Mapping Algorithm of Multi-code combination spread spectrum technology for Short Packet Transmission

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Abstract. Multi-code combined spread spectrum (MCSS) is based on M-ary spread spectrum to improve information payload by combining multiple spread spectrum sequences, which solved the contradictions between spread spectrum gain and transmission efficiency under limited channel bandwidth conditions. This paper focuses on two mapping algorithms of multi-code combination spread spectrum and their decoding algorithms for MCSS, which transmits the information by combining multiple spreading sequences. The R-combined mapping algorithm is provided to keep the sequence orthogonal and the design complexity increases with the increase of the number of correlators at the receiver while the SVC algorithm is adopted and MMP algorithm is used to realize multi-code combination spread spectrum with increasing sequences. The BER performance of the two algorithms is compared through simulation analysis.

1. Introduction
Short message transmission has wide application prospects in 5G and military wireless communication. Short message transmission system is adopted from different angles of communication concealment, anti-interception, real-time and so on. At the same time, the emergence of wireless communication requirements such as the Internet of Things (IoT) and the Internet of vehicles, as well as high-reliability and low-delay application scenarios in the future will fundamentally change the design of communication system, and the problem of short packet transmission to meet the requirements of low-time-delay and high-reliability communication is increasingly attracting people's attention [1]. With the shortening of data length, the traditional Shannon information theory and design criteria based on long code will not be able to meet the practical needs. As the latest breakthrough achievement of information theory in the post-Shannon era, the limited block length coding theory will provide an achievable boundary and a new design criterion for the efficient transmission of short messages.

In the anti-interference communication, spread spectrum communication has been widely used due to its strong anti-interference ability, low power spectral density, strong concealment and low probability of interception. However, under the condition of a certain information rate, the traditional spread spectrum system needs to increase the spread spectrum factor in order to obtain a large enough processing gain, and the system bandwidth also increases accordingly. As spectrum resources become increasingly scarce, systems with large bandwidths are often limited. In order to solve the contradiction
between the channel bandwidth and the processing gain of the traditional spread spectrum system [2] in the 1990s, Professor Zhu Jinkang proposed the parallel combination spread spectrum communication, also known as multi-code combination spread spectrum [3].

The mapping algorithm is the key to distinguish the multi-code combination spread spectrum from the general spread spectrum scheme. In essence, the mapping algorithm selects a reversible one-one mapping rule to indicate the correspondence between the information bits and the spread spectrum code. R-combined mapping algorithm is the most mainstream mapping algorithm at present. The decoding algorithm mainly uses M correlators to detect the correlation of the spread spectrum sequence and selects the one with the greatest correlation to recover the information bits. However, with the increase of transmitting bits of information, the numbers of the sequences required for mapping increases, so it is difficult to ensure that each sequence remains orthogonal. At the same time, the number of correlators required by the receiver increases with the increase of the sequence, which greatly increases the complexity of the design of the receiver correlator. Recently, the multi-code combination spread spectrum technology based on sparse vector coding is proposed. The transmitted information is mapped to the non-zero position of sparse vector for spread spectrum through the mapping algorithm, and the receiver detects through the multi-path matching tracking algorithm (MMP) to complete the signal recovery.

In the paper, we mainly introduced two kinds of mapping algorithms, and briefly introduced the decoding algorithm. We analysed by simulation the effects of combination sequence number r and modulation order M on the performance of r-combination mapping algorithm, what’s more simulated the performance of the two mapping algorithms.

2. Mapping algorithm

In multi-code combination spread spectrum, r (r>1) sequence combinations are selected from the sequence set of M orthogonal PN codes. Corresponding r bars are selected from M sequences, that is $\binom{r}{M}$ combinations are possible. Therefore, the information bits that a combination sequence can carry is $\log_2 \left( \binom{r}{M} \right)$. And r bar sequence has $2^r$ polarity states, which can carry r bit information. So the total number of information bits in the multi-code combination spread spectrum k is

$$k = r + \left\lfloor \log_2 \binom{r}{M} \right\rfloor$$

(1)

Figure 1 provides the transmitting diagram of the multi-code combination spread spectrum. In essence, the mapping algorithm selects a reversible one - one mapping rule to indicate the correspondence between information source and spread spectrum code.

![Figure 1](image_url)

**Figure 1** The transmitting diagram of the multi-code combination spread spectrum transmitter

2.1. R-combined mapping algorithm

When applying this principle to the mapping algorithm, the transmitter and receiver must use the same spread spectrum sequence sets. The spread spectrum mapping of data can be regarded as taking the input parallel data as the control information of the selection rule to select r elements from the set containing M elements. Demagnetizing means that r elements are known to be selected from the set of M elements in order to recover data from them. In the actual application of the combined mapping algorithm, the
data is also divided into $d_r$ and $d_c$, $d_r$ controls the selection of $r$ PN sequences by using Formula (2), $d_c$ controls the polarity of the selected column. The flow chart of r-combined mapping algorithm is shown in Figure 1. From M different sequences take a r element combination, if known according to the order number of $N$, the combination of the composite elements of the $a_i$ $(1 < i < r)$, be determined by the type

$$\min C_{U-a}^{r-i+1} \leq C_{U}^{r} - N - \sum_{i=1}^{r-1} C_{U-a}^{r-i+1}$$

(2)

Assume that the data sent is 1010000111, and the first 9 bits are converted to decimal $N=321$ in the first place according to the high order, according to equation (2), it can be obtained $C_{10-9}^{3} \leq C_{10}^{4} - 321 \ a_i = 4$, similarly we can get $a_2 = 10, a_3 = 12$. Therefore, the combinational elements corresponding to the combinational sequence 321 are 4, 10, and 12, in other words, the binary number 10100011 corresponds to the three PN sequences numbered 4, 10, and 12. After three to 110 and 12 13 (1 ) 1   (1 ) = 1 (1 )= 1 , so the final choice of PN sequence radix-minus-one complement for 4 and 10, 12 the original code.

The data sequence mapping algorithm based on r-combination is simple, and the one-to-one correspondence between mapping and inverse mapping is realized. The spread spectrum sequence maintains the complete orthogonal relation and has excellent performance, and at the same time can control the correlation of the selected sequences. With the increase of information bits, the mapping algorithm requires PN sequence to maintain orthogonal relation, which is difficult to achieve [4].

2.2. Sparse vector coding

However, with the increase of bits of information transmitted, a large number of PN sequences are required, so it is difficult to maintain the complete orthogonal relation of PN sequences. In [5] a mapping algorithm based on sparse vector coding is introduced. The main idea of sparse vector coding mapping algorithm is to transfer the bit information to the non-zero position of sparse vector matrix through the mapping algorithm, so as to maintain the sparsity of the mapped vector[6]. The mapping algorithm can be regarded as a permutation and combination. Take a simple example: choose r baskets from M baskets to hold r apples in which $r<M$, there are $C_r^M$ multiple choices. This is also the case with sparse vector encoding mapping. K non-zero elements are selected from M sparse vector elements, and there are a total of $C_r^M$ choices, so $b = \lceil \log_2 C_r^M \rceil$ bits information can be coded in total. When the number of elements in a sparse vector is 12, 2 non-zero elements are selected from the 12 elements for mapping. There are a total of 66 choices. Through calculation, we can find that a total of 6 bits of information can be encoded. Sparse vector coding mapping algorithm is shown in Table 1.

Table 1. Sparse vector coding mapping algorithm.

| Input: Sparse vector size N  |
|----------------------------|
| Information vector w       |
| Output: sparse vector s     |

for $i = 2:N$

for $j = 1:i-1$

if $a = w(i0)$

$s = (2^i + 2^j)_{(2)}$

end

$a = a+1$

end
And the transmission power of the channel is focused on the non-zero position of the sparse vector, which is higher than the transmission power on all codes on the traditional average distribution of transmission power. Sparse vector encoding decoding is mainly performed by identifying the positions of non-zero elements in sparse vectors, without CRC check, so the bit rate of sparse vector encoding can be lower than traditional one requiring CRC check[1]. Decoding is easier than r-combined mapping algorithm.

3. Decoding algorithm

3.1. Conciliation and expansion combined soft decision algorithm

Multi-code combination spread spectrum technology using r-combination mapping algorithm, demodulation decoding algorithm is usually used Conciliation and expansion combined soft decision algorithm. The principle of Viterbi decoding algorithm is to compare the branch length in the path and the hamming distance of the received signal through path search, and to find the minimum value as the decoding output. Based on the idea of path search, a combined soft decision algorithm for multi-code combination spread spectrum is adopted. The difference between the two is that Viterbi algorithm traverses all paths, and the output result is determined on the basis of the minimum distance from the received signal, while the search algorithm adopted in this paper searches on the basis of the path information provided by the index matrix, and chooses the maximum correlation value as the decoding output, but in essence, it is the maximum likelihood decoding.

Each element in the index matrix represents a codon symbol's correlation value with the modulation waveform, so each column selects an element for summation to obtain a "and sequence correlation value". This selection rule is called the summation path in this paper. Theoretically, if the maximum value is selected from each column, the correlation value with the sequence will be the maximum, but in reality, this is not the case: the soft-decision correlation operation is performed on all possible waveforms, and not all the summation paths exist after the combination and superposition of multi-code composite spread spectrum system. The Conciliation and extension of joint processing of soft decision flow chart shown in figure 2.

![Figure 2 Conciliation and extension of joint processing of soft decision flow chart](image-url)
3.2. Multiple-path matching pursuit
Sparse vector encoding decoding is through the adoption of any recovery can be used in support of sparse algorithm identification to complete, so can use greed is sparse recovery algorithm of sparse vector encoding decoding, the traditional method to improve the decoding performance is usually adopts maximum likelihood method, using maximum likelihood method, we need to enumerate all the base for the combination of K, but if the transmission bit too many cases, it is not realistic. So can use MMP algorithm [7], MMP algorithm is a way to perform parallel search, find more promising object, finally choose the best one, from which the more promising candidate signals, recovering from compressed data sparse signal to find the minimum residual candidate easily is modeled as a combination of tree search problems, paper [8] has proved its feasibility in the presence of noise and without noise.

It computational complexity of sparse vector decoding is marginal, because the computational complexity of greedy sparse recovery algorithm is proportional to the sparsity K. Therefore, the processing delay of SVC decoding can also be small enough. This is the opposite of Viterbi or Turbo decoding algorithm, whose computational complexity is directly proportional to the length of code string

4. Simulation results and discussion

4.1. Effects of different parameters on system performance
we simulate the Gold code with sequence period N=64, the modulation order M=16, and the channel is AWGN channel for the bit error rate(BER) curve of different R values. And the Gold code with sequence period N=64, the number of combined sequences r=3, and the BER curve of different M values simulated under AWGN channel. The simulation results are shown in Figure 3 (a) and (b).

![Figure 3](image_url)

Figure 3 (a) BER curve of different r values
From figure 3(a) we can see with the improvement of r, the BER of the system increases gradually, but in the crowded environment of the channel, it should be considered that the improvement of channel utilization will lead to the increase of the bit error rate of the system.
We can see by figure 3(b) we can see with the increase of M, bit error rate shows a step-down trend, but the increase of M leads to a sharp increase in the hardware design complexity of the receiver, so the selection of M in hardware design should not be too large.

4.2. Comparison of the performance of two mapping algorithms
We simulated the BER curve of r-combined mapping algorithm and SVC algorithm when the parameters are all set to the modulation order number M=16, combination sequence number r =3 and use QPSK modulation and the same number of spread spectrum code length N=64 to analyse their performance. The simulation results are shown in Figure 4.
From the figure 4, we can see that under this parameter, the performance of r-combined mapping algorithm and Conciliation and extension of joint processing of soft decision is better than that of the SVC and MMP algorithm. If a lot of data bits are transferred, the design complexity of correlator at the receiver of R-combined mapping algorithm is increased. We can consider using SVC algorithm for multi-code combination spread spectrum.

5. Conclusion
This paper mainly introduces and compares two mapping algorithms of multi-code combination spread spectrum and their decoding algorithms. Through simulation analysis, it is concluded that the performance of r-combination mapping algorithm is better than SVC algorithm. In the case of small data bits, r-combined mapping algorithm is usually used. However, in the case of a large number of data bits, it is difficult for The R-combined mapping algorithm to keep the sequence orthogonal and the design complexity increases with the increase of the number of correlators at the receiver. We can adopt SVC algorithm and MMP algorithm to realize multi-code combination spread spectrum.

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