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Automatic Modulation Classification of MPSK signals Using High Order Cumulants

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Abstract

A modulation classification scheme for MPSK signals is proposed. Frequency and timing synchronization is achieved before fourth-order-cumulant based modulation classification algorithm is carried out. The recognition range include BPSK, QPSK, 8PSK and π/4 DQPSK.

1. Introduction

Modulation classification is of great importance in some communication applications, such as electronic warfare and radio spectrum monitoring. In designing an intelligent receiver, it is demanded that demodulation can be performed with little priori knowledge of the received signal. Thus recognition of the modulation type and estimation of parameters for demodulation is an important step.

PSK modulation is widely used in modern communication systems. It is worthwhile to discuss the modulation recognition schemes for MPSK signals. The Fourth-order-cumulant based algorithm is an effective way, which is resistant to additive noise, and invariant to shift, scale and rotation transforms of MPSK signal constellations[1]. However, this scheme should be carried out when there are no frequency offset and timing error in the baseband signal, otherwise the performance will decrease sharply. In order to solve this problem, the algorithms for frequency offset and timing error estimation is presented in this paper. With these steps done before modulation recognition, the performance of fourth-order-cumulant based algorithm can be improved effectively compared with the situation that frequency offset and timing error exists. In section II, the signal model and overall signal-processing scheme is presented. Algorithms for frequency offset and timing error estimation is discussed in section III and IV. Section V presents the fourth-order-cumulant based recognition algorithm in detail. In order to distinguish the π/4-DQPSK from 8PSK, phase differential is carried out in section VI. Simulation results are given in section VII. Finally, We conclude with summary in section VIII.

2. Signal model

When IF signal received, the intelligent receiver estimates the carrier frequency and bandwidth. Then the signal is shifted to baseband and sampled. The sampled sequence of MPSK signal can be expressed as the following complex form:

$$r(n) = r(nT_s) = \sum_{k=-\infty}^{\infty} a_k g_T(nT_s - kT_d - \varepsilon(t)T_d) \cdot \exp(j2\pi\Delta f nT_s + \theta) + w(nT_s) \qquad (1)$$

where $g_T(t)$ is the shaping pulse. $\varepsilon(t)$ represents timing error, where $-0.5 \le \varepsilon(t) \le 0.5$. Δf is carrier frequency offset. θ is the carrier phase. $\{a_k\}$ is the transmitted symbol sequence, where $a_k \in \{\exp(j2\pi(m-1)/M), m=1,2,\ldots,M\}$. w(t) is additive Gaussian noise.

The fourth-order-cumulant based modulation classification algorithm for MPSK signal is proved a very efficient way when no frequency offset and timing error exits. But the correct classification probability decreases when frequency offset and timing error exists. So before recognize the modulation type, some step should be taken in order to estimating the frequency and timing error and correct them. The signal processing process proposed in this paper is shown in Figure 1. The first step is to estimate carrier frequency and bandwidth of the IF signal approximately from the power spectrum. Then the signal is shifted to baseband and achieved frequency and timing synchronization, Modulation recognition is done in the next step and demodulation can be carried out with these parameters.

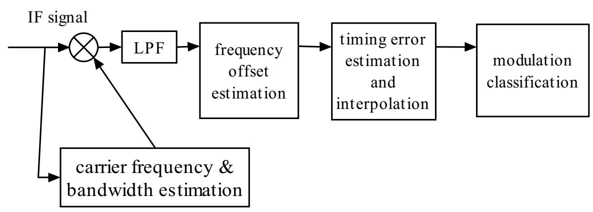

Figure1. Signal processing flow chart

The priori knowledge of the received signal is little in non-cooperative communication systems. So both frequency and timing synchronization should be achieved using non data assistant algorithms. The following sections will introduce theses algorithms to estimate these parameters

3. Frequency offset estimation

The carrier frequency estimation can be achieved either in time domain or frequency domain[5], this step is an approximately estimate of the frequency, there may be frequency offset exiting in the baseband signal. In this section, an algorithm is proposed to estimate the remaining frequency offset.

As is shown in equ.(1), the autocorrelation function of the sampled sequence {r(n)} is:

$$\hat{R}(l)=\frac{1}{L-l}\sum_{k=0}^{L-1-l} r(kT_s+lT_s)r^*(kT_s), l=0,1,...N-1 \quad (2)$$

When l not equal to zero, the expectation of $\hat{R}(l)$ hasfollowing form[2]:

$$R_e(l)=E[\hat{R}(l)]=\exp(j\Delta\omega T_s l)\frac{\sigma_s^2}{L-l}\sum_{k=0}^{L-1-l}\Phi(k,l) \quad (3)$$

where σ_s^2 is the variance of the transmitted symbols, and

$$\Phi(k,l)=\sum_n g_T((k+l)T_s-nT-\varepsilon)g_T(kT_s-nT-\varepsilon)\cdot$$

$g_T(t)$ denotes the shaping pulse of the transmitted signal, and its duration will be of finite length. That means $g_T(t)$ decreases to zero as time increases. From equ.(3), it can be concluded that $\Phi(k,l)$ will be converged to a fixed real value. So the expectation in equ.(3) will be of finite value and the frequency offset $\Delta\omega$ can be solved from the phase of $\hat{R}(l)$.

Therefore the following steps are taken in order to estimate the frequency offset:

1) Calculate R(1) and R(2) according to equ.(3).
2) Calculate u(1)=R(2)R*(1), where * denotes complex conjugation.
3) Calculate the phases of R(1) and u(1).

$$\theta_1=\arg(R(1))$$
$$\theta_2=\arg(u(1))$$

4) Calculate the mean value of θ_1 and θ_2.

$$\bar{\theta}=(\theta_1+\theta_2)/2$$

5) The normalized frequency offset is estimated:

$$\frac{\Delta f}{f_b}=\frac{\Delta f}{f_s/P}=L\frac{\bar{\theta}}{2\pi} \quad (4)$$

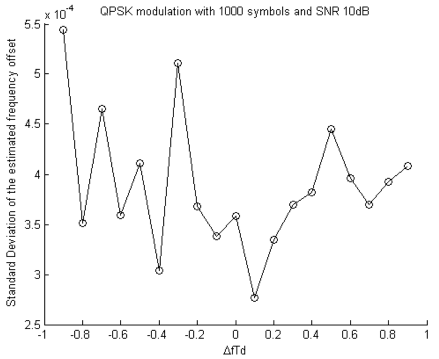

Figure2. Standard Deviation of the Estimated Frequency offset

Figure.2 shows the simulation result to verify the frequency offset estimation algorithm using QPSK signal with 1000 symbols where SNR is 10dB. The result shows the standard deviation versus normalized frequency.

After these steps, the remaining frequency offset in the baseband signal is reduced to an reasonable limit.

4. Timing error estimation & interpolation

Timing in a receiver must be synchronized to the symbol of the received signal. But in most cases, the baseband signal may not be sampled with a synchronized clock, which introduces timing error in the sampled sequence and makes modulation classification and demodulation incorrect. Timing error estimation can be achieved using the algorithm shown in figure 3, which is suitable for linear digital modulation schemes[3]. The basic principle of the algorithm is that the squared sample sequence contains a spectral component at $1/T_b$. This component can be determined by computing the complex Fourier coefficient at the symbol rate.

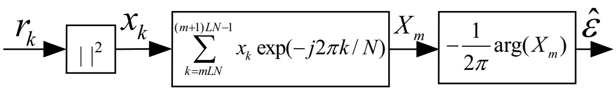

Figure3. Timing error estimation flow chart

After timing error is obtained, the sampled sequence should get timing synchronized. This step can be done by interpolating the sequence in an all digital receiver. Interpolation is the unique way using in an all digital receiver [4]. For a traditional receiver, this step is often done using phase lock loop.

For example, cubic interpolator can be used. The interpolation filter has the form:

$$y(t)=C_{-2}(\mu)x[(m+2)T_s]+C_{-1}(\mu)x[(m+1)T_s]+ \\ C_0(\mu)x[(m)T_s]+C_1(\mu)x[(m-1)T_s] \quad (5)$$

with the coefficients:

$$\begin{cases} C_{-2}(\mu) = \mu^3/6 - \mu/6 \\ C_{-1}(\mu) = \mu^3/2 + \mu^2/2 + \mu \\ C_0(\mu) = \mu^3/2 - \mu^2 - \mu/2 + 1 \\ C_1(\mu) = -\mu^3/6 + \mu^2/2 - \mu/3 \end{cases} \tag{6}$$

Fig.4 shows the constellations before and after timing error estimation and interpolation. It is obvious that ISR is reduced after interpolation.

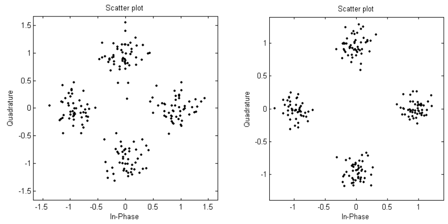

Figure 4. constellations before and after interpolation

5. Modulation classification

For MPSK signals, fourth-order-cumulant based modulation recognition algorithm is resistant to additive noise, and invariant to shift, scale and rotation transforms of MPSK signal constellations [2]. This is based on the condition that the baseband signal is frequency and timing synchronized.

The definition of fourth-order cumulant is

$$\begin{aligned} C_{X,20} &= cum(X,X) = M_{20} \\ C_{X,21} &= cum(X,X^*) = M_{21} \\ C_{X,40} &= cum(X,X,X,X) = M_{40} - 3M_{20}^2 \\ C_{X,41} &= cum(X,X,X,X^*) = M_{41} - 3M_{21}M_{20} \\ C_{X,42} &= cum(X,X,X^*,X^*) = M_{42} - |M_{20}|^2 - 2M_{21}^2 \end{aligned} \tag{7}$$

where $M_{pq} = E[X(k)^{p-q} X^*(k)^q]$.

The fourth-order cumulant of ideal MPSK signals can be calculated from the above definition. The results are listed in Table 1.

Table 1. Fourth-order Cumulant of MPSK Signals

Type	C_{21}	C_{40}	C_{41}	C_{42}
2PSK	E	$-E^2$	$-E^2$	$-2E^2$
4PSK	E	E^2	0	$-2E^2$
MPSK(M>=8)	E	0	0	$-E^2$

Define the feature vector for modulation recognition:

$$F_x = [f_{x1}, f_{x2}] = \left[\left| \frac{C_{40}}{C_{42}} \right|, \left| \frac{C_{41}}{C_{42}} \right| \right] \tag{8}$$

Use the results in Tab.1, the ideal values of F_x is:

$$F_x = \begin{cases} [1,1] & \text{BPSK} \\ [1,0] & \text{QPSK} \\ [0,0] & \text{MPSK}(M \geq 8) \end{cases} \tag{9}$$

It can be shown that F_x can be used as the classification vector, which is invariant with respect to shift, scale and rotation of MPSK signal constellations.

F_x is applied in modulation recognition, where Euclidian distance is used as the decision rule:

$$\hat{M} = \arg\min_M (\|F_r - F_x\|) \tag{10}$$

where F_r is the feature vector extracted from the received signal.

6. Phase differential

π/4-DQPSK scheme is an improved PSK modulation type with many good features and is used in many communication systems. This type of scheme has the same constellation with 8PSK. Using the algorithm proposed above, π/4-DQPSK and 8PSK cannot be distinguished.

In order to distinguish the two schemes, phase differential is used. That is to calculate the absolute phases sequence $\{\varphi(n)\}$ of the sampled baseband sequence, then obtain another sequence $\{\psi(n)\}$ by differentiating the sequence $\{\varphi(n)\}$, i.e. $\psi(n)= \varphi(n)-\varphi(n-1)$. For π/4-DQPSK signal, there are only 4 values in the $\{\psi(n)\}$ set, i.e. $\pm\pi/4$ and $\pm 3\pi/4$, which means the constellation is QPSK. Whereas the phase differential sequence of 8PSK have 8 values, which means that the constellation is still 8PSK. Using the cumulant based algorithm on the differentiated phase sequence can distinguish the two schemes. The flow char of the overall recognition algorithm for MPSK signals is shown in Fig.3

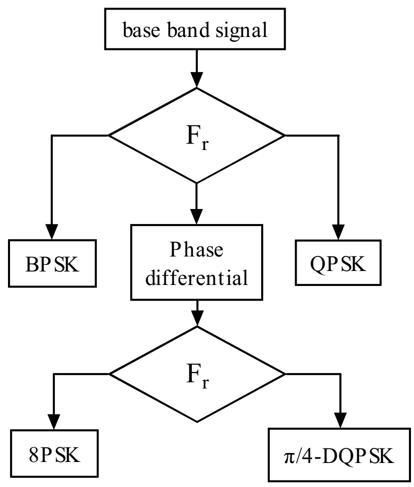

Figure 5. modulation recognition algorithm for MPSK signals

7. Simulation results

In this section, computer simulation experiments are carried out to verify the recognition probability. In each experiment, 100 Monte Carlo tests are carried out.

Fig.6 shows the correct recognition ratio of 8PSK signals after frequency and timing synchronization is achieved. The effect of data lengths on the correct ratio is compared, using 100 and 200 symbols.

Fig.7 shows the results for distinguishing π/4-DQPSK from 8PSK using the phase differential algorithm proposed in section VI.

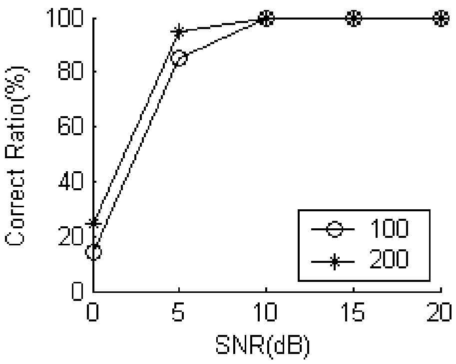

Figure 6. Recognition Probability for 8PSK

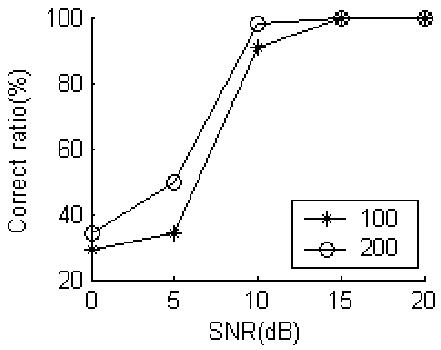

Figure 7. Recognition Probability between 8PSK and π/4-DQPSK

It is obvious that when in a low SNR environment, the correct ratio decreases. That is because additive noise affects the calculation of phases greatly. The cumulant based algorithm can suppress additive Gaussian noise only, whereas phases calculation and differentiation make additive Gaussian noise non-Gaussian. So the correct recognition ratio will decrease with low SNR presence.

8. Conclusions

In this paper, a modulation classification algorithm for MPSK signals is presented. We use the fourth-order-cumulant based modulation recognition algorithm to MPSK signals. Frequency offset and timing error is estimated and corrected before modulation classification. These steps can improve the recognition probability effectively. The computer simulation shows results of the recognition scheme

References

[1] Yang Shaoquan, Chen Weidong. “Classification of MPSK signals using cumulant invariants”, Journal of Electronics, pp.416-429, 2002.

[2] Zaihe Yu, Yun Q.Shi, Wei Su. “A Blind Carrier Frequency Estimation Algorithm For Digitally Modulated Signals”, IEEE Military Communications Conference, pp.48- 53,2004

[3] M.Oerder, H.Meyr. “Digital Filter and Square Timing Recovery”, IEEE Transactions on Communications, 5,pp.605-612, 1998.

[4] F.M. Gardner. “Interpolation in digital modems-I: Fundamentals”, IEEE Transactions on Communications,3, pp.501-507, 1993.

[5] S.Z. Hsue, S.S.Soliman. “Automatic modulation classification using zero crossing”, Radar and signal processing, IEE Proceedings F,6, pp.459-464,1990