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Detection on the Period of Long PN Code in DS/SS Signals at Low SNR

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Abstract: To accurately detect the period of long PN sequence in electronic countermeasures in Direct Sequence/Spread Spectrum (DS/SS) communication, a method is proposed in which the influence of information code on the detection of the period of SS signals was eliminated by delaying and multiplying the input DS/SS signals with the known PN rate and then the period of long PN sequence was obtained by reprocessing the power spectrum. Simulation results show that the method proposed can detect both long and short PN sequences accurately at the signal-to-noise ratio less than -13 dB and the detection is little affected by the period of symbol, but it is affected by the period of PN sequence and longer N needs longer sample time if the detected SNR is the same.

Key words: DS/SS, period detection, delay-and-multiple, spectral estimation, long code

INTRODUCTION

Spread spectrum signals have been used for several decades in military domain and civil domain to ensure the communication security, such as in GPS and Code Division Multiple Access (CDMA), because they have advantages of transmitting signals with low power density to enshroud information in noise, coding with Pseudo Noise (PN) sequence to keep signals secret and processing signals by their correlation to enhance anti-interfere performances (Hill and Ridley, 2000). In order to detect the period of PN sequence, many methods were proposed by Chaobin *et al.* (1999), Jiang *et al.* (2006) and Zhang *et al.* (2009). They are effective in the detection of the period for short PN sequence in direct sequence-spread spectrum (DS-SS). However, long PN sequence is often used (He *et al.*, 2003; Suzuki and Fukawa, 1996; Guenach and Vandendorpe, 2001; Karkkainen *et al.*, 1994) to ensure the security of communication. A long sequence which is also known as a long code, is defined to be a sequence with a period that exceeds the duration of a data symbol, so it destroys the period of PN sequence and makes its period detection difficult. As far as we know, not much work has been done on the method for the period detection of long PN sequence.

In this study, a method to detect the period of long PN sequence is proposed, in which received signals were delayed and multiplied with the known PN rate and then the period of long PN sequence was obtained by reprocessing the power spectrum. This method can be used to detect the period of both long and short PN sequences. Simulation was carried out to validate the feasibility of the method.

METHOD FOR PERIOD DETECTION OF LONG PN SEQUENCE

In the transmission of DS/SS, the signal received can be written as:

$$s(t) = \sqrt{2}A d(t)\, p(t) \cos(\omega_{o t} + \varphi_0) + n(t) \tag{1}$$

where, n(t) stands for the noise which is white, Gaussian, centered and uncorrelated with the signal. The signal to noise ratio (SNR) for the output of the receiver filter is negative, which means that the signal is hidden in the noise. $\sqrt{2}$ is the magnitude of the received signal. $p(t)\epsilon[+1, -1]$ is the PN sequence. The length of PN sequence is N and the chip duration is T_p, so, the period of the sequence is NT_p.

For the signal in Eq. 1, $\omega_o = 2\pi f_s$ and f_s is the carrier frequency, φ_0 is the initial phase and is often out of consideration in period detection, $d(t)\epsilon[+1, -1]$ is the symbol with duration of $T_M = MT_p$ and M>>1 and is centered and uncorrelated. When N is equal to M, the sequence is short PN sequence; when N is larger than M, the sequence is long PN sequence.

Here, the chip duration, T_p, is assumed to have been estimated, then the method to detect the period of long PN can be shown in Fig. 1.

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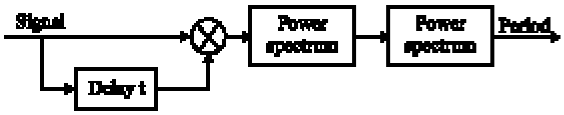

Fig. 1: The principle of period detection of long PN sequence

Without consideration of the effect of noise, the received DS/SS signal can be written as:

$$s(t)=d(t)\sqrt{2}Ap(t)\cos(\omega_0 t+\varphi_0) \quad (2)$$

Equation 2 is composed of two parts, the symbol and the DS/SS signal without consideration of symbol. Then Eq. 2 can be Rewritten as:

$$s(t)=d(t)g'(t-n'T_M)\cdot\sqrt{2}Ap(t)g(t-nT_p)\cos(\omega_0 t+\varphi_0) \quad (3)$$

Where:

$$g(t)=\begin{cases}1, & -\frac{T_p}{2}<t<\frac{T_p}{2}\\ 0, & \text{else}\end{cases}$$

and

$$g'(t)=\begin{cases}1, & -\frac{T_M}{2}<t<\frac{T_M}{2}\\ 0, & \text{else}\end{cases}$$

When the symbol is delayed by τ and multiplied by itself, i.e., $S_d(t) = d(t)\, d(t-\tau)$, then the output signal can be expressed as:

$$\begin{aligned}S_d(t)=&\sum_{n'} g'\left[\frac{T_M}{T_M-\tau}(t-n'T_M-\tau)\right]\\ &+\sum_{n'} d_n d_{n-1} g'\left[\frac{T_M}{\tau}(t-n'T_M-\tau)\right]\end{aligned} \quad (4)$$

According to Eq. 4, we can find that $S_d(t)$ is composed of a square wave with the period T_M and a dual-polarity impulse sequence. When τ = T and M = 100 (M>>1), it can be seen from Fig. 2 that the dual-polarity impulse sequence is so small that it can be ignored, so the symbol becomes a Direct Current (DC) signal after the delay and multiplication. Hence, when TM = MT_p and M>>1, the output signal of the symbol can be considered as a DC signal which can be neglected in period detection.

The spread spectrum signal without consideration of symbol in Eq. 3 is delayed by τ and multiplied by itself. The output can be written as:

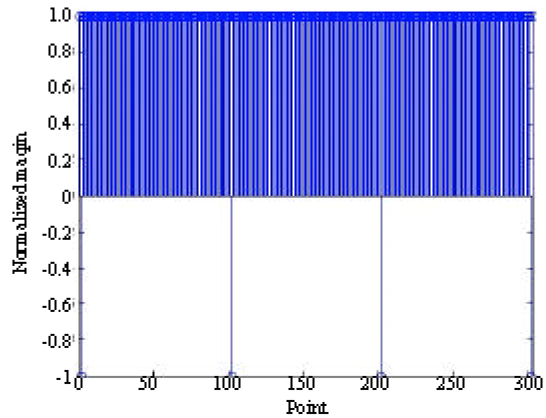

Fig. 2: The output of delayed and multiplied symbols d(t)

$$\begin{aligned}S_s(t)=A^2&\left\{\sum_n g\left[\frac{T_p}{T_p-\tau}(t-nT_p-\tau)\right]+\sum_n p_n p_{n-1}\left[\frac{T_p}{\tau}(t-nT_p-\tau)\right]\right\}\\ &\cdot\left\{\cos(\omega_0\tau)+\cos\left[\omega_0(2t-\tau)+\phi_0\right]\right\}\end{aligned} \quad (5)$$

If $\tau = T_p$, Eq. 5 can be written as:

$$\begin{aligned}S_s(t)&=A^2\sum_n p_n p_{n-1} g(t-nT_p-T_p)\cdot\left\{\cos(\omega_0 T_p)+\cos\left[\omega_0(2t-T_p)+2\phi_0\right]\right\}\\ &=A^2 S_p(t)C(t)\end{aligned} \quad (6)$$

Where:

$$S_p(t)=\sum_n p_n p_{n-1} g(t-nT_p-T_p)$$

and

$$C(t)=\cos(\omega_0 T_p)+\cos\left[\omega_0(2t-T_p)+2\varphi_0\right]$$

$S_p(t)$ is the product of PN sequence and the delayed PN sequence, whose duration is T_p. Since $S_p(t)$ depends only on the PN sequence and τ and is independent of other parameters of the received signal, $S_p(t)$ is a new stochastic sequence with the same duration and period as the original spread spectrum PN sequence. So, $S_p(t)$ can be Rewritten as:

$$S_p(t)=P_n\sum_n g(t-nT_p) \quad (7)$$

where, P_n is the new stochastic sequence, T_N is its period and T_p is its duration.

After low-pass filtering, the high-frequency signal is eliminated and Eq. 6 can be written as:

$$S_z(t) = A^2 P_n g(t)\cos(\omega T_b) \qquad (8)$$

Thus the period detection of long PN sequence (p_n) is transformed to that of short PN sequence (P_n), whose period is N and the symbol period is also N.

Based on the analysis in reference (Zhang *et al*., 2009), the power spectrum of the signal of Eq. 8 can be expressed as:

$$\begin{aligned} S_z(\omega) &= \frac{A^2T_b^2}{2}\sum_n \cos\left[T_b(\omega - nN\omega_b)\right]\left\{\mathrm{sinc}\left[\frac{T_b}{2}(\omega - nN\omega_b)\right]\right\}^2 \\ &= \frac{A^2T_b^2}{2}\sum_n \cos\left[T_b(\omega - n\omega_N)\right]\left\{\mathrm{sinc}\left[\frac{T_b}{2}(\omega - n\omega_N)\right]\right\}^2 \end{aligned} \qquad (9)$$

where, $\omega_b = 2\pi \cdot 1/T_b$ and $\omega_N = N\omega_b$ and the output of the power spectrum of $S_z(\omega)$ is shown as:

$$S(e) = \left|FT\,S(\omega)\right|^2 = \left|K^*\left(1 - \frac{|e - nT_M|}{T_b}\right)\right|^2 \quad |e - nT_M| < T_b \quad e = 0,1,2\ldots \qquad (10)$$

where $K^* = \pi A^2 T_p/2$.

As a result, after delaying and multiplying received DS/SS signal as well as reprocessing power spectrum, the signal energy is concentrated on some discrete signals with interval T_M, i.e., the period of long PN sequence.

From the above analysis, the period of long PN sequence can be detected when $N \neq M$. Because the above deduction is independent of M, the period of short PN sequence can be obtained when N = M and M>>1.

SIMULATION RESULTS

Here, Monte Carlo simulations are built up with MATLAB, the transmission of binary symbols on a AWGN channel using BPSK mapping {0→-1;1→1} is considered in this study. To validate the proposed method, assumed that the PN sequence is m sequence with N = 127, M = 100 and SNR = -10dB, the output of the reprocessed power spectrum of $S_z(t)$ is shown in Fig. 3, in which the discrete signals are clearly distinguished and the period T_p can be easily detected.

The simulation is conducted in order to analyze the relationship between M and the minimum SNR under the same sample time in period detection for long PN sequence with the assumption that the PN sequence is m sequence with N = 127 and the sample time is 16 ms and the result is shown in Fig. 4. The minimum curve changes little with M and we can draw a conclusion that M has little effect on the detection of the period of long PN sequence.

In order to analyze the relationship between N and the minimum SNR under the same sample time in the period detection for PN sequence, simulation is also conducted with the assumption that the sample time is 20 min and M is the same as the period of PN sequence. Figure 5 indicates that longer N needs longer sample time if the detected SNR is the same.

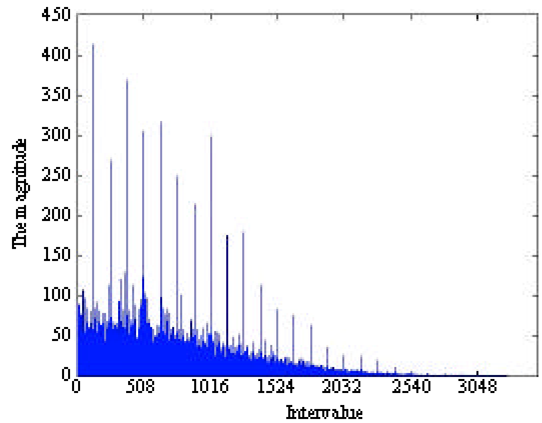

Fig. 3: Diagram of the estimation of long code PN duration

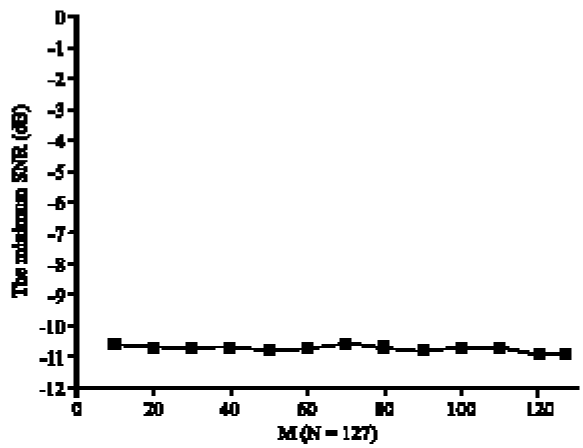

Fig. 4: The relationship between M and the minimum SNR

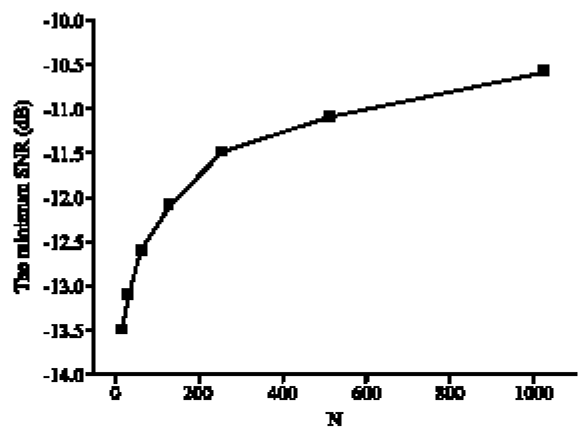

Fig. 5: The relationship between N and the minimum SNR

To sum up, we can easily obtain the period of long PN sequence and M has little effect on the detection, but N does affect the detection.

CONCLUSION

A method for the period detection of long PN sequence of a DS/SS signal is proposed. By delaying the received DS/SS signal and multiplying itself, then reprocessing the power spectrum, the period of long PN sequence can be easily obtained. Simulation results show that the proposed method provides good results even at the SNR less than -13dB. The detection is little affected by the period of symbol, but it is affected by the period of PN sequence and longer N needs longer sample time if the detected SNR is the same.

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