Narrowband Interference Suppression in Multi-Band UWB Communication Systems

Prasad Yaddanapudi and Dimitrie C. Popescu
Department of Electrical Engineering
University of Texas at San Antonio
6900 N Loop 1604 W, San Antonio, TX 78249-0669
Contact e-mail: dimitrie.popescu@utsa.edu

Abstract—In this paper we present a new method for mitigating narrowband interference in multiband OFDM (MB-OFDM) ultra wideband (UWB) systems. The method employs spectral shaping of the transmitted signal using binary signature sequences with minimum total squared correlation (TSC) to avoid the narrowband interfering signal. We illustrate the proposed method with plots that show the spectrum of the transmitted signal with and without spectral shaping, and present also simulation results that show improvement in the bit error rate (BER) performance of the system when the method is applied.

I. INTRODUCTION

Research in the area of UWB communication systems has increased since 2002 when the Federal Communications Commission (FCC) has released 7.5 GHz of spectrum in the 3.1 GHz to 10.6 GHz range for use by UWB devices [3] in unlicensed wireless networking applications that require high data rates over short distances. We note that UWB systems are robust in the presence of multipath fading which characterizes wireless channels, but requires a large bandwidth for transmission which is not available for exclusive use by UWB systems. As a consequence, UWB systems must be capable of operating in the presence of various interfering signals coming from other communication systems which are usually regarded as narrowband interfering signals for the UWB signal.

Two main approaches have been proposed in the literature for the design of UWB systems. The original approach is based on extremely short, carrierless pulses, which are transmitted at pseudo-random time intervals by means of a time-hopping sequence and is known as impulse radio [13], [14]. Alternative approaches are based on Orthogonal Frequency Division Multiplexing (OFDM) with single band systems like the one in [6], or multiband systems like those in [1], [10], [11].

The UWB system in [6] is a single band OFDM-based system designed to suppress narrowband interference by transmitting information symbols over multiple carriers and was named interference suppressing OFDM (IS-OFDM). The systems in [1], [10], [11] are multiband systems that use a combination of OFDM and time-frequency interleaving to reduce the effects of narrowband interference and to provide multiple-access capabilities.

In this paper we present a new method for mitigating the effects of narrowband interference in MB-OFDM UWB systems which improves performance. The method extends the use of the narrowband interference avoidance (NBIA) procedure used previously for IS-OFDM system [15] to MB-OFDM systems. Extension is based on replacing the regular OFDM blocks present in the multiband systems with IS-OFDM blocks in order to enable application of NBIA to shape the spectrum of the transmitted UWB signal [4] using binary signature sequences with minimum TSC [7]–[9] to avoid the narrowband interfering signal.

We illustrate the application of the NBIA procedure for MB-OFDM UWB systems with an example that displays the spectrum of the transmitted signal before and after the procedure is applied. This shows a gap in the spectrum of the transmitted signal when NBIA is applied that occurs in the frequency band of the narrowband interfering signal, and which implies that the transmitter avoids sending information in this band. We also present numerical results obtained from simulation which compare the BER performance of the MB-OFDM UWB system in the presence of narrowband interference with and without the NBIA procedure.

II. SYSTEM MODEL

We consider a MB-OFDM UWB system similar to the one used in [1], [10], [11], but in which we replace the conventional OFDM modulation and demodulation blocks with IS-OFDM blocks [6] as shown in Figure 1 and Figure 2. At the transmitter QPSK modulation is used to map data bits into complex symbols, which are then serial-to-parallel (S/P) converted. The resulting parallel symbols are fed to the IS-OFDM transmitter block, cyclic prefix added, and parallel-to-serial (P/S) converted. Similar to [1], [10], [11] the time-domain signal obtained is then modulated to one of the 3 possible center frequencies (3432 MHz, 3960 MHz, or 4488 MHz) that changes for each OFDM symbol according to a time-frequency code (TFC). At the receiver the process is reversed to decode the transmitted data bits.

We note that unlike usual OFDM, in the IS-OFDM block the frame of bits that makes up the OFDM symbol is divided in sub-blocks, and symbols in a sub-block are transmitted over multiple sub-carriers to provide better performance in the presence of narrowband interference [6]. In order to be separated at the receiver, the symbols of a sub-block are multiplied by orthogonal Hadamard sequences.
We also note that, we have observed experimentally that the use of IS-OFDM instead of conventional OFDM does not provide notable improvement in the BER performance of the MB-OFDM UWB system. Thus, in order to provide better performance we complement the system with the use of the NBIA procedure that provides good performance improvement for single band IS-OFDM UWB systems \[15\].

### III. NBIA FOR MB-OFDM UWB SYSTEMS EMPLOYING IS-OFDM

NBIA is based on spectral shaping \[4\] for mitigating the effects of narrowband interference in UWB communication systems, and the basic idea behind it is to multiply the transmitted signal in frequency domain by a sequence with zeros in the frequency band corresponding to the narrowband interfering signal. This operation shapes the spectrum of the transmitted UWB signal to avoid the narrowband interference. When IS-OFDM is employed to generate the UWB signal, spectral shaping can be accomplished by replacing the Hadamard sequences by alternate sequences that have zeros in those places corresponding to the carriers where the narrowband interference signal is present, and where the spectral gap in the transmitted signal is required. As shown in \[15\] a good choice for replacing Hadamard sequences are the binary signature sequences with minimum TSC \[7\]–\[9\].

Application of NBIA requires knowledge of the narrowband interfering signal and/or of its position in the frequency domain. This is needed to identify the band \(i\) of the three possible bands, the IS-OFDM frequency bin number \(\ell\) within band \(i\), as well as the actual \(k_f\) carriers that must be avoided. Using these parameters we construct a matrix of binary sequences with minimum TSC using the algorithms outlined in \[7\]–\[9\] to replace the Hadamard matrix in frequency bin \(\ell\) of band \(i\). The rest of the frequency bins in band \(i\) as well as in the other two bands will continue to use the orthogonal Hadamard matrix.

### IV. SIMULATIONS AND NUMERICAL RESULTS

For our simulations we consider a single-user MB-OFDM system which transmits IS-OFDM signals with bandwidth of 528 MHz using TFC that modulate them to the three possible center frequencies of 3432 MHz, 3960 MHz, and 4488 MHz. Thus, the total bandwidth of the MB-OFDM system is 1.5840 GHz, and is divided into three 528 MHz bands. However, we perform simulations in baseband, and in order to model the multiband system with narrowband interference in the first band we assume that out of the generated OFDM symbols only one in three is affected by the narrowband interfering signals. This corresponds to a time-frequency interleaving pattern in which each OFDM symbol is transmitted in a different band.

The IS-OFDM signal is obtained by dividing the 528 MHz bandwidth into \(N = 2048\) parallel channels grouped into \(L = 8\) groups, with each group having \(M = 256\) carriers. This implies that each frequency bin is 257.81 kHz wide, and that the bandwidth of a basic IS-OFDM frequency bin is approximately 66 MHz.

We considered a narrowband interfering signal with bandwidth of 5 MHz, situated between \(f_1 = 290.4\) MHz and \(f_2 = 295.416\) MHz. This was generated similar to \[6\], \[15\] by using a linear bandpass FIR filter with passband equal to 5 MHz, and stopband attenuation of \(-40\) dB, driven by white Gaussian noise with unit variance at the input. Thus, the signal occurs in the \(\ell = 5\) bin, overlaying \(k_f = 21\) carriers between \(n_s = 102\) and \(n_e = 123\). Following the NBIA procedure \[15\] we then construct a matrix \(S\) which has \(M - k_f = 235\) binary
columns that are near orthogonal and $k_f = 21$ zero columns corresponding to the carriers where the narrowband interfering signal is present. This is used to replace the Hadamard matrix of the 5th IS-OFDM group of the OFDM symbols transmitted over the first band, while the OFDM symbols transmitted in other groups of the first band as well as in the other two bands will continue using Hadamard matrices.

To illustrate the NBIA procedure we plotted the power spectral density of the transmitted signal before and after application of the NBIA procedure. Figure 3 shows the power spectral density of the transmitted signal when no NBIA procedure is employed along with the spectrum of the narrowband interference signal. Figure 4 shows the power spectral density of the transmitted signal when NBIA procedure is employed, where we notice the gap that occurs in the frequency band corresponding to the narrowband interfering signal.

We have also performed simulations to compare the raw BER performance at the physical layer (no coding was assumed) of the MB-OFDM UWB system with NBIA to that of a conventional MB-OFDM UWB system similar to those in [1], [10], [11]. Simulations were performed in AWGN, as well as multipath channel based on the modified Saleh-Valenzuela model [2], [5], [12], for different jammer-to-signal ratio (JSR) equal to 10 dB, 15 dB and 20 dB.

Figure 5 shows the BER performance in the case of AWGN and narrowband interference. We note that the BER of the conventional MB-OFDM system flattens significantly for all values of JSR. Even though the BER of the MB-OFDM system with NBIA have similar flattening, the BER at which the flattening occurs is significantly lowered. For example for JSR of 10 dB there is almost two order magnitude of improvement in the BER. Similar simulations were performed in the case of multipath channels, and the corresponding BER performance is shown in Figure 6. Again, we note that the use of NBIA in MB-OFDM UWB system lowers the BER at which the flattening occurs.

V. CONCLUSION

We have proposed a new method for mitigating narrowband interference in MB-OFDM UWB systems. The method is a direct extension NBIA method used previously for IS-OFDM system [15], and uses binary signature sequences with minimum TSC [7]–[9] to notch out those carriers located in the same frequency spectrum as the narrowband interfering signal. We have included plots showing the spectral gap in the transmitted signal where the narrowband interfering signal is located. We present also numerical results from simulations that show significant improvement in the BER performance of MB-OFDM UWB system in the presence of narrowband interference when NBIA is employed.

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REFERENCES

Fig. 3. Power Spectral Density of the transmitted signal without spectral shaping and the narrowband interfering signal.

Fig. 4. Power Spectral Density of the transmitted signal with spectral shaping.

Fig. 5. BER performance for MB-OFDM UWB system with and without NBIA in AWGN.

Fig. 6. BER performance for MB-OFDM UWB system with and without NBIA in multipath.