Multi-mode Spectral Efficient Frequency Division Multiplexing for 6G Networks

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Abstract

This article proposes multi-mode (MM) index modulation (IM) for spectral efficient frequency division multiplexing (SEFDM) to provide high data rate for 6G wireless systems. SEFDM with IM (SEFDM-IM) reduces intercarrier interference through partial activation of subcarriers which provides high energy efficiency and spectral efficiency (SE). On the other hand, partial inactivation of subcarriers results in the loss of frequency resources. This study suggests MM-SEFDM to utilize all the subcarriers of conventional SEFDM through multiple differentiable constellations. The proposed technique employs multiple lower order distinct constellations through a predefined index activation pattern. It helps in reducing inter-symbol interference inherited by non-orthogonal subcarriers of SEFDM and achieves higher SE than traditional SEFDM-IM.

Ⅰ. Introduction

Index modulation (IM) employs activation pattern of the building blocks of communication systems such as antenna, time, and frequency slots as an additional source of information along with conventional constellation symbols [1]. Frequency domain IM is initially proposed by using subcarrier activation of orthogonal frequency division multiplexing (OFDM) [2]. A partial deactivation of subcarriers provides energy efficiency (EE) and bit error rate (BER) improvement but results in the loss of frequency resources [3]. Also, information carried by index bits is much smaller than the information carried by higher order constellations. Spectral efficient frequency division multiplexing (SEFDM) with IM (SEFDM-IM) was suggested to reduce intercarrier interference (ICI) induced by non-orthogonality of classical SEFDM [4]. It improves spectral efficiency (SE) compared to OFDM, SEFDM, and OFDM-IM but wastage of frequency resources due to partially inactive subcarriers is still there [5].

In this article author has proposed multimode SEFDM (MM-SEFDM) which uses all the subcarriers of traditional SEFDM through distinct constellations which are sent over the selected subcarriers through a predefined method. It improves SE of its conventional counterparts. As all the subcarriers are being used, SE like OFDM-IM and SEFDM-IM can be achieved at lower order modulations which improves BER by increasing Euclidean distance among the symbols of adjacent subcarriers.

Ⅱ. Proposed Methodology

In Figure 1, transmission block diagram of MM-SEFDM is shown. The input bit stream has length B which is divided into G groups such that each group contains $b = B/G$ bits. In each group, b bits are further divided into index bits b_1 and constellation bits b_2. The subcarrier activation pattern will be defined by b_1 and remaining b_2 will be transmitted through constellation symbols. The system contains N_F subcarriers in total which are also divided into G groups and each group consists of $N = N_F/G$ subcarriers. The indices of subcarriers can be defined by the following equation,

$$i_g = \left[i_g(1), \quad i_g(2), \ldots i_g(N)\right]^T \tag{1}$$

where $g = 1, 2, \ldots, G$. The symbol vector mapped on i_g can be written as follows,

$$s_g = \left[s_g(1), \quad s_g(2), \ldots s_g(N)\right]^T \tag{2}$$

where $s_g \in \mathcal{M}_n$ denoting symbols of differentiable $\mathcal{M}$-ary constellations and $n = 1, 2, \ldots, N$. This activation pattern or mapping method of subcarriers is designed using look-up table (LUT) through all possible permutations of $n = 1, 2, \ldots, N$. An example of LUT for $N = 3$ is provided in Table 1. It provides $N! = 6$ different combination but for $b_1 = 2$ bits, only four combinations can be used, and others will be discarded. For this example, three distinct modes of constellations are required which can be differentiated independently at the receiver. Each subcarrier in g^{th} group will carry a symbol belonging to a distinct mode. The same procedure is being followed in all other groups therefore, the details of only one group is provided for brevity. Once a group is processed through MM block, all the groups are combined to make an MM-SEFDM block. This block is passed through $\frac{N}{\alpha}$-point inverse fast Fourier transform (IFFT) to generate non-orthogonal subcarriers of SEFDM. Where, $\alpha = \Delta f T$ is defined as the bandwidth compression factor with Δf and T representing the subcarrier spacing and symbol period, respectively. For non-orthogonal subcarriers, $(0 < \alpha < 1)$, and $\alpha = 1$ represents the classical OFDM. After that cyclic prefix (CP) is appended to avoid inter-symbol-interference (ISI). The transmitted signal x is expressed as

$$x = \frac{1}{\sqrt{T}} \sum_{n=0}^{N_F - 1} s \times exp(j2\pi n\alpha t/T) \tag{3}$$

where $s = [(s_1)^T, (s_2)^T, \ldots, (s_G)^T]$. The wireless communication channel is supposed to be unchanged during the transmission of an MM-SEFDM. Moreover, the CP length is kept greater than the channel taps. The received signal is written as follows

$$y = Hx + w \quad (4)$$

where H and w denote Rayleigh fading channel and additive white Gaussian noise (AWGN), respectively. The AWGN has zero mean and variance σ^2. On the receiver, after CP removal, FFT is employed, and signal is split into subblocks or groups. The receiver performs maximum likelihood (ML) detection in each subblock to determine index pattern and corresponding constellation symbols with the help of LUT. The SE achieved by any g^{th} group can be given as

$$R = \frac{1}{\alpha N}[\lfloor log_2(N!) \rfloor + N * log_2(\mathcal{M})] \quad (5)$$

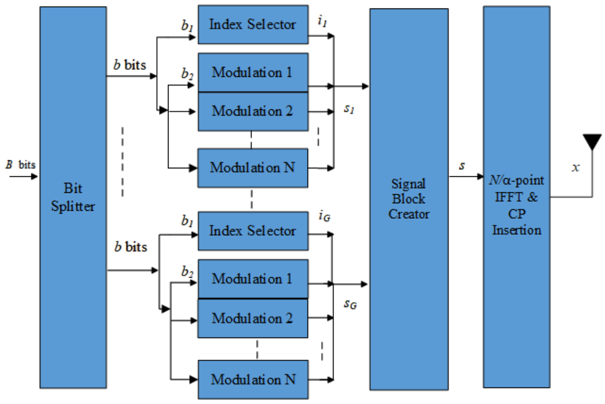

Figure 1. Block diagram for MM-SEFDM

III. Result Analysis

This section compares BER performance of MM-SEFDM with its counterparts such as OFDM-IM, and SEFDM-IM. The simulation parameters for the proposed technique include $N_F = 96$, $N = 3$, and $G = 32$. Three distinct constellations are obtained from phase shift keying (PSK) modulation such as $\mathcal{M}_1 = PSK(2)$, $\mathcal{M}_2 = \left(\frac{j\pi}{2}\right) * PSK(2)$, and $\mathcal{M}_3 = \left(\frac{j\pi}{4}\right) * PSK(2)$. These modes are readily differentiable at the receiver by using LUT in Table 1. In Figure 2, MM-SEFDM performs better providing an SE similar to counterparts. The reason lies in the diversity achieve through distinct and lower constellations which increase Euclidean distance between symbols of different subcarriers.

Table 1. Look-up Table

b_1 bits	i_g	Selected modes
00	{3,2,1}	$\mathcal{M}_3$, $\mathcal{M}_2$, $\mathcal{M}_1$
01	{ 3,1,2}	$\mathcal{M}_3$, $\mathcal{M}_1$, $\mathcal{M}_2$
10	{2,3,1}	$\mathcal{M}_2$, $\mathcal{M}_3$, $\mathcal{M}_1$
11	{2,1,3}	$\mathcal{M}_2$, $\mathcal{M}_1$, $\mathcal{M}_3$

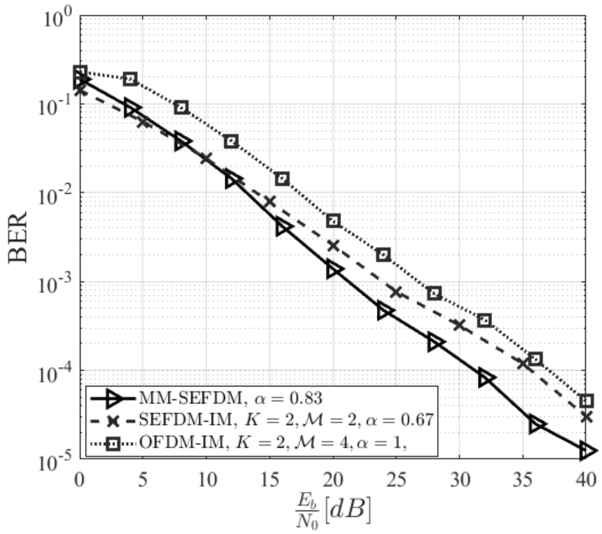

Figure 2. BER comparison

IV. Conclusion and Future Work

This study has proposed MM-SEFDM to use all the subcarriers of conventional SEFDM-IM. The SE achieved by non-orthogonal subcarriers of SEFDM is further enhanced by embedding index information through index selection pattern. MM-SEFDM has achieved better BER performance compared to its orthogonal and non-orthogonal competitors due to the diversity achieved by distinct and lower order constellations.

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Reference

[1] T. Mao, Q. Wang, Z. Wang and S. Chen, "Novel Index Modulation Techniques: A Survey," in IEEE Communications Surveys & Tutorials, vol. 21, no. 1, pp. 315-348, Firstquarter 2019.

[2] E. Başar, Ü. Aygölü, E. Panayırcı and H. V. Poor, "Orthogonal Frequency Division Multiplexing with Index Modulation," in IEEE Transactions on Signal Processing, vol. 61, no. 22, pp. 5536-5549, Nov.15, 2013.

[3] T. Mao, Q. Wang, Z. Wang and S. Chen, "Novel Index Modulation Techniques: A Survey," in IEEE Communications Surveys & Tutorials, vol. 21, no. 1, pp. 315-348, 2019.

[4] M. Nakao and S. Sugiura, "Spectrally Efficient Frequency Division Multiplexing with Index-Modulated Non-Orthogonal Subcarriers," in IEEE Wireless Communications Letters, vol. 8, no. 1, pp. 233-236, Feb. 2019.

[5] M. S. Sawar, M. Ahmad and S. Y. Shin, "Subcarrier Index Modulation for Spectral Efficient Frequency Division Multiplexing in Multi-Input Multi-Output Channels," in IEEE Transactions on Vehicular Technology, 2022.