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Blind interference detection and recognition for the multi-carrier signal

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Abstract

For the interference hidden in the expected multi-carrier signal, this paper proposes a novel detection and recognition algorithm. The algorithm cannot only detect the single-carrier interference (SCI) by the high-order cumulant, but also finds the multi-carrier signal based on spectrum character. Besides, the algorithm can distinguish the modulation types of the SCI. The algorithm does not depend on any prior knowledge and data-aided, which is propitious to practical applications. The analysis and simulation results demonstrate that the proposed algorithm is effective.

Keywords orthogonal frequency division multiplexing (OFDM), interference, eigenvalue, recognition

1 Introduction

With the diversification of wireless signals and complex electromagnetic environment, the problem of the co-channel interference is becoming more and more prevalent, especially in the non-cooperative reception, which will seriously affect the demodulation performance at the receiver. To suppress or eliminate the influence, the receiver first needs to detect and recognize the interference.

For the orthogonal frequency division multiplexing (OFDM) signal, the interference is divided into the intra-system and inter-system interference. The intra-system interference is coming from the same system, including the inter-carrier and inter-symbol interference, and it has been comprehensively researched. This paper will focus on the detection and recognition of the inter-system interference. At present, the research of the inter-system interference mainly focuses on the narrow-band interference (NBI) [1–6]. In Ref. [3], Gomaa et al. propose a novel approach based on compressive sensing theory to detect NBI, while its calculation time is too long. To solve this problem, an adaptive matching pursuit algorithm was proposed [4–5], which greatly shorten the calculation time. Besides, a novel recursive interference detection algorithm is researched [6], which could deduce other jammed symbols from one symbol. The above methods are usually used to find and suppress NBI, which do not care the modulation type of the interference. Thus, these methods cannot distinguish the modulation type of the SCI, and they are also useless to the multi-carrier interference (MCI). At present, the research of the mixed signal focuses on the single-carrier (SC) mixed signal [7–9]. In respect that the characters of the multi-carrier mixed signal are different from that of the SC mixed signal, the existing algorithms of the SC mixed signal are not suitable to the multi-carrier mixed signal. At present, the work on how to detect and recognize the interference hidden in the expected OFDM signal is very scarce.

In this paper, the multi-carrier mixed signals are first studied, and their characters are analyzed, including the high-order cumulant, doubling frequency and spectrum. Compared with single OFDM signal, the characters of the multi-carrier mixed signal are changed. Based on these differences, is proposed a novel detection and recognition algorithm, which does not only find the SCI and MCI, but also can recognize the modulation type of the SCI. The work fills the researching vacancy, which is a prerequisite

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to separate the multi-carrier mixed signals. According to the analysis and simulation results, we demonstrate that the proposed algorithm is valid, and its performance is affected by the signal to interference ratio (SIR) and frequency interval.

The rest of the paper is organized as follows. Sect. 2 describes the mathematic model of the interfered OFDM signal. The novel detection and recognition algorithm is introduced in Sect. 3. The simulation results and conclusions are discussed in Sects. 4 and 5, respectively.

2 System model

These days, the work mainly focus on the mixed signal consisted of two signals, so we consider that the expected OFDM signal is interfered by single signal. At the time, the interfered OFDM signal can be expressed as

$$x(t) = x_1(t) + x_2(t) + v(t) \tag{1}$$

where $x(t)$ is the interfered OFDM signal, $x_1(t)$ is the expected OFDM signal, $x_2(t)$ stands for the interfering signal, $v(t)$ is the additional white Gaussian noise, and $x_1(t)$, $x_2(t)$ and $v(t)$ are mutually independent.

$x_1(t)$ can be expressed as

$$x_1(t) = h_1 \mathrm{e}^{\mathrm{j}(2\pi f_1 t+\phi_1)} \left\{ \frac{1}{N_1} \sum_{n=-\infty}^{\infty} \sum_{k=0}^{M_1-1} \sum_{m=0}^{N_1-1} a_{m,n} \mathrm{e}^{\frac{\mathrm{j}2\pi m(k-L_1)}{N_1}} g(t - kT_1 - nM_1T_1 - t_1) \right\} \tag{2}$$

where h_1 is the channel gain, f_1 is the carrier frequency, ϕ_1 is the phase, $a_{m,n}$ is the nth modulation symbol which is transmitted in the mth subcarrier, N_1 is the number of subcarriers, L_1 is the length of the cyclic prefix, M_1 is the length of OFDM symbol, and $M_1 = N_1 + L_1$, t_1 is the transmission delay, T_1 is the symbol period, and $g(t)$ represents the shaping filter.

Without cyclic prefix, $x_1(t)$ can be simplified as

$$x_1(t) = h_1 \mathrm{e}^{\mathrm{j}(2\pi f_1 t+\phi_1)} \left\{ \frac{1}{N_1} \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N_1-1} \sum_{m=0}^{N_1-1} a_{m,n} \mathrm{e}^{\frac{\mathrm{j}2\pi mk}{N_1}} g(t - kT_1 - nN_1T_1 - t_1) \right\} \tag{3}$$

When the interfering signal $x_2(t)$ is an OFDM signal, which may be expressed as

$$x_2(t) = h_2 \mathrm{e}^{\mathrm{j}(2\pi f_2 t+\phi_1)} \left\{ \frac{1}{N_2} \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N_2-1} \sum_{m=0}^{N_2-1} b_{m,n} \mathrm{e}^{\frac{\mathrm{j}2\pi mk}{N_2}} g(t - kT_2 - nN_2T_2 - t_2) \right\} \tag{4}$$

When the interfering signal $x_2(t)$ is a SC signal, whose expression is shown as

$$x_2(t) = h_2 \mathrm{e}^{\mathrm{j}(2\pi f_2 t+\phi_1)} \left\{ \sum_{n=-\infty}^{\infty} c_n g(t - nT_2 - t_2) \right\} \tag{5}$$

where c_n is the modulation symbol of the SCI, h_2, T_2 and t_2 represent the channel gain, symbol period and transmission delay, respectively. In this paper, the SC signal includes the multiple phase shift keying (MPSK), multilevel quadrature amplitude modulation (MQAM) or multiple amplitude and phase shift keying (MAPSK) signal.

Based on the above model, the blind detection and recognition algorithm will be discussed in the next part.

3 The blind detection and recognition algorithm

In this paper, the interference is divided into two types: the SCI and MCI. In respect that the characters are distinct for the different interfered signal, the corresponding detection and recognition algorithms are also different.

3.1 The detection and recognition algorithm of SCI

The high-order cumulant does not only reflect the type of modulation signal, but also has good anti-noise ability. Besides, the high-order cumulants of different SC modulation signals are different. Thus, the high-order cumulant is considered as an identifiable feature of SCI.

For a zero-mean stationary complex random signal $y(t)$, its p order moment m_{pq} can be expressed as

$$m_{pq} = E\left\{ y^{p-q}(t)(y^*(t))^q \right\} \tag{6}$$

where ‘*’ denotes the conjugate.

Since that different transmission symbols are independent, so

$$E(a_{m,n}a_{g,k}) = \delta(m-g)\delta(n-k) \tag{7}$$

From the Eqs. (3) and (7), the 2 order moment of single OFDM signal can be expressed as

$$m_{20}^{\mathrm{OFDM}} = \frac{h_1^2}{N_1^2} \mathrm{e}^{(\mathrm{j}4\pi f_1 t+2\phi_1)} \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N_1-1} \sum_{m=0}^{N_1-1} E(a_{m,n}^2) \mathrm{e}^{\frac{\mathrm{j}4\pi mk}{N_1}} g^2(t - kT_1 - nN_1T_1 - t_1) \tag{8}$$

$$m_{21}^{\mathrm{OFDM}} = \frac{|h_1|^2}{N_1^2} \sum_{n=-\infty}^{\infty} \sum_{k=0}^{N_1-1} \sum_{m=0}^{N_1-1} E(|a_{m,n}|^2) g^2(t - kT_1 - nN_1T_1 - t_1) \tag{9}$$

When the subcarrier signal is the MPSK/MQAM signal, $a_{m,n}$ satisfies $E(a_{m,n}^2)=0$ and $E(|a_{m,n}|^2)=1$, so the Eqs. (8) and (9) can be simplified as