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BOOSTING THE SUM RATE IN A THREE USER NOMA NETWORK USING INSPIRED CR-NOMA POWER ALLOCATION

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ABSTRACT

Fifth generation (5G) network which utilizes non-orthogonal multiple access (NOMA) to achieve some of its data requirement and maintain its advantages of low latency, high throughput and spectral efficiency, which needs to be maximized to accommodate more users and enhance network capacity. This research proposes Rayleigh fading approach and inspired cognitive radio (CR-NOMA) power allocation to boost the sum rate in a three-user single carrier (SC-NOMA) system. The adopted model allocates power based on users' channels condition while guaranteeing the minimum power required by the weakest user. This leads to simulations that involve three users with different channel conditions where their total sum rate is calculated and compared with the sum rate achieved when conventional fixed (F-NOMA) power allocation is used which does not maximize the spectral efficiency in both arrangements. The results revealed that simulation with three users arranged in two different forms that is, two user NOMA system coupled with lone unpaired user communicated using orthogonal multiple access (OMA) and three user SC-NOMA where they both uses F-NOMA power allocation, yields the maximum sum rate of 1.8 x 10^{-4}bps/Hz and 0.3 x 10^{-4}bps/Hz respectively. While inspired CR-NOMA power allocation yields a maximum sum rate of 16 bps/Hz for SC-NOMA and 7.5 bps/Hz for typical NOMA-OMA arrangement. The result shows a significant improvement over the existing system from 5.8% to 47% efficiency despite loading up to three users. Furthermore, the Bit error rate (BER)of SC-NOMA was analyzed using rician fading channels which present decreasing BER from a low of 0.15 to about 0.001 for user 1 and a constant low for user 2 and 3 for inspired CR-NOMA power allocation used in SC-NOMA.

Keywords: *NOMA, OMA, SC-NOMA, CR-NOMA, F-NOMA, Sum rate*

1. INTRODUCTION

An outright utilization of fifth generation (5G) wireless systems demand more effective radio access techniques to obtain a very high data rate due to immense connectivity and continuous demand of multiple services by data ravenous applications. The international telecommunication union (ITU) rolled out requirements for the 5G network in (ITU, 2017). To meet those requirements, researchers opted for Non-orthogonal Multiple access (NOMA) because Fourth Generation (4G) network, which uses Orthogonal frequency division multiple access (OFDMA), can no longer be used due to the utilization of one resource block of 180 KHZ, which cannot be used by more than one user (Vaezi & Vincent Poor, 2019). Though, NOMA may have a different meaning from different researchers, the most common definition accepted is; NOMA refers to a mode of transmission where there is concurrent transmission via a single channel over the same resources in time and frequency (Vaezi & Vincent Poor, 2019). NOMA becomes unique because it utilizes the power domain, which has not been used in any previous multiple access (Ding, Adachi, & Poor, 2016). Although (Boccuzzi, 2019) proves that NOMA can be theoretically applied to all users jointly, in practice, it cannot support any number of users because the higher the number of users, the more the signal degradation (Islam, Zeng, Dobre, & Kwak, 2018). This brings up the idea of user pairing (UP), Beamforming and resource allocation (RA), which enable us to group the users into clusters and applied NOMA transmission within those clusters. In the NOMA downlink, the base station (BS) uses superposition coding (SC) to encode the signal before the transmitter sends the superimposed signals at the same time and frequency but different power coefficient as in the case of power domain NOMA.

2. LITERATURE REVIEW

To reduce complexity due to an overwhelming number of multiple users, the users can be paired so that in each pair there are users with distinct channel conditions (Benjebbour, Li, Kishiyama, Jiang, & Nakamura, 2014). The level of power allocation from a base station is inversely proportional to the users' channel condition such that the user with poorer channel condition is allocated higher power than a strong user (Aldababsa, Toka, Gökçeli, Kurt, & Kucur, 2018). At the receiver, Successive interference cancellation (SIC) is located where, the signal is decoded in such a way that the strong user has to decode the signal of the weak user by treating the other signals as noise before extracting its own signal, while the cell edge user or the weak user directly extracts its information signal. Figure 1 shows the arrangement of two-user downlink NOMA network.

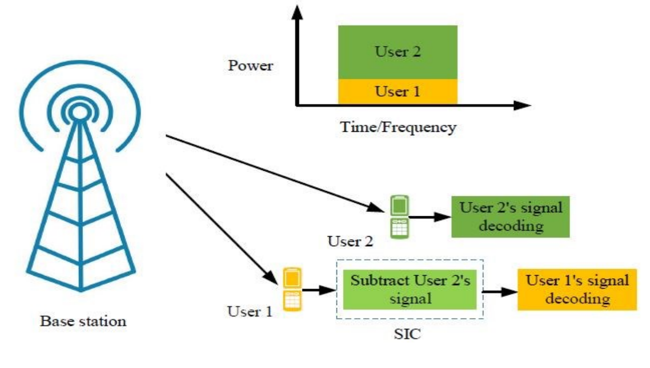

Figure 1.Typical two user NOMA Downlink Network(Zeng, Nguyen, Dobre, Poor, & Poor, 2020)

In NOMA uplink, the latency can be significantly reduced by allowing the users to transmit in a grant free manner, in such a way that where the signals are summed up and SIC iterations took place to extract the signal of mobile stations (MS) at the base station (Aldababsa et al., 2018). (Chen, Ding, Dai, & Karagiannidis, 2016) investigated and verified the Quasi-degraded channels and found that extension remains an open issue to general ones. (Zeng, Yadav, Dobre, Tsiropoulos, & Poor, 2017a) investigated the superiority of multiple input multiple output (MIMO-NOMA) over multiple input multiple output for orthogonal multiple access (MIMO-OMA) when multiple users are grouped into a cluster in terms of both channel capacity and ergodic sum rate capacity which shows that there is a compromise between the signal quality and the maximum number of admitted users. This means that the more the users admitted into the cluster, the higher the signal degradation. (Zeng et al., 2017a) proposed a user admission scheme that will balance both the maximum number of users and the minimum required rate, while (Zeng, Yadav, Dobre, Tsiropoulos, & Poor, 2017b) studied the performance of multiple input multiple output (MIMO-NOMA) over MIMO-OMA and prove that with a simple case of two users, MIMO-NOMA dominates in terms of both sum rate and ergodic sum. Hence, concluded that to maintain the performance of MIMO NOMA over MIMO-OMA in case of multiple users, the users must be grouped into clusters and share the same transmit beamforming vector within a cluster. Authors of (Ding, Adachi, et al., 2016) argued that MIMO-NOMA can only maintain better performance over MIMO-OMA if the users are paired in such a way that their channels condition are distinct. Also it is presented in (Ding, Fan, & Poor, 2016) the impact of user pairing on NOMA systems when they are operated under the constraints of inspired CR-NOMA and fixed (F-NOMA) power allocation and discovered that the achievable rate gap using F-NOMA power allocation is based on the distinction between users' channel conditions, while in inspired CR-NOMA power allocation, where the users are paired based on the cognitive radio characteristics. However, fixed F-NOMA power allocation is disadvantageous for users with high channel attenuation but beneficial for strong users (Xing, Liu, Nallanathan, Ding, & Poor, 2018). Matching theory technique in CR-NOMA called distributed matching algorithm is proposed in (Liang, Ding, Li, & Song, 2017) where a strong user and a weak user of the same cluster negotiate the minimum power allocation coefficient to be assigned to them. Also, (Auyo, Babale, & Bello, 2022) adopted inspired CR-NOMA power allocation to lower bit error rate, outage probability and improve the Achievable capacity for three users configured in SC-NOMA system while (Shili, Hajjaj, & Ammari, 2022) proposed an efficient user clustering Algorithm to improve the spectral efficiency and reduces performance loss due to channel uncertainty.

Typical NOMA system consisting of multiple users are grouped into clusters containing two users with distinct channel conditions, and NOMA applied within those clusters. In the case of odd number of users, one of the clusters contains only one user which is communicated via conventional OMA; thereby, depriving it of the benefit of NOMA system and lowering the spectral efficiency. This paper is aimed at boosting the sum rate when three users are arranged in an SC-NOMA system by using the inspired CR-NOMA power allocation to improve the sum rate while countering the effect of loading the network with more users instead of applying the conventional (F-NOMA) power allocation.

Figure 2 illustrates a typical NOMA-OMA system consisting of three users in which two users (user 1 and user 2) shares the same frequency using NOMA, but different power level while user 3 occupied a particular frequency using OMA on a different power level while figure 3 shows all the three users sharing the same frequency using SC-NOMA but different power level.

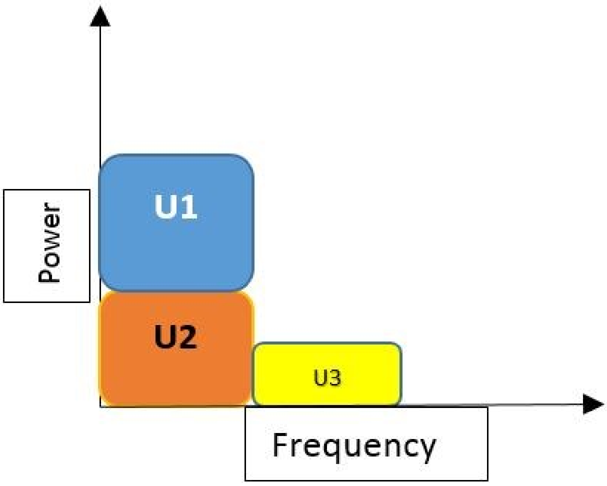

Figure 2. Showing a typical NOMA-OMA system

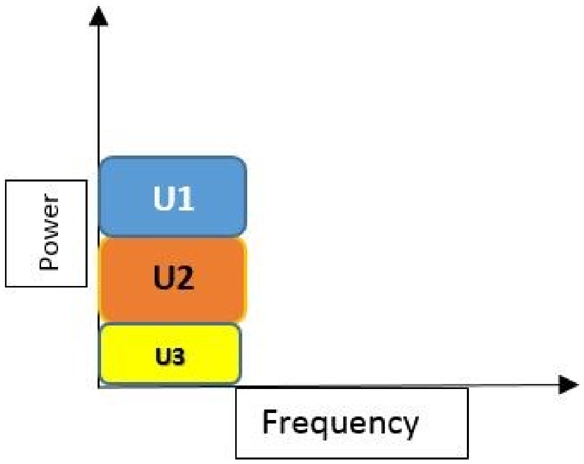

Figure 3: Showing SC-NOMA system.

The remaining part of the paper is presented as follows; section 2 described the system model used in this work while section 3 present and discusses the result and the paper is concluded in section 4.

3. METHODOLOGY

This section dicuss the Model and Methodology used in carrying out the work which is broken down into two parts, the Typical NOMA-OMA system and SC-NOMA arrangement of three users were detailed in the upcoming section.

3.1.1 Typical NOMA- OMA system

Maximum of three users were considered in this work to maximize the efficiency of the spectrum. The users are randomly deployed in a cell, as used in (Liang et al., 2017), with an outer radius R_o which also have a virtual inner radius R_i consisting of certain number of users U, which are randomly distributed within the cell coverage area. Based on their channel condition, the users located within the inner radius R_i (user 2 and user 3) are considered as strong users (SU), while the user outside the inner radius R_i but within the outer Radius R_o (user 1), which is also known as cell edge user, is considered as a weak user (WU) or primary user (PU) as shown in figure 4.

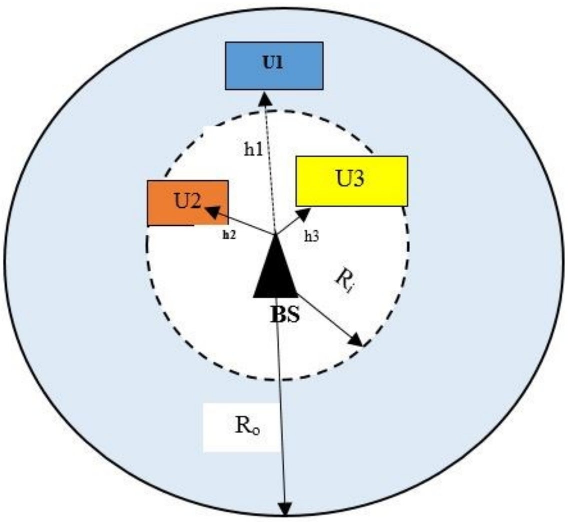

Figure 4. Configuration of three users

In this case, user 1 and user 2 are paired together due to their distinct channels while user 3 utilized its own spectrum and resources. A constraint is imposed on the strongest user in the NOMA network to make sure that the minimum required Quality of Service (QOS) is achieved by the weakest user before the two strong users transmit on the weakest user's spectrum using superposition coding at the transmitter. The weakest user which is assumed to have very poor channel condition is allocated higher percentage of the transmit power. At the receiver's end, the weakest user does not need SIC to decode its message while the remaining users need SIC process to decode their messages as shown in figure 5.

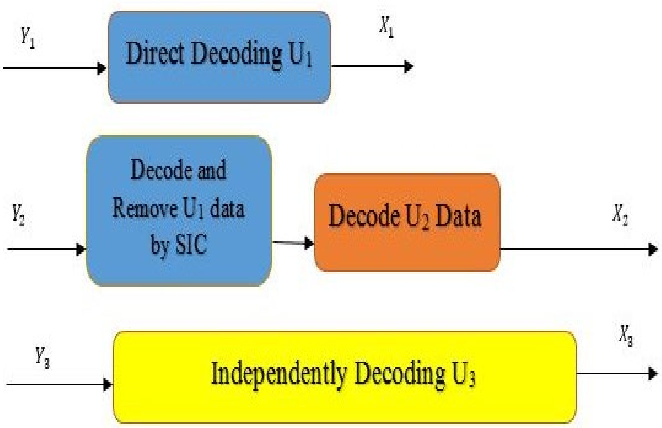

Figure 5. Configuration of three users

From figure 4, h_1, h_2 and h_3 denote their corresponding Rayleigh fading coefficients such that $|h_1|^2 < |h_2|^2 < |h_3|^2$. Channels are assumed to be Rayleigh distributed, following Gaussian noise terms, which have zero mean and a noise variance of N_o /2 per dimension. Figure 5 shows how the messages for Equations (1), (2) and (3), which were adopted from (Liang et al., 2017), could be decoded using the SIC. Furthermore, user 3 which is not in the NOMA system was decoded directly using the OMA scheme.

The signal received at the weakest user (U_1) is presented in (1):

$$y_1 = h_1\left(\sqrt{\alpha_1 P_s x_1} + \sqrt{\alpha_2 P_s x_2}\right) + n_1 \quad (1)$$

The signal received at strong user, U_2, is given by (2);

$$y_2 = h_2\left(\sqrt{\alpha_1 P_s x_1} + \sqrt{\alpha_2 P_s x_2}\right) + n_2 \quad (2)$$

The signal received at strong user, U_3, is given by (3);

$$y_3 = h_3\left(\sqrt{\alpha_3 P_t x_3}\right) + n_3 \quad (3)$$

where h is the Rayleigh fading channel, α is the power allocation coefficient, P_s is the transmit power allocated to that cluster, P_t is the total transmit power from the BS, χ is the transmitted message, and n is the Gaussian noise. The power coefficient allocation in NOMA must satisfy the conditions given in (4), (5), and (6).

$$\alpha_1 > \alpha_2 > \alpha_3 \quad (4)$$

$$\alpha_1 > \alpha_2 + \alpha_3 \quad (5)$$

$$\alpha_1 + \alpha_2 + \alpha_3 = 1 \quad (6)$$

the achievable rate for user 1 is given by (7).

$$R_1 = log_2\left(1 + \frac{\gamma_1|h_1|^2\alpha_1}{1+\gamma_1|h_1|^2(\alpha_2)}\right) \quad (7)$$

Note that γ_1 is the transmit signal to noise ratio (SNR) of user during transmission.

The achievable rate for user 2 is given by (8)

$$R_2 = 0.5log_2(1 + (\alpha_2)\gamma_2|h_2|^2) \quad (8)$$

Also, the minimum required rate of user 3 is the rate calculated when using OMA as given by (9)

$$R_3 = 0.5log_2(1 + \gamma_3|h_3|^2) \quad (9)$$

where the factor 0.5 in (9) is a multiplexing loss resulting from OMA (Liang et al., 2017).

To find the power allocated to the user 1 we make (7) greater than or equal to the rate achieved if OMA was used which is the minimum required rate.

$$log_2\left(1 + \frac{\gamma_1|h_1|^2\alpha_1}{1+\gamma_1|h_1|^2(\alpha_2)}\right) \geq 0.5log_2(1 + \gamma_1|h_1|^2) \quad (10)$$

The BS allocate the power to the users based on conditions (4) to (6)

Therefore, the minimum power coefficient allocated to user is given by (11), which is realized from (10).

$$\alpha_1 \geq \frac{\left(\sqrt{1+\gamma_2|h_2|^2}-1\right)}{\gamma_2|h_2|^2} \quad (11)$$

From (6), we derived the power coefficient allocated for the user three in the three-user pair.

$$\alpha_2 = 1 - \alpha_1 \quad (12)$$

$$\alpha_s = \alpha_1 + \alpha_2 \quad (13)$$

where α_s in (13) is the power coefficient allocated to the NOMA cluster.

Since,

$$P_T = P_s + P_3 \quad (14)$$

where, P_3 is the power allocated to user 3

Then,

$$\alpha_3 = 1 - \alpha_s \quad (15)$$

α_3 and α_s are power coefficients allocated by the BS in a fixed manner.

3.1.2 Three users SC-NOMA

In this case, all the three users are put in the same cluster to use SC-NOMA to transmit using the same resources. Refer to Figure 3, user 1 is the weakest user while user 2 and user 3 are strong users. Figure 6 shows how their information is being extracted using SIC processes.

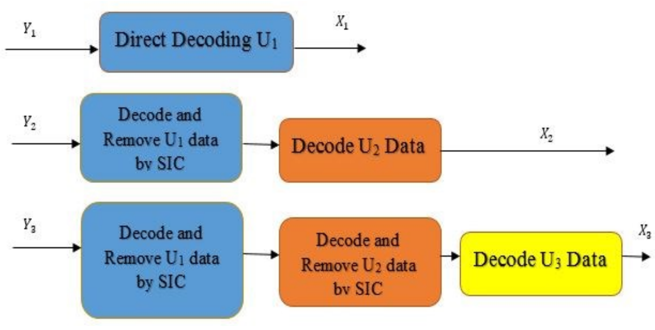

Figure 6: Configuration of three users using SIC process

the signal received at the weakest user (U_1) is given by (16)

$$y_1 = h_1\left(\sqrt{\alpha_1 P_s x_1} + \sqrt{\alpha_2 P_s x_2} + \sqrt{\alpha_3 P_s x_3}\right) + n_1 \quad (16)$$

the signal Received at user 2 is given by is given by (17).

$$y_2 = h_2\left(\sqrt{\alpha_1 P_s x_1} + \sqrt{\alpha_2 P_s x_2} + \sqrt{\alpha_3 P_s x_3}\right) + n_2 \quad (17)$$

the signal Received at user 3 is given by is given by (18).

$$y_3 = h_3\left(\sqrt{\alpha_1 P_s x_1} + \sqrt{\alpha_2 P_s x_2} + \sqrt{\alpha_3 P_s x_3}\right) + n_3 \quad (18)$$

The power allocation coefficient in this configuration must also satisfy the same conditions of (4), (5) and (6). The achievable rate for user 1 is same as (7)

The achievable rate for the user 2 in this case is given by (19).

$$R_2 = log_2\left(1 + \frac{\gamma_2|h_2|^2\alpha_2}{1+\gamma_2|h_2|^2(\alpha_3)}\right) \quad (19)$$

The achievable rate for the user 3 is same as (9).

To find the power allocated to the weakest user, (19) was made to be greater than or equal to the achievable rate when OMA was used as shown in (20). This led to the formulation of (21).

$$log_2\left(1 + \frac{\gamma_1|h_1|^2\alpha_1}{1+\gamma_1|h_1|^2(\alpha_2+\alpha_3)}\right) \geq 0.5log_2(1+\gamma_1||h_1|^2) \quad (20)$$

The minimum power allocation coefficient for user 1 is derived from (22) and is written as;

$$\alpha_1 \geq \frac{(\sqrt{1+\gamma_1|h_1|^2}-1)(1+\gamma_1|h_1|^2)}{\gamma_1|h_1|^2+(1+\gamma_1|h_1|^2)(\sqrt{1+\gamma_1|h_1|^2}-1)} \quad (21)$$

The minimum power allocated for user 2 is given by (22), which was formulated by making (19) to be greater than or equal to (9)

$$\alpha_2 \geq \frac{\left(\sqrt{1+\gamma_2|h_2|^2}-1\right)}{\gamma_2|h_2|^2} \quad (22)$$

From (6), we derived the power coefficient allocated to user 3 as (23).

$$\alpha_3 = 1 - \alpha_1 - \alpha_2 \quad (23)$$

4. RESULT AND DISCUSSION

In the design network, the Rayleigh fading coefficient of the Channels which can be any arbitrary value in such a way that the weakest user must be assigned the lowest value signaling the poor condition of its channel, the values are assigned to be 8 dB for user 1, user 2 to be 5 dB and user 3 to be 27 dB. The system Bandwidth of 1MHZ is utilized, the thermal noise power was calculated using (24).

$$N_O = KTB \quad (24)$$

where, $k = 1.38 \times 10^{-23} T = 300K$, and B is the Bandwidth making N_o to be -174 dB

4.1 Fixed power allocation

In F-NOMA the power allocation factors for the users are constants and the strongest user is allocated less power than the weakest user, as long as the order of the users' channels condition is still the same (Yang, Ding, Fan, &Al-Dhahir, 2017). In this case, the power allocation coefficients are not functions of the users' channel fading gains, i.e., the transmitter only needs to know the order of the users' channel fading gains which were provided below to perform NOMA, based on which it allocates the following power coefficients as α_1= 0.8, $\alpha_2 = 0.15,$ and $\alpha_3 =$ 0.05 according to the user's distance to the base station because they satisfy conditions given by (4), (5), and (6).User 1, User 2, and User 3 were randomly placed at a distance of 500 m, 150 m and 70 m, respectively, away from the BS, for $d_1 > d_2 > d_3$. Figure 7 shows a plot of sum rate versus SNR for three users in two different arrangements. That is, typical NOMA-OMA and SC-NOMA, using F-NOMA power allocation. It was noticed that typical NOMA-OMA is performing better as the SNR increased to up to 1.8 bps/HZ as the SNR approaches 40dB. Because the achievable rate of the lone user which occupies a whole spectrum is higher and contribute to the increase in the total sum rate which is also a function of the SNR.

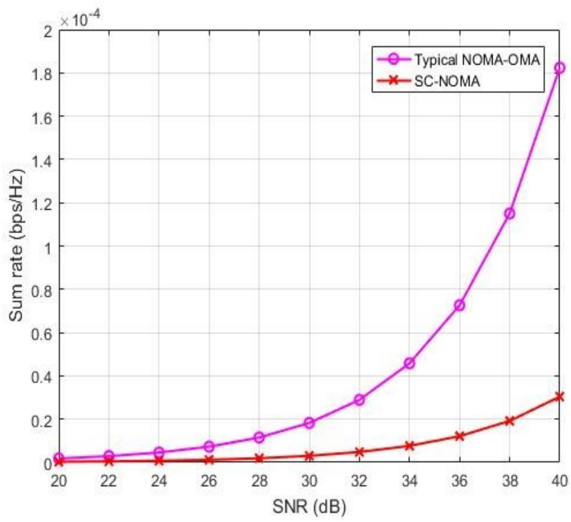

Figure 7: Plot of sum rate versus SNR when F-NOMA is used.

4.2 Inspired CR-NOMA power allocation

In Figure 8, where the inspired CR-NOMA power allocation is used for both arrangements of typical NOMA-OMA and SC-NOMA, it significantly improves the sum rate for both typical NOMA-OMA and SC-NOMA. Although that of typical NOMA-OMA has improved to about 8bps/Hz,at 20dB (SNR), the sumrate was higher at zero because of the initial sum rate of the lone user which uses OMA, also that of SC-NOMA have improved more to as high as 16bps/Hz at 34dB (SNR) which is about 47% efficiency compare to 5.8% efficiency at the same SNR. This fulfilled the goal of the research, which is boosting the sum rate in a three user SC-NOMA system and further shows that SC-NOMA with up to three users in a system can enjoy a very large sum rate if inspired CR-NOMA power allocation is used.

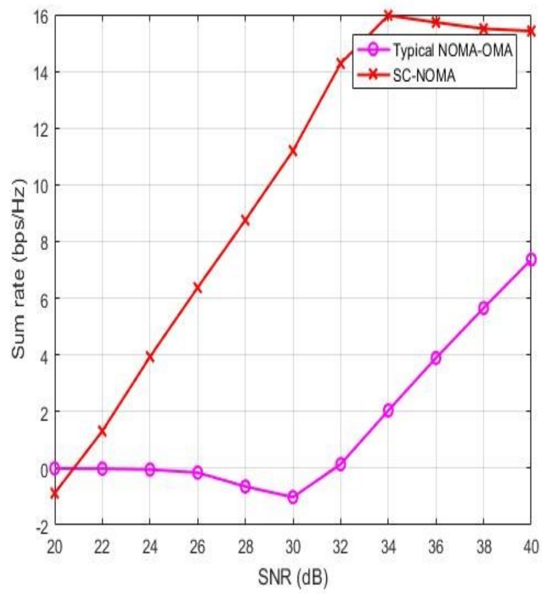

Figure 8: Plot of sum rate versus SNR when inspired CR-NOMA was used

4.2.1 BER analysis of SC-NOMA on Rician fading channels

The rician fading channels provide a more accurate rep-

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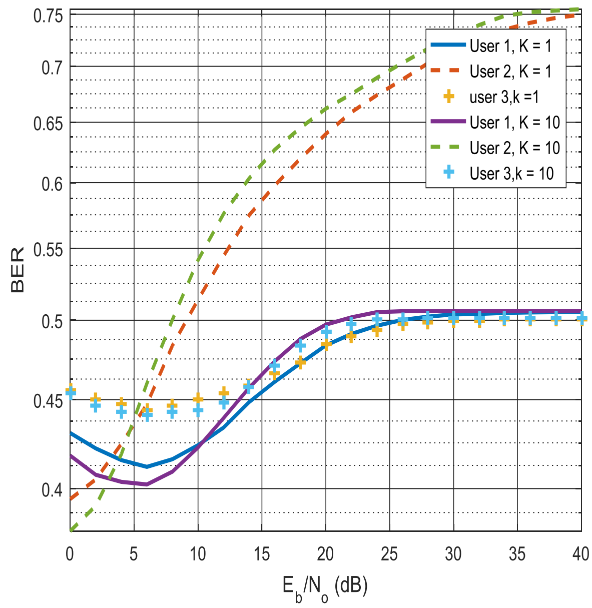
resentation of the radio channel in a dense urban environment(Khansa, Chen, Gui, & Sari, 2020), making it very important to consider before deploying 5G in cities. The BER was analysed when fixed power is allocated to the three user SC-NOMA on rician fading channels. The rician factor which is a measure of severity of fading, with k= 0 being the most severe Rayleigh fading and k = ∞ being a non-fading channelit also represents the propagation of the signal power in the line of sight(LOS) component over the scattered power. The consist of one random component which represents propagation through reflection, refractions, etc. and one deterministic component which represents LOS, the K-factor of the channel determine the energy distribution between the two components(TSE, DAVID(University of California, Berkele), Pramod Viswanath(University of Illinois, 2004). Rician fading model is given by:

$$X = \sqrt{\frac{K}{K+1}}\sigma \times \exp(j\theta) + \sqrt{\frac{K}{K+1}} CN(0, \sigma^2 \times) \quad (25)$$

Where, $\sigma^2 \times = E(|X|^2), \theta$ is a phase uniformly distributed over the interval (0,2π), and CN (0, $\sigma^2 \times$) is a zero-mean circularly symmetric complex Gaussian variable of variance $\sigma^2 \times$. Note that the real and imaginary parts of CN (0, $\sigma^2 \times$) are real gaussian variables of variance $\sigma^2 \times /2$.

Rician factor k= 1 was arbitrarily used for all the users and compared to when rician factor k= 10 was used again on all users. To determine the fading of the channels in dealing with lower or higher BER. Fixed power was allocated to obtain the result in figure 9.



Meanwhile, when the inspired CR-NOMA power allocation was used using exactly the above model, The BER drastically reduce for user 1 to as low as 10^{-4} while all users maintain a BER of less than 1 as can be seen in figure 10

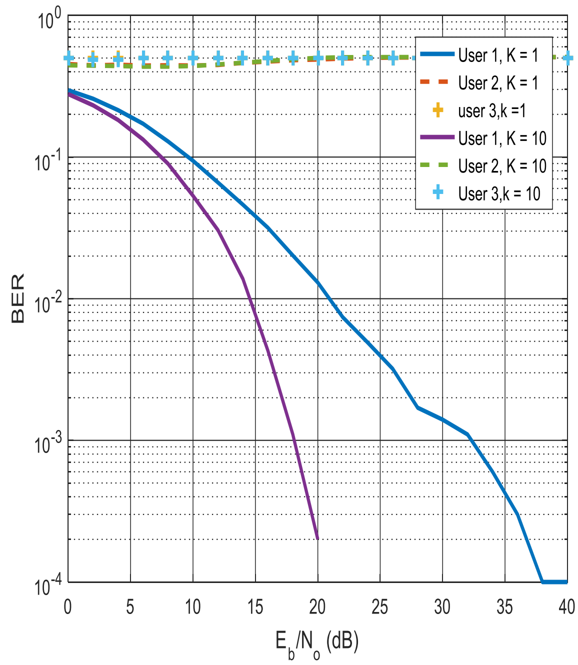


Figure 10: BER performance of SC-NOMA using CR -NOMA power allocation on rician fading channels factor K=1 and K=10.

Figure 9: BER performance of SC-NOMA using fixed poweron rician fading channels factor K=1 and K=10.

5. CONCLUSION

In this work, Inspired CR-NOMA power allocation is applied to a three user SC-NOMA in order to boost the sum rate using Rayleigh fading channels. The sum rate was analyzed using F-NOMA power allocation for two different configurations, which are typical NOMA-OMA system and SC-NOMA system where a low sum rate was observed. SC-NOMA is used to improve spectral efficiency by using a single frequency for three users, while Inspired CR-NOMA power allocation is adopted to counter the effect of loading the network by boosting the sum rate. The result shows significant improvement in the sum rate in the three user SC-NOMA when inspired CR-NOMA power allocation is applied from about -2 bps/Hz to a maximum of 16bps/Hz and the efficiency of the spectrum.has improved providing a vacant spectrum to load more users. This further shows the superiority of Inspired CR-NOMA power allocation over F-NOMA power allocation.

REFERENCES

Aldababsa, M., Toka, M., Gökçeli, S., Kurt, G. K., & Kucur, O. (2018). A Tutorial on Nonorthogonal Multiple Access for 5G and Beyond. *Wireless Communications and Mobile Computing*, *2018*, 9713450. https://doi.org/10.1155/2018/9713450

Auyo, A. M., Babale, S. A., & Bello, L. M. (2022). Effect of Inspired CR-NOMA Power Allocation on Bit Error Rate For Three User NOMA system. In *2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON)* (pp. 1–5). https://doi.org/10.1109/NIGERCON54645.2022.9803163

Benjebbour, A., Li, A., Kishiyama, Y., Jiang, H., & Nakamura, T. (2014). System-level performance of downlink NOMA combined with SU-MIMO for future LTE enhancements. In *2014 IEEE Globecom Workshops (GC Wkshps)* (pp. 706–710). https://doi.org/10.1109/GLOCOMW.2014.7063515

Boccuzzi, J. (2019). Introduction to Cellular Mobile Communications BT - Multiple Access Techniques for 5G Wireless Networks and Beyond. In M. Vaezi, Z. Ding, & H. V. Poor (Eds.) (pp. 3–37). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-92090-0_1

Chen, Z., Ding, Z., Dai, X., & Karagiannidis, G. K. (2016). On the Application of Quasi-Degradation to MISO-NOMA Downlink. *IEEE Transactions on Signal Processing*, *64*(23), 6174–6189. https://doi.org/10.1109/TSP.2016.2603971

Ding, Z., Adachi, F., & Poor, H. V. (2016). The Application of MIMO to Non-Orthogonal Multiple Access. *IEEE Transactions on Wireless Communications*, *15*(1), 537–552. https://doi.org/10.1109/TWC.2015.2475746

Ding, Z., Fan, P., & Poor, H. V. (2016). Impact of User Pairing on 5G Nonorthogonal Multiple-Access Downlink Transmissions. *IEEE Transactions on*

Vehicular Technology, *65*(8), 6010–6023. https://doi.org/10.1109/TVT.2015.2480766

Islam, S. M. R., Zeng, M., Dobre, O. A., & Kwak, K.-S. (2018). Resource Allocation for Downlink NOMA Systems: Key Techniques and Open Issues. *IEEE Wireless Communications*, *25*(2), 40–47. https://doi.org/10.1109/MWC.2018.1700099

ITU. (2017). Minimum requirements related to technical performance for IMT-2020 radio interface(s). Retrieved March 25, 2020, from https://www.itu.int/md/R15-SG05-C-0040/en

Liang, W., Ding, Z., Li, Y., & Song, L. (2017). User Pairing for Downlink Non-Orthogonal Multiple Access Networks Using Matching Algorithm. *IEEE Transactions on Communications*, *65*(12), 5319–5332. https://doi.org/10.1109/TCOMM.2017.2744640

Shili, M., Hajjaj, M., & Ammari, M. L. (2022). User Clustering and Power Allocation for Massive MIMO with NOMA-Inspired Cognitive Radio. *IEEE Transactions on Vehicular Technology*, 1. https://doi.org/10.1109/TVT.2022.3171500

Vaezi, M., & Vincent Poor, H. (2019). NOMA: An Information-Theoretic Perspective. In M. Vaezi, Z. Ding, & H. V. Poor (Eds.), *Multiple Access Techniques for 5G Wireless Networks and Beyond* (pp. 167–193). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-92090-0_5

Xing, H., Liu, Y., Nallanathan, A., Ding, Z., & Poor, H. V. (2018). Optimal Throughput Fairness Tradeoffs for Downlink Non-Orthogonal Multiple Access Over Fading Channels. *IEEE Transactions on Wireless Communications*, *17*(6), 3556–3571. https://doi.org/10.1109/TWC.2018.2803177

Yang, Z., Ding, Z., Fan, P., & Al-Dhahir, N. (2017). The Impact of Power Allocation on Cooperative Non-orthogonal Multiple Access Networks With SWIPT. *IEEE Transactions on Wireless Communications*, *16*(7), 4332–4343. https://doi.org/10.1109/TWC.2017.2697380

Zeng, M., Nguyen, P., Dobre, O., Poor, H. V., & Poor, H. (2020). Physical Layer Security for NOMA Systems.

Zeng, M., Yadav, A., Dobre, O. A., Tsiropoulos, G. I., & Poor, H. V. (2017a). Capacity Comparison Between MIMO-NOMA and MIMO-OMA With Multiple Users in a Cluster. *IEEE Journal on Selected Areas in Communications*, *35*(10), 2413–2424. https://doi.org/10.1109/JSAC.2017.2725879

Zeng, M., Yadav, A., Dobre, O. A., Tsiropoulos, G. I., & Poor, H. V. (2017b). On the Sum Rate of MIMO-NOMA and MIMO-OMA Systems. *IEEE Wireless Communications Letters*, *6*(4), 534–537. https://doi.org/10.1109/LWC.2017.2712149