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Real time implementation of downlink orthogonal frequency division multiplexing based non-orthogonal multiple access transceiver using NI USRP platform

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ABSTRACT

The growing fame and utilization of wireless multimedia approaches have led to the advancement of the wireless system. The fifth generation (5G) of wireless communication was developed to serve users with enhanced proficiency, low latency, reliable communication, and lesser battery exhausts. The non-orthogonal multiple access (NOMA) scheme is a proficient multiple access scheme to fulfil the requirement of a 5G mobile system. NOMA enables a remarkable enhancement in the systems throughput and ability to connect devices. NOMA distinguishes each user by allocating a distinct power level, superimposing all the user’s signals utilizing superposition coding while transmitting and at the reception, each user’s signals are decoded by employing successive interference cancellation (SIC). This study builds a real time downlink orthogonal frequency division multiplexing based NOMA (OFDM-NOMA) transceiver system using the NI USRP 2944R and 2901 platforms. The performance evaluation of the proposed OFDM-NOMA system is carried out in terms of signal to noise ratio by adjusting transmitting gain and the distance of users from the base station system. Experimental results show that the signal-to-noise ratio (SNR) of each user relies on the power allocation factor and proximity of users from the base station, and SIC output is compared with constellation variations.

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1. INTRODUCTION

The design of multiple-access technology generates a wireless link between users and networks, and at the same time, permits users to access mutual resources inside the coverage range of wireless networks. It is well-known that the advancement and technological revolution in multiple access schemes have massively benefited wireless systems by providing immense help in the evolution of wireless systems. However, it has become extremely challenging for traditional orthogonal multiple access (OMA) schemes to provide the high transmission rate requirements of 5G wireless systems [1]. 5G wireless systems require extremely high transmission rates, massive connectivity, and ultra-high reliability that cannot be achieved using traditional OMA schemes. Thus, the non-orthogonal multiple access (NOMA) scheme has a high potential to fulfil the aforementioned network requirements. One of the biggest advantages of adopting NOMA technology is that it can send signals to multiple different users at the same time, considering a similar time-frequency resource element [2].

The new radio (NR) interface and radio access network technology may be able to satisfy the expanding demand for the 5th generation wireless standard [3]. The potential features of NOMA can enhance spectral efficiency by allocating multiple users in each resource block and can produce massive connectivity for billions of devices that are potentially supported by NOMA [4]. This is very essential for internet of things (IoT), where users need low data rates with simultaneous usage of the same resource by multiple users [5]. NOMA supports grant-free uplink transmission, which does not require a scheduled request from the user equipment to the base station, which is usually needed in OMA techniques.

NOMA is a potential contender for future radio access with regards to capacity improvement, which is a main requirement of 5G networks [6]. However, this does not imply that NOMA will completely replace OMA schemes. In order to meet the various necessity of distinct services and applications in the future of 5G, both OMA and NOMA will coexist. However, there are certain issues with the real time implementation of the NOMA system [7]. However, most of the previous work highlights on simulation of OFDM-NOMA system. Thus, in this work real time implementation of multiuser orthogonal frequency division multiplexing based NOMA (OFDM-NOMA) is considered to improve the proficiency of resource allocation. Therefore, this article explains how to use software defined radio (SDR) to create an OFDM-NOMA downlink system. For the purpose of prototyping wireless communication systems, universal software radio peripherals (USRPs) are used. Here, NI USRP 2944R and USRP 2901 SDR are used with a power domain multiuser downlink OFDM-NOMA system implementation. Experimental results are conducted for four users' successive interference cancellation (SIC) and power distribution is tested in real-time. This paper is arranged in the following style: section 2 discusses the related work regarding NOMA methods and identifies issues related to NOMA. Section 3 describes the methodology for the implementation of the OFDM-NOMA system. Section 4 discusses the testbed results, and section 5 concludes the paper.

2. RELATED WORK

5G wireless systems require extremely high data rates, massive connectivity, and ultra-high reliability. To reinforce the connectivity of enormous users and various applications in the 5G system, several NOMA methods have been designed [8]. NOMA's fundamental idea is to eliminate interference caused by paired users by superimposing at the transmitter and subsequent decoding algorithms used at the receiver. NOMA allocates more power to the weak user to empower fairness among the users [9]. The signal power of the users should be correctly distributed based on their channel gains to enable successful SIC. Allocating more power to weaker users improves the signal to noise ratio, which results in enhanced channel capacity for weaker users [10], [11]. Thus, the overall throughput of the NOMA system has improved. NOMA also supports massive connectivity for 5G by allocating distinct kinds of users to similar resource blocks [12]. The NOMA is adaptable to existing wireless communication techniques and can be integrated easily. The spectral proficiency of the OFDM system can be improved by integrating NOMA with OFDM where several users will be allocated to a similar subcarrier. Hence, NOMA boosts the capability of conventional wireless systems. Hybrid NOMA schemes are introduced to improve the sum rate and outage probability [13]. A detailed review is performed on different hybrid NOMA systems like CR-NOMA [14], OFDM-NOMA [15]. The NOMA technique maximizes power efficiency and sum rate to a great extent. A review of the NOMA scheme is performed to minimize the complexity and delay of uplink and downlink channels [16], [17].

Different communication systems can be implemented using the software-defined radio (SDR) platform, which has tunable carrier frequencies, adjustable bandwidths, and controlled transmission power. The concept of SDR is driven by a number of factors, including the frontend's high degree of adaptability to the modulation, channel bandwidth, or carrier frequency under consideration, as well as potential cost reductions over a traditional hardware-based system [18]. SDR opens up a variety of options by ensuring new forms of radio applications are simpler to implement, which is appealing for rapid prototyping of future 5G applications. SDR offers an adjustable and affordable method for quickly prototyping a practical OFDM NOMA system and characterizing its performance [19]. Additionally, although the majority of current NOMA systems are only concerned with designing the physical and medium access control layers, there are still many difficulties and problems with designing the upper layer protocols for NOMA systems.

The USRP NI 2944R is a duplex SDR with a tunable frequency range of 10 MHz to 6 GHz. It has a single transmitting port and two functional receiving ports. The hardware was chosen because of its full duplexing capacity and tunable carrier frequency. An essential tool for testbed setting is the LabVIEW software component, particularly when the USRP radio needs to synchronize its pairs at the transmitter and receiver [20]. The LabVIEW software platform includes the front panel and block diagram as two fundamental environments. The front panel has an input/output waveform display and a configuration of system parameters. Transceiver up-down conversions are automatically carried out by USRP devices, since the configuration for sending and receiving signals across wireless channels is provided by USRPs [21]. The downlink OFDM-NOMA system experimental setup comprises a host computer running LabVIEW and USRPs [22]. In the literature, most of the work has been focused on the simulation and implementation of two user NOMA. In this work, the implementation of four user OFDM-NOMA is proposed using software defined radio's USRP 2944R and USRP 2901 for hardware-based research and test bed validation.

3. METHOD

NOMA can be integrated with OFDMA to enhance their proficiency. Here we consider hybrid NOMA, where multicarrier modulation is performed using OFDM and NOMA as multiple access schemes. In the power domain NOMA all users are superimposed in a similar resource block simultaneously using superposition coding [23]. Each user is differentiated by allocating distinct power levels depending on their channel state information. Hence, the channel capability of NOMA is improved without any extension in bandwidth utilization [24]. The power domain OFDM-NOMA downlink system model uses one transmitter, as shown in Figure 1 the transmitter node serves as the base station. Figure 2 represents the OFDM-NOMA receiver, four receiving nodes are provided as user equipment. The fundamental ideas behind NOMA are superposition encoding and sequential decoding to cancel interference [25]. Power is allocated to each user based on their individual channel gains or relative locations. Because the power assignment factor is inversely associated with the user channel state condition, users with poor channel gain use high transmit power.

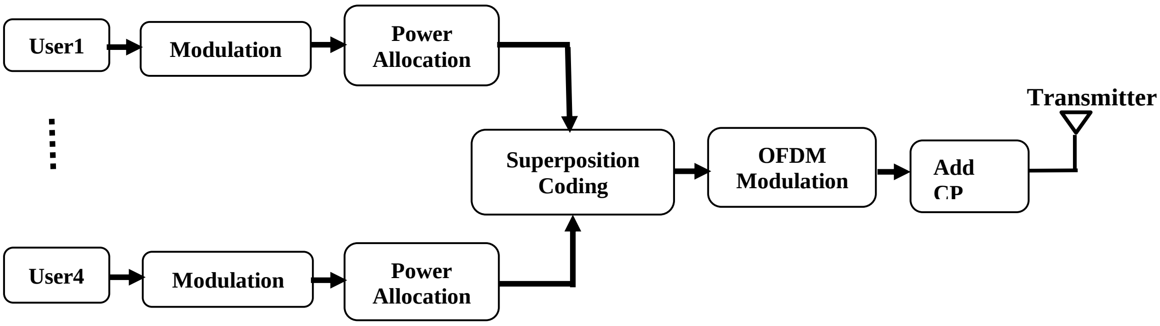

Figure 1. Block diagram of OFDM-NOMA transmitter

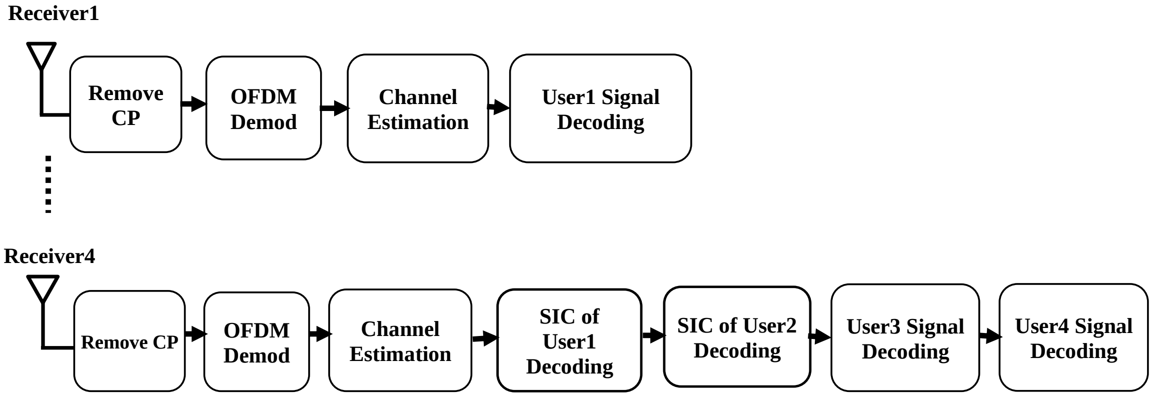

Figure 2. Block diagram of OFDM-NOMA receiver

At the receiver, SIC estimation is performed, where users are decoded depending on their power level. Users are decoded in descending sequence, the first user having more power is estimated and it is suppressed from the combined signal. Decoding a larger power signal from a combined signal results in the maximizing of the sum rate capability of the channel. Therefore, NOMA permits fairness among all users and also supports the connectivity of enormous users and improved channel capability, which leads to the utilization of NOMA in future wireless communication. Let user-transmit signals $X_1, X_2, \ldots X_N$. The base station will combine sending signals with total transmit power P for the downlink channel and give by to create the composite signal.

$$X = \sqrt{P_t a_1} X_1 + \sqrt{P_t a_2} X_2 + \cdots + \sqrt{P_t a_N} X_N \tag{1}$$

where a_1, a_2, a_3, a_4 are coefficients of power allocation. At m^{th} user, the received signal is represented as.

$$Y_m = h_m \sum_{j=1}^{N} \sqrt{a_j P_t}\, X_j + W_m \tag{2}$$

where a_j is the power allocation factor for the jth user, h_m Rayleigh fading channel coefficient of the m^{th} user, and W_m is noise with variance σ^2 [19].

The instantaneous signal-to-noise interference (SNIR) value, which was determined with respect to user m for signals of user $i \leqslant m$, can then be used to identify user i.

$$SINR_{i \to m} = \frac{a_i \gamma |h_m|^2}{\gamma |h_m|^2 \sum_{j=i+1}^{N} a_j + 1} \tag{3}$$

where the signal to noise ratio is detected by $\gamma = P_t/\sigma^2$ and $\sigma^2 = 1$. Processes for i^{th} user are implemented to get the desired information with respect to the m^{th} user. Then, SNIR for m^{th} user is expressed using (4),

$$SINR_m = \frac{a_i \gamma |h_m|^2}{\gamma |h_m|^2 \sum_{j=m+1}^{N} a_j + 1} \tag{4}$$

Similarly, after detection of N-1 users successfully, SNIR for N^{th} user is expressed using (5),

$$\sigma_M = a_i P_t |h_N|^2 \tag{5}$$

At the receiver, each user's time-domain received signal is given by (6),

$$y_{k,n} = \sqrt{\frac{P_t}{{d_k}^v}}\, x_{k,n} * h_{k,n} + w_{k,n} \tag{6}$$

where P_t represents the transmitted power at the base station, ${d_k}^v$ represents the distance between the base station and users, and the path loss coefficient, $h_{k,n}$ channel coefficient and $w_{k,n}$ noise component.

3.1. LabVIEW implementation of OFDM-NOMA

Downlink OFDM-NOMA transceiver is implemented in LabVIEW, all user signals are superimposed before the OFDM stage at the transmitter. The downlink OFDM-NOMA system's transceiver is configured using USRPs devices. The host computer does the signal processing required for the OFDM-NOMA system using the visual programming language LabVIEW 2021. For system design, LabVIEW offers a graphical user interface (GUI) with a front panel and block diagram. Figures 3 and 4 show the block diagram for the transceiver for the proposed work. In this study, user4 is located close to the base station, whereas user 1 is located at a far distance from it. User4 receives more transmission power than all other users because user4 has a bigger channel gain.

The far user signal can be directly decoded, and when the reconstituted far user signal is cancelled using SIC, the received near user signal can be decoded. There is no need to apply SIC to the user1 receiver because the signal strength of the other users is weaker. The user1 receiver interprets these as noise, and the received signals are directly decoded from the received signal. For each new user, the other users apply SIC. The bit sequence of user1 is first determined from the signal by channel equalization and demodulation. For user2 decoding, the bit sequence of user1 is subsequently re-modulated. User1's signals are cancelled, and the symbols produced are multiplied by its power allocation coefficient once and removed from the received signal. For decoding user3 two level SIC is performed to suppress interference due user1 and user3. Similarly, to decode user4 three level SIC is performed to suppress interference due to user1, user2 and user3.

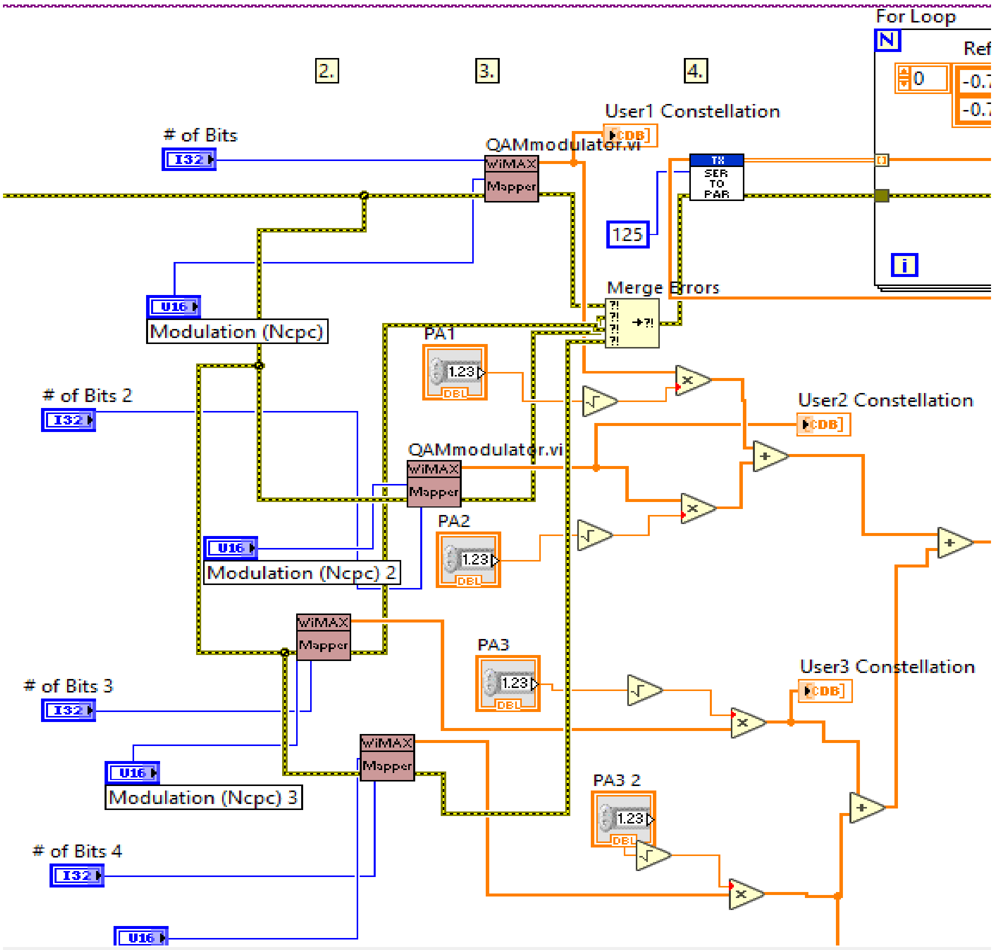

Figure 3. Power allocation and super positioning all users' signals in LabVIEW

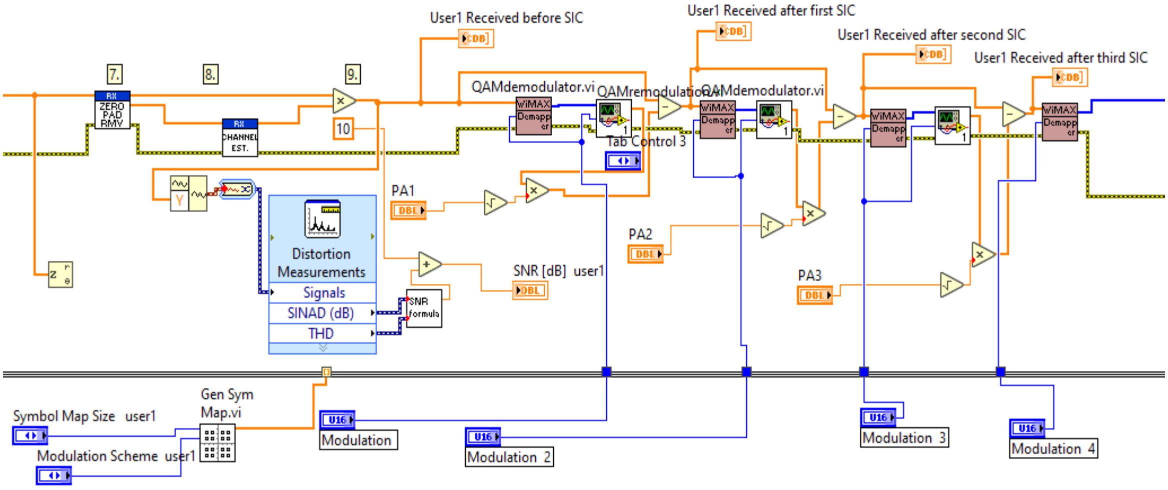

Figure 4. SIC block for near user NOMA in LabVIEW

3.2. Implementation of a downlink OFDM-NOMA system using NI USRP's

As illustrated in Figure 5, a software defined radio testbed is used to create a downlink OFDM-NOMA system with a single transmitter and four user's receivers. USRPs consist of two radio frequency channels, RF0 and RF1, each consisting of one transmitting and two receiving. The USRP 2944R serves as the transmitter (TX) as well as two near user receivers, from RF channel 0, TX0 and RX0 are served as transmitter and receiver user4 and from RF channel 1, RX1 is used as receiver user3.While two NI USRP 2901 nodes serve as far users, user1 and user2 are receivers in the testbed environment. Both USRPs 2901 are linked to a single personal computer (PC) at the receiver, where they each receive signals from RX1 and RX2. For the downlink OFDM-NOMA system testbed, the carrier frequency is set to 2.4 GHz, and the baseband I/Q sampling rate is 1million samples per second for both the transmitter and receiver pairs. The downlink OFDM-NOMA system testbed works as follows, USRP devices are configured and initialized by setting transmitter and receiver parameters, carrier frequency, I/Q sampling rate, modulation type and power allocation factors using the control panel. First, the pseudo noise bit generator is used at the transmitter to produce the payload data symbols for all four users, QPSK modulation is used to modulate the bits and all user modulated data is superimposed by allocating appropriate power to each user. Then the inverse fast Fourier transform (IFFT) performs OFDM modulation, and the cycle prefix (CP) is padded before the transmission. Then the data is transmitted through USRP 2944R TX0 RF channel 0. All four-user equipment receives transmitted data, user4 receives data through USRP 2944R RX0 RF channel 0, user3 receives data through USRP 2944R RX1 RF channel 1, user2 receives data through USRP 2901, RX0 RF channel 0 and user4 receives data through USRP 2944R, RX1 RF channel 1. Each user's incoming signals are analyzed at the receiver using fast Fourier transform (FFT) methods, and CP is eliminated. Cyclic prefix is detected using the Van De Beek algorithm for synchronization and carrier offset estimation. Data bits and reference bits are separated by each user before SIC and SIC decoding are performed to detect transmitted data.

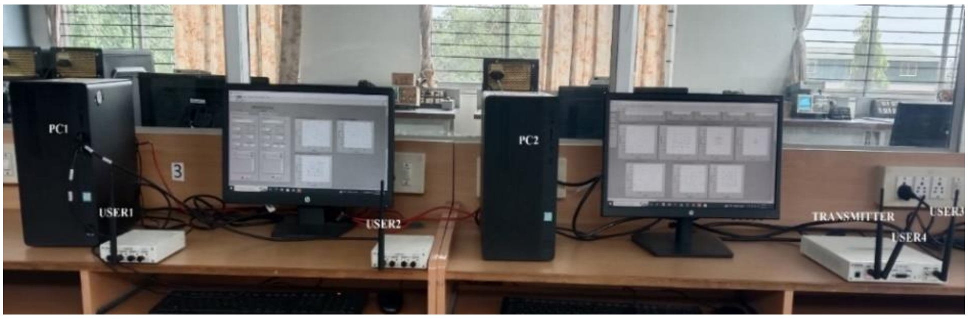

Figure 5. Prototype of four user downlink OFDM NOMA

4. RESULT AND DISCUSSION

The testbed OFDM-NOMA downlink system allows the transmission, processing, and reception of data. To obtain the original symbols, the received symbols must first be decoded. By varying the transmitting gain and separation from the base to the users, the signal-to-noise ratio (SNR) performance for all users is assessed. Figure 6 illustrates how the front panel displays all users' received signal constellations and system parameter configurations.

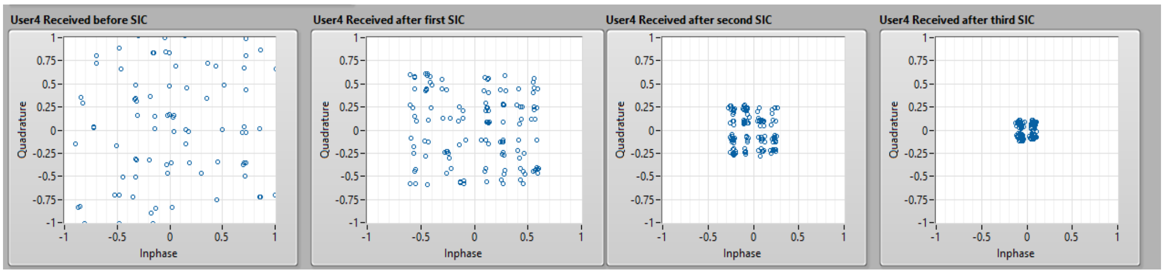

Figure 6. User4 received constellation after three level of SIC

The source generates 2500 bits for each symbol for each user. It decodes the bits of its own message from the incoming signal using a 4-QPSK mapped demodulator. Figure 6 displays the constellation of user4 retrieved after different levels of SIC. All the user equipment in the receive path employs various processing strategies. The far user signal's allocated gain must be higher in order to keep the received signal in the correct constellation section. The user1 receiver immediately decodes the superimposed signal. For user2 one stage SIC, two stage SIC for user3 and three stage SIC for user4 are performed before decoding the respective signals. Tables 1 and 2 show the impact of changing the transmitter gain on the signal-to-noise ratio of the received signal as a function of the distance between the users from the base station and the power allocation factor. The transmitter gain in this study was adjusted from 20 to 35 dB, while the receiver gains were fixed at 10 dB.

The SNR evaluation for users1, user2, user3 and user4 located at distances of 2 m, 1 m, 15 cm, and 1 cm respectively, from the base station is shown in Table 1 with power allocation coefficients of 0.752, 0.188, 0.0457, and 0.0117. Table 2 shows the SNR evaluation of users1, user2, user3 and user4 located at a distance of 4 m, 2 m, 15 cm, and 1 cm. Table 1 shows that user1 receives signals with an SNR equal to 12.13 dB placed at 2 m from the base station, and Table 2 shows that user1 receives signals with an SNR equal to 10.35 dB placed at 4 m from the base station with same power allocation coefficient 0.752. The SNR of user1 is decreased as proximity increased from the base station. These results show that the received signal SNR depends on the proximity of users to the base station as well as the power allocation factor.

Table 1. SNR evaluation of four users at distance of 2 m, 1 m, 15 cm and 1 cm

TX Gain	20 dB	25 dB	30 dB	35 dB
User1 α_1=0.752	12.13	12.24	13.42	15.25
User2 α_2=0.188	10.23	12.26	13.38	14.55
User3 α_3=0.0457	10.14	10.48	12.67	12.08
User4 α_4=0.0117	10.01	10.84	12.19	14.43

Table 2. SNR evaluation of four users at distance of 4 m, 2 m, 15 cm and 1 cm

TX Gain	20 dB	25 dB	30 dB	35 dB
User1 α_1=0.752	10.35	12.30	11.28	13.54
User2 α_2=0.188	10.19	11.96	11.32	13.67
User3 α_3=0.0457	10.08	10.38	11.21	11.03
User4 α_4=0.0117	10.11	10.59	11.73	11.99

5. CONCLUSION

In current telecommunications applications, NOMA has played an enormously significant role. NOMA is a technology that has promise for enhancing enormous connections and spectral competency. In this study, a real time downlink OFDM-NOMA system has been used to validate and assess the performance of four user NOMA. A real-time downlink OFDM-NOMA testbed was implemented using USRP NI-2944R and USRP 2901 hardware radios with LabVIEW software. NOMA system performance was assessed for near user and far user in terms of signal to noise ratio by adjusting transmitting gain and the distance of users from the base station. Superposition coding was employed to merge the transmitting signals of four users, and consecutive interference cancellation techniques for the close users were carried out at the receiver. Based on testbed outcomes, we can infer that the user's distance from the base station and the power allocation coefficients affect the SNIR. Especially when SIC is employed in real time on the SDR platform, it increases the receiver complexity.

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REFERENCES

[1] B. Makki, K. Chitti, A. Behravan, and M. S. Alouini, “A survey of noma: Current status and open research challenges,” *IEEE Open Journal of the Communications Society*, vol. 1, pp. 179–189, 2020, doi: 10.1109/OJCOMS.2020.2969899.

[2] M. Kokilavani, R. Siddharth, S. M. Riyaz, P. Ramesh, S. Ezhilarasi, and P. T. V. Bhuvaneswari, “Downlink performance analysis of 5G PD-NOMA system,” in *2022 IEEE Global Conference on Computing, Power and Communication Technologies, GlobConPT 2022*, IEEE, Sep. 2022, doi: 10.1109/GlobConPT57482.2022.9938331.

[3] M. Vaezi, Z. Ding, and H. Vincent Poor, *Multiple access techniques for 5G wireless networks and beyond*. Springer International

Publishing, 2018, doi: 10.1007/978-3-319-92090-0.
[4] Q. Luo *et al.*, “An error rate comparison of power domain non-orthogonal multiple access and sparse code multiple access,” *IEEE Open Journal of the Communications Society*, vol. 2, pp. 500–511, 2021, doi: 10.1109/OJCOMS.2021.3064504.
[5] Z. Yuan, G. Yu, W. Li, Y. Yuan, X. Wang, and J. Xu, “Multi-user shared access for internet of things,” in *IEEE Vehicular Technology Conference*, IEEE, May 2016, doi: 10.1109/VTCSpring.2016.7504361.
[6] O. Maraqa, A. S. Rajasekaran, S. Al-Ahmadi, H. Yanikomeroglu, and S. M. Sait, “A survey of rate-optimal power domain NOMA with enabling technologies of future wireless networks,” *IEEE Communications Surveys and Tutorials*, vol. 22, no. 4, pp. 2192–2235, 2020, doi: 10.1109/COMST.2020.3013514.
[7] S. M. R. Islam, M. Zeng, O. A. Dobre, and K. Kwak, “Nonorthogonal multiple access (NOMA): How it meets 5G and beyond,” *Wiley 5G Ref*. Wiley, pp. 1–28, Dec. 2019, doi: 10.1002/9781119471509.w5gref032.
[8] B. S. K. Reddy, K. Mannem, and K. Jamal, “Software defined radio based non-orthogonal multiple access (NOMA) systems,” *Wireless Personal Communications*, vol. 119, no. 2, pp. 1251–1273, Feb. 2021, doi: 10.1007/s11277-021-08260-2.
[9] S. M. R. Islam, N. Avazov, O. A. Dobre, and K. S. Kwak, “Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges,” *IEEE Communications Surveys and Tutorials*, vol. 19, no. 2, pp. 721–742, 2017, doi: 10.1109/COMST.2016.2621116.
[10] A. Mahmood, M. Marey, M. M. Nasralla, M. A. Esmail, and M. Zeeshan, “Optimal power allocation and cooperative relaying under fuzzy inference system (FIS) based downlink PD-NOMA,” *Electronics (Switzerland)*, vol. 11, no. 9, Art. no. 1338, Apr. 2022, doi: 10.3390/electronics11091338.
[11] F. Kara and H. Kaya, “BER performances of downlink and uplink NOMA in the presence of SIC errors over fading channels,” *IET Communications*, vol. 12, no. 15, pp. 1834–1844, Aug. 2018, doi: 10.1049/iet-com.2018.5278.
[12] P. N. Thakre and S. B. Pokle, “A survey on power allocation in PD-NOMA for 5G wireless communication systems,” in *International Conference on Emerging Trends in Engineering and Technology, ICETET*, IEEE, Apr. 2022, doi: 10.1109/ICETET-SIP-2254415.2022.9791576.
[13] A. Bal and R. Tajwar, “Execution of hybrid NOMA schemes concerning outage performance and sum rate interplay,” in *2021 IEEE International IOT, Electronics and Mechatronics Conference, IEMTRONICS 2021 - Proceedings*, IEEE, Apr. 2021, doi: 10.1109/IEMTRONICS52119.2021.9422485.
[14] M. Zeng, W. Hao, O. A. Dobre, and Z. Ding, “Cooperative NOMA: State of the art, key techniques, and open challenges,” *IEEE Network*, vol. 34, no. 5, pp. 205–211, Sep. 2020, doi: 10.1109/MNET.011.1900601.
[15] S. Mukhtar and G. R. Begh, “Performance analysis of filtered OFDM based downlink and uplink NOMA system over Nakagami-m fading channel,” *Journal of Telecommunications and Information Technology*, vol. 2021, no. 2, pp. 11–23, Mar. 2021, doi: 10.26636/jtit.2021.148020.
[16] H. Asgharimoghaddam, J. Kaleva, and A. Tolli, “Capacity approaching low density spreading in uplink NOMA via asymptotic analysis,” *IEEE Transactions on Communications*, vol. 69, no. 3, pp. 1635–1649, Mar. 2021, doi: 10.1109/TCOMM.2020.3040409.
[17] A. Mahmood, S. Khan, S. Hussain, and M. Zeeshan, “Performance analysis of multi-user downlink PD-NOMA under sui fading channel models,” *IEEE Access*, vol. 9, pp. 52851–52859, 2021, doi: 10.1109/ACCESS.2021.3070147.
[18] Y. Qi, X. Zhang, and M. Vaezi, “Over-the-air implementation of NOMA: New experiments and future directions,” *IEEE Access*, vol. 9, pp. 135828–135844, 2021, doi: 10.1109/ACCESS.2021.3116613.
[19] P. Kheirkhah Sangdeh, H. Pirayesh, Q. Yan, K. Zeng, W. Lou, and H. Zeng, “A practical downlink NOMA scheme for wireless LANs,” *IEEE Transactions on Communications*, vol. 68, no. 4, pp. 2236–2250, Apr. 2020, doi: 10.1109/TCOMM.2020.2965520.
[20] N. Rupasinghe and I. Guvenc, “Capturing, recording, and analyzing LTE signals using USRPs and LabVIEW,” in *Conference Proceedings - IEEE SOUTHEASTCON*, IEEE, Apr. 2015, doi: 10.1109/SECON.2015.7132939.
[21] J. Angjo, M. M. Tuncer, E. Akertek, H. Alakoca, M. Basaran, and L. Durak-Ata, “On the channel estimation performance of NOMA systems: Experimental implementation of real-time downlink NOMA-OFDM,” in *2020 IEEE International Black Sea Conference on Communications and Networking, BlackSeaCom 2020*, IEEE, May 2020, doi: 10.1109/BlackSeaCom48709.2020.9234965.
[22] E. Sfeir, R. Mitra, and G. Kaddoum, “A random Fourier feature based receiver detection for enhanced BER performance in nonlinear PD-NOMA,” *IEEE Transactions on Vehicular Technology*, vol. 72, no. 2, pp. 2701–2706, Feb. 2023, doi: 10.1109/TVT.2022.3213811.
[23] R. Parameswaran and P. T. V. Bhuvaneswari, “Performance analysis of NOMA under power control mechanism,” in *3rd IEEE International Virtual Conference on Innovations in Power and Advanced Computing Technologies, i-PACT 2021*, IEEE, Nov. 2021, doi: 10.1109/i-PACT52855.2021.9696636.
[24] X. Yue, Y. Liu, Y. Yao, X. Li, R. Liu, and A. Nallanathan, “Secure communications in a unified non-orthogonal multiple access framework,” *IEEE Transactions on Wireless Communications*, vol. 19, no. 3, pp. 2163–2178, Mar. 2020, doi: 10.1109/TWC.2019.2963181.
[25] H. Yahya, E. Alsusa, and A. Al-Dweik, “Exact BER analysis of NOMA with arbitrary number of users and modulation orders,” *IEEE Transactions on Communications*, vol. 69, no. 9, pp. 6330–6344, May 2021, doi: 10.1109/TCOMM.2021.3088526.

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