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Abstract

Dynamic bandwidth multicode interleaved direct sequence (MCIDS), an enhanced MCIDS based Ultra-wideband (UWB) application is proposed in this paper, featuring a cognitive transmission bandwidth adaptation without any adverse effect on the data rate. By introducing a specific lowpass filtering and down-sampling into the traditional MCIDS algorithm, this system can decrease the transmission bandwidth into part of its original bandwidth but still be able to recover all the transmitted data from the reduced bandwidth. This solution can efficiently improve the coexistence ability of UWB devices in a cognitive manner without increasing hardware complexity.

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Dynamic Bandwidth MCIDS - A Cognitive Solution for MCIDS based UWB Communications

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Abstract—**Dynamic bandwidth multicode interleaved direct sequence (MCIDS), an enhanced MCIDS based Ultra-wideband (UWB) application is proposed in this paper, featuring a cognitive transmission bandwidth adaptation without any adverse effect on the data rate. By introducing a specific lowpass filtering and down-sampling into the traditional MCIDS algorithm, this system can decrease the transmission bandwidth into part of its original bandwidth but still be able to recover all the transmitted data from the reduced bandwidth. This solution can efficiently improve the coexistence ability of UWB devices in a cognitive manner without increasing hardware complexity.**

I. INTRODUCTION

Ultra-wideband (UWB), based on the description by the Federal Communications Commission (FCC), is a wireless transmission technology that spreads transmitted information over a large bandwidth. The UWB technology employs an unlicensed spectrum between 3.1-10.6 GHz allocated by the FCC. This spectrum can be shared by multiple users to achieve an efficient use of radio bandwidth. There are many UWB applications, including high data rate, low power wireless connectivity, and lower data rate but longer-range applications, such as ranging and imaging systems. Currently UWB has two main development directions, one is the direct sequence (DS) based UWB [1]. Another is the multi-band orthogonal frequency division multiplexing (MB-OFDM) [2]. For the DS based UWB, as it occupies a large bandwidth at the same time, it is unavoidable to overlap with existing narrowband transmissions, causing interference between different systems.

As a solution to the above coexistence issue, cognitive radio (CR) is currently receiving more and more attention worldwide. Cognitive radio was first proposed in [3], with which spectrum utilization can be improved significantly. The authors in [4] reviewed CR as an environmentally aware extension of software defined radio (SDR). Any radio with the capability to hop around the spectrum for optimizing power, range and required data rates can satisfy the definition of CR. Cognitive radio adapts SDR's ability of changing communications protocols, and meanwhile adds another dimension - the capability to perceive the surrounding environment and learn from its experience. The learning ability of recognizing dead zones, interference and usage patterns sets CR apart conceptually from other spectrum management techniques.

Until now most research on cognitive DS based UWB has focused on how to generate an UWB pulse for matching the FCC spectral mask [5], [6]. Traditional MCIDS spreading [7] has already given a solution to resolve intersymbol interference (ISI). However, there has been no method proposed any method to avoid interference with other devices. This paper extends the traditional MCIDS algorithm and proposes a solution called Dynamic Bandwidth MCIDS that enables MCIDS spreading algorithm to receive and recover the whole user data from part of the received signal bandwidth. Since this solution is implemented in software without increasing hardware complexity of the system, it provides an opportunity for cognitive UWB transmission in a simple and efficient way.

This paper is organized as follows. In Section II, an enhanced MCIDS based UWB system model is introduced. In Section III, discussions on the proposed system model and simulation results are included. Conclusions are drawn in Section IV.

II. ALGORITHM OF DYNAMIC BANDWIDTH MCIDS

Original MCIDS spreads a signal for a block of N data bits $a_0, a_1, \ldots, a_{N-1}$ with bit duration T_b, where, $a_i = \pm 1$ can be described mathematically as [7].

$$\sum_{i=0}^{N-1} \sum_{j=-P_0}^{P-1} b_{i,j} g(t - iT_c - jNT_c) =$$
$$\sum_{i=0}^{N-1} a_i \sum_{j=-P_0}^{P-1} c_i[(j)_P] g(t - iT_c - jNT_c)$$

(1)

where $c_i[(j)_P]$ is the orthogonal spreading sequence with period P, $c_i(j) = 0, 1, \ldots P - 1$ is one period of this periodic sequence with duration T_c and $(j)_P$ denotes j modulo P, $g(t)$ is defined as a unit amplitude pulse which is zero outside the interval $[0, T_c]$. An example of MCIDS spreading is presented in Fig.1 [8], where (a) shows the spread signal obtained by spreading symbol +1 with its corresponding spreading code $\{+1, +1, \ldots, +1\}$, (b) shows the spread signal obtained by spreading signal with its corresponding spreading code $\{-1, +1, \ldots, -1\}$ and (c) is obtained in the

same way. Altogether a block interleaver then can output data as $\{a_0, b_0, c_0, \ldots, a_1, b_1, c_1, \ldots, a_{N-1}, b_{N-1}, c_{N-1} \ldots\}$ shown in (d). A length P_0 cyclic prefix (CP) is also added in this example, which is the same as the last segment of the block interleaved signal.
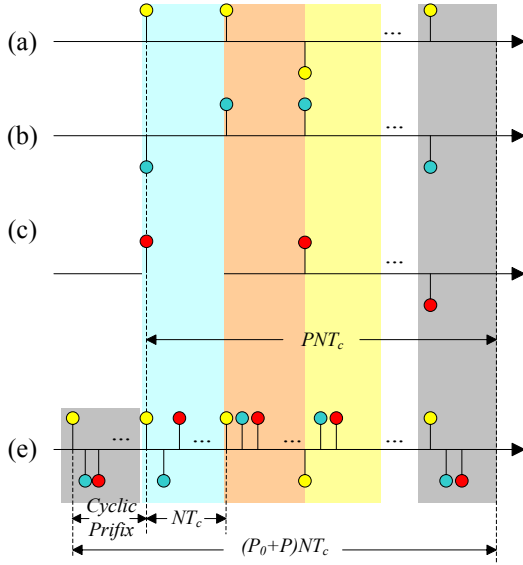

Fig. 1. Example of MCIDS spreading.

Now let us introduce an enhancement over the original MCIDS spreading. This enhanced system enables signal recovery from part of the original bandwidth of the MCIDS system by using a wider signal impulse. The width of the impulse is controlled by a lowpass filter with bandwidth $|f| = 2^{-m} (1/T_c)$, where $m = 0, 1, \ldots \ldots log_2 N$. For each impulse, decreasing its bandwidth to 2^{-m} also means increasing its width to $2m$. This leads to overlapping of successive impulses. Taking $m = 0, 1, 2$ for example, after spectral shaping and matched filtering, each impulse is reshaped in the time domain as illustrated in Fig. 2. Note that the limited bandwidth must be exactly 2^{-m} times of the original bandwidth to facilitate further processing.

In Fig. 2, when $m = 0$, at sampling points, no ISI is produced since the impulse is zero at integer multiples of T_c. The MCIDS signals are fully passed in the frequency domain. This condition can be considered as that of the unfiltered MCIDS signal, and signal processing can be performed in the traditional way [8]. When $m = 1$, however, signal bandwidth is reduced to half of the original bandwidth. Each input impulse has nonzero amplitudes at integer multiples of T_c. When $m = 2$, signal bandwidth is reduced to quarter of the original bandwidth. In other words, when impulse is filtered, each output impulse sample is a contribution of several impulses. The signal in Fig.1 becomes the spectral shaped signal shown in Fig. 3.

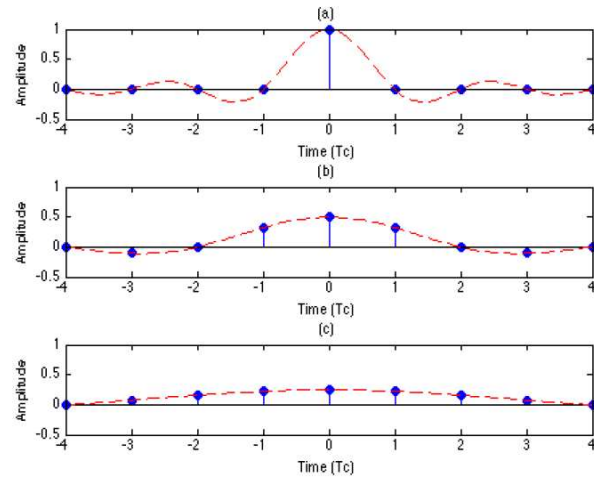Fig.4 shows the equivalent lowpass filtering model for this

Fig. 2. Example fo filtered impulses, (a) m = 0, with full bandwidth, (b) m =1, impulse with half bandwidth (c) m =2, impulse with quarter bandwidth

enhanced system.

In order to focus on investigating the possibility of recovering the signal though partial bandwidth, channel $h(t)$ is assumed to be a single path slow fading channel and the received signal can be expressed as

$$r(t) = x(t) * h(t) + z(t) \qquad (2)$$

where $z(t)$ is the additive white Gaussian noise (AWGN) with double sided power spectral density N_0. The received signal is first sampled with sampling period T_c, then passed though the matched filter. The filtered signal sequence can be described as:

$$r(n) = \sum_{i=0}^{N-1} \sum_{j=-P_0}^{P-1} \alpha_{i,j} \times$$
$$\sum_{k=i-2^m+1}^{i+2^m-1} a_k c_k [(j)_P] g [(n - i_c - jN) T_c] + z_n \qquad (3)$$

where z_N is the white discrete-time Gaussian noise. $\alpha_{i,j}$ are tap coefficients that relate to the filter and channel response. Since slow channel fading is assumed, $\alpha_{i,j}$ can be treated as constants. Note that $a_{-1}, c_{-1} = a_{N-1} c_{N-1}$ due to the cyclic prefix in front of each signal block.

Despread operation in this system is the same as in the original MCIDS system [7]. Received samples are filled column-wise into a matrix. First P_0 columns of the matrix are deleted in order to remove the CP. To despread, samples are originally read out row-wise. However, in this system, samples are kept in the matrix for further processing. The remainder of the $N \times P$ matrix is illustrated is Fig.5, taking

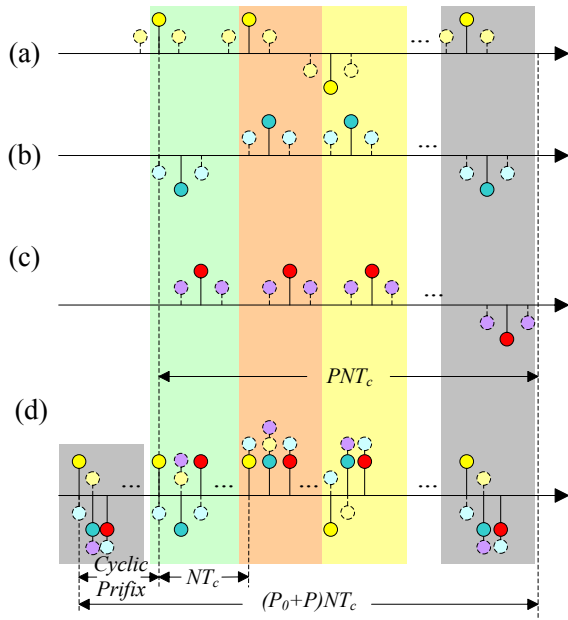$$E_{i,j} = \sum_{k=i-2^m(i-1)}^{i+2m-1} a_k c_k [(j)_P]$$
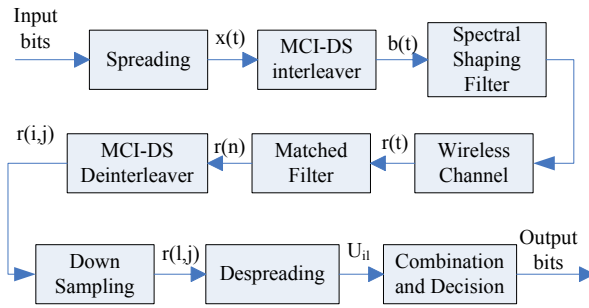
Fig. 3. Spectral shaped signal sequence

Fig. 4. block diagram of equivalent lowpass system model

Based on Equation (3), each received sample contains information of nearby 2^m original samples. Therefore only $N/2^m$ samples are required to recover all transmitted data. Then, by down-sampling the above matrix in a row-wise manner by 2^m, each sampled unit in the matrix can be expressed as:

$$r(l+1, j+1) = \alpha_{2^m,j} \sum_{k=2^m(l-1)-1}^{2^m(l+1)} a_k c_k [(j)_P] + Z_{2^m l,j} \quad (4)$$

where $l = 0, 1, \ldots, 2^{-m}N - 1; j = 0, 1, \ldots, P-1$. Down-sampled matrix $r_i j$ with size $N/2^m \times P$ is shown in Fig. 6. The dispreading code is defined as

$$d_i [n] = \sum_{j=0}^{P-1} c_i [j] \quad (5)$$

$$\begin{bmatrix} \alpha_{00}E_{00} + z_{00} & \alpha_{01}E_{01} + z_{01} & \ldots & \alpha_{0,P-1}E_{0,P-1} + z_{0,P-1} \\ \alpha_{10}E_{10} + z_{10} & \alpha_{11}E_{11} + z_{11} & \ldots & \alpha_{1,P-1}E_{1,P-1} + z_{1,P-1} \\ \alpha_{20}E_{20} + z_{20} & \alpha_{21}E_{21} + z_{21} & \ldots & \alpha_{2,P-1}E_{2,P-1} + z_{2,P-1} \\ \ldots & \ldots & \ldots & \ldots \\ \alpha_{N-1,0}E_{N-1,0} + z_{N-10} & \alpha_{N-1,1}E_{N-1,1} + z_{N-1,1} & \ldots & \alpha_{N-1,P-1}E_{N-1,P-1} + z_{N-1,P-1} \end{bmatrix}$$

Fig. 5. Despread samples stored in matrix

$$\begin{bmatrix} \alpha_{00}E_{00} + z_{00} & \alpha_{01}E_{01} + z_{01} & \ldots & \alpha_{0,P-1}E_{0,P-1} + z_{0,P-1} \\ \alpha_{2^m,0}E_{2^m,0} + z_{2^m,0} & \alpha_{2^m,1}E_{2^m,1} + z_{2^m,1} & \ldots & \alpha_{2^m,P-1}E_{2^m,P-1} + z_{2^m,P-1} \\ \alpha_{2^{m+1},0}E_{2^{m+1},0} + z_{2^{m+1},0} & \alpha_{2^{m+1},1}E_{21} + z_{2^{m+1},1} & \ldots & \alpha_{2^{m+1},P-1}E_{2^{m+1},P-1} + z_{2^{m+1},P-1} \\ \ldots & \ldots & \ldots & \ldots \\ \alpha_{N-1-2^m,0}E_{N-1-2^m,0} + z_{N-1-2^m,0} & \alpha_{N-1-2^m,1}E_{N-1,1} + z_{N-1-2^m,1} & \ldots & \alpha_{N-1-2^m,P-1}E_{N-1-2^m,P-1} + z_{N-1-2^m,P-1} \end{bmatrix}$$

Fig. 6. Down-sampled matrix

For detection of each bit a_i. Each row of the matrix is circularly correlated with $d_i [n]$. Dispread signal U_{il} are overlapped components with contributions from nearby l samples. Mathematically, we have

$$U_{il} = \sum_{j=0}^{P-1} r(l+1, j+1) c_i [(j)_P] \quad (6)$$

Suppose that U_i are the decision variables. To collect energy from all lsamples, we have

$$U_i = Re \left[\sum_{l=1}^{2^{-m}} U_i l \cdot \alpha_{2^m,j}^* \right]$$

$$= Re \sum_{l=1}^{2^{-m}N} \sum_{j=0}^{P-1} \alpha_{2^m l,j}^* \alpha_{2^m l,j} \sum_{k=2^m(l-1)}^{2^m(l+1)-1} a_k c_k [(j)_P] c_i [(j)_P]$$

$$+ Re \sum_{l=1}^{2^{-m}N} \alpha_{2^m i,j}^* \sum_{j=0}^{P-1} z_{2^m i,j} \quad (7)$$

Because $c_i [(j)_P]$ are orthogonal sequences, they satisfy

$$\sum_{k=2^m(l-1)}^{2^m(l+1)-1} a_k c_k [(j)_P] c_i [(j)_P] = \begin{cases} P & \text{i=k=1} \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

The decision variable U_i become

$$U_i = P \sum_{l=1}^{2^{-m}N} \sum_{j=0}^{P-1} |\alpha_{2^m l,j}|^2 a_i + Re \sum_{l=1}^{2^{-m}N} \alpha_{2^m i,j}^* \sum_{j=0}^{P-1} z_2^{mi,j} \quad (9)$$

Therefore, all the symbols are fully recovered from 1/2m of the original bandwidth. The calculation process of U_i using [6], [7] is shown in Fig. 7.

III. DISCUSSION AND RESULTS ANALYSIS

In dynamic bandwidth MCIDS based UWB system, the constant m determines both filtered bandwidth $|f| = 2^{-m} (1/T_c)$
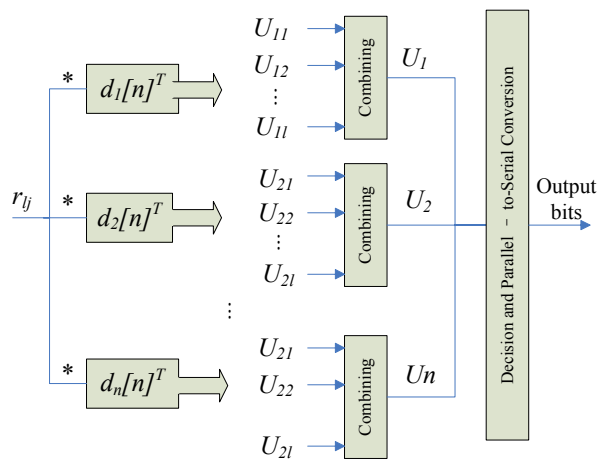
Fig. 7. Despreading and combining structure

in transmitter end and down-sampling rate 2^m in receiver end. Value of m can be chosen according to applications and/or channel environment.

In the ideal conditions, a higher value of m will efficiently decrease the wireless transfer bandwidth without risking data rate loss. Thus systems with a high value of m are very suitable for the conditions where multiple wireless devices share the bandwidth. A lower transmit bandwidth improves their coexistence ability with other devices while retaining a high data rate.

On the other hand, a lower value of m means a higher transfer bandwidth. This lower value leads to more frequent sampling at the receiver end. Since each date symbol is carried out by more signal samples, collecting more samples will gather more energy and thus increase the processing gain. However, a wider bandwidth causes coexistence issues.

This paper focuses on proving that it is possible to fully recover data under a variable transmission bandwidth in an MCIDS UWB system, with the assumptions of a slow fading single path channel and interference with white Gaussian noise. Also, the filter in this model is only a lowpass filter. Thus, we can dynamically select the signal bandwidth to provide a solution to the coexistence issue.

In our future work, a multipath fading channel and other interference factors will be considered to reflect more practical scenarios. In addition, different filtering methods such as highpass, bandpass or bandstop filters will be considered to realize more efficient bandwidth adaptation. Related signal recovering algorithms will be also investigated.

Simulations based on the algorithm and architecture of the lowpass filtering MCIDS system has been also performed. In these simulations, $T_c = 4 \times 10^{-8}$, Hadamard sequences are employed as spreading codes with $P = 16$, the length of CP, $P_0 = 4$, and a root raised cosine filter is used for lowpass filtering, with $m = 0, 1, 2$. Also, tap coefficients $\alpha_{i,j}$

are gained by sending training sequence which is known by both transmitter and receiver. Fig. 8 shows the system bit error rate curves in white Gaussian noise channel.

Based on the results in Fig. 8, the bit error rates under three transmission bandwidths are very close to each other. These results prove that the enhanced MCIDS algorithm which proposed in this paper is able to fully recover signals under different bandwidth without jeopardy in performance. Note that the 2dB losses in each curve in Fig. 8 are caused by CP. This is comfirmed by Fig. 9, which shows the system performance when the same parameters as those in Fig 8 are used but no CP is added.
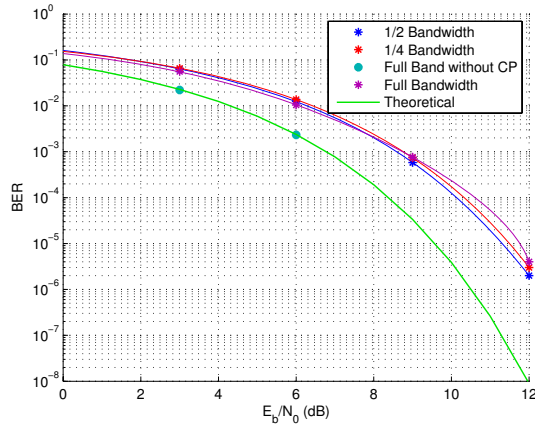

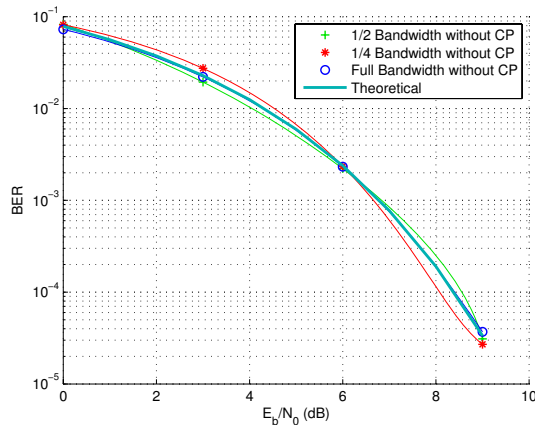Fig. 8. Performance with different transmission bandwidth

Fig. 9. Performance without cyclic prefix

IV. CONCLUSIONS

The dynamic bandwidth MCIDS based UWB system proposed in this paper enables full signal recovery under $1/2, 1/4$

or less of the original transmission bandwidth. Therefore, with filtering, sampling, circular dispreading and combining, this enhanced system is able to dynamically adjust its transmission bandwidth without deceasing its data rate or increasing hardware complexity. Unlike other cognitive UWB approaches that try to generate specific UWB impulse under FCC spectrum mask, this paper extended tradition MCIDS algorithm to achieve lossless bandwidth adjustment and thus provides another efficient cognitive solution for UWB.

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