

# EXPLOITING TIME DIVERSITY TO IMPROVE BLOCK SPREAD OFDM

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## ABSTRACT

*This paper presents a new method to improve on block spread OFDM by exploiting time diversity to ensure that the blocks are independent and uncorrelated. Simulation results have shown significant improvement over conventional OFDM and Block Spread OFDM.*<sup>1</sup>

**Key Words-**OFDM, Spreading Matrices, Block Spread-OFDM, Time Diversity

## 1. INTRODUCTION

A method used to implement mutually orthogonal signals is called Orthogonal Frequency Division Multiplexing (OFDM) and this is done by setting up multiple carriers at a suitable frequency separation and modulating each symbol stream separately [1]. By increasing the number of carriers the data rate per carrier can be reduced for a given transmission.

The symbol streams do not interfere with each other because of the carriers being mutually orthogonal. It is possible to mitigate fading through suitable interleaving and coding. One method of ensuring the signals are independent of each other is to select the frequency separation between each signal in a manner which will achieve orthogonality over a symbol interval. This can be seen in Figure 1. OFDM's operation can also be seen in Figure 2.

While OFDM will combat the effect of multipath transmission, other methods need to be used to mitigate the effect of fading and two are mentioned above. Another way of achieving this is called Diversity Transmission. Diversity transmission can be used to reduce or remove the effect of fading by the transmitted signal power being "split between two or more subchannels that fade independently of each other, then the degradation will most likely not be severe in all subchannels for a given binary digit" [2]. Then when all the outputs of these subchannels are recombined in the proper way the performance achieved will be better than the single transmission. There are a number of ways to achieve

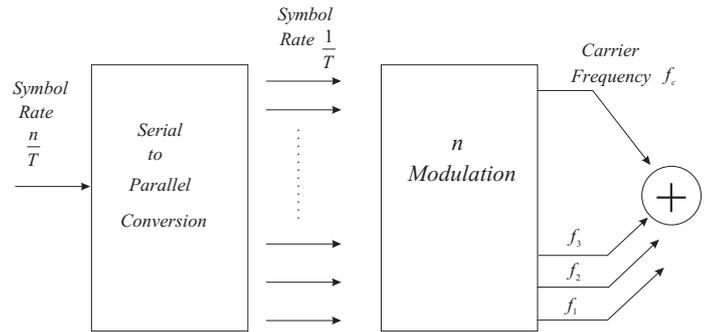


Fig. 1. Transmitter for multi-carrier modulation [1].

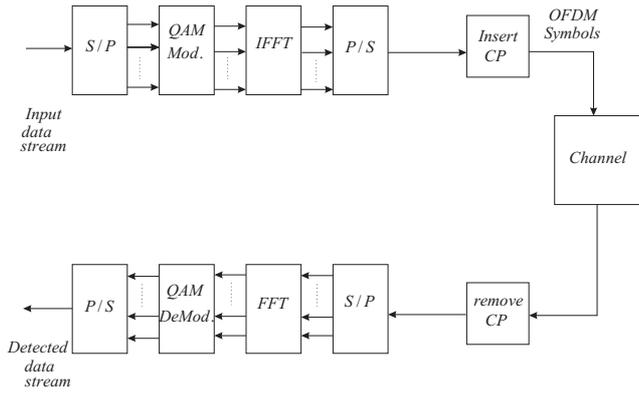
this diversity and the main methods include "transmission over spatially different times (space diversity), at different paths (time diversity) or with different carrier frequencies (frequency diversity)" [2].

Block Spread OFDM (BSOFDM) has been used to achieve frequency diversity and in frequency selective channels has shown significant improvement over conventional OFDM. This is done by dividing the  $N$  subcarriers into  $M$  sized blocks and spreading them by multiplying these blocks by spreading codes such as the Hadamard matrix.

This paper introduces a new method for improving the BSOFDM by exploiting time diversity. If the Rayleigh channel is represented by the Bessel Function of the first order it can be shown that if a delay  $\tau$  is chosen, the blocks can become independent and uncorrelated and can achieve improvement in Flat Fading environment where BSOFDM could not.

The remainder of this paper is setup in the following format. In Section two Block Spread OFDM (BSOFDM) is briefly presented and discussed. Section three of this paper presents the new delayed BSOFDM (dBSOFDM). The results are presented in Section four and finally the conclusion is given in Section five.

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**Fig. 2.** A simplified block diagram of an OFDM system [4].

## 2. BLOCK SPREAD OFDM

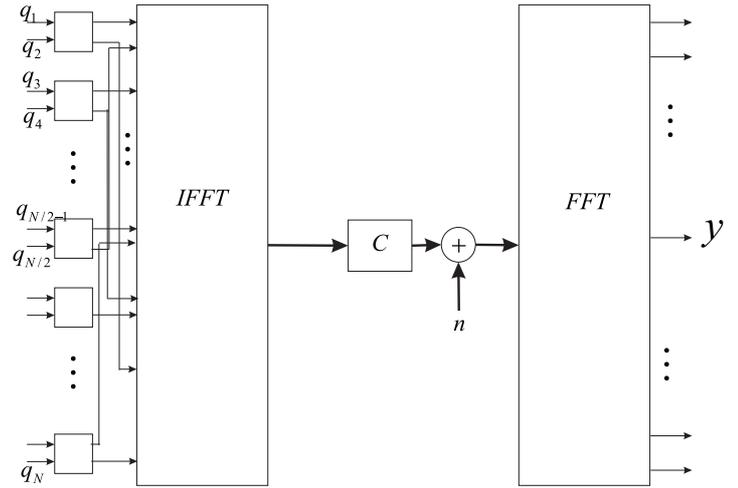
In [3] a study into an optimal block spreading code for block spread OFDM is presented, where the main idea of BSOFD is to “split the full set of subcarriers into smaller blocks and spread the data symbols across these blocks via unitary spreading matrices in order to gain multipath diversity across each block at the receiver” [3]. They found that their optimal spreading code was optimal for the quadrature amplitude modulation (QAM), binary phase shift keying (BPSK) and quadrature-phase shift keying (QPSK) modulation. The BOFD channel model is shown in Figure 3.

The output of the receiver’s FFT processor is

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

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” [3]. 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 [3].

The block spreading matrices are used to introduce dependence among the subcarriers.  $N$  subcarriers are split into  $\frac{N}{2}$  for blocks of size 2. Then each of the blocks are multiplied by a  $2 \times 2$  unitary matrix  $U_2$ . “The resulting length 2 output vectors are then interleaved to separate the entries in each block as far as possible across the frequency band so that they will encounter independent fading channels” [3]. The transmitter’s IFFT has the interleaved data passed through it and this data is sent across the frequency



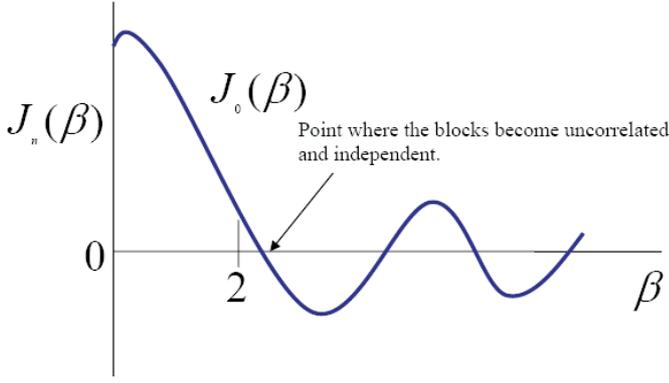
**Fig. 3.** Block diagram representation of the BSOFD channel for a block length of two [3].

selective channel. The data is passed through an FFT processor at the receiver and deinterleaved before using block by block processing. This optimal spreading matrix is compared to rotated Hadamard and shows improvement with  $MPSK$  modulation for  $M > 4$ . The optimal code and the rotated Hadamard code produced the same results for BPSK and [3] says that the rotated Hadamard is optimal for this case and therefore the optimal code does not outperform this. The author of [3] showed in his results that no improvement is achieved if the Rotated Hadamard was compared to his optimal code when using BPSK and QPSK modulation for  $M = 2$  blocks.

## 3. DESCRIPTION OF DELAYED BLOCK SPREAD OFDM

The idea behind the delayed Block Spread OFDM (dB-SOFDM) is to exploit time diversity to further improve BSOFD. The functionality is similar to BSOFD discussed above except the  $q$  blocks are spread across a number of OFDM symbols rather than just the one OFDM symbol as depicted in Figure 3. As shown in Figure 5, the odd blocks are spread across the first OFDM symbol and the even blocks are spread across the second OFDM symbol introducing time diversity among the blocks. The motivation behind this is the fact that although conventional BSOFD improves on the system performance of the conventional OFDM in frequency selective channel, our studies have shown that it does not do so under flat fading conditions which does occur during transmission. This can be seen in Figures 6 and 7.

The Rayleigh channel can be modelled by using the



**Fig. 4.** Plot of the Bessel function of the first kind.

Bessel Function of the first order. To exploit time diversity between the blocks, the time delay  $\tau$  is chosen by taking the point on the time axis to be 2.5, this can be seen in Figure 4. If one was to take the case of using the maximum doppler shift  $f_d$  at 100Hz, then the delay between the blocks to be chosen to achieve the time diversity is calculated as follows,

$$\tau = \frac{2.5}{2 \times \pi \times f_d} \quad (2)$$

$$= 3.9 \times 10^{-3} \quad (3)$$

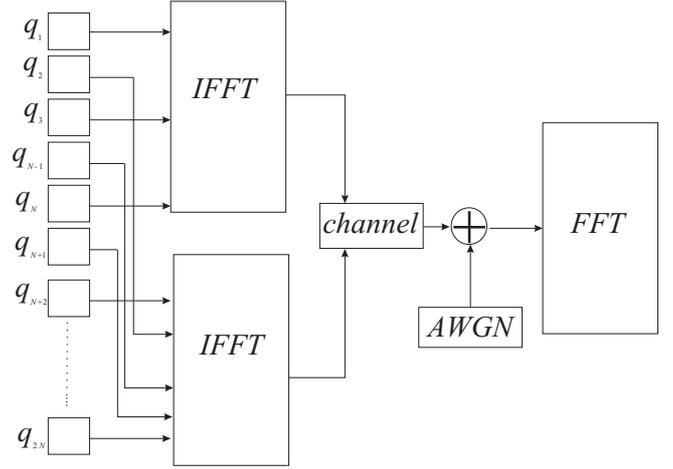
If  $\tau$  is chosen incorrectly or not accurately enough, while the blocks are not fully correlated, the blocks are not independent of each other. The initial studies have shown promise and do, as expected, improve on the conventional BSOFD. So any improvement in flat fading will translate into improvement in frequency selective channel. These results can be seen in Figures 8 and 9. Below is a description of the system proposed.

The data is transmitted and modulated using the Binary Phase Shift Keying modulation. After this the spread matrix is set using the parameters of the transmitted data. The spreading matrix used for this experiment was the rotated Hadamard matrix and the following is used to set this matrix up.

$$U = \frac{1}{\sqrt{2}} \times H_{m \times m} \times \text{diag}(\exp(j \frac{\pi \times m}{W})) \quad (4)$$

Where the  $H_{m \times m}$  is the Hadamard matrix. Where  $m = [0 < m < M - 1]$  and  $M$  is the size of the block, in this case 2. The  $W$  is chosen so that  $\frac{2\pi i}{C}$  is the smallest angle which the constellation rotates back onto itself. For MPSK this equals two and for QAM this equals four.

The incoming data is divided into  $M$  sized blocks and then these blocks are spread using the orthogonal codes



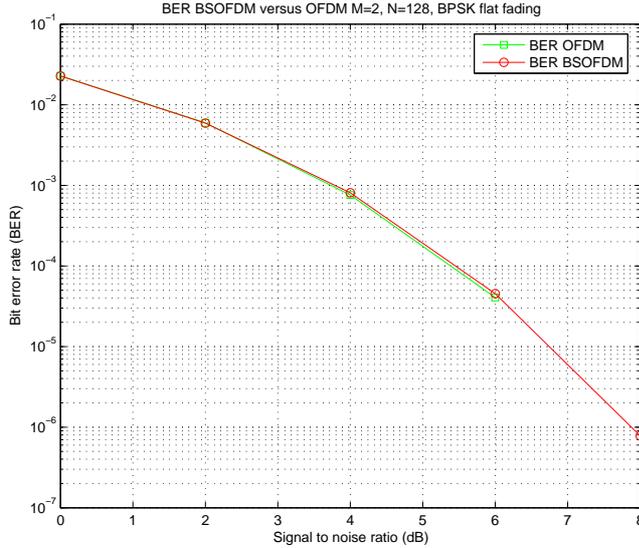
**Fig. 5.** Block diagram representation of delayed Block Spread OFDM.

across the different symbols. 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 modulated data is multiplied by the  $M$  sized spreading orthogonal matrix and  $M$  sized blocks are formed ( $q$ ). The  $q$  blocks are interleaved using a general block interleaver. In our case we are using the random permutation (more work and study will be taken to ensure it is the best option available, in [3] the author “interleaves the data as far away as possible”). These interleaved blocks, which are spread across the OFDM symbols, depicted in Figure 5 are then passed through the IFFT block that the conventional OFDM uses. Cyclic Prefix is added to the symbol by copying the tail of the symbol to the head. Then these are corrupted using frequency selective channel or flat fading channel and white gaussian noise is added.

At the receiver end the CP are removed and the data is sent through the FFT block. The symbols are deinterleaved and de-spread by using the inverse of the spreading matrix and are demodulated.

## 4. RESULTS

As can be seen from Figures 6 and 7, which depict the bit error rate (BER) and the packet error rate (PER) in the flat fading environment, no improvement is achieved using block spread OFDM versus conventional OFDM. Therefore using BSOFD in a flat fading environment merely increases the complexity of the system without any advantage. The new proposed delayed BSOFD improves the conventional BSOFD by taking advantage of time diversity and this can be seen in Figures 8 and 9. Comparing the two sets of Figures it can be seen by exploiting Time Diversity, BSOFD

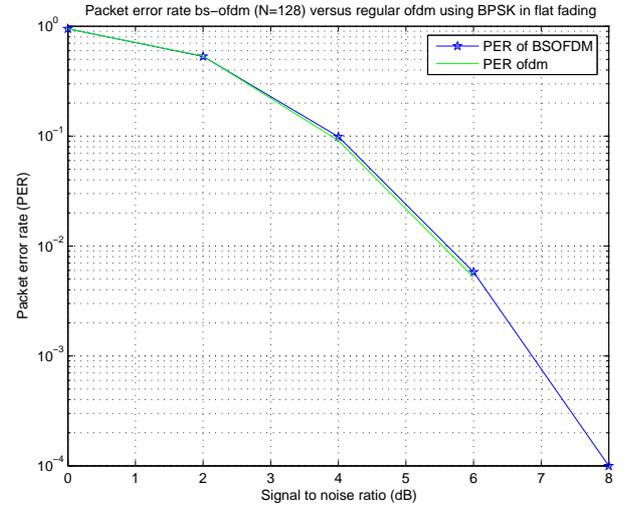


**Fig. 6.** Bit Error Rate versus SNR comparing the BSOFDM and OFDM in Flat Fading environment.

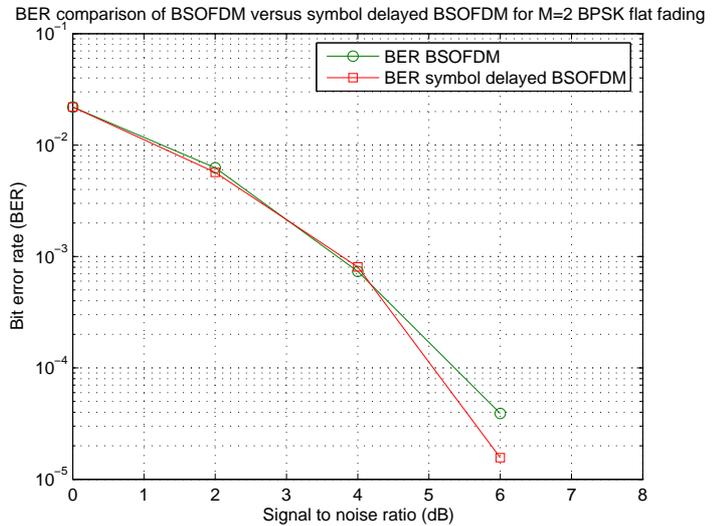
can be improved. It is very important to calculate the  $\tau$  in seconds very accurately to achieve the best results possible. If the delay  $\tau$  is calculated using the incorrect point on the time axis of the Bessel Function, one will be able to achieve a point which is not fully correlated but not independent. The results shown are where BPSK modulation is used with the Rotated Hadamard Matrix as the spreading code in flat fading environment. The block size used is  $M = 2$ . The number of packets simulated is 10000 and the number of subcarriers used is  $N = 128$ .

## 5. CONCLUSION

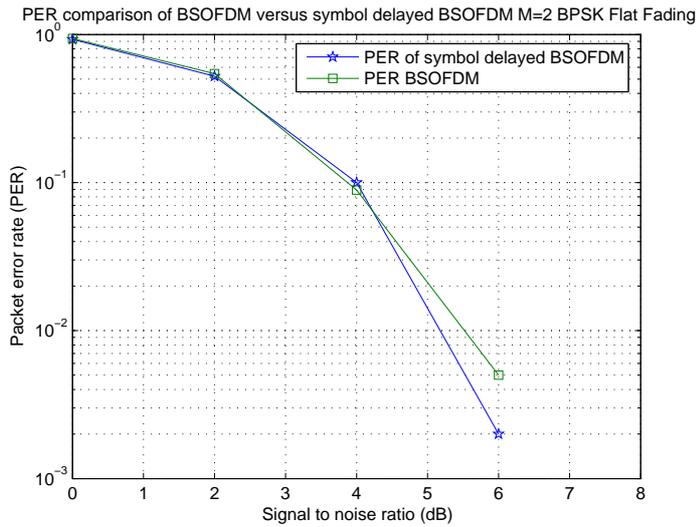
In conclusion this paper introduced a new method of further improving the block spreading OFDM called delayed Block Spread OFDM by exploiting time diversity between the  $M$  sized blocks and has shown using simulation results that there is improvement over conventional OFDM and block spread OFDM. The delayed BSOFDM introduces diversity among the  $q$  blocks by calculating the delay  $\tau$  using the Bessel Function of the first order to ensure that the blocks are uncorrelated and independent of each other. It is very important to note that if the point on the time-axis of the Bessel function is chosen incorrectly, while the blocks are not fully correlated which can achieve improvement, they are not independent, which will lead in lose of performance.



**Fig. 7.** Packet Error Rate versus SNR comparing the BSOFDM and OFDM in Flat Fading environment.



**Fig. 8.** Bit Error Rate versus SNR comparing the delayed BSOFDM and BSOFDM in Flat Fading environment.



**Fig. 9.** Packet Error Rate versus SNR comparing the delayed BSOFDM and BSOFDM in Flat Fading environment.

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