Non-orthogonal multiple access system based on time diversity for 5G applications

Amira I. Zaki[1] · Amal A. Samy[1] · Amit Kumar Garg[2] · Moustafa H. Aly[1]

Abstract

Novel coding and modulation methods are required for fulfilling the demands of 5G and beyond cellular communication systems. In this paper, an innovative time diversity non-orthogonal multiple access (TD-NOMA) approach is proposed for 5G applications. The suggested system uses time diversity (TD) in conjunction with NOMA to improve the system bit error rate (BER) performance. The NOMA technique basically employs data transmission based on non-orthogonal basis functions. The data pass through the channel, and the desired signal can be obtained by a successive interference cancelation (SIC) receiver. Using different subcarriers and channel models, different modulation schemes such as QPSK and BPSK are investigated. When compared to conventional methodologies, the simulation results reveal that the proposed system outperforms them; it reduces the effect of fading for the multipath channel and enhances the BER.

Keywords TD-NOMA · SIC · QPSK · BPSK · BER

1 Introduction

Various multiple access schemes including time division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA) are used in all current cellular networks. In such conventional methods, the inter-user interference is managed by allocating users to resources which are orthogonal in the time, frequency, and coding domains (Vaezi et al. 2019). Further improvements in mobile communication systems are required since cloud services are rapidly expanding through the mobile internet. Video streaming in cellular applications is growing rapidly and continuously. So,

✉ Moustafa H. Aly
drmosaly@gmail.com

Amira I. Zaki
amzak10@aast.edu

1 Department of Electronics and Communications Engineering, College of Engineering and Technology, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt

2 Department of Electronics and Communications Engineering, Indian Institute of Information Technology, Kota, Kota, India

the methods can not match the high requirements of next generation radio access systems (Arora and Singh 2020).

NOMA is a promising approach for improving system performance. It is basically different from above mentioned multiple access methods, which are responsible to provide users with orthogonal access in time, frequency, code, or space. NOMA superimposes numerous users in the domain, allowing non-orthogonally multiplexed users to be differentiated by utilizing the progressive SIC receivers (Saito et al. 2013).

NOMA uses power or code domain multiplexing to permit multipe users to access the resources in time and frequency in the same spatial layer. Several NOMA systems have gained and attracted a lot to its users. One can categorize them into two groups: power and code domain multiplexing. Power domain multiplexing means different users are provided with the different power levels based on their channel environments to maximize system performance (Manglayev et al. 2016). The power allocation is also useful for separating multiple users, as SIC is frequently used to suppress the multi-user interference. The other multiplexing technology i.e. code domain multiplexing works in the same way as CDMA or multicarrier CDMA (MC-CDMA), in which multiple users are allotted different codes and after that multiplexed over the similar time–frequency resources (Dai et al. 2015).

Bariah et al. (2018) displayed the NOMA method and discussed its capability to enhance the overall spectral efficiency of wireless communication systems. They showed that the maximum conceivable order of diversity is proportionate to the order of the users. The optimization probem is formulated by obtaining the error probability expressions in order to reduce the overall bit error rate. Ghaffari et al. presented a new NOMA technique which is known as Sparse Code Multiple Access (SCMA) technique (Ghaffari et al. 2019). SCMA provide better BER performance and higher spectral efficiency as compared to the other similar techniques. Though, to gain the BER performance and spectral efficiency, complex decoders are needed. Yingmin et al. studied the performance of various NOMA schemes in 3GPP (Wang et al. 2016), showing better performance for various NOMA schemes as compared to the other conventional OMA. Ahmed et al. (2018) showed that the proper identification of power allocation method is critical to make NOMA a more effective approach. The main advantages of power allocation are superior spectral efficiency achieved by transmitting data from multiple user equipment on the same time and frequency resource, supporting massive user equipment connectivity, and flexible power control. For power allocation and signal separation in NOMA, the near-far effect of the cell center and cell edge user signals are used.

In this manuscript, we emphasis on the impact of different power assignments and time diversity on the performance of ideal SIC for downlink NOMA. A TD-NOMA method is proposed to resolve the issues of next generation 5G systems by enhancing data rate and throughput. The proposed TD-NOMA also improves the wireless system BER using the SIC receivers. This is carried out by using TD, where every data stream is modulated using non-orthonormal basis functions. Then, the frame of the two users is divided into two sequences and the modulated symbols are encoded. The symbols, after modulation, are transmitted over the channel.

The remaining part of the paper is discussed as follows. Section 2 illustrates the conventional system. Section 3 describes the proposed system. System evaluation and simulation results are mentioned and described in Sect. 4. Section 5 concludes the manuscript.

2 Conventional NOMA

Signals from many users are non-orthogonally multiplexed and they are in the power domain at the transmitter in the downlink NOMA, and SIC processing is used at the receiver to separate the superposed signals. Single Input Multi Output (SIMO) systems are considered, in which the number of transmit antennas at the base station (BS) is one and the number of receive antennas at the user equipment (UE) is two. For the sake of simplicity, two users are examined for downlink NOMA, and it is assumed that they are superposed on the same resource block. User 1 is a cell edge user, while User 2 is a cell center user. The power allocation ratios for users 1 and 2 are p_1 and p_2, respectively, where $p_1 + p_2$ equals 1 in this case. Because User 1 has a low signal to noise ratio (SNR), a high power ratio is assigned to it to operate effectively in such a setting. At the transmitter, the data streams are s_1 and s_2 for each user path through channel encoding (H1 and H2) and modulation technique. Then, NOMA power allocation (p_1 and p_2) is performed by a direct multiplication between each user and its power, as follows.

The transmitted code word is defined as

$$x = x_1 + x_2 \tag{1}$$

$$x = s_1 \cdot \sqrt{p_1} + s_2 \cdot \sqrt{p_2} \tag{2}$$

At the receiver side, the received signal at User n (n = 1, 2) can be described by

$$y_{n,m} = h_{n,m}\left(\sqrt{p_1}s_1 + \sqrt{p_2}s_2\right) + n_{n,m} \tag{3}$$

where $y_{n,m}$ denotes the received signal for n^{th} User (n = 1,2), at the mth receive antenna (m = 1, 2). $h_{n,m}$ represents the channel amid transmit antenna and the mth receive antenna of User n, s_i represents signal for User n with an allocated power ratio p_n, and $n_{n,m}$ denotes the Additive White Gaussian Noise (AWGN) with a zero mean.

2.1 SISO conventional receiver

After receiving the signals, they are passed through the maximum ratio combining (MRC) signal of cell edge user (User1) and is spotted. An SIC can be implemented to cancel the from cell edge use interference. After that, the signal of the cell center user (User2) is aso spotted.

The received signal after applying MRC at nth user (n = 1, 2) in the SISO system can be represented by (Bariah et al. 3)

$$z_n = \frac{h_{n,1}^* \cdot y_{n,1}}{\left|h_{n,1}\right|^2} \tag{4}$$

The estimation of the transmitted signal of the cell edge user (User1) at the receiver of user 1, after NOMA decoding and demodulation, can be written as

$$\widehat{s}_1 = \lfloor \frac{z_1}{\sqrt{p_1}} \rfloor \tag{5}$$

where $\lfloor \cdot \rfloor$ denotes demodulation with hard decision.

After the signal of cell edge (User 1) is detected, an SIC is applied to cancel the interference from the cell edge user (User 1). Therefore at the receiver of the center cell user (User 2) the data of the first user is detected again as follows

$$\hat{s}_1 = \lfloor \frac{z_2}{\sqrt{p_1}} \rfloor \tag{6}$$

and

$$\hat{z}_2 = z_2 - \sqrt{p_1}.s_1 \tag{7}$$

NOMA decoder uses $\hat{s}_1$ to detect the second user symbol as follows

$$\hat{z}_2 = z_2 - \sqrt{p_1}.\hat{s}_1 \tag{8}$$

After SIC processing, the detected signal, $\hat{s}_2$, of the cell center user (User 2) is represented as

$$\hat{s}_2 = \lfloor \frac{\hat{z}_2}{\sqrt{p_2}} \rfloor \tag{9}$$

2.2 SIMO conventional receiver

This section describes the structure of downlink NOMA receiver of the conventional SIMO-NOMA (Yan et al. 10) as shown in Fig. 1. After receiving the signal $y_{n,m}$ with AWGN, then, the maximum ratio combining (MRC) is performed with equalizer. The signal of cell edge user is detected and an SIC processing is applied to cancel the interference from cell edge user signal. After that, the signal of cell center user is detected.

After receiving the signal $y_{n,m}$ as shown in Eq. (3), it passes through an MRC at user n, which is represented as

$$z_n = \frac{h_{n,m}^* . y_{n,m} + h_{n,m}^* . y_{n,m}}{|h_{n,m}|^2 + |h_{n,m}|^2} (n = 1, 2) \tag{10}$$

Then, the signal is decoded using a NOMA decoder and the transmitted signal of the cell edge user (User1) at the receiver of User 1 can be written as
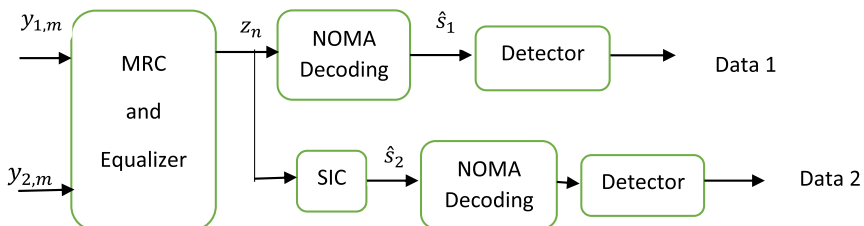

Fig. 1 Conventional SIMO receiver

$$\widehat{s}_1 = \lfloor \frac{z_1}{\sqrt{p_1}} \rfloor \tag{11}$$

The estimated signal of User 1 at receiver 2 is given by Eq. (6). When the signal from the cell edge (User 1) is identified, an SIC is used to cancel the interference from the cell edge user (User 1), as estimated in Eq. (7). The detected cell center user (User 2) signal after SIC processing is introduced in Eq. (9).

3 Proposed TD-NOMA system model

The structure of the transmitter of TD-NOMA is shown in Fig. 1. At the transmitter side, assume the transmitted symbol frame length of User 1 and User 2 is N. In the proposed TD-NOMA, the frame of the two users is divided into two sub-frames and are encoded using the following code word, s_n

$$s_n = \left[w_n (-1)^{n-1} . w_n \right] (n = 1, 2) \tag{12}$$

where $n = 1, 2$, $s_n \in \mathbb{C}(N \times 1)$ and w_n is half the s_n frame and $w_n \in \mathbb{C}\left(\frac{N}{2} \times 1 \right)$.

Then, the NOMA power allocation is performed by a direct multiplication between each user and its power, as shown in Eq. (2).

The received signal at user n (n = 1, 2) is described by Eq. (3).

3.1 SISO-(TD-NOMA) receiver

On the receiver side, the user has one single receiver antenna. The received signals pass through time decoding which divides the number of symbols per frame (N) into two sequences, and then applies NOMA decoding to get signals for User1 and User2.

In the SISO-TD-NOMA system, and using Eq. (10), the received signal after applying MRC at User n = 1, 2 can be represented as

$$z_n = \frac{h_{n,1}^* . y_{n,1}}{\left| h_{n,1} \right|^2} \tag{13}$$

The TD decoding of the received code word takes place by dividing them into two code words as follows

$$D_n = \left[z_n (1 : N/2) + (-1)^{n+1} . z_n (N/2 + 1 : N) \right] \tag{14}$$

The estimation, $\widehat{s}_1$, of the communicated signal of the cell edge user (User1) can be represented as

$$\widehat{s}_1 = \lfloor \frac{D_1}{2\sqrt{p_1}} \rfloor \tag{15}$$

and, for the cell center user, the estimated signal, $\widehat{s}_2$, can be obtained as

$$\hat{s}_2 = \lfloor \frac{D_2}{2\sqrt{P_2}} \rfloor \tag{16}$$

3.2 SIMO-(TD-NOMA) receiver

To enhance the the cell center user and cell edge user performance, we use TD-NOMA with two receiver antennas at each user as shown in Fig. 2. After MRC, the signals pass through time decoding and each frame will be divided into two sequences. Then, decoded signals are detected to get the desired signals.

The signal after MRC at the first antenna at User n (n=1, 2) is given by

$$z_{n,1} = \frac{h_{n,1}^* \cdot y_{n,1}}{|h_{n,1}|^2} \tag{17}$$

$$z_{n,1} = \frac{|h_{n,1}|^2 \left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2 \right) + h_{n,1}^* n_1}{|h_{n,1}|^2} \tag{18}$$

and after canceling the channel effect

$$z_{n,1} = \left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2 \right) + \frac{h_{n,1}^* n_1}{|h_{n,1}|^2} \tag{19}$$

$$z_{n,1} = \left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2 \right) + \varepsilon_1 \tag{20}$$

At the second antenna after MRC at User n (n=1, 2), it is represented as

$$\begin{aligned}
z_{n,2} &= \frac{h_{n,2}^* \cdot y_{n,2}}{|h_{n,2}|^2} = \frac{|h_{n,2}|^2 \left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2 \right) + h_{n,2}^* n_2}{|h_{n,2}|^2} \\
&= \left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2 \right) + \frac{h_{n,2}^* n_2}{|h_{n,2}|^2} \\
&= \left(\sqrt{P_1}s_1 + \sqrt{P_2}s_2 \right) + \varepsilon_2
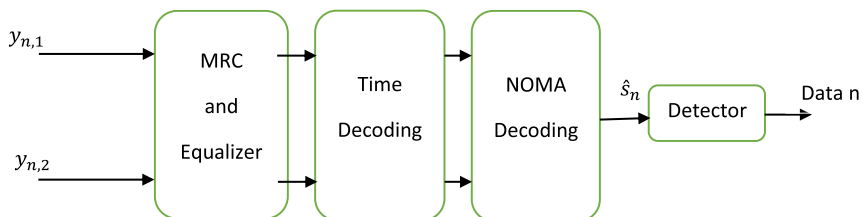\end{aligned} \tag{21}$$

Fig. 2 Proposed SIMO-(TD-NOMA) receiver

The communicated signal of the cell edge user (User1) can be obtained as

$$\tilde{s}_1 = \frac{\left[z_{n,1}(1 : N/2) + z_{n,1}(N/2 + 1 : N) \right]}{2} \tag{22}$$

$$\tilde{s}_1 = \frac{\left[\sqrt{p_1} s_1 \left(1 : \frac{N}{2} \right) + \sqrt{p_2} s_2 \left(1 : \frac{N}{2} \right) + \sqrt{p_1} s_1 \left(\frac{N}{2} + 1 : N \right) - \sqrt{p_2} s_2 \left(\frac{N}{2} + 1 : N \right) \right] + \varepsilon_1 + \varepsilon_2}{2} \tag{23}$$

Then, the estimated signal of User1, in terms of $\tilde{s}_1$, is

$$D_1 = \lfloor \frac{\tilde{s}_1}{\sqrt{p_1}} \rfloor \tag{24}$$

$$D_1 = \lfloor s_1 + \frac{\varepsilon_1 + \varepsilon_2}{\sqrt{p_1}} \rfloor \tag{25}$$

After applying TD decoding, the two code words defined in Eq. (26) are subtracted to estimate the transmitter symbol of User2. Hence, the detected signal of the cell center User (User2) can be written as

$$\tilde{s}_2 = \frac{\left[z_{n,2}(1 : N/2) - z_{n,2}(N/2 : N) \right]}{2} \tag{26}$$

$$\tilde{s}_2 = \frac{\left[\sqrt{p_1} s_1 \left(1 : \frac{N}{2} \right) + \sqrt{p_2} s_2 \left(1 : \frac{N}{2} \right) - \sqrt{p_1} s_1 \left(\frac{N}{2} : N \right) + \sqrt{p_2} s_2 \left(\frac{N}{2} : N \right) \right] + \varepsilon_1 + \varepsilon_2}{2} \tag{27}$$

where the two factors used in Eq. (27) are used to maintain the same energy of the transmitted signal.

The estimation signal of User 2 after applying the NOMA system can be represented as

$$D_2 = \lfloor \frac{\tilde{s}_2}{\sqrt{p_2}} \rfloor \tag{28}$$

$$D_2 = \lfloor s_2 + \frac{\varepsilon_1 + \varepsilon_2}{\sqrt{p_2}} \rfloor \tag{29}$$

4 Results and discussion

The proposed TD-NOMA technique is estimated and compared to conventional NOMA. The modulation schemes, number of subcarriers, and channel taps, a series of tests are carried out. A TD-NOMA system is considered with N = 64. The modulation schemes BPSK and QPSK are examined with L, the number of channel taps, equal to 1, 3 with SNR = 30 dB, which is considered the acceptable level of SNR to establish good connectivity. A conventional NOMA system with N = 64 subcarriers is also analyzed for

Table 1 Simulation parameters

Channel type	Rayleigh fading channel
Number of channel taps, L	1 and 3
Modulation type	BPSK and QPSK
Number of subcarriers, N	64

Fig. 3 BER performance for TD-NOMA as compared to conventional technique at N = 64 and L = 1 using BPSK for User 1
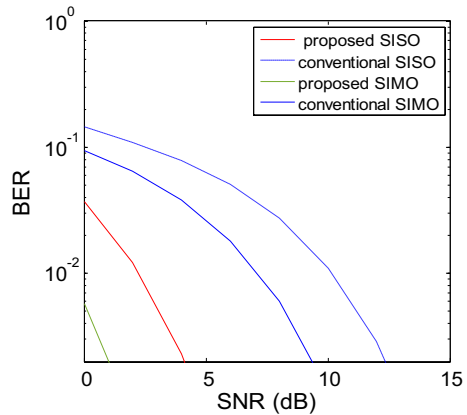
comparison. The impact of both modulation schemes, as well as the number of channel taps are investigated. Table 1 lists the parameters utilized in simulations.

4.1 Impact of modulation scheme

The proposed system TD-NOMA with SISO and MIMO receivers is compared, in Fig. 3, to the conventional SISO and MIMO receivers using BPSK with several subcarriers N = 64 and number of channel taps L = 1, 3.

As illustrated in Fig. 3, the difference in SNR between SISO TD-NOMA and conventional SISO techniques for User 1 is 9 dB at BER = 10^{-4}. When comparing the SIMO TD-NOMA to conventional SIMO, we notice that the difference in SNR between them is ~ 9 dB at BER = 10^{-4}, while the SNR difference between two conventional approaches SISO and SIMO is 4 dB. The proposed SISO TD-NOMA and SIMO TD-NOMA systems have a 3 dB difference in SNR. The BER of the proposed system outperforms the other techniques due to the repetition of a sub-code word which enhances performance due to time diversity.

The difference in SNR between SIMO TD-NOMA and conventional SIMO techniques for User 2 is 4 dB at BER = 10^{-2}, as illustrated in Fig. 4. When comparing the SISO TD-NOMA to the conventional SISO, we find that the difference in SNR is ~ 4 dB at BER = 10^{-2}. The SNR between the proposed SISO TD-NOMA and SIMO TD-NOMA systems is 4 dB, while the difference in SNR between conventional systems is 3 dB and the difference in SNR between proposed systems is 3 dB at BER = 10^{-2}.

In Fig. 5, due to spatial diversity, the performance of the proposed system shows an improvement over the conventional systems with a difference in SNR equals 8 dB at BER = 10^{-2}.
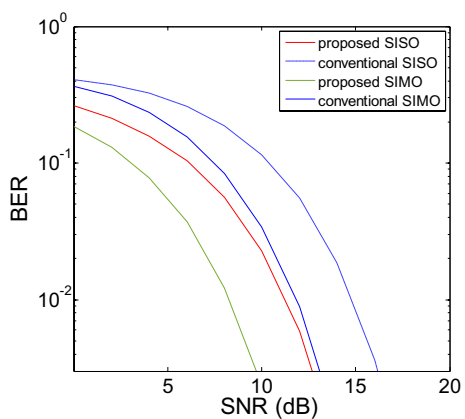
Fig. 4 BER performance for
TD-NOMA as compared to con-
ventional technique at N = 64 and
L = 1 using BPSK for User 2
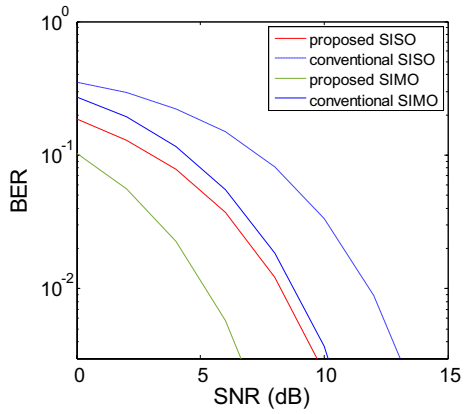
Fig. 5 BER performance for
TD-NOMA as compared to con-
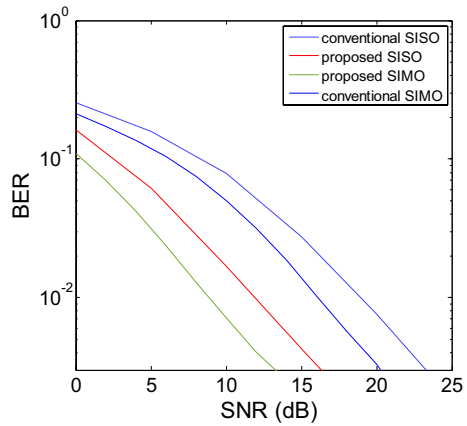ventional technique at N = 64 and
L = 1 using QPSK for User 1
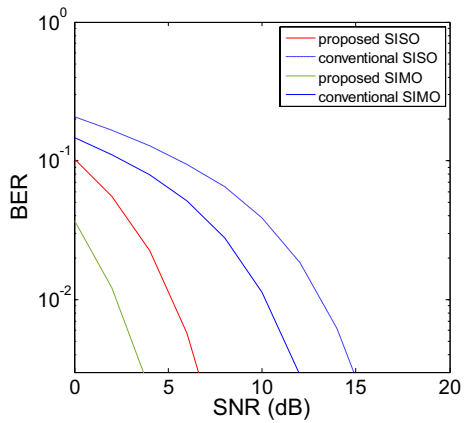
Fig. 6 BER performance for
TD-NOMA as compared to con-
ventional technique at N = 64 and
L = 1 using QPSK for User 2

For User 2, Fig. 6 shows that the SNR results of the SISO TD-NOMA system and the conventional SIMO system are very similar with a slight difference. This indicates the improvement resulting from using the TD system.

Fig. 7 BER performance for
TD-NOMA as compared to con-
ventional technique at N = 64 and
L = 3 using BPSK for User 1

Fig. 8 BER performance for
TD-NOMA as compared to con-
ventional technique at N = 64 and
L = 3 using BPSK for User 2
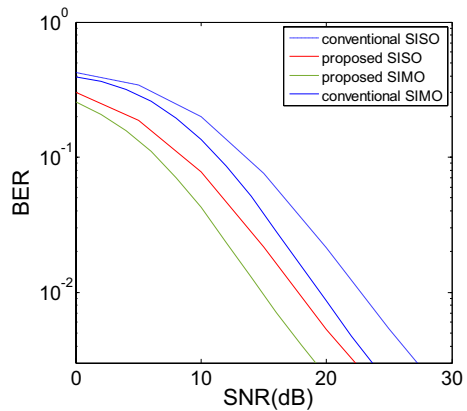
The effect of increasing the taps of the channel on the proposed system appears in
Fig. 7. Increasing the channel taps from 1 to 3 leads to a little bit increase in the per-
formance of the proposed system at an SNR greater than 10 dB.

Despite the increase in the channel taps, the proposed system still has priority over
the conventional system at the same BER as shown in Fig. 8.

At BER $= 10^{-2}$, the difference in SNR between SISO TD-NOMA and conventional
SISO approaches for User 1 is 7 dB at BER $= 10^{-2}$. When SIMO TD-NOMA is com-
pared to conventional SIMO, an SNR difference of ∼ 7 dB is noticed at the same BER,
as shown in Fig. 9.

Figure 10 displays the constellation of both the proposed system and the conven-
tional one showing that both are close to each other. This appears at BER $= 10^{-2}$, where
the difference in SNR between the SISO TD-NOMA and conventional SIMO system
is approximately 2 dB. The SNR of the SIMO TD-NOMA and conventional SIMO is
18 dB and 22.5 dB, respectively, at BER $= 10^{-2}$.

The experiments are carried out again and again for various modulation techniques
for channel taps of 1, and 3. The simulation results are depicted in Table 2 (Tables 3,
4).

Fig. 9 BER performance for
TD-NOMA as compared to con-
ventional technique at N = 64 and
L = 3 using QPSK for User 1
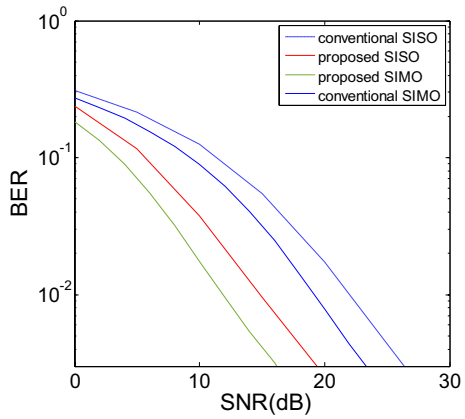
Fig. 10 BER performance for
TD-NOMA as compared to con-
ventional technique at N = 64 and
L = 3 using QPSK for User 2
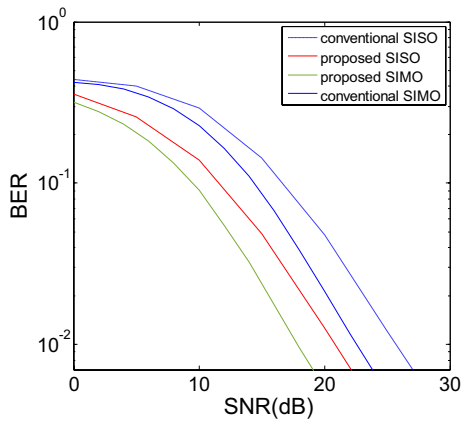
Table 2 simulation results for
various modulation techniques
for various channels taps

Channel taps L	User 1		User 2	
	L = 1	L = 3	L = 1	L = 3
SISO				
Conventional SISO using BPSK	10	19	12	23
Proposed SISO using BPSK	2	12	8.5	18
Conventional SISO using QPSK	13	19	15	27
Proposed SISO using QPSK	5	15	11	22.5
SIMO				
Conventional SIMO using BPSK	7	16	9	19
Proposed SIMO using BPSK	0.8	9	5	15
Conventional SIMO using QPSK	10	19	12	23.5
Proposed SIMO using QPSK	2	12	8	19

Table 3 Comparison of SNR (dB) simulation results for User 1 between proposed and conventional systems at BER $=10^{-2}$ for different modulation schemes and different channels taps

Comparison for User 1	BPSK		QPSK	
	Difference in SNR (dB)	% Enhancement	Difference in SNR (dB)	% Enhancement
L = 1				
SISO proposed versus conventional	6	60	8	61.5
SIMO proposed versus conventional	6.2	88.57	8	80
L = 3				
SISO proposed versus conventional	7	36.8	4	21.05
SIMO proposed versus conventional	7	43.75	7	36.84

Table 4 Comparison of SNR (dB) simulation results for User 2 between proposed and conventional systems at BER $=10^{-2}$ for different modulation schemes and different channels taps

Comparison for User 2	BPSK		QPSK	
	Difference in SNR (dB)	% Enhancement	Difference in SNR (dB)	% Enhancement
L = 1				
SISO proposed versus conventional	3.5	29.16	4	26.6
SIMO proposed versus conventional	4	44.4	4	33.33
L = 3				
SISO proposed versus conventional	5	21.73	4.5	16.66
SIMO proposed versus conventional	4	21.05	4.5	19.14

5 Conclusion

To improve the BER performance, a new SISO and SIMO TD-NOMA technique is proposed. The new technique is TD-NOMA to improve the system bit error rate (BER) performance. The proposed system is studied with different channel models and modulation schemes; BPSK and QPSK. The proposed system reveals superiority over the conventional system in enhancing the BER.

The simulation results show that when a 1-tap Rayleigh fading channel is employed, the SISO TD-NOMA system SNR for users 1 and 2 using the BPSK modulation technique is equal to 7 dB and 14 dB, respectively at BER $=10^{-3}$. While the SIMO TD-NOMA system SNR for users 1 and 2 using BPSK modulation technique is, respectively, 4 dB and 10 dB at BER $=10^{-3}$. The SISO TD-NOMA system SNR for users 1 and 2 using QPSK is 10 dB and 16 dB, respectively, at BER$=10^{-3}$ when a 1-tap Rayleigh fading channel is used. The SNR of the SIMO TD-NOMA system for users 1 and 2 utilizing QPSK modulation is equivalent to 7 dB and 13 dB at BER $=10^{-3}$, respectively.

The SNR of the SISO TD-NOMA system for users 1 and 2 using the BPSK modulation technique is equal to 21 dB and 27 dB, respectively at BER $=10^{-3}$, when 3-tap Rayleigh fading channel is used and the SNR of the SIMO TD-NOMA system using BPSK modulation technique for users 1 and 2 is equal to 18 dB and 24 dB at BER $=10^{-3}$ when 3-tap Rayleigh fading channel is used. The obtained results reveal that when a 3-tap Rayleigh fading channel is employed, the SISO TD-NOMA system SNR for users 1 and 2 utilizing QPSK is 24 dB and 21 dB, respectively, at BER $=10^{-3}$. The SIMO TD-NOMA system's SNR for users 1 and 2 using QPSK is 20 dB and 18 dB, respectively, at BER $=10^{-3}$.

Author contributions We are enclosing herewith a manuscript entitled "Non-Orthogonal Multiple Access System Based on Time Diversity for 5G Applications" for publication in Optical and Quantum Electronics Journal. With the submission of this manuscript I would like to undertake that: All authors of this research paper have directly participated in the planning, execution, or analysis of this study; All authors of this paper have read and approved the final version submitted; The contents of this manuscript have not been copyrighted or published previously; The contents of this manuscript are not now under consideration for publication elsewhere; The contents of this manuscript will not be copyrighted, submitted, or published elsewhere, while acceptance by the Journal is under consideration; There are no directly related manuscripts or abstracts, published or unpublished, by any authors of this paper.

References

Ahmed, T., Yasmin, R., Homyara, H., Hasan, R.: Generalized power allocation (GPA) schemes for non-orthogonal multiple access (NOMA) based wireless communication system. Int. J. Comput. Sci. Eng. Inf. Technol. **8**(5/6), 1–9 (2018)

Arora, G., Singh, N.P.: Performance enhancement of wireless network by adopting downlink non-orthogonal multiple access technique. In: 2020 First IEEE International Conference on Measurement, Instrumentation, Control, and Automation (ICMICA), pp. 1–5 (2020)

Bariah, L., Al-Dweik, A., Muhaidat, S.: On the performance of non-orthogonal multiple access systems with imperfect successive interference cancellation. In: 2018 IEEE international conference on communications workshops (ICC workshops), pp. 1–6 (2018). https://doi.org/10.1109/ICCW.2018.8403617

Dai, L., Wang, B., Yuan, Y., Han, S., Chih-lin, I., Wang, Z.: Non-orthogonal multiple access for 5G: solutions, challenges, opportunities, and future research trends. IEEE Commun. Mag. **53**(9), 74–81 (2015). https://doi.org/10.1109/MCOM.2015.7263349

Ghaffari, A., Léonardon, M., Cassagne, A., Leroux, C., Savaria, Y.: Toward high-performance implementation of 5G SCMA algorithms. IEEE Access **7**, 10402–10414 (2019). https://doi.org/10.1109/ACCESS.2019.2891597

Manglayev, T., Kizilirmak, R.C., Kho, Y.H.: Optimum power allocation for non-orthogonal multiple access (NOMA). In: 2016 IEEE 10th international conference on application of information and communication technologies (AICT), pp. 1–4 (2016). https://doi.org/10.1109/ICAICT.2016.7991730

Saito, Y., Kishiyama, Y., Benjebbour, A., Nakamura, T., Li, A., Higuchi, K.: Non-orthogonal multiple access (NOMA) for cellular future radio access. In: 2013 IEEE 77th Vehicular Technology Conference (VTC Spring), Dresden, Germany (2013)

Vaezi, M., Schober, R., Ding, Z., Poor, H.V.: Non-orthogonal multiple access: common myths and critical questions. IEEE Wirel. Commun. **26**(5), 174–180 (2019). https://doi.org/10.1109/MWC.2019.1800598

Wang, Y., Ren, B., Sun, S., Kang, S., Yue, X.: Analysis of non-orthogonal multiple access for 5G. China Commun. **13**(Supplement 2), 52–66 (2016). https://doi.org/10.1109/CC.2016.7833460

Yan, C., Harada, A., Benjebbour, A., Lan, Y., Li, A., Jiang, H.: Receiver design for downlink non-orthogonal multiple access (NOMA). In: 2015 IEEE 81st vehicular technology conference (VTC Spring), pp. 1–6 (2015). https://doi.org/10.1109/VTCSpring.2015.7146043