PSK and QAM Classification by Likelihood under Unknown SNR Condition

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Abstract

Modulation classification is a key technology in current wireless communication systems. The technology is used to find the modulation employed or estimate channel state information (CSI). In this paper, a modulation classification method is proposed for phase shift keying (PSK) and quadrature amplitude modulation (QAM) under an unknown signal-to-noise ratio (SNR) condition. The method works without carrier synchronization and is based on likelihood estimation using the probability density function (pdf) of the received signal envelope. The superior classification error rate of the proposed method is demonstrated by computer simulations.

1. Introduction

Adaptive systems have become increasingly important in many wireless communication systems. Modulation classification is a key technology in the adaptive systems, as well as in cognitive radios, power control and military applications. In adaptive modulation and coding (AMC), the receiver is required to recognize the modulation employed, which is selected by the transmitter with CSI. In cognitive radios, it is necessary to estimate SNR to prevent interference by unlicensed secondary users. In general, SNR estimations require knowledge of the modulation.

Many studies have been performed on modulation classification techniques. In [1], a higher-order correlation-based approach was presented for FSK. In [2], [3], the likelihood ratio was employed for PSK classification. These works assumed ideal carrier synchronization. In [4], a method using moments of the received signal phase was examined. This method classifies the modulation order for MPSK under a known SNR condition. However, the SNR estimation methods are only applicable for a known modulation [5], [6]. In [7], a classification method based on moments was presented without knowledge of SNR. Although this method can be used for PSK and QAM classification, the performance was degraded at a high SNR.

In this paper, a new method of modulation classification is proposed. The method is based on the likelihood and can estimate SNR and classify the modulation simultaneously without carrier synchronization. The classification results for PSK, 16QAM and 64QAM in computer simulations are presented. These results show that the performance of the proposed method is better than that of the moment-based method [7]. In particular, when the candidate modulations are 16QAM and 64QAM, the proposed method outperforms the moment-based method.

2. Classification Method

In this section, the classification method based on the log-likelihood is presented for PSK, 16QAM and 64QAM. The log-likelihood is calculated from the pdf of the normalized received signal envelope. We consider the additive white Gaussian noise (AWGN) channel. Figure 1 shows a block diagram of the proposed method. The received signal $r_n (n = 1, 2, \ldots, N)$ is represented by

$$r_n = s_n + w_n$$

where $s_n$ is a transmitted signal, $w_n$ is the AWGN with zero mean and variance $\sigma^2$ and $n$ is the time index in the observation interval. The signal constellation has different amplitudes $A_q (q = 1, 2, \ldots, Q)$ with probability $p_q$. The pdf of the
received signal envelope can be considered as the sum of the Nakagami-Rice distribution conditioned by $A_q$ and $p_q$. $|r_n|$ is normalized by the second moment $M_2$ to yield $y_n$. The normalized received signal envelope $y_n$ is defined by

$$y_n = \frac{|r_n|}{\sqrt{M_2}} \quad (2)$$

where

$$M_2 = E[|r_n|^2] \quad (3)$$

and $E[\cdot]$ denotes the expectation. Since $M_2$ is obtained theoretically and is not available in an experiment, the following estimated second moment $\hat{M}_2$ is used.

$$\hat{M}_2 = \frac{1}{N} \sum_{n=1}^{N} |r_n|^2 \quad (4)$$

The pdf of $y_n$ is expressed by [6]

$$g(y_n|\omega, \gamma) = \sum_{q=1}^{Q} p_q \times 2(\gamma + 1)y_n I_0[2\omega \sqrt{\gamma(\gamma + 1)y_n}] \times \exp[-(\gamma + 1)y_n^2 - h_q^2] \quad (5)$$

where $I_0[\cdot]$ represents the first-kind zero-order modified Bessel function. $\gamma$ and $h_q$ are defined by

$$\gamma = \frac{E[A_q^2]}{2\sigma^2} \quad (6)$$

$$h_q = \sqrt{\frac{E[A_q^n]}{2\sigma^2}} \quad (7)$$

where $\gamma$ is SNR and $h_q$ is the ratio of each amplitude level to the average amplitude level. $Q$, $p_q$ and $h_q$ depend on the modulation $\omega$ as shown in Table 1. The computational complexity depends on $Q$. Using Eq. (5), the log-likelihood function $LL(\gamma|\omega)$ of $\gamma$ is defined by

$$LL(\gamma|\omega) = \sum_{n=1}^{N} \log g(y_n|\omega, \gamma) \quad (8)$$

We assume that $\omega_1$ and $\omega_2$ are candidate modulations, where

$$\omega_1 : \text{true modulation}$$

$$\omega_2 : \text{false modulation}$$

This method can be used for any modulation with the knowledge of only $Q$, $h_q$ and $p_q$. In this paper, the candidates are PSK, 16QAM and 64QAM. Max($LL(\gamma|\omega_1)$) and Max($LL(\gamma|\omega_2)$) are calculated as shown in Fig. 2. Max($LL(\gamma|\omega)$) is the maximum likelihood of $\gamma$ assuming that the modulation is $\omega$. In the comparator, the classified modulation is that having the larger maximum likelihood. The classified modulation $\hat{\omega}$ is given by

$$\hat{\omega} = \arg \max_{\omega_1, \omega_2} \{\max(LL(\gamma|\omega))\} \quad (9)$$

Figure 2 shows an example of Eq. (9). In Fig. 2,

$$\gamma_1 = \arg \max_{\gamma} LL(\gamma|\omega_1)$$

$$\gamma_2 = \arg \max_{\gamma} LL(\gamma|\omega_2)$$

where $\gamma_i$ is regarded as the estimated SNR when $\hat{\omega}$ is $\omega_i$. When the modulation classification error rate is low, this method estimates SNR very accurately. A modulation classification error occurs when

$$\max(LL(\gamma|\omega_1)) < \max(LL(\gamma|\omega_2)) \quad (10)$$

| Table 1: Parameters $h_q$ and $p_q$ |
|-----------------|----------------|----------------|
| $q$ | $h_q$ | $p_q$ | $h_q$ | $p_q$ |
| 1 | 1 | $\frac{1}{\sqrt{3}}$ | 2 | $\frac{1}{\sqrt{2}}$ |
| 2 | 1 | $\frac{1}{2}$ | $\frac{1}{2}$ | $\frac{1}{2}$ |
| 3 | $\frac{1}{\sqrt{3}}$ | 2 | $\frac{1}{\sqrt{2}}$ | $\frac{1}{\sqrt{2}}$ |
| 4 | $\frac{1}{\sqrt{3}}$ | $\frac{1}{3}$ | $\frac{1}{\sqrt{2}}$ | $\frac{1}{\sqrt{2}}$ |
| 5 | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ |
| 6 | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ |
| 7 | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ |
| 8 | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ |
| 9 | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ | $\sqrt{\frac{7}{21}}$ | $\frac{1}{2}$ |
3. Simulation Results

Simulation results are presented for the proposed modulation classification method. The modulation classification error rate is obtained for PSK, 16QAM and 64QAM. As the results obtained for PSK do not depend on the modulation order, 8PSK is employed in the simulations. Figure 3 shows the classification error rate of the proposed modula-

![Figure 3: Classification error rate](image)

![Figure 4: Classification error rate of proposed and moment-based methods](image)
tion classification method, where the number of symbols \( N \) is 1000, 5000, 10000. The number of experiments is 10000. Three cases are considered, where the modulation candidates are \{PSK, 16QAM\}, \{PSK, 64QAM\} and \{16QAM, 64QAM\}, as shown in Fig. 3. When the modulation candidates are \{PSK, 64QAM\} (Fig. 3(b)) and the true modulation is PSK, the maximum likelihood of 64QAM does not converge at a high SNR. The search is terminated at SNR larger than 17dB. In the case where the true modulation has a higher-order than the other candidate, Figs. 3(a), 3(b) and 3(c) show that the modulation classification error rate is lower when SNR < 0dB and \( N = 1000 \). This clearly appears when SNR is low and \( N \) is small. The received signals are distributed more widely at a low SNR, so that the pdf of the received signal envelope is similar to the higher-order modulation. At a high SNR, the modulation classification error rate decreases as \( N \) increases.

Figure 4 shows a comparison of the proposed method with the moment-based method [7]. Since the numerical results of the moment-based method are limited to the Rayleigh fading channel, the method is applied to the AWGN channel for comparison. The number of experiments is 10000 and the number of symbols, \( N \), is set to 10000. From Fig. 4, it is found that the proposed method yields better performance than the moment-based method. When the candidates are \{PSK, 16QAM\} and \{PSK, 64QAM\}, Figs. 4(a) and 4(b) respectively show that the performance of the proposed method is 1dB better than that of the moment-based method. In Fig. 4(c), the proposed method has significantly higher performance than the moment-based method for \{16QAM, 64QAM\}.

4. Conclusions

In this paper, a maximum likelihood method has been presented for PSK and QAM modulation classification without knowledge of SNR. The proposed method works without carrier synchronization. Simulation results have shown that the proposed method yields superior classification performance to the moment-based method, especially in the case where the candidates are 16QAM and 64QAM.

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