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Effects of IQ imbalance for simultaneous transmit and receive based cognitive anti-jamming receiver

Haitao Li *, Yiming Qian

Electronic Information and Control Engineering, Beijing University of Technology, Beijing, China

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ABSTRACT

In order to enhance the anti-jamming capability of Cyberspace data-link (CDL) in the complex electromagnetic environment, the performance of jamming sensing of simultaneous transmit and receive based cognitive anti-jamming (SCAJ) receiver impaired by IQ imbalance is investigated. Firstly, energy detection (ED) based the jamming detection and false-alarm probabilities in closed-form for single- and multi-channel SCAJ receiver are derived. Then, the image channel interference cancellation (IC) scheme is proposed to mitigate the image channel crosstalk. Simulation results show that the false-alarm probability is increased by IQ imbalance, and the proposed interference cancellation scheme can reduce the adverse effect of IQ imbalance, thus the anti-jamming performance of SCAJ receiver in CDL system can be improved.

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1. Introduction

As an important part of Cyberspace, data link mainly for interception, jamming and attacking enemy combat system is the focus of attack and defense sides, which directly affects combat efficiency of the Cyberspace battlefield. Therefore, it is significant to explore advanced anti-jamming technology to enhance the countermeasure of Cyberspace data link (CDL). Generally, anti-jamming method for data link include frequency domain processing, such as direct sequence spread spectrum (DSSS), frequency hopping (FH); spatial methods, such as adaptive antennas; time domain scheme, such as burst communication. These schemes are blind anti-jamming technologies, namely anti-jamming capability is predefined. Once the targeted enemy interference beyond the jamming margin of data link, the transmission of CDL may be interrupted. In a complex electromagnetic environment, the conventional anti-jamming technology cannot meet to the requirements of reliable transmission.

Recently, anti-jamming communication technology based on Cognitive radio (CR) was put forward. The basic principle of this scheme firstly establish sending chain to communication, and operate in fixed-frequency turn to FH mode once be effective jammed, and automatically update frequency set to ensures normal communication with high reliability. Due to reaction time existing in enemy jammer for transmitting signal, CR based anti-jamming (CAJ) communication system take advantage of this interval to perceive electromagnetic environment, analyze the characteristic of jamming signal, and dynamically select the best frequency to transmission, so as to enhance the anti-jamming capability of the CDL.

On the other hand, it is worth noting that the In-band full-duplex (FD) wireless communication, i.e. simultaneous transmission and reception at the same frequency, promises up to 2x spectral efficiency. The main limitation impacting FD transmission is managing the strong self-interference signal imposed by the transmit antenna on the receive antenna within the same transceiver. For a full-duplex system to achieve its maximum efficiency, the self-interference signal has to be significantly suppressed to the receiver's noise floor. In literatures [1,2] joint analog and digital interference cancellation (JADIC) is proposed for FD based simultaneous transmit and receive (STAR) system, it can eliminate the self-interference generated by high power signal. So that the spectrum efficiency of CAJ communication system can be doubled by FD operation mode using JADIC scheme. And the full duplex based STAR cognitive anti-jamming (SCAJ) technology can be utilized for CDL in complex electromagnetic environment and the spectrum efficiency of CDL is improved [3].

For SCAJ communication system, the spectrum sensing of receiver, namely the detection of jamming source is the key to realize the cognitive anti-jamming, which directly affects the anti-jamming performance of CDL. It is necessary to design high performance SCAJ receiver for CDL. By far, many researchers have carried on beneficial exploration on CAJ technology, most of which only

* Corresponding author.
E-mail addresses: lihaitao@bjut.edu.cn (H. Li), qianym0728@163.com (Y. Qian).

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considered the ideal receiver [4–6]. But the practical receiver exist RF impairments, including the nonlinear distortion of power amplifier, the local oscillator phase noise, IQ imbalance and so on, seriously reduces the performance of receiver [7,8]. In this paper, we study the effects of IQ imbalance for SCAJ receiver, particularly in the high-speed broadband receiver, the conjugate spectrum of sub-carrier and its image sub-carrier is overlapped by slight imbalance, which amplitudes of I、Q branch are not strictly equal and phases are not strictly orthogonal, so the image channel interference increases the jamming false-alarm probability, which leads the anti-jamming capability of CDL to be reduced.

The IQ imbalance of wireless communication receiver has been studied deeply. For example, impacts of IQ imbalance and sampling frequency offset on the spectrum sensing algorithms are discussed in [9], but the analysis was limited to single-channel receiver. Another recent work in the context of single-channel OFDM sensing is provided in [10] where IQ imbalance coefficients are known. On the other hand, multi-channel sensing under IQ imbalance is reported only within very few works among [11], where a multi-level hypothesis testing principle is shortly introduced. Furthermore, these studies are limited in half-duplex (HD) radio system.

In this paper, we deeply analysis the impacts of IQ imbalance on energy detection (ED) based jamming sensing for both single-channel and multi-channel SCAJ receiver. The rest of this paper is organized as follows. Section 2 presents the system model of SCAJ transceiver in detail, and the classical ED is discussed together with the corresponding false-alarm and detection probabilities. In Section 3, the IQ-imbalanced signal model is presented where a single-channel receiver is assumed. The false-alarm and detection probabilities of the ED are derived for the corresponding signal model. Then in Section 4, multi-channel detection impaired by IQ imbalance is considered. The impaired multi-channel signal model is introduced and the corresponding false-alarm and detection probabilities are derived in closed form for the energy detector. An image channel interference cancellation method is proposed for compensation in Section 5. In Section 6, simulations are provided to illustrate that the proposed method can compensate for the performance loss in SCAJ receiver under IQ imbalance very efficiently. Finally the conclusions are drawn in Section 7.

2. SCAJ system model

The receiver of SCAJ communication system is shown in Fig. 1. In the transmission end (TX), the bit streams are sent to the wireless channel after digital-to-analog conversion (DAC) and transmitting filter. It is assumed that the power of transmitted signal is such that the desired transmit power is reached after the amplification by IQ mixer and power amplifier (PA). For simultaneous transmit and receive mode, the signal of transmitting and reception is operated simultaneously, self-interference (SI) is generated by transmitting signal splitting into the receiver end (RX). Specially, in case of STAR applications in military radio with high transmitted power, the self-interference should be eliminated to meet the requirement of military anti-jamming communication. The JADIC scheme is introduced to cancel the SI which is proposed in literature [1,12]. Therefore, the received RF signals stem from analog self-interference cancellation, band-pass filter (BPF), low noise amplifier (LNA), IQ de-hopping and low pass filter (LPF), analog-to-digital conversion (ADC), digital self-interference cancellation, then conversion to demodulation in baseband, etc. In addition, the utilization of the electromagnetic frequency spectrum is inspected by the jamming sensing unit, and it is feedback to the receiver and transmitter. The frequency band with lower interference would be selected by the SCAJ receiver if the strong interference from current frequency band is detected.

For a SCAJ radio pair composed of remote and local station, assuming that there were no transmitting signals from the remote radio in the sensing interval, the received signal $y_\theta^{ideal}(n)$ corresponding to the ideal receiver of local radio, is given by

$$y_\theta^{ideal}(n) = \theta x(n) + \varepsilon s(n) + w(n) \quad \theta \in \{0, 1\} \tag{1}$$

where the two hypotheses, namely absence/presence of jamming signal, will be denoted with parameter $\theta \in \{0\ \ 1\}$. $x(n)$ is the received jamming signal (assumed to be a zero-mean independent identical distribution (iid) random process with variance σ_x^2). $s(n)$ is the self-interference signal generated by TX end (assumed to be a zero-mean iid signal with variance σ_s^2). Let ε be a factor that represents the degree of self-interference, $\varepsilon \in [0, 1]$, namely the residual self-interference after JADIC technique. $w(n)$ is the zero-mean circularly symmetric complex white Gaussian (CSCWG) with variance σ_w^2.

For SCAJ receiver, the key to implement cognitive anti-jamming is able to determine an available frequency channel. We focus on energy detection (ED) based jamming sensing, the main idea is to calculate the average energy of N received signal samples within a sampling period, and compare it with a threshold λ to determine whether the channel is being jammed or not, i.e., channel is available if the power is smaller than the threshold or not available otherwise. We analytically study two metrics to measure the performance of ED algorithm, namely the detection and false-alarm probabilities. The average energy of N received signal samples is defined as

$$T_\theta^{ideal} = \frac{1}{N}\sum_{n=0}^{N-1}\left|y_\theta^{ideal}(n)\right|^2 = \frac{1}{N}\sum_{n=0}^{N-1}\left\{Re\left(y_\theta^{ideal}(n)\right)\right\}^2 + \left\{\mathrm{Im}\left(y_\theta^{ideal}(n)\right)\right\}^2 \quad \theta \in \{0\ \ 1\} \tag{2}$$

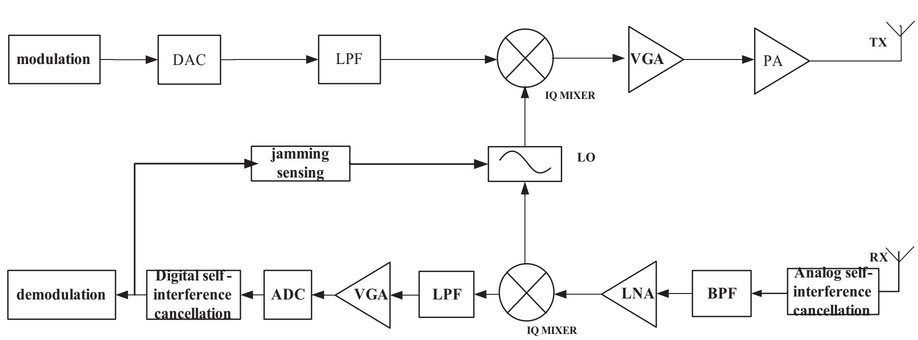

Fig. 1. SCAJ receiver.

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