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Blind Estimation of Carrier Frequency and Symbol Rate Based on Cyclic Spectrum Density

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Abstract

A blind estimation method based on cyclic spectrum density is proposed to estimate carrier frequency and symbol rate with respect to non-cooperative communication. The cyclostationarity of modulated signals is used to estimate carrier frequency and symbol rate within frequency domain and cyclic frequency domain separately. Both theoretical analysis and simulation results show that the presented method is noise-insensitive and robust.

Keywords: cyclic spectrum density (CSD); carrier frequency; symbol rate

1. Introduction

Carrier frequency and symbol rate play important roles in demodulation. In non-cooperative communication environment like military scouting, residential radio regulation and software receiver, the two parameters are necessary for decoding signals. As a result, more and more attention is paid to the research over the past few decades.

Recently, there are many methods for estimating carrier frequency. The zero-crossings algorithm[1] based on time-domain analysis is computation-simple but noise-sensitive. Periodogram and frequency-centered algorithm[2][3] are based on frequency-domain analysis, which apply to signals with strong carrier power and symmetrical power spectrum density. The ESPRIT algorithm[4][5] based on matrix decomposition is accuracy-high but computation-complex. Two main methods[6] are for symbol rate

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estimation: the method based on wavelet transform[7] and that on circular correlation[8]. All the above methods themselves are limited. Some of them even call for prior knowledge.

An algorithm for the joint estimation of carrier frequency and symbol rate is proposed based on cyclic spectrum density (CSD), which can estimate the two parameters exactly even when there is no available prior knowledge. The rest of the paper is organized as follows. In section two, the principle of CSD is briefly introduced. In section three, the method for jointly estimating carrier frequency and symbol rate is presented based on the properties of CSD. The fourth section shows the simulation results and some summaries are made in the last section.

2. Cyclic Spectrum Density

It is assumed that $x(t)$ is a non-stationary signal with zero mean, whose auto correlation is periodic with period T . That can be described as

$$R_x\left(t+\tau/2, t-\tau/2\right) = R_x\left(t+\tau/2+nT, t-\tau/2+nT\right) \tag{1}$$

Then $x(t)$ is called second order cyclostationary process. Describe its cyclic auto correlation function as

$$\begin{aligned} R_x^{\alpha}(\tau) &= \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} R_x\left(t+\tau/2, t-\tau/2\right) e^{-j2\pi\alpha t} dt \\ &= \lim_{T\to\infty} \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} x\left(t+\tau/2\right) x^*\left(t-\tau/2\right) e^{-j2\pi\alpha t} dt \end{aligned} \tag{2}$$

Where $\alpha = n/T$, which is called cyclic frequency, and n is an integer. The result of Fourier transform for the left hand of Equation (2) is

$$S_x^{\alpha}(f) = \int_{-\infty}^{+\infty} R_x^{\alpha}(\tau) e^{-j2\pi f\tau} d\tau \tag{3}$$

That is called cyclic spectrum density or CSD for short.

Take a MPSK signal for example, whose analytical form is

$$x(t) = Re\left\{x_c e^{j\left(2\pi f_c t + \phi_0\right)}\right\} \tag{4}$$

$$x_c(t) = \sum_{k=-\infty}^{\infty} q_{rc}(t-nT_b) e^{j\theta_k} \tag{5}$$

Where $x_c(t)$ is the complex envelop of $x(t)$, f_c is the carrier frequency, ϕ_0 is the initial phase, $q_{rc}(t)$ is the shaping filter, T_b is the symbol period, $\theta_k \in \left\{2\pi(k-1)/M\right\}, k = 1,\cdots,M$.

Suppose that

$$S_c^{\alpha}(f) = Q_{rc}(f+\alpha/2) Q_{rc}^*(f-\alpha/2) \tag{6}$$

Where $Q_{rc}(f) = FFT\left[q_{rc}(t)\right]$, the CSD of which can be got through frequency-domain smoothing algorithm[9] as follows.

When $M = 2$, the CSD of BPSK signal is

$$\begin{cases} S_x^{\alpha}(f)=\frac{1}{4T_b}\left[S_c^{\alpha}(f+f_c)+S_c^{\alpha}(f-f_c)+S_c^{\alpha+2f_c}(f)e^{-j2\phi_0}+S_c^{\alpha-2f_c}(f)e^{j2\phi_0}\right] \\ \alpha=\pm 2f_c+kT_b \text{ , } \alpha=kT_b \text{ , } k \text{ is an integer} \end{cases} \tag{7}$$

When $M = 4$, the CSD of QPSK signal is

$$\begin{cases} S_x^{\alpha}(f)=\frac{1}{4T_b}\left[S_c^{\alpha}(f+f_c)+S_c^{\alpha}(f-f_c)+S_c^{\alpha+2f_c}(f)e^{-j2\phi_0}+S_c^{\alpha-2f_c}(f)e^{j2\phi_0}\right] \\ \alpha=kT_b \text{ , } k \text{ is an integer} \end{cases} \tag{8}$$

With respect to stationary white noise, its spectrum density is concentrated in the area $\alpha = 0$ [10]. In area $\alpha \neq 0$, the impact of noise is little. As a result, the method for estimating parameters through CSD may restrain the noise effectively.

3. Carrier Frequency & Symbol Rate Estimation

Considering the shaping filter, $Q_{rc}(f)$ may get its maximum at $f = 0$. And when $\alpha = 0$, CSD is just the power spectrum density (PSD). With the CSD being estimated, the carrier frequency and symbol rate may be calculated within frequency domain and cyclic frequency domain separately. The process can be described as follows.

- First step is to estimate the CSD $S_x^{\alpha}(f)$ of $x(t)$;
- As a second step, suppose $\alpha = 0$, and $S_x^{0}(f)$ is the PSD of $x(t)$. Then the carrier frequency $\hat{f}_c$ will be estimated through frequency-centered algorithm [3] as Equation (9).

$$\hat{f}_c = \frac{\sum_{i=1}^{N} f(i)P(i)}{\sum_{i=1}^{N} P(i)} \tag{9}$$

- The third step, suppose $f = \hat{f}_c$, then the symbol rate $\hat{R}_b$ may be estimated through peak search within the area $S_x^{\alpha}(\hat{f}_c)$ except $\alpha = 0$ as Equation (10).

$$\hat{R}_b = arg \max_{\alpha \neq 0} \left\{ S_x^{\alpha}\left(\hat{f}_c\right) \right\} \tag{10}$$

4. Examples and Performance

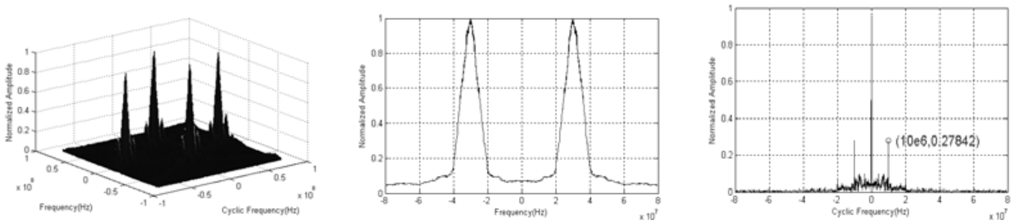
In this section, some experiment results for the method based on CSD are presented. And the performance of the algorithm is analyzed with the signal to noise ratio (SNR) varying.

4.1. Estimation accuracy

Suppose that there is a BPSK signal, whose length is 2048 and SNR is 5dB. The sampling rate is 160MHz and roll-off factor of the raised cosine shaping filter is 0.35. The carrier frequency and symbol rate are listed in table 1. Its CSD may be got through frequency-domain smoothing algorithm [10] as shown in Fig. 1(a). Fig. 1(b) shows the section $S_x^{0}(f)$ at $\alpha = 0$ and the estimated value $\hat{f}_c$ can be calculated through frequency-centered algorithm [3]. Fig. 1(c) shows the section $S_x^{\alpha}\left(\hat{f}_c\right)$ at $f = \hat{f}_c$ and the symbol rate $\hat{R}_b$ can be obtained through peak search, except the maximum at $\alpha = 0$, as listed in Tab.1.

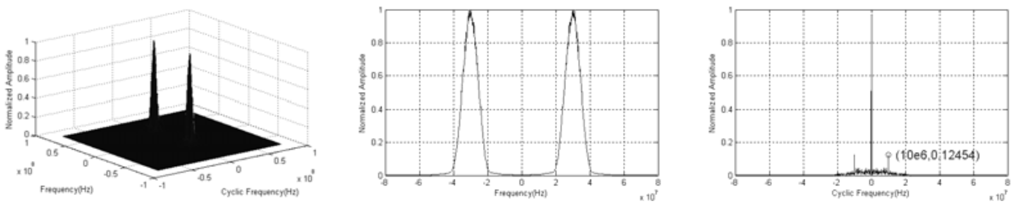
Table 1. Parameters for BPSK signal

Type	Carrier frequency (MHz)	Symbol rate (MB)
Theoretical value	30.00	10.00
Estimation value	30.58	10.00



(a) (b) (c)

Fig. 1. BPSK signal: (a) CSD; (b) section $S_x^0\left(f\right)$ at $\alpha = 0$; (c) section $S_x^{\alpha}\left(\hat{f}_c\right)$ at $f = \hat{f}_c$



(a) (b) (c)

Fig. 2. QPSK signal: (a) CSD; (b) section $S_x^0\left(f\right)$ at $\alpha = 0$; (c) section $S_x^{\alpha}\left(\hat{f}_c\right)$ at $f = \hat{f}_c$

Suppose that a QPSK signal, with the same parameters with the BPSK one, is processed through the presented method based on CSD. The results are shown in Fig.2(a)、Fig.2(b) and Fig.2(c), and the values of the two parameters are listed in Tab.2.

Table 2. Parameters for QPSK signal

Type	Carrier frequency (MHz)	Symbol rate (MB)
Theoretical value	30.00	10.00
Estimation value	30.30	10.00

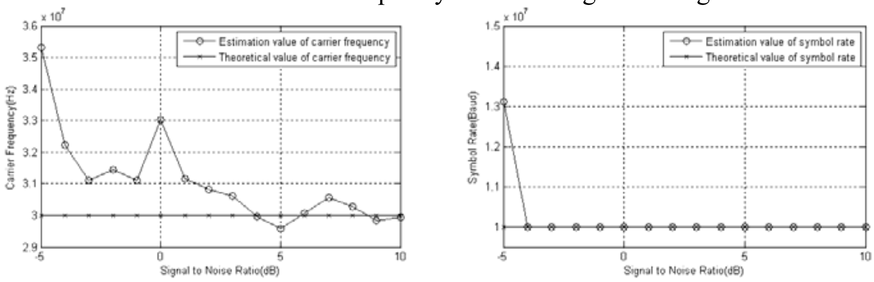
Tab.1 and Tab.2 show that error exists between the estimation value of carrier frequency and the theoretical one through the presented method. But the estimation value of symbol rate is so accurate. The accuracy of the symbol rate remains high when the error of carrier frequency is small.

4.2. Estimation performance with SNR varying

With the same BPSK signal as in the previous section, suppose the SNR varies within -5dB~10dB and the estimation results of carrier frequency and symbol rate are shown in Fig. 3(a) and Fig. 3(b) separately.

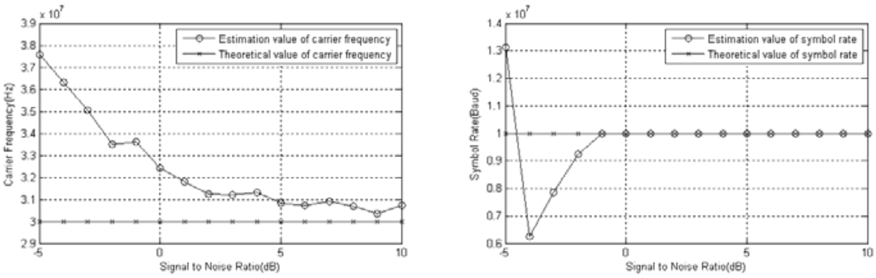
Similarly for QPSK signal, the SNR is changed from -5dB to 10dB and the estimated results of carrier frequency and symbol rate are shown in Fig. 4(a) and Fig. 4(b) respectively.

From Fig. 3 and Fig. 4, it is easy to find that the relative error of the carrier frequency estimated through CSD is smaller than 3% when $SNR \geq 3dB$. And the estimation result of the symbol rate is highly accurate when $SNR \geq -1dB$. But the accuracy would go down and down with the SNR decreasing since the error of the estimation result for carrier frequency becomes larger and larger.



(a) (b)

Fig. 3. The relation diagram between SNR and the estimated results for BPSK signal: (a) carrier frequency; (b) symbol rate



(a) (b)

Fig. 4. The relation diagram between SNR and the estimated results for QPSK signal: (a) carrier frequency; (b) symbol rate

5. Conclusion

A method of joint estimation for carrier frequency and symbol rate is presented in the paper based on the research on CSD. The simulation results show that the estimation values are still accurate when the SNR is low. Especially, the estimation value of the symbol rate is highly close to its theoretical one when $SNR \geq -1dB$, though the value will deviate when the estimated carrier frequency is not exact. As a result, it is necessary to solve the problem of improving the accuracy of carrier frequency in the future and then the estimated symbol rate through CSD would be more robust to noise.

References

[1] Z S Hsue, S S Soliman. Automatic modulation classification using zero-crossing [J]. *IEE Proc Part F Radar signal process*, 1990, 137(6): 459-464.

[2] M I Skolnik. *Introduction to Radar Systems* [M]. Second Edition. New York: McGraw-Hill, Inc, 1980.

[3] Feng Xiang, Liang Weiyang. Carrier Frequency Estimation Algorithms for Digital Modulated Signals [J]. *Research & Development*, No.1, 2006: 105-107.

[4] J Villares, G Vazquez. Sample Covariance Matrix Based Parameter Estimation for Digital Synchronization[C]//. *IEEE Proc of Globecom*,Taiwan Taipei, Nov. 2002.

[5] Yim in Jiang, Robert L Richmond, John S Baras. Carrier Frequency Estimation of MPSK Modulated Signals[R]. *Center for Satellite and Hybrid Communication Networks*, 1999.

[6] Liu Kai, Zuo Zhenyong. Research on Symbol Rate Blind Estimation Algorithms in Communication Countermeasrues [J]. *System Simulation Technology*, July, 2009. 5(3):149-155.

[7] Ou Xin, Symbol rate estimation of MPSK based on many wavelets [J]. *Signal Processing*, Mar. 2009, 25(3):469-471.

[8] Liu Shigang. Cyclocorrelation Based Symbol Rate Estimation [J]. *Signal Processing*, Aug. 2004, 20(4): 356-359.

[9] Gao Yulong. Modulation Recognition and High Dynamic Synchronization Based on Cyclic Spectral Density[D]. *Harbin Institute of Technology*, Mar. 2007:21-25.

[10] Chen Hui. Modulation Recognition of Communication Signals Using Spectral Correlation Approach[D]. *Beijing Jiaotong University*. Dec. 2006:10-14.