New AMR(Automatic Modulation Recognition) algorithm based on the phase difference tendency of unknown communication signal

Chung-Sup Kim
Radio Source Laboratory
ETRI
Daejeon, Republic of Korea
kcs@etri.re.kr

Hyuk-Je Kim
Radio Source Laboratory
ETRI
Daejeon, Republic of Korea
hjkim@etri.re.kr

Sung-Woong Choi
Radio Source Laboratory
ETRI
Daejeon, Republic of Korea
swchoi@etri.re.kr

Kwan-Woong Ryu
Radio Source Laboratory
ETRI
Daejeon, Republic of Korea
kwryu0730@etri.re.kr

Jun-Seok Kim
Radio Resource Laboratory
ETRI
Daejeon, Republic of Korea
kjs1994@etri.re.kr

Abstract—This paper is about the practical algorithm of an AMR (Automatic Modulation Recognition) algorithm that automatically classifies the modulation scheme without no prior knowledge of communication signal. In general, most of the previously proposed AMR algorithms assume that a certain level of information known in advance but most of all make it difficult to apply to signals in real environments such as hostile communication.

In this paper, to obtain modulation information for the target signal, the phase difference tendency of the input signal is used to classify it into PSK (Phase Shift Keying) and FSK (Frequency Shift Keying) classes and then the characteristics of the M-signal are used. Squared Auto Correlation Function (ACF) processed vector to determine modulation index M for MPSK signal. This paper is for an algorithm that proposes a method to determine the modulation index M of an MPSK signal without complex calculations using the M-square characteristic of ACF.

Keywords—AMR, Phase difference, modulation index, PSK, FSK, ACF

I. INTRODUCTION

In general, transmitted communication signals are modulated using various modulation methods in communication systems. Modulation recognition, an intermediate step between signal detection and signal demodulation, is used in real-world applications such as cognitive radio, signal recognition, threat assessment and spectrum monitoring. Automatically and accurately extracting modulation schemes is a key element in surveillance and reconnaissance. Automatic modulation recognition (AMR) offers quite a bit of flexibility in dealing with different communication standards. A single receiver circuit can be enabled to recognize different modulation schemes and then demodulate those in coming signals which have been transmitted using different standards. . Automatic modulation recognition can also be used in interference identification, signal confirmation and spectrum management. The proposed algorithm aims to design an intelligent communication system where the receiver can detect the modulation scheme of the signal it receives using an automatic modulation recognition (AMR) algorithm, without having minimum or no prior knowledge. The automatic modulation recognition algorithm developed to identify the characteristics of unknown signals was developed based on the assumption that a certain level of signal information is known in advance. In general, most of the previously proposed algorithms are composed on the premise of frequency offset restoration, but in real environments, it is difficult to completely restore the transmission frequency offset, resulting in performance degradation. Existing signal classification methods use algorithms based on the rate of change of signal amplitude, which is greatly affected by the channel environment, this paper proposes a new phase-differential AMR algorithm that is not affected by the residual offset of the transmission frequency and is robust to the channel environment.

In addition, in order to determine the modulation index of the MSPK modulated signal, a method with a large amount of computation using frequency domain transform commonly used. However, we propose a new computationally efficient method of determining the modulation index with a simple slope comparison of the autocorrelation function (ACF) of the M-squared input communication signal.

II. METHODS

A. Decision of PSK, FKS classification

In general, the main algorithm of the automatic modulation method is a baseband-based transmission frequency removal signal characteristic extraction algorithm, so it is important to accurately find transmission frequency information. Therefore, in general, it is necessary to distinguish in advance into PSK class, which is a single carrier method in which transmission frequency information does not change, and FSK class, in which frequency information changes according to transmission symbols. Since the efficiency of the transmission frequency recovery method is different for each class, it is important to accurately separate it into two series to estimate the transmission frequency of the input signal. Figure 1 below is a block diagram of the algorithm proposed to determine the modulation method without restoring the transmission frequency. Also, it shows how to determine the modulation index (M) for each class after dividing it into PSK and FSK classes by taking an unknown communication signal. Step 1 of Figure 1 shows the γ_{max} extraction algorithm used to classify unknown signals into PSK and FSK classes. Unlike the existing proposed algorithms, which used magnitude vectors as inputs to distinguish between digital signals and analog signals with many variations in magnitude, As shown in Equation 1, an averaged vector using the characteristics of a phase difference vector that is robust against noise was used.

Here, a simple first-order low pass filter principle was additionally used, which further revealed the deviation of PSK and FSK phase difference characteristics, making it easy to distinguish PSK and FSK signals.

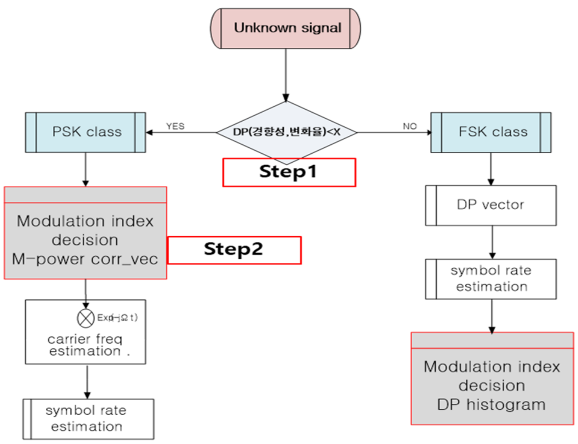

Fig. 1. Block Diagram of AMR algorithm proposed

In general, the phase difference of the PSK signal changes in proportion to the sampling rate of the signal at the symbol change point, and the phase difference of the FSK signal changes by the symbol rate at the symbol change point.

The following equation-based modulation method classification algorithm was proposed as a method of maximizing the specificity of the PSK and FSK signals. When the frequency domain transform is performed on the phase difference vector as shown in Equation 1, the characteristics of the time domain can be estimated with the magnitude value information of the frequency channel. The PSK series with a large phase difference change has a larger value than the voice-type analog signal and the FSK class signal with a relatively small phase difference change.

$$y' = \frac{1}{N}\sum_{n=1}^{N-1}(\tan^{-1}x_{n+1} - \tan^{-1}x_n), \quad x_n = mean(x_{n-1}:x_{n+1})$$

$$y = (\tan^{-1}x_{n+1} - \tan^{-1}x_n) - y'$$

$$a_{cn} = \frac{|y|}{E[|y|]} - 1$$

$$\gamma_{max} = \max\frac{|FFT(a_{cn})|^2}{N_s} \qquad (1)$$

Equation 1 represents a γ_{max} extraction algorithm used to classify signals of unknown information into PSK and FSK series. The value of γ_{max} is based on the phase of the input signal which phase difference vector corrected for the transmission frequency. when the characteristics of the input signal are greatly affected by noise and interference in the real environment as the SNR decreases, and it is difficult to distinguish PSK and FSK series. Therefore, in order to accurately classify the input signal into the PSK and FSK groups, the method for maximizing the FSK and PSK characteristics was expressed in Equation 2, and the final characteristics were extracted using the first and second differential characteristics of the input signal. Equation 2 is a part of pre-processing for generating features that are robust to noise in order to more precisely classify it into a PSK or FSK signal group. Here, DP (Differential Phase) is the phase difference vector of the input signal, and DDP (Second order DP) is the vector obtained by Second derivative of input signal, and DP and DDP are used as input vectors to obtain the $Last_{feature}$. Here the slope (tendency) value of the difference vector was used as the main characteristic.

After obtaining the threshold (γ_{last}) according to the condition of Equation 3 below, if $Last_{feature}$ is greater than threshold, it is determined as a PSK series signal, in the opposite case, is determined as an FSK series signal. Existing algorithms exist that classify PSK and FSK signals using the number of peaks in the frequency domain after performing FFT. In this algorithm, if an interference signal exists, it is difficult to determine the number of peaks, and thus the performance of the classification algorithm deteriorates. In addition, due to the nature of the frequency domain determination, a determination condition of a certain dB or higher is required than the noise level, which is detrimental in terms of SNR.

$$Last_{feature} = \frac{\gamma_{max}(DP) * \gamma_{max}(DDP)}{\gamma_{max}(DP) + \gamma_{max}(DDP)} \qquad (2)$$

$$Low_{mean} = mean(low_{\bar{x}}), \quad High_{mean} = mean(high_{\bar{x}})$$
$$IF\ (Slope_{DP} > 0) \quad \gamma_{low} = \frac{mean(\bar{x}) + Low_{mean}}{2}$$
$$Else \quad \gamma_{high} = \frac{mean(\bar{x}) + High_{mean}}{2}$$
$$\gamma_{last} = \gamma_{max} * \gamma_{low} + \gamma_{high} * \gamma_{max}$$
$$If\ \gamma_{last} < Last_{feature} \quad \text{"PSK signal class"}$$
$$Else \quad \text{"FSK signal class"} \qquad (3)$$

B. Decision of Modulation index for MPSK signal

Step 2 of Figure 1 block diagram explains how to determine the modulation index for a signal judged as a PSK signal class.

The proposed method generally uses the fact that the transmission frequency residual offset range is a value smaller than the symbol rate. When we get the ACF value after the input signal is squared by M with sequential the increase of M, there is an effect that the sampling rate frequency of the actually generated signal is relatively smaller than the symbol rate. In addition, here is a proposed method of determining the actual modulation index after comparing the result of the M-squared autocorrelation function with the slope value of M=1(no squared data) without need to use a method such as frequency conversion to obtain the power spectrum for frequency offset recovery which requires a lot of computation process.

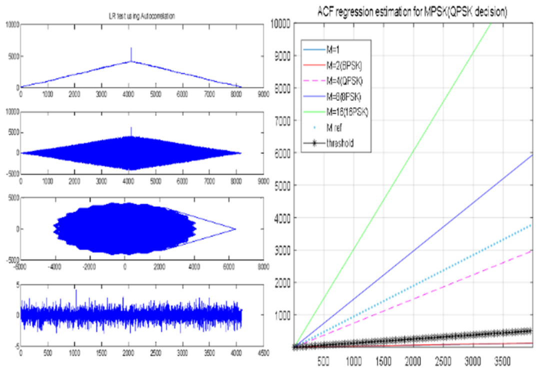

Fig. 2. Feature characteristics for decision of MPSK modulation index

The left part of Figure 2 shows the entire process of obtaining the absolute value after squaring the input signal by M, and the figure on the right shows that the ACF result feature can be properly separated by the threshold value after squaring M for all MPSK cases.

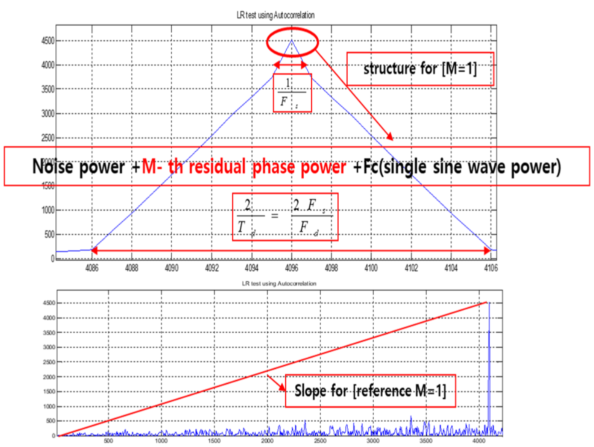

Fig. 3. MPSK decision method : Peak Power structure(Up), Reference Slope @M=1(Down)

Figure 3 shows the characteristics of the autocorrelation function with M=1 in the case of the PSK modulation method input signal. In addition, it shows that noise power, transmission frequency power, and power related to the modulation type by the modulation index (M) are generated near the maximum point of the result. This slope value is a reference value for comparison with slopes of the ACF for M squared data as an increase in M. As shown in Equation 3, if the result of the M degree of the autocorrelation function according to the M value coincides with the actual modulation index (M), the modulation type power by the modulation index disappears. Therefore, M times faster transmission frequency power and noise power only exist, and at this time, when the absolute value is taken and the slope is obtained, a unique linear component is generated. The slope value obtained by ACF signal processing of the M squared input signal was compared with the representative slope of M = 1, and it was determined that the MPSK signal having a greater than the representative slope had a linear component of the modulation index. Finally, the minimum M value that satisfies the condition for generating a linear component is selected and determined as the actual modulation index (M) of the input signal.

$$TH_M = \frac{LR\_xcorr\ (X^M)}{var\,(xcorr\ (X^M))^{1/2}}\ @M = [1:5]$$
$$\text{if } (TH_M > 1),\ Last\ _M = \min(M) \quad (4)$$

Equation 4 is a formula for obtaining the result of the autocorrelation function for the MPSK series signal, and the final modulation index is determined by selecting the smallest M that satisfies the condition that it is greater than the slope of the representative slope LR-s1(Linear Regression slope 1 case of M=1).

III. Results

A. Result of PSK, FKS classification

FSK and PSK series classification methods of existing algorithms using signal magnitude vectors as feature can distinguish modulation schemes under the assumption that magnitude values change significantly even if filtering PSK signals. In addition, real environment noise is not theoretical Gaussian noise, so it is difficult to distinguish between PSK and FSK. Table I below shows the parameters used to obtain the simulation results.

TABLE I. Simulation Parameter

Signal to be classified	**Non-Digital, FSK(include MSK) MPSK(BPSK, QPSK, 8PSK, 16PSK)**
Symbol rate	**10k symbol/sec**
SNR	**0~30dB**
Channel State.	**White Gaussian channel**

Here, looking at the left part of Figure 4, it can be seen that the change in the γ_{last} value of the MPSK and FSK signals can see more clearly as the SNR increases. In addition, the threshold value for separation the MPSK and FSK series signals determined according to Equations 1,2 and 3 is set appropriately, showing that signal classification is possible even at an SNR of 0dB when the modulation index is small.

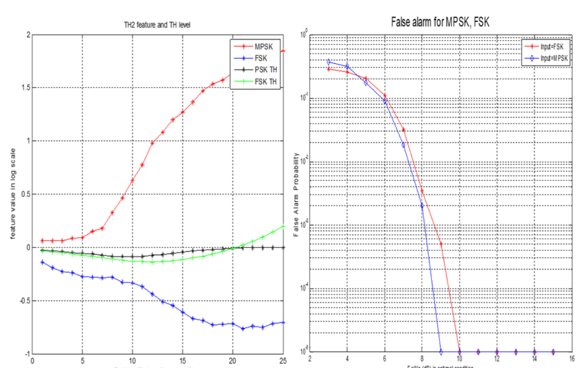

Fig. 4. γ_{max} Feature char. For PSK/FSK classification(Left) & Flase Alarm Accuracy(PSK, FSK) for Unknown signals (Right)

B. Result of MPSK Modulation Index accuracy

In the proposed method, since it is a method of determining the actual modulation index using the result of the autocorrelation function obtained M squared spectrum and the slope value of the input data of M = 1, not using the transmission frequency conversion method, the amount of processing time is relatively small.

As can be seen in the figure 5 & 6, it shows the accuracy of modulation index estimation with a probability of over 99% at an SNR of over 8dB for signals over Non-PSK, BPSK, QPSK, and 8PSK, while a high-order signal whose input signal has a modulation index of 16PSK or higher, it is possible to estimate the modulation index with 99% accuracy at an SNR of 15dB. Therefore, for higher-order MPSK, modulation index estimation can be seen that a new algorithm is required.

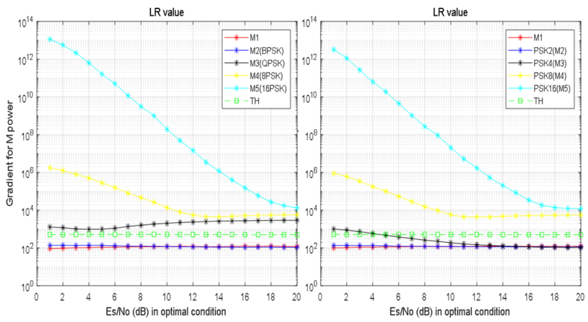

Fig. 5. QPSK(left), 8PSK(right) Feature & TH value

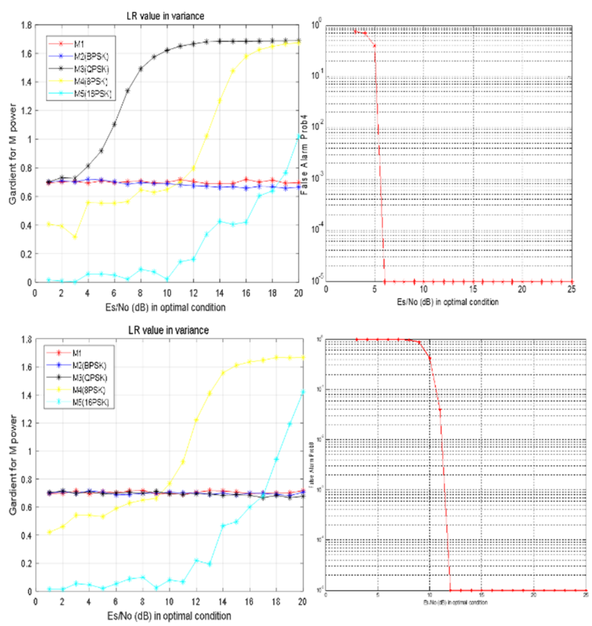

Fig. 6. QPSK(up), 8PSK(bottom) Classification Accuray

IV. Conclusion

The proposed algorithm has the advantage of not requiring separate signal processing to estimate the transmission frequency because the modulation method can be determined without estimating the transmission frequency.

In addition, the proposed algorithm can estimate the modulation method without information about the input signal, such as transmission frequency estimation, in a real wireless environment, and has excellent automatic classification performance of various modulation methods. The improved result can be used in the field of recognizing various modulation schemes in the future.

Next time, additional simulations for complex mobile communication channel environments are needed. In addition, an additional classification algorithm capable of improving performance for MPSK signals having a high modulation index is required. We will present test results assuming additional complex communication scenarios

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