Research and Improvement on Detection Algorithm of SCMA System

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Abstract. In this paper, a grouping low-complexity MPA detection algorithm (DPG-MPA) based on dynamic pruning is proposed to solve the problem of high computational complexity at the receiver of SCMA system. In this algorithm, users are grouped into groups, and the user nodes in the group adopt the serial message transmission mode, and the priority of updating user information is judged according to the node convergence degree of user information. After a predetermined number of iterations, residual values of user nodes are calculated, nodes whose residual values are lower than the threshold value are marked as trusted nodes, and information values on trusted nodes are stopped in subsequent iterations. Simulation results show that the proposed algorithm can accelerate convergence and reduce redundant operations without losing the system's excellent bit error performance.

Keywords: SCMA · MPA · Algorithm

1 The Introduction

5G and satellite Iot systems connect everything through information processing and transmission technology, which supports a large number of users and fierce competition for spectrum resources. Multiple access technology has an important impact on the overall capacity and access capacity of the system. Sparse Code Multiple Access (SCMA) technology can realize overload transmission. However, with the increase of overload, the interference between codes and words increases, and the system error performance deteriorates, and the decoding complexity is very high. Therefore, it is worth studying to reduce the decoding complexity of high order systems on the premise of good error performance. In this paper, a new DPG-MPA algorithm is proposed to reduce the decoding complexity of SCMA system effectively.

2 Research on Principle and Decoding Algorithm of Serial SCMA System

2.1 System Description

Figure 1 shows the block diagram of the codec scheme of the serial SCMA system, which contains the first-level SCMA coding module at the transmitting end and P – 1

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Pattern matrix module $\mathbf{G}_p$, where c The whole transmitting module is divided into P sub-modules. In the serial encoding SCHEME of SCMA system, user binary bits are first mapped to low order SCMA(K_1, N_1, M_1) complex field code words by the first level SCMA system. Then it is processed by the P – 1 order $\mathbf{G}_p$ serial subsystem. The system overload is increased step by step, and finally the coding words of high order SCMA system are obtained.

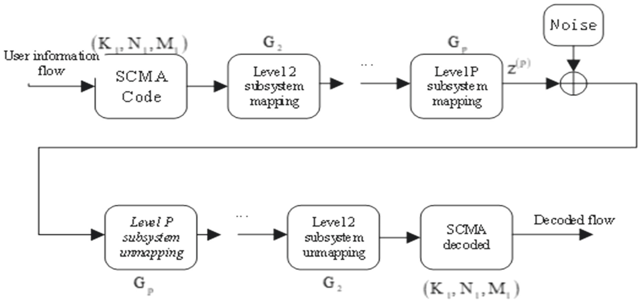

Fig. 1. Block diagram of codec scheme of serial SCMA system

2.2 Algorithm Research and Design

SCMA code words are sparse, the MPA algorithm originally used in LDPC decoder can be used for multi-user detection. However, with the expansion of the system scale, the complexity of MPA algorithm is still too high, resulting in high requirements on hardware, which is impossible to implement in reality. Therefore, it is necessary to further study how to reduce the computational complexity of MPA algorithm. The process of traditional MPA algorithm is as follows.

Step 1: initialize the prior probabilities of all code words for each user and the function information at the resource node.

Assuming that the code word sent by the user is prior and equal, the information at the user node is initialized as:

$$I^0_{v_j \to g_k}(x_j) = \frac{1}{M}, \forall j \tag{1}$$

The conditional probability is calculated at the resource node

$$\phi_k = \exp\left(-\frac{1}{2\sigma^2}\left\| y_k - \sum_{m \in \xi_k} h_{k,m} x_{k,m} \right\|^2\right) \tag{2}$$

Where $I^t_{g_k \to v_j}(x_j)$ represents the message update value of the t round iteration, $h_{k,m}$ and $x_{k,m}$ represent the channel coefficient and codebook component of user M transmitted on subcarrier K.

Step 2: Iterate message passing based on factor graph to update message values from RN to UN.

$$I_{g_k \to v_j}^t(x_j) = \sum_{\sim x_j} \left\{ \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{1}{2\sigma^2} \left\| y_k - \sum_{m \in \xi_k} h_{k,m} x_{k,m} \right\|^2 \right) \times \prod_{l \in \xi_k / \{j\}} I_{v_l \to g_k}^{t-1}(x_l) \right\} \tag{3}$$

where, $I_{g_k \to v_j}^t(x_j)$ represents the message update value in the t iteration, $h_{k,m}$ and $x_{k,m}$ represent the channel coefficient and codeword component of user M transmitted on subcarrier K respectively. $\xi_k / \{j\}$ is all the elements in ξ_k minus j.

Step 3: Update the message values from UN to RN.

$$I_{v_j \to g_k}^t(x_j) = N\left(\Pr(x_j) \prod_{m \in \zeta_j / \{k\}} I_{g_m \to v_j}^t(x_j) \right) \tag{4}$$

where $\Pr(x_j)$ represents the prior probability of the code word $x_j.N(\cdot)$ represents a normalized function.

Step 4: Output the decoding result.When the number of iterations reaches the target number of iterations T, the decision is made. Calculate the probability value of each code word:

$$Q(x_j) = \prod_{k \in \zeta_j} I_{g_k \to v_j}^T(x_j), \forall j \tag{5}$$

The maximum value of $Q(x_j)$ corresponds to the code word information and the detected code word information of user J.

The S-MPA scheme takes advantage of the principle that new messages obtained when updating a single node can be immediately used for message updating of other nodes in the same iteration, thus sequential updating of UN messages during the same iteration. For $1 \le j \le J$ and $k \in \zeta_j$, the message update processes for RN and UN are processed jointly.Message update processes for RN and UN are processed jointly. The convergence process can be accelerated by using more reliable messages during iteration, and Formula (3) is modified as

$$\begin{aligned} & I_{g_k \to v_j}^t(x_j) \\ & = \sum_{\sim x_j} \left\{ \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{1}{2\sigma^2} \left\| y_k - \sum_{m \in \xi_k} h_{k,m} x_{k,m} \right\|^2 \right) \times \prod_{\substack{l \in \xi_k / \{j\} \\ l < j}} I_{v_l \to g_k}^t(x_l) \prod_{\substack{l \in \xi_k / \{j\} \\ l > j}} I_{v_l \to g_k}^{t-1}(x_l) \right\} \end{aligned} \tag{6}$$

PM-MPA algorithm introduces two user parameters M and R_s, based on these two parameters to control the algorithm complexity. The current number of cycles is t, the total number of cycles is t. At that time, the resource node fed back information to the user node according to the original MPA algorithm. When $t = m$, select $i = R_s/d_c$

element in $\hat{\mathbf{x}}^m$. $\hat{\mathbf{x}}^m$ represents the estimator of user node information $\hat{\mathbf{x}}$ obtained after the mth iteration. The PM-MPA algorithm selects the last i elements, $\hat{\mathbf{x}}^m$ are divided into two parts. When $t > m$, the last i elements $\breve{\mathbf{x}}$ are used in place of x, and the information of the first node in x is updated during the subsequent loop.And updates the information of the previous $J - i$ node in x during the subsequent loop.

Max-log-MPA introduce MPA algorithm into logarithmic domain and use maximum approximation, the original large number of exponential operations and multiplication operations are simplified into simple operations such as summation and comparison. Use the following relationship:

$$\log\left(\sum_{i=1}^{N}\exp(f_i)\right) \approx \max_{i=1,\ldots,N}\{f_1, f_2, \ldots, f_N\} \tag{7}$$

By applying the above formula to MPA detection algorithm and combining with Formula (3), the original formula can be simplified as

$$L^t_{g_k\to v_j}\left(x_j\right) \doteq \max\left(-\frac{1}{2\sigma^2}\left\|y_k - \sum_{m\in\xi_k} h_{k,m}x_{k,m}\right\|^2\right) + \sum_{l\in\xi_k/\{j\}} L^{t-1}_{v_l\to g_k}(x_l) \tag{8}$$

Combining formula (7) and Formula (4), it can be obtained:

$$L^t_{v_j\to g_k}\left(x_j\right) = \sum_{m\in\zeta_j/\{k\}} L^{t-1}_{g_m\to v_j}\left(x_j\right) + \Pr\left(x_j\right) \tag{9}$$

The algorithm proposed in this paper comprehensively utilizes the advantages of the above three improved schemes, proposes a grouping of low-complexity MPA (DPG-MPA) based on dynamic pruning, and further optimizes the performance of MPA algorithm. The process is as follows:

Step 1: Input known information, including user codebook, factor graph matrix, noise and channel parameters, signal **y** received by decoding end, number of user groups G, total number of iterations T, number of pruning start iteration T1, node residual value threshold TH, etc.

Step 2: initialize the user node information according to Formula (1). The update sequence set of user nodes is seted as $\Phi(t)$, initialized as $\Phi(1) = \{1, 2, \ldots, J\}$, and update the user node information in the original order. After each iteration, the user subscript order in $\Phi(t)$ will be updated according to the convergence degree of user nodes.

Step 3: Start iterating when t < T. Starting from the user node corresponding to the subscript of the first element in set $\Phi(t)$, determine which group this user node belongs to, calculate the updated message $L^t_{g_k\to v_j}\left(x_j\right)$ at this user node according to Formula (8), and jointly update $L^t_{v_j\to g_k}\left(x_j\right)$ according to formula (9).

All the edge residuals $R^t_{v_j\to g_k}$ were calculated according to the factor graph, and the convergence degree M_j was reached according to the edge residuals. Set $\Phi(t)$ was updated as $\Phi(t+1)$ for the next iteration.

If $t < T_1$, t = t + 1. if $t \geq T_1$, Then compute the node residuals R^t_j of all user nodes that are not marked as trusted nodes. Mark the user node $R^t_j <$ th as a trusted node. And delete the subscript of this node in $\Phi(t+1)$, Then, T = T + 1.

Step 4: End the iteration and obtain the decoding result according to Formula (5).

2.3 Performance Analysis of Decoding Algorithm

Figure 2 shows the calculation amount of MPA, PM-mpa, S-MPA and DPG-MPA algorithms in addition, multiplication and exponential operation in an SCMA system with 6 users and 4 resource nodes. In the PM-MPA algorithm $m = 3$, $R_s = 2$ In the DPG-MPA algorithm, $T_1 = 1$, th $= 10^{-6}$.

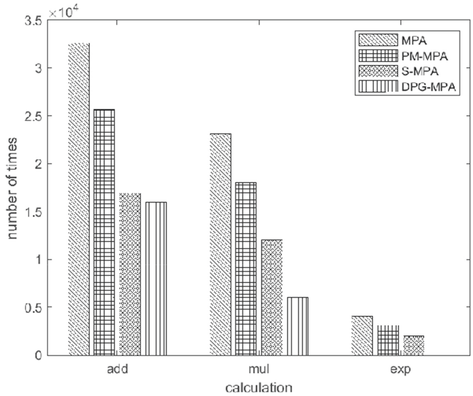

Fig. 2. Comparison of computation amount between different decoding algorithms

It can be seen from Fig. 2 that compared with MPA algorithm, DPG-MPA algorithm can reduce the amount of computation by about 50%, and the degree of reduction varies according to the threshold value, the number of initial iterations of pruning operation and other parameters.

Figure 3 shows the ber curves of MPA algorithm, S-MPA algorithm and DPG-MPA algorithm under different iterations. The SCMA system adopted has 6 users, 4 resource nodes, 150% overload and SNR = 6. In the PM-MPA algorithm $m = 3$, $R_s = 2$ In the DPG-MPA algorithm, $T_1 = 1$, th $= 10^{-6}$.

According to Fig. 3, when the number of iterations is large enough, the ber of each algorithm tends to converge. Both S-MPA algorithm and DPG-MPA algorithm can accelerate the convergence process, thus achieving lower computational complexity. In addition, the bit error rate of DPG-MPA algorithm is lower than that of S-MPA algorithm in the first three iterations, indicating that DPG-MPA algorithm has better convergence performance.

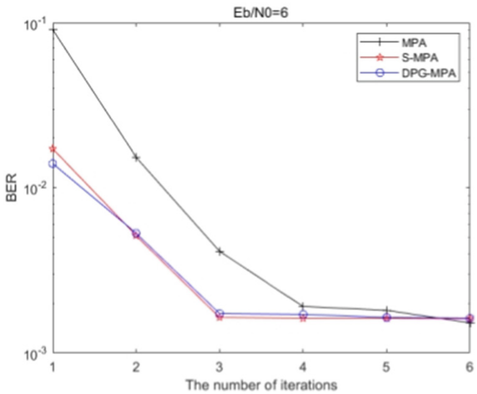

Fig. 3. SER performance curve of different decoding algorithms changing with the number of iterations

3 Conclusion

All the decoding algorithms studied in this paper are based on the improvement of MPA algorithm. The DPG-MPA algorithm proposed in this paper can further reduce the complexity of the decoding algorithm while ensuring less loss of the system's bit error performance.

At the same time, the decoding research work in this paper is based on the ideal condition of complete synchronization of signals at the receiving end, and the synchronization deviation of signals will greatly affect the performance of the decoding end. How to minimize synchronization deviation has important research value and can be further studied.

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