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LETTER

Suppression of IEEE 802.11a interference using SVD-based algorithm for DS-UWB systems in wireless multipath channels

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Abstract

IEEE 802.11a systems which operate around 5 GHz and overlap the band of UWB signals will interfere with UWB systems significantly. In this letter, a novel narrow-band interference (NBI) suppression technique based on the singular value decomposition (SVD) algorithm is proposed in direct sequence ultra-wideband (DS-UWB) systems in wireless multipath channels. SVD is used to approximate the interference which then is subtracted from the received signals. In contrast to the conventional suppression methods such as the notch filter and the maximal-ratio combining partial RAKE (MRC PRAKE) receiver, our proposed technique is simple and robust, the hardware complexity of the receiver can be reduced greatly.

Keywords: Narrow-band interference (NBI); Singular value decomposition (SVD); Direct sequence ultra-wideband (DS-UWB); Maximal-ratio combining partial RAKE (MRC PRAKE)

1. Introduction

The ultra-wideband (UWB) systems transmit data over a very large bandwidth with appropriate restrictions on effective radiated power ($-41\,\mathrm{dBm/MHz}$) thus making the UWB signal have little impact on other devices operating in the same frequency band. Nevertheless, the low energy per pulse makes them susceptible to this strong narrow-band interference (NBI) even though UWB systems may enjoy a high spreading gain due to the large bandwidths. Especially, IEEE 802.11a systems operate around 5 GHz which overlap the band of UWB signals regulated by the FCC, leading to the significant interference to UWB systems.

By modeling NBI as a single carrier BPSK modulated waveform or a cosinusoidal tone, NBI suppression has been investigated with a minimum mean square error (MMSE) RAKE receiver [1], a notch filter [2] and designing of a special pulse [3]. Although these techniques are effective to suppress single NBI, the NBI suppression technique is still an eminent challenge since the proposed solutions either have high complexity requirements of UWB receivers or behave ineffective against strong NBI. Furthermore, surprisingly, the interference suppression technique on IEEE 802.11a systems received very little attention so far. With the bandwidth as large as several hundred MHz, IEEE 802.11a interference may not be modeled as a BPSK modulated signal or as a cosinusoidal tone. Recently, both analytically and empirically, it has been demonstrated that IEEE 802.11a signals can be modeled as bandlimited additive white Gaussian noise (AWGN) [4,5].

In our work, we provide a novel technique based on the singular value decomposition (SVD) to suppress IEEE 802.11a signals for the direct sequence UWB (DS-UWB) system. The SVD algorithm is used to estimate NBI which then is subtracted from the received signals. This work is

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an extension of our previous work [6] to deal with wireless multipath channels case and also includes the conventional notch filter and the maximal-ratio combining partial RAKE (MRC PRAKE) receiver for comparison. Simulation results confirm that our method can suppress NBI effectively and robustly, the hardware complexity of the receiver can be reduced greatly.

2. System model

Consider the single-user DS-UWB system model with NBI which takes the form

$$s(t) = \sum_{j=iN_s}^{(i+1)N_s-1} \sum_{n=0}^{N_{ss}-1} d_i C_n w_{tr}(t - jT_f - nT_c), \tag{1}$$

where w_{tr} is the transmitted pulse with the duration of T_p; T_f and T_c are the frame period and the chip period, respectively, such that the spread spectrum processing gain $N_{ss} = T_f/T_c$; N_s is the number of pulses required to transmit a single information bit and $T_b = N_s T_f$ denotes the bit duration; $d_i \in \pm 1$ represents the ith transmitted information bit and $C_n \in \pm 1$ are the spreading chips. Let $h(t) = \sum_{l=0}^{L-1} \alpha_l \delta(t - \tau_l)$ denote the multipath channel with L paths, the received signal can be expressed as

$$\begin{aligned} r(t) = \sum_{l=0}^{L-1} \sum_{j=iN_s}^{(i+1)N_s-1} \sum_{n=0}^{N_{ss}-1} \alpha_l d_i \; C_n w_{rx}(t - jT_f - nT_c \\ - \tau_l) + i(t) + n(t), \end{aligned} \tag{2}$$

where w_{rx} is the received pulse at the output of the antenna; $i(t)$ represents the NBI signal and $n(t)$ is the AWGN with two-sided power spectral density (PSD) $N_0/2$; α_l and τ_l are the channel attenuation and the channel delay associated with the lth path which are assumed to be known at the receiver. Defining $\alpha = [\alpha_1, \alpha_2, \ldots, \alpha_L]^T$ and $\tau = [\tau_1, \tau 2, \ldots, \tau_L]^T$ as the channel attenuation vector and the channel delay vector, respectively (Superscripts T and H denote transpose and complex transpose of a matrix). To reduce the receiver complexity, we use a PRAKE which adopts first L_p paths out of L available diversity paths and combines them according to MRC. A MRC RAKE receiver employs the weighs vector $\beta = \alpha$ and maximizes the signal to noise ratio (SNR) when no interference exists in the system. The template waveform of the kth frame for the lth correlator with the time delay τ_l is given by

$$\phi_l(t) = \sum_{n=0}^{N_{ss}-1} C_n w_{rx}(t - kT_f - nT_c - \tau_l) \tag{3}$$

producing the output

$$r_l(t) = \sum_{j=0}^{N_s-1} \int_{(j-1)T_f}^{jT_f} r(t)\phi_l(t)\,\mathrm{d}t \tag{4}$$

which can be denoted by a vector as $\boldsymbol{r} = [r_1, r_2, \ldots, r_L]^T$. So the RAKE output can be expressed as $y(t) = \beta^T r = \sum_{l=0}^{L_p-1} \beta_l r_l(t)$.

As a most likely co-exist technology with UWB in the future, IEEE 802.11a systems employ the orthogonal frequency division multiplexing (OFDM) based transmission and possess three 100 MHz wide frequency bands. Both analytically and empirically, it has been demonstrated [4,5] that when the number of subcarriers is large enough a complex baseband OFDM signal can be modeled as a bandlimited AWGN process. With 52 subcarriers, IEEE 802.11a signals satisfy the condition and can be modeled as bandlimited AWGN. In this letter, the worst situation which means IEEE 802.11a signals occupy the full 300 MHz bandwidth is considered. This might not happen in the real situation but gives the worst performance in UWB systems.

3. NBI suppression technique

For a time series $r(k)$ with $k = 1, 2, \ldots, N$ (N is the sampling number of points), we can construct a Hankel matrix with $M = N - L + 1$ rows and L columns illustrated as follows:

$$\mathbf{R} = \begin{bmatrix} r(1) & r(2) & \ldots & r(L) \\ r(2) & r(3) & \ldots & r(L+1) \\ \vdots & \vdots & & \vdots \\ r(N-L+1) & r(N-L+2) & \ldots & r(N) \end{bmatrix}. \tag{5}$$

Using the SVD, $\mathbf{R}$ can be factorized as $\mathbf{R} = U\Sigma V^H$ where $U(M \times M)$ and $V(L \times L)$ are unitary matrices. $\Sigma = \mathrm{diag}(\sigma_1, \sigma_2, \ldots, \sigma_m)$ is a diagonal matrix with diagonal entries called the singular values of $\mathbf{R}$ which are arranged in the decreasing order and are square roots of the eigenvalues of $\mathbf{R}^H\mathbf{R}$ or $\mathbf{R}\mathbf{R}^H$.

With the characteristic of white noise, the UWB signal has similar singular values which are all close to zero in the absence of high-energy NBI. After NBI are introduced to the UWB system, there will exist several dominant singular values to represent such interference. In this case, the data matrix $\mathbf{R}$ is the superposition of the UWB signal space and the noise space and can be partitioned into two subspaces as follows:

$$\begin{aligned} \mathbf{R} &= [\mathbf{U}_R \;\; \mathbf{U}_S] \begin{bmatrix} \Sigma_R & 0 \\ 0 & \Sigma_S \end{bmatrix} [\mathbf{V}_R \;\; \mathbf{V}_S]^H \\ &= \mathbf{U}_R \Sigma_R \mathbf{V}_R^H + \mathbf{U}_S \Sigma_S \mathbf{V}_S^H \\ &= \mathbf{R}_R + \mathbf{R}_S, \end{aligned} \tag{6}$$

where $\Sigma_R = \mathrm{diag}(\sigma_1, \sigma_2, \ldots, \sigma_k)$ and $\Sigma_S = \mathrm{diag}(\sigma_{k+1}, \sigma_{k+2}, \ldots, \sigma_m)$ with $\sigma_1 > \sigma_2 > \cdots \geqslant \sigma_{k+1} > \sigma_{k+2} > \cdots > \sigma_m$ corresponds to the singular values in the interference subspace $\mathbf{R}_R$ and the data subspace $\mathbf{R}_S$, respectively. By subtracting