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NARROW BAND INTERFERENCE MITIGATION IN DS-UWB SYSTEMS USING THE WAVELET TRANSFORM AND FFT

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ABSTRACT

Because of its importance, DS-UWB communication is an open research area, particularly in the context of its coexistence with OFDM based systems. In this paper, we present an analysis of the effect of the Narrow Band Interference of OFDM WLAN 802.11a systems, on the performance of BPSK-DS -UWB in terms of BER, along with a proposed interference mitigation technique based on both the discrete wavelet transform and the Fast Fourier Transform to improve the BER performance in the presence of the Narrow Band OFDM interfering signal. Simulation results show that the proposed method show an excellent performance especially at high signal to noise ratio.

Keywords--*DS-UWB; WLAN 802.11a;Wavelet*

1. INTRODUCTION

The Ultra Wide Band (UWB) technology is based on single band systems employing carrier free or impulse radio communications. Impulse radio (IR) refers to the generation of a train of impulse like waveforms, each of duration in the hundreds of picoseconds [1], [2] and [3]. This type of transmission does not require the use of additional carrier modulation and is a baseband signaling approach. UWB technology provides high data rate with low power spectral density due to modulation of extremely short pulses [4]. The very low transmission power and the large bandwidth enable an UWB system to co-exist with narrowband communication [5] without being a considerable source of interference. However, in an increasingly overcrowded frequency spectrum, interference due to coexistence with other spectrally overlapping wireless Narrow Band (NB) system degrades the performance of UWB systems [6]. The interference caused may jam the UWB receiver completely. According to Electromagnetic Compatibility (EMC) reports submitted to FCC [7], the narrowband interferences (NBI) expected by the UWB receivers are ,for example, computer motherboard of emission level 42.7dBm at 1.9 GHz, IEEE 802.11b at centre frequency 2.4 GHz, network interface card (NIC) of emission level 49.8dBm at 3.75 GHz, LAN switch of 44.3dBm at 3.75 GHz, peripheral component interconnect (PCI) card for a personal computer 3.75 GHz and IEEE 802.11a (WLAN system) at centre frequency 5.25 GHz [5]. Study of the impact and suppression of NBI is one of the important issues associated with UWB applications [8], [9] and [10] and [11]. Performance enhancement by employing effective NBI mitigation techniques is an area of competition. It is convenient to model the interference at the UWB receiver front-end as a single tone sinusoidal signal. Many of the existing literature use this assumption as the basis of estimating the center frequency of the NB interfering signal in some interference mitigation techniques [12], a complex and time wasting task especially in multi band interference. In this paper we introduce an interference cancellation technique based on the use of the discrete wavelet transform that is independent of the frequency of the interfering NB signal. The rest of the paper is organized as follows, in Section II; the system model is presented with an expression for the DS-UWB signal and the WLAN interfering signal. Section III provides a theoretical analysis of the NB interference problem on the DS-UWB system. In Section IV the proposed interference mitigation technique that depends on the wavelet transform is presented with a block diagram that graphically describes the proposed technique. Section V presents numerical results and comparisons illustrating the BER performance of the DS-UWB system in the presence of multiple MB-OFDM interferers. Finally, concluding remarks are given in Section IX.

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2. SYSTEM MODEL

A. DS-UWB Transmitted signal model

For DS-UWB systems, the transmitted signal is generated usually through the following two step process: first, the periodic pseudo-random binary spreading PN code is generated with length $\mathbf{N_c}$ chips and applied to the binary information sequence via a spreader. Second, the spreaded signal is applied directly to an UWB pulse train generator with the proper polarity (polar signaling is considered here since it is the baseband equivalent for BPSK modulation). In the proposed system, data is transmitted on a block by block basis. The emission signal can be expressed as:

$$s(t) = \sqrt{P_{DS}} \sum_{i=-\infty}^{\infty} b_i c(t - iT_b) \tag{1}$$

Where $\mathbf{P_{DS}}$ is the transmitted power, $\mathbf{T_b}$ is the bit duration. The spreading code can be expressed as

$$s(t) = \sum_{n=0}^{N_c-1} c_n p(t - nT_c)$$
$$= \sum_{i=1}^{L} b_i \sum_{n=0}^{N_c-1} c_n p(t - nT_c - iT_b) \tag{2}$$

With T_c is the chip duration .It does not necessarily that the chip duration is equal to the transmitted pulse width. It may be equal to or greater than the pulse duration. The sequence $b_i \in \{+1,-1\}$ is the i^{th} transmitted bit. It is assumed that b_i is an independent and identically distributed (i.i.d) random binary sequence with zero mean and unit variance. We also assume that the spreading code $c(t)$ that has unit energy and consists of N_c chips; hence the block consists of $N_c L$ chips. The chip is an UWB second order monocycle pulse, that is, the second derivative of a Gaussian function defined as

$$p_2(t) = (1 - \frac{t^2}{\sigma^2})\exp(\frac{t^2}{2\sigma^2}) \tag{3}$$

Thus the DS-UWB signal can be written as

$$s(t) = \sqrt{P_{DS}} \sum_{i=-\infty}^{\infty} b_i \sum_{n=0}^{N_c-1} c_n p_2(t-nT_c-iT_b) \tag{4}$$

B. Narrow Band Interfering Signal model

A typical IEEE 802.11a OFDM WLAN transmitted signal consists of a stream of complex valued QPSK modulated symbols appearing at the output of the mapper and is divided into groups of data symbols multiplexed with pilot symbols to form a frame size of N_{fft} symbols. Each group of N_{fft} symbols of data and pilots are then fed to an Inverse Fast Fourier Transform (IFFT) block that performs multi carrier modulation at the base band level and transmitted as one OFDM symbol of N_{fft} samples with duration *of* T_s seconds. This symbol interval consists of two parts: a useful symbol with duration T_u and a cyclic Prefix with duration T_{CP} . The cyclic prefix is a copy of the last L samples of the symbol part and attached at the header of each symbol when the symbol is sent. Based on the previous description to the WLAN signal, a general expression for the OFDM signal can be written as,

$$s_{OFDM} = \sqrt{E_{OFDM}} \sum_{k=0}^{N_{fft}-1+L} s_k \exp(j2\pi kn/N_{fft}) \tag{5}$$
$$0 \le n,k \le N_{fft} - 1$$

With E_{OFDM} is the energy of the transmitted OFDM symbol, k is the IFFT index, n is the time domain index, N_{fft} is the total number of sub carriers used to create the OFDM symbol. The above equation represents the Narrow Band Interfering signal that will be used during the performance analysis and simulation.

C. Channel model

In this paper, four different versions of the DS-UWB system is evaluated using the UWB multi path channel model based on the indoor channel measurements in the 2-8GHz frequency band accepted by the IEEE 802.15-SG3a standard [10]. The UWB indoor channel model adopts a double-exponential decay intensity profile based on the Saleh -Valenzuela model.

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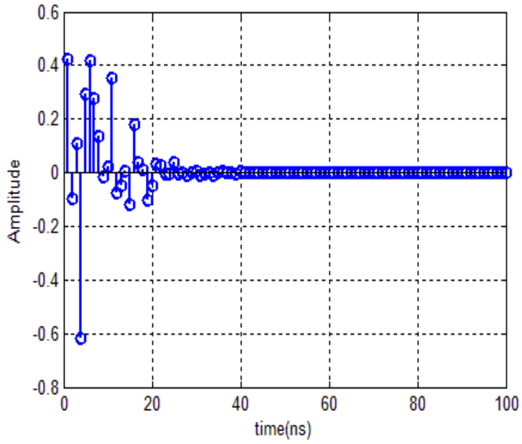

Figure (1), Typical UWB Channel Impulse Response

The channel model contains four different channel propagation scenarios named CM1-CM4. It provides enough degrees of freedom to match channel measurements, and can be used to match both LOS and NLOS channel characteristics separately. The channel impulse response of the IEEE model can be expressed as [10],

$$h(t) = X \sum_{l=1}^{LC} \sum_{k=1}^{K} \alpha_{l,k}\,\delta(t - T_l - \tau_{l,k}) \quad (6)$$

Table(I): IEEE 802.15.3a UWB Channel Characteristics

Channel Characteristics	**CM1**	**CM2**	**CM3**	**CM4**
τ_m **[ns]** (mean excess delay	**5.05**	**10.38**	**14.18**	
τ_{rms} **[ns]** (rms delay spread)	**5.28**	**8.03**	**4.28**	**25**

where X is a log-normal random variable representing the amplitude gain of the channel, LC is the number of observed clusters, K the number of multi-path contributions from rays received within the l^{th} cluster, $\alpha_{l,k}$ the coefficient of the k^{th} multi-path contribution of the l^{th} cluster, T_l the time of arrival of the l^{th} cluster, and $\tau_{l,k}$ the delay of the k^{th} multi-path contribution within the l^{th} cluster. The channel coefficient $\alpha_{l,k}$ can be defined as follows: $\alpha_{l,k} = B_{l,k}\beta_{l,k}$, where $B_{l,k}$ is a discrete binary random variable assuming values ± 1 with equal probability and $\beta_{l,k}$ the log-normal distributed channel coefficient of multi-path contribution k belonging to cluster l. Table (1) lists the parameter settings for the IEEE channel models. Simulated sample realizations of Channel impulse response for each of the channel models defined in Table (1) via its parameters is shown in Figure (1). The channel impulse response (CIR) can be expressed in a general form that is consistent with any multi path channel. Thus, the channel impulse response in Equation (6) can be expressed as,

$$h(t) = \sum_{p=1}^{NP} w_p\,\delta(t - \tau_p) \quad (7)$$

With $h(t)$ is the CIR, $NP = LC \times K$ is the total number of paths in the channel, w_p is the attenuation coefficient of the path number p and τ_p is the corresponding delay. The channel weights w_p are assumed to be complex in general, but in an UWB channel they are real as UWB systems are base band systems.

D. Received signal model

At each receiver input, the received signal is the result of the convolution of the transmitted signal with the channel impulse response corrupted by noise at the receiving antenna, and the received signal of any user can be expressed as,

$$y(t) = s(t) * h(t) + n(t) \quad (8)$$

Where (*) denotes the linear convolution operator. At the receiver, the received signal is expressed as,

$$r(t) = \sum_{p=1}^{NP} w_p \sqrt{P_{DS}} \sum_{i=-\infty}^{\infty} b_i \sum_{n=0}^{N_c-1} c_n p_2(t - nT_c - iT_b - \tau_p)$$
$$+ \sum_{p=1}^{NP} w_p \sqrt{E_{OFDM}} \sum_{k=0}^{N_{fft}-1+L} s_k \exp(j2\pi kn/N_{fft}),\ 0 \le n,\ k \le N_{fft} - 1$$
$$+ n(t) \quad (9)$$

With $n(t)$ is the additive white Gaussian noise, a realization of the Gaussian random process $\eta(t)$ which has zero mean and a variance of $\sigma_n{}^2$. At each receiver, the received signal is then chip matched filtered, sampled at the chip rate and a vector **r** is formed by collecting N_c sampler

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outputs together. After chip matched filtering and sampling at the chip rate, the sampler output is thus,

$$r_i[n] = \frac{1}{T_c}\int_{nT_c}^{(n+1)T_c} r(t)dt$$
$$= \frac{1}{T_c}\int_{nT_c}^{(n+1)T_c} \left(y(t) + NBI(t)\right)dt \quad (10)$$

The chip matched filtering is simply an "*integrate and dump*" operation performed over a time interval equal to the chip duration. An observation vector $\mathbf{r_i[n]}$ is formed on a bit by bit basis by collecting together N_c successive outputs from the sampler output. Thus each observation vector corresponds to one bit duration. The vector **r** corresponding to the i^{th} bit can be expressed as,

$$r_i = [r_{i1,......,}r_{iNc}] \quad (11)$$

3. BER Analysis In The Presence Of NB Interference

In this section the Bit Error Rate (BER) of the matched filter receiver is provided .According to [ ], the BER of a DS-UWB matched filter receiver can be expressed as

$$P_e = Q(\sqrt{SNR}) \quad (12)$$

An intuitive modification is that the SNR that appears in the argument of the Q function is instead the Signal to Interference plus Noise ratio (SINR), which can be written in terms of SNR and the Signal to Interference Ratio (SIR) separately as follows,

$$SINR = \frac{S}{I+N} = \frac{1}{1/SIR + 1/SNR} \quad (13)$$

The SIR can be written in terms of the number of WLAN interfering users as,

$$SIR = \frac{P_{DS}}{\sum_{i=1}^{m} P_i} \quad (14)$$

Where P_{DS} is the power of the DS-UWB signal , P_i is the power of the i^{th} interfering user at the receiver's input and *m* is the total number of interfering users being active and accessing the UWB channel. Assuming that all the interfering users transmit equal powers thus,

$$P_e = Q\left(\sqrt{\frac{N_c}{\frac{\frac{E_b}{N_0}\eta}{mSNR_{OFDM}} + \frac{1}{\frac{E_b}{N_0}\eta}}}\right) \quad (15)$$

With SNR_{DS} is the SNR of the DS-UWB signal and SNR_{OFDM} is the adequate signal to noise ratio of the OFDM interfering signal per user, both are defined at the receiver's input. The adequate value of SNR_{OFDM} specified by the IEEE802.11a physical layer standard is found to be [] dB. The SNR of the DS system can be expanded in terms of the ratio of the bit energy E_b to the single sided power spectral density N_o and the spectral efficiency η which may also expanded as R_b / BW_t , with R_b is the bit rate and BW_t is the transmission band width of the UWB signal (typically 3GHz).

4. PROPOSED NB INTERFERENCE MITIGATION TECHNIQUE

Figure (2) shows the architecture of the block diagram of the proposed NB mitigation technique. It consists of the conventional correlator receiver in which the received signal is multiplied by a monocycle pulse train and then integrated over an interval that is equal to the chip duration .The output of the correlator is then sampled at the chip rate.

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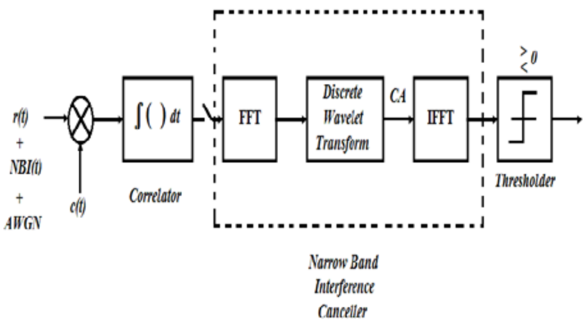

Figure (2), Block Diagram Of The DS-UWB Correlator Receiver With The Proposed NBI

Each N_c samples, corresponding to one bit, are then grouped and transformed from the time domain to the frequency domain by an FFT operation. The transformed samples are then analyzed using a discrete wavelet transform which produces two coefficient vector each consisting of $\lceil N_c / 2 \rceil$ samples .The first coefficient vector, **CA** , is then fed to the IFFT while the second coefficient vector , **CD** , is neglected .The idea behind using the wavelet transform as a NB interference mitigation technique for DS-UWB systems is that in the frequency domain, the NB signal appears as a tone for the DS-UWB signal .The wavelet transform analyzes the spectrum of both the DS-UWB signal and the NB signal into a an array of detailed coefficients, **CD**, and an array of approximate coefficients**, CA** .It can be correctly concluded that the NB signal spectrum is concentrated in the detailed coefficients array where the spectrum of the DS-UWB signal tends to concentrate in the approximate coefficients array. The approximate coefficients that represent the desired DS-WB signal is returned to the time domain by an IFFT operation and the output of IFFT is then fed as the input to the threshold device which decides the value of the estimated information bit according to the following equation,

$$\hat{s}(n) = \frac{\mathrm{sign}[r_{eq}(n)] + 1}{2} \quad (16)$$

With $\hat{s}(n)$ is the estimated version of the nth transmitted symbol in the DS-UWB system, $\mathrm{sign}(.)$ is the sign function and r_{eq} is the value of the wavelet filtered symbol in the time domain, i.e. after the Inverse Fast Fourier Transform operation.

5. SIMULATION RESULTS AND ANALYSIS

In this section, we present some numerical results for the BER performance of the DS-UWB system in the presence of NB - OFDM interferers. General simulation parameters of the systems used are shown in Table (II).The transmission data rate of the DS-UWB system is 100 Mbps, one of the optional data rates recommended by the IEEE 802.15.3a standard. The number of DS-UWB transmitted is equal to 10,000 BPSK symbols (bits) each including a spreading sequence of lengths $N_c = 15$ chips which is the same as the spreading factor. We consider the IEEE 802.11a OFDM based system with 256 subcarriers with a sub carrier spacing of 312.5, fixed-point platform that is considered for simulations. We have used the IEEE 802.15.3a channel models (CM1- CM4) for our simulation study. These channel models are based on both Line Of Sight (LOS) and None Line Of Sight NLOS channel measurements performed over a coverage area of (4–10 m).The bandwidth of the DS-UWB signal is considered to be 3GHz while the bandwidth of the OFDM interferer is 16.66MHz. The BER performance of the DS-UWB system is evaluated in both cases of the absence and existence of the NBI over the range of E_b/N_o from0dB to 20dB.As the SNR of the WLAN system is about 25dB and the two systems experience the same attenuation, the signal to interference ratio (SIR) is in the range of about 20dB.

Table (II)

System	**DS-UWB**
Modulation	BPSK
Transmission Bit Rate	100 Mbps
Spreading codes	*Maximal length* pn sequence
Code length	15chips
Spreading factor	15
Chip duration	2/3 ns
Pulse shape	2^{nd} derivative monocycle
Pulse duration	2/3ns
Channel Model	IEEE 802.5.13a CM1-CM4
Receiver type	Correlator
System	**IEEE WLAN 802.11a**
Modulation	QPSK
Transmission Bit Rate	48 Mbps
FFT size	256

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Sampling rate	16.66MHz
Sub carrier spacing	312.5kHz
Symbol duration	4μs
Center Frequency	5.2GHz

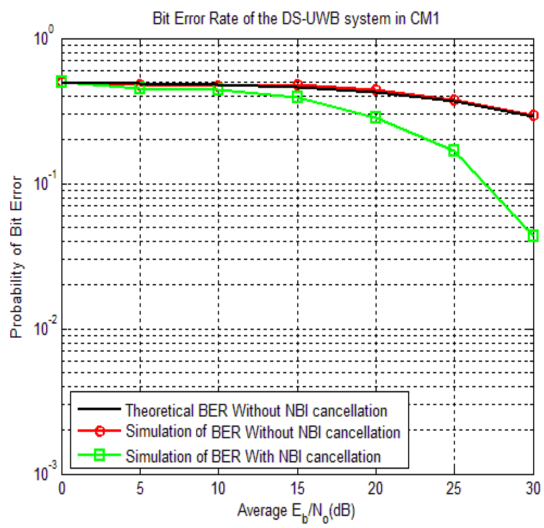

Figure (3-A), BER Performance Of The Correlator Receiver In The Presence Of NBI Under The Channel

Figure(3-a) illustrates the BER performance comparison between the conventional UWB correlation receiver with and without the wavelet based NB interference canceller considering the UWB channel model CM1.Channel models CM2, CM3 and CM4 are also illustrated in Fig (3-b),Fig (3-c) and Fig (3-d) respectively. The BER performance is severely degraded due to the addition of a single NB interferer. In all of the channel models the BER is above the 10^{-1} floor. The analytically derived expression shows an excellent agreement with simulations in the four UWB channel models. It can be seen that the suggested new technique is provides a significant improvement in the receiver's performance and the proposed correlator receiver is efficiently able to mitigate interference and improve the BER performance of DS-UWB system. For example, in channel model CM1, Figure (3-a), it can be seen that the SNR enhancement at a BER of 10^{-1} is larger by more than 5dB. This true also for the channel model CM2. This significant enhancement is attributed to the ability of the wavelet transform to decompose the spectral components into its detailed structure and eliminate these details in the spectrum of the received signal caused by the presence of the single tone NB signal. However, the other two channel models CM3 and CM4 suffers from strong Inter Symbol Interference between adjacent chips due to their relatively larger time spread and mean excess delay. This, of course, raises the total interference level and hence the BER enhancement is not as significant as in the first two channel models.

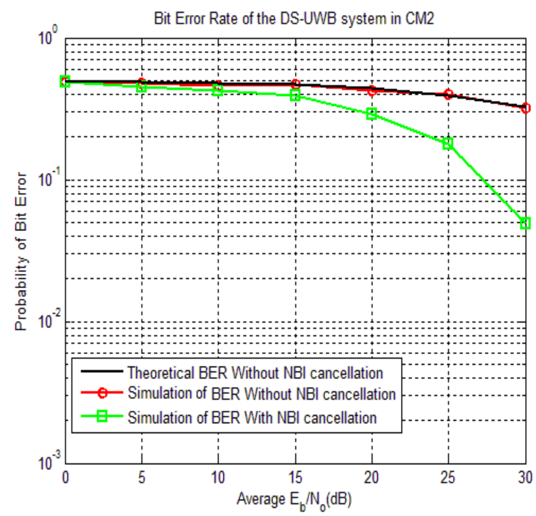

Figure (3-B), BER Performance Of The Correlator Receiver In The Presence Of NBI Under The

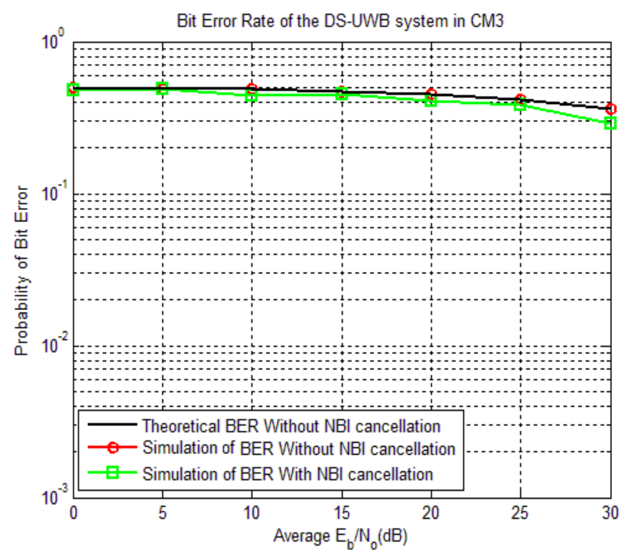

Figure (3-C), Ber Performance Of The Correlator Receiver In The Presence Of Nbi Under The Channel

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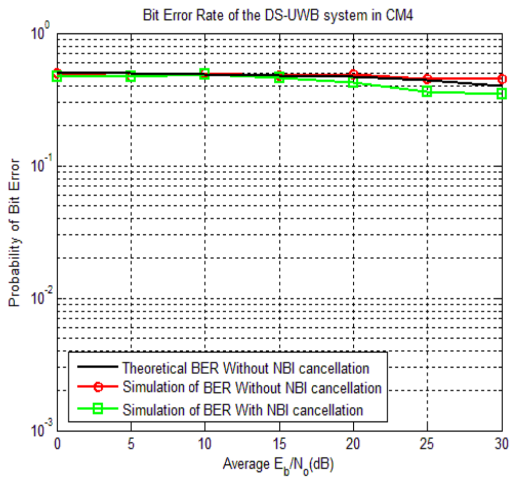

Figure (3-D), BER Performance Of The Correlator Receiver In The Presence Of NBI Under The Channel Model CM4

6. CONCLUSION

The impact of NB interference on the BER performance of DS-UWB systems has been analytically studied, considering the IEEE 802.15.3a UWB channel model with its four different propagation scenarios and the IEEE802.11a WLAN system and signal models in the performance analysis. This model is much simpler than methods based on the Gaussian approximation that fails in the case of single NB interferer and the pulse collision models that is much more complex. Also a wavelet transform based interference cancellation technique is proposed .It is shown, through simulations, that is the proposed algorithm has an excellent performance especially in channel models CM1 and CM2.

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