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Abstract

This paper continues the work on the new Rotation matrix developed for BSOFDM which showed improvement in frequency selective channels such as the UWB IEEE defined CM1 to CM4 and overall system performance. This paper presents a method by which higher order Rotation matrix can be derived and simulation results are used to show that the higher order Rotation matrix outperforms the Hadamard matrix in frequency selective channels.

Keywords

Rotation spreading matrix, BSOFDM, Frequency selective channel

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HIGHER ORDER ROTATION SPREADING MATRIX FOR BLOCK SPREAD OFDM

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ABSTRACT

This paper continues the work on the new Rotation matrix developed for BSOFDM which showed improvement in frequency selective channels such as the UWB IEEE defined CM1 to CM4 and overall system performance. This paper presents a method by which higher order Rotation matrix can be derived and simulation results are used to show that the higher order Rotation matrix outperforms the Hadamard matrix in frequency selective channels.

¹ **Key Words**-Rotation spreading matrix, BSOFDM, Frequency selective channel

1. INTRODUCTION

Many solutions have been presented to allow a communications system to improve its frequency diversity efficiency by using spreading matrices such as the Hadamard to increase the correlation between the transmitted symbols and therefore improving the overall system performance. At the transmission the BPSK or QPSK modulation schemes are used and by using the spreading matrix a higher order modulation scheme, such as 16QAM, is achieved and as such increase in correlation is possible. Varying modulation schemes are achievable depending on the size of the block M used with the Block Spread OFDM (BSOFDM). Using $M = 2$ can achieve 16QAM, using $M = 4$ can achieve 64QAM as an example. A new spreading matrix called Rotation spreading matrix was proposed in [1] to increase the correlation between the symbols for BSOFDM through the use of a rotation angle, and depending on the rotation angle, α , a new and higher order modulation is used in the transmission of the system to increase the correlation between the transmitted symbols to improve the BER performance through frequency diversity. This paper presents a method by which higher order matrices for the new Rotation matrix can be achieved and when comparing the Rotation matrix with existing solutions such as the Hadamard

in frequency selection channels, it again showed that it outperforms them in terms of BER. This paper is organized in the following way. Section 2 provides a brief description of the system used to validate the performance of the Rotation matrix. Section 3 provides a brief description of the Rotation matrix presented in [1]. Section 4 proposes the method used to obtain the higher order Rotation matrix. Section 5 provides the simulation results and Section 6 concludes this paper with recommendations for future work.

2. SYSTEM DESCRIPTION

Primarily this new spreading matrix is used in what has been described as Block Spread OFDM (BSOFDM), which is when the full set of subcarriers are divided into smaller blocks and using spreading matrices to spread the data across these blocks so to achieve frequency diversity across frequency selective channels [2] [3] and [4]. The BSOFDM channel model is shown in Figure 1.

$$y = Cq + n \quad (1)$$

The output of the receiver's FFT processor is given in Equation 1 where y is the FFT output, $q \in A^N$ is the vector of transmitted symbols, each drawn from an alphabet A , C is a diagonal matrix of complex normal fading coefficients, and n is a zero mean complex normal random vector. Equalization of the received data is done through multiplication by C^{-1} and then "quantized independently on each subcarrier to form the soft or hard decision $\hat{q}$ which may be further processed if the data bits are coded" [4]. There is no loss in performance when the detection is performed independently on each carrier due to the noise being independent and identically distributed with fading been diagonal [4].

The block spreading matrices are used to introduce dependence among the subcarriers. N subcarriers are split into $\frac{N}{M}$ blocks, where $M = 2$ is used for this example. Then each of the blocks are multiplied by a 2×2 unitary matrix U_2 . The length two output vectors are interleaved

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Fig. 1. Block diagram representation of the BSOFDM channel for a block length of two [4].

using general block interleaving to ensure the symbols are statistically independent so as to encounter independent fading channels. This will ensure in a dispersive frequency selective channel the data is statistically less likely to become corrupted and studies and simulations have shown this to be correct.

The transmitter's IFFT has the interleaved data passed through it and this data is sent across the frequency selective channel. The data is passed through an FFT processor at the receiver and deinterleaved before using block by block processing.

The spreading matrices are generally used to increase the correlation between the transmitted symbols after the transmission has occurred. Unlike adaptive modulation schemes where depending on the system, a higher order modulation scheme is used to retransmit the data, this scheme utilizes spreading matrices to increase the correlation between the symbols, rather than retransmitting. This is depicted in Figure 2. So say at the transmission the system modulates the data using QPSK modulation, with spreading matrices a higher order modulation is used to increase correlation and therefore overall system performance. There are a number of matrices available and well studied, this paper continues the work on the Rotation paper studied in [1] and discusses a method to achieve higher order Rotation matrix and presents simulation results to compare with existing matrices such as the Hadamard for sizes 4×4 , 8×8 and 16×16 .

3. NEW ROTATION SPREADING MATRIX

In [1], a new spreading matrix known as the Rotation spreading matrix was presented and it was shown to outperform other spreading matrices such as the Hadamard and the Rotated Hadamard in UWB channels *CM1* to *CM4*. It was noted for its flexibility in producing varying types of matrices as well as unique combinations. The structure of this new Rotation matrix can be seen in Equation 2.

$$U = \begin{bmatrix} 1 & \tan(\alpha) \\ \tan(\alpha) & -1 \end{bmatrix} \quad (2)$$

Fig. 2. The process through which the transmitted modulation is converted into a higher order modulation and then returned at the receiver.

Fig. 3. Constellation points for Rotation matrix using $\alpha = \frac{\pi}{3}$.

Varying modulation schemes are achievable and they depend on the angle α chosen. Figure 3 depicts the new modulation scheme after the $M = 2$ sized blocks are multiplied by the new Rotation spread matrix U using $\alpha = \frac{\pi}{3}$. It was shown in [6] that the angle $\frac{\pi}{3}$ in UWB *CM1* channel achieved the better result, this can be seen in Figure 4 comparing three different angles.

The new Rotation matrix matrix has been proven to outperform other spreading matrices in UWB channels [1] and they can be seen in the Figures 5, 6 and 7. The simulation results used $N = 64$ subcarriers, Maximum Likelihood decoder at the receiver, $M = 2$ block size and 20000 packet simulations. All the UWB channels are used for the experiment.

4. HIGHER ORDER ROTATION MATRIX

The following method is used to produce higher order Rotation matrix, this method is similar to the method used for the Hadamard matrix. If it can be assumed that the new Rotation matrix is a square matrix U_N of dimensions $N \times N$ with the three kinds of elements $\tan(\alpha)$, 1 and -1 , which

Fig. 4. Comparing the Rotation matrix with angles $\frac{\pi}{6}$, $\frac{\pi}{3}$ and $\frac{\pi}{7}$.

Fig. 6. The new Rotation matrix shown outperforming Rotated Hadamard and Hadamard matrices in UWB *CM2* using the ML decoder

Fig. 5. The new Rotation matrix shown outperforming Rotated Hadamard and Hadamard matrices in UWB *CM1* using the ML decoder

Fig. 7. The new Rotation matrix shown outperforming Rotated Hadamard and Hadamard matrices in UWB *CM3* using the ML decoder

satisfies,

$$U_N U_N^T = U_N^T U_N \quad (3)$$

$$= N I_N \quad (4)$$

where U_N^T stands for transpose of U_N and I_N is the identity matrix of order N . Equation 3 can be shown that any two sequences given by rows or columns of U_N are orthogonal. Then the Rotation spreading matrix of $N = 2^n$ ($n \geq 0$) can be generated using the simple recursive procedure,

$$U_{2N} = \begin{bmatrix} U_N & U_N \\ U_N & -U_N \end{bmatrix} \quad (5)$$

So using the method describes in Equation 5 for the new Rotation spread matrix the 4×4 would look like the following,

$$U_4 = \begin{bmatrix} 1 & \tan(\alpha) & 1 & \tan(\alpha) \\ \tan(\alpha) & -1 & \tan(\alpha) & -1 \\ 1 & \tan(\alpha) & -1 & -\tan(\alpha) \\ \tan(\alpha) & -1 & -\tan(\alpha) & 1 \end{bmatrix} \quad (6)$$

Then the higher order New Matrix $U = 8 \times 8$ looks like the following, where $t = \tan$

$$U_8 = \begin{bmatrix} 1 & t(\alpha) & 1 & t(\alpha) & 1 & t(\alpha) & 1 & t(\alpha) \\ t(\alpha) & -1 & t(\alpha) & -1 & t(\alpha) & -1 & t(\alpha) & -1 \\ 1 & t(\alpha) & -1 & -t(\alpha) & 1 & t(\alpha) & -1 & -t(\alpha) \\ t(\alpha) & -1 & -t(\alpha) & 1 & t(\alpha) & -1 & -t(\alpha) & 1 \\ 1 & t(\alpha) & 1 & t(\alpha) & -1 & -t(\alpha) & -1 & -t(\alpha) \\ t(\alpha) & -1 & t(\alpha) & -1 & t(\alpha) & -1 & -t(\alpha) & 1 \\ 1 & t(\alpha) & -1 & -t(\alpha) & -1 & -t(\alpha) & 1 & t(\alpha) \\ t(\alpha) & -1 & -t(\alpha) & 1 & -t(\alpha) & 1 & t(\alpha) & -1 \end{bmatrix} \quad (7)$$

5. RESULTS

Figure 8 depicts the result of the BER of the new Rotation spreading matrix using $M = 16$ blocks with the Rotation matrix $U = 16 \times 16$ compared to the Hadamard matrix in a two ray fading channel and as can be seen the Rotation matrix outperforms the Hadamard by $2dB$. Figure 9 depicts the new Rotation matrix using $M = 8$ comparing the Hadamard 8×8 matrix. As can be seen from this figure the Rotation matrix outperforms the Hadamard by approximately $2dB$. Figure 10 depicts the new Rotation matrix with the block size $M = 4$ versus the Hadamard 4×4 matrix. As can be seen from this figure the Rotation matrix outperforms the Hadamard by $2dB$.

6. CONCLUSION

This paper presented a method to produce higher order Rotation matrix for Block Spread OFDM using a similar method used for the expansion of the Hadamard matrix. The higher order Rotation matrix was shown to outperform the stated matrices and results in 2 ray fading channels have shown

Fig. 8. BER M=16 Rotation matrix versus Hadamard in 2 ray model channel N=32 subcarriers.

Fig. 9. BER M=8 Rotation matrix versus Hadamard in 2 ray model channel N=32 subcarriers.

Fig. 10. BER M=4 Rotation matrix versus Hadamard in 2 ray model channel N=32 subcarriers.

this. This new Rotation matrix has been proven to be a good solution to what has become known as BSOFDM. The Rotation matrix improves a systems performance by introducing frequency diversity and in frequency selective channels has proven to increase overall system performance. Future work will include a new method used in [7] to obtain the higher order of this new Rotation matrix and an analysis will be carried out.

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