hat{D}_i)$ represents the residual clipping noise which can be further removed in the next iteration if necessary.
4) Return to step 1) and replace Y with $\tilde{Y}$.

Remarkably, the MPA scheme operates in an iterative way and it has been proved that the BER performance of MPA scheme can reach the optimal MAP scheme. Besides, the soft output Output(x_m) of the MPA in last iteration can be used as the initialization input $Q^{(0)}_{u_i\to r_k}(x_m) = \text{Output}(x_m)$ in current iteration, which will definitely make the MPA performs better than using the equal probability distribution $Q^{(0)}_{u_i\to r_k}(x_m) = 1/M$. The proposed iterative clipping noise elimination scheme is able to estimate and remove the clipping noise in the current iteration, and then the observation vector in the next iteration is closer to the original non-clipping signal. Thus, the estimation of the clipping noise will also be more accurate and the iterative clipping noise elimination based MPA detection scheme will achieve better decoding performance in the next iteration. In general, by eliminating the clipping noise in such an iterative way, the proposed scheme is capable of making the decoding process more and more accurate and prominently improves the BER performance of the SCMA-OFDM system.

To the best of our knowledge, the number of iterations will result in extremely high complexity for iterative schemes. As shown in Fig. 4, each iteration of the proposed iterative clipping noise elimination scheme requires I (the number of users) pairs of IFFT/FFT operations and one MPA decoding operation only. During the MPA decoding process, the soft output $Output(x_m)$ obtained in last iteration can be used as the initialization input $Q^{(0)}_{u_i\to r_k}(x_m)$ in current iteration, which can significantly accelerate the convergence rate of the MPA detection scheme. Besides, the simulation results in part IV illustrate that the proposed iterative clipping noise elimination scheme just requires two iterations to reach the near optimal BER performance of the SCMA-OFDM system.

Therefore, the proposed iterative clipping noise elimination scheme endures the acceptable complexity increase while it can achieve obvious system performance gains.

IV. SIMULATION RESULTS

In this subsection, simulation results are introduced to show the PAPR reduction of SCMA-OFDM signals after clipping. The BER performance comparison among the diverse MPA detectors is provided to prove the veracity of the analytic clipping noise, including the MPA without clipping noise, the MPA with statistic clipping noise and the MPA with analytic clipping noise. And then the BER performance of the proposed iterative clipping noise elimination scheme is presented to verify the efficiency of the proposed scheme. The simulation parameters are listed in Table 1.

TABLE 1. Simulation parameters.

Parameter	Value
Number of users(J)	6
Resource elements(K)	4
Codebook size(M)	4
Number of resources each user occupies (d_u)	2
Number of users each RN connects (d_r)	3
Number of subcarriers(N)	256
Oversample factor(L)	4

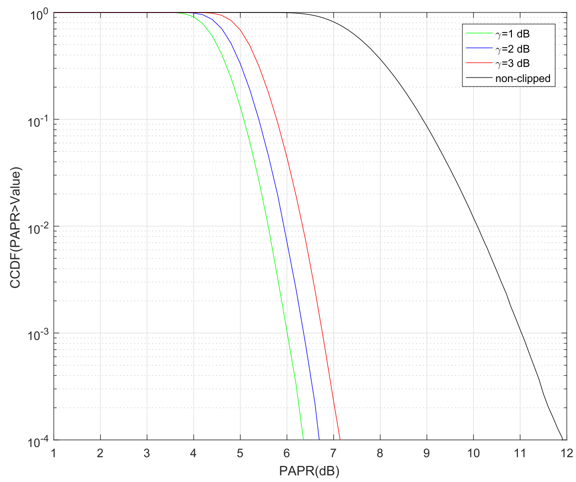

FIGURE 5. PAPR distribution for a SCMA-OFDM signal with different clipping ratio γ.

Fig. 5 shows the complementary cumulative distribution functions (CCDFs) of the PAPR for SCMA-OFDM signals with different clipping ratio. As shown in Fig. 5, the PAPR of SCMA-OFDM signal can be significantly reduced after the clipping process. In addition, the lower the clipping ratio is, the lower the PAPR of SCMA-OFDM signal will be. Due to the filtering operation after clipping, the PAPR of the SCMA-OFDM signal suffers peak regrowth obviously.

In MPA detection scheme, the variance parameter should be equivalent to the overall noise for decoding accurately. When the variance parameter is larger or lower than the overall noise, the MPA detector suffers BER performance penalty. As mentioned before, the clipping process brings extra noise to the SCMA-OFDM signal and makes the overall noise larger. Therefore, the clipping noise should be taken into account for decoding accurately.

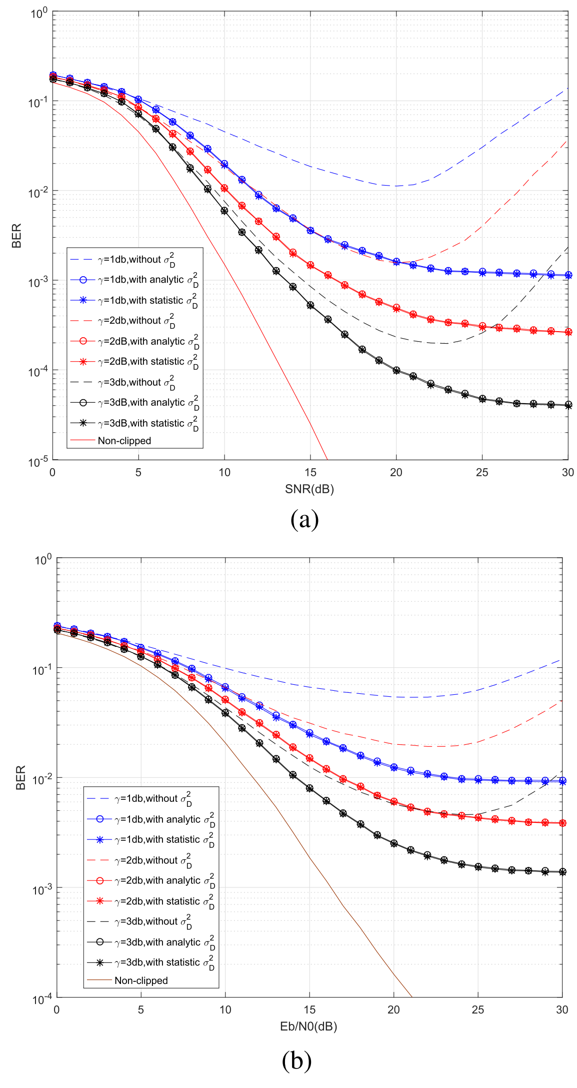

FIGURE 6. BER performance of MPA with different noise variance σ^2 over AWGN channel and Rayleigh channel. (a) AWGN channels. (b) Rayleigh channels.

In Fig. 6 describes the BER performance of the involved MPA schemes with different noise variances under the condition of AWGN channel and Rayleigh channel. Note that the received signal Y is decoded directly in the case that the clipping noise is not taken into account. As shown in Fig. 6, the MPA detector greatly suffers the BER performance degradation due to the existence of clipping noise, which will result in the inaccurate decoding in SCMA-OFDM system. Conversely, the BER performance of MPA detector improves obviously when the clipping noise is taken into consideration to achieve accurate decoding. Besides, for verifying the correctness of the analytic clipping noise, the simulation curves about the statistic clipping noise are also presented and overlap with the analytic clipping noise based simulation curves.

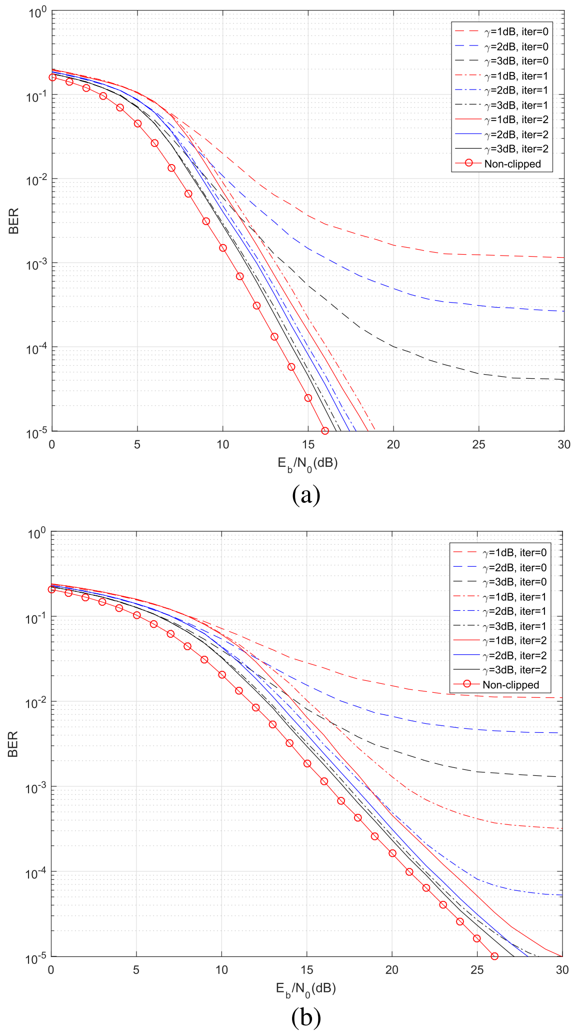

FIGURE 7. BER performance of the proposed iterative clipping noise elimination scheme over AWGN channel and Rayleigh channel. (a) AWGN channels. (b) Rayleigh channels.

Fig. 7 (a) shows the BER performance of the proposed iterative clipping noise elimination scheme with different iterations of clipping noise elimination over AWGN channel. When the iterative number of the clipping noise elimination satisfies $iter = 0$, the proposed scheme does not impact on the clipped SCMA-OFDM signals. As shown in Fig. 7 (a), the proposed scheme with $iter = 1$ achieves about 10 dB, 4 dB, 3 dB performance gains at E_b/N_0 when the clipping ratio is $\gamma = 1$dB, 2dB, 3dB respectively. With the increasing of the E_b/N_0, the clipping noise plays a more and more important role, so the proposed scheme can obtai the better BER performance gain at high E_b/N_0 range. The BER performance of the proposed iterative clipping noise elimination scheme ($iter = 2$) can be restored to only about 2dB, 1 dB, 0.5 dB worse than the non-clipped scheme when the clipping ratio satisfies $\gamma = 1$ dB, 2 dB, 3 dB, respectively. Similar to the case in AWGN channel, Fig. 7 (b) depicts the BER performance of the proposed scheme over Rayleigh fading channel.

According to the previous discussion, the BER performance of the clipped and filtered SCMA-OFDM system can be restored significantly by adopting the proposed iterative clipping noise elimination technique at the receiver. It is worth noting that the performance gain of the proposed MPA scheme mainly concentrates on the first iteration while the proposed MPA scheme just obtains limited performance gain with second or higher iteration, whether it is AWGN channel and Rayleigh fading channel. Through the analysis of the equation (24), the vast majority of the clipping noise is estimated and eliminated for the first iteration. Therefore, the BER performance of the proposed MPA detection scheme improves slightly for the second or higher iteration.

V. CONCLUSIONS

This paper considers that combines the SCMA with OFDM together to form a SCMA-OFDM system and proposes an iterative clipping noise elimination scheme to restore the system performance via eliminating the clipping noise at receiver side. We analyze the extra noise brought by clipping process and then give the analytic expression of the clipping noise. Subsequently, the AWGN and the clipping noise are merged together (overall noise) in MPA detector for decoding accurately. Hence, the proposed iterative clipping noise elimination scheme can restore the BER performance of SCMA-OFDM system significantly and will act a pivotal role in 5G wireless communications.

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