Analysis of Digitally Modulated Signal in Fading Environment for Classification at Low SNR

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Abstract— Automatic Modulation Classification (AMC) is the process of deciding, based on observations of the received signal, what modulation is being used at the transmitter. It has long been an important component of noncooperative communications in which a listener desires to intercept an unknown signal from an adversary. It is also becoming increasingly important in cooperative communications, with the advent of the Software-Defined Radio (SDR). Software radio technology is expected to play an important role in the development of Fourth Generation (4G) wireless communication systems. In this paper, a method of digital modulation classification is described. The method was applied to signals with FSK, BPSK, MSK, QAM-16 and QPSK modulations. The feature extraction method has been used for the modulation type recognition. This classification method was examined on signals corrupted by Gaussian noise after their transmission through multipath Rayleigh fading channel. Simulation results show that the proposed method has a high success rate for recognition of different digital signal types, even at low Signal to Noise Ratio (SNR).

Keywords- Modulation Classification; digital modulation ; AWGN ; Raleigh fading

I. INTRODUCTION

Over the past two decades, a major transition has occurred from analog modulation to digital modulation techniques in communication systems. Moreover, while communication systems were initially established as voice networks, they now have to accommodate computer data as well as multimedia content. And, as more and more users join the communication network the need for efficient use of available bandwidth in the RF spectrum becomes even more important. Digital modulation techniques provide more information carrying capacity, better quality communication, data security and Radio Frequency (RF) spectrum sharing to accommodate more services when compared to analog modulation. Automatic Modulation Classification (AMC) is a problem of current and future significance for both commercial and military communication systems. In an adaptive communication system, the modulation format can be changed according to the channel state to achieve high efficiency communication. Usually supplementary information about the modulation format is transmitted. However, blind techniques can be used instead in a flexible intelligent receiver, such as software-defined radio, to increase the transmission efficiency. High-level amplitude modulated signals M-ASK M-FSK, M-QAM etc. have an excessive number of symbol status and therefore incline to be disturbed by noise. So it is difficult to identify the high-level amplitude modulated signals at low SNR.

Most of the automatic digital signal type classifiers have been proposed for recognition of signal formats in Additive White Gaussian Noise (AWGN) channels. However, in real world, communication environments, such as wireless communication channels suffer from fading. A major task of such systems is the automatic recognition of the modulation format of an incoming signal. The design of a modulation classifier essentially involves two steps: signal preprocessing and proper selection of the classification algorithm. Preprocessing tasks may include noise reduction, estimation of carrier frequency, symbol period, signal power, etc. Depending on the classification algorithm chosen in the second step, different preprocessing tasks are required.
Without any knowledge of the transmitted data and many unknown parameters at the receiver, blind identification is a difficult task. Particularly, classification process is even more challenging in real world scenarios with multipath fading, frequency selective, and time varying channels.

In this paper, a digital signal type classifier for fading environments is proposed. In the proposed method a digital modulation identifier using instantaneous features and stochastic features for identification for ASK, QAM, PSK and FSK signals has been proposed and studied in this paper. Preprocessing of modulated signals involves use of median filters to remove the peaks introduced due to AWGN noise. Instantaneous features are derived and stochastic features based on instantaneous features are then used for classification. Simulations showed that the percentage of correct identification is higher, when SNR is not lower than 6 dB.

Automatic identification of the digital modulation type of a signal is a rapidly evolving area [1]. The techniques are proposed to distinguish digitally modulated signals such as Quadrature Amplitude Modulation signal, Phase Shift Keying signal and Frequency Shift Keying signal. [2]. The features for identification may be either time based or frequency based. Time domain features may be amplitude, instantaneous frequency or phase of complex envelop of modulated signal. In frequency domain power spectrum may be analyzed or parameters such as variance, skewness, etc may be analyzed. [3-4]. Another approach for digital modulation types identification is to use wavelet transform (WT) [5-6]. Artificial neural network approach has been applied to classify identification schemes [7]. The approaches followed in blind modulation classification can be broadly divided into two groups: decision-theoretic approach and feature-based approach. Decision-theoretic approaches [11]-[13] treat the modulation classification problem as a multiple hypothesis testing problem. The decision-theoretic classifiers with the maximum likelihood tests are optimal, but the corresponding closed-form solutions are either unavailable or involve numerical search of high computational complexity. This approach is not robust to the model mismatch in the presence of phase or frequency offsets, residual channel effects and so on. On the other hand, feature-based methods[14] rely on the features derived from the data for modulation classification. The problem of modulation classification in multipath environments is a challenging and complex problem. [18-24]. In [18], a method is proposed for classification of PSK2 and PSK4 in a flat Rayleigh fading. In [19], a quasi-optimal solution based on the approximation of the log-likelihood function is proposed to identify FSK signals in a fading channel. In [20], signal formats PSK2, QPSK4, π/4 - QPSK and QAM16 were classified by applying the nearest neighbor rule in a two-dimensional feature space, i.e. the variance of differential phase between consecutive symbols and standard deviation of the instantaneous amplitude. In [21], a method has been proposed based on a combination of the fourth order cumulants and power moment matrices for identification of PSK2, PSK4, QAM8, ASK2 and ASK4 digital signals in multipath environment. In this method a multi-layer perceptron (MLP) neural network is used as the classifier. In [22], a SVMs-based classifier is used for identification of PSK2, PSK4, PSK8, ASK2 and ASK4. In this method a combination of the fourth order cumulants and symmetry of the received signal are used as the features. Once the modulation format is correctly identified, other operations, such as signal demodulation and information extraction, can be subsequently performed.[23]

II. MATHEMATICAL MODEL

The mathematical model to implement the analysis is shown in Fig.1

![Figure 1: Transmission channel](image)

For slow flat fading channel the attenuation and phase shift of the signal is constant over at least one symbol period

\[ r(t) = x(t) e^{j\theta(t)} + n(t), 0 \leq t \leq T \]  \hspace{1cm} (1)

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\[ a(t) = \text{gain of the channel} \]  
\[ \theta(t) = \text{phase shift of the channel} \]  
\[ n(t) = \text{additive Gaussian noise} \]

to evaluate \( P(e) \) in flat fading channel, average the probability of error of particular modulation in AWGN channel over possible ranges of signal strength due to fading. The probability of error in AWGN channel is viewed as conditional probability where the condition is that \( a \) is fixed.

Probability of error in slow flat fading channel is obtained by averaging the error in AWGN channels over fading probability density function as in Eq.2
\[ P_e(X) = \int_0^{\infty} P_e(x)p(x) \, dx \]  

\( P_e(X) \) is the probability of error for arbitrary modulation at a specific value of signal to noise ratio \( X \)
\( X = \text{Signal to noise ratio} \)
\( p(X) \) is the probability density function of \( X \) due to fading channel. For Raleigh fading channel fading amplitude \( \alpha \) has a Raleigh distribution equal to fading power and \( X \) has chi-square distribution with two degrees of freedom. Similarly probability of error for BPSK and BFSK is computed.\[24\]

### III. DESCRIPTION OF IDENTIFICATION ALGORITHM

“Fig. 2” shows the Modulation classification algorithm is shown in fig 2. The received signal is preprocessed using median filters, statistical features are then derived, and based on the threshold values decision tree classifier is developed to classify various signals.

The received signal is simulated through fading channel and Gaussian noise. Noise arises from a variety of sources; Thermal noise can be modeled as Additive White Gaussian Noise (AWGN). If the SNR is high (i.e. the signal power is much greater than the noise power) few errors will occur. However, as the SNR reduces, the noise may cause symbols to be modulated incorrectly, and errors will occur. The Bit Error Rate (BER) of a system indicates the quality of the link. Usually, a BER of \( 10^{-3} \) is considered acceptable for a voice link, and for a data link. A coherent QPSK system requires a SNR of greater than approximately 12dB for a BER of better than \( 10^{-3} \).\[25\]

Amplitude variation occurs as the receiver moves behind buildings and the propagation paths are obscured. Variations of up to 20dB will cause handovers and change quality-of-service. The received signal in a multipath channel exhibits large variations in magnitude. At these times the system will experience a large number of errors. A multipath channel without a significant deterministic component can be approximated to a Rayleigh distribution. The received signal experiences large variations in magnitude. [25-26]. “Fig.3” shows that the effects of the multipath channel (Rayleigh fading) severely degrade the system performance in the presence of Additive White Gaussian Noise.

![Figure 3: BER vs Eb/No in presence of AWGN and Raleigh fading](image)

### IV. RESULTS AND DISCUSSIONS

Modulated signals corrupted by noise as input signal are tested for classification with the software tools of MATLAB. The developed algorithm is verified for BPSK, 16 PSK, 32PSK, 2QAM, 8QAM, 16QAM, and MFSK modulation schemes. Instantaneous amplitude, frequency, and phase are first derived stochastic features are then derived from instantaneous parameters. Five Feature vectors are extracted from stochastic features. “Fig.4” shows 2ASK signal with AWGN noise and multipath Rayleigh fading. Similarly 4FSK, 16QAM signals are shown in “Fig.5” and “Fig.6”. These signals are considered under varying parameters where SNR is varied from 30db to as low as 0 db. Even the parameters for fading environment are varied and generated signals are analyzed.
Plot of feature vector 1 (amplitude mean) vs snr for different modulated signals is shown in Fig. 5. It can be seen that above 5 DB, 4ASK can be distinguished where as 2ASK, 2FSK, 4FSK etc overlap therefore other feature vectors are required to differentiate these signals. Feature vector 2 (amplitude square mean) could differentiate only one signal. “Fig.8” shows plot of feature vector 3 (phase square mean) vs snr varying from 0 to 20 db. This feature allows to clearly distinguish 4PSK and 16 QAM but shows overlapping for 2FSK and 4FSK. Feature vector 4 (frequency mean) was used to distinguish 4FSK.
“Fig.9” shows that feature vector 5 (frequency square mean) can be used to distinguish 2FSK and 4FSK clearly even in the presence of fading channel for as low as 0Db.

V. CONCLUSION

The developed algorithm for classification is suited for number of modulation schemes employed in SDR; the algorithm developed is used to test for various modulated corrupted by AWGN noise and under the effect of multipath Raleigh fading channel. The simulated results using statistical features are analyzed. Decision tree classifier based on features is developed to classify the signals. It is also concluded that one feature alone cannot be used to distinguish all signals as the threshold values vary for different signals. The developed classifier provides a high probability of correct classification in a short observation interval, for a range of signal-to-noise ratio (SNR) and capable to recognize many different modulations in environments with diverse propagation characteristics. Perfect classification is shown at SNR of 20dB. As the SNR decreases, the rate of successful classification slightly decreases. Experimental results indicates that the proposed method can be effectively used to classify M-ary ASK, M-ary PSK and M-ary FSK. Simulated results show that correct modulation identification is possible for varying SNR. Performance of classifier can be further improved by incorporating channel equalization.
REFERENCES