Single Link Performance of UWB Systems Based on Cognitive Radio in the AWGN UWB Channel

Shuo Lin

Abstract—**The single link performance of UWB systems in the AWGN UWB channel is investigated. Based on Cognitive Radio(CR) spectrum allocation and the restriction of Federal Communications Commission (FCC) emission mask, the second derivative Gaussian pulse with the diverse shaping factors and the diverse spectral moving factors act as basis functions. The iterative combination pulse method is put to use to design pulses. The time domain waveform of iterative combination pulse based on FCC signed as UWB system 1. The time domain waveform based on cognitive radio signed as UWB system 2 and UWB system 3. The single link bit error probability (BER) of three different pulse (UWB system 1, UWB system 2 and UWB system 3) for UWB system in Additive White Gaussian Noise (AWGN) channel are simulated and compared. The better performance and stability are validated based on cognitive radio UWB pulse for UWB system.**

Index Terms—**Ultra wideband communication, cognitive radio, spectrum allocation, bit error probability.**

I. Introduction

Ultra-wideband (UWB) is a very promising high capacity wireless communication technology. The energy spectrum of UWB impulse signal is extended from the direct current to the gigahertz magnitude. UWB system shares spectrum resources with other wireless communication applications. Therefore, the possible interferences with other communication systems have to be limited within a certain range [1]. Currently, this power standard was set by the Federal Communications Commission (FCC). However, many studies have shown that [2], spectrum utilization above 3GHz band is very low, 3~4GHz band frequency spectrum utilization is 0.5%, and 4~5GHz band frequency spectrum utilization is only 0.3%. In the relatively crowded spectrum bands (below the 3GHz frequency), there are 70% of the spectrum is not used. Such authorization allocation strategy based on spectrum ownership exclusively resulted in substantial spectrum resources in the idle state. Because resources are wasted and wireless communication requires access to a large number of bands, spectrum resources are so scarce that the cognitive radio came into being.

The basic idea of cognitive radio is the device accesses system based on a policy without affecting the authorized user (Premier User) [3]. The cognitive radio has the learning ability [4], [5], can exchange information with the surrounding environment, percept and use free spectrum (spectrum holes) [6].

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Parr [7], Beaulieu [8], Zeng [9] etc. have studied the UWB pulse design methods, and the spectrum of those UWB pulses are designed to meet the FCC power limit in certain extent [10]. However, in fact, the available frequency band for wireless communication systems is dynamic spectrum. In certain spatial or time domain, the spectrum may not fully satisfies the FCC limit. In other words, the restriction of FCC emission mask for UWB is the minimum requirement. Based on cognitive radio idea, the impulse pulse are designed results from the results of cognitive radio identification. The Single link bit error probability of different pulse for UWB system in Additive White Gaussian Noise channel are simulated and compared. The better performance and stability are validated based on cognitive radio UWB pulse for UWB system.

II. Spectrum Structure Based on the Results of CR Identification

It is considered that the spectrum occupancy is a random process within the scope in the UWB. However in the range 0 ~ 12GHz, the probability of occupied spectrum is quite different. Taking into account the structure of FCC emission mask, 0 ~ 12GHz frequency band can be divided into three different bands: band I: 0 ~ 1.5GHz, band II: 1.5 ~ 3.1GHz, band III: 3.1 ~ 12GHz. Because band III spectrum efficiency is relatively low, bands I and II were studied on pulse design, which results are Table II and Table III. Table I describes FCC emission mask. Table II and Table III describe two assuming results based on cognitive radio identification.

TABLE I: FCC Emission Mask

Frequency band（GHz）	0~0.96	0.96~1.61	1.61~1.99	1.99~3.1
PSD（dBm/MHz）	-41.3	-75.3	-53.3	-51.3

TABLE II: The First Result of CR Identification

Frequency band（GHz）	0~1.1	1.1~1.61	1.61~1.99	1.99~2.5	2.5~3.1
PSD（dBm/MHz）	-41.3	-75.3	-53.3	-51.3	-41.3

TABLE III: The Second Result of CR Identification

Frequency band（GHz）	0~0.96	0.96~1.61	1.61~1.99	1.99~2.5	2.5~3.1
PSD（dBm/MHz）	-41.3	-75.3	-53.3	-41.3	-51.3

III. UWB Communication Pulse PSD Based on the Result of CR Identification

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In UWB wireless communication, the second derivative of the Gaussian impulse has been extensively studied as a receiving pulse [11]. Single Gaussian pulse spectrum can not well match the emission mask based on cognitive radio. However, the different Gaussian shape factor α and spectrum shifting factor f_0 can change the radiated signal power spectral density (PSD) and power distribution. By combination of a plurality of base pulses, the distribution of power spectral density of the combination pulse may approximate the UWB system radiated power limit based on the result of cognitive radio identification.

A. Communication Pulse PSD Based on FCC Emission Mask

The normalized second order differential Gaussian pulse with a shape factor α and spectrum shifting factor f_0 is expressed as

$$p^{(2)}(t|\alpha, f_o) = e^{-2\pi(\frac{t}{\alpha})^2} \cdot \left\{ \cos(2\pi f_o t)\left[\frac{(4\pi t)^2}{\alpha^4} - \frac{4\pi}{\alpha^2} - (2\pi f_o)^2\right] + 4\pi f_o \frac{4\pi t}{\alpha^2} \cdot \sin(2\pi f_o t) \right\} \quad (1)$$

We chose six functions as the base function system

$$\left\{ p_i^{(2)}(t) \middle| \alpha = \alpha_i, f_o = f_{oi}, i = 1, 2, \cdots, 6 \right\} \quad (2)$$

The corresponding parameters of basis functions can be set:

$$\alpha = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6)^T = (2, 0.2, 0.5, 0.3, 0.2, 0.2)^T \text{ns} \quad (3)$$

$$f_o = (f_{o1}, f_{o2}, f_{o3}, f_{o4}, f_{o5}, f_{o6})^T = (0.001, 2, 4, 6, 7, 13)^T \text{GHz} \quad (4)$$

The base vector is represented as

$$p = (p_1^2(t), p_2^2(t), p_3^2(t), p_4^2(t), p_5^2(t), p_6^2(t))^T \quad (5)$$

The weight vector is

$$w = (w_1, w_2, w_3, w_4, w_5, w_6)^T \quad (6)$$

In general, the UWB communication pulse is represented as

$$p_c(t) = w^T \cdot p \quad (7)$$

The same method to references [11] is put to use. The weight vector is

$$w_{\text{UWB system 1}} = (0.2, 1, 10, 95, 20, 10)^T \quad (8)$$

The time domain waveform of iterative combination pulse signed as UWB system 1. The approximation between power spectral density of UWB system 1 and FCC emission mask is shown in Fig. 1.

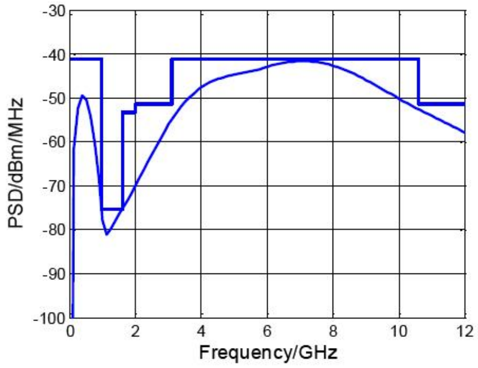

Fig. 1. The approximation between power spectral density of UWB system 1 and FCC emission mask.

B. The PSD of UWB Pulse Based on CR Identification

For a UWB system with cognitive radio function, it is assumed that the available spectrum holes which are shown in Table 2 have been identified. As with Section III A, the parameteres for every base function about $\boldsymbol{\alpha}$ and $\boldsymbol{f}_o$ can be set:

$$\alpha = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6)^T = (2.3, 3, 3, 0.5, 0.3, 0.2)^T \text{ns} \quad (9)$$

$$f_o = (f_{o1}, f_{o2}, f_{o3}, f_{o4}, f_{o5}, f_{o6})^T = (0.001, 2.05, 2.05, 4, 6, 10)^T \text{GHz} \quad (10)$$

The weight vector is

$$w_{\text{UWB system 2}} = (1, 0.02, 0.1, 30, 100, 15)^T \quad (11)$$

The time domain waveform based on cognitive radio signed as UWB system 2. The approximation between power spectral density of UWB system 2 and FCC emission mask is shown in Fig. 2.

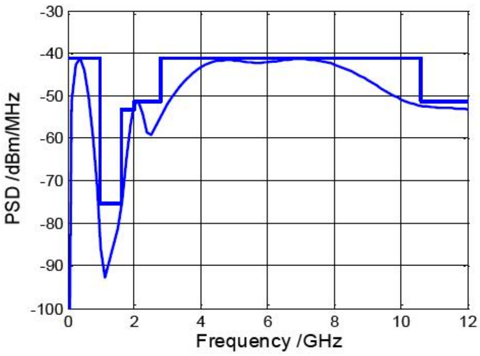

Fig. 2. The approximation between power spectral density of UWB system 2 and FCC emission mask.

It is a random process that the spectrum hole can be recognized and uesd in certain temporal and spatial. So we can again assume another recognition result which is shown in Table III. As with Section III-B, the parameteres for every base function about $\boldsymbol{\alpha}$ and $\boldsymbol{f}_o$ can be set

$$\alpha = (\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6)^T = (2, 3, 0.5, 0.3, 0.2, 0.1)^T \text{ns} \quad (12)$$

$$f_o = (f_{o1}, f_{o2}, f_{o3}, f_{o4}, f_{o5}, f_{o6})^T = (0.001, 2.21, 4, 6, 10, 11)^T \text{GHz} \quad (13)$$

The weight vector is

$$w_{\text{UWB system 3}} = (1.3, 0.5, 0.1, 25, 100, 15)^T \quad (14)$$

The time domain waveform based on cognitive radio signed as UWB system 3 the approximation between power spectral density of UWB system 3 and FCC emission mask is shown in Fig. 3.

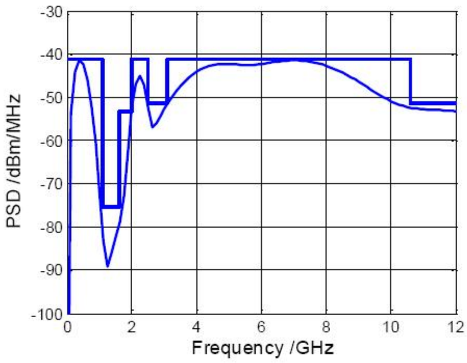

Fig. 3. The approximation between power spectral density of UWB system 3 and FCC emission mask.

IV. Simulation and Compare on UWB BER Based on CR

According to the spectrum identification results based on cognitive radio are listed in Table II and Table III, the UWB bit error probability are simulated and compared among UWB system 1, UWB system 2 and UWB system 3 in Additive White Gaussian Noise (AWGN) channel.

A. Communication Pulse PSD Based on FCC Emission Mask

A typical time-hopping format of the simple impulse radio transmitter output signal $s(t)$ is given by [12]

$$s(t) = \sqrt{E_{bs}} \sum_{j=-\infty}^{\infty} p(t - jT_f - c_j T_c - d_{[j/N_s]}\varepsilon) = \sqrt{E_{bs}} \sum_{j=-\infty}^{\infty} p(t - \varphi_j) \quad (15)$$

where t is time, $p(t)$ represents the Gaussian pulse which is normalized to satisfy $\int_{-\infty}^{\infty} p^2(t)dt = 1$;

N_s is the number of pulses used to transmit a single information bit in time-hopping UWB systems, called the length of the repetition code. In time-hopping systems, the bit duration $T_b = N_s T_s$;

$\sqrt{E_{bs}} = \sqrt{E_b / N_s}$ is normalization factors that make system has the energy in the information bit, E_b;

T_f is the time duration of a frame；

T_c is the hopping width in pulse position modulation time-hopping UWB systems satisfying $T_f = N_h T_c$;

The hopping sequences $c=(c_j)$ are pseudorandom with period, with each element an integer in the range $0 \le c_j \le N_h$, where N_h is the number of hops;

d_i represents the i_{th} binary data bit transmitted by the source；

δ is the offset of pulse position in a time clip T_c.

Single link correlation reception is given by

$$Z = \int_0^{T_b} r(t)m(t)dt \quad (16)$$

corresponding receiver masking is

$$m(t) = \sum_{j=0}^{N_s - 1} v(t - jT_f - c_j^{(k)} T_c) \quad (17)$$

where, $v(t) = p(t) - p(t - \varepsilon)$, $p(t)$ is UWB System 1, UWB System 2 or UWB System 3，respectively.

B. Single Link Performance of UWB Systems Based on Cognitive Radio in the AWGN UWB Channel

Simulation conditions:

Pulse average transmitted power $p_o = -30dBm$;

Sources of information bits $N_b = 10$;

$T_f = 60ns$;

$N_s = 1$;

$N_h = 5$;

$N_p = 10$;

Pulse width $T_p = 0.5ns$;

$\varepsilon = 0.5ns$.

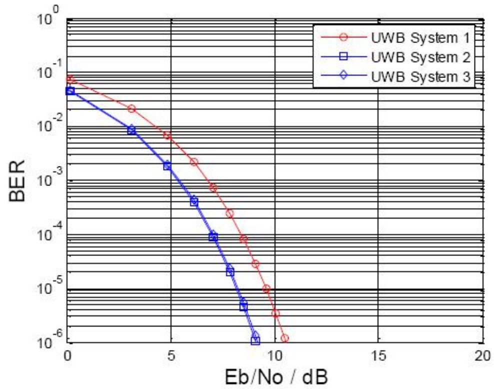

Fig. 4. Single link BER in AWGN channel.

The bit error probability simulation results are shown in Fig. 4. Fig. 4 gives an illustration which UWB system 2 and UWB system 3 have a lower bit error rate than UWB system 1, and the advantage is 11.2dB, where the SNR is 8dB.

Assuming the cognitive spectrum allocation is random process, Fig. 4 gives us a good example that the bit error probability of UWB system 2 and UWB system 3 are very approximate in spite of their being different. So we can conclude that the performance of UWB based on cognitive radio is stabilized and easy to implement.

V. Conclusion

UWB system meeting to FCC emission mask shares spectrum resource with other wireless communication system. However, cognitive radio provides another method for abundantly taking advantage of wireless spectrum resource. According to cognitive radio spectrum allocation, taking into account FCC emission mask, the bit error probability of pulse position modulation time-hopping UWB system which transmits different UWB pulse was studied. Simulation results show that the performance of UWB based on cognitive radio is better, and the system performance is stable.

References

[1] H. S. Sheng, P. Orlik, and A. M. Haimovich, "On the spectral and power requirements for ultra-wideband transmission," in *Proc. 2003 IEEE ICC Conf.*, 2003, pp. 738-742.

[2] N. K. Hoven, "On the feasibility of cognitive radio," M.S. Thesis, Dept. Electron. Eng., University of California, Berkeley, USA, 2005.

[3] Q. H. Wang, B. T. Ye, Y. Tian, W. Z. Li, S. L. Lu, and D. X. Chen, "Survey on spectrum allocation algorithms for cognitive radio networks," *Acta Electronica Sinica*, vol. 40, no. 1, pp. 147-154, Jan. 2012.

[4] J. F. Sun, J. C. Gao, Y. A. Liu, and G. Xie, "Clustering method for cognitive radio user based on the results of spectrum sensing," *Journal of Electronics & Information Technology*, vol. 34, no. 4, pp. 782-786, Apr. 2011.

[5] Z. Y. Sun, C. H. Che, and T. Zhao, "Spectrum sensing research of ultra wideband signals based on cognitive radio," *Journal of Chongqing University of Posts and Telecommunications* (*Natural Science Edition*), vol. 22, no. 4, pp. 426-430, Aug. 2010.

[6] W. F. Du, Y. T. Liu, Z. Ming, and Y. X. Sui, "Interference elimination based spectrum allocation algorithm for cognitive radio," *Journal on Communications*, vol. 33, no. 5, pp. 106-114, May 2012.

[7] A. B. Parr, B. L. Cho, and Z. Ding, "A new UWB pulse generator for FCC spectral masks," in *Proc. 2003 VTC-spring Conf.*, 2003, pp. 1664-1666.

[8] N. C. Beaulieu and B. Hu, "A novel pulse design algorithm for ultra-wideband communications," in *Proc. 2004 IEEE GLOBECOM Conf.*, 2004, pp. 3220-3224.

[9] X. R. Wu, Z. Tian, and T. N. Davidson, "Optimal waveform design for UWB radios," in *Proc. 2004 IEEE ICASSP Conf.*, 2004, pp. iv-521-iv-524.

[10] H. Bo and N. C. Beaulieu, "Pulse shapes for ultra wideband communication systems," *IEEE Trans. Wireless Commun.*, vol. 4, no. 4, pp. 1789-1797, July 2005.

[11] Z. Y. Lin and P. Wei, "A novel UWB communication pulse design method," *Journal on Communications*, vol. 10, no. 7, pp. 103-137, July 2006.

[12] W. P. Siriwongpairat, M. M. Olfat and K. J. R. Liu, "Performance analysis of time hopping and direct sequence UWB space-time systems," in *Proc.* 2004 *IEEE GLOBECOM*, *Conf.*, 2004, pp. 3526-3530.

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