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The Performance Improvement of Automatic Modulation Recognition Using Simple Feature Manipulation, Analysis of the HOS, and Voted Decision

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Abstract**—**The use of High Order Statistics (HOS) analysis is expected to provide so many candidates of features that can be selected for pattern recognition. More candidates of the feature can be extracted using simple manipulation through a specific mathematical function prior to the HOS analysis. Feature extraction method using HOS analysis combined with Difference to the N^{th}-Power manipulation has been examined in application for Automatic Modulation Recognition (AMR) to perform scheme recognition of three digital modulation signal, i.e. QPSK-16QAM-64QAM in the AWGN transmission channel. The simulation results is reported when the analysis of HOS up to order-12 and the manipulation of Difference to the N^{th}-Power up to $N = 4$. The obtained accuracy rate of AMR using the method of Simple Decision obtained 90% in SNR > 10 dB in its classifier, while using the method of Voted Decision is 96% in SNR > 2 dB.

Keywords**—**modulation, automatic modulation recognition, feature analysis, feature manipulation.

I. Introduction

THE use of the High Order Statistics (HOS) analysis up to order-8 in feature extraction of radio signals for identifying the modulation scheme in the system of Automatic Modulation Recognition (AMR) has been suggested in the previous publications [1–4]. The development of several methods of AMR was also discussed historically and comprehensively [1]. However, the use of feature manipulation in order to extract more feature candidates has not been proposed in any publication, even in current papers. Modulation scheme is one of the most important characteristics to note in the monitoring activity and identification of radio signals. Modulation recognition system must be able to make the correct classification of the modulation scheme of the received signal under interference. AMR is required in both military and civilian applications, such as surveillance, electronic warfare, threat assessment, signal confirmation, interference identification, software defined radio, and spectrum management [2]. AMR will also be believed to play an important role in the implementation of the 4th-Generation wireless communication system (4G) [3].

In this paper, the use of HOS feature analysis and the feature manipulation in affecting the accuracy rate of the AMR is based on simulation results. The feature extraction which applies feature manipulation and feature analysis is purposed to characterize and extract features of the radio signal which have been defined in three modulation schemes, i.e. QPSK, 16QAM, and 64QAM. The methods of classifier used are Simple Decision and Voted Decision. The design of threshold values in Simple Decision and Voted Decision are determined trough some simple observations based on the characteristic of features extraction of received signals in the various levels of disturbance under an Additive White Gaussian Noise (AWGN) transmission channel.

The novel methods for identification of digital modulated signal schemes in AMR contributed here are the use of feature manipulation in the Difference to the N^{th}-Power up to $N = 4$, utilization of Voted Decision for classifier, and increasing the order of HOS up to order-12. These methods are expected to be useful for pattern recognition in various fields.

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II. Feature Extraction in AMR

The related concepts to build the discussed AMR model are feature extraction, the HOS feature analysis, and also Difference to the N^{th}-Power feature manipulation. The concept about digital modulation signal is also very important to be discussed, especially in three schemes of QPSK-16QAM-64QAM under an AWGN channel, as the object to be identified in recognition process by the AMR.

A. Digital Modulation Signals in a AWGN Channel

A classifier is supposed to correctly decide the modulation format of the received signal from a pool of N_{mod} candidate modulations denoted by the integers i = 1, ..., N_{mod}. Next, we focus to only QPSK, 16QAM, and 64QAM classification.

The model of digital signal recognized at a receiver is a baseband complex received signal envelope [5], [6]:

$$r(t) = s(t;\mathbf{u}_i) + n(t) \tag{1}$$

where $n(t)$ is complex AWGN and $s(t;\mathbf{u}_i)$ is the noise-free baseband complex envelope of the received signal:

$$s(t;\mathbf{u}_i) = a_i \sum_{k=1}^{K} e^{j\phi_k} s_k^{(i)} g(t-(k-1)T-\varepsilon T); 0 \le t \le KT \tag{2}$$

In the process of classification of N_{mod} modulation scheme, then for i = 1, 2, ..., N_{mod}:

$$\mathbf{u}_i = [a_i \quad T \quad g(t) \quad \{\phi_k\}_{k=1}^{K} \quad \{s_k^{(i)}\}_{k=1}^{K}]^{\mathrm{T}} \tag{3}$$

where:

- a_i = the averaged of signal amplitude from the i-th modulation type
- T = the symbol period
- $g(t)$ = $p_{TX}(t) \otimes h(t)$, the receiver pulse shape
- $p_{TX}(t)$ = the transmitter pulse shape
- $h(t)$ = the channel impulse response
- K = the amount of complex data symbols
- $\{s_k^{(i)}\}_{k=1}^{K}$ = K complex symbols in the i-th modulation type
- $\{\phi_k\}_{k=1}^{K}$ = the phase jitter

With the symbol sequence $s_k^{(i)}$, k = 1, ..., K given by the signals from the constellation normalized by unit variance, then the model for the rectangular M-ary quadrature amplitude modulation signal M-ary QAM is:

$$\begin{aligned} &s_k^{M\text{-QAM}} = s_{k,I}^{M\text{-QAM}} + j s_{k,Q}^{M\text{-QAM}}; \\ &s_{k,I}^{M\text{-QAM}}, s_{k,Q}^{M\text{-QAM}} \in \{(2m-1-M^{1/2})/\sigma_{s(M\text{-QAM})}, m=1,\ldots,M^{1/2}\} \end{aligned} \tag{4}$$

Three modulation schemes QPSK, 64QAM, 16QAM can be regarded as M-ary QAM each with M = 4, 16, 64, then it has elements of the signal symbols as follows:

$$s_{k,I}^{\text{QPSK}}, s_{k,Q}^{\text{QPSK}} \in \frac{1}{\sigma_s^{\text{QPSK}}}\{-1;+1\} \tag{5}$$

$$s_{k,I}^{16\text{QAM}}, s_{k,Q}^{16\text{QAM}} \in \frac{1}{\sigma_s^{16\text{QAM}}}\{-3;-1;+1;+3\} \tag{6}$$

$$s_{k,I}^{64\text{QAM}}, s_{k,Q}^{64\text{QAM}} \in \frac{1}{\sigma_s^{64\text{QAM}}}\{-7;-5;-3;-1;+1;+3;+5;+7\} \tag{7}$$

where σ_s^{QPSK}, $\sigma_s^{16\text{QAM}}$, and $\sigma_s^{64\text{QAM}}$ respectively are standard deviations of the signal in QPSK, 16QAM and 64QAM scheme or averaged voltage of the signal, i. e. $\sigma_s^{\text{QPSK}} = 1$; $\sigma_s^{16\text{QAM}} = 5^{\mathbf{0.5}}$, and $\sigma_s^{16\text{QAM}} = 21^{\mathbf{0.5}}$.

B. Feature Extraction

Feature extraction of the modulation signal is intended to support the AMR system depicted in Fig. 1, which consists of pre-processing, feature acquisition, feature analysis, feature selection, and feature classification.

In this study, we propose feature manipulation as a new method that is intended to improve the performance of features analysis. The pre-analysis feature manipulation is inserted in the process of signal features recognition, which is intended between features acquisition and feature analysis.

C. HOS Feature Analysis

HOS (High Order Statistics) consists of automoment, autocumulant, cyclicmoment, cycliccumulant, autocummulant derivative, and cycliccumulant derivative. Feature analysis may use one or more of them and also in some of its order.

For a random variable s_k, the definition for the i-th moment is given by [3]

$$\mu_i = \sum_{k=1}^{N} (s_k - \mu)^i f(s_k) \tag{8}$$

where N is the data length and $f(s_k)$ is the probability density function (pdf) of s_k. For the random variable is $s_{\mathbf{k}} = a_k + j\, b_k$ is a finite sequence data of the complex baseband discrete signal, the definition of complex automoment can be obtained as

$$M_{pq} = E[(s-\mu)^{p-q}(s^* - \mu^*)^q] \tag{9}$$

where p is called the automoment order, q is its conjugate order, and s* stands for complex conjugation of s. Higher order p will give more candidates of features can be selected in feature extraction.

Because of possible very wide range of M_{pq}, it can be proposed its logarithmic scale, so the analysis is called as Logarithmic Complex Automoment (Log-M_{pq}), which is calculated as follows:

$$[M_{pq}] = 10 \log M_{pq} \tag{10}$$

D. Feature Manipulation

The additional feature manipulation can be conducted in accordance with a simple mathematical operation to the acquired data samples of the received modulation signal as the recognized object as shown in Fig. 2. The manipulation process of the feature data in this research suggested as a pre-analysis step prior to the feature analysis. The suggestion is hypothesized to improve the analysis of signal features with the results of the stronger characterization.

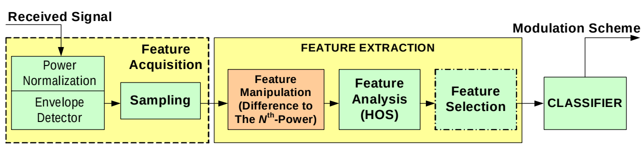

Fig. 1. Feature Extraction for Modulation Recognition.

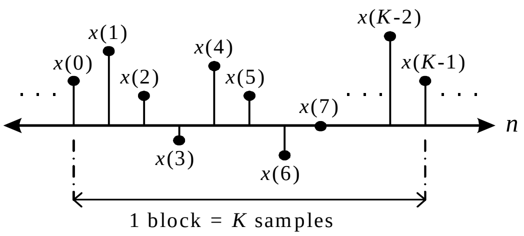

Fig. 2. The Acquired Samples of the Received Modulation Signal.

There are so many alternative mathematical operations can be exploit with several reasoning related with its effectiveness of usage. In this study, we exploit feature manipulation conducted in accordance with operation of

$$x_m(n) = [x(n) - x(n-1)]^N \,. \tag{11}$$

The manipulation is called the Difference to the N^{th}-Power. Effectiveness of the operation could be also exploited with variation of N integer, in this study we use $N = 1$ up to 4.

III. The Model of AMR

The simulation model of signal recognition in AMR is tested only to identify three digital modulation schemes, i.e. QPSK, 16QAM, and 64QAM as used in WiMAX IEEE 802.16x. Pre-Processing Sub-system have been equipped with AGC (Automatic Gain Controller) which is always found in the radio receiver system with the task of implementing normalization received signal power, after the previous power signal is received by the fluctuation of fading, even in the AGC model is assumed perfect. The method of signal envelope detection is Complex Shanon Wavelet.

There are two classifiers designed in the system model, i.e. the Simple Decision Classifier and Voted Decision Classifier as depicted in Fig. 3 and Fig. 4 respectively.

In the Simple Decision as shown in Fig. 3, classification to one of three modulation schemes QPSK-16QAM-64QAM is decided based on two successive comparison between V_{F1} against V_{Th1} and then between V_{F2} against V_{Th2}. The value of V_{F1} is the parameter of HOS feature analysis M_{pq} for the first modulation scheme (QPSK) calculated by using (9) and (10) in the moment order p and the conjugate order q with the most distinct value of M_{pq} then two other modulation schemes (16QAM-64QAM). Next, the value of V_{F2} is also M_{pq} calculated by using (9) and (10) in another p and q for the second modulation scheme (16QAM) with the most distinct value then the remaining modulation schemes (64QAM).

The threshold V_{Th1} is concurrently determined in which has maximum distance to the value of $[M_{pq}]$ for the first modulation scheme (QPSK) and two other modulation schemes (16QAM-64QAM). Next, the threshold value V_{Th2} is concurrently determined in which has maximum distance to the value of $[M_{pq}]$ for the second modulation scheme (16QAM) and the remaining modulation schemes (64QAM).

In the Voted Decision as depicted in Fig. 4, the Simple Decision is modified with repeating in certain iteration. Each batch of the iteration results a simple decision about a recognized modulation scheme. After all of the total *Vote* batches are completed, the final decision of recognition is made in accordance with a maximally voted modulation among three schemes.

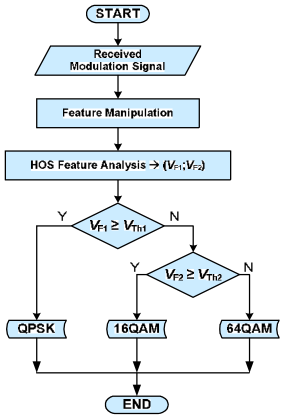

Fig. 3. The Simple Decision for Three Modulation Scheme Identification.

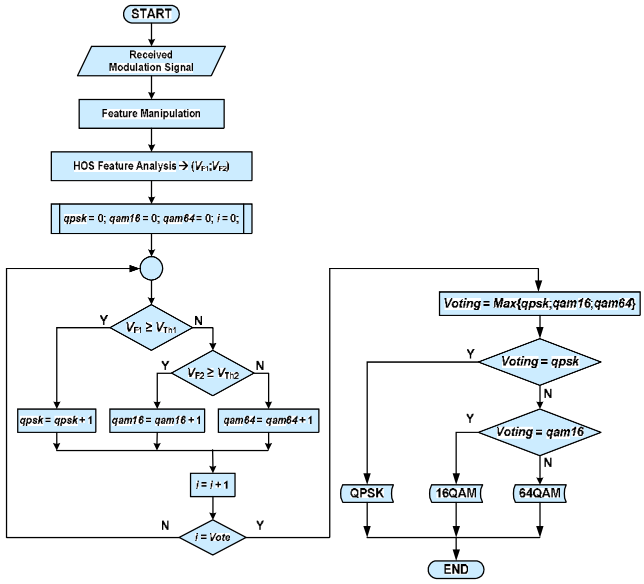

Fig. 4. The Voted Decision for Three Modulation Scheme Identification.

AMR system performance is expressed in the accuracy rate based on the correct of the classification process of equi-probable N_{mod} modulation. The average probability of correct N_{mod} classification is defined as:

$$P_{cc} = N_{\text{mod}}^{-1} \sum_{1}^{N_{\text{mod}}} P_c(i \mid i) \,. \tag{12}$$

IV. Simulation Results

A. Modulation Signal Waveforms

Fig. 5 shows the comparison of waveforms of modulation signal of QPSK, 16QAM, and 64QAM in channel disturbed by the AWGN on different conditions in SNR = 30 dB, 5 dB, and 0 dB respectively. It is shown, when a signal is more seriously disturbed, waveform of the signal will be more difficult to be distinguished each other. On the various level of disruption,

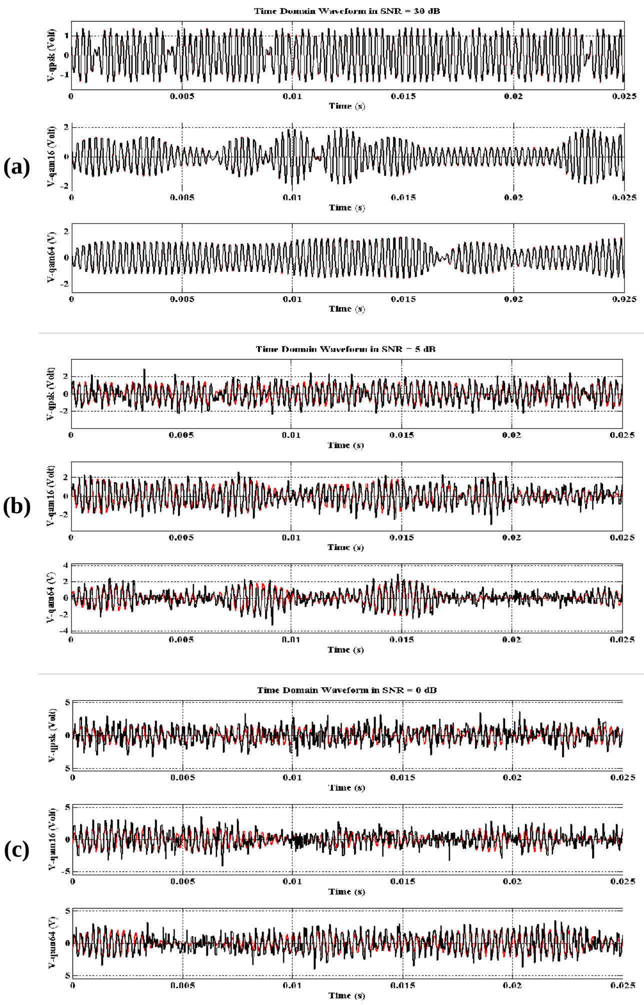

Fig. 5. Modulation Signal Waveform QPSK, 16QAM, dan 64QAM
(a) SNR = 30 dB; (b) SNR = 5 dB; (c) SNR = 0 dB

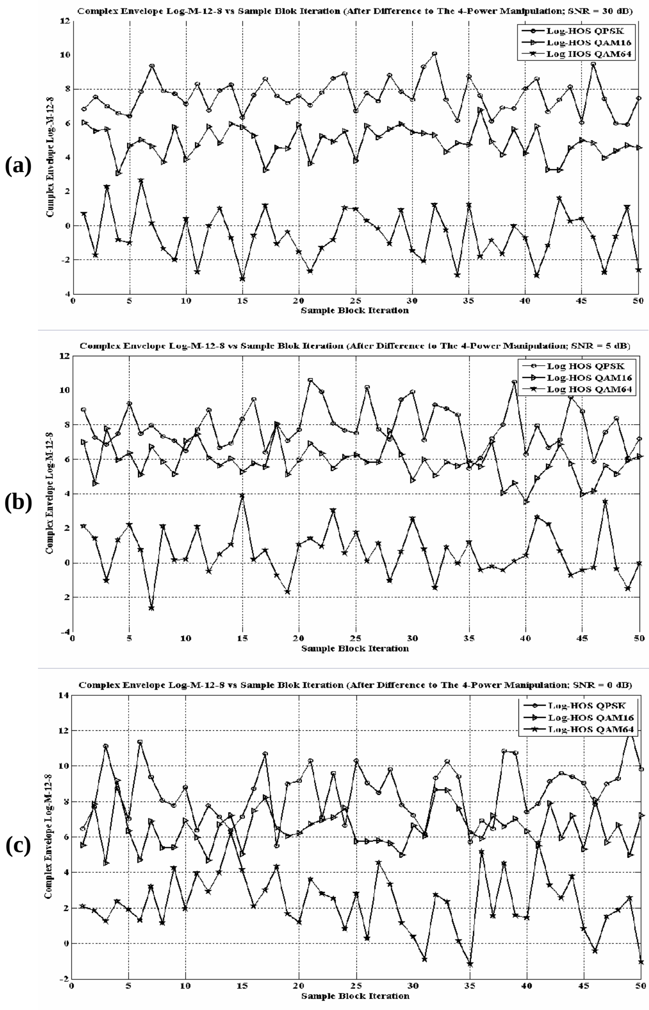

Fig. 6. Logarithmic Complex Automoment in Order 12-8, $[M_{12\text{-}8}]$
(a) SNR = 30 dB; (b) SNR = 5 dB; (c) SNR = 0 dB

the system of AMR must carry out the tasks to make a decision about identification of the received signals, whether the modulation is QPSK, 16QAM, or 64QAM.

B. Features Extraction Results

Some feature extraction results of modulation signal QPSK, 16QAM, and 64QAM using Logarithmic Complex Automoment in 12-8 $[M_{12\text{-}8}]$ are depicted in Fig. 6. Each of the analysis order is shown in some conditions of AWGN channel, with the SNR of 30, 5, and 0 dB. Fig. 6 shows the superimposed of $[M_{12\text{-}8}]$ of three modulated signals QPSK-16QAM-64QAM in the range of 50 observation block iterations, with in each block involving 300 samples or signal symbols. Fig 6(a), 6(b), and 6(c) respectively depicted the value of $[M_{12\text{-}8}]$ of the tree modulations in various conditions of disturbance with the SNR of 30, 5, and 0 dB. It can be observed that lower SNR will make more difficult to separate the values of $[M_{12\text{-}8}]$ resulted by each modulation signal.

Next, in Fig. 7 are reported the average conditions of the parameters on the statistical features analysis of the logarithmic complex automoment to modulation signal QPSK-16QAM-64QAM in the SNR vary form 0 dB up to 30 dB. Fig 7(a) depicts the averaged value of $[M_{12\text{-}8}]$ with Manipulation of the Difference to the 4th-Power. Each point in Fig. 7(a) represents the averaged of 200 values of $[M_{12\text{-}8}]$ in a condition of SNR. When Fig. 6 shows only 50 value of $[M_{12\text{-}8}]$ in spread sample axis, then Fig. 7(a) shows the average of 200 value of $[M_{12\text{-}8}]$ in a point for a value of SNR and it is spread for variation of SNR. In the same way, the values of $[M_{11\text{-}5}]$ are depicted in Fig. 7(b).

This simulation results discussed $[M_{12\text{-}8}]$ and $[M_{11\text{-}5}]$ only, which are used in feature measurement applied in AMR, because their characteristics are good enough to support the classification process. As depicted in Fig. 7(a), the value of $[M_{12\text{-}8}]$ is far enough when the AMR receiving 64QAM signal to the value with the QPSK and 16QAM scheme, so it can be taken $V_{F2} = [M_{12\text{-}8}]$. As shown in Fig. 7(b), the value of $[M_{11\text{-}5}]$ when the AMR receiving QPSK signal is far enough to the value in 16QAM and 64QAM scheme, so $V_{F1} = [M_{11\text{-}5}]$ can be taken for classifier. Threshold values V_{th1} and V_{th2} are designed in certain values which are stable for supporting the decision process. As described in Fig. 1, the value of $[M_{12\text{-}8}]$ and $[M_{11\text{-}5}]$ will be classified to make decision about the modulation scheme of the received signal using the algorithm of Simple Decision in Fig. 3 and Voted Decision in Fig. 4.

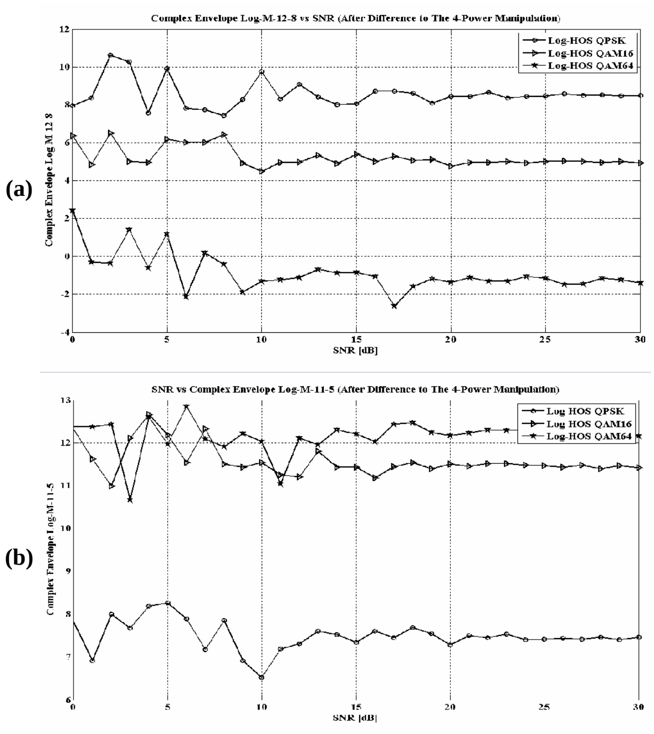

Fig. 7. The Average Condition of Logarithmic Complex Automoment with Manipulation of the Difference to the 4th-Power: (a) [$M_{12\text{-}8}$]; (b) [$M_{11\text{-}5}$]

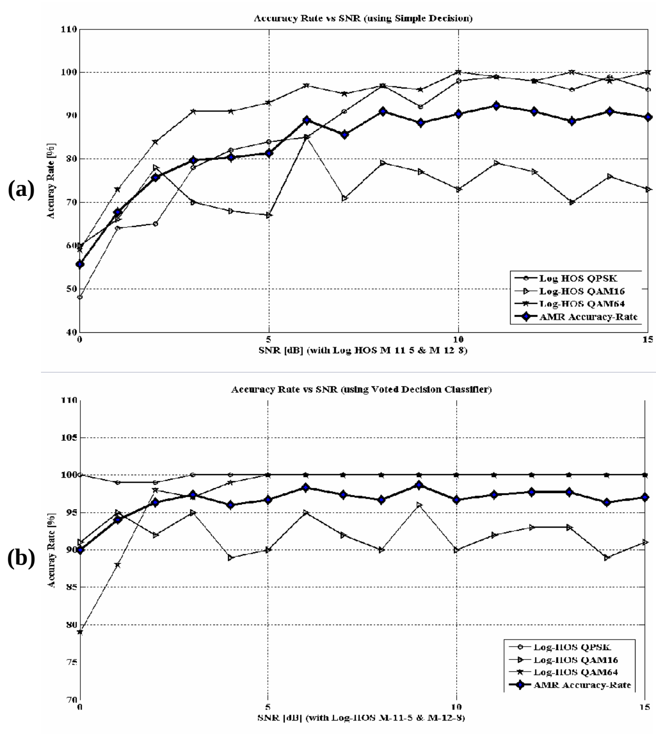

Fig. 8. The Accuray Rate of AMR vs SNR
(a) Using Simple Decision Classifier; (b) Using Voted Decision Classifier

C. The Performance of AMR

Fig. 8 depicts the performance test of AMR based on accuracy rate of the modulation signal recognition QPSK, 16QAM, and 64QAM. Fig. 8(a) depicts the accuracy rate of AMR when the process of classification using Simple Decision based on comparison feature analysis parameters to each threshold. Each value of parameter is based on the characteristics of the statistical calculation of the 300 symbol samples of complex envelope signal. For the accuracy rate test, the decisions of modulation recognition is examined in the condition of signal in SNR from 0 dB up to 15 dB, with in each condition of signal to be identified in 100 times. The performance test examined turns of the modulation scheme QPSK, 16QAM, and 64QAM. The accuracy rate is determined in accordance with (12) for this three modulation (N_{mod} = 3). Fig. 8(b) depicts the accuracy rate of AMR when the process of classification on the classifier uses Voted Decision with the voting period *Vote* = 5 batch of repeated Simple Decision.

As shown in Fig. 8(a), the system of AMR performs scheme recognition of three digital modulation signal (QPSK-16QAM-64QAM) with an accuracy rate 90 % in SNR > 10 dB can be obtained when the process of classification using Simple Decision. As shown in Fig. 8(b), the accuracy rate of AMR can be obtained in 96 % with SNR > 2 dB.

V. Conclusion

The method of pre-analysis manipulation Difference to the 4th-Power has been able to fix the parameter values of the statistical feature analysis of modulation signal, which can improve the performance of decision making in the recognition process of AMR. The higher order analysis of HOS will give the more feature parameter candidates that can be selected, especially when it is scaled in logarithmic. The system of AMR performs recognition of three digital modulation scheme (QPSK-16QAM-64QAM) received signal, which can obtain the accuracy rate 90% on the AWGN channel in SNR > 10 dB when using Simple Decision Classifier, and the accuracy rate 96% with SNR > 2 dB when using Voted Decision Classifier.

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