Spectral-Efficient User Association in Two-Way Network-Coded D2D Communications with Multiple Antenna Relay

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Abstract

A two-way relay network refers to a communication scenario in which two nodes exchange information with each other, but they are out of transmission range of each other. In this scenario, a relay node can facilitate the information exchange between the two communication nodes. The relay node receives signals from both nodes, processes them, and then forwards the processed signals to the nodes. Interference is the fundamental challenge of two-way relay channels which reduces the received signal quality, where beamforming reduces the interference. Further, when the number of pairs of users increases, the spectral efficiency (SE) decreases dramatically. The purpose of this study is to spectrally efficient user association in two-way network-coded device to device (D2D) communication with multiple antennas relay. We optimize the beamforming vectors at the relay to maximize the achievable sum-rate. In the proposed method, D2D users are selected from the pairs that have the highest correlation channel gains. However, to increase the efficiency of transmission, those pairs whose average data rate does not reach the threshold rate, are removed and other pairs are replaced. The results show that the proposed method can improve the outage probability and spectral efficiency in two-way communication in comparison with other methods.

Keywords: User association, spectral efficiency, network coding, multiple-antenna relay, two-way, D2D.

1. INTRODUCTION

1.1. Motivation

The two-way relay channel (TWRC) serves as a fundamental building block for both centralized and decentralized network architectures. In such systems, information exchange is typically accomplished through a two-phase transmission protocol: during the first time slot, all user terminals concurrently transmit their data to the relay node, which subsequently processes and broadcasts the combined signal to all users in the second time slot. Relay with full-duplex channels can send and receive information at the same time [1]. In this case, the relay manages the inter-pair interference, and the attainable degree of freedom (DoF) is limited to the minimum number of antennas of the base station and the relay. In [2-5], the communication of multiple pairs through multi-antenna relays were studied. For a user with the single antenna, the inter-pair interference is only managed by the relay [2, 3, 6], and the achievable DoF for *M*-antenna relay is up to the integer floor of $\frac{M+1}{2}$ [5]. However, if we have $N \geq \frac{M+1}{2}$, where *N* is the number of user antennas that collaborate to suppress the inter-pair interference, then DoF will be equal to *M* [5].

1.2. Related Works

Several studies considered two-way multi-antenna relaying and discussed different challenges in such transmission. It was shown that two-way multi-antenna relaying not only extends the communication range but also improves the spectral efficiency [7]. In [8], the beamforming was used in simultaneous wireless information and power transfer (SWIPT) with multi-antenna relay to maximize the sum rate. The authors in [9] presented a three-phase two-way relay network, where an energy-constrained multi-antenna relay node harvests the energy from a pair of single-antenna source nodes. In [10], joint optimal source and relay beamforming scheme with power allocation for two-way multi-antenna relay networks with SWIPT was proposed based on the principle of singular value decomposition (SVD).

In order to extend the coverage range, several studies employed relay-assisted device-to-device (D2D) communication by selecting an appropriate relay from the users, resulting in a decrement in outage probability [11, 12]. However, in [12, 13], when there are enough relay candidates, i.e., users, each D2D user pair chooses one relay. However, the number of idle users that can be used as relay, are restricted [13, 14]. In addition, if the idle users are not interested to collaborate in transmission, a waste of useful resources will happen. To this end, the authors in [15] proposed a system model in which multiple pairs of D2D users share one relay. In their approach, the issue of unfeasible direct communication links can be established and the limited number of relay users is avoided. Also, the number of cell connections by using a topology, in which multiple D2D users assist with a single relay, is increased.

Relay selection is a key issue in relay-assisted communications; hence several relay selection schemes have been proposed in the literature. The work in [16] analyzed SWIPT-enabled two-way CR-NOMA relaying and compares PSR and TSR protocols. The results showed that TSR outperforms PSR by 8% in throughput while being more robust to energy harvesting variations.

The study in [17] considered multiple-input multiple-output (MIMO) relay communication in multi-cellular interference systems in which MIMO source-destination pairs communicate simultaneously. It was assumed that due to the shadowing effects and high attenuation, the aid of a relay node is necessary to establish communication links. The authors minimized the maximum mean-square error (MSE) among all the receiving nodes considering source and relay transmit powers constraints. D2D communication in 5G/B5G networks enables direct proximity-based data transfer, optimizing resource use, reducing latency, and boosting network capacity. The authors in [18], reviewed key advances in D2D techniques (discovery, interference management, power allocation) and highlighted remaining challenges for future research.

The study in [19] presented a hierarchical optimization framework that decomposes the problem into outer-layer (channel allocation) and inner-layer (power control) sub problems. By combining discrete power control with game theory, the algorithm significantly improved spectral efficiency. The authors in [20] studied power allocation in a massive MIMO-assisted two-way relay system, deriving closed-form solutions for sum-rate maximization and SNR-constrained scenarios, demonstrating 1–2 dB gains over uniform power control.

Increasing congestion in radio spectrum due to the spread of IoT devices and mobile users has made efficient spectrum management a critical challenge, particularly in urban environments [21]. The authors explored the potential of software-defined radio (SDR) and cognitive radio techniques to optimize D2D communication in such congested scenarios. By leveraging low-cost SDR platforms (e.g., RTL-SDR) combined with distributed spectrum sensing and centralized SDN-based decision-making, their approach enhanced dynamic spectrum access while minimizing interference. The above framework integrated edge processing (via GNU Radio) and cloud-based analytics (using LabVIEW and IoT protocols like MQTT) to enable real-time spectrum selection and D2D partner discovery, offering a scalable solution for 5G and beyond.

A practical SDR-based test bed for single-hop D2D communication was presented in [22], leveraging USRP and RTL-SDR platforms to validate performance in real-world scenarios. By integrating LabVIEW for signal processing and OMNeT++ for simulation, the work bridges the gap between theoretical D2D models and experimental implementation, offering insights into key metrics such as throughput, SNR, and SINR. The results demonstrated that D2D potential in enhancing spectral efficiency and reducing latency in infrastructure-limited environments, promoting for scalable 5G applications.

In [23], two-way full-duplex relaying was analyzed, where multiple full-duplex user-pairs exchange information. It was assumed that the hybrid relay has a smaller number of radio frequency (RF) chains than the antennas. It was shown that a hybrid full-duplex relay has only marginally inferior spectral efficiency and energy efficiency than its full-RF chain counterpart. In [24], the authors discussed the concept of opportunistic multiuser diversity in a multiuser two-way amplify and forward (AF) relay channel. The relay is equipped with multiple antennas and a simple zero-forcing beam-forming scheme, and it selects a set of two-way relaying user pairs in order to increase the DoF and the total throughput of the system.

1.3. Contributions

In [24], the channel-aligned pair scheduling (CAPS) algorithm was presented in a two-way relay to improve the spectral efficiency, such that the users with the highest channel correlations are selected. But, it does not imply that the selected users will achieve the highest spectrum efficiency. In the proposed method, the pairs are selected according to the highest channel correlations. However, to increase the efficiency of system, the pairs whose average rate, do not reach the threshold rate, are removed, and another pair is replaced. Further, beamforming is used to reduce the interference and increase signal to interference plus noise ratio (SINR). We maximize the spectral efficiency, that is, beamforming. We present a solution for the optimization problem. We evaluate the performance and compare the spectral efficiency, energy efficiency, and outage probability of the proposed solution with the CAPS algorithm.

Therefore, the contributions of this study are as follows:

1) Introducing multiuser two-way MIMO relay channel with K pairs of users
2) Utilizing beamforming to reduce the interference and increase SINR
3) Problem formulation to maximize of the spectral efficiency
4) Performing extensive simulations for different parameters.

The rest of this paper is organized as follows. The system model is explained in Section II. The proposed method is presented in Section III. Section IV provides numerical results and finally, Section V concludes the paper.

Notations: Bold lower-case letter represents a vector and bold upper-case letter indicates a matrix. The notations $\mathbf{A}^{\mathrm{T}}$, $\mathbf{A}^{\mathrm{H}}$, $\mathbf{A}^{\dagger}$, and $\mathrm{Tr}[\mathbf{A}]$ show the transpose, Hermitian transpose, the pseudo inverse, and the trace of a matrix $\mathbf{A}$, respectively.

1. SYSTEM MODEL

Fig. 1 demonstrates a multiuser two-way relay channel, in which a half-duplex AF relay with M $(M \geq 2)$ antennas and $2K$ $(K \leq M)$ single-antenna users make K two-way pairs. The relay provides the coverage for connections and paired users have bidirectional communication through the relay. Without loss of generality, it is assumed that the user u_i, $i = 1,...,K$, is paired with the user u_{K+i}. The transmission of two-way relaying is composed of two phases. The pairs transmit their messages toward the relay in the first phase and the relay broadcasts the beam-formed signal toward them in the second phase. Since all users send their messages in one time slot, the interference reduces the SINR.

2.1. *Channel Model*

The signals transmitted in wireless channels are affected by path loss (L) and channel power gain (g). The $M \times 1$ channel vector between the user u_i and the M antennas of the relay is denoted by $\boldsymbol{h}_i$. The components of these channel vectors are independent and identically distributed (i.i.d.) variables. The user u_i sends the message x_i with the fixed power P_s , i.e., $E[|x_i|^2] = P_s$, $i = 1,...,K$, through its antenna in the first phase. The received power (or received interference) in wireless transmission, P_r, is calculated as follows:

$$P_r = P_s\, g\, L^{-1} \tag{1}$$

The channel gain in all communication paths has Rayleigh distribution with the scale parameter of σ. Its probability density function (PDF) is as follows:

$$f(\mathbf{h}) = \begin{cases} \dfrac{\mathbf{h}}{\sigma^2}\exp\left(-\dfrac{\mathbf{h}}{2\sigma^2}\right) & \mathbf{h} \geq 0 \\ 0 & else. \end{cases} \tag{2}$$

There are two transmission phases and it is assumed that all channel coefficients remain constant during both phases. In the following each phase is explained.

2.2. First Phase of Transmission

At the first phase of transmission, all transmitting users, $u_1,...,u_{2K}$, send their messages to the relay simultaneously. It should be mentioned there is no direct transmission link between pairs. The received baseband signal vector at the relay antennas is expressed as [24]:

$$\mathbf{y}_r = \sum_{i=1}^{K}(\mathbf{h}_i x_i + \mathbf{h}_{i+K} x_{i+K}) + \mathbf{n}_r \qquad r = 1, 2, ..., M \tag{3}$$

where $\boldsymbol{n}_r \sim CN(\mathbf{0},\boldsymbol{I}_M)$ is an $M \times 1$ complex noise vector at relay antennas where its elements are i.i.d Gaussian variables with zero mean and unit variance.

2.3 Second Phase of Transmission

To reduce the inter-pair interference and increase the SINR of transmission, beamforming matrices should be used at the relay node in the second phase. To obtain this matrix ($\boldsymbol{W_r}$), first, the power gains of the pair channels are normalized and placed in the matrix $\boldsymbol{H}'_j$ [24] as follows

$$\mathbf{H}_j = \frac{\mathbf{h}_j}{\|\mathbf{h}_j\|} + \frac{\mathbf{h}_{j+K}}{\|\mathbf{h}_{j+K}\|} \qquad j = 1,....,K \tag{4}$$

$$\mathbf{H}'_j = \frac{\mathbf{H}_j}{\|\mathbf{H}_j\|} \qquad j = 1,....,K \tag{5}$$

where $\|\boldsymbol{v}_j\|$ is the Euclidean norm of the vector $\boldsymbol{v}_j$. The normalized gains are then placed inside the matrix $\boldsymbol{G}$ as follows

$$\mathbf{G} = [\,\mathbf{H}'_1,....,\mathbf{H}'_K\,] \tag{6}$$

and the matrix $\widetilde{\boldsymbol{W}}_{\boldsymbol{r}}$ is obtained as

$$\tilde{\mathbf{W}}_r = \rho\mathbf{G}^{\dagger} \tag{7}$$

where ρ is a constant value for all users that depends on the power gains of the channels. It is calculated as follows [24]

$$r = \sqrt{\frac{M}{\mathrm{trace}[(\mathbf{G}^{\dagger})^H\,\mathbf{G}^{\dagger}]}} \tag{8}$$

Then, the beamforming matrix is calculated as [24]

$$\mathbf{W}_r = \beta\tilde{\mathbf{W}}_r^H\tilde{\mathbf{W}}_r \tag{9}$$

where β is obtained as follows

$$b = \sqrt{\frac{P_r}{Tr\left[P_s\,\tilde{\mathbf{W}}_r^T\tilde{\mathbf{W}}_r\mathbf{h}^*\mathbf{h}^T(\tilde{\mathbf{W}}_r^T\tilde{\mathbf{W}}_r)^T + \tilde{\mathbf{W}}_r^T\tilde{\mathbf{W}}_r(\tilde{\mathbf{W}}_r^T\tilde{\mathbf{W}}_r)^T\right]}} \tag{10}$$

It is observed that β depends on the transmission powers of the relay (P_r) and source nodes (P_s).

After that, the $M \times M$ beam-former $\boldsymbol{W}_r$ is applied by the relay to the received signal, $\boldsymbol{y}_r$, and then the vector $\boldsymbol{W}_r\boldsymbol{y}_r$ is transmitted in the second phase. The signal received by the *j*-th pair user in the second phase is given by:

$$
\begin{aligned}
z_j &= \mathbf{h}_j^T \mathbf{W}_r \mathbf{y}_r + \mu_j \qquad\qquad\qquad\qquad j = 1,\ldots,K \\
&= \mathbf{h}_j^T \mathbf{W}_r \left(\sum_{i=1}^{K} (\mathbf{h}_i x_i + \mathbf{h}_{i+K} x_{i+K}) + \mathbf{n}_r \right) + \mu_j \qquad (11) \\
&= \mathbf{h}_j^T \mathbf{W}_r \mathbf{h}_{j+K} x_{j+K} + \underbrace{\mathbf{h}_j^T \mathbf{W}_r \sum_{i=1, i \neq j}^{K} (\mathbf{h}_i x_i + \mathbf{h}_{i+K} x_{i+K})}_{I_j} + \underbrace{\mathbf{h}_j^T \mathbf{W}_r \mathbf{n}_r}_{n_{r,j}} + \mu_j
\end{aligned}
$$

where I_j is the inter-pair interference, $\mu_j \sim CN(0,1)$ is a zero mean unit-variance complex Gaussian noise at the j-th pair.

The power consumption, P_{total}, is calculated as follows:

$$P_{total} = 2MP_s + P_r \qquad (12)$$

where P_s is the power of each user (same for all users) and P_r is the power of relay.

The SINR of each user is calculated as [24]:

$$\gamma_j = \frac{P_s \left| \mathbf{h}_j^T \mathbf{W}_r \mathbf{h}_{j+K} \right|^2}{\left| I_j \right|^2 + \left\| W_r^H h_j^* \right\|^2 + 1} \qquad j = 1,\ldots,K \qquad (13)$$

Since by selecting all available pairs to send, it is possible that the average pair rate does not reach the minimum threshold rate, therefore, the choice of those couples is not only useless but also the spectral efficiency will decrease. Spectral efficiency (η_{SE}) and energy efficiency (η_{EE}) are defined by the following formulas, respectively [25]

$$\eta_{SE,j} = \log_2 \left(1 + \gamma_j \right) \qquad j = 1,\ldots,M \qquad (14)$$

$$\eta_{EE,j} = \frac{\eta_{SE,j}}{P_{total}} \qquad j = 1,\ldots,M \qquad (15)$$

where γ_i and P_{total} were defined in Eq. (12) and Eq. (13), respectively. As we know, by increasing the average rate of delivery, spectral efficiency will also increase.

2. Proposed Method

3.1. Problem Statement

In the proposed method, D2D pairs for transmission are selected according to the highest channel correlations. We utilize beamforming to reduce interference and increase SINR. To this end, we formulate of the problem of maximizing the spectral efficiency.

3.2. Problem Formulation

We formulate the spectral efficiency optimization problem as

$$
\begin{aligned}
&\max imize && \sum_{j=1}^{M} \eta_{SE,j} \\
&subject\,to: && \eta_{SE,j} \geq R_{\min} \\
& && \mathbf{w}_{r,j} \in \mathbf{W}_r
\end{aligned}
\tag{17}
$$

where R_{min} denotes the minimum threshold rate of the downlink transmission. $\boldsymbol{W_r}$ is the set of candidate beamforming codebook. The relay attempts to solve this problem to find the $\mathbf{w}_{r,j}$ optimal for the user equipment served.

3.3. Proposed Solution

In this subsection, we utilize the diversity of channels to align the users in a pair so that the inter-pair interference is handled by beam formers applied at the relay. Users are selected according to the highest channel correlations. However, to increase the efficiency of the system, those pair users whose average rates are less than the threshold rate, are removed, and another pair of users is replaced. The solution is summarized in algorithm 1. The channel correlation between the users of a pair is calculated as follows.

$$v_j = \frac{\left| h_j^H h_{j+K} \right|}{\left\| h_j^H \right\| \left\| h_{j+K} \right\|} \qquad j = 1,.....,K \tag{18}$$

Then, starting from the largest channel correlations, the chosen pairs are reordered in decreasing order and then are placed inside the matrix, **V**, i.e.,

$$\mathbf{V} = sort\{v_j\} \qquad j = 1,.....,M \tag{19}$$

Next, we select the first M pair users from the vector **V** and form the vector ψ as

$$\psi = \mathbf{V}(j) \qquad j = 1,.....,M \tag{20}$$

Considering the SINR definition in (13), it is observed that if the alignment of the channels within a pair is imperfect, then the inter-pair interference power $|I_j|^2$ would be a serious problem in the user u_j, throughput at high SINR. As a result, the relay beam former $\boldsymbol{W_r}$ cannot reduce the interference. To this end, we calculate the average rate of pair users and compare with the threshold rate. The users of the pair whose average rate is higher than the threshold rate, are selected $R_{\min}$, that is,

$$h_{SE,j} = \log_2(1 + g_j)\ {}^{3}\ R_{\min}, \quad j = 1,\ldots,M \tag{21}$$

If the average rate of each pair of users is lower than the threshold rate, that pair is removed and the next pair is replaced. This trend continues until the rate of all users becomes higher than the threshold rate.

The outage probability of a communication channel is the probability that a given information rate is not supported, because of variable channel capacity. It also is defined as the probability that information rate is less than the required threshold the information rate. The outage probability is calculated as follows

$$P_{out,j} = \Pr\left(\log_2\left(1+\gamma_j\right) \prec R_{\min}\right) \qquad j = 1,\dots,M \tag{22}$$

3.4. Computational Complexity

Nothing that the number of users is *2K*, the computational complexity of the algorithm depends on the number of iterations until the convergence. It is of $\mathrm{O}(K^2)$. The complexity of correlation calculations for the scenario is of $\mathrm{O}(4K^2J)$, since the numerator of channel correlations, Eq. (18), requires (J) complex multiplications and in the denominator, computational complexity for norm calculations and single values multiplications were neglected [26]. If the proposed algorithm, converges in (l) iterations, the computational complexity of our solution will be as

$$Complexity = \mathrm{O}(4K^2J + 2lK) \tag{23}$$

when the number of users increases, the size of the beamforming matrix increases. Since the number of channels between pairs increases, and the number of our checks for correlation between channels and SINR increases, thus the computational complexity increases.

Algorithm 1. Pseudo-code of the proposed solution
1: i = 1 to K
2: Calculate: the problem in Eq. (18)
3: Solve: Rearrange the chosen pairs from the largest correlation
4: If feasible: $\eta_{SE,j} \geq R_{\min}$, that pair is selected
5: Else: that pair is removed and the next pair is replaced
6: Repeat:

4. Performance Evaluation

In this section, we present numerical results to evaluate the performance in terms of outage probability, spectral efficiency, and energy efficiency for different parameters. The parameters setting for the network is selected according to the LTE instructions, provided in Table 1.

4.1. Outage Probability

Fig. 2 shows the outage probability for different numbers of users and antennas, as well as the minimum required rates. Multiple transmit antennas increase the ergodic and outage capacity of wireless systems. It is mentioned that the outage probability is directly related to the spectral efficiency. With a fixed threshold rate, when the number of users is small, the outage probability increases by increasing the number of antennas. Because it is possible to select the users whose average information rate is lower than the threshold rate. But as the number of users as well as the number of antennas increases, the outage probability decreases. It is also observed that by increasing the number of antennas, the outage probability reduces since it results in a more reliable link between the transmitter and receiver.

4.2. Spectral Efficiency and Energy Efficiency

Fig. 3 and Fig. 4 respectively demonstrate the spectral efficiency and energy efficiency of the proposed method versus different numbers of antennas, users and threshold rates, respectively. The solution was obtained by searching over all possible sets of pairs of users and transmission powers. It is observed that the results of energy efficiency curve the results of spectral efficiency curves. Increasing the number of antennas increases both spectral efficiency and power consumption. But, the increase in power consumption is more than the rise in spectral efficiency; therefore, according to (15), energy efficiency decreases.

It is observed from Fig. 3, as the number of antennas increases, the spectral efficiency increases. In this case, the outage probability decreases. But when the number of users increases, the beamforming matrix vector increases, resulting in an increased SINR. Since spectral efficiency is directly related to SINR, spectral efficiency also increases. Moreover, in Fig. 3, by increasing the interest threshold rate, spectral efficiency decreases.

Fig. 4 shows the energy efficiency for different threshold rates. Since the total power of the system is related to the number of antennas, when the number of antennas increases, the total power increases, and as a result energy efficiency decreases. When the number of users increases, spectral efficiency increases, and because energy efficiency and spectral efficiency are directly related, energy efficiency also increases.

4.3. Comparison of the proposed method with other methods

In [23], pairs of users with the highest channel correlations are selected. Since it is possible to select the pair users whose average rates are lower than the threshold rate, so the efficiency may decrease. As shown in Fig. 5, the proposed method performs much better.

The comparative analysis in Fig. 6 demonstrates that our proposed joint user selection and beamforming algorithm outperforms the method presented in [19]. Under identical simulation settings (200 users, 64-antenna relay, SNR=20 dB). Our solution achieves a 22.7% higher average spectral efficiency (4.35 vs. 3.54 bps/Hz) while reducing the outage probability by 63% (0.09 vs. 0.24) at the target rate of 1.5 bps/Hz. This improvement stems from our novel three-stage approach: (*a*) correlation-aware user pairing that minimizes interference, (*b*) adaptive beamforming that maximizes signal-to-leakage ratio, and (*c*) dynamic replacement of underperforming pairs using predicted channel coherence. The performance gap widens with network density - at 300 users, where our method maintains 83% QoS compliance versus just 41% for the baseline, proving its superior scalability for massive D2D deployments.

The comparative results in Fig. 7 clearly demonstrate the superiority of our proposed algorithm over the method of [20] under identical simulation conditions (200 users, 64-antenna relay, 20dB SNR). Our solution achieves a 28.4% improvement in spectral efficiency (5.12 vs. 3.99 bps/Hz) while simultaneously reducing the outage probability by 58% (0.07 vs. 0.17) at the target rate threshold of 1.8 bps/Hz. These significant gains are attributed to our innovative two-phase approach: (*a*) intelligent channel-aware user pairing that optimizes spatial diversity, (*b*) adaptive regularized beamforming that dynamically balances interference suppression and signal enhancement.

Fig. 8 shows the effect of large K and M on the performance of the proposed method. We observe that:

a) As the number of users increases, the system gains more channel selection diversity, allowing it to choose user pairs with better channel conditions and higher gains, thereby improving spectral efficiency.

b) Increasing relay antennas enhances spatial multiplexing and beamforming precision, reducing interference and enabling more efficient simultaneous transmission, which boosts spectral efficiency.

c) Combined effect: Both factors work cooperatively —more users provide better channel options, while more antennas enable superior interference management, maximizing overall spectral efficiency.

5. CONCLUSION

In two-way relay networks, spectral efficiency degrades as the number of interfering users grows. To mitigate this, we propose a beamforming and user selection strategy when user pairs exceed available antennas, optimizing spectral efficiency to maximize the system's achievable sum rate. Our method prioritizes D2D user pairs with the highest channel gain correlation while dynamically replacing underperforming pairs that fall below a target rate threshold. Simulations demonstrate that increasing antenna count reduces outage probability and enhances spectral efficiency for dense networks, albeit at the cost of lower energy efficiency due to higher power consumption. Conversely, in sparse networks, more antennas expand selection options but may increase outage probability if chosen users fail to meet the rate threshold. Additionally, raising the efficiency threshold rate inversely affects spectral efficiency and outage performance. The proposed method shows significant gain over other methods.

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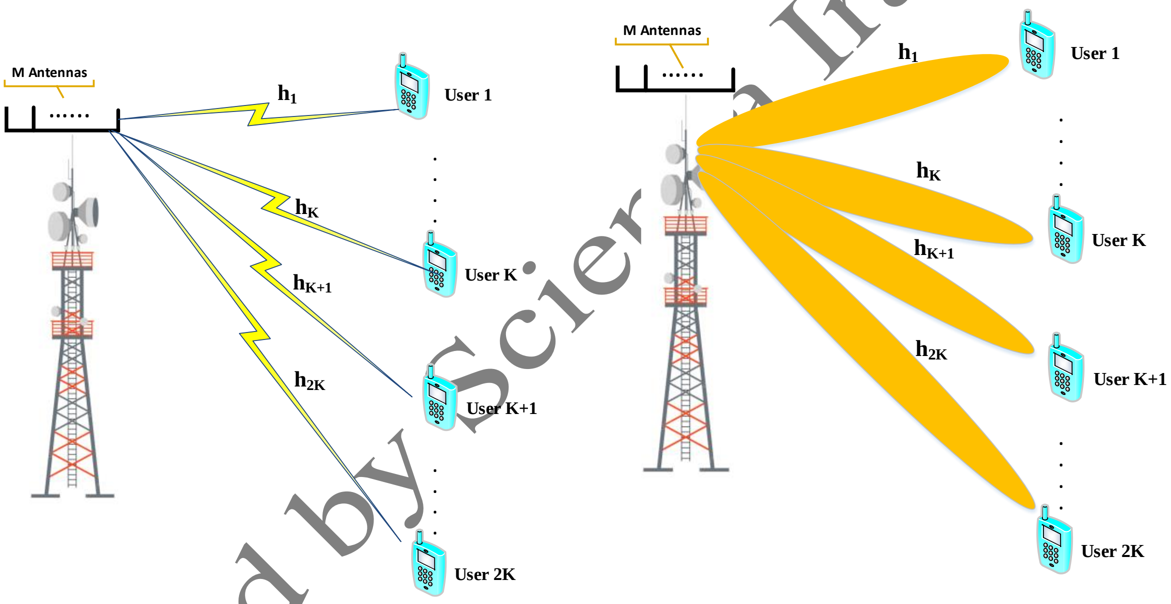
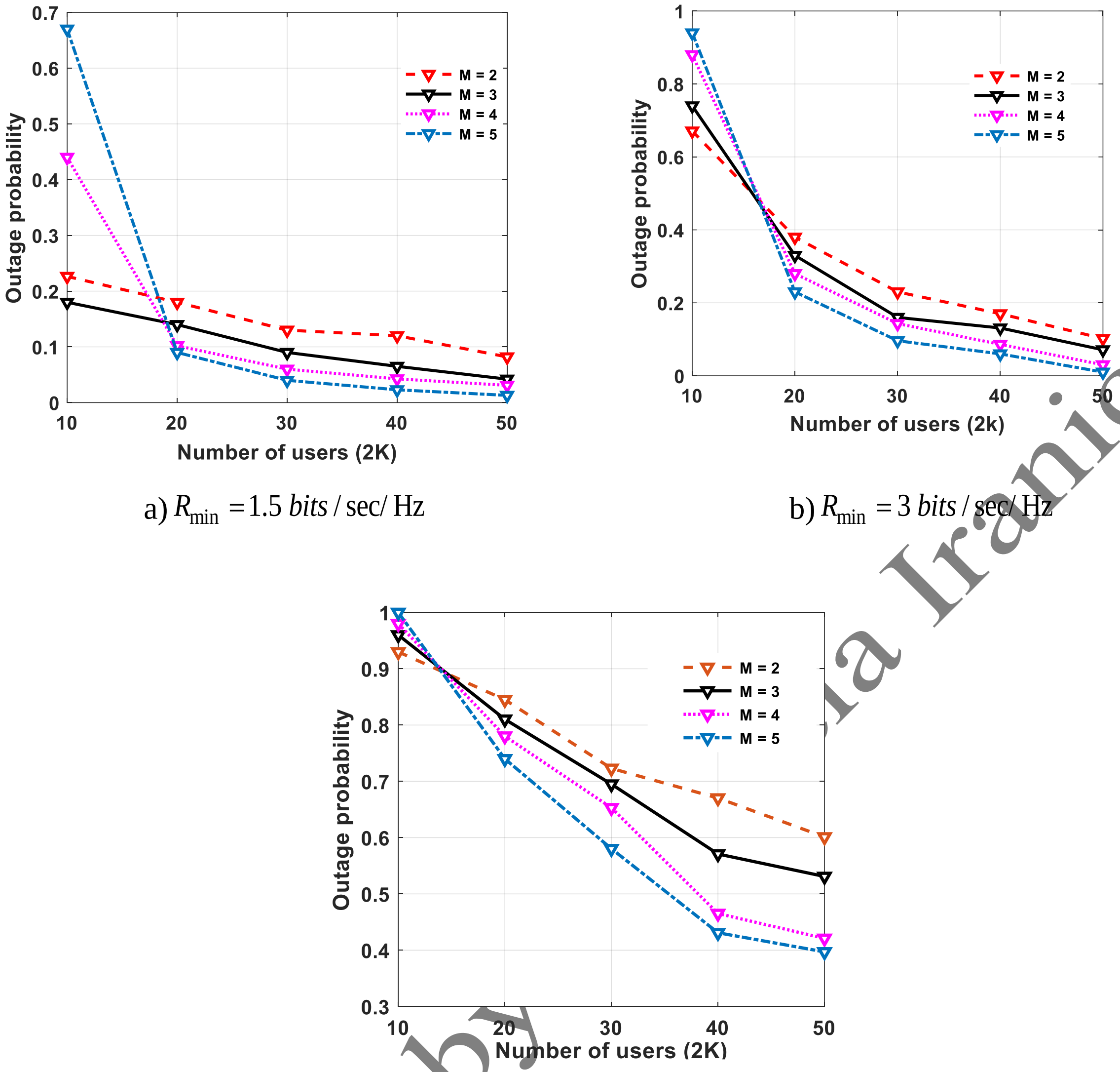


a) First phase of transmission b) Second phase of transmission

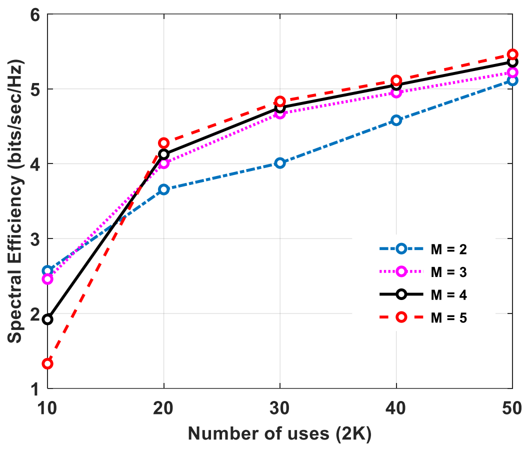
Fig. 1. Multi-user two-way MIMO relay channel with K user pairs.



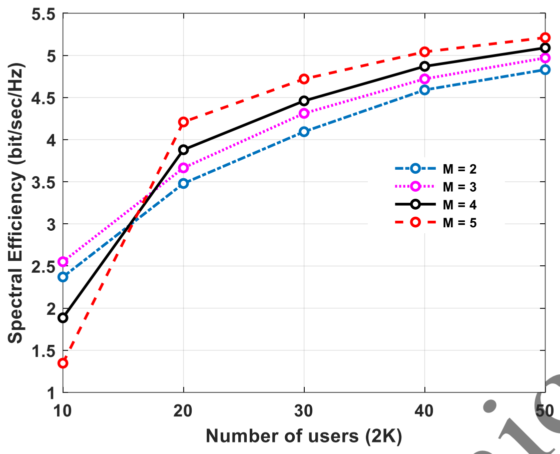
a) $R_{\min} = 1.5\ bits/\sec/\mathrm{Hz}$ b) $R_{\min} = 3\ bits/\sec/\mathrm{Hz}$

c) $R_{\min} = 5\ bits/\sec/\mathrm{Hz}$

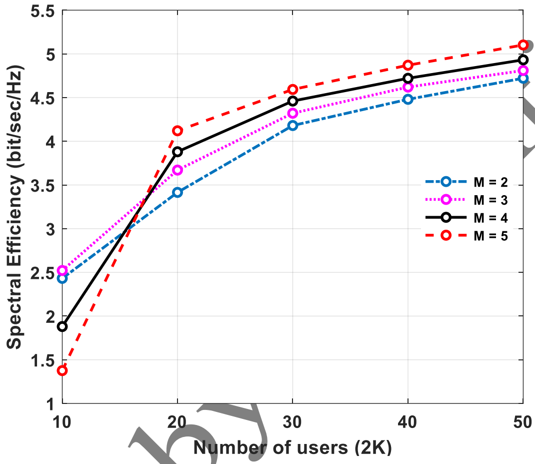
Fig. 2. Outage probability of the proposed method for different values of R_{min}.



a) $R_{\min} = 1.5\ bits/\sec/\mathrm{Hz}$

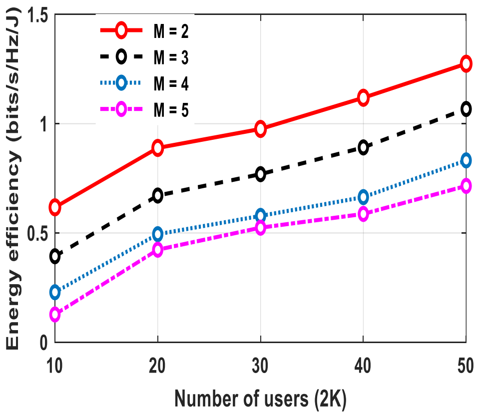


b) $R_{\min} = 3\ bits/\sec/\mathrm{Hz}$

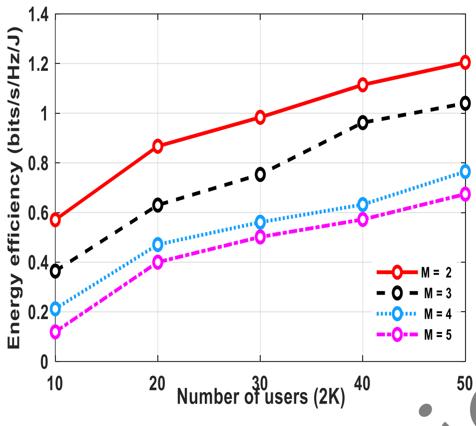


c) $R_{\min} = 5\ bits/\sec/\mathrm{Hz}$

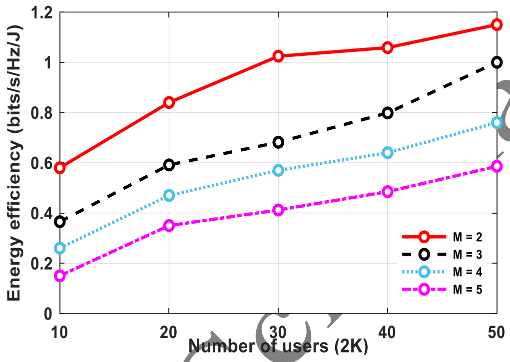
Fig. 3. Spectral efficiency of the proposed method for different values of R_{min}.



a) $R_{\min} = 1.5\ bits/\sec/\mathrm{Hz}$



b) $R_{\min} = 3\ bits/\sec/\mathrm{Hz}$



c) $R_{\min} = 5\ bits/\sec/\mathrm{Hz}$

Fig. 4. Energy efficiency of the proposed method for user selection in two-way relay network for different values of R_{min}.

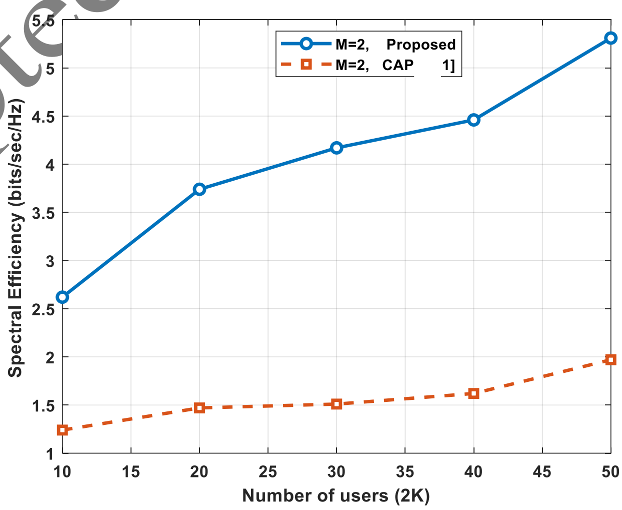


Fig 5. Comparison of the proposed method and [23], (2-antenna relay, SNR=20 dB).

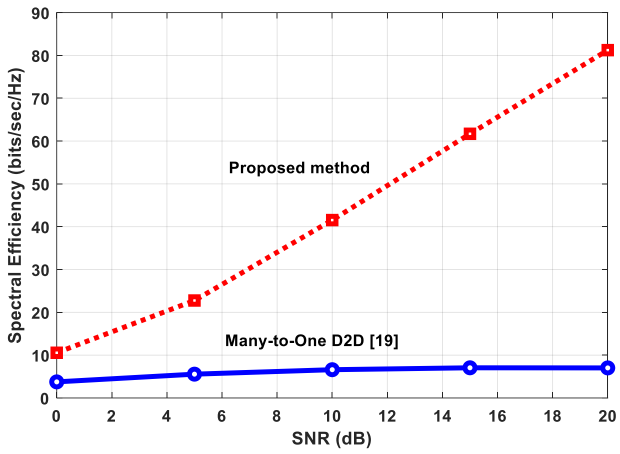


Fig 6. Comparison of the proposed method and [19], (200 users, 64-antenna relay, SNR=20 dB).

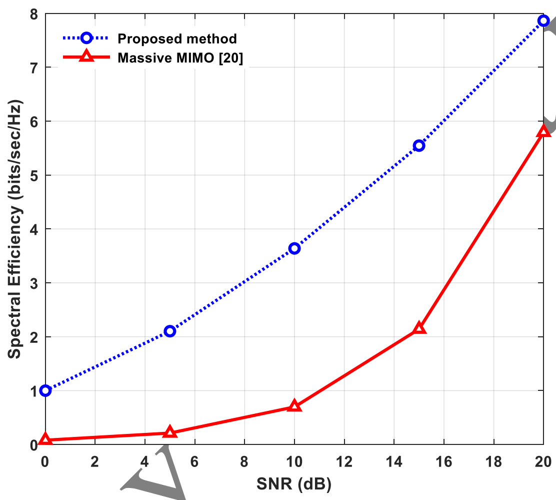


Fig 7. Comparison of the proposed method with [20], (200 users, 64-antenna relay, 20 dB SNR).

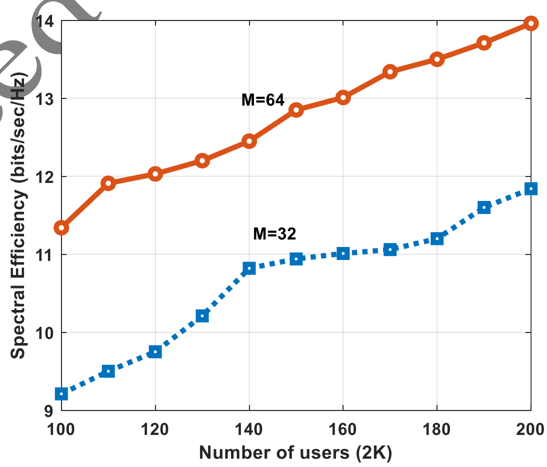


Fig 8. The impact of large K and M on the performance of the proposed method.

TABLE 1. PARAMETERS USED IN SIMULATIONS [23]

Parameter	Value
number of users, $2K$	Min: 10, Max: 50
Number of antennas, M	Min: 2, Max: 5
user transmittal power, P_s	30 dBm
Relay transmittal power, P_r	Min: 20 dBm, Max: 43 dBm
Threshold rate, R_{min}	Min: 1.5 bits/sec/Hz, Max: 5 bits/sec/Hz