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Blind Parameter Estimation for Co-channel Digital Communication Signals

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Abstract With the rapid development of wireless communication technology, modulation signals are more and more intensive in the same frequency. Time-frequency overlapped signal over co-channel widely exists in the shortwave, ultrashort wave and satellite channels, so the research on the time-frequency overlapped signals in non-cooperation receiver is of great significance. This paper firstly studies on blind estimation of amplitude of time-frequency overlapped signals. On the basis of deep analysis of cyclic stationary characteristic in the time-frequency overlapped signals, an amplitude estimation method of time frequency overlapped signal over co-channel based on four-order cyclic cumulants is proposed. The magnitude of the signal components is estimated by using the amplitude value of four-order cyclic cumulants of overlapped signals in certain cyclic frequency. And then an initial phase estimation method based on four-order cyclic cumulants is proposed in this paper. Experiments are conducted to verify the proposed parameter estimation method of time-frequency overlapped signals in this paper. Simulation results show that the

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proposed blind estimation method can achieve better estimation performance in low signal-to-noise ratio (SNR) conditions.

Keywords co-channel signals · cyclic cumulants · cyclic spectrum · parameter estimation

1 Introduction

In communication systems, multiple signals often appear in the same frequency band at the same time, which is the so-called time-frequency overlapped signal, such as co-channel or adjacent channel interference in mobile communication, mutual interference of frequency bands in satellite communication, and multiple echoes in the radar system. Therefore, It is very important to realize non-cooperative blind estimation in co-channel. In order to successfully implement blind demodulation of the received signal, it is necessary to make a comprehensive and accurate estimation of the modulation parameters of the received signal. Therefore, blind parameter estimation of communication signals is an indispensable key technology in non-cooperative communication.

For time-frequency overlapped signals, the amplitudes of the signal components cannot be separated when they are superimposed, which further increases the difficulty of amplitude estimation. Traditional signal amplitude estimation is mostly for a single signal, and there are mainly maximum likelihood estimation methods [1], which determine the signal amplitude based on the maximum likelihood estimation value of the sampled samples, but the amount of calculation is relatively large. Fourier spectrum analysis methods in [2-3], the disadvantage of these methods are spectrum leakage, which reduces the accuracy of signal amplitude estimation. In view of the problem of poor amplitude estimation performance of existing methods when the signal-to-noise ratio (SNR) is low, a amplitude estimation method of co-channel time-frequency overlapped signal based on the fourth-order cyclic cumulants is proposed. This method employs the fourth-order cyclic cumulants amplitude spectrum of the overlapped signal to estimate the amplitude at the cycle frequency of the respective signal symbol rate, thereby obtaining the amplitude estimation value of each signal component.

Furthermore, the initial phase estimation for the signal is also the key issue to be studied in this paper. It can be divided into two categories, one is the initial phase estimation based on auxiliary data [4-6], and the other is the blind estimation of the initial phase without auxiliary data. In non-cooperative communication systems, auxiliary data such as pilot frequency and training sequence are all unknown information and cannot be obtained from the received signal. Therefore, the paper mainly studies the blind estimation method of initial phase without auxiliary data. This paper firstly introduces a initial phase estimation method for time-frequency overlapped signal based on fourth-order cyclic cumulants. This method constructs a test statistic based on the ratio of the fourth-order cyclic cumulants, and estimates the initial phase of each signal component based on the phase information of the test statistic.

In order to solve the poor performance in amplitude estimation when the SNR is low, this paper introduces an amplitude estimation method based on the four-order cyclic cumulants for time-frequency overlapped signals over co-channel. Simulation results show that the proposed method has a good anti-noise performance. In addition, an initial phrase blind estimation method based on four-order cyclic cumulants is introduced in this paper. Simulation results show that the proposed method can effectively estimate the initial phase parameters of co-channel time-frequency overlapped signals and the proposed method has a better estimation performance compared with the existing methods.

2 System Model

The model of time-frequency overlapped signal can be given as [7]

$$x(t) = \sum_{i=1}^{N} s_i(t) + n(t), \tag{1}$$

where $s_i(t) = \sum_{m=1}^{M_i} A_i a_i(m) q\left(t - mT_{bi} - \tau_i\right) \exp\left[j2\pi f_{ci} t + \theta_i\right]$. These elements A_i, $a_i(m)$, M_i and f_{ci} represent signal amplitude, symbol sequence, symbol number and carrier frequency of every signal component, respectively. Also, T_i is a symbol cycle, whose reciprocal is symbol rate f_{ci}; θ_i is initial phase; $q_i(t)$ is pulse shape function. Note that if $q_i(t)$ is rectangular shape, it can be expressed as $q_i(t) = \begin{cases} 1, & |t| \le \frac{T_i}{2} \\ 0, & others \end{cases}$, and we also note that if it raised cosine, it can be expressed as $q_i(t) = \frac{\sin \pi t / T_i}{\pi t / T_i} \cdot \frac{\cos \alpha \pi t / T_i}{1 - 4\alpha^2 t^2 / T_i^2}$, where α(α=0.35 usually) is roll-off factor, τ_i is signal delay, $n(t)$ is the additive Gaussian noise. Signals in this model are mutually independent, and the same to each signal and noise.

3 Amplitude Estimation for Co-channel Digital Communication Signals

Cyclostationarity is one of the prominent characteristics of digital communication signals. Hence, cyclic cumulant has been an effective tool to analyze digital communication signals. Given the property of cyclic cumulants, the cyclic cumulants of stationary and non-stationary Gaussian (color) noise are zero if its order is greater than 2, so that received signals cyclic cumulants have a good ability to resist noise. This paper proposes an amplitude estimation method about time-frequency overlapped signal by using four-order cyclic cumulants. The four-order cyclic cumulants $C_{42}^{\alpha}\left(\tau_1, \tau_2, \tau_3\right)$ is defined as

$$C_{42}^{\alpha}\left(\tau_1, \tau_2, \tau_3\right) = M_{4s}^{\alpha}\left(\tau_1, \tau_2, \tau_3\right) - M_{2s}^{\alpha}\left(\tau_1\right) \cdot M_{2s}^{\alpha}\left(\tau_3 - \tau_2\right)$$

$$-M_{2s}^{\alpha}(\tau_2) \cdot M_{2s}^{\alpha}(\tau_1 - \tau_3) - M_{2s}^{\alpha}(\tau_3) \cdot M_{2s}^{\alpha}(\tau_2 - \tau_1). \quad (2)$$

If $\tau_1 = \tau_2 = \tau_3 = 0$, (2) can be given as

$$C_{42}^{\alpha} \underline{\underline{\Delta}} C_{42}^{\alpha}(0,0,0) = M_{40}^{\alpha}(0,0,0) - 2M_{21}^{\alpha}(0) \cdot M_{21}^{\alpha}(0) - M_{20}^{\alpha}(0) \cdot M_{20}^{\alpha}(0), \quad (3)$$

and (3) can also be written as

$$C_{42}^{\alpha} = \begin{cases} \frac{A^4 C_{\alpha,42}}{T_s} \int_{-\infty}^{+\infty} \prod_{j=1}^{4} (q(t)) e^{-j2\pi\alpha t} dt, \alpha = \pm\frac{d}{T_s}, d \in Z \\ 0, \quad others \end{cases}, \quad (4)$$

where $C_{\alpha,42}$ is the four-order cyclic cumulants value of $s(t)$. if $q(t)$ is reaise cosine pulse, $C_{42}^{\alpha}(\tau_1, \tau_2, \tau_3)$ is non-zero in $\alpha = \pm d/T_s, d \in Z$. Besides, its maximum value appears at $\alpha = 0$,and the secondary is at $\alpha = \pm 1/T_s$.

We should notice that cyclic cumulants have another key property, which is signal selectivity. Consider the following multi-channel model, whose signals and noise are mutually independent. So (1) can be expressed as

$$x(t) = s_1(t) + \ldots + s_M(t) + n(t), \quad (5)$$

and its cyclic cumulants can be expressed as

$$C_{kx}^{\alpha}(\tau) = \sum_{i=1}^{M} C_{ks_i}^{\alpha}(\tau) + C_{kN}^{\alpha}(\tau). \quad (6)$$

For the cyclic cumulants of stationary and non-stationary Gaussian (color) noise is zero when the order of value is greater than 2, the four-order cyclic cumulants of noise is 0. Hence (6) can be written as

$$C_{kr}^{\alpha}(\tau) = \sum_{i=1}^{M} C_{kx_i}^{\alpha}(\tau). \quad (7)$$

Combining with the model in this section, the cycle frequency of time-frequency overlapped signal in the co-channel is

$$\alpha = \bigcup_{i=1}^{N} \alpha_i = \bigcup_{i=1}^{N} (k/T_{si}), k = 0, 1. \quad (8)$$

According to the property of cyclic cumulants, we can conclude that the cyclic cumulants have linear properties and the received signal in the co-channel is the linear combination of original signal. An achievement can be made that the cyclic cumulants to the received signal and the sum of every signals cyclic cumulants are the same. This property indicates that cyclic cumulants can reflect the cyclostationarity of every independent signal component and it is suitable for the estimation on time-frequency signal in the co-channel.

For MPSK signals, the expression can be written as

$$s\left(t\right)=\sum_{k}Aa_{k}q\left(t-kT_{s}\right)e^{j\left(2\pi f_{c}t+\varphi_{0}\right)}, \tag{9}$$

where a_k is the symbol sequence of signals in interval $t \in (kT_s - T_s/2, kT_s + T_s/2)$, $a_k \in \left\{e^{j2\pi(m-1)/M}, m = 1, 2, \ldots, M\right\}$, and $q(t - nT_s)$ is cosine shaping pulse whose roll-off factor is 0.35. f_c, T_s and φ_0 are carrier frequency, symbol period and initial phase, respectively. Substitute the expression of MPSK signals into the definition of four-order cyclic cumulants and MPSK signals four-order cyclic cumulants can be given as

$$C_{42-MPSK}^{\alpha}=\frac{A^{4}C_{\alpha,42}}{T_{s}}\int_{-\infty}^{+\infty}\prod_{j=1}^{4}(q(t))e^{-j2\pi\alpha t}dt, \tag{10}$$

where $C_{\alpha,42}$ is four-order cyclic cumulants value of $s(t)$. For QPSK signals, because $a_k = e^{j(m-1)2\pi/4}, m = 1, 2, \cdots, 4$ and $a_k^2 = \pm j, a_k^4 \equiv 1$, so four-order cyclic cumulants of QPSK signals can be given as

$$C_{\alpha,42-QPSK}=M_{\alpha,42}-2(M_{\alpha,21})^{2}-\left|M_{\alpha,20}\right|^{2}=-\frac{1}{N}\sum_{k=1}^{N}{a_{k}}^{4}=-1. \tag{11}$$

Further known, the expression of four-order cyclic cumulants of QPSK signals are

$$C_{42-QPSK}^{\alpha}=-\frac{A^{4}}{T_{s}}\int_{-\infty}^{+\infty}\prod_{j=1}^{4}(q(t))e^{-j2\pi\alpha t}dt. \tag{12}$$

The $|C_{42}^{\alpha}|$ value of QPSK signals is shown in Fig. 1. From Fig. 1, we can see that the maximum value of $|C_{42}^{\alpha}|$ appears at $\alpha = 0$, and the secondary at $\alpha = \pm 1/T_s$. So that we can estimate signals component amplitude based on the value of great discrete spectrum line.

For 8PSK signals, because of $a_k = e^{j(m-1)2\pi/8}, m = 1, 2, \cdots, 8$, its four-order cyclic cumulants is given as

$$C_{\alpha,42-8PSK}=M_{\alpha,42}-2(M_{\alpha,21})^{2}-\left|M_{\alpha,20}\right|^{2}=-\frac{1}{N}\sum_{k=1}^{N}{a_{k}}^{4}=-1. \tag{13}$$

For 16QPSK signals, because of $a_k = e^{j(m-1)2\pi/16}, m = 1, 2, \cdots, 16$, the four-order cyclic cumulants can be given as

$$C_{\alpha,42-16PSK}=M_{\alpha,42}-2(M_{\alpha,21})^{2}-\left|M_{\alpha,20}\right|^{2}=-\frac{1}{N}\sum_{k=1}^{N}{a_{k}}^{4}=-1\ . \tag{14}$$

Hence, the four-order cyclic cumulants of 8PSK can be expressed as follows

$$C_{42-16PSK}^{\alpha}=-\frac{A^{4}}{T_{s}}\int_{-\infty}^{+\infty}\prod_{j=1}^{4}(q(t))e^{-j2\pi\alpha t}dt. \tag{15}$$

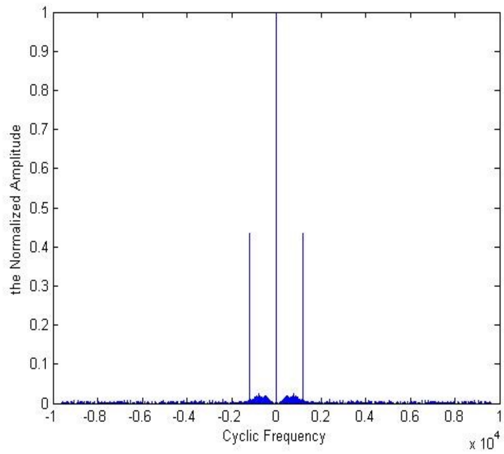

Fig. 1: $\left|C_{42}^{\alpha}\right|$ of co-channel two QPSK overlapped signals.

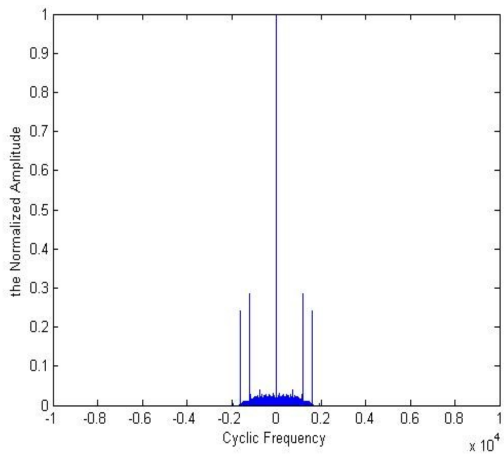

Fig. 2: $\left|C_{42}^{\alpha}\right|$ of co-channel QPSK and 16PSK overlapped signals.

From the above analysis, QPSK, 8PSK and 16PSK have the same expression for four-order cyclic cumulants. Moreover, the value of their cyclic cumulants is non-zero at the cycle frequency $\alpha = \pm k/T_s, k \in Z$, the maximum value at $\alpha = 0$, and the secondary at $\alpha = \pm 1/T_s$. Fig.2 shows $|C_{42}^{\alpha}|$ value of the co-channel QPSK and 16PSK overlapped signals. In Fig.2, the maximum value of $|C_{42}^{\alpha}|$ appears at $\alpha = 0$, but signals are overlapped and can not be distinguished. Every signal component's discrete spectrum line exists in the area where the cycle frequency equals the symbol rate. If $\alpha = \pm 1/T_s$ and roll-off coefficient of raised cosine takes a fixed value, the integral term of four-order cyclic cumulants $\int_{-\infty}^{+\infty} \prod_{j=1}^{4} (q(t))e^{-j2\pi\alpha t}dt$ is given by constant number and be expressed by G_i. In conclusion, we need to make the four-order cyclic cumulants constant to ensure that we can distinguish discrete spectrum lines. It is only in this case that the symbol rate of time-frequency overlapped signals component are not equal and do not exist any integer multiple relationship, we can estimate the symbol cycle T_{s_i} by detecting the position of discrete spectrum line.

This paper uses raised discrete spectrum line to estimate discrete spectrum line. Specific process is as follows: assume that $u(f)$ is the amplitude spectrum of four-order cyclic cumulants, wheref_0 means the frequency when $|u(f)|$ takes the maximum. The ratio of $|u(f_0)|$ and the mean of $|u(f)|$ can express the prominence off_0. If the ratio is bigger than a certain threshold, there shall be a discrete spectrum line atf_0. Because of frequency resolution, there are many approximate discrete spectrum line of four-order cyclic cumulants but only one. In order to prevent these discrete spectrum line which has a bad effect when searching the maximum during the next time, we need to set $|u(f)|$ zero in a section $[f_0 - \delta_0, f_0 + \delta_0]$, where $\delta_0 > 0$. If $\alpha_1 = 1/T_1$, $\alpha_2 = -1/T_1$, the first signal component's symbol cycle $\hat{T}_1 = \frac{2}{|\alpha_1 - \alpha_2|}$. In the same way, we can estimate symbol cycle of other signals. Substituting these values into (16), respectively, and we can acquire the value of every signal component' amplitude estimation.

$$\hat{A}_i = \sqrt[4]{|C_{42}^{\alpha}| \cdot T_{s_i}/G_i}. \tag{16}$$

In conclusion, this paper proposes a method of amplitude estimation on time-frequency overlapped signals based on four-order cyclic cumulants in co-channel. The steps of the proposed method are as follows.

Step 1: Search the value of four-order cyclic cumulants $\left|C_{r,42}^{\alpha}\right|$ of time-frequency overlapped signals $r(t)$ in co-channel. And then we obtian the amplitude spectrum of four-order cyclic cumulants overlapped signals $\alpha - \left|C_{r,42}^{\alpha}\right|$;

Step 2: When the symbol rate of time-frequency overlapped signals component is not equal and does not exist integer multiple relationship, we can estimate the symbol rate of signal component $1/T_{s_i}$ according to discrete spectrum line detection method;

Step 3: According to the symbol rate $1/T_{s_i}$, we search the value of $C_{x,40}^{1/T_{s_i}}$ in $\alpha - \left|C_{r,42}^{\alpha}\right|$ when $\alpha_i = 1/T_{s_i}$;

Step 4: According to the value of step 2 and step 3, we search the amplitude estimation value of every signal component $\hat{A}_i = \sqrt[4]{|C_{42}^{\alpha}| \cdot T_{s_i}/G_i}$.

4 Initial Phrase for Co-channel Digital Communication Signals

The definitions of four-order cyclic cumulants $C_{a,40}$ and $C_{a,42}$ are as follows,

$$C_{40}^{\alpha}=\frac{E^2C_{a,40}e^{j4\varphi_0}}{T_s}\int_{-\infty}^{\infty}p^4\left(t\right)e^{-j2\pi(\alpha-4f_c)t}dt, \tag{17}$$

and

$$C_{42}^{\alpha}=\frac{E^2C_{a,42}}{T_s}\int_{-\infty}^{\infty}p^4\left(t\right)e^{-j2\pi\alpha t}dt, \tag{18}$$

where φ_0 is initial phrase, f_c is carrier frequency, and $1/T_s$ is symbol rate.

The commonly used modulation signals in digital communication are BP-SK, QPSK, 16QAM and 64QAM. For example, the value of the 4-order cyclic cumulants for BPSK signal are

$$C_{40-BPSK}^{\alpha}=-\frac{2E^2e^{j4\varphi_0}}{T_s}\int_{-\infty}^{+\infty}p^4(t)e^{j2\pi(\alpha-4f_c)t}dt, \tag{19}$$

and

$$C_{42-BPSK}^{\alpha}=-\frac{2E^2}{T_s}\int_{-\infty}^{+\infty}p^4(t)e^{-j2\pi\alpha t}dt. \tag{20}$$

We can note that C_{40}^{α} includes initial phrase information, but C_{42}^{α} does not. So that we can use the ratio of C_{40}^{α} and C_{42}^{α} to estimate the initial phrase. When $\alpha=4f_c+1/T_s$, the expression of C_{40}^{α} is

$$C_{40}^{4f_c+1/T_s}=\frac{E^2C_{a,40}e^{j4\varphi_0}}{T_s}\int_{-\infty}^{\infty}p^4\left(t\right)e^{-j2\pi t/T_s}\,dt, \tag{21}$$

and when $\alpha=1/T_s$ the expression of C_{42}^{α} is given as

$$C_{42}^{1/T_s}=\frac{E^2C_{a,42}}{T_s}\int_{-\infty}^{\infty}p^4(t)e^{-j2\pi t/T_s}dt. \tag{22}$$

In order to make it more intuitive, the four-order cyclic cumulants C_{40}^{α} and C_{42}^{α} are shown in Fig. 3 and Fig. 4, respectively. From Fig. 3 and Fig. 4, we can see that the value of C_{40}^{α} and C_{42}^{α} are bigger and not zero at $\alpha=4f_c+1/T_s$ and at $\alpha=1/T_s$, respectively. Besides, it can find it that the integral part of the two expressions are the same from (21) and (22), but only (21) has initial phrase information. Therefore, we can estimate the signal component's initial phrase by structuring characteristic parameters T. In order to make the characteristic parameter T contain the initial phase information, the ratio of C_{40}^{α} and C_{42}^{α} is used to construct T. The expression of T is

$$T=\frac{C_{40}^{4f_c+1/T_s}}{C_{42}^{1/T_s}}=\frac{\frac{E^2C_{a,40}e^{j4\varphi_0}}{T_s}\int_{-\infty}^{\infty}p^4\left(t\right)e^{-j2\pi t/T_s}\,dt}{\frac{E^2C_{a,42}}{T_s}\int_{-\infty}^{\infty}p^4\left(t\right)e^{-j2\pi t/T_s}\,dt}=\frac{C_{a,40}e^{j4\varphi_0}}{C_{a,42}}. \tag{23}$$

As $C_{a,40}$ of BPSK, QPSK, 16QAM and 64QAM are all real, the initial phrase information is included in parameter T. Thus, we can estimate the initial phrase by detecting T, the estimator of initial phrase ϕ_i is

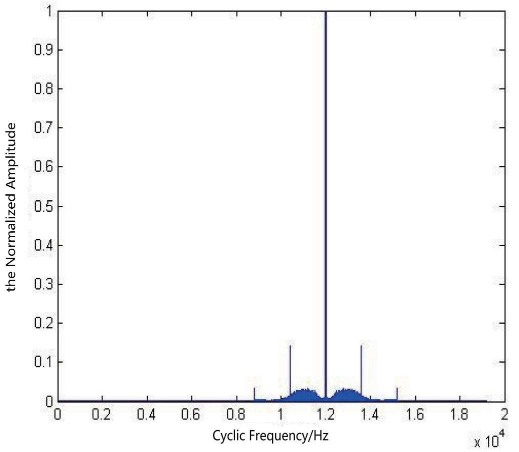

Fig. 3: The four-order cyclic cumulants $\left|C_{40}^{\alpha}\right|$ of QPSK.

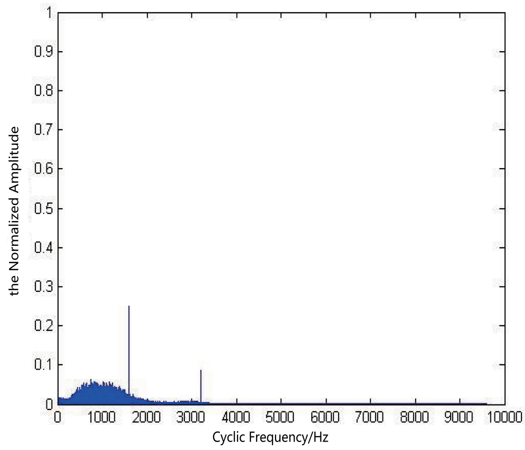

Fig. 4: The four-order cyclic cumulants $\left|C_{42}^{\alpha}\right|$ of QPSK.

$$\hat{\phi}_i = \frac{1}{4}\arg(T), \tag{24}$$

where $\arg(\cdot)$ means compute phrase for plural.

In conclusion, the specific steps of initial phrase estimation method based on four-order cyclic cumulants are as follows:

Step 1: Computing four-order cyclic cumulants $C_{x,40}^{\alpha}$ and $C_{x,42}^{\alpha}$ of time-frequency overlapped signals by (21) and (22), then get the four-order cyclic cumulants spectrum $\alpha - C_{x,40}^{\alpha}$ and $\alpha - C_{x,42}^{\alpha}$;

Step 2: According to the known signals' carrier frequency f_{c1} , f_{c2} and symbol rate $1/T_{s1}$, $1/T_{s2}$, get the value $C_{x,40}^{4f_{c1}+1/T_{s1}}$ of $\alpha - C_{x,40}^{\alpha}$ at $\alpha = 4f_{c1} + 1/T_{s1}$ and $C_{x,40}^{4f_{c2}+1/T_{s2}}$ at $\alpha = 4f_{c2} + 1/T_{s2}$;

Step 3: According to symbol rate of the known signals $1/T_{s1}$ and $1/T_{s2}$, get the value $C_{x,42}^{1/T_{s1}}$ of $\alpha - C_{x,42}^{\alpha}$ at $\alpha = 1/T_{s1}$ and $C_{x,42}^{1/T_{s2}}$ at $\alpha = 1/T_{s2}$;

Step 4: According to the four values coming from step 2 and step 3, structure characteristic parameters $T_1 = C_{x,40}^{4f_{c1}+1/T_{s1}} / C_{x,42}^{1/T_{s1}}$ and $T_2 = C_{x,40}^{4f_{c2}+1/T_{s2}} / C_{x,42}^{1/T_{s2}}$

Step 5: Computing phrase angle Φ_1 of characteristic parameters T_1 and Φ_2 of T_2 , then get the initial phrase $\varphi_{01} = \Phi_1/4$ and $\varphi_{02} = \Phi_2/4$.

5 Numerical Results and Discussion

Simulation experiment has been done by using MATLAB to validate the effectiveness of the estimation methods in this paper. Time-frequency overlapped signals and additive white Gaussian noise are adopted in this experiment.

5.1 Amplitude Estimation

In order to assess the performance of the method in different ways, we take different kinds of signals (QPSK, 8PSK and 16PSK) into simulation experiment, and the coefficient of roll-off is 0.35. We also takes 1000 Monte Carlo tests. The evaluation criteria of amplitude estimation by mean squared error (MSE).

Experiment 1: In order to measure the SNRs effects on the performance of amplitude estimation on time-frequency overlapped signals, we can put the arbitrary combination of two signal in QPSK, 8PSK and 16PSK signals, and the parameter setting are as follows: carrier frequency $f_{c1} = 2.7KHz$ and $f_{c2} = 3.3KHz$, symbol rate $f_{b1} = 1.2KBaud$ and $f_{b2} = 1.6KBaud$, sample rate $f_s = 19.2KHz$, and data length 5000. The simulation results is shown as Fig.5. As can be seen from the Fig. 5, when the SNR is bigger than 0, the method of amplitude estimation can achieve ideal estimation performance, and with the increase of SNR , the estimation performance increase.

Experiment 2: In order to test the influence of sample data length to the amplitude estimation of time-frequency overlapped signals, we can put the arbitrary combination of two in QPSK, 8PSK and 16PSK signals, and the SNR is 10dB. the parameter setting are as follows: carrier frequency $f_{c1} = 2.7KHz$ and $f_{c2} = 3.3KHz$, symbol rate $f_{b1} = 1.2KBaud$ and $f_{b2} = 1.6KBaud$, and sample rata $f_s = 19.2KHz$. The simulation results is shown as Fig. 6.

As can be seen from Fig.6, the estimated performance increases for the decrease of the amplitude estimation MES from time-frequency overlapped double signals with the increase of sample data length. The reason is that

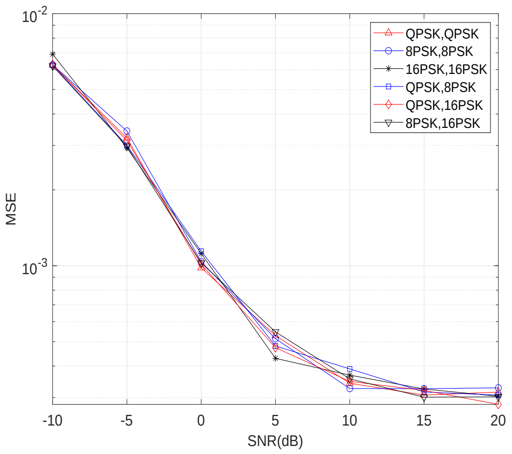

Fig. 5: Amplitude estimation performance of time-frequency overlapped signals with different SNRs.

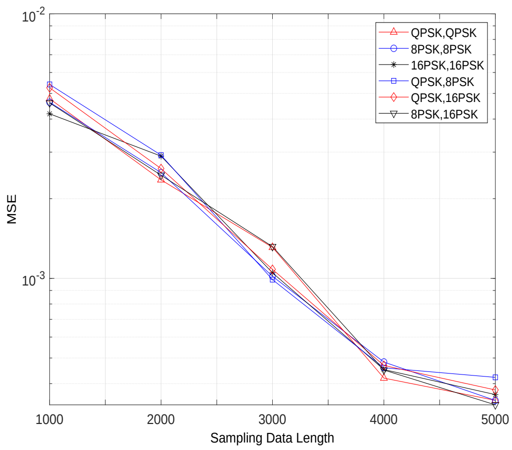

Fig. 6: Amplitude estimation performance of time-frequency overlapped signals with different data length.

cyclostationarity which is reflected by cyclic cumulants is an asymptotic property, so that the estimation performance of amplitude estimation method can be improved by increasing the data length.

Experiment 3: In order to measure the influence of spectrum overlapped rate to the performance of amplitude estimation on time-frequency overlapped signals, we can put the arbitrary combination of two in QPSK, 8PSK and 16PSK signals, and the SNR is 10dB. The parameter setting are as follows: sample rate $f_s = 19.2KHz$, data length is 5000, carrier frequency combination are

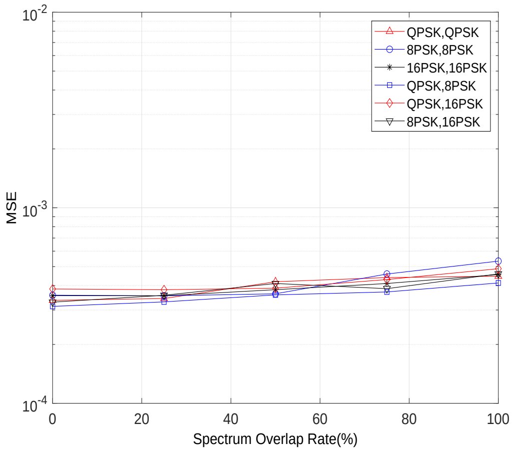

Fig. 7: Amplitude estimation performance of time-frequency overlapped signals with different spectrum overlapped rates.

$f_{c1} = 1.9KHz$ and $f_{c2} = 3.3KHz$; $f_{c1} = 2.2KHz$ and $f_{c2} = 3.3KHz$; $f_{c1} = 2.5KHz$ and $f_{c2} = 3.3KHz$; $f_{c1} = 3.1KHz$ and $f_{c2} = 3.3KHz$ respectively. Symbol rate $f_{b1} = 1.2KBaud$ and $f_{b2} = 1.6KBaud$. The simulation results is shown as Fig. 7. As can be seen from 7, spectrum overlapped rate has a little influence on amplitude estimation. The reason is that when data length is fitful, if the symbol rate of signal component is different, using cyclic cumulants of signals to estimate amplitude is helpful in distinguishing different signals amplitude information, while its performance will not be affected by other signals.

Experiment 4: In order to measure the influence of power ratio to the performance of amplitude estimation on time-frequency overlapped signals. We can put the arbitrary combination of two in QPSK, 8PSK and 16PSK signals, and the SNR is 10dB. the power ratio of two signals is 1.2. The parameter setting of the two signals are as follows: carrier frequency $f_{c1} = 2.7KHz$ and $f_{c2} = 3.3KHz$; symbol rate $f_{b1} = 1.2KBaud$ and $f_{b2} = 1.6KBaud$; sample rata $f_s = 19.2KHz$; data length 5000. The simulation result is as Fig. 8. Compare with Fig. 8, it can be seen that the increase of signals components power ratio can make the estimation performance decrease from Fig. 8. When the power ratio of two signals is 1.2 and the SNR is 10dB, the amplitude estimation method can achieve an ideal performance. As the four-order cyclic cumulants estimation in face is done with the biquadrate magnitudes of signals, the change of signals power can bring a big change to the four-order cyclic cumulants. From Fig. 9, the method in this paper has a better performance than the method which is based on max-min method in the same simulation condition. In the case of low SNR, the proposed method in this paper can be better, due to the fact that cyclic cumulants can suppress the noise.

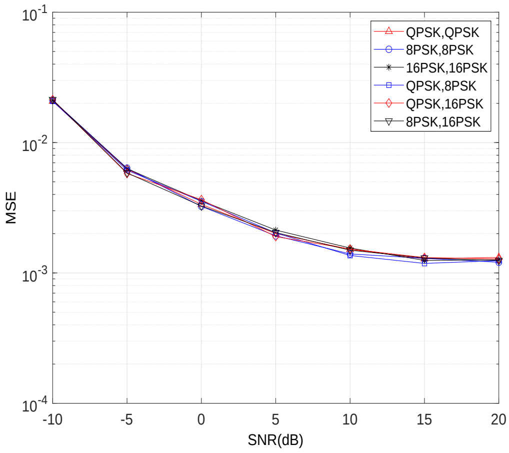

Fig. 8: Amplitude estimation performance of time-frequency overlapped signals when the power ratio is 1.2

Experiment 5: In order to compare the performance of the method in this paper with the existing method, the overlapped signals are two mixed QPSK. In the same simulation environment and the parameter setting, the method in this paper has to compare with the method in [13]. The results is shown in Fig. 9.

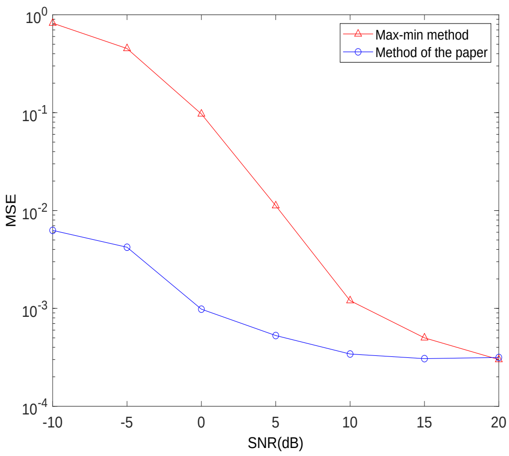

Fig. 9: Amplitude estimation performance comparison with different methods.

The method in [13] needs $4\left(M+N\right)-6$ times addition of complex number and $4N$ multiplication of complex number, where M is window length. However, the times of addition and multiplication of complex are $2N\log_2 N + N$ and $N\log_2 N + 5N$ in this paper, so that the algorithm complexity of the proposed method is bigger, but the performance is better than that in [13] form Fig. 9, especially in the low SNR condition.

5.2 Initial Phrase

For evaluating performance of the proposed method, the following simulation experiment uses time-frequency overlapped signals whose type are MPSK and MQAM. The signals use raised cosine shaping function whose roll-factor is 0.35. We take Monte Carlo experiments 1000 times, and the evaluative criteria of initial phrase is MSE.

Experiment 1: In order to test impact of SNR to time-frequency overlapped signals initial phrase estimation, any two random combination from BPSK, QPSK, 16QAM,64QAM. Any two signals parameter setting are as follows: carrier frequency $f_{c1} = 2.7KHz$ and $f_{c2} = 3.3KHz$, symbol rate $f_{b1} = 1.2KBaud$ and $f_{b2} = 1.6KBaud$, sample rata $f_s = 19.2KHz$, and data length is 5000. The simulation result is shown in Fig. 10. As seen from Fig. 10, when input SNR is bigger than 5dB, the proposed method in this paper can achieve ideal performance. With the increase of SNR, the estimation performance is also improved.

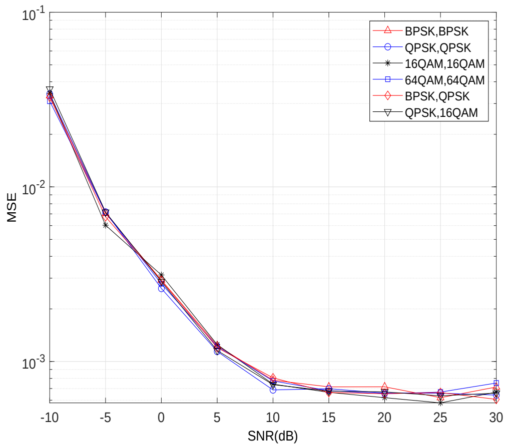

Fig. 10: Initial phrase estimation performance of time-frequency overlapped signals with different SNRs

Experiment 2: In order to test the impact of data length on time-frequency overlapped signals initial phrase estimation, we should combine any two random signals from BPSK, QPSK, 16QAM,64QAM(the SNR is 10dB). Signals parameter setting are as follows: carrier frequency $f_{c1} = 2.7KHz$ and

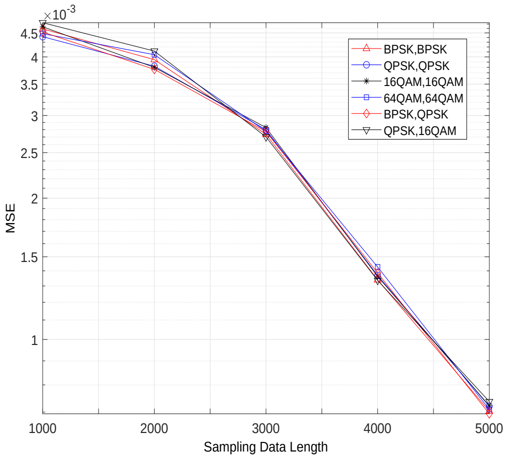

Fig. 11: Initial phrase estimation performance of time-frequency overlapped signals with different data length

$f_{c2} = 3.3KHz$, symbol rate $f_{b1} = 1.2KBaud$ and $f_{b2} = 1.6KBaud$, and sample rata $f_s = 19.2KHz$. The simulation results is shown as Fig. 11. From Fig. 11, we can see that the MSE of time-frequency overlapped signals the estimation performance increase with the increase of sampling data length. As the cyclostationarity reflected by cyclic cumulants is an asymptotic behavior, thus we can improve estimated performance by increasing data length.

Experiment 3: In order to test the impact of spectrum overlapped rate on initial phrase estimation performance for overlapped signals, we should combine any two random signals from BPSK, QPSK, 16QAM, 64QAM (SNR is 10dB). Data length 5000, and any two signals performance setting are as follows: carrier frequency combination are $f_{c1} = 1.9KHz$ and $f_{c2} = 3.3KHz$, $f_{c1} = 2.2KHz$ and $f_{c2} = 3.3KHz$, $f_{c1} = 2.5KHz$ and $f_{c2} = 3.3KHz$, $f_{c1} = 3.1KHz$ and $f_{c2} = 3.3KHz$, respectively. Symbol rate $f_{b1} = 1.2KBaud$ and $f_{b2} = 1.6KBaud$. The spectrum overlapped rates of each combination are 0%, 25%, 50%, 75% and 100%, respectively. Symbol rate are $1/T_{s1} = 1.2KBaud$ and $1/T_{s2} = 1.6KBaud$. The simulation results is shown in Fig. 12.

From Fig.12, we can know that the impact of spectrum overlapped rate on initial phrase estimation is small. Because as the increase of spectrum overlap rate, the interval of signal components cyclic cumulants will become smaller. Therefore, it can make the signal components be influenced more. As long as the symbol rate of every signal component are different, due the cyclostationarity that we can get the amplitude and phrase information, and decrease the impact of other signal components at the same time.

Experiment 4: In order to assess the performance of the method in this paper and the existing method, the overlap signal contains two QPSK. Under the same simulation environment and parameter setting, the method introduced

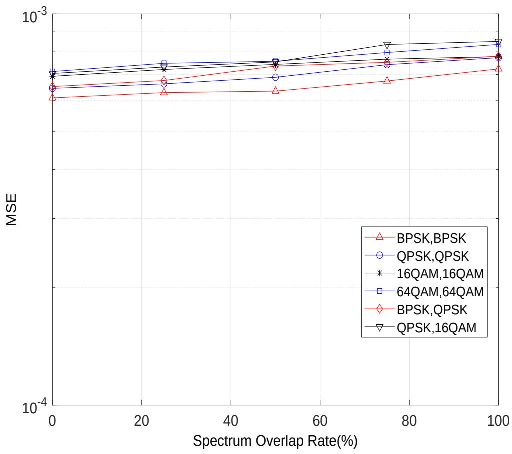

Fig. 12: Initial phrase estimation performance of time-frequency overlapped signals with different spectrum overlapped rates.

in this paper has to compare with the method in [22], the results is shown in Fig.13.

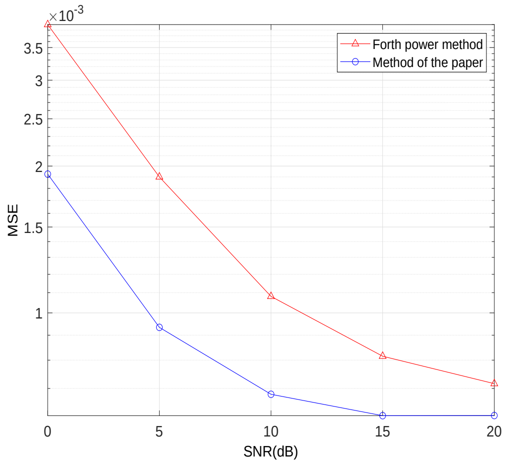

Fig. 13: Initial phrase estimation performance comparison with different methods

From Fig.13, it draws that as the increase of SNR, the EMS of initial phase estimation decrease. Under the same simulation condition, the method introduced in this paper is better than the existing method based on biquadrate. The method of biquadrate needs $2(N-1)^2+1$ times addition of complex quantities and $8N(N+1)$ times complex multiplication. The proposed method needs addition of complex quantities and complex multiplication $2N\log_2 N+N$ times and $N\log_2 N + 5N$ times and the calculation complexity reflected in complex multiplication. In a word, the calculation complexity of the proposed method in this paper is smaller.

6 Conclusion

In order to solve the poor performance in amplitude estimation when the SNR is low, this paper introduces an amplitude estimation method based on the four-order cyclic cumulants for time-frequency overlapped signals over co-channel. Simulation results show that the proposed method has a good anti-noise performance. In addition, an initial phrase blind estimation method based on four-order cyclic cumulants is introduced in this paper. The proposed method employs the ratio of four-order cyclic cumulants by C_{40}^{α} and C_{42}^{α} in carrier frequency and symbol rate of every signal component constructing characteristic parameter, then it adopts the phrase angle information of characteristic parameter to estimate initial phrase. Simulation results show that the proposed method can effectively estimate the initial phase parameters of co-channel time-frequency overlapped signals and has a better estimation performance compared with the existing methods.

7 Declarations

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Availability of date and material: Not applicable.
Code availabilty: Not applicable.
Authors' conributions: Mingqian Liu: Methodology, Writing-original draft. Shenghan Yu: Data curation, Conceptualization. Yunfei Chen: Writing- review & editing. Shuo Chen: Software, Validation.

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