A NARROWBAND INTERFERENCE IDENTIFICATION APPROACH FOR UWB SYSTEMS

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ABSTRACT

Ultrawideband (UWB) has been attracting attentions by promising very high data rates along with low cost hardware and low power consumption. However, since UWB occupies a very wide frequency band, it is forced to coexist with numerous powerful licensed communication systems transmitting in the same band. The interference caused by these systems may complicate or even block the UWB communications. In the literature, there is considerable amount of work regarding narrowband interference (NBI) suppression. Most of the proposed methods, which can be classified as NBI avoidance and NBI cancellation techniques, require interference statistics. In this paper, we propose an NBI identification approach, which aims at figuring out some useful interference statistics by assuming some preliminary information about the possible sources of NBI.

INTRODUCTION

Ultrawideband (UWB) has emerged as a tempting solution for wireless applications requiring very high data rates and low cost circuitry. This rather new technology is assigned the frequency band of 3.1 GHz to 10.6 GHz by the FCC, where it is permitted to coexist with the other licensed and unlicensed communication systems without requiring a licence. This permission, however, is valid under the condition that the transmitted UWB signal has a very low power spectral density (PSD).

Due to the restraint on their transmission power level, the UWB systems unavoidably suffer from the interference caused by the coexisting systems, which are narrowband relative to UWB and transmit at much higher power levels. This narrowband interference can sometimes be so effective that the UWB communications is totally prevented. Therefore, NBI suppression is of primary importance for UWB systems.

NBI is not a recent problem. For other wideband systems such as code division multiple accessing (CDMA), this issue has been studied extensively. In these systems, NBI is partially handled with the processing gain, and by employing interference cancellation techniques including notch filtering, predictive techniques, minimum mean square error (MMSE) detectors, and transform domain techniques. However, NBI problem in UWB is more challenging due to certain reasons. First, compared to the licensed CDMA systems, the unlicensed UWB extends a much wider frequency band, but transmits less power. This forces the UWB systems to coexist with a higher number of powerful interferers. Secondly, in carrier modulated wideband systems, the received signal is down-converted to the baseband and sampled above the Nyquist rate, which allows it to be processed digitally. However, the UWB signal, being already in the baseband, can not be sampled at the Nyquist rate with the existing technology. Therefore, the numerous NBI suppression techniques proposed for other wideband systems, which can be realized by means of advanced signal processing methods, are not applicable to UWB systems.

In the literature, there are numerous influential studies focusing on NBI suppression for UWB systems. The methods proposed in these studies can be classified as avoidance and cancellation techniques. NBI avoidance methods are based on avoiding the transmission over the frequencies of strong narrowband interferers. Multi-carrier approach [1], multi-band schemes [2], [3], and pulse shaping [4] are among the various avoidance methods. The cancellation methods, on the other hand, aim at eliminating the effect of NBI on the received UWB signal. MMSE combining [5]-[7], frequency

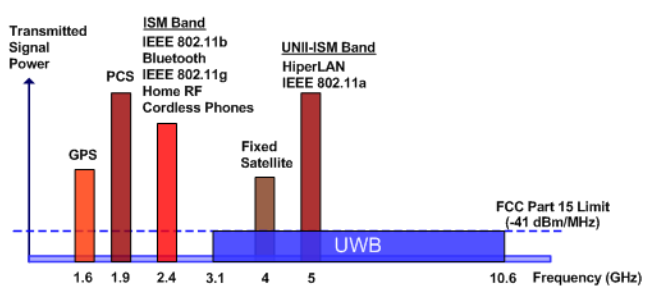

Fig. 1. Spectrum crossover of the narrowband interferers in UWB systems.

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domain techniques such as notch filtering, time-frequency methods like wavelet transform [8] and time domain approaches [9] constitute the primary cancellation methods. A significant feature common to almost all of these studies is that an approach, in which no information about the interference statistics is assumed, is exhibited. However, suppressing NBI without any interference statistics is a quite challenging task and as a result of this, many of the methods proposed in the literature are infeasible because of their high complexity. Hence, some preliminary knowledge about the interference sources is strongly needed for practical implementation of both avoidance and cancellation techniques.

When dealing with NBI in UWB systems, it should be considered that there are some potential interferers with predetermined center frequencies and bandwidths. These interferers are the narrowband systems operating in the frequency band of 3.1 GHz to 10.6 GHz, and the most effective one among them is the IEEE 802.11a (see Fig.1). In the light of this information, in this paper, we detect the existence of NBI and try to determine its statistical characteristics, which are necessary for suppressing NBI, assuming that the interferer's center frequency and bandwidth are known exactly or are confined to a possibility region. From this point of view, our approach can be named as 'NBI identification'.

INTERFERENCE MODEL

Investigation of the NBI models is a necessary initial step for identifying the interference. Narrowband interference can be modeled in many ways depending on its type. One of the commonly used models considers NBI as a single tone, leading to

$$i(t) = A\sqrt{2P_i}\,cos(2\pi f_c t + \phi_i)\ , \tag{1}$$

where A denotes the channel gain, P_i is the average power, f_c is the frequency of the sinusoid, and ϕ_i is its phase. Another frequently employed model is based on the assumption that NBI is caused by a band limited interferer. The corresponding model is a zero-mean Gaussian random process and its power spectral density (PSD) can be shown as

$$S_i(f) = \begin{cases} P_{int}, & f_c - \frac{B}{2} \le |f| \le f_c + \frac{B}{2} \\ 0, & otherwise \end{cases}\ , \tag{2}$$

where B and f_c are the bandwidth and the center frequency of the interferer, respectively and P_{int} is the power spectral density within B.

The received signal can be shown as

$$\chi(t) = v(t) + i(t) + n(t)\ , \tag{3}$$

where $v(t)$ denotes the UWB signal, $i(t)$ is NBI, and $n(t)$ is the additive white Gaussian noise (AWGN) with a PSD of N_0. In the NBI identification analysis, the correlation between the samples of the received signal plays a significant role. Depending on the fact that the UWB signal has autocorrelation properties quite similar to that of AWGN (see Fig. 2), $v(t)$ can be assumed to be a part of $n(t)$ for the sake of algorithm development. Along with this assumption, it has to be considered that $n(t)$ is not correlated to $i(t)$ and has an impulsive autocorrelation. Hence, if NBI is modeled as a single tone, the correlation between the samples of the received signal can be shown as [10]

$$R_i(\tau) = P_i\,|A|^2\,\cos(2\pi f_c \tau) + N_0\delta(\tau)\ , \tag{4}$$

where τ is the duration between the received samples. In the case of the band limited interferer, the correlation function becomes

$$R_i(\tau) = 2P_{int}\,B\,\cos(2\pi f_c \tau)\,sinc(B\tau) + N_0\delta(\tau)\ . \tag{5}$$

NBI IDENTIFICATION

Determination of interference statistics is a highly required pre-process for both NBI cancellation and avoidance techniques. In the proposed NBI identification approach, the main purpose is to obtain statistical information about the interference, which can facilitate NBI suppression. In order to extract the features of NBI, we utilize some preliminary knowledge about the potential interferers.

The most significant source of interference inside the UWB frequency band (3.1-10.6 GHz) is the IEEE 802.11a WLAN systems, whose frequency allocations are shown in Table I [11]. These systems have a fixed bandwidth of 20

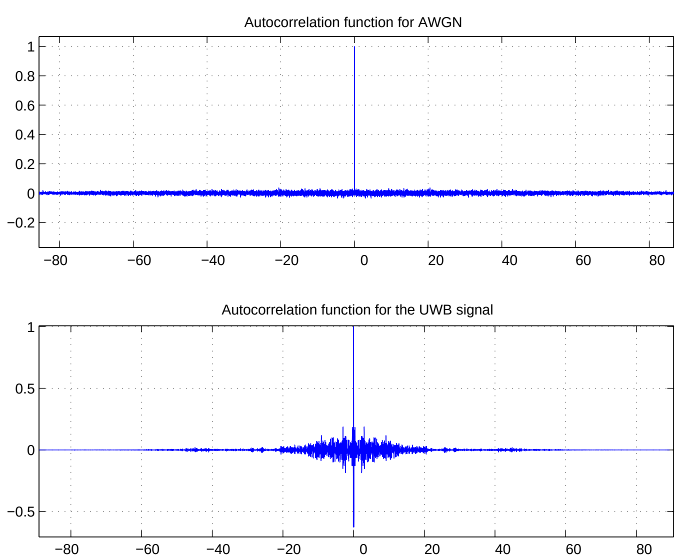

Fig. 2. Autocorrelation functions for AWGN and the UWB signal.

TABLE I

FREQUENCY ALLOCATIONS FOR 802.11A WLAN

Band (GHz)	Channel #	Center Freq. (MHz)
U-NII lower band (5.15-5.25)	36 40 44 48	5180 5200 5220 5240
U-NII middle band (5.25-5.35)	52 56 60 64	5260 5280 5300 5320
U-NII upper band (5.725-5.825)	149 153 157 161	5745 5765 5785 5805

MHz and their center frequency lies in the 5.15-5.35 GHz or 5.725-5.825 GHz band.

The three main factors characterizing the interference are its model, center frequency, and bandwidth. There are numerous possible NBI related scenarios depending on the existing preliminary information about these three factors. In each scenario, the main objective is to detect the existence of interference and if it exists, to find its statistics, most importantly the interference power.

Determined Center Frequency

The first case regarding NBI is the one in which the interferer is a single tone and f_c is already known. In order to find P_i, the correlation between the samples of the received signal is computed. When determining the correlation, attention should be paid that τ is not very close to 0, such that, according to (4), the AWGN related component has a negligible contribution to the correlation. Using the correlations computed for many different τ values, a decision about the existence of NBI is automatically made and the received interference power is easily estimated.

A different situation occurs when the interference is band limited and f_c is given. In (5), which is the correlation function corresponding to this case, there is a $sinc(B\tau)$ term. Considering that B has the fixed value of 20 MHz for 802.11a systems and does not exceed 50 MHz for any other narrowband interferer, and τ is in the nanosecond range, a reasonable assumption can be $sinc(B\tau) \simeq 1$. With the help of this assumption and using the correlation of the received data samples, the system can decide about the presence of NBI. P_{int} is determined perfectly for 802.11a systems, but with some proximity for interferers without explicitly known bandwidth.

Even if the model of the interferer is undetermined, the problem does not become more complicated as long as the center frequency of NBI is known. Repeating the assumption $sinc(B\tau) \simeq 1$, the correlation functions (4) and (5) become almost the same equation except the B factor. Hence, the interference power can still be found exactly or roughly depending on the knowledge about the bandwidth.

Undetermined Center Frequency

Another possible scenario is being aware of the NBI model, i.e. knowing whether it is a band limited or tone interferer, but having poor information about its center frequency. An 802.11a system, transmitting somewhere inside the lower and middle U-NII bands constitutes a proper example, since its bandwidth is known as 20 MHz but its center frequency can be anywhere in the 5.15-5.35 GHz band. Even without known f_c, it is still possible to detect the existence of NBI in the UWB channel by measuring the correlation between the samples. P_{int}, however, can only be estimated under the conditions that the center frequency is confined to a certain region ($f_c - \frac{\Delta f}{2} \leq f_c \leq f_c + \frac{\Delta f}{2}$), and the duration between the received samples (τ) is made as small as possible. These two requirements are to ensure that the value of the $f_c\tau$ product in the correlation functions (4) and (5) does not vary too much, so that the interference power can be estimated reliably.

Effect of Sampling Interval

For the case of unknown f_c, the accuracy of estimating P_{int} heavily depends on the sampling interval. Again, considering the 802.11a system described above, where the center frequency has an uncertainty of 200 MHz, for a reliable interference power estimation (in which the

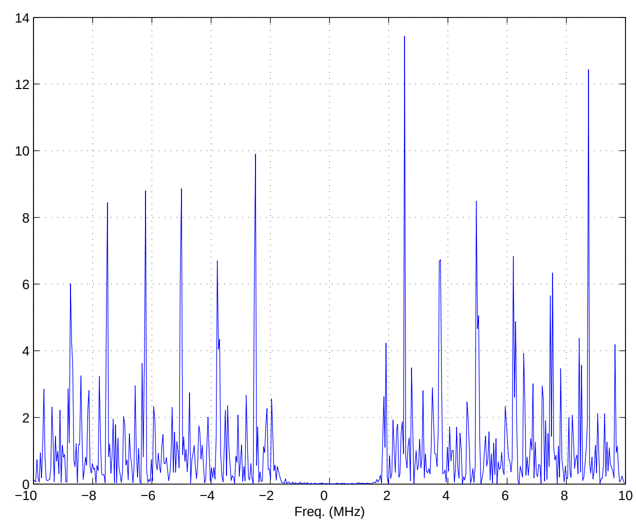

Fig. 3. IEEE 802.11a OFDM Signal in the baseband.

maximum error does not exceed 2%), τ has to be less than or equal to 0.1 ns. However, there are two basic drawbacks regarding such a small τ value. First, if the samples taken are so close to each other, noise is not uncorrelated anymore and the noise contribution in (5) can not be ignored. Second, in order to have such a τ, the sampling rate should be even higher than chip-spaced, which is not feasible with the current technology. This problem can be overcome by exploiting the periodicity of the cosine term in (5). Considering

$$\cos\left(2\pi(f_c \pm \frac{\Delta f}{2})\tau\right) = \cos\left(2\pi(f_c \pm \frac{\Delta f}{2})(\tau + \frac{k}{f_c \pm \frac{\Delta f}{2}})\right), \quad (6)$$

where k is any integer, it is seen that this periodicity feature allows τ to be increased by any multiple of $1/\left(f_c \pm \frac{\Delta f}{2}\right)$. Hence, by selecting an adequately high value for k, a realizable sampling rate can be achieved and a reliable estimation for P_{int} can be made.

The NBI identification approach is not limited to detecting the existence of interference or finding the NBI power. It can also be employed to find the entire correlation function $R(\tau)$ by computing the correlation values for all τ. $R(\tau)$ is required by many of the NBI avoidance and cancellation methods [5], [7], [10], [12]. Although obtaining $R(\tau)$ can be a rather long process in the real implementation, it is worth its hardship, because having the complete knowledge about the correlation function simplifies NBI suppression substantially.

SIMULATIONS

The efficiency of the proposed ideas is tested by simulating NBI and the interfered UWB signal. In the simulations, the channel models in [13] are used and IEEE 802.11a OFDM signals (shown in Fig. 3) are employed as the source of interference.

The uncertainty in the center frequency of the interfering 802.11a system can be as high as 600 MHz, if it is not known, in which U-NII band this system is located. Therefore, an investigation of the effect of Δf on the interference power estimation error is considered necessary. Numerous samples, which are separated by $0.1ns + \frac{k}{f_c \pm \Delta f/2}$ (a small value such as 0.1 ns is intentionally chosen for a reliable estimation), are taken from the received signal. By correlating these samples and taking the NBI bandwidth as 20 MHz, the interference power is computed for different Δf values. According to the resulting error curve shown in Fig. 4, even in the worst case, the error percentage hardly exceeds 15%. It is also seen that the error is limited to 2%, as long as it is determined, in which U-NII band the 802.11a interferer is found.

For the 802.11a system, the complete correlation function ($R(\tau)$), which can be very beneficial in suppressing NBI, is also obtained. It is determined by computing the correlation values for τ values between 0 to 500 ns, increasing τ with a very small increment. The resulting function, which is demonstrated in Fig. 5, has a shape that matches with (5) to a large extent.

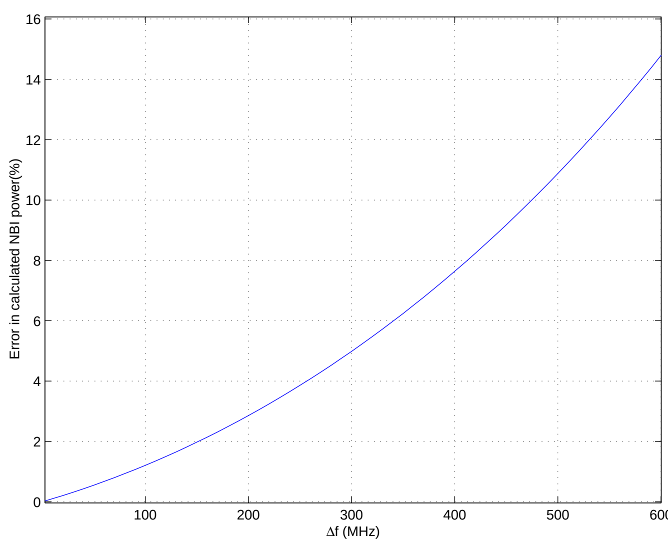

Fig. 4. The error percentage in the calculated NBI power depending on the uncertainty in the center frequency.

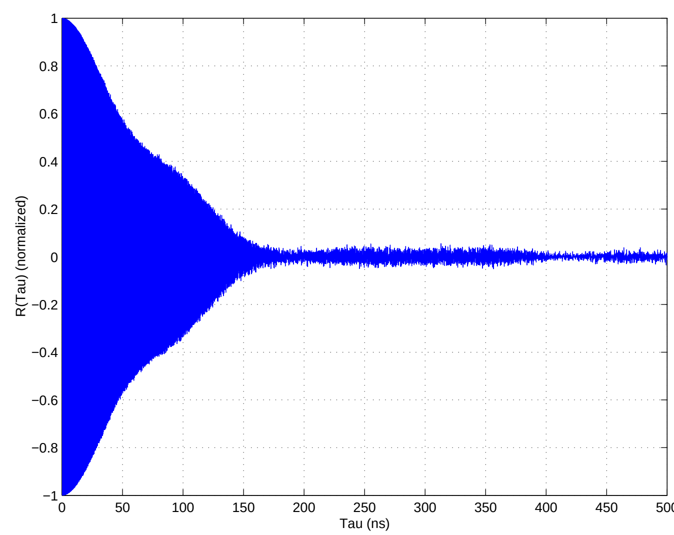

Fig. 5. The correlation function for an 802.11a system obtained from the received samples.

CONCLUSION

In order to combat the narrowband interference effects in UWB systems, both NBI avoidance and NBI cancellation methods necessitate statistical information about NBI. In this paper, an NBI identification approach, in which some basic information about the interference is assumed, is presented. In this approach, first, the existence of NBI is detected. Then, the statistics of NBI, particularly the interference power, which is generally the most vital input for a UWB system, are determined. Lastly, the entire correlation function, which is necessary for numerous NBI suppression methods, is also computed.

In the paper, different models for NBI are introduced and the corresponding correlation functions are presented. It is investigated how to compute the interference power under different scenarios regarding the existing preliminary knowledge. The focus is mainly on the IEEE 802.11a WLAN systems as the source of interference in order to reflect the real-world scenario best. For the case of NBI with unknown center frequency, these systems are considered and the proposed method is applied to estimate the interference characteristics. The effect of amount of uncertainty in the center frequency is quantified and shown. The entire correlation function is also found and demonstrated.

The identification approach presented in this paper is considered a useful means facilitating NBI suppression in real UWB communication systems because it can be easily combined with both avoidance and cancellation techniques.

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