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Introduction

1.1 MOTIVATION

Automatic modulation classification (AMC) is an intermediate step between signal interception and demodulation and has an important role in various military and civil applications. Blind detection of the modulation scheme of the received signal is an exciting task in commercial systems, especially in software-defined radio (SDR). Usually, with the message signal, extra information called overhead is transmitted to adapt the SDR system with the transmitted signal configuration. Blind AMC methods can be implemented with the receiver to improve the bandwidth efficiency. The design and implementation of such AMC techniques is the need for intelligent and flexible communication systems for real-time demodulation of blind signals.

In military applications like electronic warfare, threat analysis, and surveillance, signal modulation needs to be identified for message detection and jamming signal generation. Friendly signals should be firmly transmitted and received, whereas hostile signals must be traced, identified, and jammed. To prevent the communication between adversary units, the modulation used at the transmitter is identified and the interference signal of high power is generated with the same modulation. Figure 1.1 shows the jamming signal generation method. Security of our signal is also important. For this application, the friendly transmitter needs to identify the modulation used by the jamming unit and switch to another modulation for successful transmission.

In the field of civil applications, link adaptation is an important technique for reliable and spectrum efficient transmission. The adaptive modulator selects the modulation scheme based on the channel state information (CSI) provided by the receiver. If the channel is noisy and complex, the transmitter decides the lower order modulation like Binary Phase Shift Keying (BPSK), or Quadrature Phase Shift Keying (QPSK) for high reliability while for strong

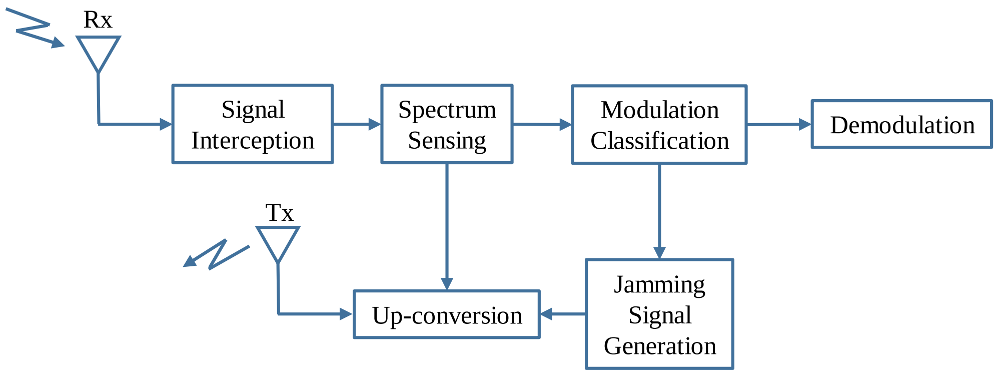

Figure 1.1 : Military application of AMC

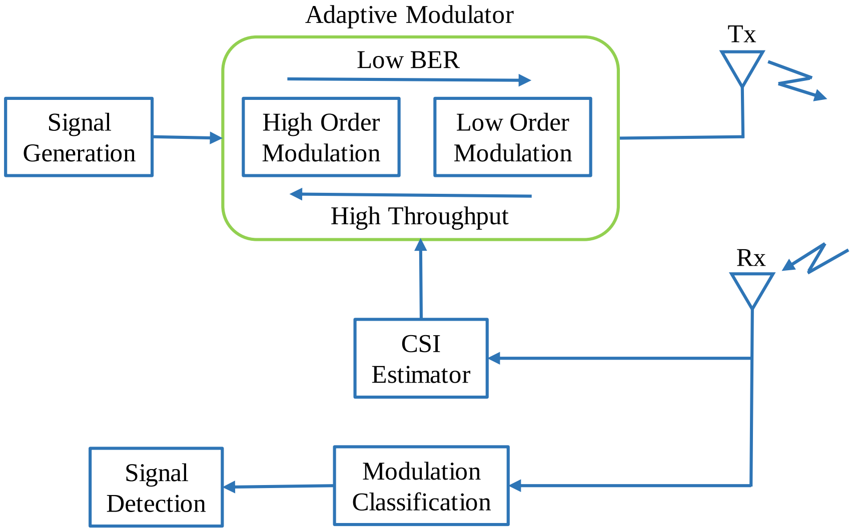

Figure 1.2 : Link Adaptation

channel condition, higher modulation like 16-Quadrature Amplitude Modulation (16-QAM), or 64-Quadrature Amplitude Modulation (64-QAM) scheme is selected for high throughput as shown in Figure 1.2.

Spectrum is a limited resource in communication and needs to be utilized intelligently and efficiently. In recent decades, the spectrum regulators assign the spectrum to the dedicated users called primary users (PU) for minimal interference. Other users who have not been assigned a particular spectrum is called secondary users (SU) are not allowed to use it, which leads to spectrum scarcity. It has been observed that the portion of the spectrum remains idle most of the time which is the main cause of spectrum scarcity. It can be avoided by letting SU's to use the spectrum in such a way that they do not cause interference to PU, overlay, or underlay. The SU is equipped with cognitive radio (CR) to sense the spectrum holes (not being used by PU) for communication and switch to another spectrum when the PU starts using it. This method is called opportunistic access and the model is shown in Figure 1.3.

1.2 PROBLEM FORMULATION

It is assumed that the transmitter is transmitting a coded signal modulated with a modulation scheme unknown to the receiver and chosen from a set of modulation schemes known to the receiver. The receiver aims to identify the modulation used by the transmitter. The receiver estimates the carrier frequency of the signal and down-converts it to the baseband. The signal is sampled with the sampling frequency satisfying the Nyquist criterion for further processing to identify the modulation scheme. The received sampled signal $r[n]$ can be given as

$$r[n] = \alpha s[n] + \eta[n] \tag{1.1}$$

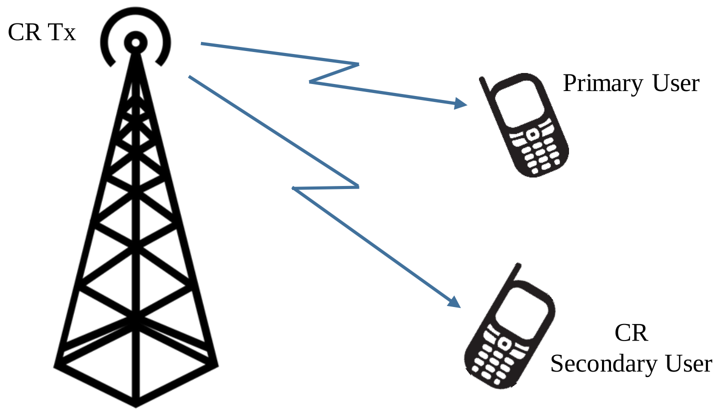

Figure 1.3 : Opportunistic spectrum utilization

In this expression, α contains all the impairment imposed by the channel, $s[n]$ is transmitted baseband signal and, $\eta[n]$ is additive white Gaussian noise (AWGN). The AMC task is generally performed in two steps, preprocessing and modulation classification. In the preprocessing stage, carrier frequency (CF), symbol rate (SR), carrier frequency offset (CFO), symbol time offset (STO), and phase offset (PO) are estimated and different offsets are corrected. In the modulation classification part, a signal corrected from all the impairments is given to the classifier for identification of the modulation scheme used at the transmitter. It is required to develop a system which can classify more number of modulations to employ the system in different application scenario without modification. In general, a system that classifies more modulation schemes comes with higher computation complexity. In real-time processing, the system needs to be quick to provide the result which is possible by considering a fewer number of modulation schemes. In other application which requires flexibility to choose modulation schemes needs to compromise with the computation complexity.

1.3 CONTRIBUTIONS

Following contributions are believed to be concluded from the work done:

1. A method has been proposed for modulation classification using curve fitting. Linear regression and circle fitting are applied and based on MSE modulation domain classification is done.
2. The symmetric dot pattern (SDP) has been introduced as a feature for modulation classification. The adaptive local power-law transform (ALPLT) method is used for color image generation using the SDP density matrix. Efficient DCNN models, ResNet-50 and Inception ResNet V2 are employed for modulation classification.
3. The constellation density pattern is used as a classification feature. The constellation density matrix (CDM) is transformed into a color image using three masking filters of different shapes and ResNet-50 and Inception ResNet V2, DCNN models are employed for the classification task.

4. The two-dimensional Fast Fourier Transform (2D-FFT) is applied to the CDM for frequency-domain feature extraction. A lightweight DCNN model is designed and employed for modulation classification.

5. A method is developed for modulation classification, symbol rate and, phase offset estimation with oversampling factor alteration. The generated method is deployed and tested on the FPGA platform.

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