Wavelet-Enabled SEFDM with Index Modulation for Efficient Multiuser NOMA Transmission

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Abstract

This study presents a NOMA system that integrates index-modulated spectrally efficient frequency division multiplexing with wavelet-based pulse shaping (WNOMA-SEFDM-IM). Unlike conventional orthogonal frequency division multiplexing (OFDM), SEFDM improves spectral efficiency by allowing subcarrier overlap, at the cost of induced inter-carrier interference (ICI). To address this, wavelet transforms are employed instead of Fourier transforms, offering better spectral confinement and reduced ICI. Information is conveyed through both $M-ary$ symbols and the indices of selected subcarriers. NOMA allocates power based on user distance, enabling efficient multiple access. The proposed scheme demonstrates enhanced spectral efficiency and improved robustness under a non-orthogonal resources scenario.

1. Introduction

Next-generation wireless networks, especially those targeting beyond 6G applications, are progressively integrating advanced transmission techniques such as SEFDM, IM, NOMA, over-the-air computation, and quantum-inspired designs [1, 2].

SEFDM improves spectral efficiency (SE) by compressing subcarrier spacing, albeit at the cost of introducing inter-carrier interference (ICI) due to the loss of orthogonality inherent in conventional OFDM systems [3]. To mitigate this, IM activates only a subset of subcarriers based on a shared bit-pattern between transmitter and receiver, offering gains in energy and error performance [4]. NOMA further enhances SE by enabling multiple users to access the same resources via power domain multiplexing, and its combination with SEFDM has shown promising results [5]. However, when the SEFDM compression factor is low, a trade-off arises between SE and bit-error rate (BER).

Recent studies highlight the potential of discrete wavelet transform (DWT) as a pulse shaping technique for OFDM, owing to its excellent spectral localization, multi-resolution analysis, and the inherent elimination of cyclic prefix (CP) overhead [6]. By replacing the traditional Fourier basis with wavelets, DWT-based OFDM—often referred to as wavelet OFDM (WOFDM)—offers superior side-lobe suppression and improved robustness against multipath fading and narrowband interference. These features not only enhance bandwidth efficiency but also contribute to better time-frequency resolution. As a result, DWT has emerged as a promising waveform candidate for advanced multiple access schemes like NOMA, particularly in 5G and beyond wireless systems where spectral efficiency, low latency, and interference resilience are critical [7]. The proposed design aims to improve BER performance and spectral efficiency, especially under low compression settings, and is benchmarked against traditional FFT-based approaches.

2. System Model

A downlink NOMA system based on SEFDM is considered. The base station (BS) generates SEFDM-IM signals to transmit to the users using the same frequency and time resources by implementing superposition coding (SC). The users receive the signal from the BS as a composite signal. The locations of the users are assumed to be as; UE_n, the farthest user; UE_{n-1}, less far than UE_n and eventually UE_1, the nearest user. Based on the distance of the users from the BS, $UE_n \rightarrow$ BS, $UE_{n-1} \rightarrow$ BS, and $UE_1 \rightarrow$ BS channel gains are represented as $|h_n|^2$, $|h_{n-1}|^2$, and $|h_1|^2$, respectively, such that $|h_n|^2 < |h_{n-1}|^2 < ... < |h_1|^2$. Hence, the BS, in a simplistic approach, allocates the highest amount of power to UE_n, then a little less UE_{n-1}, and eventually the lowest power to UE_1.

Let B denote the total number of bits transmitted by the base station (BS) to each user $u \in \{UE_1, UE_2, \ldots, UE_n\}$. For each user, the BS sends B bits, partitioned equally into g groups, where each group contains $d = B/$ bits. These d bits are then mapped onto subblocks, each consisting of $b = \frac{N_f}{g}$ subcarriers, with N_f representing the total number of subcarriers available. Each SEFDM-IM subblock is created by dividing the bits into two separate segments. The first segment comprises $b_{u,1} = \left\lfloor \log_2 \binom{O}{K_u} \right\rfloor$ bits, which are utilized to determine the indices of K_u active subcarriers selected from a total of O possible subcarriers. This selection is achieved via a look-up table, generating the active subcarrier indices $I_u(e) = [i_{u,1}(e), i_{u,2}(e), \ldots, i_{u,K_u}(e)]^{\mathrm{T}}$. $b_{u,2} = K_u \log_2(M_u)$ bits, encoding the modulation symbols assigned to each active subcarrier, with M_u indicating the modulation order. Where $i_{u,l}(e)\epsilon(l = 1, 2, \ldots, K_u)$. And the latter is to determine the M-ary modulation symbols over the activated indices, $S_u(e) = [s_{u,1}(e) \ \ldots \ s_{u,k_u}(e)]^{\mathrm{T}}$.

The rest of the subcarriers $(O - K)$ in the group are in a zero state. The SEFDM-IM signal block for different users is created, subblock by subblock, based on the $I_u(e)$ and $S_u(e)$. The total signal of the g group for a particular user can be represented as

$$x_u = [x_{u,1}(1), x_{u,1}(2), \ldots, x_{u,k}(e)]^{\mathrm{T}}, \quad e = 1, 2, \ldots, g. \tag{1}$$

The data rate (bps/Hz) for the e^{th} subblock can be written as

$$R = \frac{1}{\alpha O}\left(\left\lfloor \log_2 \binom{O}{K} \right\rfloor + K \log_2 M\right), \tag{2}$$

where α is the bandwidth compression factor ($\alpha < 1$ for SEFDM).

With normalized power at the BS (per subcarrier), a simple power allocation is performed, such that $\sum_{u=UE_1}^{UE_n} P_u = P_{BS} = 1$. The allocated power follows an opposite trend of the channel gain ($P_{UE_n} > P_{UE_{n-1}} > \ldots > P_{UE_1}$). The composite signal at the BS after exploiting SC is $\mathbf{x} = \sum_{u=1}^{U}\left(\sqrt{P_u}\, x_u\right)$.

The data stream is pulse-shaped by taking the inverse DWT for the SEFDM-IM symbols before transmission. CPs are not needed with the data stream, and therefore, a CP removal is not required at the receiving end. The received signal is equalized for non-ideal channels and transformed using DWT. Followed by this de-mapping to bits is performed. For the nearest user, the $(n - 1)$ users' signal is subtracted from the composite signal after SIC, while for the farthest user, the other users' low-power signals are processed as noise.

3. Simulation Results

Figures 2 and 3 illustrate the BER and sum SE performance of the proposed system using QPSK, compared against the conventional FFT approach. Perfect channel state information (CSI) is considered for both systems with parameters $K = 2, O = 4$, and $\alpha = 0.7$. For wavelet transform, Daubechies wavelet (db4) with 3 levels is used. For both BER and sum SE, WNOMA-SEFDM-IM appears to outperform Fourier transformed NOMA-SEFDM-IM.

4. Conclusion

This work presented wavelet transformed NOMA-SEFDM-IM that performs better than the Fourier transformed counterpart. A detailed system architecture with proper performance analysis for reasonable communication scenarios is due for future research.

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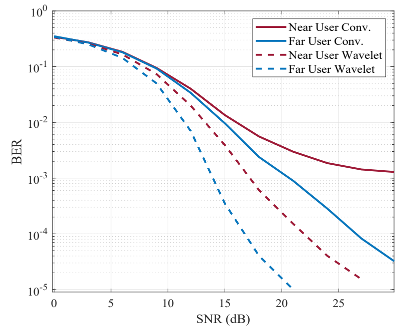

Figure 1. BER comparison of wavelet transformed NOMA-SEFDM-IM with the conventional FFT approach with QPSK ($K = 2, O = 4, \alpha = 0.7$) .

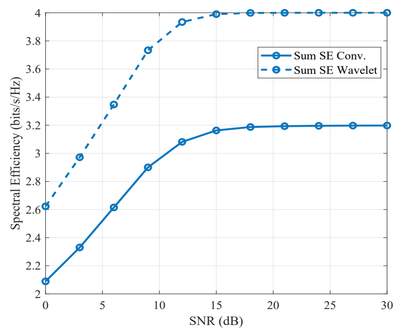

Figure 2. Sum SE performance of wavelet transformed NOMA-SEFDM-IM and conventional FFT approach with QPSK ($K = 2, O = 4, \alpha = 0.7$).

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