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Multiple Transmitter Antenna Selection Schemes in Cooperative NOMA System

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Abstract— Recently, non-orthogonal multiple access (NOMA) has been developed as an alternative to orthogonal multiple access (OMA) to fulfill the need of connecting massive number of devices with high requirements of 5G wireless communication. In this work, two types of transmitter antenna selection (TAS) are employed - in down link NOMA amplify and forward cooperative relay system over Rayleigh fading channels - to enhance the bit error rate (BER) performance. The first TAS, which is based on maximum ratio combining at relay is applied on the first hop, and the second TAS with maximum likelihood and successive interference cancellation detection based on minimizing average BER at mobile end user is applied on second hop. The obtained results reveal that the proposed TAS schemes enhance the performance of NOMA cooperative relay system significantly compared to other TAS that were used as a reference in this work, namely antenna random selection scheme and equal gain combining of all antennas.

Keywords— Non orthogonal multiple access; Transmitter antenna selection; Maximum ratio combining; Maximum likelihood; Successive interference cancellation; Bit error rate.

1. INTRODUCTION

The new generation of mobile wireless communication systems became an essential part of modern life, especially with new trend of internet of things (IoT), in which large number of devices and objects are connected to wireless communication networks that utilize wireless communication resources. Therefore, the demands in radio spectrum resources became a significant key factor to fulfil the requirements of new generation devices such as high spectral efficiency, low latency, very high data rate and throughput [1-3]. So many techniques have been developed and investigated in order to satisfy the aforementioned high requirements. Non-orthogonal multiple access (NOMA) is considered as one of the most promising solutions for 5G wireless communication. It differs from orthogonal multiple access (OMA) by enabling multiple users to be served using the same resources such as time slot, single carrier and spreading code concurrently. These techniques yield a significant improvement in terms of spectral efficiency, reliability, connectivity and - at the same time - some degree of interference at receiver [3-5]. NOMA schemes are classified into two main types: power domain and code domain. In code domain, NOMA uses random Gaussian codes at the transmitter, and exploits compressive sensing at the receiver to maximize user's detection and minimize symbol error rates. In power domain of NOMA, different users are allocated at different power coefficients according to their channel conditions. Different user's signals are superimposed at transmitter side and assigned different power coefficients while at the receiver side, successive interference cancellation (SIC) is used to detect the desired user's signal [6].

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Cooperative communication has gain great attention since relaying network extends coverage area and enhances performance against multipath fading [7, 8]. The most common cooperative relays schemes are: Amplify and Forward (AF) and Decode and Forward (DF). In AF, the source transmits the signal through relay (R) in first hop. The R amplifies received signal by amplifying the gain and forward it again. It is worth mentioning here that amplification of gain either depends on channel state information (CSI) by estimating channel fading coefficients between source and relay or is considered a constant (M. Aldababsa and O. Kucur, 2019). According to relaying process, relay can be classified into two types: half duplex (HD) and full duplex (FD). FD differs from HD by keeping simultaneous transmission and reception at the same frequency and time slot (M. Aldababsa and O. Kucur, 2019). Therefore, the integration between cooperative relay system and NOMA is considered an attractive solution to improve the efficiency of a communication system, especially considering that power allocation principle can be applied by assuming different channel conditions in a cooperative relay system. Many scenarios have been investigated and analyzed in the literature based on this integration [10-15].

On the other hand, multiple input multiple output (MIMO) provides many advantages in wireless communication such as increasing capacity and improving performance and diversity. However, computational and hardware complexity increases with the number of utilized antennas. Therefore, antenna selection (AS) has been developed as an alternative to MIMO in many applications to reduce complexity. AS along with NOMA have recently attracted a big attention in wireless communication and have been investigated widely [16, 17]. However, this approach is still infancy. The performance of MIMO-NOMA with cooperative relaying and AS has been studied recently [18-21]. On the other hand, integration of multiple types of transmitter antenna selection (TAS) with cooperative relay NOMA and bit error rate (BER) performance has not been investigated widely with all possible scenarios.

In this work, the performance of down link NOMA with AF cooperative relay system has been investigated with two different types of TAS. TAS based on maximum ratio combining (MRC) at relay and TAS with maximum liklihood (ML) and SIC detection based on minimizing BER at mobile end user are both applied. To the best of our knowledge, different TAS in cooperative relay NOMA system has never been studied before, especially by predicting average error rate by TAS/ML that minimizes BER at end user side. Two different TAS schemes were chosen between relay and mobile end user to achieve balance between maximum diversity and acceptable amount of system complexity. MRC detection is chosen at the relay to achieve reasonable amount of diversity order and received signal to noise ratio (SNR) with less complexity compared to ML detection that achieves best performance. The proposed system performance was examined with transmitted power (p_t) versus BER. To evaluate the efficiency of the proposed system, a comparison between suggested multiple TAS with NOMA cooperative relay is carried out with two different TAS scenarios, namely antenna random selection and equal gain combining (EGC) of all antennas at relay and mobile user end. Although a comprehensive investigation about different system factors of the proposed system - such as users' separation α and number of users N- was done, modulation schemes and their direct effect on BER performance was also studied extensively.

2. SYSTEM MODEL

The model adopted in this study is cooperative relay NOMA downlink system, which consists of the R, base station (BS), and number of mobile users (N). The BS is equipped with N_t transmitter antennas and considered as a source in cooperative system. The R is AF, which is equipped with single receive antenna and M_t transmitting antenna. Mobile users are equipped with single transmit and receive antenna. The system is assumed HD and the direct link between base station and mobile users are assumed not existent due to poor channel conditions and physical obstacles. All channels either from BS to R or from R to mobile users are assumed to experience independent Rayleigh fading during transmission.

2.1. Transmission Protocol

Mobile users are distributed in the coverage area with different distances from BS and R, while R is located between BS and mobile users as shown in Fig. 1. The distance between the n_{th} user and BS is denoted as d_{Un} where $d_{U1} < d_{U2} \cdots < d_{UN}$ and $1 \leq n \leq N$ and calculated as:

$$d_{U(n+1)} = \alpha d_{Un} \tag{1}$$

where α is a positive integer.

The distance between BS and R is denoted as d_{SR} and usually fixed. According to different separation distances between users and BS, different power levels are allocated to different users to achieve NOMA principle. The transmitted power allocated to user n_{th} as in (A. Almohamad, S. Althunibat, M. Hasna and K. Qaraqe, 2020) is $p_n = a_n p_t$, where p_t is the transmitted power and $0 < a \leq 1$ represents the power allocation coefficient to user n, where a_n is calculated as [22]:

$$a_n = \frac{d_{Un}}{\sum_{i=1}^{N} d_{Ui}} \tag{2}$$

During the first time slot, the BS broadcasts x signal to N users via R using N_t transmitter antennas, and the transmitted signal x is superimposed as $x = \sum_{n=1}^{N} \sqrt{a_n s_n}$ where s_n represents the complex baseband symbol to be transmitted to user n. The channel coefficients of BS to R and from R to users are denoted by h_{sr} and h_{rd}, respectively and assumed to be independent random variables.

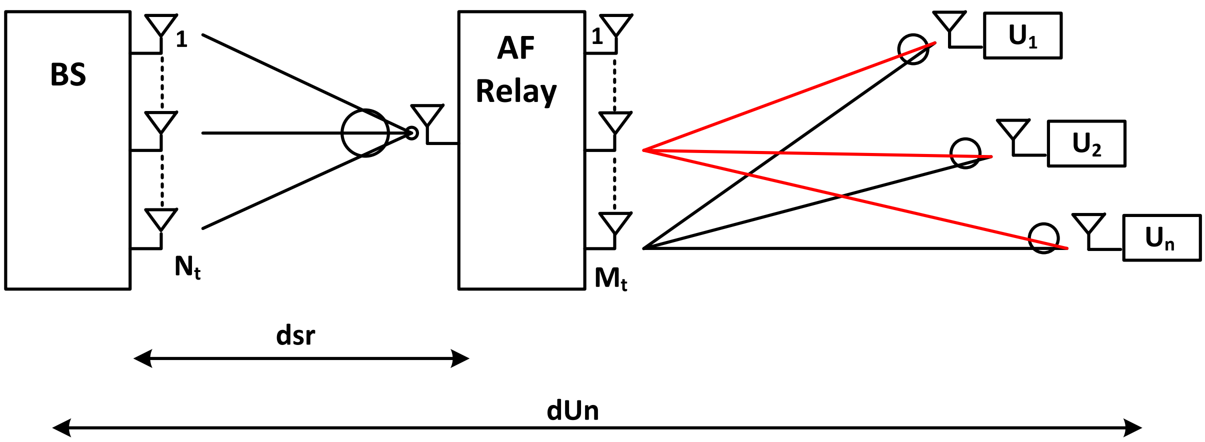

Fig. 1. System model.

2.2. Antenna Selection at Relay

Based on the system model, the AF protocol as proposed in (L. Cao, X. Zhang, Y. Wang and D. Yang, 2009) was complied with two different antenna selection schemes. Transmitter antenna selection using maximum ratio combining (TAS/MRC) from BS to R and transmitter antenna selection using maximum likelihood detection (TAS/ML) from R to users to achieve a form of MIMO-NOMA relaying. It is worth to mention here that the antenna selection scheme at R is independent of antenna selection at user end. Let h_{sr} be the channel coefficient matrix with size of $N_t \times 1$ where $1 \leq i \leq N_t$. The received vector for the transmitted signal at single relay antenna is:

$$y_{sri} = \sqrt{p_{1\,r.n}}\, h_{sr\,i}\, x + n_{sr\,i} \tag{3}$$

where i is defined as $1 \leq i \leq N_t$, $h_{sr\,i}$ is the channel fading coefficient vector between the i^th^ transmitter antenna at BS and receive antenna at R in the first time slot, which is independent and identically distributed $\mathcal{CN}$ (0, ${\sigma_{sr}}^2$) random variables, $n_{sr\,i}$ is the additive white Gaussian noise with variance ${\sigma_{sr}}^2$ at relay, and $p_{1r.n} = p_t\,(d_{sr})^{-\lambda}$ is the received power at R, where λ is the path loss component. The R performs MRC on y_{sr} to get single symbol for the next stage transmission. The single selected transmitter antenna is denoted by I which maximizes the total received signal power at R and is determined by [24]:

$$I = \underset{1\leq i\leq Nt}{argmax}\{C_i = \textstyle\sum_{i=1}^{Nt} |h_{sr\,i}|^2\} \tag{4}$$

The amplification factor for the next time slot is selected as:

$$\beta = \sqrt{p_t/(p_t |h_{sr\,i}|^2 + {\sigma_{sr}}^2} \tag{5}$$

The symbol to be transmitted in the next time slot after the MRC is:

$$x_d = \beta\, h_{sr\,i}\, y_{sr\,i} \tag{6}$$

In the second time slot, the R broadcasts x_d signal to N users using M_t transmitter antennas. The received vector for the transmitted signal from R to nth mobile user antenna is:

$$y_{rdn\,i} = \sqrt{p_{2r.n}} h_{rd\,ni}\, x_d + n_{rd\,ni} \tag{7}$$

where $h_{rdn\,i}$ is the channel fading coefficient vector between the ith transmitter antenna at R and receiver antenna at nth mobile user in the second time slot, $n_{rdn\,i}$ is the additive white Gaussian noise with variance ${\sigma_{rd}}^2$ at user end that equals 0.5 and $p_{2r.n} = p_t\,(d_{Un} - d_{sr})^{-\lambda}$ is the received power at nth user.

2.3. Antenna Selection at Mobile User End

As mentioned before, the end users are equipped with N_t receiver antennas while the R is equipped with M_t transmitter antennas. It is worth to mention that multiple antennas are chosen to be in the R side to reduce complexity and computing at user end and to enhance the error performance and the average BER of the system as well . The detection process for NOMA received signal at user end is based on two detection techniques. The first is successive interference cancellation SIC, where each user receiver detects a signal that is stronger than its own signal and then subtracts it from the received signal. This process continues until the user's own signal is detected. In other words, each user detects his own signal by considering users with low power coefficient as noise. The second detection technique is the ML to choose the best transmitted codewords - among all possible transmitted candidates - that minimize the average BER. The following equation clarifies the previous mentioned process for NOMA cooperative relay system [22]:

$$\widehat{s_{n}} = arg_{min_{j=2^B}} \left| y_{rd\,n} - L \sum_{k=n+1}^{N} \sqrt{a_k}\, \widehat{s_k} - L s^{(j)} \right| \quad (8)$$

where $L = \sqrt{p_{r1.n}}\sqrt{p_{r2.n}}\, h_{sr\,ni} h_{rd\,ni}$, $\widehat{s_n}$ is the decoded symbol for user n, and $s^{(j)}$ represents the j[th] candidate transmitted codeword and B is the number of transmitted bits per symbol (according to modulation scheme $B = log_2 M$ where M is the modulation level) for each user. After calculating the $\widehat{s_n}$, the average BER in NOMA based system with a single antenna at transmitter is calculated as in (A. Almohamad, S. Althunibat, M. Hasna and K. Qaraqe, 2020) over all transmitter antennas at R and, accordingly, the antenna with min BER will be selected [22]:

$$BER = \frac{1}{2^{NB} log_2 M} \sum_{l=1}^{2^{NB}} \sum_{\hat{l}}^{2^{NB}} \tau_{l.\hat{l}} \left(1 - \sqrt{\frac{{w_{l.\hat{l}}}^2}{{d_{Un}}^{-\lambda} + {w_{l.\hat{l}}}^2}}\right) \quad (9)$$

where $\tau_{l.\hat{l}}$ is the hamming distance between the transmitted symbol x_l and the detected symbol $x_{\hat{l}}$ for the corresponding user , and ${w_{l.\hat{l}}}^2$ is given as [22]:

$$w_{l.\hat{l}} = \frac{\sqrt{p_t p_n}\left| {s_{l.\hat{l}}}^2 \right| + 2\sqrt{p_t}\, Re\{y_{rdn} s_{l.\hat{l}}\}}{\sqrt{2\left|s_{l.\hat{l}}\right| {\sigma_d}^2}} \quad (10)$$

where $s_{l.\hat{l}} = s^{(l)} - s^{\widehat{(l)}}$, and $Re\{.\}$ is the real component.

Two different TAS with NOMA cooperative relay is applied in this work as a reference to the suggested TAS such as antenna random selection and EGC of all antennas at relay and mobile user end.

3. SIMULATION RESULTS AND DISCUSSION

In this section, the proposed joint TAS schemes over MIMO cooperative relay NOMA system is validated for Rayleigh fading channels. An equal power per active transmit antenna either on BS or R is assumed. The channel state information of Rayleigh fading channel either between BS and R or from R to mobile end users are perfectly estimated. TAS with MRC at relay is integrated with ML detection based on selecting transmitter antenna with minimum BER at mobile end user. The performance was evaluated by average BER versus transmitted power p_t . Different system parameters were examined such as number of transmitter antennas N_t at BS or M_t at R, separation distances α between users and BS or R, number of mobile users N, and different modulation schemes such as BPSK, QPSK, and 8PSK. All results for the proposed joint TAS schemes for cooperative relay NOMA schemes are compared with two scenarios with either no cooperative relay TAS-NOMA or cooperative relay NOMA with random selection of antenna in R and mobile user end. A further comparison is carried out utilizing all transmit antennas with EGC for all received signal copies at R and mobile user end.

In Fig. 2, the BER performance versus P_t is shown for MIMO cooperative relay NOMA with TAS/MRC at R and TAS/ML that minimize average BER at mobile user end for Rayleigh fading channel with BPSK. In this case, the BS and R are equipped with $N_t \,.\, M_t = 2$ transmitter antennas. The relay is positioned with $\frac{d_{sr}}{d_{U1}} = \frac{50}{100}$ and $\frac{d_{sr}}{dU2} = \frac{50}{200}$ between BS and users 1 and 2, respectively. The separation between users 1 and 2 is 100 with $\alpha = 2$ according to Eq. (1). It can be noticed from BER curves that user 1 with the proposed TAS selection schemes with TAS/MRC at R and TAS/ML at mobile user end achieves BER $=10^{-4}$ at $p_t = 15$ dB while user 2 achieves the same BER at 18 dB.

Also, it can be noticed that the proposed TAS for user 1 outperforms all antennas EGC technique and random selection technique with 10 dB and 17 dB, respectively. It can be concluded that the proposed TAS can provide much better performance compared to all antennas and random selection schemes.

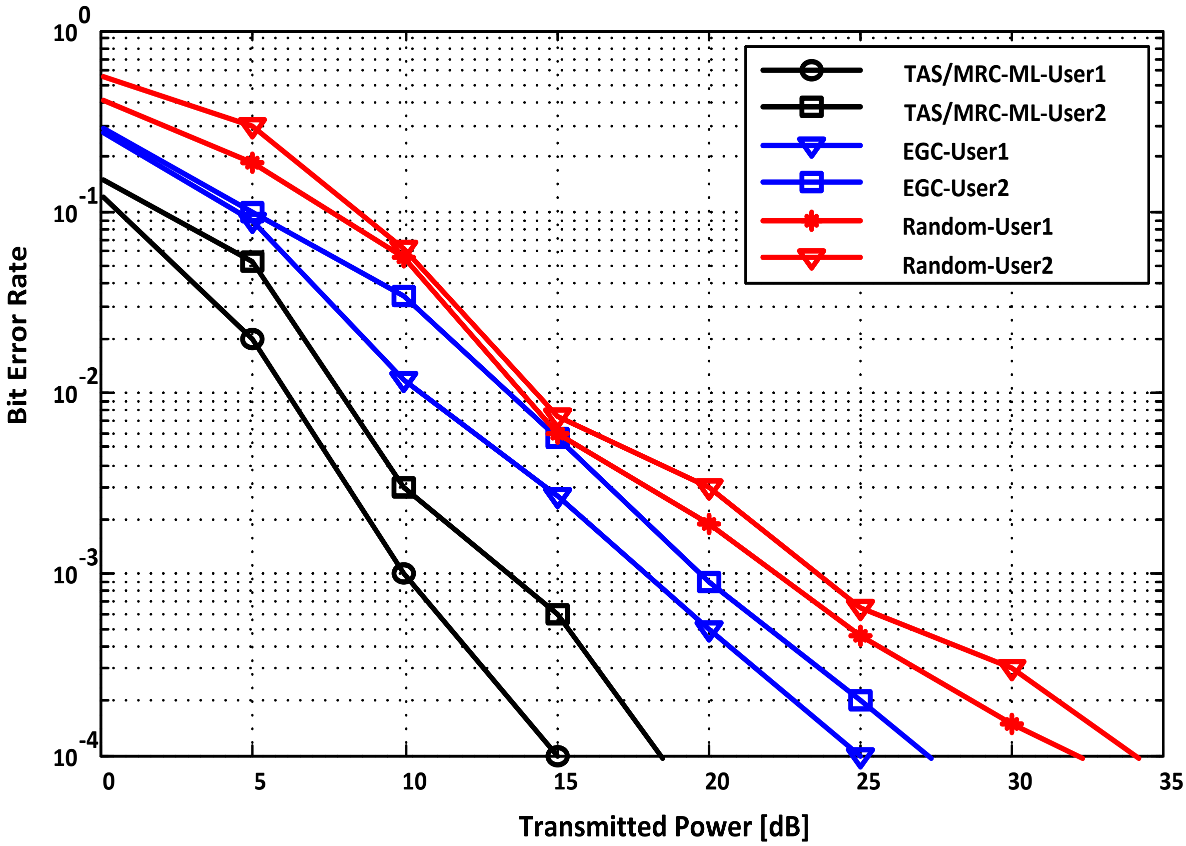

Fig. 2. Cooperative relay NOMA with $\alpha = 2$, N=2, $N_t \, . M_t = 2$, with BPSK and different TAS schemes.

In Figs. 3 and 4, the BER performance for users 1 and 2 was investigated for the same system model depicted in Fig. 2 but with different separation distances between users. It can be noticed that the BER performance improves for users as the separation distance between them increases. For $\alpha = 6$, user 1 achieves $BER = 10^{-4}$ at $p_t = 10$ dB with 3 dB and 5 dB gain over $\alpha = 4$ and $\alpha = 2$, respectively.

Also, in Fig. 4, for user 2, the BER performance improves as the separation distance between users increases. According to these results, the efficiency of SIC increases as the separation distance between users increases, so the TAS/ML scheme at mobile user end improves as the interference from other user decreases, especially for user 1 as the distance from R and BS is fixed compared to other users. Hence, it can be noticed that performance improvement in Fig. 4 is not with the same amount for user 1 in Fig. 3 as the distance α between user 2 and BS and R increases.

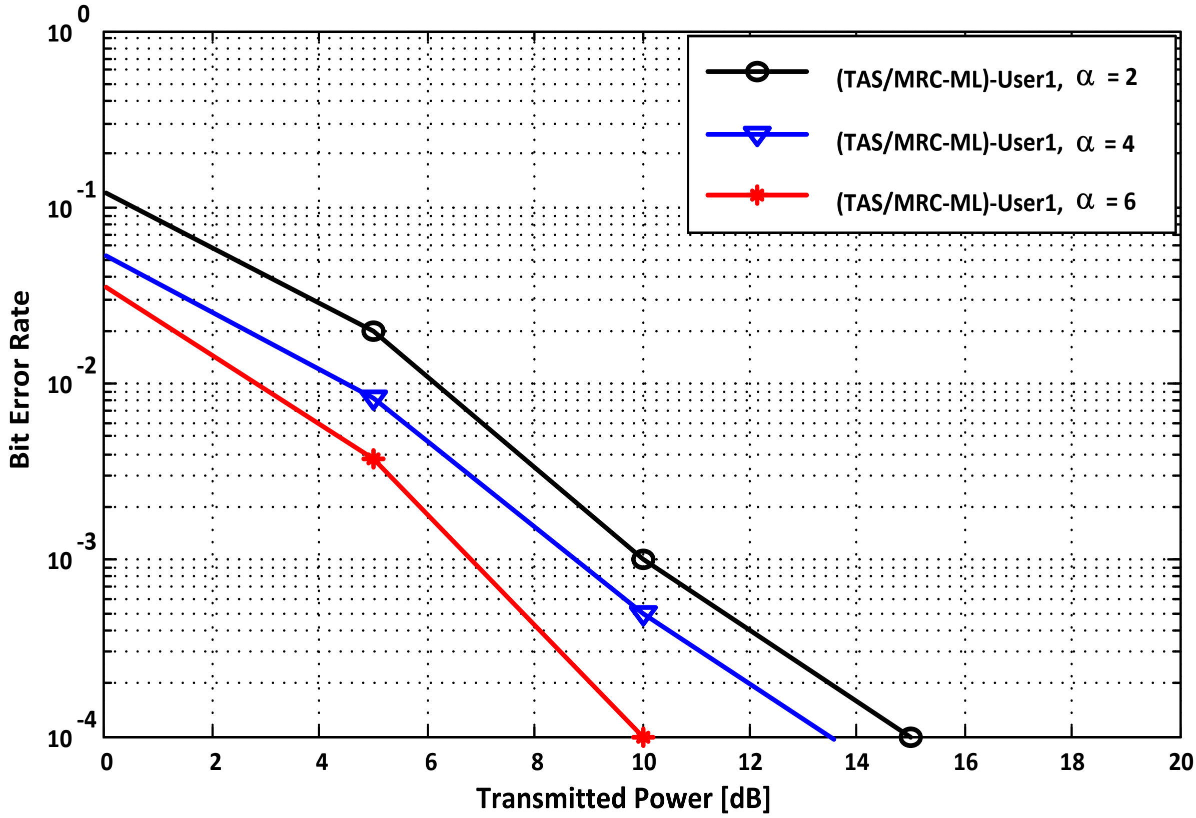

Fig. 3. BER performance at user 1 with cooperative relay NOMA for the TAS/MRC-TAS/ML with different separation distances between users $\alpha = 2, 4, 6$ and N=2, $N_t \,.\, M_t = 2$, using BPSK.

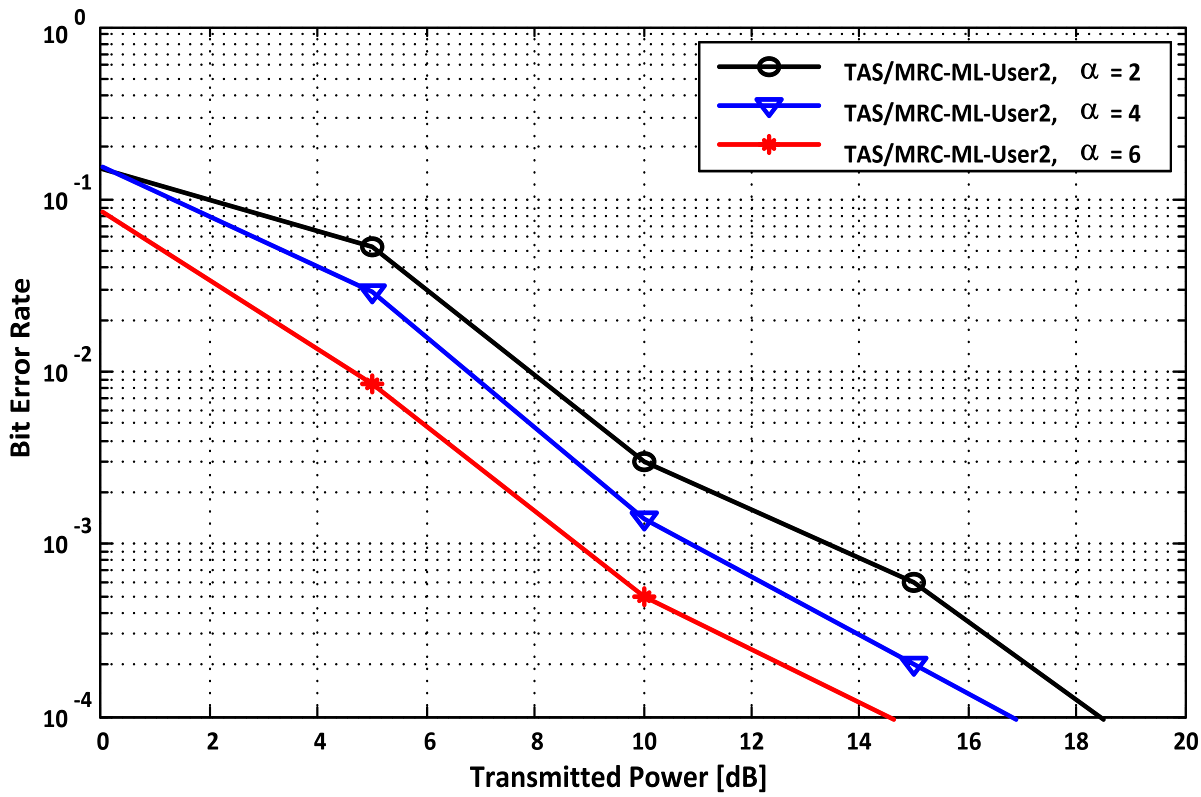

Fig. 4. BER performance at user 2 with cooperative relay NOMA for the TAS/MRC-TAS/ML with different separation distances between users $\alpha = 2, 4, 6$ and N=2, $N_t \,.\, M_t = 2$, using BPSK.

In Fig. 5, BER performance with different number of transmitter antenna at BS and R was investigated with NOMA cooperative relay system. The number of users in this scenario N=2 and the separation factor between users is $\alpha = 6$. It can be noticed that BER performance is enhanced clearly as the number of transmitter antennas increased due the improvement of TAS/MRC at R and TAS/ML at BS performance, as more diversity is available for selection process to maximize I in Eq. (4) and minimize BER in Eq. (9).

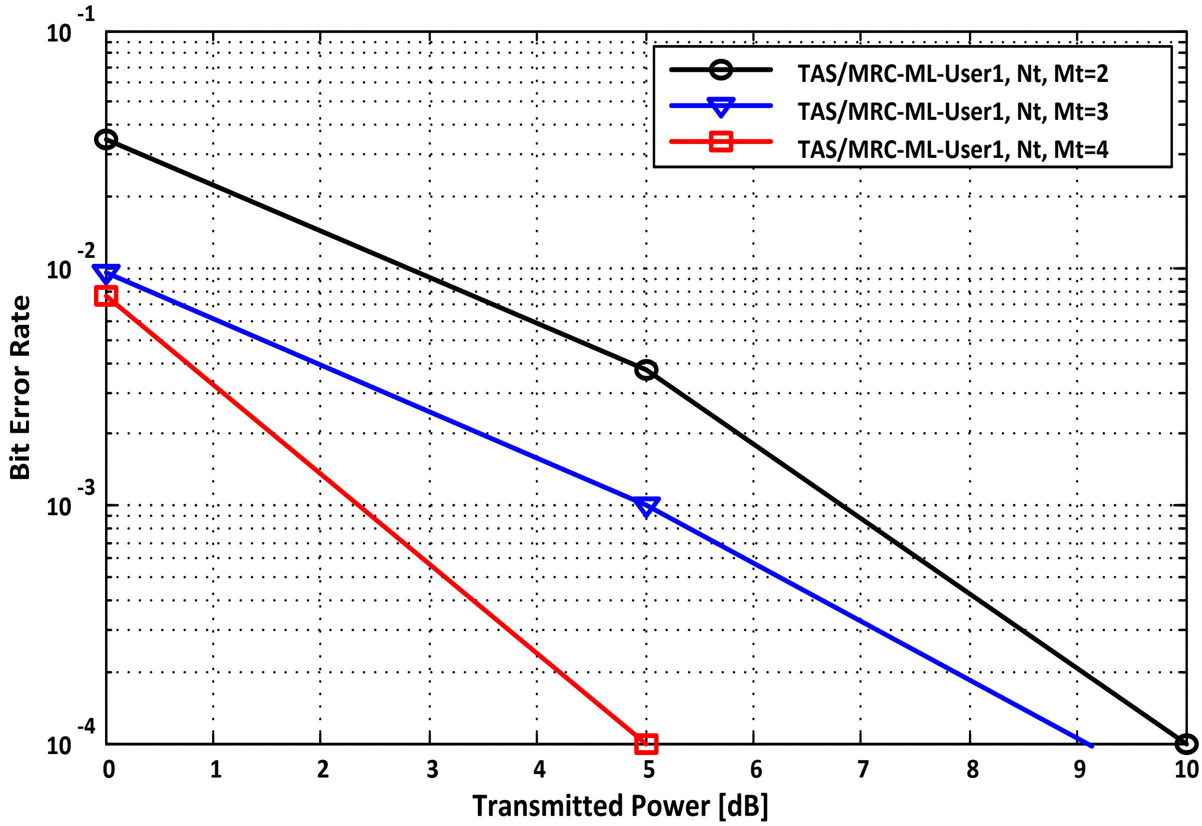

Fig. 5. BER performance at user 1 with cooperative relay NOMA for the TAS/MRC-TAS/ML, with $\alpha = 6$, N=2, and different transmitter antennas at BS and R.

In Fig. 6, the effect of increasing the number of users on the proposed system BER performance is investigated compared to number of users in previous scenarios shown in Fig. 3. It can be noticed here that the performance of user 1 is worse than his performance shown in Fig. 3 with the same separation distance from BS and other users (α = 6 in both cases). The last result proves that as the number of users N increases, a degradation in the performance of the SIC and TAS occurs in the mobile user end. This degradation in SIC and TAS occurs as a result of interference increase from other users.

In Fig. 7, different modulation schemes are utilized with NOMA cooperative relay with TAS. It can be noticed that as the order of modulation increases, the BER performance degrades. BPSK achieves $BER = 10^{-4}$ at 10 dB while QPSK and 16PSK achieves the same BER at 15 dB and 20 dB, respectively. Accordingly, it can be concluded that as the order of modulation increases, the performance degrades due to increasing the number of bits per symbol.

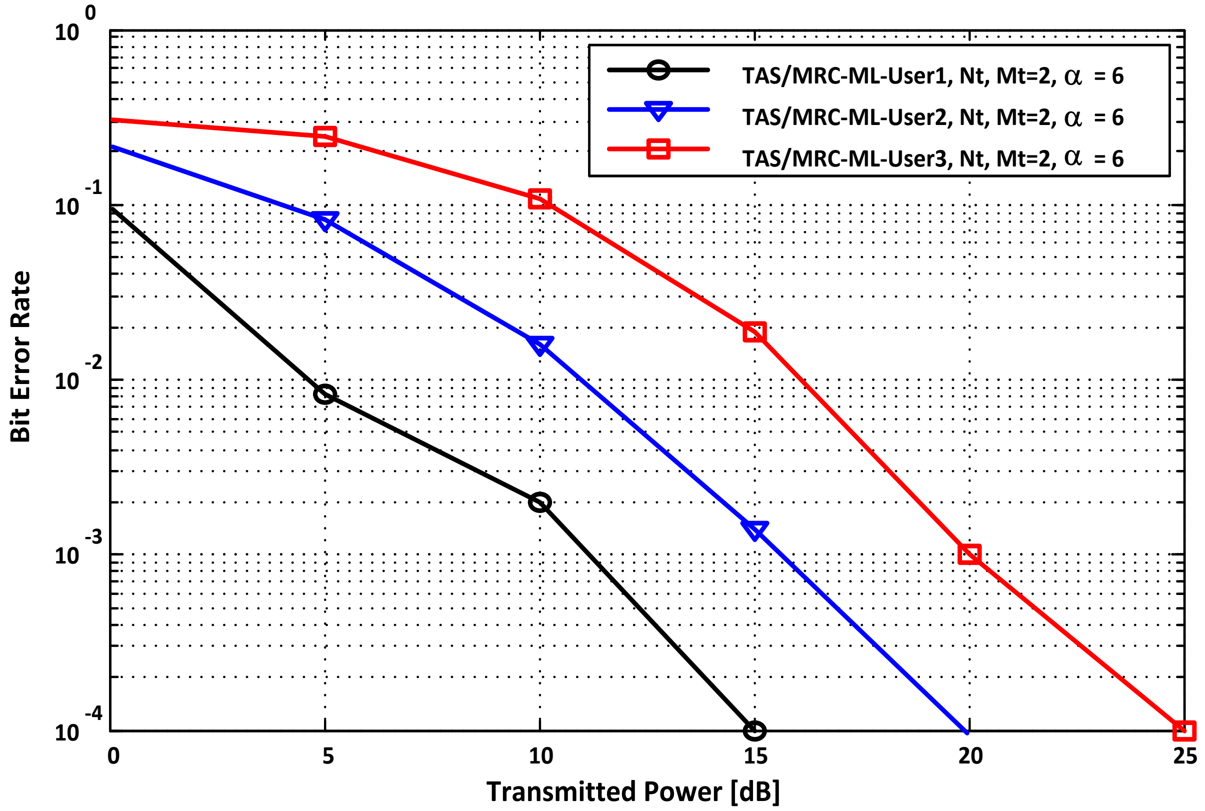

Fig. 6. Users BER performance with cooperative relay NOMA for the TAS/MRC-TAS/ML with $\alpha = 6$ and N=3.

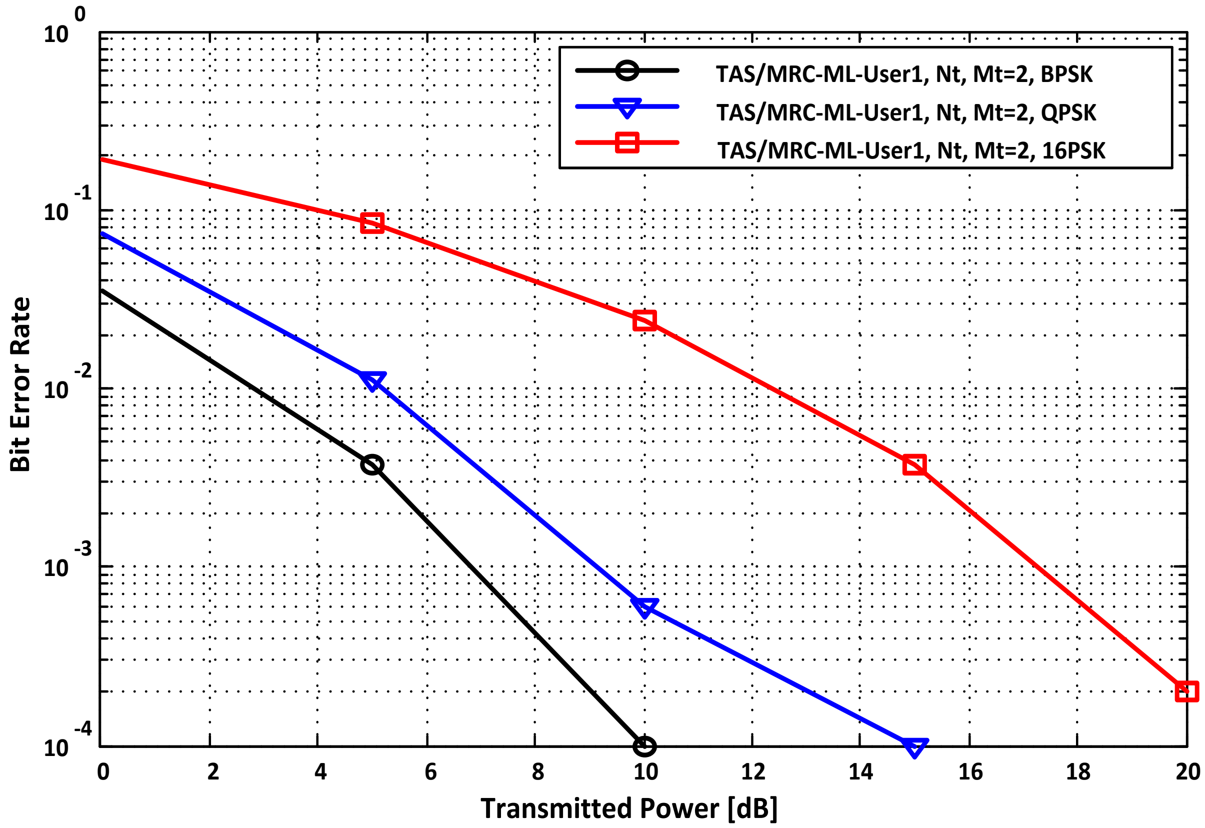

Fig. 7. Users BER performance with cooperative relay NOMA for the TAS/MRC-TAS/ML with $\alpha = 6$, N=2 and different modulation schemes.

4. CONCLUSIONS

In this paper, a comprehensive performance investigation in terms of BER of NOMA was presented. The BER of NOMA was considered in dual hop AF cooperative relay system with two different integrated types of TAS over Rayleigh fading channels. The first is TAS based on MRC at relay, and the second is TAS with ML and SIC detection based on minimizing BER at mobile end user. It was found that the suggested two different TAS schemes either on relay or at mobile user end enhanced the performance of NOMA cooperative relay system significantly compared to other TAS schemes like antenna random selection scheme and EGC of all antennas. Additionally, different factors of the proposed system model were examined to study their effect on BER performance. Those factors included α, the separation distance between users and BS, number of users, and modulation schemes. The simulation results revealed a significant improvement in BER as the separation between users increases. Additionally, degradation in the BER of the proposed model was noticed as a result of increasing the number of mobile users or the order of modulation scheme. This can be justified by degradation of SIC performance that results from the interference increase from other users or the increase in the number of bits per transmitted symbol.

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