

Energy Efficiency Analysis of novel Index Modulation-based Non-Orthogonal Multiple Access (IMNOMA) system for 5G Networks

Shwetha H M

Department of Electronics and Communication Engineering
National Institute of Technology, Warangal
Telangana, India
shwethahmutt@gmail.com

Anuradha S

Department of Electronics and Communication Engineering
National Institute of Technology, Warangal
Telangana, India

Abstract— The requirements for high data rates, spectrum efficiency, energy efficiency, and worldwide connectivity should be addressed by future generations of wireless communication networks. The orthogonal multiple access systems cannot meet these demands. Resources are allocated to each user orthogonally in OMA techniques, including TDMA, FDMA, CDMA, and OFDMA. In a NOMA system, all users can concurrently share resources that are available to them. NOMA is the novel multiple access technology as it satisfies the requirements for high data speeds, spectrum efficiency, widespread connectivity. Users are informed in Index modulation utilising both constellation symbols as well as index symbols. This work proposes IM-NOMA, a unique Index Modulation-based NOMA system. A detailed analysis of the proposed scheme's energy efficiency is performed. Energy efficiency of the proposed scheme is analyzed in detail for different parameters. When compared to the existing modulation schemes, the suggested IM-NOMA performs significantly better.

Index Terms— Index modulation, Non-orthogonal Multiple Access, Energy efficiency, Spectral efficiency.

I. INTRODUCTION

Due to the advancement of wireless technology, massive connectivity and data rates are in high demand. OMA approach includes the multiple access methods used in 1G, 2G, and 3G that use frequency, time, and code, as well as OFDMA in 4G. Resources such as frequency, time, code are orthogonally allotted to each user in OMA [1].

The users supported by OMA technology depend on the resources availability. High spectral efficiency, massive connection, and demand for data rates have all increased as a result of the development of 5G. OMA-based networks are unable to satisfy these needs since the number of concurrent users a network can handle greatly depends on the availability of orthogonal resource blocks. NOMA supports high spectral efficiency, massive connectivity because users can use the same frequency and temporal resources as traditional OMA

techniques. Consider NOMA technology instead of OMA technology to dramatically increase 5G network capacity. Fig.1 provides a graphic comparison between NOMA and OMA. [2] Code-domain and Power-domain are the two main NOMA

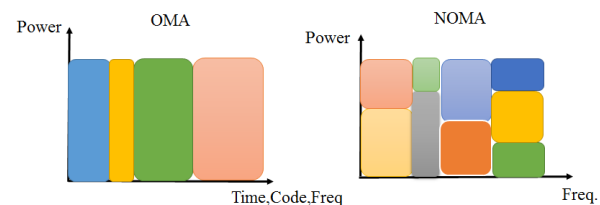


Fig. 1. Graphic comparison of NOMA and OMA

subcategories. NOMA multiplexing uses power domains and code domains to allow more users to share the limited resources available, boosting capacity of 5G networks. Users in PD-NOMA are given varying levels of power so that they can all access the same resource blocks for time, frequency, and code. [3] A unique code is issued to each user in CD-NOMA so they can share the same resource blocks. Superposition coding (SC) at the transmitting side, successive interference cancellation (SIC) at the receiver are the core techniques of NOMA [4].

Index modulation (IM) is a simple but effective digital modulation method that sends extra information bits via the resource indices of a matching communication system. Compared to conventional communication systems, IM offers significant spectrum and energy efficiency, making it a potential approach for the future. By using subcarriers in addition to the conventional M-ary signal topologies, index modulation transmits data in a novel way. The benefits of IM-assisted NOMA over orthogonal approaches are high SE as well as EE [5] [6]. The IM-NOMA for downlink has been addressed in this study. A network comprising two users is intended to implement the proposed system. In this paper, a novel IMNOMA system is proposed. The results demonstrate the fact that the IM-

Identify applicable funding agency here. If none, delete this.

NOMA SE performs well than the OMA system. The topics of spectrum and energy efficiency are briefly discussed. The proposed IM-NOMA system is discussed in further detail in Section 2 of the study. The simulation results for SE and EE are shown and discussed in Section 3. In Section 4, the paper is concluded.

II. SYSTEM MODEL

NOMA system shown in Figure 2 consists of a single Base station (BS) connected with two users.

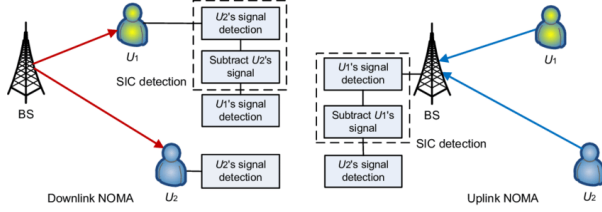


Fig. 2. Two User NOMA Network

A. IMNOMA system

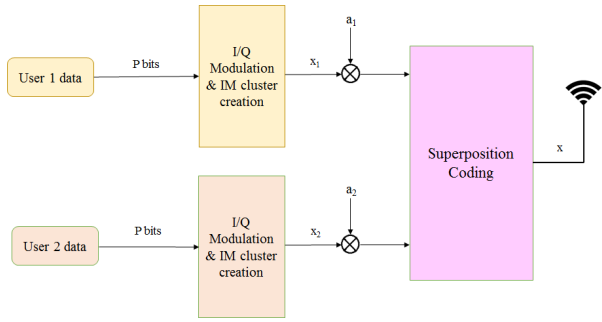


Fig. 3. Downlink IM-NOMA system model

Consider an IMNOMA network that has only one BS serving N_T users. The whole bandwidth is broken up using L_T orthogonal subcarriers. There is a B_c bandwidth for each subcarrier. L close-by subcarriers provide service to the $N \leq N_T$ users. Each user gets P bits. As in the index modulation idea, every user sends P bits that are split into the two blocks: - The indices of active subcarriers combination and M -ary constellation symbols. In the first part, which is made up of $K \log_2 M$ bits, and the second part, which is made up of $\log_2 \binom{L}{K}$ bits, each user will receive a total of P bits, where K ranges from 1 to L combined make up the P bits that will be sent to user. The first part is modulated by using conventional modulation technique. The next part is taken into consideration while choosing an active subcarrier to carry the associated modulated complex symbol C_n . As a result, $\log_2 \binom{L}{K} + K \log_2 M$ bits reach the system's transmitter during each transmission interval. The signal transmitted over subcarrier 1 is specifically represented as, for the n th user. [7]

$$x(\varepsilon) = \begin{cases} s(\varepsilon) & \text{for } \varepsilon \in I \\ 0 & \text{for } \varepsilon \notin I, \varepsilon \in 1, 2, \dots, N \end{cases} \quad (1)$$

Similar procedure is followed by each user, the modulated M -ary symbol and active sub-carriers are transmitted. The processes are then followed as in power domain NOMA. FU having weak channel coefficient is given more power than near user. The superimposed signal after SC process that is transmitted for user n is given by,

$$x_{SC} = \sum_{n=1}^N \sqrt{a_n P_{BS}} [x_n(\alpha_k)] \quad (2)$$

Where, P_{BS} - transmit power per sub-carrier at the base station. Hence, each user follows the same process for selecting the complex symbol and active subcarriers which carries the symbols. As in conventional Power domain NOMA systems, the signals to be transmitted are multiplexed over all active subcarriers and simultaneously transmitted to the different users. According to the superposition coding principle, additional power is apportioned to the far user which has weak channel coefficient compared to the near user. Information

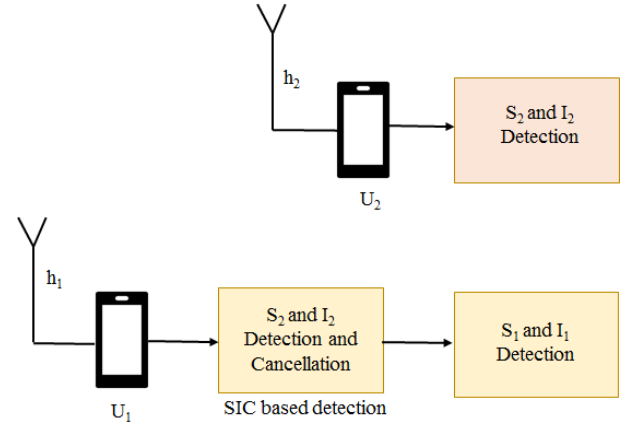


Fig. 4. SIC detection of IM-NOMA

signal received by the user is given by,

$$Y = Hx_{SC} + W \quad (3)$$

The channel matrix is as follows,

$$H = \text{diag} \{h(1) \dots h(N)\} \quad (4)$$

w symbolizes the AWGN vector,

$$w = [w(1) \dots w(N)]^T \quad (5)$$

$W \sim CN(0, \sigma^2)$. H follows the rayleigh fading channel distribution. According to the Superposition Coding, near user with good channel conditions is allotted with less power coefficient than that of far user. In SIC, each user nearer to the Base Station (BS) detects and removes the signals that are far from the BS compared to that user and treats all other user's signal as noise. The decoded signal will be removed from the received signal, the same process continues till it decodes its own signal. All user's signals are allotted with power coefficients by the BS according to the SC technique

III. ENERGY EFFICIENCY

Spectral efficiency is the fraction of the sum rate to the bandwidth.

$$SE = \frac{R_T}{W} \quad (6)$$

In orthogonal multiple access technology, each user is assigned with the single channel. The spectral efficiency is,

$$SE_{OMA} = \log_2(M) \quad (7)$$

In OMA, SE is independent of L.

In NOMA technique, all users use the available channels available in the network. The SE for NOMA is given below,

$$SE_{NOMA} = L \log_2(M) \quad (8)$$

The spectral efficiency of IM-NOMA is given below [8],

$$SE_{IM-NOMA} = \log_2\left(\frac{L}{K}\right) + K \log_2 M \quad (9)$$

Where, $K \leq L$ - total active channels.

Trade-off between BER and SE is achieved using flexible setups since only active channels are used to carry symbols. Only active channels will carry symbols so that trade-off between BER and SE can be made through flexible setups. [bpcu] stands for bits per channel use.

Energy efficiency (EE) is the ratio between the sum rates to the base station's power. The message signal power and the circuit power represent the total power consumption at the transmitting side.

$$EE_{IM-NOMA} = R_T / P_T \quad (10)$$

According to Shannon's theory, the relationship between EE and SE will not consider the power consumption of the circuit, so it is monotonic. SE and EE are inversely proportional to each other i.e., EE increases for lesser SE region and EE decreases for higher SE region. Peak of the curve denotes the EE at its maximum value. EE-SE relationship is linear for the positive slope of the curve. SE increases with the rise in EE.

IV. 4. RESULTS AND DISCUSSION

The energy efficiency of the proposed IMNOMA system is analyzed for different values of subcarriers. Following are the different system parameters chosen for Monte-Carlo simulation. Modulation order range is $M = 2, 4$ and the values of active subcarriers considered are $k = 1, 2, 3$. Circuit Power is assumed to be 60W and the bandwidth considered is 6×10^6 . From the Figure 5, we can observe that for a given M and L, the energy efficiency increases with the increase in the number of active subcarriers. Energy efficiency also increases with the increase in the modulation order. The Figure 6 shows the EE versus the number of active subcarriers K for different values of $L = 2, 4, 8$ with the modulation order $M=4$. For a given value of L, the energy efficiency increases with the increase in active subcarriers K. The graph indicates that when $K = L/2$, the energy efficiency attains its maximum point. Once the EE

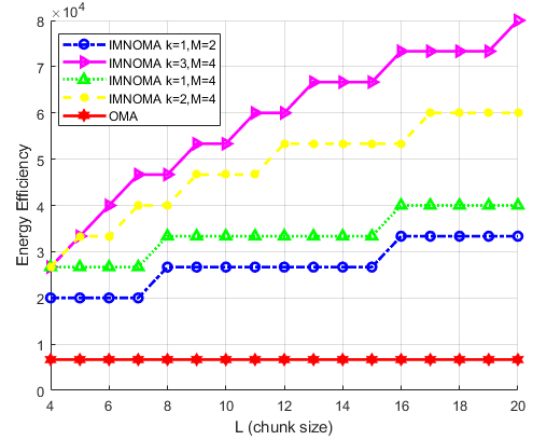


Fig. 5. Energy efficiency versus L for different values of K

attains the maximum value, for the next values of K, the EE decreases with the increase in K.

The Figure 7 indicates the Energy Efficiency of IMNOMA

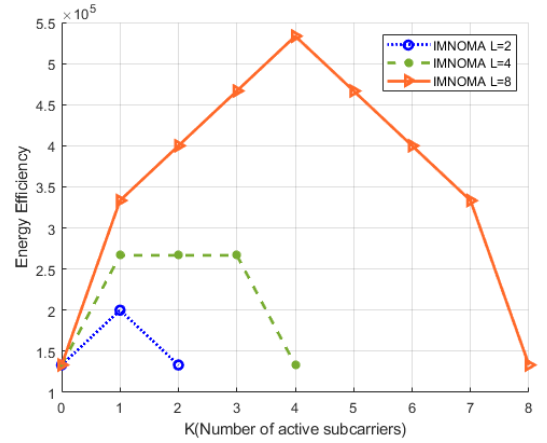


Fig. 6. Energy efficiency versus K for different values of L

scheme versus the modulation order M for different values of K and L. OMA and IMNOMA spectral efficiency results are compared. In OMA system, the energy efficiency is independent of L and hence there is no enhancement in EE. However, IMNOMA has additional $\log_2\left(\frac{L}{K}\right)$ bps/Hz compared to OMA system. In Figure 7, IMNOMA achieves higher EE compared to OMA irrespective of the modulation order.

The Figure 8 shows the energy efficiency versus the transmit power in dBm. Two subcarriers are made active out of four subcarriers. i.e., $L = 4, K = 2$. Circuit power range is assumed to be $P_c = 40W, 50W, 60W$. Modulation order $M=2$ is considered. From the figure 8, we can observe that when P is smaller than or equal to a certain threshold, the graph indicates the same energy efficiency value. Once P reaches the threshold value, the EE begins to decline. Hence, the optimal energy efficient systems work at the exact value of P when the power crosses the threshold value. The tradeoff between

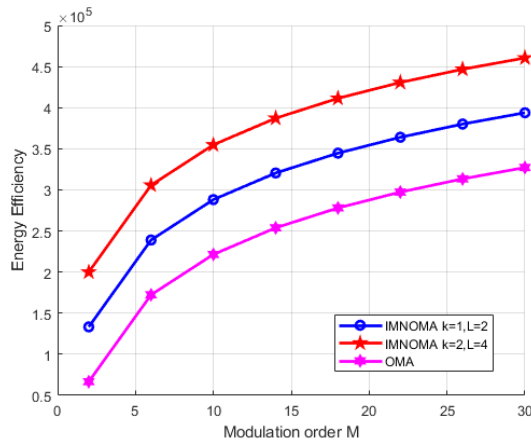


Fig. 7. Energy efficiency versus M for different values of L and K

EE and SE can be accomplished by adjusting the power. Since OMA system is independent of L, IMNOMA outperforms the OMA as shown in the Figure 8. We can also observe that the energy efficiency increases with the decrease in circuit power.

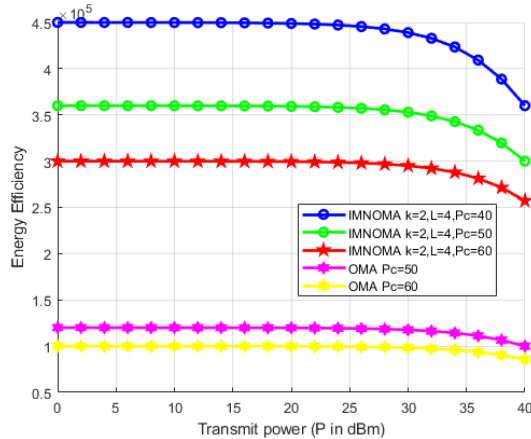


Fig. 8. Energy efficiency versus transmit power P for different values of $L = 4$, $K = 2$, $P_c = 40W, 50W, 60W$.

V. CONCLUSION

A novel IMNOMA system is proposed and energy efficiency of the proposed system is analyzed. According to the results of the simulation, IM-NOMA offers a greater energy efficiency than the existing OMA systems. The number of active sub-carriers rises along with the energy efficiency for a given M and L. The point at which energy efficiency reaches its greatest is when $K = L/2$. P must be less than or equal to a predetermined threshold in order for the graph to display the same energy efficiency value. In comparison to OMA, IMNOMA performs better in terms of energy efficiency for different system parameters.

REFERENCES

- [1] Z. Zhang, Y. Xiao, Z. Ma, M. Xiao, Z. Ding, X. Lei, G. K. Karagiannidis, and P. Fan, "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," *IEEE Vehicular Technology Magazine*, vol. 14, no. 3, pp. 28–41, 2019.
- [2] L. Dai, B. Wang, Z. Ding, Z. Wang, S. Chen, and L. Hanzo, "A survey of non-orthogonal multiple access for 5G," *IEEE Communications Surveys and Tutorials*, vol. 20, no. 3, pp. 2294–2323, 2018.
- [3] H. M. Shwetha and S. Anuradha, "Analysis of Downlink and Uplink Non-orthogonal Multiple Access (NOMA) for 5G," in *Proceedings of Third International Conference on Sustainable Computing SUSCOM 2021*, 2022, pp. 385–395. [Online]. Available: https://link.springer.com/10.1007/978-981-16-4538-9_38
- [4] M. Liaqat, K. A. Noordin, T. Abdul Latef, and K. Dimiyati, "Power-domain non orthogonal multiple access (PD-NOMA) in cooperative networks: an overview," *Wireless Networks*, vol. 26, no. 1, pp. 181–203, 2020. [Online]. Available: <https://doi.org/10.1007/s11276-018-1807-z>
- [5] H. M. Shwetha and S. Anuradha, "Index Modulation-Based Non-orthogonal Multiple Access (IM-NOMA): Spectral Efficiency Analysis," in *Proceedings of Second International Conference on Computational Electronics for Wireless Communications*, 2023, pp. 517–526. [Online]. Available: <http://link.springer.com/10.1007/978-981-13-8222-2>
- [6] M. Irfan, B. S. Kim, and S. Y. Shin, "A spectral efficient spatially modulated non-orthogonal multiple access for 5G," *2015 International Symposium on Intelligent Signal Processing and Communication Systems, ISPACS 2015*, pp. 625–628, 2016.
- [7] H. M. Shwetha and A. Sundru, "A novel multicarrier index keying-aided non-orthogonal multiple access systems in presence of uncertain channel state information," *International Journal of Communication Systems*, no. May, pp. 1–22, 2023.
- [8] H. M. Shwetha and S. Anuradha, "Performance Analysis of Novel Index Modulation-Based Non-Orthogonal Multiple Access Systems over Nakagami-m Fading Channels with Imperfect CSI," *Radioengineering*, vol. 32, no. 3, pp. 425–437, 2023.