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Mitigation of spectral leakage for single carrier, block-processing cognitive radio receivers

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A R T I C L E I N F O

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A B S T R A C T

Cognitive radio (CR) is a multiuser, wireless communication concept that allows for a dynamic and adaptive assignment of spectral resources. The coexistence of multiple users, often transmitting at significantly different power levels, makes CR receivers vulnerable to spectral leakage caused by components' nonlinearities and time-truncation of the processed signal records. In this work we propose a method for mitigating the latter with an adaptive choice of the length of the processing block size. With simulations we show that a significant leakage reduction that leads to receiver dynamic range improvement of around 10 dB can be achieved with the proposed method.

1. Introduction

Cognitive radio (CR) is a wireless communication concept that aims for an efficient use of spectral resources through dynamic spectrum management [1]. A conventional wireless receiver uses a variable-frequency oscillator and a filter to tune the desired signal to a common intermediate frequency or baseband, where it is then sampled and quantized by an analog-to-digital converter (ADC). Unlike conventional wireless transceivers, operating in preallocated sub-bands, CRs need to support any momentarily unoccupied sub-bands in a wide frequency range of interest. As an example of a practical application of CR, consider the recently developed IEEE 802.22 standard [2] that was aimed at using CR for opportunistic transmissions in a 50–700 MHz frequency band that became sparsely allocated [3] after the switchover to digital television in the United States in June 2009. An ideal architecture for an opportunistic cognitive radio receiver would be a wideband low-noise-amplifier (LNA) and an analog-to-digital converter directly following the receiving antenna. A digital processor would then process the output of the ADC in order to extract information from a dynamically assigned channel of interest. Such an architecture, while appealing with its flexibility, poses significant implementation challenges. The CR wideband RF antennas receive signals from various transmissions, often at significantly different power levels. Since the interfering transmissions cannot be removed by analog filtering, the CR RF front-end needs to have the capability of receiving a weak signal of interest in the presence of a very strong interferer. Two main reasons for the distortion of the weak message signal in strong interference, and therefore the degradation of the receiver's dynamic range, are nonlinearities in the receiver's components and time-truncation of the blocks of processed signal records. In this work we consider the latter cause of degradation and propose a method for adaptation of the processing window size for a dynamic range improvement.

Multiple techniques have been considered in the past for dynamic range enhancement for cognitive radio. In [4], the authors proposed spatial filtering techniques for multiple antenna CR systems. In [5] Yang et al. considered a multi-stage receiver architecture, in which the interference is estimated and subtracted in the initial stage of the receiver. In [6], exclusion of parts of the spectrum classified as quasi-stationary was proposed. The time-domain limitation of signal processing blocks and effects of windowing have been studied in [7].

Block transmissions, for which groups of data symbols are processed as a unit, allow for the implementation of frequency domain channel equalization (FDE), which for broadband transmissions in rich multi-path environments can bring significant complexity relaxations when compared to time-domain equalization [8]. To allow for FDE, block transmissions employ a cyclic prefix (CP). The CP is a copy of the end of the signal block attached in front of the block. To avoid inter-block interference (IBI), the length of the CP is chosen larger than the maximum delay spread of the channel. Due to the dynamic character of wireless channels, the value of the delay spread changes over time and space [9]. For the high reliability demanded of modern communication systems, the tail of the distribution of the delay spread dictates a

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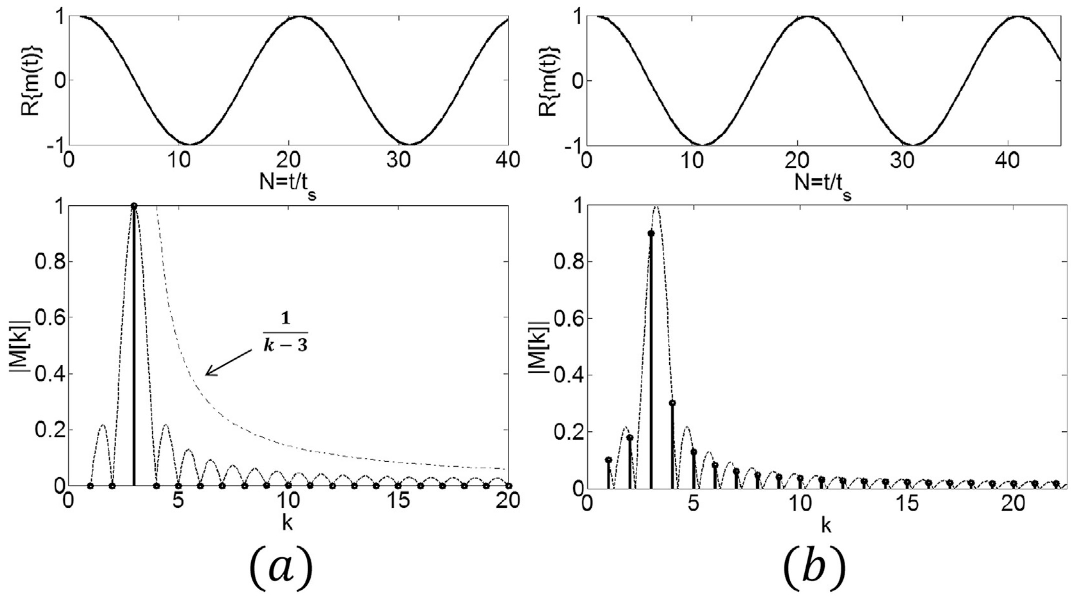

Fig. 1. Spectral representation of a sampled complex sinusoid with the DFT. Observation time is such that: (a) the frequency of the oscillation overlaps with one of the DFT grid points; (b) the frequency lies off the grid which leads to the spectral leakage.

conservative choice of the length of the cyclic prefix, which is fixed during the design stage.

Since truncation in the time domain causes spreading in the frequency domain, weak signals in a block transmission can be corrupted by strong in-band interferers (see Section 2). In this work we propose enhancement of the dynamic range of a block processing CR receiver by an adaptive choice of the processing block size to minimize the spectral leakage into the frequency sub-bands occupied by the signal of interest. In particular we will show that with an adaptive non-complete removal of the CP at the receiver, which can be employed in wireless environments with channel delay spreads even slightly shorter than the length of the CP, significant receiver dynamic range improvements can be achieved for block transmissions. The proposed method can be used together with the previously researched approaches, listed above, in order to further improve the receiver's dynamic range. It is important to stress that while the receiver adaptively changes the size of the processing block, no changes are applied to the transmission scheme. In particular, the transmitter block size is not subject to the adaptive change.

2. Problem statement

The discrete Fourier transform (DFT) is an invertible signal processing operation that projects a time-limited signal onto a set of complex frequencies, and gives a discrete representation of the signal's spectrum. The values of the frequencies that the signal is projected onto build a discrete grid, equidistantly dividing the entire sampling bandwidth. A complex sinusoid oscillating with a frequency off the discrete frequency grid cannot be represented with a single element of the grid, and its energy *leaks* between multiple elements, which leads to misinterpretation of its spectral content. This is visualized in Fig. 1, where the observation time of a complex oscillation is shown for two different cases: (a) the frequency of the sinusoid overlaps with that of one of the grid points (left subplots); (b) the frequency of the sinusoid lies off the grid which leads to spectral leakage (right subplots). For wide-band, block-processing receivers, the finite block length can cause misinterpretation of the Fourier coefficients of the in-band interference, possibly orders of magnitude stronger than the message of interest, which can lead to significant contamination of the message.

A cyclic prefix is employed in the single-carrier frequency division multiplexing (SC-FDM) scheme [10], which is often considered for broadband transmissions over wireless channels. For example SC-FDM has been selected as an uplink communication scheme for the Long Term Evolution (LTE) standard for wireless, high-speed data communication for mobile phones and data terminals [11]. Similar to orthogonal frequency division multiplexing (OFDM), SC-FDM processes data in blocks; however, unlike OFDM, it utilizes a single carrier modulation at

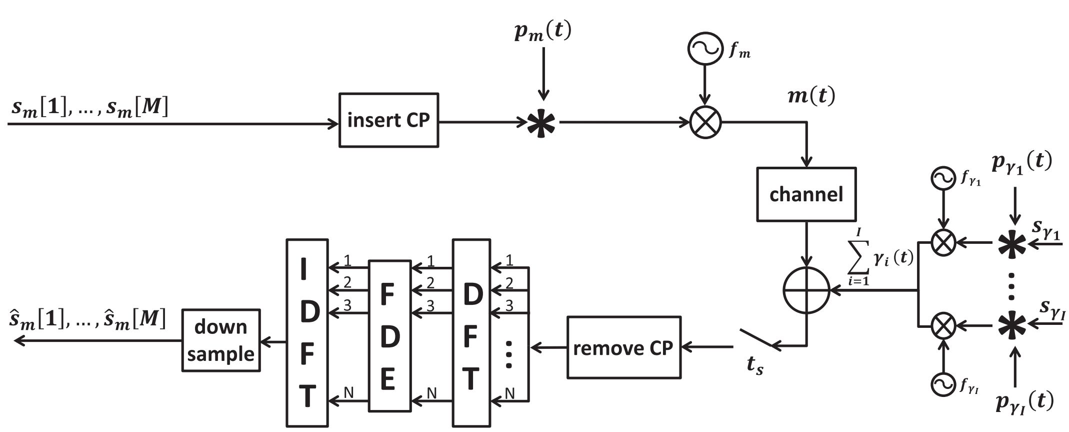

Fig. 2. Block diagram for a single carrier frequency division multiplexing cognitive radio transmission subject to interference.