Hybrid SEFDM-IM and NOMA System: A Synergistic Approach to Multi-User Networks in dynamic channel conditions

Faisal Ayub Khan, Soo Young Shin*
Department of IT Convergence Engineering, Kumoh National Institute of Technology Gumi. South Korea
faisal@kumoh.ac.kr , *wdragon@kumoh.ac.kr

Abstract

Multi-user communication in dynamic channel conditions and utilizing available bandwidth efficiently face various challenges. Facilitating multiple users with different requirements also increases the complexity. In response to the challenges mentioned, we introduced a new hybrid system comprising SEFDM-IM and NOMA. The proposed system increases the spectral efficiency and thus the available spectrum is utilized more efficiently. Multiple users were facilitated with reduced ICI and better Bit Error Rate (BER) values were achieved. Overall, the proposed synergistic integration of SEFDM-IM and NOMA proved to be a more reliable, flexible and efficient solution for multi-user dynamic channel condition scenarios.

I. Introduction

During the recent decades, wireless communication technologies have evolved miraculously. As a result, we have numerous communication services and technologies available to hand. Now we are paving the way for Sixth Generation (6G) and beyond. The innovation of new technologies and techniques has provided us with significant advancements have been made in wireless communication systems. However, the increasing demand for higher system capacity, wider coverage and facilitating multiple users with dynamic channel conditions keeps on posing new advancements [1] . Providing proper communication in dynamic channel conditions while facilitating multiple users with efficient use of the available spectrum is a challenging task. Moreover, the diverse needs of multiple users in a dynamically changing environment are another scenario that needs to be analyzed.

For efficiently utilizing the available bandwidth there are two techniques Non-Orthogonal Multiple Access (NOMA) and spectrally efficient frequency division multiplexing (SEFDM). NOMA is a technique used in wireless communication that allows multiple users to share the same time-frequency resources[4]. By doing so multiple users will be able to utilize the same time slot and same frequency band at one time [2]. NOMA particularly utilizes superposition coding, where with different power levels, a number of signals are transmitted with the same frequency and at the same time. On the receivers side these signals are decoded on the basis of different power levels. Now coming to SEFDM, in efficiently utilizing the available bandwidth SEFDM proves itself to be very useful. Multiple sub-carriers are transmitted through a bandwidth, but they are not orthogonal to each other thus we are able to gain better spectral efficiency [3][5]. Since non-orthogonality prevails in SEFDM, thus we have increased interference and we have to utilize index modulation to mitigate that increased interference. To facilitate better wireless communication where we encounter dynamic channel conditions, and multiple users, efficiently utilizing available bandwidth, this paper proposes a novel approach to SEFDIM-NOMA. The proposed method will be able to deal with dynamic channel conditions and facilitate multiple users with reduced interference. Figure 1 explains the block diagram model of our proposed system. Multiple users are shown transmitting data modulating through SEFDM-IM and multiple users are also using the same frequency resources. Before transmission, all the signals are given separate power levels.

II. Methodology

Our proposed system of hybrid SEFDM-IM and NOMA considers multiple users and transmits data to them in dynamic channel conditions. We utilized the same bandwidth spectrum for all the users. Before transmitting the signals undergo various phases. After the SEFDM modulator, we perform IM, and then all the signals are assigned different power levels. The purpose of doing so is to allow the differentiation of signals for various users at the receiver end. Once power levels are assigned to our signals, they are superimposed in the time domain [1]. Data that is transmitted in SEFDM is modulated onto the non-orthogonal subcarriers which is denoted as the following in continuous time-domain signal:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi \alpha n k/N} \qquad (1)$$

X_k represents the symbol of QAM in the Q^{th} sub-carrier, T is Time Duration and α is the bandwidth compression coefficient. Since SEFDM sub-carriers overlap one another, therefore it occupies less bandwidth space and transmits the same data over T. So, when same signal is sampled at nT/N, n = 0, 1, N-1 above equation takes on new form:

$$X[n,m] = \sum_{k=0}^{N-1} \sum_{l=0}^{M-1} x[k,l] e^{-j2\pi\left(\frac{ml}{M} - \frac{nk}{N}\right)} \qquad (2)$$

Suppose M_1 $(l \in 1, ..., L)$, and it typifies multiple legitimate receivers (LRs) sets of the l^{th} cluster. Since we will encounter interference in this phase, we will use NOMA and SIC [1]. All the LRs will be sorted according to their channel gains. Therefore, signal received from l^{th} cluster and m^{th} LR is given by:

$$\begin{aligned} y_{l,m} =& \mathbf{h}_{l,m}\mathbf{A} \sum_{j=1}^{m} \mathbf{d}_l \sqrt{p_{l,j}} s_{l,j} \\ &+ \mathbf{h}_{l,m}\mathbf{A} \sum_{i \neq l} \sum_{j=1}^{M_i} \mathbf{d}_i \sqrt{p_{i,j}} s_{i,j} + n_{l,m}. \end{aligned} \qquad (3)$$

Sub-carriers are allocated in a non-orthogonal manner for both SEFDM and SEFDM-IM, in the frequency domain their separation is relatively smaller for efficiency in bandwidth [4]. Bandwidth compression factor α is equal to ΔfT and $(\alpha < 1)$, now Δf gives us the least possible separation among subcarriers in the frequency domain. So, in our proposed system of hybrid SEFDM-IM and NOMA, the transmission rate is given by $R = (1/\alpha)(\lfloor \log_2 (M) \rfloor + K \log_2 P/M)$. In this section, $K \log_2 P$ are the bits carrying information through index modulation (IM) and amplitude and phase shift keying(APSK) symbols. So, in the time-domain proposed system signal is represented as:

$$x(t) = \frac{1}{\sqrt{T}} \sum_{n=0}^{N-1} s_n \exp(j2\pi n\alpha t/T). \quad (4)$$

$$\Pr(\mathbf{s} \rightarrow \mathbf{s}') = Q\left(\sqrt{\frac{\|\mathbf{M}(\mathbf{s}-\mathbf{s}')\|_F^2}{2N_0}}\right) \quad (5)$$

The BER of our proposed system is derived by utilizing the ML detectors. In this section, we will analyze the performance of our proposed system on the basis of simulation results. BER of our hybrid system was deduced by dynamic values of δ and α. Fig 2 explains the BER curve results which are associated with the $E_{\mathrm{b,opt}}/N_0$ function, which contemplates various bandwidth compression variables and δ value was fixed to be 6 dB. SNR was fixed to be 30 dB. The BER curve shows variation when the value of α is less than 1. So, we can deduce that when data is sent to user 1, it will have a low BER. While on the other hand, user 2 will get a higher BER because of the high power level. Our results show that by increasing α, ICI will decrease and thus better BER performance. In general terms, we can conclude that if we have multiple users with varying needs and variable channel conditions we can reduce the interference, achieve better throughput with lower bit error rate values and also utilize the available spectrum efficiently since we used SEFDM-IM. Thus, various users are facilitated with dynamic channels according to their needs, by maintaining lower BER and increased spectral efficiency.

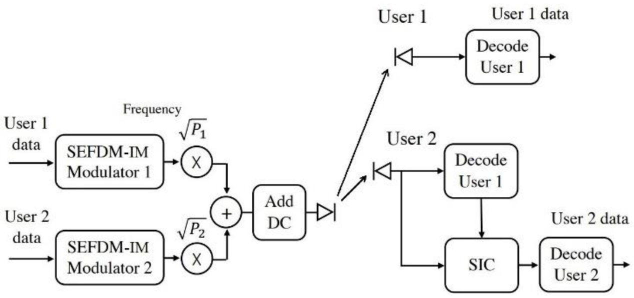

Figure 1. The Hybrid system model for SEFDM-IM and NOMA for multi-user wireless communication.

III. Conclusion

This paper provided a novel approach towards multi-user wireless communication in dynamically changing channel conditions and efficiently utilizing the available bandwidth. The proposed hybrid system merges SEFDM-IM and NOMA to mitigate ICI and facilitate multiple users according to their needs. Simulated results of the proposed system showed better BER performance, increased spectral efficiency, and reduced ICI. By exploring the challenges of multi-user scenarios, the study paves the way for more reliable, flexible and an efficient solution for multi-user dynamic channel condition scenarios. Moreover, enhancing capacity, peak-to-average power ratio (PAPR) and signal-to-noise ratio (SNR) are the foremost KPIs for our future work to explore utilizing our proposed hybrid model.

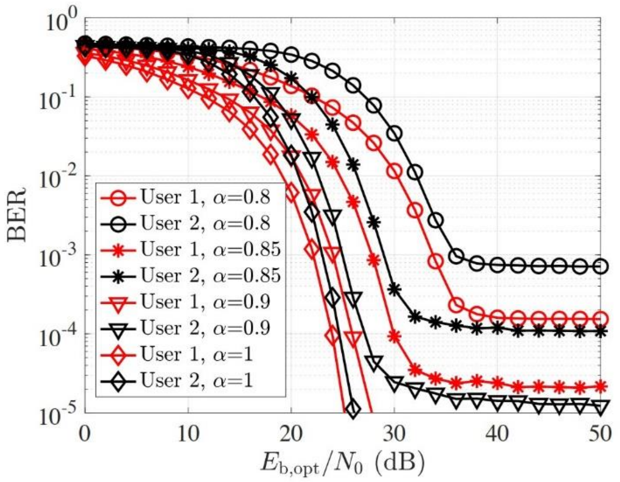

Figure 2. BER values vs $E_{\mathrm{b,opt}}/N_0$ for varying values of α and fixed values of δ

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