

The Design of Multiple Detection Parallel Combined Spread Spectrum Communication System

Lixin Tian, Wei Xue

Abstract—Many jobs in society go underground, such as mine mining, tunnel construction and subways, which are vital to the development of society. Once accidents occur in these places, the interruption of traditional wired communication is not conducive to the development of rescue work. In order to realize the positioning, early warning and command functions of underground personnel and improve rescue efficiency, it is necessary to develop and design an emergency ground communication system. It is easy to be subjected to narrowband interference when performing conventional underground communication. Spreading communication can be used for this problem. However, general spread spectrum methods such as direct spread communication are inefficient, so it is proposed to use parallel combined spread spectrum (PCSS) communication to improve efficiency. The PCSS communication not only has the anti-interference ability and the good concealment of the traditional spread spectrum system, but also has a relatively high frequency band utilization rate and a strong information transmission capability. So, this technology has been widely used in practice. This paper presents a PCSS communication model-multiple detection parallel combined spread spectrum (MDPCSS) communication system. In this paper, the principle of MDPCSS communication system is described, that is, the sequence at the transmitting end is processed in blocks and cyclically shifted to facilitate multiple detection at the receiving end. The block diagrams of the transmitter and receiver of the MDPCSS communication system are introduced. At the same time, the calculation formula of the system bit error rate (BER) is introduced, and the simulation and analysis of the BER of the system are completed. By comparing with the common parallel PCSS communication, we can draw a conclusion that it is indeed possible to reduce the BER and improve the system performance. Furthermore, the influence of different pseudo-code lengths selected on the system BER is simulated and analyzed, and the conclusion is that the larger the pseudo-code length is, the smaller the system error rate is.

Keywords—Cyclic shift, multiple detection, parallel combined spread spectrum, PN code.

I. INTRODUCTION

SPREAD spectrum communication means that the frequency spectrum of the information to be transmitted is converted into a broadband signal by a specific spreading spectrum function. The signal is transmitted over a channel, and it is compressed at the receiving end by using the corresponding method to obtain the transmitted information [1]. Spread spectrum communication has strong anti-interference ability, low interception rate, and it also has a series of advantages such as the achievement of code division multiple access, great signal concealment, and easy access to network [2]. The PCSS is a type of spread spectrum. The PCSS communication system is

presented based on the M-ary and Mb-ary communication systems [3]. At the transmitting end, the PCSS system firstly completes the serial-to-parallel conversion of the information to be transmitted, and then it selects r spreading sequences from M alternate orthogonal spreading sequences to complete the equal-magnitude amplitudes addition according to the data-sequence mapping relationship in order to achieve information combinations [4]. Then, the system modulates the combined information and sends it out. At the same time, the system can transmit bit data at a time. Compared with ordinary spread spectrum system, the PCSS communication system has higher information transmission capabilities, higher frequency band utilization [5], and also maintains the strong anti-interference, high reliability, and low BER of traditional spread spectrum communications [6].

This paper presents a PCSS communication model-MDPCSS communication system. Firstly, at the transmitting end, the system accomplishes the block processing and cyclic shifting of the candidate sequence. At the receiving end, the pseudo code sequence number is determined firstly when despreading. Then, the symbol block in the selected sequence is determined. Finally, the phase of selected symbol block is determined. Those processes must be completed in order to achieve multiple detections. Multiple detections can ensure that the system has a low BER and improve the communication quality of the system. In addition, both parties can also agree on a shift plan, thereby increasing the confidentiality of system communications.

II. THE PRINCIPLE OF MDPCSS COMMUNICATION

In a general PCSS communication system, since there is a large amount of noise and interference in the actual communication process, misjudgment often occurs during despreading, which degrades the performance of the entire communication system. Taking this as a starting point, this paper presents a type of PCSS communication system called MDPCSS communication system. Different system parameters have different effects on the BER of the system. After analysis, the PN code type we choose is a Gold code with 127 bits. The Gold sequence is implemented on the m-sequence, and two m-sequences with the same cycle and the same clock rate complete the mod 2 in order to obtain the Gold sequence [7]. The Gold sequence has good correlation and spectral performance, and the quantity is enough to meet the requirements of communication multiple access in a PCSS system. At the same time, in order to guarantee the anti-interference ability and confidentiality of the PCSS system, the balanced Gold code is selected as the spread spectrum sequence

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of the PCSS system [8]. When implementing the data-sequence mapping, the number of alternative PN sequences is M , and r PN sequences are selected from the alternative sequences for combination. The principle of MDPCSS communication system will be given below. The so-called MDPCSS communication system is due to the addition of double detection rules on the basis of the general PCSS system, which can further reduce the misjudgment in the process of despreading. At the same time, the BER of the system is further reduced.

MDPCSS is different from the general PCSS system. At the transmitting end, a PN code sequence is selected from the alternative PN code sequence as a fixed transmission sequence, here set it to PN_1 . And then $r-1$ sequences are selected from other $M-1$ sequences to combine. Since a PN code sequence is fixed, the system's ability to transmit information is reduced. Now the number of symbols that can be transmitted at a time is

$$k = r + \lceil \log_2(C_{M-1}^{r-1}) \rceil \quad (1)$$

At the transmitting end, some changes need to be made in the PN code sequence to provide the preconditions for subsequent multiple detections. The PN code chosen here is a 127-bit Gold, which is complemented by 0 to form a 128-bit pseudo-code sequence [9]. The detected PN code is firstly partitioned into a

total of 16 symbol blocks $PN_j \{j=1,2,\dots,16\}$, and each PN_j is further divided into 8 symbols, which is exactly 128 bits. After grouping PN_i , we can get PN_{ij}^x , where i denotes the index of the alternative sequence $i \in [2,16]$, j denotes the number of blocks in the PN_i sequence $j \in [1,16]$, and x denotes the phase of the selected block $x \in [1,8]$. The sequence division diagram is shown in Fig. 1, where $j=6$.

After the block ends, a cyclic shift of the PN code is required, and the number of shifts is related to the PN code sequence. PN_1 remains unchanged, and the cyclic shift starts from the second symbol sequence. First of all, according to the shift of the symbol block PN_j , the PN_{i1} in the sequence PN_i begins to shift left $8 \times (i-1)$ bits. And the block of symbols that are in front is PN_i , as shown in Fig. 2.

In the PN_i symbol block, the whole sequence needs to shift left x bits again, where x represents the remainder after i divided by 8. So much for that, the shift of the PN code is completed. The following is a description of the second sequence as an example in Fig. 3.

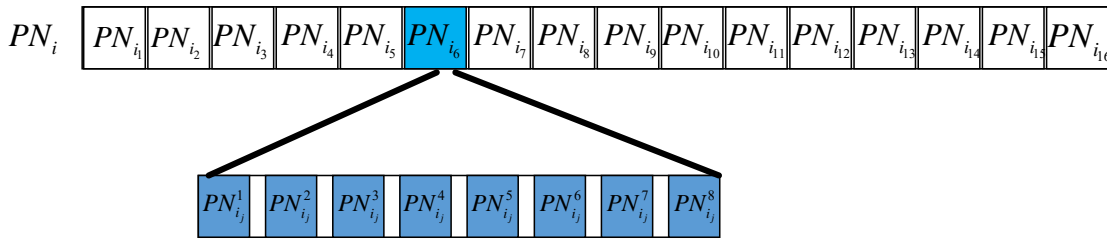


Fig. 1 PN code grouping diagram

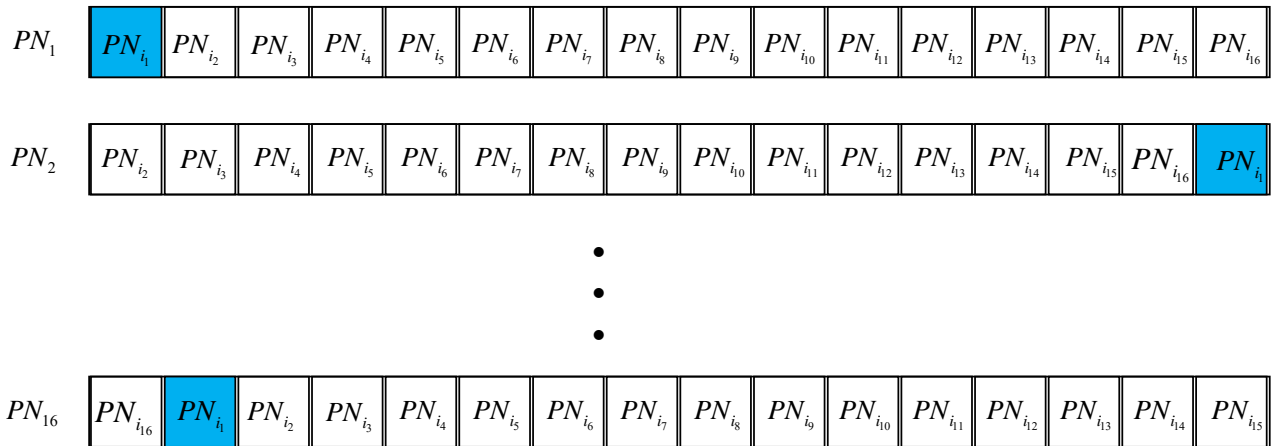


Fig. 2 PN code shift diagram

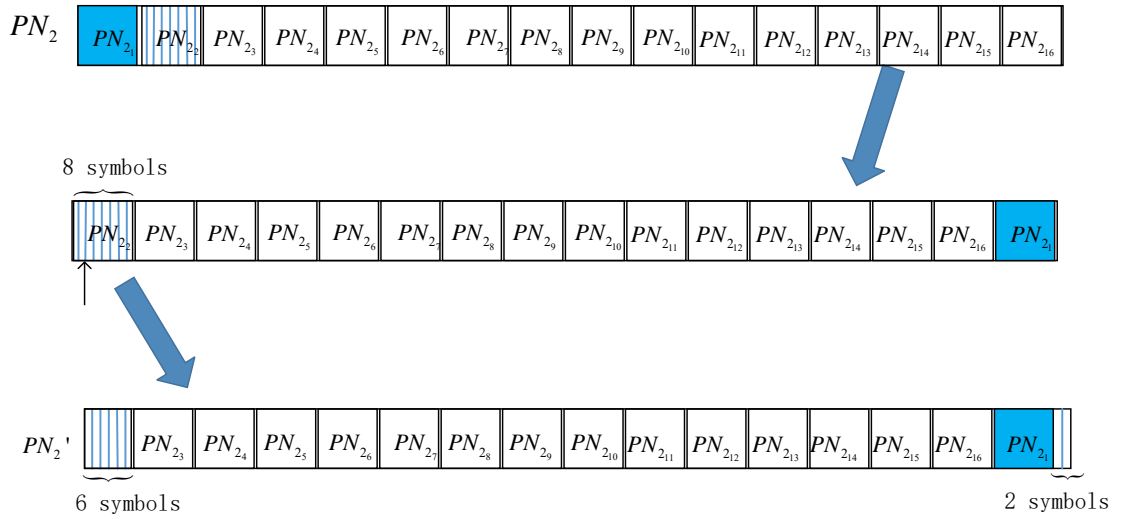
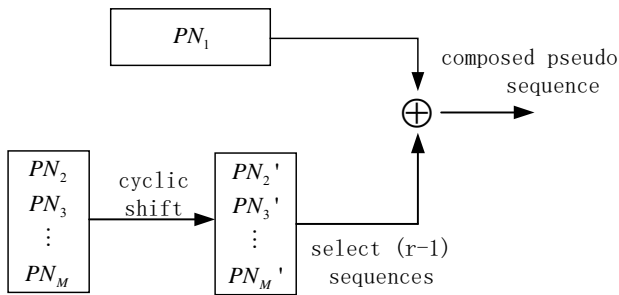

 Fig. 3 PN_2 sequence cyclic shift diagram


Fig. 4 PN code combination diagram

So the number of bits n that PN_i needs to shift is:

$$n = 8 \times (i - 1) + x \quad (2)$$

where x represents the remainder after i divided by 8.

The cyclically shifted PN code sequence is denoted by PN' . So the combination of the PN code at the transmitter is shown in Fig. 4. Therefore, the MDPCSS transmitter schematic is shown in Fig. 5.

The original data are converted from serial data into parallel data by the parallel-serial converter, and then $r-1$ sequences is selected from the alternative sequences to complete the data-sequence mapping [10]. The selected sequence is cyclically shifted, and then the shifted sequence is added and combined by PN_1 . Then the combined sequence is subjected to carrier modulation and amplification, thereby completing the transmitter design of the multiple detection of the PCSS system [11]. The combined pseudo-code sequence can be written as:

$$MD_1(t) = q_1 PN_1 + \sum_{j=2}^{r-1} q_{i_j} PN_{i_j}'(t) \quad (3)$$

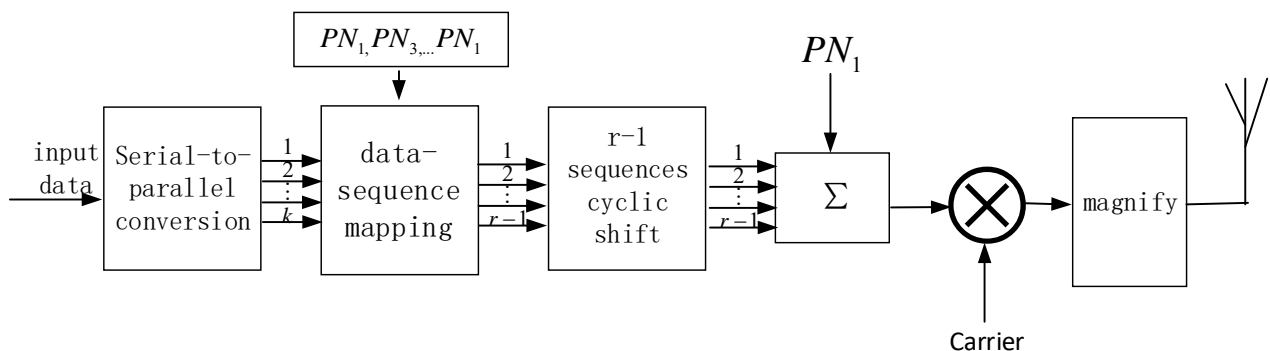


Fig. 5 Schematic diagram of MDPCSS communication transmitter

After the mapping is completed, a combined pseudo-code sequence is obtained. Then, the combined sequence is subjected to carrier modulation and the modulated signal is set to $S'(t)$ [12]. Then:

$$S'(t) = \sqrt{2P} \cdot MD_1(t) \cos(\omega t + \phi) \quad (4)$$

where P is the signal power of a single transmitted sequence and $MD_1(t)$ is the combined multivalued sequence.

Despreading at the receiving end is the process of implementing multiple detection. The receiving end of the MDPCSS communication system is shown in Fig. 6.

After the signal is received, it is firstly to be done related calculation with the sequence obtained by PN_1 and its cyclic shift to achieve pseudo code synchronization. What needs to be done then is to do related calculations with the local PN code. In the process of correlation calculation, some transformations of the PN code sequence are needed. The pseudo code sequence $PN_2 \sim PN_M$ needs to be cyclically shifted. Here, the length of

the PN code sequence is 128 bits, so 128 shifts are needed, and the number of shifts is respectively correspond to 1~128. The number of pseudo-code sequences finally obtained is $15 \times 128 = 1920$. During the correlation calculation, after each shift is completed, the 15 PN code sequences should be done related calculations with the combined sequence after demodulation to obtain a maximum value. So, after the shift ends, a total of 128 maximum values are obtained. And then these 128 values are sorted to select the $r-1$ maximum value, and the first detection is completed at this time. Then, the label of the PN code sequence should be determined to complete the next two detections.

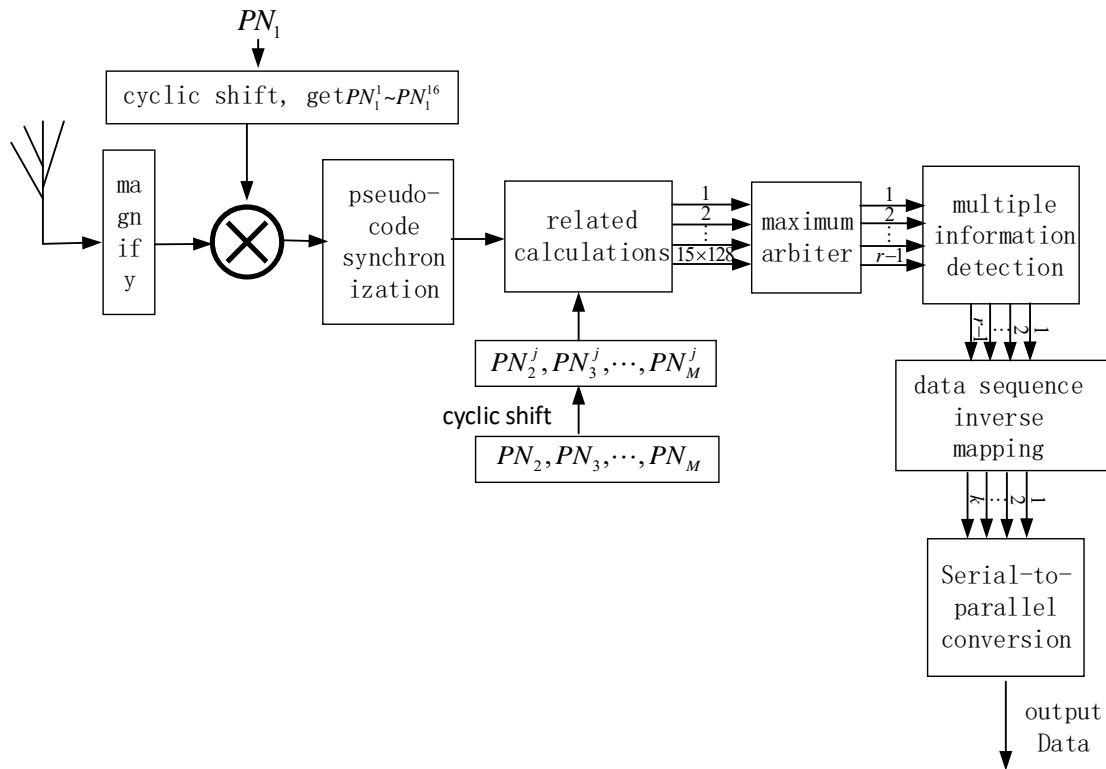


Fig. 6 Schematic diagram of MDPCSS communication receiver

Assume that the largest $r-1$ values correspond to the pseudo-code PN_{ij}^x , where $i \in [2, 15]$, $j \in [1, 16]$, $x \in [1, 8]$, and then judge on x . At the transmitting end, the PN_i code sequence is divided into blocks of 16 $PN_{ij} \{j=1, 2, \dots, 16\}$, and then 8 symbols are further divided in the block of symbols. Therefore, at the time of judging x , the symbol block PN_{ij} should be firstly determined. At this time, the second detection is completed. And then x is continuously judged to determine whether the phase in the symbol block is i , and the third detection is completed.

The specific implementation is as follows: suppose $x/8$, then get m and n , where m represents the quotient of x divided by 8,

and n represents the remainder. The corresponding PN code sequence at the transmitting end is PN_{ij}^x , which represents the cyclically shifted sequence of the i -th sequence, and the number of shifts is $n = 8 \times (i-1) + x$. The first step is to determine the order of the symbol blocks. If $m = i-1$, the second detection is completed and continue to the next step of detection, otherwise take next related value to calculate. After completing the second detection, it is judged whether or not n is equal to i . If n is equal to i , the judgment is correct; otherwise, next relevant value is taken to continue detection. The flow chart for the receiver to complete the multiple detection is shown in Fig. 7.

In the foregoing, we introduced the concept of MDPCSS. It can be known that a total of three detections are performed. It is firstly to detect the sequence number of the PN code, then detect

the block of symbols in the selected sequence, and finally detect the phase of the selected symbol.

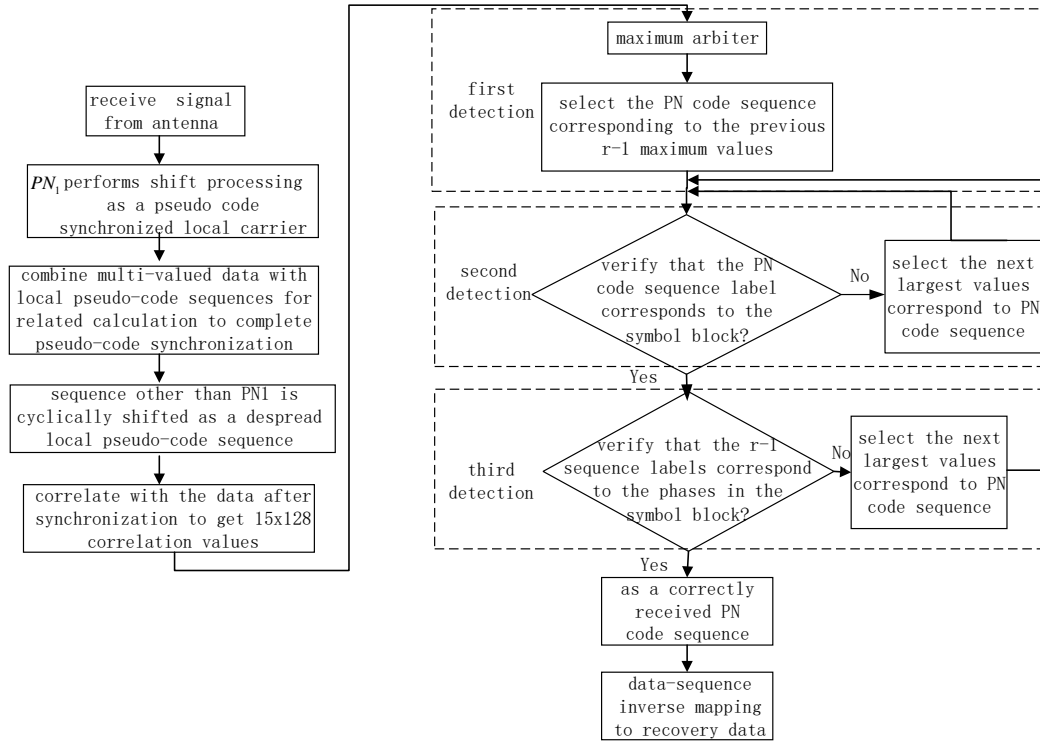


Fig. 7 Receiver multiple detection block diagram

III. SYSTEM BER SIMULATION AND ANALYSIS

Compared with the traditional PCSS communication system, the MDPCSS system firstly selects the sequence corresponding to the $M-1$ maximum value from $M \times L$ correlation value at the receiving end, and the probability that a sending sequence is one of the sequences corresponding to the $M-1$ maximum values is:

$$P'_m = \int_0^{+\infty} p(|V_i| > |V_m|)^{M \times L - (M-1)} p(V_i) dV_i$$

$$= \frac{1}{\sqrt{2\pi}} \int_{-\sqrt{h}}^{\infty} e^{-x^2/2} \left[1 - \operatorname{erfc}\left(\frac{x+\sqrt{h}}{\sqrt{2}}\right) \right]^{(M \times L - M + 1)} dx \quad (5)$$

where: $h = 2kE_b/rN_0$ is the input SNR of the i -th despreading correlator, $\operatorname{erfc}(\cdot)$ is the complementary error function, and L is the length of the pseudo code sequence

The probability that the sequence number and the shift bit number in each selected sequence is the same:

$$P'_i = \frac{M-1}{M \times L} \quad (6)$$

Then, the probability that a sending sequence is despread correctly at the receiving end is:

$$P'_r = P'_m \times P'_i$$

$$= \frac{M-1}{M \times L} \cdot \frac{1}{\sqrt{2\pi}} \int_{-\sqrt{h}}^{\infty} e^{-x^2/2} \left[1 - \operatorname{erfc}\left(\frac{x+\sqrt{h}}{\sqrt{2}}\right) \right]^{(M \times L - M + 1)} dx \quad (7)$$

Then, the probability that all the r sequences obtained by verification are correct is:

$$P_r = (P'_r)^r \quad (8)$$

The BER of the PCSS communication system based on multiple information matching can be expressed as:

$$P_e = 1 - P_r$$

$$= 1 - \left[\frac{M-1}{M \times L} \cdot \frac{1}{\sqrt{2\pi}} \int_{-\sqrt{h}}^{\infty} e^{-x^2/2} \left[1 - \operatorname{erfc}\left(\frac{x+\sqrt{h}}{\sqrt{2}}\right) \right]^{(M \times L - M + 1)} dx \right]^r \quad (9)$$

Since the probability of error in the polarity information in the PCSS communication system is far less than the probability of despreading and demodulation errors in the spread spectrum pseudo code sequence, it can be ignored. Therefore, the BER formula for the MDPCSS communication system can be obtained as:

$$P_{e_p} = \frac{k-r}{2k}(1-P_r) \quad (10)$$

In the previous section, the principle model of the MDPCSS system was analyzed and introduced. The system model will be simulated to observe the system's BER. The 127-bit Gold code is selected as the pseudo-code sequence, and it is complemented by 0 to form a 128-bit sequence, so $L=128$. And then the ordinary PCSS communication system with $M=16$, $r=3$ is selected to compare the system's BER with the MDPCSS system. Fig. 8 is obtained by using MATLAB for simulation. From the figure, it can be seen that the BER of the multiple detection system is smaller than that of the conventional 16-to-3 PCSS communication system.

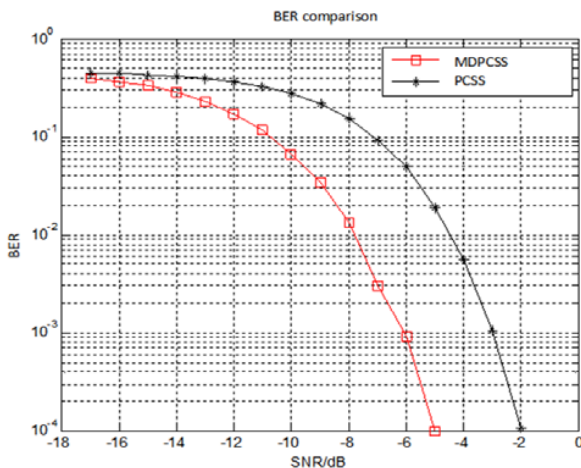


Fig. 8 Comparison of BER between MDPCSS and PCSS system

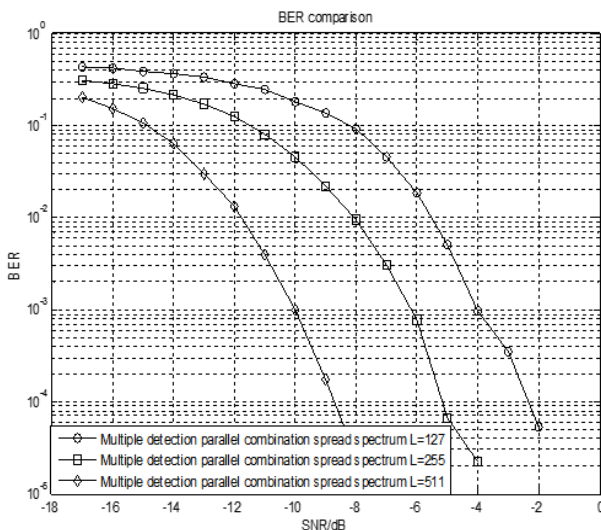


Fig. 9 Simulation of BER for different length pseudo-code sequences in MDPCSS communication system

When analyzing the principle model, the length of the PN code is 128 bits. If the PN code is of other length L , for example,

256, 512, etc., the PN code is also divided into 16 symbol blocks when dividing. But, the number of symbols in each symbol block becomes $L/8$, and then we continue the discussion according to the above method. Here, MATLAB is used to analyze the pseudo-code sequences of different lengths. The pseudo code length L is chosen as 128, 256, and 512. After the simulation, the BER comparison chart is obtained, as shown in Fig. 9.

It can be seen from the figure that with the increase of the length of the pseudo code, the BER of the system is reduced, which is in line with the general performance characteristics of MDPCSS communication.

IV. CONCLUSION

Through the elaboration of the principle, modeling and simulation analysis, we can get the conclusion that the MDPCSS system retains the advantages of high information transmission capability, high frequency band utilization, strong anti-interference, and high reliability. At the same time, compared to the ordinary PCSS, the system can guarantee a low BER of the system and improve the communication quality of the system. Both parties can also agree on a shift scheme, thereby increasing the confidentiality of the system communication. This technology has broad research value and application prospects.

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