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Sum-Rate Performance of A NOMA-based Two-Way Relay Approach for A Two-User Cellular Network

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Abstract

This paper considers a cellular two-way relay network with one base station (BS), one relay station (RS), and two users. The two users are far from the BS and no direct links exist, and the two users exchange messages with the BS via the RS. A non-orthogonal multiple access (NOMA) and network coding (NC)-based decode-and-forward (DF) two-way relaying (TWR) scheme TWR-NOMA-NC is proposed, which is able to reduce the number of channel-uses to three from four in conventional time-division multiple access (TDMA) based TWR approaches. The achievable sum-rate performance of the proposed approach is analyzed, and a closed-form expression for the sum-rate upper bound is derived. Numerical results show that the analytical sum-rate upper bound is tight, and the proposed TWR-NOMA-NC scheme significantly outperforms the TDMA-based TWR and NOMA-based one-way relaying counterparts.

Keywords: cellular two-way relay, NOMA, decode-and-forward, sum-rate performance

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1. Introduction

Non-orthogonal multiple access (NOMA) is a promising solution to improve the spectral and energy efficiency of wireless communication networks [1][2]. By allowing multiple wireless terminals share the same radio resources, NOMA significantly improves transmission efficiency as compared with conventional time-division multiple access (TDMA) or frequency-division multiple access (FDMA) schemes.

The NOMA technique has been recently applied in wireless relay networks to further improve the sum-rates and the outage performance [3]-[6]. The authors in [3] proposed a three-user cooperative NOMA scheme, where the two near users with better link quality acts as relays to forward the signals to the far user. In [4], Yue et al, considered a two-user NOMA system, where the strong user helps the far user by decoding and forwarding the received NOMA signal. In their scheme, the strong user switches between full-duplex (FD) and half-duplex (HD) mode to improve the data rate, which is difficult to implement as designing such small-size FD mobile device is challenging. For wireless networks with dedicated relays, the authors in [5][6] proposed NOMA-based relaying schemes that the relay node and the direct link user forms a NOMA pair, and the relay forwards signal to the indirect link user with DF [5] or amplify-and-forward (AF) [6] relaying.

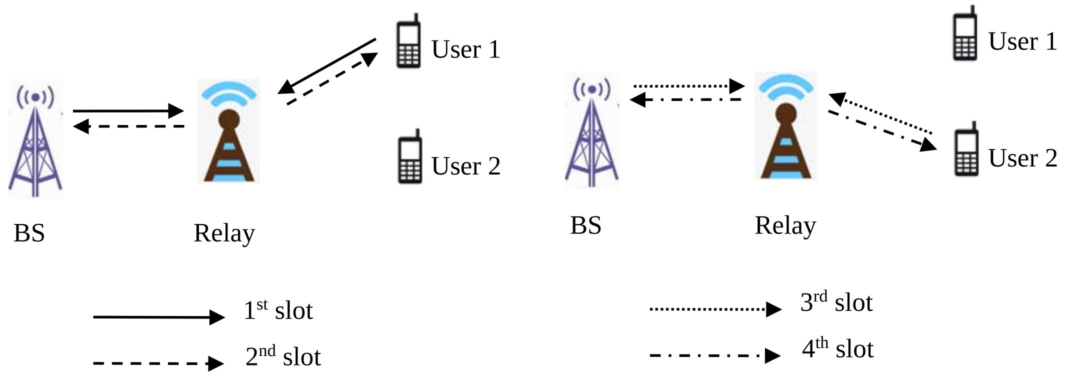
All these aforementioned NOMA-based relaying schemes involve one-way relaying only, i.e., the NOMA signal is transmitted from the source to the destination via the relay. The combination of NOMA and two-way relaying (TWR) was studied recently in [7]-[12]. In [9], the authors investigated a two-group NOMA TWR system, where the users are divided into two groups, and exchange data with one relay. In [10], a hybrid two-way relaying scheme was proposed, which combined the NOMA and network coding techniques. The authors in [11] investigated a NOMATWR network (TWRN) with multiple relays. It was shown in [11] that the spectral efficiency and the spatial diversity can be enhanced with NOMA transmission and relay selection.

Note that all these works [7]-[10] considered the classic two-way relay network model, i.e., two users exchange messages with the help of relay nodes. For more sophisticated two-way relaying systems, such as multipair TWRN [13-15] and multi-way relay network (MWRN) [16][17], the system throughput can also be improved by applying NOMA. In [13], the authors considered a multipair TWRN with NOMA transmission, in which multiple pairs of users communicate with each other with the help of several relay nodes. A rate splitting scheme with successive decoding was proposed to combat the interference. The authors in [14] proposed a cognitive radio inspired NOMA-based network coding scheme to improve the spectral efficiency of multipair TWRNs. In [15], Zhang and Jia designed beamforming matrices for performance optimization in a NOMA-based multi-pair TWRN. In [17], the authors investigated an unmanned aerial vehicle (UAV)-aided NOMA MWRN. Numerical results showed that these proposed approaches [15]-[17] can significantly improve the sum-rates.

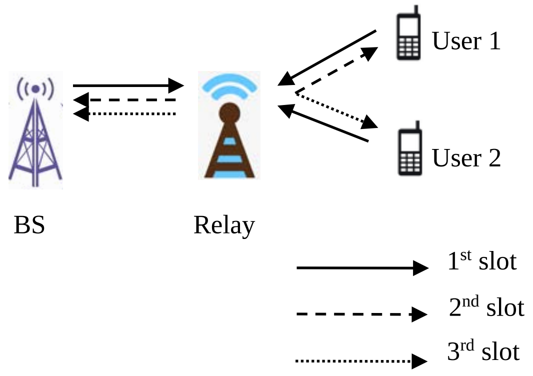
In this work, we consider another important two-way relaying model, namely the cellular two-way relay network (cTWRN), which consists of a base station (BS), multiple mobile users and relay stations (RSs) [18]-[22]. For such a cTWRN as shown in **Fig. 1**, there exist four data streams in each round of transmission, i.e., two downlink data streams from the BS to the two users via the RS, and two uplink data streams from the two users to the BS via the RS. Existing schemes, such as those in [23][24], requires at least four time slots to complete each round of transmission due to the half-duplex mode of the relay.

To reduce the number of required time slots, this paper proposes a TWR-NOMA-NC approach based on NOMA, network coding (NC), and TWR DF relaying. In TWR-NOMA-NC, only three time slots are needed for the two users to exchange data with the BS, as shown in **Fig. 1**(b). In the proposed scheme, an uplink NOMA is constructed at the relay in the first slot, and network-encoded signals are constructed in the second and third time slots. The main contributions of the paper are summarized as follows.

- A new NOMA and NC-based TWR scheme with DF relaying is proposed, which require only three time slots to exchange data between the BS and two distant users, substantially improving spectral utilization and efficiency as compared with existing schemes.
- The achievable sum-rate of the proposed TWR-NOMA-NC scheme is analyzed. Based on a SINR upper bound, a closed-from upper bound is derived for the ergodic sum-rate of the proposed TWR-NOMA-NC. The upper bound is shown to be tight.
- Numerical results show that the proposed TWR-NOMA-NC scheme significantly outperforms conventional TDMA-based TWR transmission approach and NOMA-based one-way relaying approach.



(a) Conventional TDMA-based scheme



(b) The proposed scheme

Fig. 1. Conventional TDMA-based scheme and the proposed TWR-NOMA-NC scheme.

2. The Proposed TWR-NOMA-NC Scheme

Fig. 1 shows a two-user one-relay cTWRN, where a BS and two users $U_k, k = 1,2$, exchange messages with a relay. All the nodes are half-duplex and the time-division duplex

(TDD) mode is adopted. There are no direct links between the two users $U_k, k = 1,2$, and the BS due to shadowing or deep fading. The channels are assumed to be reciprocal, Rayleigh flat fading. It is assumed that the channels remain unchanged during each round of transmission. The channel between the BS and the relay, and that between user U_k and the relay are denoted by h_{BR} and $h_{UR,k}, k = 1,2$, respectively.We also assume that the BS and the relay have perfect knowledge of all the channels as assumed in [18]-[23]. Note that in practical systems, the BS can obtain the channel state information between the relay and the two users via channel feedback from the relay.

For conventional TDMA-based transmissions, four time slots are usually required for such a two-user cTWRN. That is, the BS exchanges messages with U_1 via the relayin the first and second time slots, while in the third and fourth time slots, the BS exchanges messages with U_2 via the help of the relay. To improve the spectral efficiency, this paper proposes a NOMA-based TWR-NOMA-NC scheme that can reduce the number of required time slots into three. Specifically, in the first slot, the BS and the two users send signals to the relay simultaneously to construct an uplink NOMA. The relay broadcasts the network-encoded signal to the BS and U_1 in the second slot. While in the third time slot, the relay broadcasts the network-encoded signal to the BS and U_2.

2.1 The First Slot

At the BS, let $s_{B,k}, k = 1,2$, be the data symbol for user U_k with a data rate of $R_{DL,k}$. The two information streams $s_{B,1}$ and $s_{B,2}$ are jointly encoded into a single data stream s_B. s_B is then transmitted to the relay with a power of P_B . Meanwhile, user U_k transmits $x_{U,k} = \sqrt{P_{U,k}} s_{U,k}$, to the relay, where $s_{U,k}$ is the symbol atU_k , and $P_{U,k}$ is the power budget.

In the first slot, the relay's received signal is given by

$$y_R = h_{BR}\sqrt{P_B} s_B + \sum_{k=1}^{2} h_{UR,k}\sqrt{P_{U,k}} s_{U,k} + z_R. \tag{1}$$

where $z_R \sim CN(0, \sigma^2)$ is the noise.

From (1), an uplink NOMA is constructed at the relay in the first time slot. As the transmit power of the BS $P_B$is usually much higher than the users, the relay detects the signal s_B from the BS first, by treating the signals from the users as noises. Then, s_B is removed from y_R to detect $s_{U,1}$ by treating $s_{U,2}$ as interference, and $s_{U,2}$ is detected at last. Here, it is assumed that user U_1 is the strong user with a better channel quality. Hence, $s_{U,1}$ is decoded before detecting $s_{U,2}$.

From (1), in the first slot, the transmission rate from the BS to the relay is given by

$$R_{BR} = \frac{1}{3}\log_2\left(1 + \frac{|h_{BR}|^2 P_B}{\sum_{k=1}^{2} |h_{UR,k}|^2 P_{U,k} + \sigma^2}\right). \tag{2}$$

After s_B is successfully decoded, the signal s_B is removed from y_R to obtain

$$y_{R,1} = y_R - h_{BR}\sqrt{P_B} s_B = \sum_{k=1}^{2} h_{UR,k}\sqrt{P_{U,k}} s_{U,k} + z_R. \tag{3}$$

Note that the relay detects $s_{U,1}$ by treating $s_{U,2}$ as interference in (3), and $s_{U,2}$ is detected at last. From (3), the data rate from $U_1$to the relay is

$$R_{UR,1} = \frac{1}{3}\log_2\left(1 + \frac{|h_{UR,1}|^2 P_{U,1}}{|h_{UR,2}|^2 P_{U,2} + \sigma^2}\right), \tag{4}$$

while that from U_2 to the relay can be expressed as

$$R_{UR,2} = \frac{1}{3}\log_2\left(1 + \frac{|h_{UR,2}|^2 P_{U,2}}{\sigma^2}\right). \tag{5}$$

2.2 The Second Slot

In the second slot, the relay performs XOR network coding as: $s_{R,1} = s_{B,1} \oplus s_{U,1}$. The transmit signal of the relay is generated as $x_{R,1} = \sqrt{P_R} s_{R,1}$, where P_R is the transmit power budget of the relay. $x_{R,1}$ is then broadcasted to user U_1 andthe BS.

The received signal at the BS and user U_1 in the second slot are respectively given by

$$y_{B,1} = h_{BR}\sqrt{P_R} s_{R,1} + z_{B,1}, \tag{6}$$

and

$$y_{U,1} = h_{UR,1}\sqrt{P_R} s_{R,1} + z_{U,1}, \tag{7}$$

where $z_{B,1} \sim CN(0, \sigma^2)$ and $z_{U,1} \sim CN(0, \sigma^2)$ are the AWGNs.

From (7), both the BS and user U_1 are able to detect the desired signals directly. The achievable data rates from the relay to the BS, and that from the relay to user U_1 are given by

$$R_{RB,1} = \frac{1}{3}\log_2\left(1 + \frac{|h_{BR}|^2 P_R}{\sigma^2}\right), \tag{8}$$

and

$$R_{RU,1} = \frac{1}{3}\log_2\left(1 + \frac{|h_{UR,1}|^2 P_R}{\sigma^2}\right), \tag{9}$$

respectively.

2.3 The Third Slot

The signal transmission and reception in the third slot is analogous with that in Section 2.2. The relay first performs XOR network coding and then forward signal $x_{R,2} = \sqrt{P_R} s_{R,2}$ to user U_2 and the BS, where $s_{R,2} = s_{B,2} \oplus s_{U,2}$ is the network−encoded signal.

The received signals at the BS and users in the third slot are receptively given by

$$y_{B,2} = h_{BR}\sqrt{P_R} s_{R,2} + z_{B,2}, \tag{10}$$

and

$$y_{U,2} = h_{UR,2}\sqrt{P_R} s_{R,2} + z_{U,2}, \tag{11}$$

where $z_{B,2} \sim CN(0, \sigma^2)$ and $z_{U,2} \sim CN(0, \sigma^2)$ are the AWGNs.

The data rates from the relay to the BS and user U_2 are given by

$$R_{RB,2} = \frac{1}{3}\log_2\left(1 + \frac{|h_{BR}|^2 P_R}{\sigma^2}\right), \tag{12}$$

and

$$R_{RU,2} = \frac{1}{3}\log_2\left(1 + \frac{|h_{UR,2}|^2 P_R}{\sigma^2}\right), \tag{13}$$

respectively.

3. Sum-Rate Performance

3.1 Achievable Sum-Rate

Let $R_{DL,k}$ and $R_{UL,k}$ denote the downlink and uplink data rates of user $U_k, k = 1,2$, respectively. For downlink transmission, from (2), for the link from the BS to the relay, $R_{DL,1}$ and $R_{DL,2}$ should satisfy:

$$R_{DL,1} + R_{DL,2} \leq R_{BR}. \tag{14}$$

On the other hand, the downlink rates should not exceed that of the relay-user links in (9) and (13), i.e.,

$$R_{DL,1} \leq R_{RU,1}, R_{DL,2} \leq R_{RU,2}. \tag{15}$$

From (14) and (15), the achievable down link sum-rates of the proposed approach is given by

$$R_{DL,1} + R_{DL,2} = \min(R_{BR}, R_{RU,1} + R_{RU,2}). \tag{16}$$

For uplink transmission, from (4), (5), (8) and (12), we have

$$R_{UL,1} = \min(R_{UR,1}, R_{RB,1}), \tag{17}$$

and

$$R_{UL,2} = \min(R_{UR,2}, R_{RB,2}). \tag{18}$$

The sum-rate of the TWR-NOMA-NC scheme is then given by

$$R_{sum} = \sum_{k=1}^{2} \min\left(R_{UR,k}, R_{RB,k}\right) + \min(R_{BR}, R_{RU,1} + R_{RU,2}). \tag{19}$$

3.2 Ergodic Upper Bound

The exact ergodic sum-rate in (19) is quite difficult to analyze. In the following, we derive a sum-rate upper bound for TWR-NOMA-NC. Let $\rho_B = P_B/\sigma^2$, $\rho_R = P_R/\sigma^2$, and $\rho_{U,k} = P_{U,k}/\sigma^2$. The mean channel gains are denoted by $G_{BR} = E(|h_{BR}|^2)$, and $G_{UR,k} = E(|h_{UR,k}|^2), k = 1,2$, respectively. We have the following result.

Theorem 1: The ergodic sum-rate of the proposed TWR-NOMA-NC scheme is upper bounded by

$$\begin{aligned} E(R_{sum}) \le E(R_{sum}^{UB}) &= \frac{1}{3\ln 2(1-c_1)}\left[\Theta(c_2) - \Theta(c_2/c_1)\right] + \frac{1}{3\ln 2}\Theta(c_3) \\ &+ \sum_{k=1}^{2} \frac{1}{3\ln 2}\Theta\left(\frac{1}{\rho_R G_{UR,k}},\right) \end{aligned} \tag{20}$$

where $E(\cdot)$ denote the expectation, $\Theta(x) = e^x E_1(x)$, $E_1(x)$ is the exponential integral function, $c_1 = \rho_{U,2}G_{UR,2}/\rho_{U,1}G_{UR,1}$, $c_2 = \frac{1}{\rho_{U,1}G_{UR,1}} + \frac{1}{\rho_R G_{BR}}$, and $c_3 = \frac{1}{\rho_{U,2}G_{UR,2}} + \frac{1}{\rho_R G_{BR}}$.

Proof: Using the inequality that $\min(X, Y) \le Y$, we have $\min(R_{BR}, R_{RU,1} + R_{RU,2}) \le R_{RU,1} + R_{RU,2}$. Then, R_{sum} in (19) can be upper bounded by

$$R_{sum} \le R_{sum}^{UB} = \sum_{k=1}^{2} \min\left(R_{UR,k}, R_{RB,k}\right) + R_{RU,1} + R_{RU,2}. \tag{21}$$

Note that $R_{RU,k} = \frac{1}{3}\log_2(1 + \gamma_{RU,k}), k = 1,2$, where

$$\gamma_{RU,k} = |h_{UR,k}|^2 \rho_R, \tag{22}$$

whose cumulative distribution function (CDF) is given by

$$F_{\gamma_{RU,k}}(x) = 1 - e^{-\rho_R G_{UR,k} x}. \tag{23}$$

Then, the ergodic downlink rate of U_k is given by

$$\begin{aligned} E\left(R_{RU,k}\right) &= \int_0^{+\infty} \frac{1}{3}\log_2(1 + x) f_{\gamma_{RU,k}}(x)dx \\ &= \frac{1}{3\ln 2}\int_0^{+\infty} \frac{1 - F_{\gamma_{RU,k}}(x)}{1 + x} dx \\ &= \frac{1}{3\ln 2}\int_0^{+\infty} \frac{1}{1 + x} e^{-\rho_R G_{UR,k} x} dx \\ &= \frac{1}{3\ln 2}\Theta\left(\frac{1}{G_{UR,k}\rho_R}\right), \end{aligned} \tag{24}$$

where $\Theta(x) = e^x E_1(x)$, $E_1(x)$ is the exponential integral function, and the last step in (24) is based on the equation $\int_0^{+\infty} e^{-ax}/(b + x)dx = e^{ab}E_1(ab)$ (cf. [25], eq.(5.1.28)).

For uplink transmission of user U_1, the achievable rate can be expressed as

$$\begin{aligned} R_{UL,1} &= \min\left(R_{UR,1}, R_{RB,1}\right) \\ &= \frac{1}{3}\log_2\left(1 + \min(\gamma_{UR,1}, \gamma_{RB,1})\right), \end{aligned} \tag{25}$$

where $\gamma_{UR,1} = \frac{\rho_{U,1}|h_{UR,1}|^2}{1+\rho_{U,2}|h_{UR,2}|^2}$, and $\gamma_{RB,1} = \rho_R |h_{BR}|^2$.

The CDF of $\gamma_{UR,1}$ is given by

$$F_{\gamma_{UR,1}}(x) = 1 - \frac{1}{1+c_1 x} e^{-\frac{x}{\rho_{U,1} G_{UR,1}}}, \tag{26}$$

where $c_1 = \rho_{U,2} G_{UR,2} / \rho_{U,1} G_{UR,1}$.

The CDF of $\gamma_{RB,1} = \rho_R |h_{BR}|^2$ is

$$F_{\gamma_{RB,1}}(x) = 1 - e^{-\frac{x}{\rho_R G_{BR}}}. \tag{27}$$

Then, the CDF of $\gamma_{UL,1} = \min(\gamma_{UR,1}, \gamma_{RB,1})$ is given by

$$\begin{aligned} F_{\gamma_{UL,1}}(x) &= 1 - P(\min(\gamma_{UR,1}, \gamma_{RB,1}) \le x) \\ &= 1 - (1 - F_{\gamma_{UR,1}}(x))(1 - F_{\gamma_{RB,1}}(x)) \\ &= 1 - \frac{1}{1+c_1 x} e^{-c_2 x}, \end{aligned} \tag{28}$$

where $c_2 = \frac{1}{\rho_{U,1} G_{UR,1}} + \frac{1}{\rho_R G_{BR}}$.

Based on (28), the ergodic uplink rate for user U_1 is given by

$$\begin{aligned} E(R_{UL,1}) &= \int_0^{+\infty} \frac{1}{3} \log_2(1+x) f_{\gamma_{UL,1}}(x) dx \\ &= \frac{1}{3\ln 2} \int_0^{+\infty} \frac{1}{(1+x)(1+c_1 x)} e^{-c_2 x} dx \\ &= \frac{1}{3\ln 2 (1-c_1)} [\Theta(c_2) - \Theta(c_2/c_1)]. \end{aligned} \tag{29}$$

For uplink transmission of user U_2, the achievable rate can be expressed as

$$\begin{aligned} R_{UL,2} &= \min(R_{UR,2}, R_{RB,2}) \\ &= \frac{1}{3} \log_2(1 + \min(\gamma_{UR,2}, \gamma_{RB,2})), \end{aligned} \tag{30}$$

where $\gamma_{UR,2} = \rho_{U,2} |h_{UR,2}|^2$, $\gamma_{RB,2} = \rho_R |h_{BR}|^2$.

The CDF of $\gamma_{UR,2}$ is given by

$$F_{\gamma_{UR,2}}(x) = 1 - e^{-\frac{x}{\rho_{U,12} G_{UR,2}}}. \tag{31}$$

While the CDF of $\gamma_{RB,2} = \rho_R |h_{BR}|^2$ is

$$F_{\gamma_{RB,2}}(x) = 1 - e^{-\frac{x}{\rho_R G_{BR}}}. \tag{32}$$

Then, the CDF of $\gamma_{UL,2} = \min(\gamma_{UR,2}, \gamma_{RB,2})$ is given by

$$F_{\gamma_{UL,2}}(x) = 1 - e^{-c_3 x}, \tag{33}$$

where $c_3 = \frac{1}{\rho_{U,2} G_{UR,2}} + \frac{1}{\rho_R G_{BR}}$.

Based on (33), the ergodic uplink rate for user U_2 is given by

$$\begin{aligned} E(R_{UL,2}) &= \int_0^{+\infty} \frac{1}{3} \log_2(1+x) f_{\gamma_{UL,2}}(x) dx \\ &= \frac{1}{3\ln 2} \int_0^{+\infty} \frac{1}{1+x} e^{-c_3 x} dx \\ &= \frac{1}{3\ln 2} \Theta(c_3). \end{aligned} \tag{34}$$

From (24), (29) and (34), we obtain the sum-rate upper bound in (20).

4. Computer Simulation

In the simulation, the mean channel gains are set to be $G_{BR} = 0$ dB, $G_{UR,1} = -10$ dB and $G_{UR,2} = -20$ dB. The transmit power of the two users are the same: $P_{U,1} = P_{U,2} = P_U$, and the power budget of the BS is 30 dB higher than P_U, while P_R is 10 dB higher than P_U. The noise variance is $\sigma^2 = -20$ dBm.

Fig. 2 shows the sum-rate of TWR-NOMA-NC under various SNRs, where the SNR in the figure is define as $SNR = P_U/\sigma^2$. The sum-rate bound in (20) is also shown in the figure. The sum-rate performance of the TDMA-based TWR NOMA scheme proposed in [23] (labeled as "TWR-NOMA scheme") and the NOMA-based one-way relaying scheme in [24] (labeled as "OWR-NOMA scheme") are also shown in the figure. Note that the OWR-NOMA scheme proposed in [24] was designed for the downlink transmission only. We extended this scheme to the considered cTWRN for two-way transmission. Specifically, in the first slot, the BS transmits to the relay, while the relay broadcasts NOMA signals to the two users in the second time slot. Similar uplink transmission takes place in the third and fourth time slots. From **Fig. 2**, it can be seen that the derived upper bound of TWR-NOMA-NC is tight, especially in the low-to-moderate SNR region. Compared with the conventional TWR-NOMA scheme and OWR-NOMA scheme, the proposed TWR-NOMA-NC scheme is able to achieve a much higher sum-rate in the whole SNR region. For instance, a sum-rate gain of 22% is obtained when $SNR = 16$ dB as compared with TWR-NOMA.

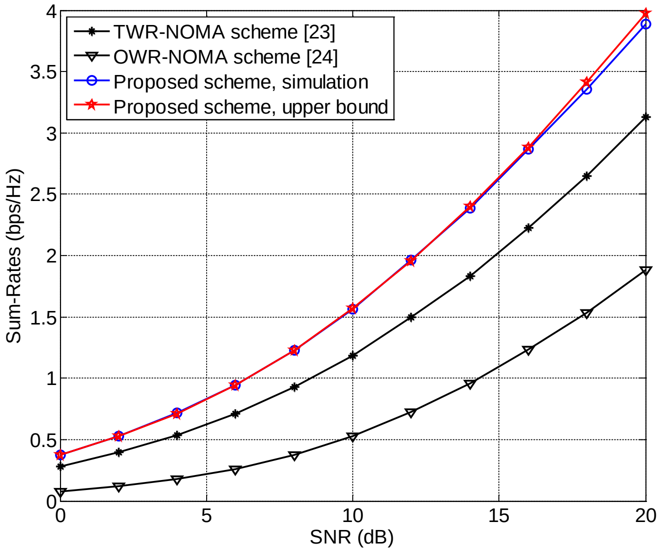


Fig. 2. Sum-rate performance of TWR-NOMA-NC.

The individual user rates of these three schemes are shown in **Fig. 3**. The simulation parameters are the same as in **Fig. 2**. For all these schemes, it can be seen that user U_1 is able to achieve a higher data rate and a lower outage probability, as user U_1 is the "strong" user with a better channel quality than user U_2. It is also shown that with TWR-NOMA-NC, both users are able to achieve a higher data rate than that of TWR-NOMA and OWR-NOMA schemes. Among all these three schemes, the OWR-NOMA scheme achieves the worst performance. This is due to the fact that in the downlink transmission in OWR-NOMA, the achievable data rate of user U_1 is limited by the power allocation factors at the BS.

The outage probability of the TWR-NOMA-NC scheme is shown in **Fig. 4**. The target downlink data rate is 0.5 bps/Hz for each user, while that of the uplink is 0.1 bps/Hz. In **Fig. 4**, one can see that the proposed scheme outperforms TWR-NOMA and OWR-NOMA in terms of outage performance. For all these schemes, user U_1 achieves a lower outage probability than user U_2 since U_1 has a better channel condition than user U_2 . For both TWR-NOMA-NC and TWR-NOMA schemes, the achievable data rate of user U_1 increases with the SNR, hence the corresponding outage probability decreases rapidly with the increased SNR. While for the OWR-NOMA scheme, the achievable data rates are limited by the power allocation factors. Hence, the outage probabilities of both users decrease slowly with the increased SNR.

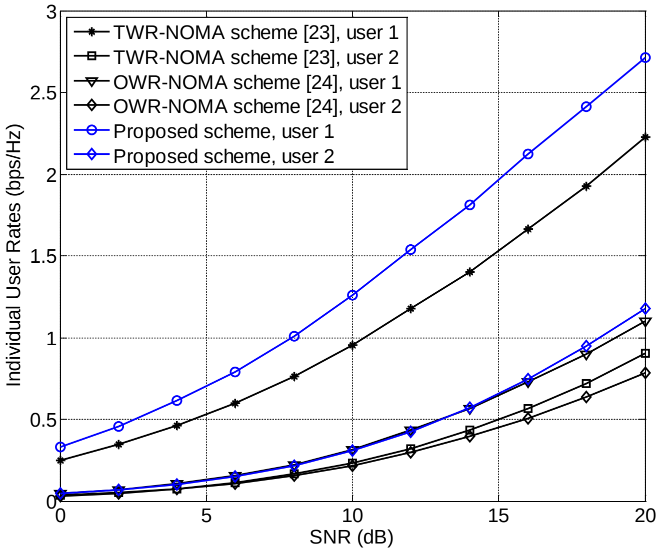


Fig. 3. Individual rate performance of TWR-NOMA-NC.

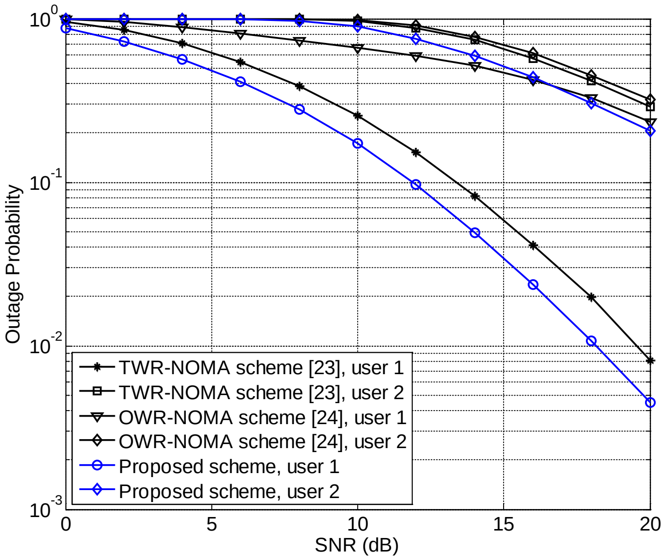


Fig. 4. Outage performance of TWR-NOMA-NC.

Next, **Fig. 5** investigates the sum-rate performance under different BS power budgets. The power of the relay is fixed to be 10 dBm, while those of the users are fixed to be 0 dBm in the figure. From the figure, it can be seen that the sum-rate of TWR-NOMA-NC increases with the BS power, and outperforms the other two schemes. This is due to the fact that increasing the power of the BS can improve the downlink rates of both users in TWR-NOMA-NC. However, the sum-rates of all these schemes approach to certain constants for large P_B. This is due to the fact that for sufficient large BS power, the downlink rates are bottlenecked by the link from the relay to the users. Hence, the downlink rates approach to a constant as P_R is fixed during the simulation.

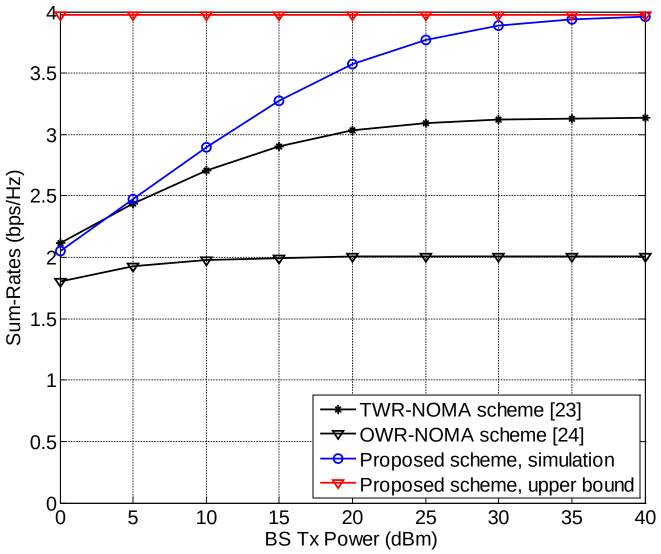


Fig. 5. Sum-rate vs BS power for TWR-NOMA-NC.

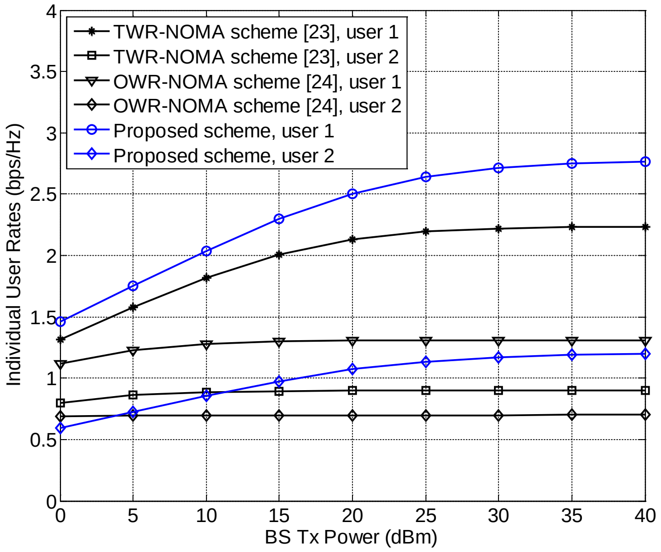


Fig. 6. Individual rate vs BS power for TWR-NOMA-NC.

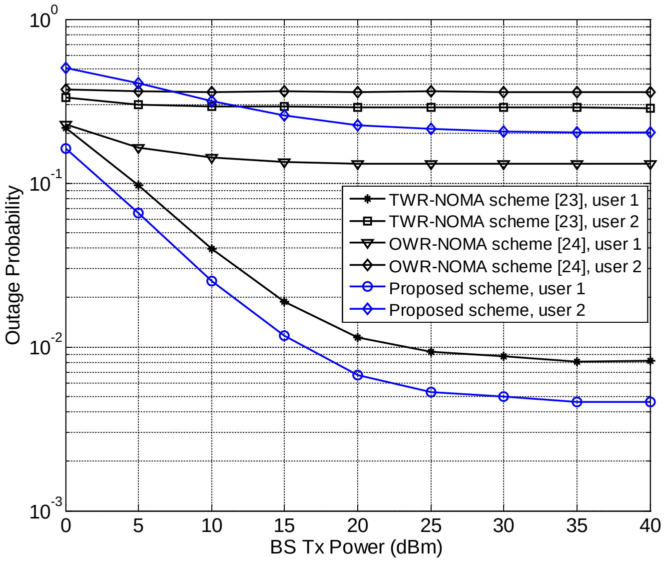


Fig. 7. Outage performance vs BS power for TWR-NOMA-NC.

Similar results can be observed for the individual rate performance shown in **Fig. 6**, where the achievable data rates of both users approach to certain constants for large BS power budgets. Again, the OWR-NOMA scheme achieves the lowest data rates among the three schemes. Especially for the strong user U_1, there is a large performance gap as compared to the other two schemes. There is little performance improvement for user U_1 in the OWR-NOMA scheme by increasing the transmit power of the BS. As a result, the OWR-NOMA scheme achieves a much lower sum-rate as shown in **Fig. 5**. From **Fig. 7**, it can be seen that a lower outage probability can be achieved by the TWR-NOMA-NC scheme for both users, while the outage probabilities for OWR-NOMA are always high regardless of the BS's power budgets. From these results, we see that TWR-NOMA-NC outperforms the other two schemes in terms of both sum-rate and outage performance.

5. Conclusion

This paper proposes an efficient TWR-NOMA-NC scheme for a cTWRN with two users. With the proposed scheme, the two users are able to exchange data with the BS within three time slots. The sum-rate performance of TWR-NOMA-NC is analyzed and a closed-form expression for the sum-rate upper bound is derived. Numerical results show that the derived bound is tight in most cases, and the proposed TWR-NOMA-NC scheme outperforms conventional TDMA-based TWR-NOMA scheme and NOMA-based one-way relaying scheme OWR-NOMA in terms of sum-rate and outage performance.

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