NEW HIGHER ORDER ROTATION SPREADING MATRIX FOR BSOFDM

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ABSTRACT

Previously a new matrix called the Rotation spreading matrix was proposed for Block Spread OFDM which had advantages over other well known spreading matrices such as the Hadamard in frequency selective channels such the UWB channels. Then a new paper discussed a method to expand this Rotation spreading matrix into higher order allowing the system BSOFDM to achieve higher order matrices which still showed excellent orthogonal properties which can be used in these frequency selective channels. This work is continued on the Rotation spreading matrix and this paper presents another method to expand the Rotation spreading matrix based on Complete Complementary Sets of Sequences which the authors have shown to have excellent properties in higher order matrices. This paper discusses the new method and presents a comparison between the two mentioned methods.

[1] ***Key Words-****Rotation spreading matrix, BSOFDM, Frequency selective channel, Complete Complementary Sets of Sequences*

1. INTRODUCTION

Spreading matrices for OFDM based systems have been studied and have shown to greatly improve the overall system performance over frequency selective channels due to their orthogonal properties. The new systems have been called Block Spread OFDM (BSOFDM). This is where the N subcarriers of the OFDM systems are divided into M blocks. The M blocks are spread using spreading matrices such as the Hadamard matrix which in turn increases the correlation between the transmitted symbols. This ensures that in frequency selective channels the losses are minimized. Using block size $M = 2$ it can achieve a modulation scheme of 16QAM, using a block size $M = 4$ it can achieve a modulation scheme of 64QAM for example when the modulation used at the transmission is QPSK.

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 matrix was shown to outperform other spreading matrices such as the Hadamard matrix and the Rotated Hadamard matrix in frequency selective channels such as the IEEE defined UWB channels. In [2] a method was proposed to obtain higher order Rotation spreading matrix to be used with larger M block sizes for BSOFDM. For example, when a system requires the use of a larger M block, this must then use a higher order Rotation spreading matrix. The higher order Rotation method again showed that it outperformed the other mentioned matrices in frequency selective channels as well as slow fading channels. The reason for this was due to the Rotation spreading matrix maintaining its orthogonality.

This paper present a new method to obtain higher order Rotation spreading matrix which utilizes a scheme proposed in [3]. There are advantages to this new method and will be discussed below. This paper is organized in the following way. Section 2 describes the system of Block Spread OFDM. Section 3 briefly presents the Rotation matrix presented in [1]. Section 4 describes the new method to be used to obtain the higher order Rotation spreading matrix. Section 5 presents the experimental results testing the new expansion method against other spreading matrices. This section also compares the previous method used to expand the Rotation matrix which was presented in [2] in slow fading channels. Finally a conclusion is given in Section 6 with some recommendations for future work.

2. SYSTEM DESCRIPTION

Figure 1 depicts a block diagram of Block Spread OFDM (BSOFDM) and this is when the full set of subcarriers N are divided into smaller blocks M and using spreading ma-

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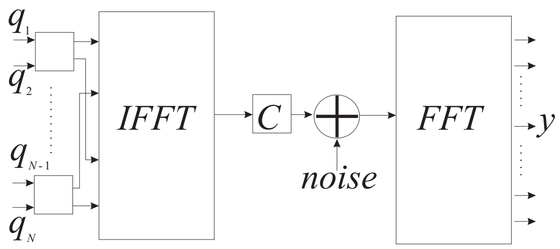

Fig. 1. Block diagram representation of the BSOFDM channel for a block length of two [4].

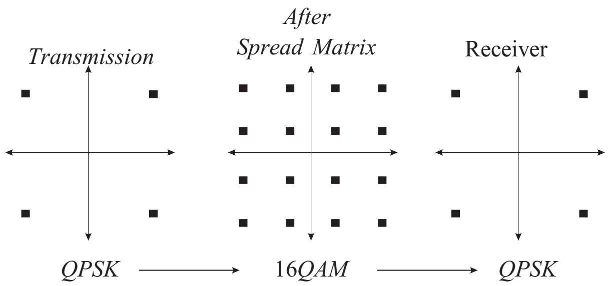

Fig. 2. The process through which the transmitted modulation is converted into a higher order modulation and then returned at the receiver.

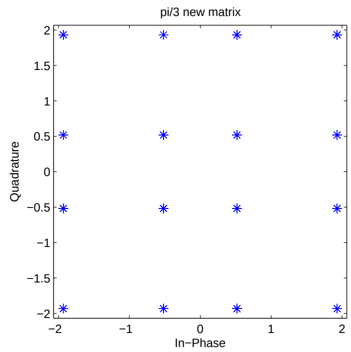

Fig. 3. The Rotation matrix for $M = 2$ BSOFDM with rotation $\frac{pi}{3}$.

trices to spread the data across these blocks so to achieve frequency diversity across frequency selective channels [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 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 spreading matrices are generally used to increase the correlation between the transmitted symbols after the transmission has occurred [5], [6] and [7]. 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. For example at the transmission the system modulates the data using QPSK modulation, with spreading matrices a higher order modulation is used to increase correlation to 16QAM when using block size $M = 2$ and can be seen in Figure 3. When the block size of $M = 4$ and rotation angle $\alpha = \frac{\pi}{9}$ is used a higher modulation scheme is achieved and can be seen in Figure 4. There are a number of matrices available and well studied, this paper continues the work on the Rotation matrix studied in [1], [2] and discusses a new method to achieve higher order Rotation matrix based on [3], and presents simulation results to compare with existing higher order Rotation spreading matrix as well as existing matrices used for BSOFDM such as the Hadamard matrix for sizes $U = 4 \times 4$, $U = 8 \times 8$ and $U = 16 \times 16$.

3. 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 $CM4$ which can be seen in Figure 5 depicting the Rotation spreading matrix outperforming the Rotated Hadamard and Hadamard matrix in UWB channel $CM1$. This was also true for the other channels of UWB. The simulation results used $N = 64$ subcarriers, Maximum Likelihood decoder at the receiver, $M = 2$ block size and 20000 packet simulations. 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 1.

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

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 $\alpha = \frac{\pi}{3}$. Figure 4 depicts new modulation scheme after larger block size $M = 4$ are multiplied by Rotation spreading matrix with rotation angle $\alpha = \frac{\pi}{9}$.

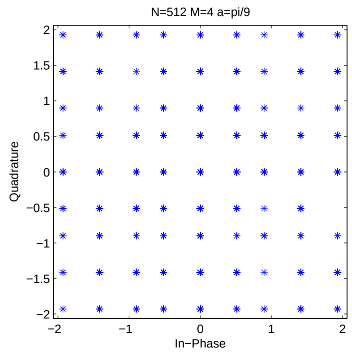

Fig. 4. The Rotation matrix for $M = 4$ BSOFDM with rotation $\frac{pi}{9}$.

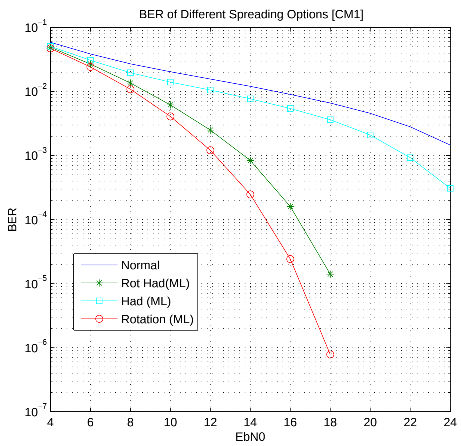

Fig. 5. The new Rotation matrix shown outperforming Rotated Hadamard and Hadamard matrices in UWB $CM1$.

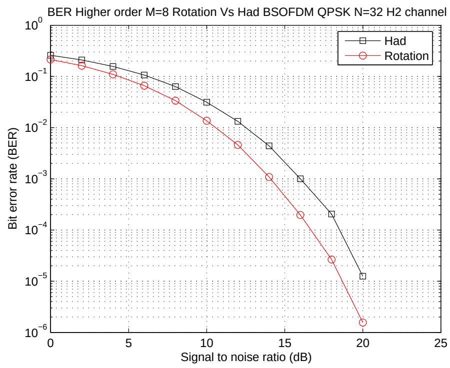

Fig. 6. BER $M = 8$ Rotation matrix versus Hadamard in 2 ray model channel $N = 32$ subcarriers.

4. HIGHER ORDER ROTATION MATRIX USING THE COMPLETE COMPLEMENTARY SETS OF SEQUENCES

In [2] it was shown that a method based on the Hadamard expansion for the Rotation spreading matrix, this showed that the higher order Rotation matrix maintained its orthogonality and showed it outperformed the other existing solutions for BSOFDM in frequency selective channels. This can be seen in Figure 6 which depicts the new Rotation matrix using block size $M = 8$ using the Hadamard expansion method presented in [2] comparing with the Hadamard 8×8 matrix. The Rotation spreading matrix outperforms the Hadamard matrix by approximately $2dB$.

In [3], the authors showed a new method to expand the Hadamard matrix into higher order and which showed superior properties in frequency selective channels. In this paper we utilize this new method to expand the Rotation spreading matrix which can be described as follows,

$$U_{2N} = \begin{bmatrix} U_N & \tilde{U_N} \\ U_N & -\tilde{U_N} \end{bmatrix} \tag{2}$$

Where $\tilde{U_N} = P_N U_N Q_N$ which denotes an equivalent Rotation matrix obtained by permuting the rows and columns of U_N, P_N and Q_N are arbitrary monomial permutation matrices have exactly one non-zero entry in every row and column and therefore satisfying the conditions,

$$\begin{aligned} P_N P_N^T &= P_N^T P_N && (3)\\ &= Q_N Q_N^T && (4)\\ &= Q_N^T Q_N && (5)\\ &= I_N && (6) \end{aligned}$$

Where P_N is,

$$P_N = \begin{bmatrix} 0 & I_{\frac{N}{2}} \\ I_{\frac{N}{2}} & 0 \end{bmatrix} \quad (7)$$

and $Q_N = I_N$. Which means that $\tilde{H}$ is obtained by exchanging the upper and lower half half of H_N and it was shown in [3] to have good complementary properties.

So, the Rotation spreading matrix will have the following structure for a $U = 4 \times 4$ matrix,

$$U_4 = \begin{bmatrix} 1 & tan(\alpha) & tan(\alpha) & -1 \\ tan(\alpha) & -1 & 1 & tan(\alpha) \\ 1 & tan(\alpha) & -tan(\alpha) & 1 \\ tan(\alpha) & -1 & -1 & -tan(\alpha) \end{bmatrix} \quad (8)$$

The $U = 8 \times 8$ Rotation spreading matrix based on the CCSS expansion can be shown as follows, where $t = \tan(\alpha)$

$$U_8 = \begin{bmatrix} 1 & t & t & -1 & 1 & t & -t & 1 \\ t & -1 & 1 & t & t & -1 & -1 & -t \\ 1 & t & -t & 1 & 1 & t & t & -1 \\ t & -1 & -1 & -t & t & -1 & 1 & t \\ 1 & t & t & -1 & -1 & -t & t & -1 \\ t & -1 & 1 & t & -t & 1 & 1 & t \\ 1 & t & -t & 1 & -1 & -t & -t & 1 \\ t & -1 & -1 & -t & -t & 1 & -1 & -t \end{bmatrix} \quad (9)$$

Higher order $M \times M$ Rotation spreading matrices can be achieved when the method described in Equation 2 is used. This ensures that the higher order matrix maintains orthogonality for larger M sized blocks.

5. RESULTS

The following experimental results show that the expansion based on CCSS method also outperforms the Hadamard and Rotated Hadamard using block sizes of $M = 16$, $M = 8$ and $M = 4$ across frequency selective channels and slow fading channels. As can be seen from Figures 7, 8 and 9 the Rotation spreading matrices outperforms the Rotated Hadamard and Hadamard matrices is BSOFDM across fading channels by more than 2dB. The rotation angle used for these figures was $\alpha = \frac{\pi}{3}$, with the subcarriers ranging from $N = 16$ to $N = 64$.

This then can allow us to compare the expansion in UWB channels of both methods of expanding the Rotation matrix and as can be seen there is a small difference in terms of BER when using the MMSE decoder across UWB channels defined from $CM1$ to $CM4$.

In Figure 11 it can be seen when using block size of $M = 4$ with the number of subcarriers $N = 64$ in UWB

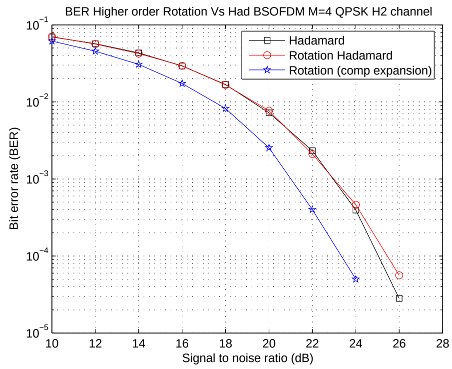

Fig. 7. Comparing Rotation matrix ($\frac{\pi}{3}$) higher order using CCSS with Rotated Hadamard and Hadamard in $H2$ ray channel $N = 16$ $M = 4$.

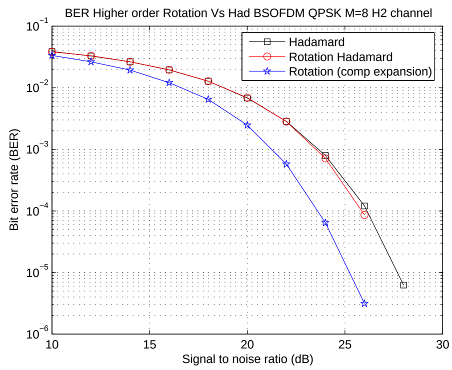

Fig. 8. Comparing Rotation matrix ($\frac{\pi}{3}$) higher order using CCSS with Rotated Hadamard and Hadamard in $H2$ ray channel $N = 16$ $M = 8$.

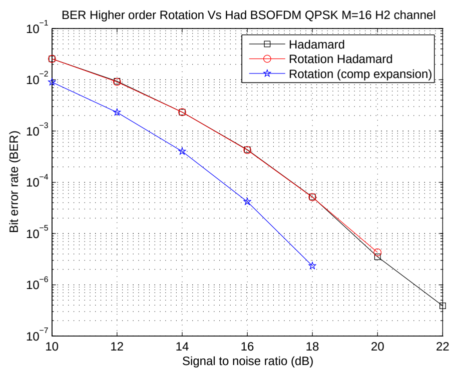

Fig. 9. Comparing Rotation matrix ($\frac{\pi}{3}$) higher order using CCSS with Rotated Hadamard and Hadamard in $H2$ ray channel $N = 64$ $M = 16$.

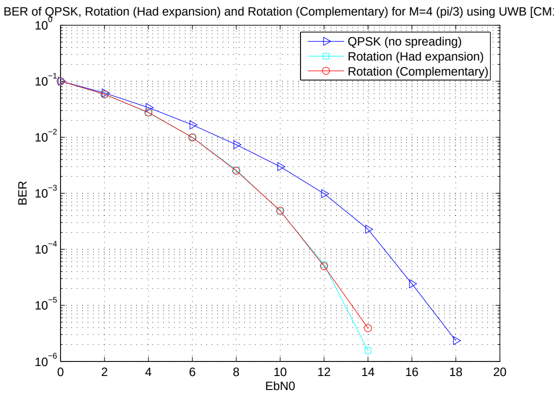

Fig. 10. Comparing Had method with CCSS method expansion $M = 4$ $N = 64$ in UWB $CM1$.

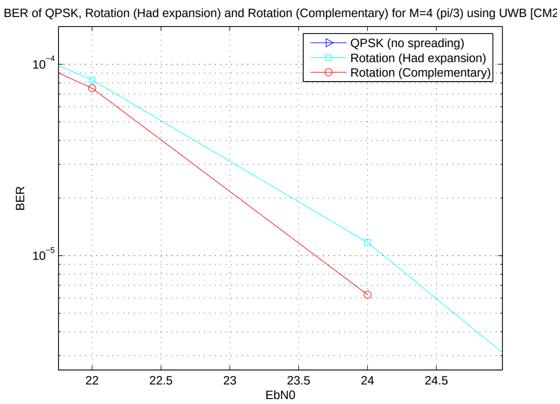

Fig. 11. Comparing Had method with CCSS method expansion $M = 4$ $N = 64$ in UWB $CM2$.

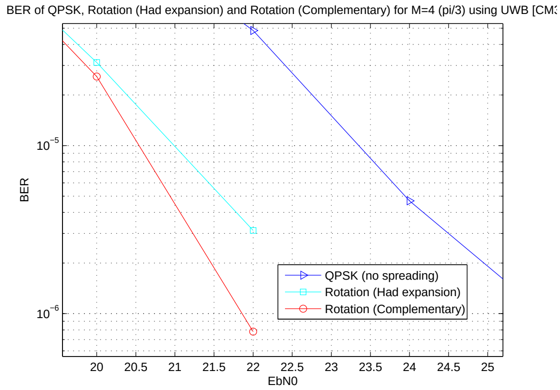

Fig. 12. Comparing Had method with CCSS method expansion $M = 4$ $N = 64$ in UWB $CM3$.

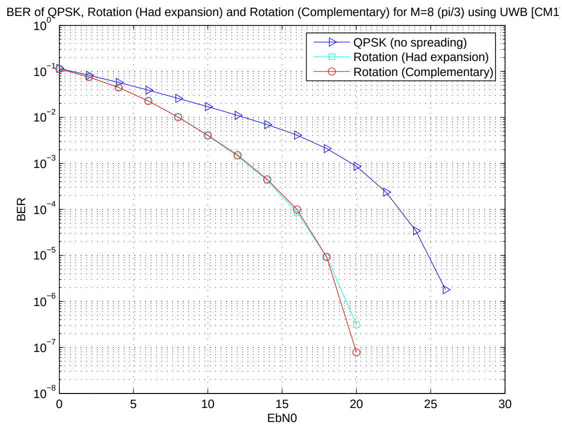

Fig. 13. Comparing Had method with CCSS method expansion $M = 8$ $N = 64$ in UWB $CM1$.

channel $CM2$, the CCSS expansion method for the Rotation spreading matrix there was a gain of 0.5dB.

In Figure 12, there is a further improvement of the CCSS expansion method over the Hadamard expansion method when the two are compared for block size of $M = 4$ using $N = 64$ subcarriers across the UWB channel $CM3$ of approximately 1.5dB.

Similar results can be seen for block size $M = 8$ for the UWB channels $CM1$ to $CM4$.

When the CCSS expansion method is compared with the Hadamard expansion method for higher order Rotation spreading matrix in slow fading channel, it can be seen in Figure 15 that the two method have a very similar result and no advantage can be observed over the other in terms of BER gain. Both expansion methods still outperformed the Rotated Hadamard by approximately 2dB.

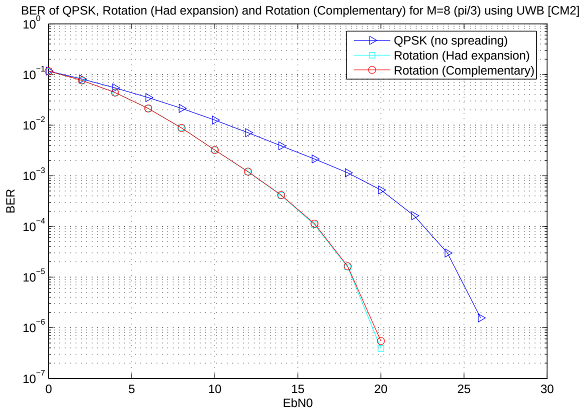

Fig. 14. Comparing Had method with CCSS method expansion $M = 8$ $N = 64$ in UWB $CM2$.

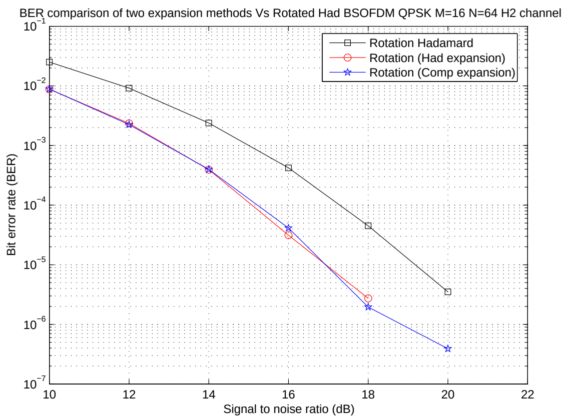

Fig. 15. Comparing Had method with CCSS method expansion $M = 16$ $N = 64$ in 2 ray channel.

6. CONCLUSION

This paper presented a new method to expand the Rotation matrix presented in [1]. This new method is based on the work presented in [3] which was compared with a method for expansion of the Rotation spreading matrix based on the Hadamard expansion presented in [2]. Both methods showed the Rotation spreading matrix has excellent properties in frequency selective channels such as the UWB channels and slow fading channels due to their ability to maintain their orthogonal properties as the matrix is expanded. An experimental study was carried out comparing the two methods in UWB for block sizes $M = 4$ and $M = 8$ and it was shown that the CCSS method had a small improvement over the Hadamard expansion method when using the MMSE decoder.

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