Research on the performance of multi-user detection algorithm based on serial and threshold in the IoT

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Abstract. In the 5G system for the Internet of Things (IoT), the detection and identification of a large number of IoT users or devices has become a key issue in the research of IoT technology. In the multi-user detection algorithm based on 5G technology, due to the slow convergence speed and high complexity of the traditional algorithm, people began to consider the conditions of adding serial and threshold to study, in order to improve the performance of multi-user detection in the IoT based on 5G. In this paper, based on the research of Maximum logarithm Message Passing Algorithm (Max-log-MPA) based on threshold, the serial condition setting is added to analyze the performance of Max-log -MPA algorithm based on serial and threshold (S-T-Max-log-MPA) and Max-log-MPA algorithm based on threshold (T-Max-log-MPA), so as to obtain a better multi-user detection algorithm based on 5G in the Internet of things. The simulation results show that the S-T-Max-log-MPA algorithm has lower bit error rate and better performance in the experiment, which is more suitable for multi-user detection in the Internet of things based on 5G.

Keywords: Internet of things, sparse code multiple access technology, MPA algorithm, bit error rate, serial

1 Introduction

In recent years, with the rapid development of big data, cloud computing, smart city, etc., the network is facing the growing demand of high capacity, high transmission rate and low delay, and the Internet of Things (IoT) industry has entered a stage of rapid development [1]. Especially with the rapid development of 5G technologies, the application of the IoT breaks the established concept of people to people interconnection of the existing mobile network, and realizes the real IoT, people to people and people to things [2], bringing great convenience to people's production and life. In the application of IoT based on 5G, the number of users is usually large. How to use multi-user detection to solve such problems as reducing the cost of machine terminals, resource allocation and low-cost IoT terminal coverage has become an important research issue [3].

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Sparse Code Multiple Access (SCMA) is one of the core technologies of 5G. It is a new orthogonal multiple access technology using sparse codebook, and it is the extension of Low Density Signal (LDS) [4] [5]. When detecting the accuracy of data and dealing with multi-user access problems, SCMA multiple access technology realizes the capacity of more users under the same number of resources, increases the overall throughput of the network, and realizes massive connections through code field sparse expansion and non-orthogonal superposition. In addition, LDS integrates the modulation idea of sparse spread spectrum and high-dimensional modulation technology, mapping the bit data stream in the link to the multi-dimensional codeword in the preset codebook, to solve the system overload problem caused by a large number of data connections [6]. However, in the existing SCMA system, when the Message Passing Algorithm (MPA) performs multi-user detection of the received signal [7], the calculation complexity of the algorithm is too high and the transmission accuracy is poor, so it is difficult to apply it to the actual decoding process [8]. Therefore, the accuracy of multi-user detection algorithm in the transmission of information is still one of the important challenges in the multi-user detection of the IoT [9]. In reference [10], it is described that in the context of IoT communication, compressed sensing is used for multi-user detection. Many studies assume that the channel information is known, and in practical applications, channel estimation is also needed which improves the complexity of the system. The Maximum logarithm Message Passing Algorithm (Max-log-MPA) based on log domain and the algorithm based on serial MPA (S-MPA) are proposed in reference[11] [12], it reduces the computational complexity, but the system loss is large. In reference [13], an improved multi-user detection algorithm based on partial edge is proposed. Although the complexity of the algorithm is reduced, the BER performance is also reduced. In reference [14], an improved serial scheduling based MPA (ISS-MPA) detection scheme is proposed. Although it can maintain good bit error rate performance, the complexity effect of the detection algorithm is not particularly good. In reference [15], a threshold based MPA algorithm is proposed, which uses a threshold to control the algorithm, so as to reduce the complexity of detection algorithm. In reference [16], an algorithm is proposed to reduce the decoding complexity of SCMA by introducing a weighting factor instead of the iterative process of MPA algorithm. In reference [17], a threshold-based Max-log-MPA low complexity multiuser detection algorithm is proposed. The influence of the change of signal-to-noise ratio on complexity is analyzed to reduce the complexity of multiuser detection better.

Among the above algorithms, a new method is proposed to compare with the traditional MPA algorithm, so as to prove the superior performance of the proposed algorithm and analyze the performance of each algorithm. Therefore, based on the research of Max-log-MPA algorithm based on threshold, this paper adds serial condition setting to analyze the performance of the Max-log-MPA algorithm based on serial and threshold (S-T-Max-log-MPA) and the Max-log MPA algorithm based on threshold (T-Max-log-MPA), so as to select an optimal multi-user detection algorithm to solve the problem of multi-user detection in the application of IoT based on 5G.

2 SCMA system model

Sparse code multiple access(SCMA) is a non-orthogonal access method based on code domain[18]. At the transmitter, each user has its own codebook [19], and the transmitter consists of two parts: multidimensional modulation and sparse spread spectrum [20-22]. Sparse spread spectrum plays an important role in transmission. The information bits of different users are mapped into multi-dimensional codewords after channel coding, and then are non-orthogonal stacked on the same resource block by sparse spread spectrum.

The SCMA uplink model consists of transmitter, transmission channel and receiver, as shown in Figure 1. It can be seen that in the multi-user SCMA system, different binary bitstreams are mapped to the codewords of SCMA multi-dimensional codebook by different users through different codebooks. Assuming that the number of users and codebook of IoT is J, and the codebook length is K (J > k), then the users of IoT $u_j(u_1, u_2, \cdots, u_J)$ get binary bit data stream $b_j(b_1, b_2, \cdots, b_J)$ after source coding and channel coding. When entering the SCMA encoder transmission, the j-th user's bit stream is mapped to the orthogonal subcarrier through the codebook. The mapping process can be expressed as $f: B^{log_2 M} \rightarrow \chi$[23][24], B represents the set of binary numbers, and χ is the user's codebook. Because the channels of each layer of the upper link are different, the channel factor is different. Suppose the channel factor is $h_j(h_1, h_2, \ldots, h_J)$.

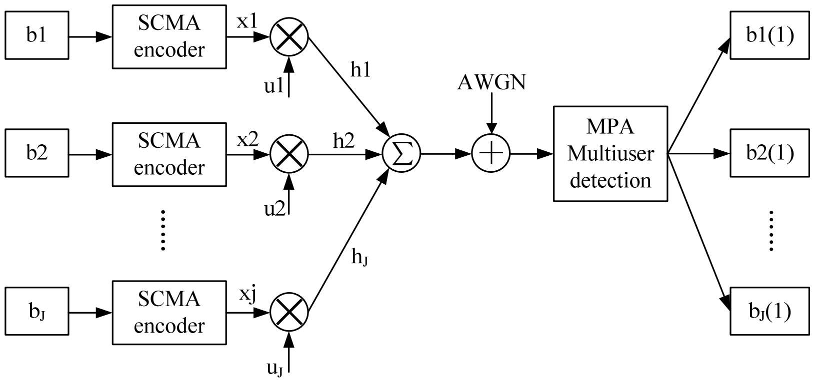

Figure1 uplink SCMA communication system model

M in $B^{log_2 M}$ represents the size of codebook. Assuming that the user node data is divided into several groups according to a-bit, the size M of codebook is:

$$M = 2^a \tag{1}$$

First, define an overload factor $\lambda = J/K$, assume that there are 6 user nodes and 4 time-frequency resource blocks, as shown in Figure 2. It can be seen that at this time, the overload factor λ= 1.5, in other words, the system has 150% overload capacity. As shown in Figure 3, user1,…, user6 represents six different user nodes. The bit information of these six user nodes is mapped to the codewords of different codebooks, and each user node has and only has one codebook corresponding to it.

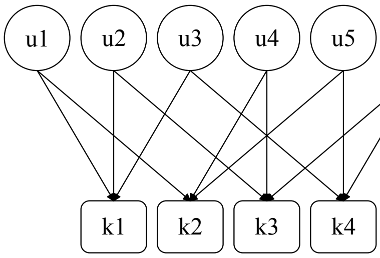

Figure 2 SCMA factor diagram

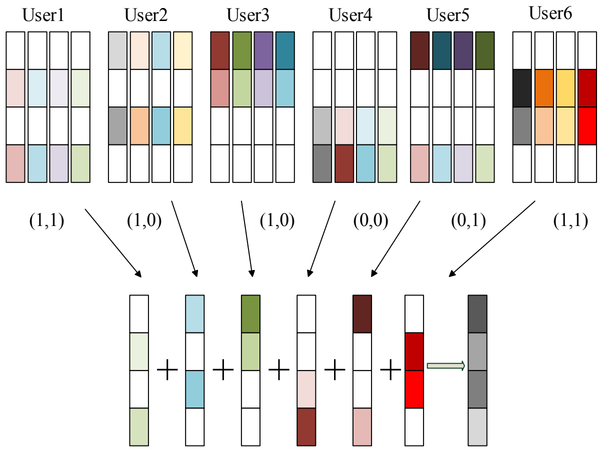

Figure 3 SCMA coding principle

From figure 2 and Figure 3, it can be seen that the area where element 0 is located is a white area, and the area where element 1 is located is a colorful area, it means that in user1, orthogonal time-frequency 1, 3 resources transmit signals, 2, 4 resources do not transmit signals, and so on, the following matrix can be obtained:

$$F_{4\times 6} = \begin{bmatrix} 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{bmatrix} \tag{2}$$

Assuming that the time of each IoT user is synchronous, the signal received by the base station is the weighting of all signals:

$$y = \sum_{j=1}^{J} diag\left(\mathrm{h}_j\right) x_j + n \tag{3}$$

Where, $x_j = [x_{1,j}, x_{2,j}, \cdots, x_{K,j}]^T$ is the codeword sent by user j. $\mathrm{h}_j=[\mathrm{h}_1, \mathrm{h}_2, \ldots, \mathrm{h}_K]^T$ represents the receiver channel vector, which is the channel gain matrix. n represents the Gaussian white noise in the transmission channel $n \sim CN(0, \sigma^2 I)$. In this case, the signal received by the time-frequency resource at K can be expressed as:

$y_k = \sum_{j=1}^{j} h_k, x_k^j + n_k$ .Because of its sparsity, the code word conflict at time-frequency resource K will be greatly reduced[25].

3 T-Max-log-MPA algorithm

The T-Max-log-MPA algorithm is based on the Threshold based MPA algorithm (T-MPA), adding the judgment of the necessary conditions for the stability of user nodes. Before updating the message, first judge whether the user information nodes meet the necessary conditions for the stability of user nodes, and then judge whether they pass the threshold conditions. Only when users who meet the threshold conditions and pass the necessary condition of user node stability can be decoded in advance.

In the SCMA iteration process, if the user node u_j in the factor graph is in the same position in the i-th cycle iteration process, that is, the i-th iteration is equal to the result of the i'-th iteration [26]: $arg \max_{1 \le m \le M} q^i(\chi_{j,m}) = arg \max_{1 \le m \le M} q^{i'}(\chi_{j,m}), i < i' < I_{\max}$, This indicates that the user u_j node is stable. Therefore, in the i-th iteration and the (i+1)-th iteration, the same position of the largest element in the codeword credibility vector is a necessary condition for the stability of the user node, $arg \max_{1 \le m \le M} q^i(\chi_{j,m}) = arg \max_{1 \le m \le M} q^{i+1}(\chi_{j,m})$.

The algorithm can be divided into three steps:

Step 1: receive condition initialization:

$$I^0_{c_k \to u_j}\left(x_j\right) = \frac{1}{M} \tag{4}$$

$$I^t_{c_k \to u_j}\left(x_j\right) = \sum_{\sim x_j} \left\{ \frac{1}{\sqrt{2\pi}\delta} \exp\left(-\frac{1}{2\delta^2} \left\| y_k - \sum_{v \in \xi_k} h_{k,v} x_{k,v} \right\|^2 \times \prod_{m \in \varsigma_k / j} I^{t-1}_{c_m \to u_k}\left(x_j\right) \right) \right\} \tag{5}$$

Where, *t* is the number of iterations , ξ_K and ζ_k represents the non-zero position set of row k and column j in the *F* matrix respectively.

Step 2: update the asset node:

$$I^t_{u_j \to c_k}\left(x_j\right) = \prod_{m \in \xi_j / k} I^t_{u_k \to c_m}\left(x_j\right) \tag{6}$$

Step 3: when formula (5) and formula (6) reach the maximum number of iterations, the output probability after MPA decoding $Q(x_j)$ is:

$$Q\left(x_j\right) = \prod_{k \in \xi_j} I^{t_{\max}}_{c_k \to u_j}\left(x_j\right) \tag{7}$$

By combining formula (4) - (7), we can get:

$$I^{t}_{c_k \to u_j}\left(x_j\right) = \frac{1}{\sqrt{2\pi}\delta} \times \max_{i=1,2,\ldots,\mathrm{N}} \left\{ -\frac{1}{2\delta^2} \left\| y_k - \sum_{v\in\varepsilon_k} h_{k,v} x_{k,v} \right\|^2 + \sum_{v\in\varepsilon_k} I^{t-1}_{u_j \to c_k}\left(x_j\right) \right\} \quad (8)$$

$$I^{t}_{u_j \to c_k}\left(x_j\right) = \sum_{v\in\varepsilon_k/\mathrm{m}} I^{t}_{c_m \to u_j}\left(x_j\right) \quad (9)$$

Where, t still represents the number of iterations. When the algorithm passes the maximum number of iterations, the output probability of each user's codeword is:

$$Q\left(x_j\right) = \sum_{v\in\varepsilon_j} I^{t_{\max}}_{c_k \to u_j}\left(x_j\right) \quad (10)$$

4 S-T-Max-log-MPA algorithm

Based on the Max-log-MPA algorithm, the S-T-Max-log-MPA algorithm introduces the serial update algorithm and threshold MPA algorithm, in the Max-log-MPA algorithm, index (EXP) algorithm is changed into sum algorithm and maximum value. In the serial update algorithm, user node message update is integrated into resource node information update to reduce the complexity of information storage. In the threshold MPA algorithm, hard decision is used to effectively reduce the user node information that needs to be updated in each cycle. This algorithm combines the advantages of the three, can effectively reduce the complexity of the detection algorithm while maintaining a good bit error rate.

Because the S-T-Max-log-MPA algorithm first judges the stability of IoT users in the iterative update process, the formula (5) of the resource node update process of the algorithm is modified as follows:

$$I^{t}_{c_k \to u_j}\left(x_j\right) = 2 \times \frac{1}{\sqrt{2\pi}\delta} \times \max_{\sim x_j} \left\{ -\frac{1}{2\delta^2} \left\| y_k - \sum_{v\in\xi_k} h_{k,v} x_{k,v} \right\|^2 \times \prod_{m\in\varsigma_k/j} I^{t-1}_{c_m \to u_k}\left(x_j\right) \right\} \quad (11)$$

After that, the log likelihood ratio (LLR) of each user's coding bit determines the user:

$$Q\left(x_j\right) = ap_v\left(x_j\right) \times \prod_{m\in\xi_k/j} I_{c_m \to u_k}\left(x_j\right) \quad (12)$$

Where, $ap_v(x_j)$ represents the prior probability of the user J code word.

$$\mathrm{LLR}_{j,x} = \log\left(\frac{P\left(b_i = 0\right)}{P\left(b_i = 1\right)}\right) = \log\left(\frac{\sum_{m:b_{m,i}=0} Q\left(x_j\right)}{\sum_{m:b_{m,i}=1} Q\left(x_j\right)}\right) \quad (13)$$

Where, $LLR_{j,x}$ is the log likelihood ratio, $\sum_{m:b_{m,i}=0} Q\left(x_j\right)$ represents the output probability of the decoded variable node, $\sum_{m:b_{m,i}=1} Q\left(x_j\right)$ represents the output probability of the variable node to be decoded. $P(b_i = 0)$ represents the probability of the decoded variable node VN, and $P(b_i = 1)$ represents the probability of the variable node VN to be decoded.

5 Analysis of BER performance

In the SCMA system, the T-Max-log-MPA algorithm combines the codeword credibility and user node stability, eliminates the exponential operation, and increases the judgment of the necessary conditions for the user node stability. Before the message is updated, the stability and threshold conditions of the user node are judged successively, which can not only increase the reliability of the decision codeword, but also reduce the loss of posterior soft information during the transmission process, which improves the accuracy of message delivery and BER performance. The S-T-Max-log-MPA algorithm adds the serial mode to the T-Max-log-MPA algorithm. Because of the serial mode, the asynchronous mechanism is also added to the algorithm. Because of the existence of the asynchronous mechanism, in each iteration, all resource nodes can process and deliver messages at the same time, and the received messages can be delivered in a timely manner, which accelerates the convergence performance of the algorithm, and achieves the desired effect when the number of iterations is small, and further improve BER performance.

6 Analysis of simulation results

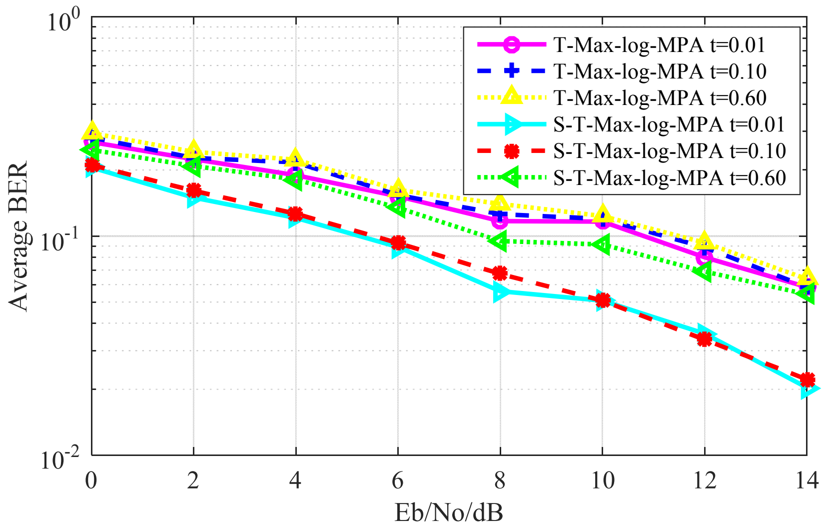

Figure 4 BER performance comparison between T-Max-log-MPA algorithm and S-T-Max-log-MPA algorithm when $T_{max} = 2$

Figure 4 shows the BER performance comparison between T-Max-log-MPA algorithm and S-T-Max-log-MPA algorithm when T_{max}= 2. It can be seen from Figure 4 that when T_{max}= 2, the overall BER performance of S-T-Max-log-MPA algorithm is higher than that of T-Max-log-MPA algorithm within the threshold value range of $0 \leq E_b/N_o \leq 14$dB, and the smaller the threshold, the more obvious the change, and the greater the BER performance difference. Comparing the BER performance of S-T-Max-log-MPA and T-Max-log-MPA with the change of signal-to-noise ratio, we can see that when $E_b/N_o = 0$, if the threshold value th = 0.01, the BER of them are 20.55% and 26.83% respectively, and the BER of S-T-Max-log-MPA is 6.28% lower than that of T-Max-log-MPA. If the threshold value th = 0.10, the BER performance of the two algorithms are 21.08%, 28.13% respectively, and the BER performance of S-T-Max-log-MPA is 7.05% lower than that of T-Max-log-MPA. When the threshold value th = 0.6, the BER performance of the two algorithms is 24.7%, 29.48% respectively, which is lower than 4.78% of T-Max-log-MPA algorithm. When $E_b/N_o = 14$, calculate the BER when the thresholds are th = 0.01, th = 0.1, th = 0.6 respectively. The BER performance of the S-T-Max-log-MPA algorithm under the above three thresholds are: 2.033%, 2.177%, 5.417%, T-Max-log-MPA algorithm are 5.85%, 5.85%, 6.367%, and their bit error rates differ by 3.817%, 3.673%, 0.959%. It can be seen from the above that under the same threshold, with the increase of E_b/N_o, the smaller the bit error rate is, the better the optimization effect is. Therefore, when $T_{max}= 2$, the performance of S-T-Max-log-MPA is better than that of T-Max-log-MPA.

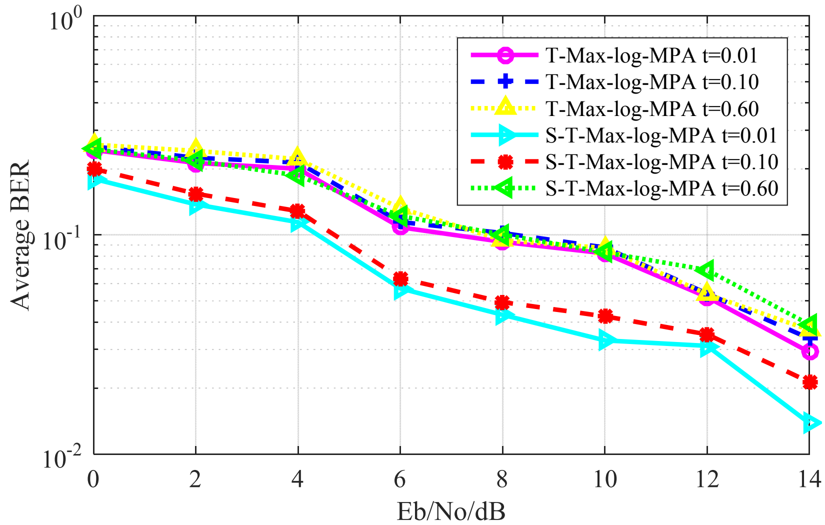

Figure 5 BER performance comparison between T-Max-log-MPA algorithm and S-T-Max-log-MPA algorithm when T_{max}=3

Figure 5 shows the performance comparison between S-T-Max-log-MPA algorithm and T-Max-log-MPA algorithm when T_{max}=3. When E_b/N_o =0, S-T-Max-log-MPA algorithm at the threshold value th=0.01, 0.1, 0.6, the corresponding BER performance is 18.02%, 20.03%, 24.58%, T-Max-log-MPA algorithm corresponding values are 24.38%, 25.32%, 25.78%, and the BER performance differs by 6.36%, 5.29%, and 1.2%. The performance of S-T-Max-log-MPA algorithm is best. When E_b/N_o =14, S-T-Max-log-MPA algorithm at the threshold value th=0.01, 0.1, 0.6, the corresponding BER performance is 1.383%, 2.133%, 3.9%, and T-Max-log-MPA algorithm corresponding values are 2.917%, 3.367%, 3.683%. It can be seen from the results that when the threshold is less than 0.6, the performance of S-T-Max-log-MPA is better than that of T-Max-log-MPA. Therefore, when T_{max}=3, the threshold value is less than 0.6, S-T-Max-log-MPA performance is better than T-Max-log-MPA.

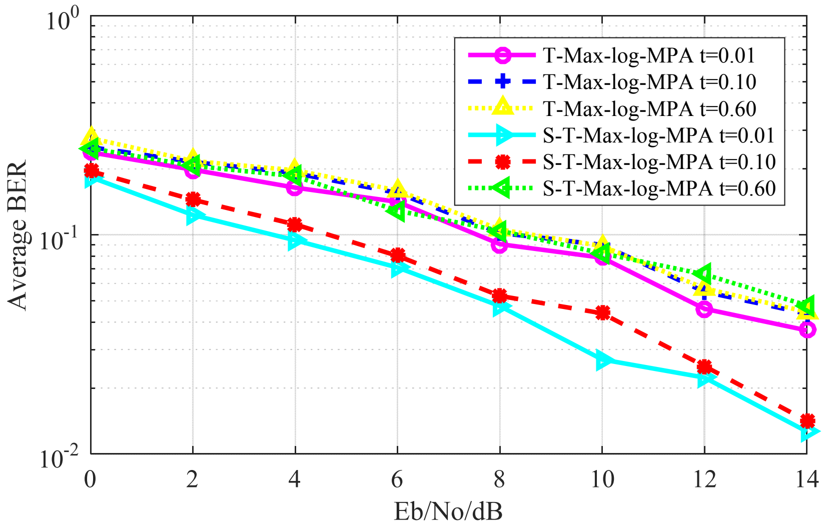

Figure 6 BER performance comparison between T-Max-log-MPA algorithm and S-T-Max-log-MPA algorithm when T_{max}=5

Figure 6 shows that when T_{max}=5 and the BER performance of S-T-Max-log-MPA algorithm and T-Max-log-MPA algorithm under the same threshold. As can be seen from the Figure 6, the BER performance of the S-T-Max-log-MPA algorithm is the best when the E_b/N_o changes from 1 to 14 and th is less than 0.6. However, when th=0.6, the BER of S-T-Max-log-MPA algorithm is worse than T-Max-log-MPA algorithm, which indirectly shows that the best threshold value is less than 0.6 in the calculation process of the algorithm. Therefore, when selecting the optimal result, the part with threshold value th<0.6 is taken.

7 Conclusion

Based on the research of 5G based multi-user detection method in the IoT, this paper in-depth the S-T-Max-log-MPA algorithm and the T-Max-log-MPA algorithm. Through the comparison of experimental simulation, when the maximum number of iterations is 2, 3 and 5, when the threshold value is less than 0.6, with the change of Eb/No of signal-to-noise ratio, the BER performance of S-T-Max-log-MPA algorithm is better than that of T-Max-log-MPA algorithm, and the smaller the threshold value, the more obvious the curve change, the more significant the BER performance improvement. It can be concluded that BER performance of S-T-Max-log-MPA algorithm is better than that of T-Max-log-MPA algorithm. The former algorithm can better solve the problem of poor BER performance of threshold messaging algorithm at low threshold, and can be better applied to multi-user detection based on 5G IoT.

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