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Full-Duplex Decode-and-Forward Cooperative Non-Orthogonal Multiple Access

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Abstract—Non-orthogonal multiple access (NOMA) scheme is considered as a promising technology for 5G networks due to its ability to increase the spectral efficiency. In this paper, by combining the principle of NOMA and full-duplex (FD) transmission, a downlink FD cooperative NOMA (C-NOMA) scheme is proposed to enhance the system performance. We consider a practical approach where the weak user's signal is only forwarded in the second timeslot after it is decoded, while at the same time the base station (BS) retransmits the weak user's signal again and new information to the strong user. The analytical expressions for the sum rate using maximal ratio combining (MRC) and maximum ratio transmission (MRT) are formulated to investigate the performance of the proposed schemes. Also, in contrary to the conventional C-NOMA method of assuming the two signals from both the BS and strong user can be resolved at the weak user, we assume that the two signals are not resolvable, and hence, accurate analytical sum rates for half-duplex (HD) C-NOMA with MRC and MRT are derived. Numerical simulation results demonstrate that the proposed FD C-NOMA system using MRT offers better sum rate performance than FD C-NOMA using MRC, the HD C-NOMA schemes. Furthermore, the proposed scheme attains a close sum rate performance compared to NOMA and a superior fairness for the weak user.

Index Terms—Non-Orthogonal Multiple Access (NOMA), Cooperative NOMA (C-NOMA), full-duplex (FD), sum rate.

I. INTRODUCTION

IT is expected that Fifth-generation (5G) wireless communication will incur a remarkable change in data speed and latency due to the high demand of data traffic from industry and consumers, and the dramatic growth for both the mobile internet as well as the internet of things (IoT) [1]. However, 5G requires a new future radio access technology that is reliable, efficient and flexible. Non-orthogonal multiple access (NOMA) has emerged as an enabling radio access in 5G technology, since it can offer high spectral efficiency [2]. It also provides better user fairness, low latency, throughput gain and unique capability to utilize a huge number of simultaneous signal transmission with limited resources [3]-[5]. Research within NOMA indicates that NOMA has a superior performance compared to other multiple access schemes [6]-[10]. In [7], the performance of the outage probability and ergodic sum rate in downlink (DL) NOMA scenario with randomly deployed user was investigated. In [8], a sum rate optimization of an uplink NOMA scheme was proposed. The impact of user pairing of two NOMA scenarios was studied in [9] by considering the sum rate of

a fixed power allocation (FPA) and a cognitive radio inspired power allocation (CR-NOMA). The resource allocation and an optimization method to maximize the sum rate of a DL NOMA system were considered in [10].

Cooperative communication has received a lot of interests, as it can offer spatial diversity to minimize fading [11], [12]. The key feature of NOMA is that the strong user is aware of the information of other users; therefore, the integration of cooperative communication can be applied with NOMA. Cooperative NOMA (C-NOMA) leads to enhanced system capacity and reliability, especially for the weak user. Studies on C-NOMA was started with half-duplex (HD) relaying [13]. In [13] the performance of the outage probability in HD user cooperation NOMA was firstly investigated, and it was proved that the outage probability can obtain the maximum diversity gains for all multiplexed users. The capacity analysis and the achievable average rate of relaying system using NOMA was explored in [14]. In [15], the performance analysis of outage probability in C-NOMA with SWIPT was proposed. The impact of power allocation on C-NOMA with SWIPT was studied in [16]. In [17], a C-NOMA multiple-input single-output (MISO) with SWIPT was proposed, in which the BS power ratio and beamforming vectors was jointly optimized.

By using C-NOMA with HD relaying, the rate of the strong user will drop significantly due to the additional timeslots. C-NOMA with full-duplex (FD) relaying can double the spectral efficiency and potentially overcome this problem by assuming that the strong user can transmit and receive simultaneously [18]-[20]. In [18], the outage probability and capacity analysis of out-band FD C-NOMA relaying were studied. [19] considered the achievable rate region of in-band FD relaying in NOMA system with perfect self-interference cancellation. The outage performance of FD user cooperation C-NOMA was investigated in [20]. The outage probability and ergodic capacity of a DL FD C-NOMA were proposed in [21]. In [22], the maximum achievable rate region in a FD C-NOMA was optimized. Existing work assume that the two signals from the strong user and the BS are fully resolvable; hence, they can be co-phased and combined by applying MRC [13], [15], [17], [20]. However, they often are not the case because SIC process requires either the strong user's signal is much stronger or weaker

than the signal from the BS.

A. Motivation and Contributions

In this work, considering the practical issue of decoding, we do not assume the strong user can relay the weak user's signal simultaneously in the same timeslot. Instead, we consider two timeslots in the transmission, and the full duplex transmission is only implemented in the second timeslot after the weak user's signal is completely decoded. We propose several transmission schemes and derive their sum rate expressions. In addition, different from the conventional FD C-NOMA assumption where the two signals from the BS and strong user can be resolved [13], [15], [17], [20], we consider that the two signals are not resolvable. The main reason is that it is not usually the case when the signal from the strong user is much stronger or weaker than the signal from the BS. In this work, the capacity analysis of C-NOMA with HD, FD using MRC is derived. Furthermore, the use of maximum ratio transmission (MRT) [23] is used in C-NOMA with FD and C-NOMA with HD, and the rate equations for both strong and weak user are analysed.

B. Organization

The remainder of this paper is organized as follows. In Section II, the system model considering FD C-NOMA is proposed. In Section III, new analytical expressions for the rate are derived for different C-NOMA schemes. In Section IV, numerical simulation results are presented, which is followed by the conclusion in Section V.

II. SYSTEM MODEL

Consider a downlink C-NOMA system with a BS that serves two paired users U_1 and U_2 , as illustrated in Figure 1. The near user U_2 acts as a FD relay to forward the information to the far user U_1 and receive new information from the BS. The far user U_1 receives its information three times (twice from the BS and one from the strong user). We assume U_1 is uniformly distributed within a distance of R_{D2} to R_{D1} from the BS, and U_2 is uniformly distributed within radius R_{D2} . The total BS power P_t is divided between the two transmission phases. The total system bandwidth B_t is divided between N resource blocks (RBs) of equal bandwidth B . Each RB experiences flat fading as the coherence bandwidth is assumed to be larger than the RB bandwidth B . Nevertheless, all channels are assumed to experience independent and identically distributed (i.i.d.) frequency selective fading. The channel gain for both users are denoted as $|h_i|^2 = \frac{\delta_i |H_i|^2}{PL_i}$, where $i \in \{1, 2, 3\}$, δ_i is the log-normal shadowing, PL_i is the path loss, and H_i is the effect of frequency selective fading. The channels are also to be slowly varying and remain static for two consecutive timeslots. Without loss of generality and for brevity, the following system model and derivations consider one RB only, which can easily be extended to multiple RBs in the simulation. It must be noted that we do use multiple RBs in the simulation to evaluate the performance. The decode-and-forward (DF) protocol strategy is applied at the user relay and the FD C-NOMA includes two phases, detailed in the following.

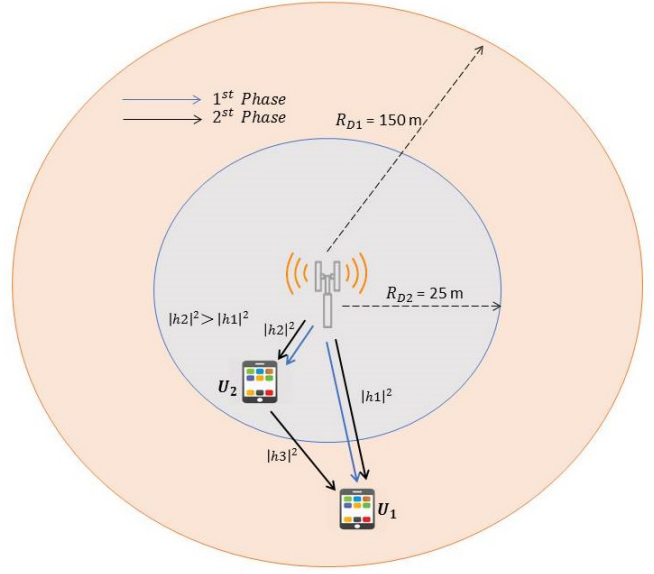


Figure 1. System Model.

A. Phase 1: Direct Transmission

The BS transmits a superposed signal $X_1 = p_1x_1 + p_2x_2$ using NOMA to U_1 and U_2 simultaneously at the first timeslot, in which x_k is the information symbol for U_k , where $k \in \{1, 2\}$. The channel gains are sorted as $0 < |h_1|^2 < |h_2|^2$. p_1 is the allocated power for U_1 and p_2 is the allocated power for U_2 . The received signal at U_1 is given as

$$r_1 = h_1\sqrt{p_1}x_1 + h_1\sqrt{p_2}x_2 + n_1, \quad (1)$$

where n_1 represents the additive Gaussian noise (AWGN) at the reception with power spectral density N_0 . Similarly, the received signal at U_2 is expressed as

$$y_{2(1)} = h_2\sqrt{p_1}x_1 + h_2\sqrt{p_2}x_2 + n_1. \quad (2)$$

With NOMA, U_2 applies SIC to decode the signal of U_1 and subtract it from the combined signal. So in the first phase, the received SINR at U_2 to detect x_1 is expressed as

$$\gamma_{s,U_2(1)}^{x_1} = \frac{p_1 |h_2|^2}{p_2 |h_2|^2 + BN_0}. \quad (3)$$

The received SNR at U_2 to detect its own information is expressed as

$$\gamma_{s,U_2(1)}^{x_2} = \frac{p_2 |h_2|^2}{BN_0}. \quad (4)$$

B. Phase 2: Direct Transmission + Cooperative Transmission

Due to superposition coding, the weak user's signal x_1 can only be decoded after the entire packet is received. Therefore, the strong user can only forward x_1 in the second timeslot. To enhance the sum rate, the BS also transmits new information to the strong user together with x_1 for the weak user in the same timeslot, denoted as $X_2 = p_1x_1 + p_2x_3$, where x_3 denotes the new information symbol to U_2 . Hence the strong user

is operating in FD mode by simultaneously transmitting x_1 while receiving the new signal X_2 from the BS. Therefore, U_1 receives two signals from the BS and from U_2 . The received signal at U_1 at the second phase is given as

$$\begin{aligned} r_2 &= h_1\sqrt{p_1}x_1 + h_1\sqrt{p_2}x_3 + h_3\sqrt{p_3}x_1 + n_2, \\ &= x_1 [h_1\sqrt{p_1} + h_3\sqrt{p_3}] + h_1\sqrt{p_2}x_3 + n_2. \end{aligned} \quad (5)$$

where p_3 is the power allocated to U_2 to apply the cooperative transmission. The received signal at U_2 is expressed as

$$y_{2(2)} = h_2\sqrt{p_1}x_1 + h_2\sqrt{p_2}x_3 + h_{3,2}\sqrt{p_3}x_1 + n_2, \quad (6)$$

where $h_{3,2}\sqrt{p_3}x_1$ is the self-interference due to the use of full-duplex. As the strong user receives x_1 again in the second phase, the self-interference will be combined with the x_1 part of the received signal. Therefore, we can assume the SIC process in the strong user can also remove the self-interference due to FD. Thus, the received SNR at U_2 to detect its own information is expressed as

$$\Upsilon_{s,U_2(2)}^{x_3} = \frac{p_2 |h_2|^2}{BN_0}. \quad (7)$$

From (4) and (7), the rate equation for the strong user (U_2) can be written as

$$R_2 = \frac{1}{2}B\log_2 \left(1 + \Upsilon_{s,U_2(1)}^{x_2} \right) + \frac{1}{2}B\log_2 \left(1 + \Upsilon_{s,U_2(2)}^{x_3} \right). \quad (8)$$

III. PERFORMANCE ANALYSIS

In this section, the capacity equation of the weak user (U_1) using MRC and MRT is derived. Furthermore, the rate expressions of HD C-NOMA using MRC and a new HD scheme with MRT are formulated.

A. MRC

At U_1 , it receives r_1 in the first phase and r_2 in the second phase. MRC is performed by multiplying these signals with the conjugate of the channel gains. Hence, the MRC combined signal at U_1 is given as

$$\begin{aligned} y_{1MRC} &= h_1^*r_1 + \beta^*r_2, \\ &= x_1 [h_1^*h_1\sqrt{p_1} + \beta^*\beta] + h_1^*h_1\sqrt{p_2}x_2 \\ &\quad + \beta^*h_1\sqrt{p_2}x_3 + h_1^*n_1 + \beta^*n_2, \end{aligned} \quad (9)$$

where $\beta = h_1\sqrt{p_1} + h_3\sqrt{p_3}$.

The instantaneous SINR is given as

$$\begin{aligned} \Upsilon_{U_1}^{MRC} &= \frac{[h_1^*h_1\sqrt{p_1} + \beta^*\beta]^2}{|h_1|^2 p_2 [|h_1|^2 + |\beta|^2] + BN_0 [|h_1|^2 + |\beta|^2]}, \\ &= \frac{|h_1|^4 p_1 + |\beta|^4 + 2|h_1|^2 \sqrt{p_1} |\beta|^2}{[|h_1|^2 + |\beta|^2] [|h_1|^2 p_2 + BN_0]}. \end{aligned} \quad (10)$$

So, the capacity equation of U_1 can be written as

$$R_1 = \frac{1}{2}B\log_2 \left(1 + \Upsilon_{U_1}^{MRC} \right). \quad (11)$$

MRC works best when the multiple received signals are completely independent. However from (5), it can be seen that in the second phase, the signal from the BS and from U_2 will be combined at the receive antenna, and hence optimal weighting cannot be applied. Therefore, from (10), it is evident that the conventional approach of summing the SNRs from each observation does not hold in FD C-NOMA.

B. MRT

With the limitations of MRC in FD C-NOMA, we explore the use of MRT as different transmit weighting can be applied to the signal from the BS and U_2 . The received signal at U_1 at the first phase is given as

$$r_1 = w_1 h_1 \sqrt{p_1} x_1 + w_1 h_1 \sqrt{p_2} x_2 + n_1. \quad (12)$$

where $w_1 = \frac{h_1^*}{\|h_1\|}$, which is the weight used by the BS. The received signal at U_1 at the second phase is presented as

$$\begin{aligned} r_2 &= w_1 h_1 \sqrt{p_1} x_1 + w_1 h_1 \sqrt{p_2} x_3 + w_3 h_3 \sqrt{p_3} x_1 + n_2, \\ &= x_1 [w_1 h_1 \sqrt{p_1} + w_3 h_3 \sqrt{p_3}] + w_1 h_1 \sqrt{p_2} x_3 + n_2, \end{aligned} \quad (13)$$

where $w_3 = \frac{h_3^*}{\|h_3\|}$, which is the weight used by U_2 .

Let $\phi = 2w_1 h_1 \sqrt{p_1} + w_3 h_3 \sqrt{p_3}$, the combined received signal at U_1 becomes

$$\begin{aligned} y_{1MRT} &= x_1 \phi + w_1 h_1 \sqrt{p_2} x_2 \\ &\quad + w_1 h_1 \sqrt{p_2} x_3 + n_1 + n_2. \end{aligned} \quad (14)$$

The instantaneous SINR is expressed as

$$\begin{aligned} \Upsilon_{U_1}^{MRT} &= \frac{\phi^2}{[w_1 h_1 \sqrt{p_2}]^2 + [w_1 h_1 \sqrt{p_2}]^2 + 2BN_0}, \\ &= \frac{4p_1 |h_1|^2 + p_3 |h_3|^2 + 4|h_1| \sqrt{p_1} |h_3| \sqrt{p_3}}{2[p_2 |h_1|^2 + BN_0]} \end{aligned} \quad (15)$$

The rate expression of U_1 using MRT is given as

$$R_1 = \frac{1}{2}B\log_2 \left(1 + \Upsilon_{U_1}^{MRT} \right). \quad (16)$$

By comparing (10) with (15), it can be seen that the interference term is reduced when MRT is applied.

C. HD C-NOMA with MRC

In order to compare our proposed scheme with more conventional C-NOMA approaches but with the correct SINR expression, we derive the SINR equation for the HD C-NOMA with MRC. In this case, the BS sends a superposed NOMA signal at the first timeslot to both users and the strong user U_2

will relay the weak user's signal in the second time slot. The received signal at U_1 at the direct phase is expressed as

$$r_1 = h_1\sqrt{p_1}x_1 + h_1\sqrt{p_2}x_2 + n_1. \quad (17)$$

The received signal at the cooperative phase is given as

$$r_2 = h_3\sqrt{p_3}x_1 + n_2. \quad (18)$$

Therefore, the combined receive signal for both direct and cooperative transmission is

$$y_{1_{MRC}} = h_1^*r_1 + h_3^*r_2. \quad (19)$$

The instantaneous SINR is given as

$$\begin{aligned} \gamma_{U_1}^{HD-MRC} &= \frac{\left[|h_1|^2\sqrt{p_1} + |h_3|^2\sqrt{p_3}\right]^2}{|h_1|^4 p_2 + \left[|h_1|^2 + |h_3|^2\right]BN_0}, \\ &= \frac{|h_1|^4 p_1 + |h_3|^4 p_3 + 2|h_1|^2|h_3|^2\sqrt{p_1}\sqrt{p_3}}{|h_1|^4 p_2 + \left[|h_1|^2 + |h_3|^2\right]BN_0}. \end{aligned} \quad (20)$$

Since the strong user only receives its signal in the first phase, it is expected that this conventional HD C-NOMA scheme will have a lower sum rate than the proposed ones, where new information is sent to the strong user in the second phase as well.

D. HD C-NOMA with MRT

For the previous HD case, the BS is idle in the second timeslot. To enhance the performance but maintaining the use of HD relay, the BS can also transmit the same signal again to the weak user in the second phase. Since the transmitted signal from the BS and the strong user will combine at the antenna, it is best to perform MRT. Therefore, similar to the previous case, the first phase consists of NOMA transmission to U_1 and U_2 . At the second phase, U_2 forwards the information x_1 to U_1 , and at the same time the BS retransmits x_1 to U_1 . The received observation at U_1 at the first phase using MRT is similar to (12). the received observation at U_1 at the second phase using MRT is expressed as

$$\begin{aligned} r_2 &= w_1 h_1 \sqrt{p_{1(2)}} x_1 + w_3 h_3 \sqrt{p_3} x_1 + n_2, \\ &= x_1 \left[w_1 h_1 \sqrt{p_{1(2)}} + w_3 h_3 \sqrt{p_3} \right] + n_2, \end{aligned} \quad (21)$$

where $p_{1(2)}$ is the allocated power for the weak user at the second phase. the received signal at U_1 after combining is given as

$$y_1 = r_1 + r_2. \quad (22)$$

Let $\psi = w_1 h_1 \sqrt{p_1} + w_1 h_1 \sqrt{p_{1(2)}} + w_3 h_3 \sqrt{p_3}$, the received observation is obtained as

$$y_{1_{MRT}} = x_1 \psi + w_1 h_1 \sqrt{p_2} x_2 + n_1 + n_2. \quad (23)$$

The instantaneous SINR is

$$\begin{aligned} \gamma_{U_1}^{HD-MRT} &= \frac{\psi^2}{\left[w_1 h_1 \sqrt{p_2}\right]^2 + 2BN_0}, \\ &= \frac{|h_1|^2 \left[p_1 + p_{1(2)}\right] + p_3 |h_3|^2 + \Phi}{p_2 |h_1|^2 + 2BN_0}, \end{aligned} \quad (24)$$

where

$$\Phi = 2|h_1|^2\sqrt{p_1}\sqrt{p_{1(2)}} + 2|h_1||h_3|\sqrt{p_3}\left[\sqrt{p_1} + \sqrt{p_{1(2)}}\right]. \quad (25)$$

As we can see from (24), the interference part has been reduced compared to (15). The main reason is that the second phase transmission does not include any new information to the strong user, which reduces the interference to the weak user. However at the same time, the strong user only receives one packet of information and hence will have a lower rate.

It is clear that the allocated power for the weak user at the first and second phase is different in this case, while it is the same in the FD C-NOMA with MRC and MRT schemes. The main reason is that the BS only retransmits the information to the weak user in the second timeslot in HD C-NOMA with MRT scheme. Therefore, the power of the BS at the second phase is totally allocated to the weak user. This leads to enhance the rate of the weak user further. The allocated power p_1 and p_2 at the first phase as well as p_3 are similar to FD C-NOMA with MRC and MRT.

Note that the SNR for U_2 in case C and D is given as

$$\gamma_{s,U_2(1)}^{x_2} = \frac{p_2 |h_2|^2}{BN_0}. \quad (26)$$

IV. SIMULATION RESULTS

In this section, numerical simulation results of the sum rate for the proposed FD C-NOMA with MRC and MRT as well as HD C-NOMA with MRC and MRT are presented to facilitate the performance evaluations. The power allocation in all NOMA schemes is Fixed Power Allocation (FPA), with $p_1 = \alpha_1 P_{BS}$ and $p_2 = \alpha_2 P_{BS}$. P_{BS} is the BS transmit power for each phase which is equal $P_{BS} = 0.4P_t$. α_1 and α_2 is the power ratio for U_1 and U_2 , respectively with $\alpha_1 = 0.8$ and $\alpha_2 = 0.2$. p_3 denotes the power allocated to U_2 to apply the cooperative transmission which is $0.2P_t$. In the HD C-NOMA with MRC scheme, the value of p_1 and p_2 are doubled as the BS only transmits in the first phase. For the HD C-NOMA with MRT, the allocated power for the weak user at the second phase is $p_{1(2)} = 0.4P_t$, while the power allocation at the first phase is same as in FD C-NOMA for both users. It must be noted that the power allocation here is fixed to provide a fair comparison of different schemes, and can be optimized to enhance the performance. All existing schemes are compared with NOMA with the same total transmitted power. In the considered network, U_1 and U_2 are uniformly distributed within a circular cell diameter of 300m with the

BS at the centre. The cooperative transmission is made when the distance between U_1 and U_2 is less than the distance between the BS and U_1 . The channel is affected by path loss, shadowing effect, and frequency selective fading. The simulation parameters are illustrated in Table 1.

Table I
SIMULATION PARAMETERS

Parameters	Value/Model
Total Bandwidth, B_t	5 MHz
No. of RB	25
Bandwidth per RB, B	200 kHz
Path Loss at 2 GHz band, P_L	$15.3 + 37.6 \log_{10}(d_i)$
Shadowing standard deviation, σ	8dB
Noise Power Density, N_0	-174dBm/Hz
Frequency Selective Fading	ITU Pedestrian B

In Figure 2, the sum rate is evaluated for the proposed schemes against NOMA. It is clear the two proposed FD C-NOMA with MRC and MRT schemes perform significantly better than the two HD C-NOMA schemes. This is because in HD C-NOMA, the use of an additional timeslot significantly reduces the rate for the strong user. Although the performance for the weak user is enhanced, the sum rate is still significantly lower. On the other hand for the proposed FD schemes, as new information is sent to the strong user in the second timeslot, the strong user can maintain a high rate while cooperation improves the rate of the weak user; thus achieving a much better sum rate. The figure also shows that FD C-NOMA with MRT performs better than the FD C-NOMA with MRC. On the contrary, the HD C-NOMA with MRC performs slightly better than the HD C-NOMA with MRT. The main reason is that in FD C-NOMA with MRC, the received signal in the second phase is equally combined at the antenna rather than optimally combined. Therefore, the performance is worse than the MRT scheme. On the other hand in HD C-NOMA with MRT, although the weak user's signal is retransmitted in the second phase by the BS, it reduces the allocated power to the strong user in order to enhance the weak user's rate by increasing the power allocation of the weak user in the second phase. Therefore, this result in a slightly lower sum rate. Finally, the conventional NOMA schemes slightly outperform the proposed FD C-NOMA schemes because it does not require a second timeslot. However as shown in the next two figures, the proposed FD C-NOMA schemes achieves better fairness between the two users.

Figure 3 shows the performance of the strong user U_2 , and it can be noticed that the rate of the FD proposed schemes have better capacity than HD C-NOMA. This is because in our proposed schemes the problem of the additional timeslot at the strong user is eliminated by sending new information to the strong user at the second phase. In this figure, because of the power splitting in FD, NOMA gives better result than FD C-NOMA. FD C-NOMA with MRT and MRC have the same capacity performance, since the MRC and MRT only affects how the weak user combines the signal and obtain diversity, and as such do not affect the strong user's capacity. Moreover,

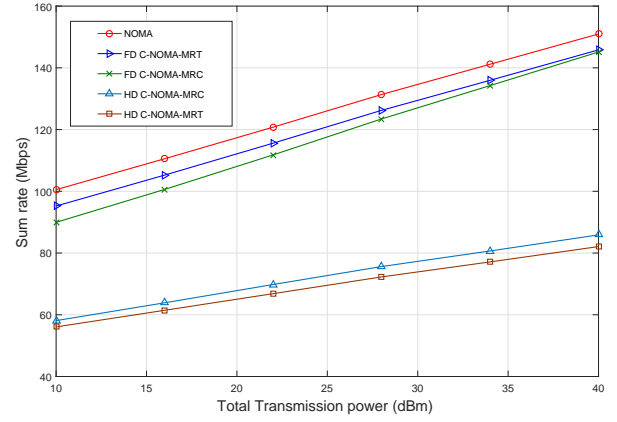


Figure 2. Sum rate performance versus total transmission power.

the results of HD C-NOMA with MRC is better than MRT, since the allocated power for the strong user in MRT case is lower.

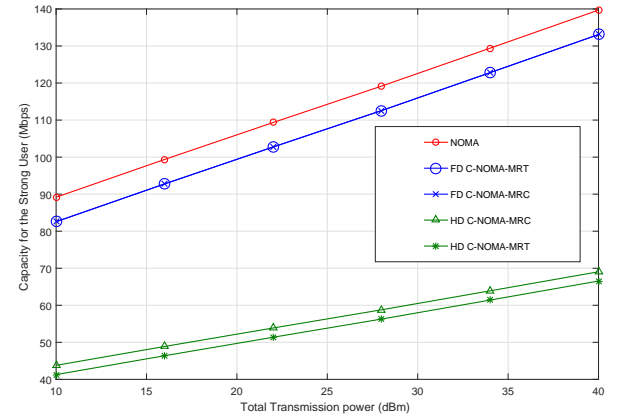


Figure 3. Capacity for strong user U_2 .

In Figure 4, the capacity performance of the weak user U_1 versus the total power is presented. HD C-NOMA with MRC obtains the best result compared with other schemes. The reasons are that, in the HD C-NOMA with MRC, there is no interference in the second transmission phase, and the the BS is idle in the second phase which means the allocated power is not divided between the two phases. HD C-NOMA with MRT performs close to HD C-NOMA with MRC. Figure 4 also indicates that FD C-NOMA with MRT provides better result compared to FD C-NOMA-MRC and NOMA. It is worse than the HD schemes because the second transmission phase from the BS includes new information to the strong user, which causes significant interference to the weak user. Nonetheless, it outperforms the conventional NOMA schemes and thus provides a better fairness for the weak user while achieving a sum rate that is close to the conventional NOMA scheme.

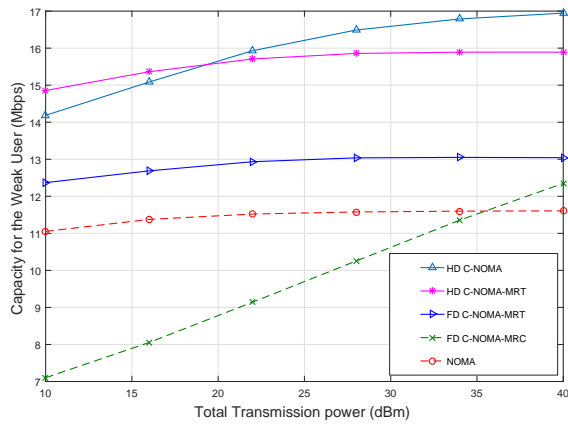


Figure 4. Capacity for weak user U_1 .

V. CONCLUSIONS

A downlink FD C-NOMA system is proposed in this paper to enhance the rate of the weak user without significantly degrading the performance of the strong user as in conventional cooperative scheme. A practical scenario is considered where the two signals from the BS and strong user cannot be resolved at the weak user. The rate expressions for FD C-NOMA with MRT and MRC, as well as HD C-NOMA with MRC and MRT are derived. Numerical simulation results show that FD C-NOMA with MRT achieve a good degree of fairness and obtain better performance than FD C-NOMA with MRC and the HD C-NOMA.

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