Journal of Southeast University (English Edition) Vol. 28, No. 3, pp. 272 - 275 Sept. 2012 ISSN 1003—7985

Narrowband interference suppression in TR-UWB system based on cognitive radio theory

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Abstract: A cognitive radio transmitted reference ultra-wideband (CR-TR-UWB) system is proposed to improve the performance of TR-UWB systems with narrowband interference (NBI) from primary users (PU). The transmitter of the CR-TR-UWB system detects the band of PU, and then sends prolate spheroidal wave functions (PSWF) pulses with the same limited band as PU's to reduce interference with PU. The receiver uses a notch filter before autocorrelation to eliminate NBI from PU. The simulation results show that the bit error rate (BER) performance of the CR-TR-UWB system is close to that of TR-UWB systems without NBI when the system is interfered by single or double NBIs with a signal to interference ratio (SIR) of 0 dB, and if the signal to noise ratio(SNR) is 10 dB and the SIR varies from −20 to 10 dB, BER performance varies no more than an order of magnitude. The system has excellent resistance to NBI, strong robustness BER performance at different SNRs, and smaller interference with the same frequency band PU.

Key words: transmitted reference ultra-wideband (TR-UWB); cognitive radio; narrowband interference; prolate spheroidal wave function (PSWF); coexistence communication

doi: 10.3969/j.issn.1003 −7985.2012.03.003

UWB[1] systems can transmit extremely narrow pulses by employing pulse position modulation (PPM) or pulse amplitude modulation (PAM). The key motivation for using UWB systems is their ability to highly resolve the multipath, as well as the availability of technology to implement and generate UWB signals with relatively low complexity[2]. TR signaling uses the transmission of a pair of reference and data signals, which are separated in time domain. Due to its simplicity, there is renewed interest in TR signaling for UWB systems[3], which can exploit multipath diversity inherent in the environment without the need for channel estimation and stringent acquisition. The receiver can simply be an autocorrelation receiver (AcR).

Due to its large transmission bandwidth, TR-UWB systems need to coexist and contend with many narrowband communication systems. AcR front-ends for TR-UWB systems are more vulnerable to narrowband interference (NBI), since the reference pulse is also exposed to NBI[4]. In order to improve the performance of TR-UWB systems with NBI, the effect of the NBI on AcR was investigated in Ref. [5]. The effect of the finite resolution with NBI was discussed in Ref. [6]. Some NBI mitigation schemes for TR-UWB systems were proposed, such as threshold detection, MMSE[7], notch filter[8], chip time differential transmitted reference(Tc-DTR)[9]. When interfering with PU, TR-UWB systems also affect the performance of PU. Cognitive ultra-wideband systems were proposed in Ref. [10], which use pulse with the same limited band as PU's to reduce the interference with PU. This method is used to improve the performance of UWB with NBI in Ref. [11]. An improved Parks-McClellan method is used to design ultra-wideband impulse in Ref. [12], which has high spectrum efficiency and avoids interference with other systems. Time reversal is used in the coexistence between TR-UWB systems and IEEE 802.11a WLAN in Ref. [13].

In order to improve the performance of TR-UWB systems with NBI, and to have a better coexistence with narrowband PU, a kind of CR-TR-UWB system based on the cognitive radio method is proposed in this paper.

1 Design of CR-TR-UWB System

1.1 Model of CR-TR-UWB system

As shown in Fig. 1, the transmitter detects the PU band, and uses PWSF pulse with the same limited band as PU's. The receiver uses the notch filter to eliminate NBI from PU before AcR.

1.2 Spectrum sensing

It is necessary to detect PU band before designing PSWF pulse with limited band and notch filter. Since the peak power spectrum of the CR-TR-UWB system is significantly lower than PU's, the PU band can be detected when the predefined threshold value is compared with the total power spectrum.

The peak power spectrum of the CR-TR-UWB system is 20 dB lower than PU's in Fig. 2 where the SIR is −10

Received 2012-02-09.

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Foundation items: The National Research and Development Program of China(863 Program) (No. 2007AA12Z238), the Natural Science Foundation of Jiangsu Higher Education Institutions of China (No. 12KJD510008).

Citation: Zhao Hua, Yin Kuixi, Shao Jianhua. Narrowband interference suppression in TR-UWB system based on cognitive radio theory[J]. Journal of Southeast University (English Edition), 2012, 28(3): 272 − 275. [doi: 10.3969/j.issn.1003 −7985.2012.03.003]

dB with double PU.

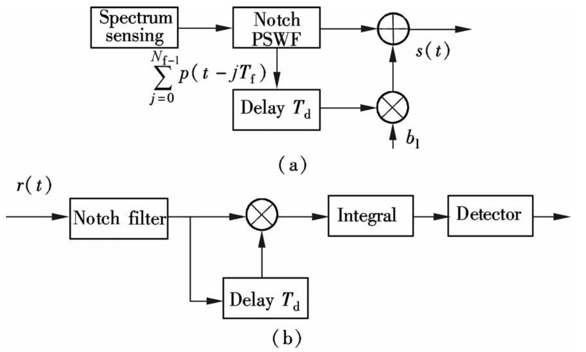

Fig. 1 Diagram of CR-TR-UWB system. (a) Transmitter; (b) Receiver

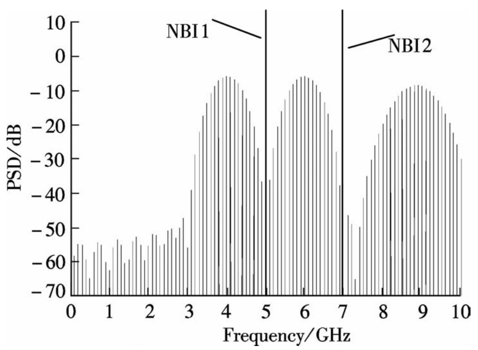

Fig. 2 PSD of CR-TR-UWB system with 5 and 7 GHz PU

1.3 Design of PSWF with limited band

Gaussian pulse[11-12] combination and PSWF pulse[10] can both be used to design pulses. Gaussian pulse combination is very complex and not suitable for applications of low power consumption, so the PWSF pulse is adopted in this system. To simplify the calculation, the PSWF pulse can be obtained by the Hermitian matrix decomposition [14]:

$$\lambda p[n] = \sum_{m=-N/2}^{N/2} p[m]h[n-m] \qquad n = -N/2, \ldots, N/2 \tag{1}$$

where λ is the eigenvalue; $h(t)$ is the sample of the waveform which meets the need of power spectra; $p[n]$ is eigenvector which is the sample of PSWF. The greater the an eigenvalue, the better the power spectrum. Therefore, only if the eigenvectors correspond to the largest eigenvalues, can they be taken as pulse designs and selected for implementation. According to this method, we can obtain PSWF with double limited bands, which also meet FCC mask. The PSD of PSWF with 5 and 7 GHz limited bands is shown in Fig. 3, which is 50 dB lower than the peak PSD.

1.4 Design of notch filter

Because IIR controls notch bands better than FIR does with the same order, we use a 5th-order Butterworth stop band filter to obtain single and double notch filters. The amplitude frequency responses in 5 and 7 GHz are 60 and 70 dB lower than the peak in Fig. 4.

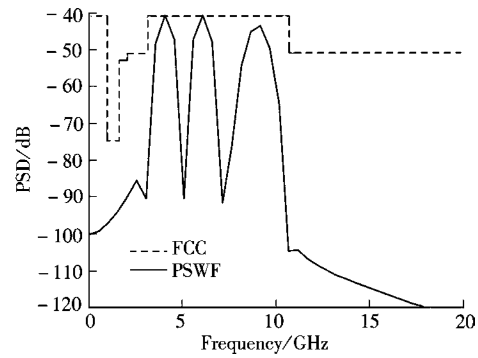

Fig. 3 PSD of PSWF with 5 and 7 GHz limited bands

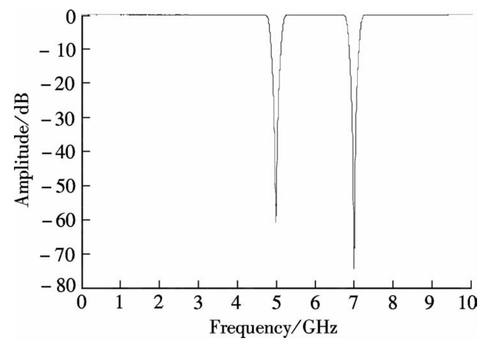

Fig. 4 Amplitude-frequency response of double notch filters

2 BER Performance with NBI

One transmission signal can be denoted as

$$s(t) = \sum_{j=0}^{N_f-1} g(t-jT_f) + \sum_{j=0}^{N_f-1} bg(t-jT_f-T_d) \tag{2}$$

where $g(t)$ is the PWSF pulse with limited bands; T_f is the frame length; T_d is the delay to reference; N_f is the repeated frame number. Channel impulse response is assumed as $h(t)$, and then the receiver signal through the channel is

$$r(t) = \sum_{j=0}^{N_f-1} p_h(t-jT_f) + \sum_{j=0}^{N_f-1} bp_h(t-jT_f-T_d) \tag{3}$$

where $p_h(t) = g(t) * h(t)$.

The NBI signal is assumed as

$$i(t) = \sqrt{2P_i}\cos(2\pi f_i t + \theta) \tag{4}$$

where f_i is the central frequency; θ is a random phase which is distributed uniformly between $[0, 2\pi)$; P_i is the power of NBI.

The received signal is

$$r(t) = \sum_{j=0}^{N_f-1} p_h(t-jT_f) + \sum_{j=0}^{N_f-1} bp_h(t-jT_f-T_d) + i(t) + n(t) \tag{5}$$

where $i(t)$ is the NBI signal; $n(t)$ is the zero-mean white Gaussian noise with two-sided power spectral density $N_0/2$.

Through notch filter $h_n(t)$, the NBI $i(t)$ is eliminated. The power of signal and noise loses a little through the filter.

$$r'(t) = \sum_{j=0}^{N_f-1} p_{hn}(t - jT_f) + \sum_{j=0}^{N_f-1} bp_{hn}(t - jT_f - T_d) + n_n(t) \tag{6}$$

where

$$p_{hn}(t) = p_h(t) * h_n(t) \approx p_h(t)$$
$$n_n(t) = n(t) * h_n(t) \approx n(t)$$

After autocorrelation receiver in T_{mds} (T_{mds} is shorter than half of T_f), the soft decision output is

$$z(T_{mds}) = \sum_{j=0}^{N_f-1} \int_{jT_f}^{jT_f+T_{mds}} r'(t + T_d) r'(t) \mathrm{d}t \tag{7}$$

The BER formula of CR-TR-UWB with NBI is

$$P_e = Q\left(\frac{1}{2N_0/(N_f E_f) + 2T_{mds} B (N_0/E_f)^2 / N_f}\right) \tag{8}$$

where E_f is the energy of a received frame.

3 Simulations and Analysis

3.1 Single NBI(5 GHz)

$T_f = 20$ ns, $T_d = 10$ ns, $N_f = 8$, $g(t)$ is the 2nd-Gaussian pulse and the PWSF pulse with a 5 GHz limited band.

From Fig. 5(a), if the notch filter is used before the autocorrelation receiver with single NBI, the BER decreases from 0.25 down to 2×10^{-3} when the SNR is 10 dB. If we use the PSWF pulse to replace the Gaussian pulse, the BER decreases down to 1×10^{-3}, close to the performance without NBI. From Fig. 5(b), if the SNR is high and the SIR varies from -20 to 10 dB, the BER varies from 5×10^{-3} to 2×10^{-3}. And four curves are closer to each other when the SNR is 10 dB.

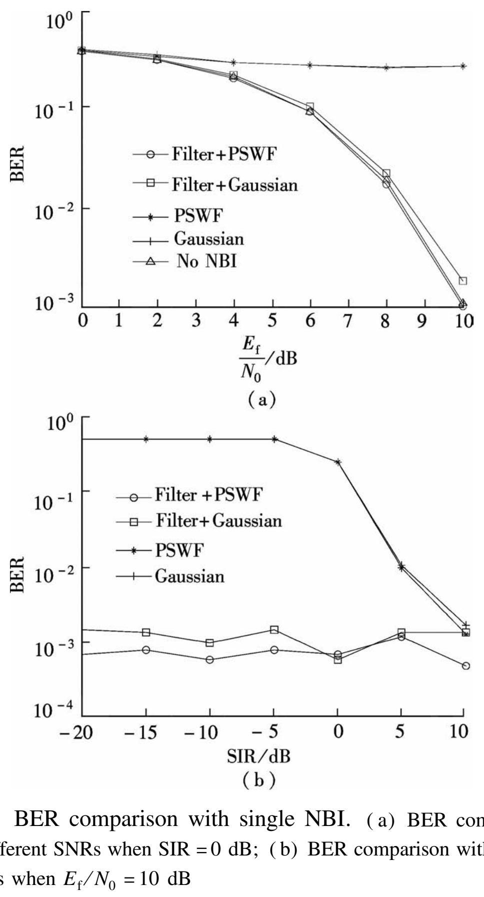

Fig. 5 BER comparison with single NBI. (a) BER comparison with different SNRs when SIR = 0 dB; (b) BER comparison with different SIRs when $E_f/N_0 = 10$ dB

3.2 Double NBIs(5 and 7 GHz)

$T_f = 20$ ns, $T_d = 10$ ns, $N_f = 8$, $g(t)$ is the 2nd-Gaussian pulse and the PWSF pulse with 5 and 7 GHz limited bands. From Figs. 6(a) and (b), the system performance characteristics with double NBIs are similar to those with single NBI.

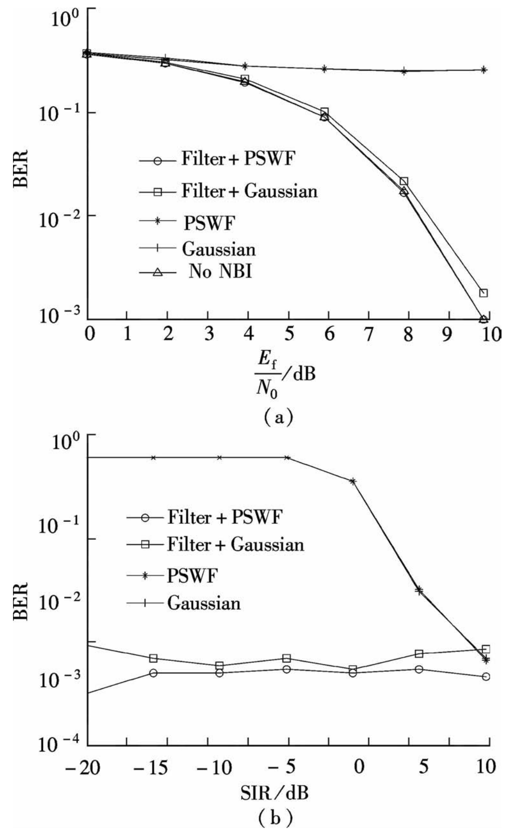

Fig. 6 BER comparison with double NBIs. (a) BER comparison with different SNRs when SIR = 0 dB; (b) BER comparison with different SIRs when $E_f/N_0 = 10$ dB

4 Conclusion

Based on the cognitive radio method, a CR-TR-UWB system is proposed in this paper. The simulations and analysis show that the transmitter pulses with limited bands can obviously reduce interference with PU, improve BER performance in UWB systems[11] and have little influence on BER performance in TR-UWB systems. With the help of the notch filter, the pulse with limited bands further improves the BER performance which is very close to the performance without NBI. This CR-TR-

UWB system has good resistance to NBI ability and good coexisting characteristics when working with other wireless systems. The performance of the system is better than that of traditional TR-UWB systems, especially in high SNR and low SIR, and has robustness in high SNR when SIR varies.

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基于认知无线电的传输参考超宽带系统窄带干扰抑制技术

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摘要:为了改善主用户窄带干扰下的传输参考超宽带系统的性能,提出了一种认知传输参考超宽带系统. 认知传输参考超宽带系统的发射机在检测主用户工作的频段后,采用在该频段陷波的椭球波发射脉冲以降低对主用户的干扰;接收机在相关接收处理前采用陷波滤波来降低主用户带来的窄带干扰. 仿真结果表明:该系统在信干比为 0 dB 的单个或 2 个窄带干扰影响下,误码性能接近于无窄带干扰下的系统性能;在信噪比为 10 dB 且信干比在 -20 ~ 10 dB 范围内变化时,误码性能变化不超过一个数量级. 该系统具有极佳的抗窄带干扰能力,误码性能在不同信噪比下具有很强的健壮性,具有对同频段主用户更小的干扰.

关键词:传输参考超宽带;认知无线电;窄带干扰;椭球波函数;共存通信

中图分类号:TN92