Weighted Soft Decision of QPSK Modulation in Parallel Combinatory Spread Spectrum System

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Abstract

In parallel combinatory spread spectrum (PCSS) system, the soft decision of QPSK modulation will make the superposed Pseudo-Noise (PN) sequences lose its correlation, which leads to the failure of the demodulation. According to the characteristics of QPSK modulation, the superposed sequence is mapped to two sequences, and then a new weighed summation algorithm is proposed to keep the correlation properties of superposed sequences. Applying the algorithm in QPSK modulation in PCSS system, soft decision can be obtained in the receiver. This weighed soft decision resolves the problem that conventional soft decision QPSK modulation cannot apply in PCSS system. The system model is built and simulated in the paper. The simulation results show that the reliability of proposed soft decision QPSK modulation is better than that of hard decision QPSK modulation and this method is useful in engineering application.

1. Introduction

The parallel combinatory spread spectrum (PCSS) communication system, as an improvement to the soft spread spectrum system, has a high efficiency. Meanwhile, it also inherits the advantages of anti-jamming and low probability of detection/intercept of traditional spread spectrum system. In engineering applications, the commonly used modulation schemes in PCSS system include MASK, coded BPSK and ASK. However, MASK and ASK are both non-constant envelope modulation, which may cause amplitude fading and spectrum broadening, leading to system performance degradation. The coded BPSK has a low rate. The parallel spread spectrum signal with QPSK modulation can only be received via hard decision, that is to say, the symbol data of every spread spectrum code has to be demodulated and decided before de-spreading, thus the optimum performance cannot be obtained. To solve this problem, the correlation of PN sequences after constant amplitude superposition in PCSS system is studied, based on which, a weighted soft decision QPSK modulation based on PCSS system is proposed, which improves the BER performance of PCSS system and proves useful in engineering applications.

2. Correlation of Superposed PN Sequences

Correlation of Superposed PN Sequences is studied based on PCSS system. The QPSK modulation is a type of quadrature phase shift keying, so the number of symbol states after PN sequence superposition in PCSS system should be 4. From reference [1], it can be known that the number of PN code symbol states is $r+1$ after spread spectrum symbols of the parallel spread spectrum signal are superposed. The study here is made taking $r=3$.

2.1 Property of Superposed PN Sequences

Assume A,B,C,D are a set of bipolar PN spread spectrum sequences with length of N. Then, the cross correlation function of PN sequences should have the following property (since the system is assumed to be fully synchronized, only the cross correlation function value obtained at $t=0$ is studied): $R_{AB}(0)=0$, $R_{AC}(0)=0$, $R_{AD}(0)=0$, $R_{BD}(0)=0$, $R_{BC}(0)=0$, $R_{CD}(0)=0$.

Suppose Sequence $E=A+B+C$, then $E=\left(e_0,e_1,\cdots,e_{N-1}\right)$, $e_i\in(+3,+1,-1,-3)$ $(i=0,1,\cdots,N-1)$ .It can be derived that the correlation values of Sequence E with A, B and C that constitute E at zero satisfy the following relation:

$$R_{AE}(0)=R_{BE}(0)=R_{CE}(0)=N \tag{1}$$

While the correlation value of Sequence E with D within the sequence set at zero is

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$$R_{DE}(0)=0 \tag{2}$$

From expression (1) and (2), it can be known that, 3 sequences within a set of PN sequences, after constant amplitude superposition, still have the property of pseudo random sequences, or, the correlation function of the new sequence with any original sequence that constitutes the new one is N, and is 0 with the sequence within the set that doesn't participate in the new sequence.

2.2 Weighted Correlation of Orthogonal Mapping

To fit QPSK modulation, Sequence E is mapping modulated with Sequence I and Q. Suppose Sequence I is X and its symbol is x_i and Sequence Q is Y and its symbol is y_i (where $X=\left(x_0,x_1,\cdots,x_{N-1}\right)$, $x_i\in(\pm1,0)(i=0,1,\cdots,N-1)$, $Y=\left(y_0,y_1,\cdots,y_{N-1}\right)$, $y_i\in(\pm1,0)(i=0,1,\cdots,N-1)$, the mapping is as follows:

$$\begin{cases} x_i=e_i, y_i=0 & |e_i|=1 \\ x_i=0, y_i=\dfrac{e_i}{3} & |e_i|=3 \end{cases} \tag{3}$$

As can be seen, some amplitude information of the sequence is lost in this type of QPSK mapping. Without subsequent processing, the correlation between sequences will be lost. Based on the mapping and expression (4), $E=X+3Y$ can be obtained. Then, correlation functions of E with other sequences within the set are the same as showing in expression (1) and (2).

The mapped Sequence X and Y are correlated respectively with the original sequence set. Have the correlation value multiplied respectively by weight coefficient 1and 3, and then summed, the amplitude information lost in mapping will be recovered, which maintains the correlation between the superposed sequences and the original sequence set.

The modulation scheme with such mapping is QPSK. In traditional QPSK, the soft decision is implemented by summing I and Q directly, which can't make up for the amplitude information lost during mapping in PCSS system, and thus the correlation of PN sequences can't be retained and correct modulation can't be achieved. With the above method of weighted summation at the receiving end, the sequence correlation can be retained and soft decision of QPSK modulation be implemented.

3 QPSK Modulation Based on PCSS System

3.1 Transmitter of QPSK Modulation Based on PCSS System

The k bits of data transmitted by PCSS system is denoted as $d=(d_1,d_2,\cdots,d_k)$, $k=r+\left[\log_2 \mathrm{C}_M^r\right]$. The k bits of data are sent into the data spread spectrum (SS) sequence mapper, and r sequences and the correspondent r sequence polarities are selected from the M orthogonal SS sequences according to the lexicographical order [2-3]. The r sequences are combined in parallel and summed in constant amplitude (+1 or -1 values summed) to form the multi-value composite signal [4-5]:

$$MD(r,t)=\sum_{j=1}^{r} q_{lj} PN_{lj}(t) \tag{4}$$

where $q_{lj}\in(+1.-1),(j=1,2,\cdots,r)$. Under the condition of studying the performance of PCSS system with QPSK modulation, $r=3$ is selected; then the values of the symbol in $MD(r,t)$ are +3，-3，+1，-1. According to the analysis of symbol mapping in the above section, the mapping between symbol and carrier modulation can be established. Take care that ±1 mapping and ±3 mapping must be orthogonal to ensure the correlation in demodulation.

$$\begin{bmatrix} +1 \\ -1 \\ -3 \\ +3 \end{bmatrix} \Rightarrow \begin{bmatrix} +\cos(2\pi f_s t) \\ -\cos(2\pi f_s t) \\ -\sin(2\pi f_s t) \\ +\sin(2\pi f_s t) \end{bmatrix} \tag{5}$$

Let $IPN(t)=\sum_{i=1}^{N} a_{Ii} g(t-iT_C)$, $QPN(t)=\sum_{i=1}^{N} a_{Qi} g(t-iT_C)$, Where N is the symbol number in PN sequence period, $g(t)=\begin{cases}1 & 0\le t\le T_C \\ 0 & others\end{cases}$. $a_{Ii}, a_{Qj} \in (-1,0,+1)$, if $i=j$, either a_{Ii} or a_{Qj} is 0, and the other is +1 or -1, that is to say, they maintain orthogonal.

And then assume the power of the transmitted signal is P, the transmitted signal can be derived as

$$s(t)=\sqrt{6P}(IPN(t)\cos(2\pi f_s t)+QPN(t)\sin(2\pi f_s t)) \tag{6}$$

3.2 Receiver of QPSK Modulation Based on PCSS System

In Gaussian channel, the received signal is $r(t)=s(t)+n(t)$, where $n(t)$ is Gaussian white noise. At the receiver, the received signal is separated into I and Q channel for respective down conversion, serial-parallel conversion and then sent to the SS sequence correlation. After the correlation results of channel I and Q are weighted and summed, the correlation value of M SS sequences, $Z_i(t)$, will be obtained, which can be expressed as

$$Z_i(t)=\begin{cases} q_{lj}PT+n'(t) & i=l_j \\ n'(t) & i\ne l_j \end{cases} \tag{7}$$

Where $T=NT_C$; $q_{lj}PT$, representing the received signal energy; $n'(t)$ represents narrow-band guaussian noise.

From expression (1), select the spread spectrum sequences and their polarities corresponding to the r values whose absolute values are larger as the transmitted combination sequence. Send the sequence number and polarity into the data-sequence inverse mapper to obtain the transmitted k-bit data [6-7].

In PCSS system, the spread spectrum demodulation correlation also has positive-negative polarity demodulation error, which can be ignored[8], because the probability of polarity demodulation error is much less than that of spread spectrum sequence demodulation error. And then, the BER of the weighted soft decision QPSK based on PCSS system is:

$$P_{eb}=\frac{k-r}{2k}\left\{1-\left[\frac{1}{\sqrt{2\pi}}\int_{-h}^{\infty} e^{-x^2/2}\cdot\left[1-\mathrm{erfc}(\frac{x+h}{\sqrt{2}})\right]^{(M-r)} dx\right]^r\right\} \tag{8}$$

Here, $h=\sqrt{3PT/5N_0}$, $\mathrm{erfc}(\cdot)$ is the complementary error function.

4 System Simulation Analysis

Using Matlab, the modeling of QPSK modulation based on PCSS system is built, and it's performance is simulated, under the assumption that the PCSS system is completely synchronous and only additive white Gaussian noise exists in the system.

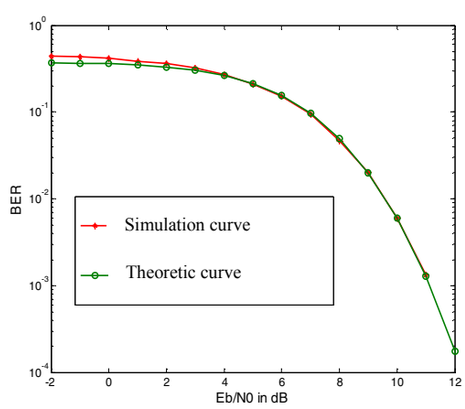

Fig. 1 BER of simulation value and theoretical value in soft decision QPSK modulation of PCSS system

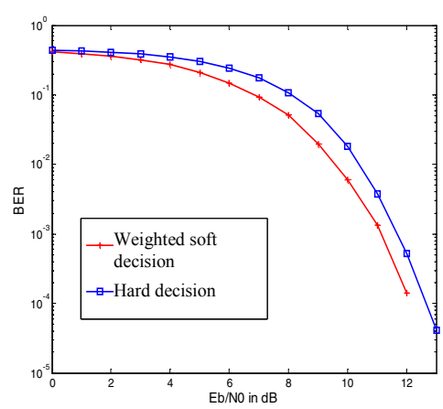

Fig. 2 BER of soft decision and hard decision QPSK modulation based on PCSS system

Fig. 1 shows the comparison of BER in the soft decision QPSK based on PCSS system obtained respectively from simulation and theoretical derivation. The main parameter settings are: the number of spread spectrum sequence $M=16$, among which $r=3$ sequences are selected; the number of spread spectrum sequence symbols in the PCSS system $N=128$, the abscissa in the simulation diagram is E_b/N_0, where E_b is the energy of each chip in the channel after spreading, N_0 is the power spectrum density of the white Gaussian noise.

As shown in the figure, the theoretic curve is essentially coincident with the simulation curve, which validates the correctness of simulation result of the soft decision QPSK modulation based on PCSS system.

Fig. 2 shows the comparison of the simulated BER in hard decision and soft decision QPSK based on PCSS system. The main parameters are set as: the number of spread spectrum sequences $M=16$, among which $r=3$ sequences are selected; the number of spread spectrum sequence symbols in the PCSS system $N=128$. The hard-decision adopts the correlation demodulation detection based on maximum likelihood principle.

As shown in the figure, the BER of weighted soft decision QPSK modulation based on PCSS system is lower than that of hard decision QPSK modulation. With the same BER, the SNR that the soft decision QPSK modulation needs is about 1dB less than that the hard decision QPSK modulation needs, and the de-spreading and demodulation can be performed simultaneously, which reduces the processing time and computation load.

5 Conclusion

The weighted soft decision of QPSK in PCSS system is discussed in this paper. According to the correlation of superposed PN sequences, after down-conversion, the received two orthogonal signals are weighted; which makes that soft decision of QPSK modulation in PCSS system could be used for the first time. The transmission rate of the weighted soft decision QPSK system is higher than that of soft decision BPSK modulation. Compared with APK and MASK modulation in the PCSS system, QPSK modulation can avoid the performance degradation due to the amplitude fading brought about by non-constant envelope modulation. Compared with the hard decision QPSK modulation in the PCSS system, the soft decision QPSK modulation is more reliable and easier to realization in engineering.

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