Impulse Series for UWB-Based Cognitive Radio System

Weihua Zhang, Hanbing Shen, Zhiquan Bai, and Kyung Sup Kwak

ABSTRACT—In this letter, we propose an impulse series for an ultra-wideband-based cognitive radio system which can utilize the spectrum dynamically by controlling the impulse positions and thus reduce the system complexity.

Keywords—Cognitive radio (CR), ultra-wideband (UWB), impulse series.

I. Introduction

Ultra-wide band (UWB) and cognitive radio (CR) are two spectrum sharing technologies. An UWB-based CR system adopts the interference suppression technology of UWB and exploits the advantages of integrating CR with UWB technologies [1].

In a CR system, a dynamic transmission spectrum control module generates transmission signals to avoid interference to and from the primary applications [2]. Multi-band orthogonal frequency-division multiplexing (MB-OFDM) and transform domain communication system (TDCS) technologies are two major candidates for dynamic transmission spectrum control [3]. However, both schemes require time-frequency transformation processing such as inverse discrete Fourier transform (IDFT), which increases the system complexity, power consumption, and processing delay.

We propose an impulse series for a UWB-based CR system in this letter. After achieving the interference frequencies, our proposed scheme can avoid interference effectively.

II. Impulse Series for UWB-Based CR System

1. UWB Modulation Scheme

For a binary pulse amplitude modulation (BPAM) UWB system, the transmitted signal is given by

$$s(t) = \sqrt{E_p}\, d_i \sum_{j=0}^{N_s-1} w(t - jT_f), \qquad (1)$$

where E_p is the pulse energy, N_s is pulse repetition number, $w(t)$ is the energy normalized transmission waveform, $d_i \in \{-1,+1\}$ is the i-th transmitted binary data, and T_f is the frame length.

We assume that a channel has N_p paths with amplitude α_k and delay τ_k and that the antenna has a flat frequency response. The received signal is given by

$$r(t) = \sum_{k=1}^{N_p} \alpha_k \sqrt{E_p}\, d_i \sum_{j=0}^{N_s-1} w(t - jT_f - \tau_k) + i(t) + n(t). \qquad (2)$$

where $i(t)$ is the interference and $n(t)$ is noise. In the receiver side, without loss of generality, a template $v(t) = w(t)$ is correlated with $r(t)$. The k-th correlation output over a bit intervals

$$r_k(i) = \sum_{j=0}^{N_s-1} \int_{jT_f+\tau_k}^{(j+1)T_f+\tau_k} r(t)v(t)dt = d_i \alpha_k s_k(i) + i_k(i) + n_k(i), \quad (3)$$

where

$$\begin{aligned} s_k(i) &= \sum_{j=0}^{N_s-1} \int_{-\infty}^{\infty} \sqrt{E_b}\, w(t)v(t)dt = N_s\sqrt{E_p}, \\ i_k(i) &= \sum_{j=0}^{N_s-1} \int_{-\infty}^{\infty} i(t + jT_f + \tau_k)v(t)dt, \qquad (4) \\ n_k(i) &= \sum_{j=0}^{N_s-1} \int_{-\infty}^{\infty} n(t + jT_f + \tau_k)v(t)dt. \end{aligned}$$

We denote, in vector notation, $\mathbf{r} = d\,\mathbf{s} + \mathbf{i} + \mathbf{n}$ for simplicity, where $\mathbf{s}$, $\mathbf{i}$, and $\mathbf{n}$ are desired, interference, and noise outputs of the correlation bank, respectively. We assume that an ARake receiver with weight vector $\mathbf{c}$ is adopted. Maximum ratio combination (MRC) is performed by setting $\mathbf{c} = \boldsymbol{\alpha}$, where $\boldsymbol{\alpha}$ is an $N_p \times 1$ channel gain vector. The output interference power of the correlator bank is $I_{\text{out}} = \boldsymbol{\alpha}^{\mathbf{H}} \mathbf{R}_{\mathbf{i}} \boldsymbol{\alpha}$, where $\mathbf{R}_{\mathbf{i}} = E\{\mathbf{i}\mathbf{i}^{\mathbf{H}}\}$ is an $N_p \times N_p$ correlation matrix, and $(.)^{\mathbf{H}}$ denotes conjugate transpose.

Manuscript received Apr. 6, 2007; revised Apr. 29, 2007.

This work was supported by the MIC (Ministry of Information and Communication), S. Korea, under the ITRC (Information Technology Research Center) support program supervised by the IITA (Institute of Information Technology Advancement) (IITA-2006-(C1090-0603-0019)).

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2. Proposed Impulse Series

The (*k*,*l*)th element of $\mathbf{R_i}$ can be given in [4] as

$$\begin{aligned}[\mathbf{R_i}]_{k,l} &= E\{i_k(t)i_l^*(t)\}\\ &= \sum_{m=0}^{N_s-1}\sum_{n=0}^{N_s-1}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}E\{i(t+mT_f+\tau_k)\cdot i(\tau+nT_f+\tau_l)w(t)w(\tau)\}dtd\tau\\ &\approx N_s\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}R_i(t-\tau+\tau_k-\tau_l)w(t)w(\tau)dtd\tau,\end{aligned} \tag{5}$$

where $R_i(t)$ is the autocorrelation of the interference $i(t)$, and τ_k and τ_l are the propagation delay of the *k*-th and *l*-th paths.

Commonly, narrow-band interference (NBI) can be approximately modeled as a single tone carrier

$$i(t) = \beta\cos(2\pi f_c t+\varphi), \tag{6}$$

where β, f_c, and φ are the amplitude, central frequency, and phase, respectively. The normalized autocorrelation function of the single tone can be given by

$$R_i(t) = \cos(2\pi f_c t). \tag{7}$$

In this study, we utilize Gaussian impulse

$$g(t) = (1-4\pi(t/t_m)^2)\exp(-2\pi(t/t_m)^2) \tag{8}$$

as the basis pulse, where t_m is the pulse width parameter. The proposed schemes utilize an impulse series as

$$w_1^{(\pm)}(t) = g(t+\delta)\pm g(t-\delta), \tag{9}$$

where the superscript '±' means that two different series are possible with sum or difference of the delayed version of *g*(*t*), and the subscript '1' represents the number of NBI to be suppressed. We assume that the UWB spectrum is basically constant over the frequency range of NB application which is centered at f_c. The (*k*,*l*)th element of $\mathbf{R_i}$ can be given by

$$\begin{aligned}[\mathbf{R_{1,i}}]_{k,l}^{(+)} &= \sum_{m=0}^{N_s-1}\sum_{n=0}^{N_s-1}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}E\{i(t+mT_f+\tau_k)i(\tau+nT_f+\tau_l)\}\\ &\qquad\cdot[g(t+\delta)+g(t-\delta)][g(\tau+\delta)+g(\tau-\delta)]dtd\tau\\ &= N_s|G(f_c)|^2[2R_i(\tau_k-\tau_l)+R_i(\tau_k-\tau_l-2\delta)R_i(\tau_k-\tau_l+2\delta)]\\ &= 4N_s|G(f_c)|^2\cos(2\pi f_c(\tau_k-\tau_l))\cos^2(2\pi f_c\delta),\end{aligned}$$

$$[\mathbf{R_{1,i}}]_{k,l}^{(-)} = 4N_s|G(f_c)|^2\cos(2\pi f_c(\tau_k-\tau_l))\sin^2(2\pi f_c\delta), \tag{10}$$

where f_c is the central frequency of the NBI *i*(*t*), and *G*(*f*) is the frequency expression of *g*(*t*). We note that when we choose $\delta=(N+0.5)/(2f_c)$ (for any integer *N*) in the $w_1^{(+)}(t)$ or choose $\delta=N/(2f_c)$ in the $w_1^{(-)}(t)$, all the elements in $\mathbf{R_i}$ equal zero, and the single tone with frequency of f_c is suppressed.

In terms of two NBIs with frequencies of f_{c1} and f_{c2}, we can construct two impulse series by

$$w_2^{(\pm)}(t) = [g(t+\delta_2)+g(t+\delta_1)]\pm[g(t-\delta_1)+g(t-\delta_2)]. \tag{11}$$

Then, the (*k*,*l*)th element of $\mathbf{R_i}$ can be obtained as

$$\begin{aligned}[\mathrm{R}_{2,\mathrm{i}}]_{k,l}^{(+)} &= 16N_s|G(f_c)|^2\cos(2\pi f_c(\tau_k-\tau_l))\\ &\quad\cdot\cos^2(\pi f_c(\delta_1+\delta_2))\cos^2(\pi f_c(\delta_1-\delta_2)),\end{aligned} \tag{12.a}$$

$$\begin{aligned}[\mathrm{R}_{2,\mathrm{i}}]_{k,l}^{(-)} &= 16N_s|G(f_c)|^2\cos(2\pi f_c(\tau_k-\tau_l))\\ &\quad\cdot\sin^2(\pi f_c(\delta_1+\delta_2))\cos^2(\pi f_c(\delta_1-\delta_2)).\end{aligned} \tag{12.b}$$

Note that if we choose

$$\delta_1 = \frac{N_1+0.5}{2f_{c1}}+\frac{N_2+0.5}{2f_{c2}} \quad\text{and}\quad \delta_2 = \frac{N_1+0.5}{2f_{c1}}+\frac{N_2+0.5}{2f_{c2}} \tag{13.a}$$

in the $w_2^{(+)}(t)$ or

$$\delta_1 = \frac{N_1}{2f_{c1}}+\frac{N_2+0.5}{2f_{c2}} \quad\text{and}\quad \delta_2 = \frac{N_1}{2f_{c1}}+\frac{N_2+0.5}{2f_{c2}} \tag{13.b}$$

in the $w_2^{(-)}(t)$, all the elements in matrix $\mathbf{R_i}$ equal zero. The two NBIs are suppressed.

Figure 1 shows the time-domain impulse series and power spectral density (PSD) of the series when two NBIs with central frequencies of f_{c1}=4.5 GHz and f_{c2}=5.3 GHz are presented. The parameters are t_m=0.1 ns, $\{N_1=2, N_2=3\}$ for $w_2^{(+)}(t)$ and $\{N_1=4, N_2=1\}$ for $w_2^{(-)}(t)$. Two single tone NBIs in the spectral domain are suppressed to zero in Fig. 1(b).

Figure 2 shows the functional diagram of the proposed schemes. First, a spectrum estimation module estimates the radio environment to find the NBI central frequencies f_{c1} and f_{c2}. Second, a parameter identification module identifies the corresponding parameters δ_1 and δ_2. An impulse series generation module utilizes the pulse waveform *g*(*t*) as well as parameters δ_1 and δ_2 to produce the proposed impulse series $w^{(\pm)}(t)$. A magnitude scaling module scales $w^{(\pm)}(t)$ to achieve the desired energy, and the transmission signal *s*(*t*) is formed by modulating the data d_i on the proposed impulse series.

III. Performance Evaluation

We evaluate system performance of the proposed scheme by computer simulation. We adopt a binary direct sequence (DS) PAM system in the simulation. The waveform *g*(*t*) is a Gaussian impulse given in (10) with the pulse width parameter t_m of 0.1 ns. The pulse width T_p of *g*(*t*) is 0.4 ns, the frame duration T_f is 2 ns, and N_s (= 10) waveforms are used to represent one bit.

We assume AWGN with S-V CM1 as the transmission channel model [5]. An ARake receiver is used to catch transmission energy. Tone waveforms are utilized for mathematical analysis, but for the simulation, we use NBIs with a bandwidth of 200 MHz. We generate two NBIs by filtering the AWGN using two band-pass filters of 200 MHz for the different central frequencies (4.5 GHz and 5.3GHz).

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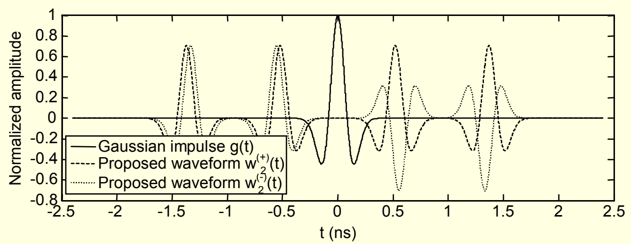
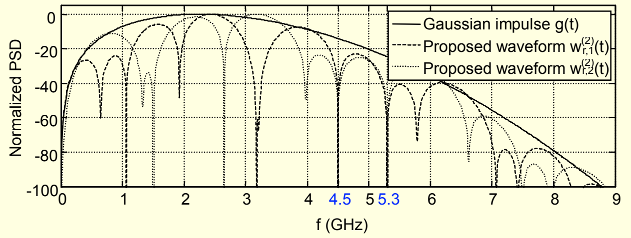


(a) Time domain waveforms



(b) Normalized PSD

Fig. 1. Illustration of (a) time domain waveforms and (b) normalized PSD of original and the proposed impulse series.

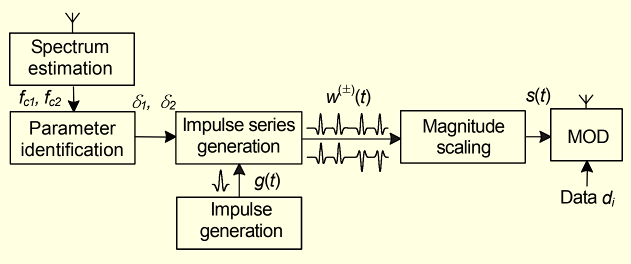


Fig. 2. Functional diagram of impulse series UWB-based CR system.

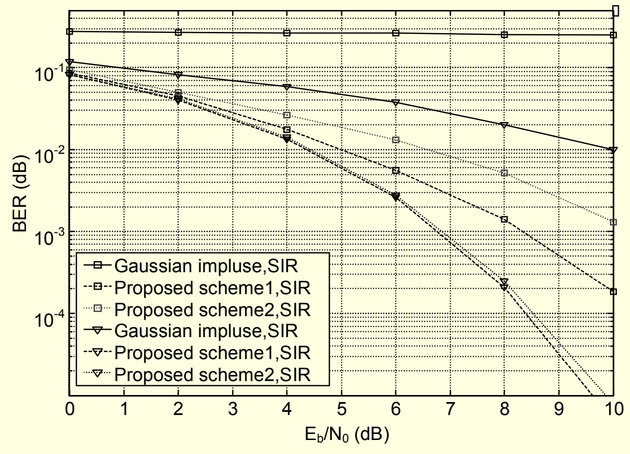


Fig. 3. BER vs. E_b/N_0 performance.

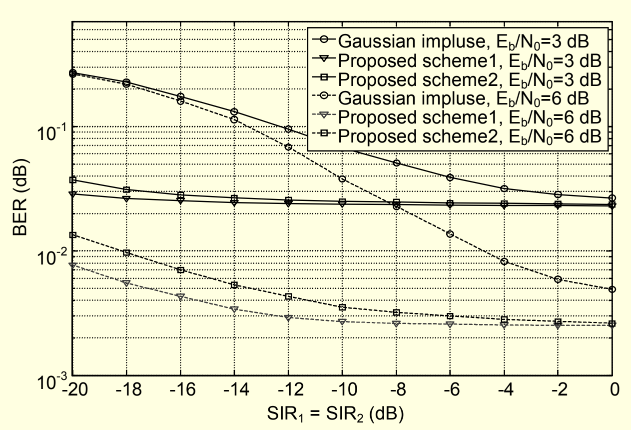


Fig. 4. BER vs. SIR performance.

Better performance is shown as the smaller bandwidth is used.

We utilize two impulse series as shown in Fig. 1. Figure 3 shows the BER vs. E_b/N_0 performance results, and Fig. 4 shows the BER vs. SIR performance. We assume $SIR_1=SIR_2$ in the simulation. From the results, we conclude that the two proposed schemes show great BER improvement compared to the conventional Gaussian impulse system for any E_b/N_0 or SIR scenarios. Figure 3 demonstrates that when SIR=−10 dB, the two schemes have E_b/N_0 gains of more than 5 dB at a BER of 10^{-2}. Figure 4 demonstrates that when E_b/N_0=6 dB, $w_2^{(-)}(t)$ has an SIR gain of 13 dB at a BER of 10^{-2} and $w_2^{(+)}(t)$ has more gains than that with the $w_2^{(-)}(t)$ for the chosen pulse waveform and parameters (N_1, N_2).

IV. Conclusion

We proposed an impulse series for an UWB-based CR system in this letter. By adopting the proposed impulse series as the modulation waveforms, NBI with given center frequencies can be suppressed. By simulation, we demonstrated that the proposed impulse series schemes are very effective for NBI suppression.

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