Abstract—In this paper we propose the use of a minimum mean square error (MMSE) detector for multiuser OFDM-based ultra wideband (UWB) systems. Performance of the proposed multiuser detector is illustrated with numerical results obtained from simulations showing the bit error rate performance (BER) at the physical layer under various UWB channel scenarios that include additive white Gaussian noise (AWGN), multipath, and narrowband interference.

I. INTRODUCTION

Ultra wideband (UWB) communication systems have recently generated great interest in both academia and industry. In February 2002 FCC approved the use of 7.5 GHz (3.1 GHz to 10.6 GHz) unlicensed band for the use of UWB radio devices. According to FCC, UWB signals must have an absolute bandwidth of at least 500 MHz or a bandwidth efficiency of 20 % or greater. UWB communication systems have many benefits, such as high data rate, good multipath mitigation, low transmission power and low cost for building transceivers. UWB technology can provide wireless personal area network (WPAN) connectivity at speeds several hundred times faster than those provided by currently available systems such as Bluetooth.

Ultra wideband (UWB) systems based on Orthogonal Frequency Division Multiplexing (OFDM) have been proposed in [1], [2], [4], [6], [8] and are categorized as Multicarrier UWB (MC-UWB), since they use multiple simultaneous carriers for transmission. The systems in [1], [2], [6], [8] are multiband systems in which OFDM symbols are time-frequency interleaved over several frequency bands, while the system proposed in [4] is a single-band system. We note that OFDM is currently used in digital audio broadcasting (DAB) and terrestrial digital video broadcasting (DVB-T), as well as broadband wireless systems being present in standards like the IEEE 802.11, and is considered for the new IEEE 802.15 standard for generating UWB signals. In OFDM the available wide bandwidth is divided into several narrow sub-channels that can be viewed as flat fading channels. Thus OFDM provides good performance in frequency selective fading channels. Also the use of cyclic prefix in each OFDM symbol allows simple channel equalization [4]. Other advantages of OFDM include the use of IFFT/FFT in the transmitter and receiver which results in simple and low-cost transceiver structures, excellent spectral efficiency and inherent resilience to narrowband interference.

In [9] the single user interference suppressing OFDM (IS-OFDM) UWB system proposed in [4] is extended for use with multiple users using a technique similar to MC-CDMA [5] and the performance of the system employing single user matched filter (MF) is tested under various wireless channel scenarios. In conventional single user matched filter detector the signal of a specific user is decoded by correlating the user signature sequence or code word with the received signal which consists of sum of signals transmitted by all the users present in the system. In the case when the signature sequences of all the users are orthogonal or uncorrelated the single user detector will be optimal. But usually in practice the signature sequences are uncorrelated, because of which the single user detector will no longer be optimal. One way to overcome this drawback is to use a detector that does not treat the other user’s signals as noise but as useful signals. This detector is known as the multiuser detector [3], [10]. Most multiuser detectors consists of a bank of correlators whose output is treated as a vector. The multiuser receiver then performs some linear or non-linear transformation on this vector. In a linear MMSE detector a linear combination of the elements of the output vector is performed and the coefficients of the linear combination are chosen so as to minimize the mean square error [7], [10].

In our paper we investigate the use of a linear MMSE multiuser detector for the IS-OFDM UWB system to mitigate multiple access interference. We perform simulations to obtain raw bit error rate (BER) performance of the system under various wireless channel scenarios such as additive white Gaussian noise (AWGN), multipath channel and/or multiuser channel, and narrowband interference.

II. SYSTEM DESCRIPTION

In IS-OFDM the available UWB bandwidth is divided into \( \tilde{N} \) frequency bins, each corresponding to a different sub-carrier frequency, and information is transmitted in frames of \( \tilde{N} \) symbols. Unlike usual OFDM, in the IS-OFDM system the \( \tilde{N} \) symbols are divided into \( L \) sub-blocks of \( \tilde{M} \) symbols each, and the power of each of the \( \tilde{M} \) symbols in a sub-block is distributed over \( \tilde{M} \) sub-carriers to provide better performance in the presence of narrowband interference [4]. This is achieved by multiplying each block of \( \tilde{M} \) symbols by a \( \tilde{M} \times \tilde{M} \) orthogonal Hadamard matrix in order to be easily separated at the receiver. Multiple access is provided by multiplying each of the \( N \) parallel symbols by unique pseudo noise (PN) signature sequence \( c_u \) of length \( \tilde{N}_c \). Each
of the $N_c$ parallel sequences are then encoded and applied to a IFFT block of length $N$ to obtain a real sequence, which is parallel to serial converted and transmitted after digital to analog conversion. The transmitter block diagram is shown in Figure1.

At the receiver corresponding to the $u$th user, the received signal is serial to parallel converted and fed to an FFT block to obtain $N$ parallel data points, which are then fed to a decoder where they are demapped. The $N$ parallel sequences of length $N_c$ are despread using the $u$th user spreading sequence. The output of the matched filter or correlator corresponding to the sub-carrier $k$ is given by

$$\hat{b}_k^{(u)} = b_k^{(u)} + \sum_{v=1,v\neq u}^{U} b_v^{(u),c} c_v^{T} c_v + n_k$$  \hspace{1cm} (1)$$

where

$$b_k^{(u),c} = \sum_{q=0}^{\tilde{M}-1} x_q^{(u),c} w_{q,k}$$ \hspace{1cm} (2)$$

and

$$x_q^{(u),c}$$ \hspace{1cm} (3)$$

where $\tilde{M}$ is the correlation matrix. A linear MMSE receiver combines the elements of $\hat{b}_k^{(u)}$ optimally and is given [7], [10] by

$$\hat{b}_k^{(u),MMSE} = [R + \sigma^2 I]^{-1}$$  \hspace{1cm} (4)$$

The estimate of $b_k^{(u)}$ is given by the $u$th element of vector $y$ given by

$$y = \hat{b}_k^{(u),T} [R + \sigma^2 I]^{-1}$$  \hspace{1cm} (5)$$
The resulting data points are then parallel to serial converted, followed by separation of the data symbols using the Hadamard sequences as discussed in [4]. The receiver diagram is depicted schematically in Figure 2.

III. SIMULATION SETUP AND NUMERICAL RESULTS

To illustrate the BER performance we consider an IS-OFDM UWB system with a total bandwidth of 528 MHz. The available bandwidth of 528 MHz is divided into a total of $N = 512$ parallel channels, that are split into $L = 8$ IS-OFDM groups, each group using $M = 64$ carriers. Pseudo-noise (PN) sequences of length 7 are used for providing multiple access. At the receiver a linear MMSE detector described in the previous section is used to decode the users.

In the case of multipath channels we used the channel model in [2], which is based on the Saleh-Valenzuela (S-V) model. In our simulations we used the numerical values associated with the CM 1 model in [2] which characterizes short range (0-4 m) line-of-sight (LOS) environment. The narrowband interfering signal with a bandwidth of 5 MHz is generated as in [4] by using a FIR bandpass filter driven at the input by AGWN with unit variance.

We first looked at the performance of the IS-OFDM UWB system in AWGN for different number of active users when a single user matched filter and the MMSE detector are used. The results of this experiment are shown in Figure 3. We note that the BER performance of the IS-OFDM system employing MMSE does not deteriorate drastically even when more users are added to the system which is not the case when single user matched filter is used. For example an IS-OFDM system with five active users employing MMSE has a gain of approximately 5 dB over a system employing matched filter and the gain is greater when there are seven active users in the system.

This was followed by a similar experiment in which we investigated the performance of the system in AWGN and multipath channel for different number of active users. The results of this experiment are shown in Figure 4. We observe that in the multipath channel the BER curves of the IS-OFDM system employing single user matched filter as well as of the system employing MMSE detector do not have a typical “water fall” shape, rather they level off. However the system employing MMSE detector displays better performance in the presence of other users in the system. For example in a system with seven active users, for the same BER of $10^{-2}$ the system employing MMSE detector requires 5 dB less $E_b/N_0$ compared to the system employing single user matched filter. We then looked at the performance of the IS-OFDM system employing MMSE detector with one and five active users, in AWGN and narrowband interference. The results of this experiment are shown in Figure 5. The performance of the system was evaluated for two different jammer to signal power ratios (JSR) of 10 dB and 20 dB. We note that when a narrowband interferer is present there is flattening of the BER curve. However the system continuous to be less sensitive to the presence of other users in the system as can be observed form Figure 5 where the BER curve of the system with five active users for both JSRs is close to that of the single user system.

We have also looked at the performance of the system with one and five active users, in multipath channel and narrowband interference. The results of this experiment is shown in the Figure 6. We observe that in all the considered scenarios the performance of the five user system is close to that of the single user system.

IV. CONCLUSION

In this paper, we investigate performance of a linear MMSE detector for the multiuser IS-OFDM UWB system to mitigate the multiple access interference. Simulation results for AWGN and multipath channels show that the IS-OFDM UWB system with MMSE detector outperforms the system employing matched filter in terms of the BER. Numerical results also show that in the presence of AWGN and/or multipath channel and narrowband interference the system is less sensitive to the presence of other users in the system.

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REFERENCES

Fig. 3. BER vs. $E_b/N_0$ in AWGN for different number of active users

Fig. 4. BER vs. $E_b/N_0$ in multipath for different number of active users

Fig. 5. BER vs. $E_b/N_0$ in AWGN and narrowband interference with one and five active users

Fig. 6. BER vs. $E_b/N_0$ in multipath and narrowband interference with one and five active users