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Review article

Optimal power allocation for NOMA-enabled D2D communication with imperfect SIC decoding☆

Shanshan Yu, Wali Ullah Khan, Xiaoqing Zhang, Ju Liu *

School of Information Science and Engineering, Shandong University, 266237 Qingdao, China

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ABSTRACT

The combination of device-to-device (D2D) communication with non-orthogonal multiple access (NOMA) is an efficient solution to enhance the spectral efficiency and connection density of beyond fifth-generation cellular networks. In the paper, we optimize the power allocation of NOMA-enabled D2D communication. In particular, we formulate sum data rate maximization problem subject to the quality of services of cellular user and transmit power of D2D communication. To obtain the efficient solution, we exploit dual theory by using sub-gradient method to solve the dual variables. To gauge the performance of the proposed optimal power allocation scheme, the results are also compared with average power allocation schemes and orthogonal multiple access schemes. The simulation results unveil that the proposed optimization scheme significantly improve the data rate of D2D communication compared to the benchmark schemes.

Contents

1. Introduction

With the increasing popularity of cellular devices and the diversification of mobile services, people's dependence on smart devices continues to increase. Hence the number of users in mobile communication networks continues to grow, the service requests of each terminal are becoming more frequent, and the demand for data traffic is continually increasing, which makes the original problem of the scarcity of spectrum resources more acute [1,2]. It is necessary to continuously enhance the next-generation mobile network in terms of capacity and spectrum utilization [3,4], which can support the growing mobile services and ensure the performance of them at the same time. As a key candidate of the 5G, Device-to-device (D2D) communication can reuse the resources of cellular users, thereby improving the spectrum utilization of the entire network and increasing the total throughput of the system [5]. In addition, on account of the terminals communicate directly, the load is completely borne by the direct link connected to the terminals, which can effectively solve the overload problem of the cellular network [6]. Furthermore, due to the short distance, the mobile terminal can obviously reduce the power consumption to extend the life of the battery. At the same time, D2D communication can also greatly increase the data rate and expand the coverage of traditional networks.

Almost all researches on improving network performance through D2D technology can be attributed to two aspects i.e. resource allocation [7] and interference management. In [8], the

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* Corresponding author.
E-mail addresses: shanshanyu@sdu.edu.cn (S. Yu), waliullahkhan30@gmail.com (W.U. Khan), xiaoqing.sdu@hotmail.com (X. Zhang), juliu@sdu.edu.cn (J. Liu).

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spectrum was fully utilized by searching the minimum transmission distance in a transmission time slot. This column generation based strategy also took into account the avoidance of interference for cellular users and guaranteed the link quality of the D2D link. Wang et al. [9] and Jiang et al. [10] both used different design of iterative algorithms to allocate the channel and control power, where the objectives were to improve the energy efficiencies of cellular user equipments. In the investigation of paper [11], an iterative algorithm was utilized to achieve optimal power allocation for energy efficient transmission of D2D networks. The difference from the previous two literatures is that the game theory is used to analyze the interaction between users and establish mutual preferences. Lin et al. [12] explored the D2D communication resource allocation schemes, which is aimed at minimizing the energy consumption between cellular users (CUs) and D2D pairs. More recently, Najla et al. [13] adopt deep learning which is the most hot method in artificial intelligence field for D2D communication to address the prediction of the D2D channel gain.

In addition, another key technology that can improve spectrum efficiency and increase the number of devices connections is non-orthogonal multiple access (NOMA) [14], which is being deeply studied by researchers. NOMA is different from previous multiple access technologies. The basic idea of NOMA is that the data between users can be transmitted in the same time slot over the same frequency band, and the data aim to different users can be separated by the different levels of transmit power [15]. It is worth to mentioning that the basic fundamental concept of NOMA is to allow D2D receivers to access data through D2D transmitter on the same frequency band and time slot with the help of superposition coding. The data of each D2D user can be accurately extracted from superimposed signal by successive interference cancellation (SIC) decoding technique [16]. Although NOMA can increase the receiver complexity compared to orthogonal transmission, it also improves the spectral efficiency of the system significantly. Besides this, the transmission of NOMA in practical system will become possible with enhancement in the chip processing capabilities. Up to the present, a number of researches on NOMA have been studied in different scenarios. For instance, Di et al. [17] maximized the system sum-rate through optimal users-subchannels mapping and the power allocation for users. Sun et al. [18] provided a suboptimal algorithm to improve the throughput of the system via a sub-carrier power allocation strategy, where the base station works in full-duplex mode, and the user runs in half-duplex mode. In [19], a sum-throughput maximization problem considering both the uplink and the downlink was formulated. This problem was solved by a user grouping strategy with utilizing the channel gain variation among disparate users and power allocation for each NOMA cluster. Moreover, earlier study of cooperative relaying system using NOMA in [20] has considered only the transmission to a single node, while the research in [21] and [22] focused on the transmission to a cluster of nodes.

1.1. Related works

Based the advantages of D2D and NOMA, the combination of D2D and NOMA provides promising prospects for the development of future communications. Expectedly, some researchers have employed NOMA in D2D communication networks. For instance, J. Zhao et al. firstly introduced the concept of "D2D group" in [23], in which the D2D transmitter sends the different signal to the two D2D receivers in the same time based on a proposed NOMA-based D2D framework. In [24], a novel matching game method is used to design a stable user clustering, and the framework of power allocation is realized through the programming method of complementary geometry and the performance of the system is analyzed. S. Alemaishat et al. [25] explored the Kuhn–Munkres (KM) technique for channel allocation for D2D users to maximize the uplink energy efficiency and throughput for them and cellular users coexisting system. In [26], as well as the multi-objective optimization framework of [27], considering a multi-cell network, a multi-objective SINR-maximizing problem is formulated and two matching algorithms are used for joint users grouping and channel assignment to solve this problem.

In addition, a dual-based iterative algorithm is designed in [28] to maximize D2D link sum rate and simultaneously minimum cellular nodes rate with SIC decoding order constraints. In [29], S. Lee et al. design a new genetic algorithm for NOMA-based D2D networks, which can be used to quickly maximize the total throughput of the paired links. Moreover, for the propose of maximizing the capacity of the D2D link with the QoS of cellular links and WiFi system, M. Sun et al. [30] decompose the non-convex mixed integer programming problem into sub-channel assignment and power control sub-problems, using a matching based licensed sub-channel allocation method and proposed an unlicensed sub-channel access approach. Further more, with almost the same target that maximizing the D2D link sum-rate with maintaining the cellular links SINR, authors in [31] utilize the many-to-many mapping method to allocate the resource blocks to both cellular users and the D2D groups to reduce interferences.

1.2. Motivation and main contributions

Most of the previous researches on NOMA-based D2D communication assumes that the SIC process is performed perfectly. However, under some actual situations, error may occur during the process of SIC. Thus, the receiver does not eliminate interference from other nodes due to the poor channel state, which will cause to the decline of system performance. Therefore, we need to investigate an effective power allocation approach to improve the system throughput of NOMA-enabled D2D communication especially considering imperfect SIC Decoding. The main contributions of the paper are as follows:

- Considering that the D2D receivers cannot always perform SIC to decode the signal successfully due to the limited decoding capability, maximizing the data rate of D2D communications through optimal power allocation with imperfect SIC decoding under a single-carrier underlay D2D communication scenario where the D2D transmitter sends signal to D2D receivers using NOMA protocol is proposed in the paper.
- The power optimization problem is formulated as a non-convex problem subject to QoS of cellular user and transmit power of D2D transmitter according to NOMA principle. The problem is transformed to a convex problem firstly and then applied dual theory to get the efficient result. To verify the performance of proposed power optimization scheme, the paper also provide the average power NOMA-enabled D2D communication and OMA based D2D communication as the benchmark schemes.
- The simulation results of proposed NOMA-enabled D2D communication demonstrate that its performance is significant better than the other two schemes. It is also clearly shown that the proposed scheme offers reasonably good fairness among D2D users. Besides this, the data rate of D2D communication declines with the increasing values of imperfect SIC parameter which shows the importance of successful SIC decoding in practical systems. In addition, the proposed algorithm has very low complexity and coverages in a few iterations.

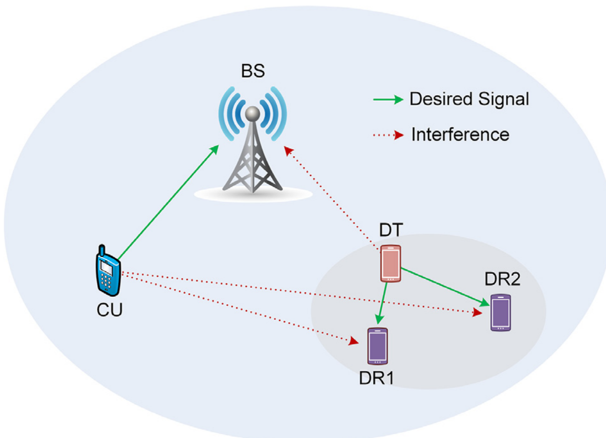

Fig. 1. System Model.

The rest of our paper can be organized as follows. Section 2 introduces the system model and establishes the problem formulation. Then, the presented power optimization scheme is described in Section 3. In Section 4, the simulation results with analysis is clarified. Finally, Section 5 concludes this article.

2. System model and problem formulation

As depicted in Fig. 1, a single-carrier downlink NOMA-enabled D2D communication system is considered, where a D2D transmitter (DT) communicates with two D2D receivers, i.e., DR1 and DR2 using NOMA protocol. In addition, the BS serves a cellular user (CU) using OMA technique in uplink transmission. In this work, we consider underlay D2D communication which reuse the same spectrum with cellular communication. We assume that: (i) All the devices in the network are using omni-directional antenna; (ii) The channel state informations are available in the network; (iii) The wireless channel among different devices undergo Rayleigh fading; (iv) In D2D communication, the DR1 has strong channel conditions and DR2 has weak channel conditions.

We denote the wireless channel from DT to DR1 and DR2 as H_1^{DT} and H_2^{DT}, respectively. Without loss of generality, we sort the channel gain of DR 1 and DR 2 as

$$|H_1^{DT}|^2 \geq |H_2^{DT}|^2. \tag{1}$$

According to (1), DR1 will apply SIC, i.e., remove the interference coming from DR2 first before decoding the desired signal. On the contrary, DR2 cannot use SIC and directly decodes the signal by considering the DR1 signal as a noise.

During the cellular transmission, CU transmits data symbol x to BS with the transmit power P_c which satisfy as

$$0 \leq P_c \leq P_{max}, \tag{2}$$

where P_{max} is the maximum battery power of CU to send the data symbol.

Meanwhile, in D2D communication, DT transmits a superimposed signal to DR1 and DR2 in which s_1 and s_2 represent the data symbols of DR1 and DR2, respectively. The power of DT for transmitting s_1 and s_2 should satisfy

$$q_1 + q_2 \leq Q_T, \tag{3}$$

where Q_T is the total battery power that the DT can use to transmit the superimposed signal while q_1 and q_2 are the transmit power of DR1 and DR2, respectively.

During the cellular transmission, the CU transmits a signal $x = \sqrt{P_c}x$ towards BS. Therefore, the received signal at BS can be given as

$$y_c = G_{BS}^c\sqrt{P_c}x + H_{BS}^{DT}(\sqrt{q_1}s_1 + \sqrt{q_2}s_2) + \omega_c, \tag{4}$$

where the first term is the desired signal of CU at BS in which G_{BS}^c is represents the wireless channel from CU to BS. The second term is the D2D communication interference in which H_{BS}^{DT} is the wireless channel from DT to BS, while the third term is the additive white Gaussian noise (AWGN) with zero mean and σ^2 variance.

During the D2D communication, the DT transmits the superimposed signal $s = \sqrt{q_1}s_1 + \sqrt{q_2}s_2$ to its DR 1 and DR 2. Thus the signal that DR1 and DR2 receive from DT can be formulated as

$$y_1 = H_1^{DT}\sqrt{q_1}s_1 + H_1^{DT}\sqrt{q_2}s_2 + \sqrt{P_c}G_1^c x + \omega_1, \tag{5}$$

and

$$y_2 = H_2^{DT}\sqrt{q_2}s_2 + H_2^{DT}\sqrt{q_1}s_1 + \sqrt{P_c}G_2^c x + \omega_2, \tag{6}$$

where G_1^c and G_2^c are the wireless channels from CU to DR1 and to DR2, respectively. In addition, ω_1 and ω_2 are the AWGN with zero mean and σ^2 variance.

Based on the received signal in (4), the data rate of CU can be expressed as

$$R_c = \log_2(1 + \Gamma_c), \tag{7}$$

where

$$\Gamma_c = \frac{|G_{BS}^c|^2 P_c}{\sigma^2 + |H_{BS}^{DT}|^2(q_1 + q_2)}, \tag{8}$$

is the SINR of CU.

As mentioned above, the D2D communication follows NOMA protocol, therefore, DR2 will decode signal by treating the signal of DR1 as a noise and DR1 will directly apply SIC to decode the signal. However, DR1 cannot always perform SIC to decode the signal correctly due to the limited decoding capability. Thus, the data rate of DR1 can be stated as

$$R_1 = \log_2(1 + \Gamma_1), \tag{9}$$

where

$$\Gamma_1 = \frac{|H_1^{DT}|^2 q_1}{\sigma^2 + q_2|H_1^{DT}|^2\beta + |G_1^c|^2 P_c}, \tag{10}$$

is the SINR of DR1. The β in (10) represents the imperfect SIC parameter which is given as $\beta = \mathbb{E}[|s_1 - \tilde{s_1}|^2]$. Note that $s_1 - \tilde{s_1}$ is the difference between the actual signal and the estimated signal.

Accordingly, the achievable data rate of DR2 can be written as

$$R_2 = \log_2(1 + \Gamma_2), \tag{11}$$

where

$$\Gamma_2 = \frac{|H_2^{DT}|^2 q_2}{\sigma^2 + q_1|H_2^{DT}|^2 + |G_2^c|^2 P_c}, \tag{12}$$

is the SINR of DR2.

The objective of our work is to improve the data rate of NOMA-enabled D2D communication through optimal power allocation. The optimization framework is also subjected to the quality of services (QoS) of CU and the power allocation at DT according to the NOMA protocol. This can be obtained through investigating the following power allocation problem:

$$\text{OP} \quad \underset{q_1,q_2}{\text{Max}}\,(R_1 + R_2) \tag{13}$$

$$s.t. \quad R_c \geq R_{c,min}, \tag{14}$$

$$q_1 + q_2 \leq Q_T, \tag{15}$$

$$q_1 \leq q_2, 0 \leq q_1, 0 \leq q_2, \tag{16}$$

where (13) is the objective function of OP for maximizing the data rate of D2D links via efficient power allocation. In addition, constraint (14) guarantees the QoS of CU while constraint (15) is the power allocation at DT according to the NOMA protocol.

3. Proposed power optimization scheme

It can be observed that the optimization problem OP is non-convex due to R_1 and R_2 [32], therefore we first transform it to convex optimization by taking the advantage of NOMA principle [33]. Let us consider that α is the power allocation coefficient of DR1. Then the optimization problem OP can be reformulated as

$$\max_{\alpha} \left\{ \log_2\left(1 + \frac{|H_1^{DT}|^2 Q_T \alpha}{\sigma^2 + Q_T(1-\alpha)|H_1^{DT}|^2 \beta + G_1^c P_c}\right) + \log_2\left(1 + \frac{|H_2^{DT}|^2 Q_T (1-\alpha)}{\sigma^2 + Q_T \alpha |H_2^{DT}|^2 + G_2^c P_c}\right)\right\} \tag{17}$$

$$s.t. \quad \log_2\left(1 + \frac{|G_{BS}^c|^2 P_c}{\sigma^2 + |H_{BS}^{DT}|^2 Q_T}\right) \geq R_{c,min}, \tag{18}$$

$$Q_T \alpha \leq Q_T(1-\alpha), \ \alpha \geq 0, \tag{19}$$

Next we adopt dual theory to calculate the efficient solution [34]. The dual problem associated with this problem can be given as

$$\min_{\phi \geq 0, \delta \geq 0} \max_{\alpha} \left\{ \log_2\left(1 + \frac{|H_1^{DT}|^2 Q_T \alpha}{\sigma^2 + Q_T(1-\alpha)|H_1^{DT}|^2 \beta + G_1^c P_c}\right) + \log_2\left(1 + \frac{|H_2^{DT}|^2 Q_T (1-\alpha)}{\sigma^2 + Q_T \alpha |H_2^{DT}|^2 + G_2^c P_c}\right) + \phi\left(\log_2\left(1 + \frac{|G_{BS}^c|^2 P_c}{\sigma^2 + |H_{BS}^{DT}|^2 Q_T}\right) - R_{c,min}\right) + \delta(Q_T(1-\alpha) - Q_T\alpha)\right\}, \tag{20}$$

where ϕ and δ are the dual variables. Now applying KKT conditions to the maximization problem, it can be expressed as

$$\frac{\partial}{\partial \alpha}\left[\log_2\left(1 + \frac{|H_1^{DT}|^2 Q_T \alpha}{\sigma^2 + Q_T(1-\alpha)|H_1^{DT}|^2 \beta + G_1^c P_c}\right) + \log_2\left(1 + \frac{|H_2^{DT}|^2 Q_T (1-\alpha)}{\sigma^2 + Q_T \alpha |H_2^{DT}|^2 + G_2^c P_c}\right)\right] - \delta Q_T \alpha = 0, \tag{21}$$

After computing the partial derivations and solving for α, it is obtained as

$$\alpha^* = \left(\frac{-\Upsilon_b \pm \sqrt{\Upsilon_b^2 - 4\Upsilon_a \Upsilon_c}}{2\Upsilon_a}\right)^+, \tag{22}$$

where $[\lambda]^+ = \max(0, \lambda)$, and the values of Υ_a, Υ_b and Υ_c can be denoted as

$$\Upsilon_a = Q_T^2 |H_2^{DT}|^2 \sigma, \tag{23}$$

$$\Upsilon_b = Q_T \sigma^2 (\delta^2 + G_2^c P_c), \tag{24}$$

and

$$\Upsilon_c = -(\sigma^2 + G_2^c P_c). \tag{25}$$

With optimal value of α^*, the problem (20) can be expressed as

$$\min_{\phi \geq 0, \delta \geq 0} \left\{ \log_2\left(1 + \frac{|H_1^{DT}|^2 Q_T \alpha^*}{\sigma^2 + Q_T(1-\alpha^*)|H_1^{DT}|^2 \beta + G_1^c P_c}\right) + \log_2\left(1 + \frac{|H_2^{DT}|^2 Q_T (1-\alpha^*)}{\sigma^2 + Q_T \alpha^* |H_2^{DT}|^2 + G_2^c P_c}\right) - \delta Q_T \alpha^* + \phi \log_2\left(1 + \frac{|G_{BS}^c|^2 P_c}{\sigma^2 + |H_{BS}^{DT}|^2 Q_T}\right)\right\}, \tag{26}$$

Lastly, we update ϕ and δ using sub-gradient method as [35]

$$\phi(1+n) = \phi(n) + \xi(n)(R_{c,min} - \log_2(1+\Gamma_c))^+ \tag{27}$$

and

$$\delta(1+n) = \delta(n) + \xi(n)(\alpha^* Q_T - Q_T(1-\alpha^*))^+ \tag{28}$$

where n shows iteration number and ξ is the step size. In each n, the minimum rate of CU and optimal power at DT are computed. The program will be terminated on convergence.

Table 1
List of parameters.

Parameters	Values
Maximum transmit power of CU	$P_{max} = 30$ dBm
Maximum transmit power of DT	$Q_{T\,max} = 30$ dBm
The imperfect SIC parameter	$\beta = 0.1, 0.2, 0.3, 0.4, 0.5$
The variance of AWGN	$\sigma^2 = 0.1$
The QoS of CU	1 bit/s/Hz
Times of Monte Carlo simulations	10^4

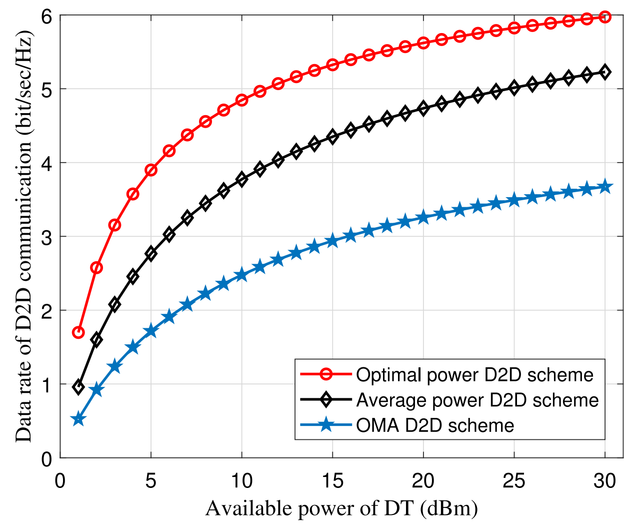

Fig. 2. Available power of DT versus data rate of the proposed optimal power D2D scheme and other benchmark schemes.

4. Simulation results

This section provides the simulation results of the proposed optimization scheme (denoted as Optimal power D2D scheme) and compare it with the benchmarks i.e., fixed power allocation scheme (stated as Average power D2D scheme) and conventional OMA scheme (represented as OMA D2D scheme), respectively. It is important to note that the OMA here refer to the traditional FDMA scheme where the spectrum is equally divided between DR1 and DR2. Moreover, we consider random user deployment in this simulation. Unless otherwise stated the parameters for obtaining results are set as shown in Table 1 .

Fig. 2 compares the data rate of the designed optimal power D2D scheme with benchmark average power D2D and conventional OMA D2D schemes. We can see that all three schemes' D2D communication data rate increases with the growth of the

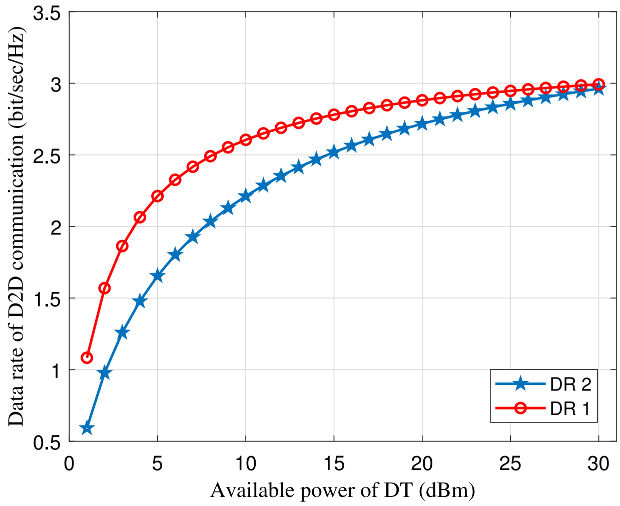

Fig. 3. Available power of DT versus data rate of D1 and D2.

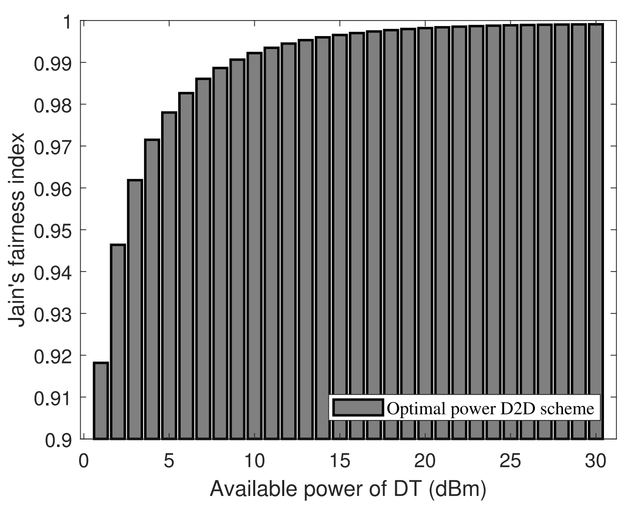

Fig. 4. Impact of DT power on the fairness.

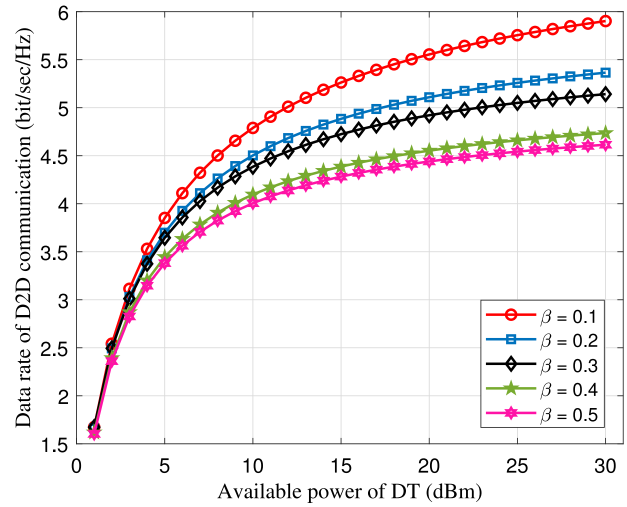

Fig. 5. Impact of imperfect SIC parameter on the data rate of D2D communication.

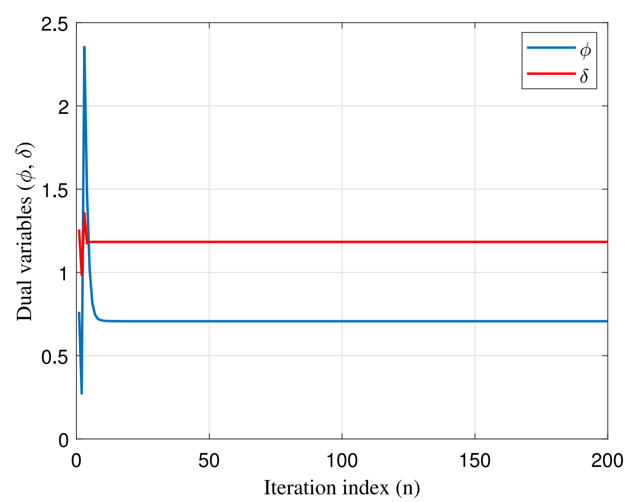

Fig. 6. Number of iteration versus data rate of D2D communication.

DT available power. However, the proposed optimal power D2D scheme significantly outperforms the average power D2D and conventional OMA schemes. For instance, with same system parameters when $Q_T = 20$ dBm, the data rate of the proposed optimization scheme and the other schemes are 5.62, 4.73 and 3.25 bit/sec/Hz, respectively. Moreover, as the available power of DT increases, the gap of data rate between NOMA schemes and OMA scheme also increases. It is because NOMA with higher transmit power provides higher spectral efficiency than OMA.

To see the impact of DT transmit power on individual data rate, Fig. 3 describes the data rate of DR1 and DR2 against increasing values of available power at DT. For this plot, we set imperfect SIC parameter as $\beta = 0.1$. It is observed that the data rate of DR1 and DR2 rise up as the transmit power of DT increases. It is also evident that with lower values of DT power, the DR1 achieves higher data rate than DR2. However, as the available power of DT increases, the difference of data rate between DR1 and DR2 is almost negligible. It shows the effectiveness of the proposed optimization scheme at high values of transmit power. Moreover, the proposed optimization scheme at high values of DT power provides fair rate between D2D users.

Fig. 4 depicts the effect of transmit power on the fairness of the proposed D2D scheme where the value of β is taken to be 0.1. We adopt Jain's fairness index to calculate the fairness of the proposed scheme [36]. It is important to note that the value of Jain's fairness index for the proposed D2D scheme is greater than 0.9, hence our scheme offers reasonably good fairness. Moreover, as the available transmit power at DT increases, the fairness of the proposed D2D scheme also increases. The possible reason of this is the effective allocation of extra available power among DR 1 and DR 2 by the proposed D2D scheme to improve the fairness. For example, when the transmit power of DT is 30 dBm, the fairness value of the proposed scheme is almost 1.

Next to see the impact of imperfect SIC parameter on the data rate of D2D communication, Fig. 5 presents the performance of the proposed scheme with different values of β. It can be seen that higher values of β reduces the data rate of D2D communication. For instance, with fixed transmit power at DT, i.e., $Q_T = 30$ dBm, the data rate of the proposed D2D communication is 5.90 bits/sec/Hz for $\beta = 0.1$. However, for the same system parameters when $\beta = 0.5$, the proposed optimization scheme can only achieve 4.61 bit/sec/Hz. It shows the importance of successful SIC decoding in practical systems.

Finally, it is important to show the complexity of the proposed algorithm in terms of iterations. In this regards, Fig. 6 denotes the convergence of the dual variables versus number of iterations.

It is evident from the figure that the dual variables converges after few iterations. For instance, the values of ϕ and δ remain unchanged when exceed 10 iterations. The complexity of the proposed algorithm depends on Eqs. (27) and (28). If the convergence precision Λ and the number of iterations N are determined, the complexity of the proposed algorithm is $\mathcal{O}((1/\Lambda)log(N))$. Thus, the proposed optimization scheme achieves high data and ensures fairness with the cost of lower computational complexity.

5. Conclusion

The combination of NOMA and D2D communication can enhance the spectral efficiency and connection density of beyond 5G networks. In this paper, we have designed a power optimization approach for NOMA-enabled D2D communication with imperfect SIC decoding. In particular, an optimization problem has been formulated to maximize the data rate of D2D communication while the constraints of CU QoS and DT transmit power are taken into account. The problem has been first transformed and then solved by dual theory where the dual variables are updated using sub-gradient method. It has been found from the results that the proposed optimization scheme significantly improves the data rate of D2D communication with reasonably good fairness. In addition, the proposed scheme also have lower complexity and converges after few iterations. The proposed scenario can also be extended to a multi-user multi-carrier communication, we will study this in the future works subsequently.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Shanshan Yu received the B.Sc. degree in electronics and information systems and the M.Sc. degree in signal and information processing from Ocean University of China, Qingdao, China, in 2002 and 2006, respectively. He is currently pursuing the Ph.D. degree in the School of Information Science and Engineering at Shandong University, Qingdao, China. From 2006 to 2014, he was a lecturer in the School of Information Science and Engineering, Qufu Normal University, Rizhao, China. His research interests include device-to-device communications, physical-layer security and cooperative communications.

Wali Ullah Khan received his B.Sc. degree in telecommunication from the University of Science and Technology Bannu, Khyber Pakhtunkhwa, Pakistan, in 2014, and the M.Sc. degree in Electrical Engineering from COMSATS University, Islamabad, Pakistan, in 2017 and the Ph.D. degree in Information and Communication Engineering from Shandong University, Qingdao, China, 2020. His research interests include convex/non-convex optimization, Internet of things, backscatter communication, vehicular communication, machine/deep learning physical layer security.

Xiaoqing Zhang received the B.Sc. degree in communication engineering and the Ph.D. degree in information and communication engineering from Shandong University, Qingdao, China, in 2014 and 2019, respectively. From October 2017 to April 2019, funded by the China Scholarship Council, she was a visiting Ph.D. student supervised by Prof. L. Hanzo in the School of Electronics and Computer Science, University of Southampton, UK. Her research interests include massive MIMO, precoding, pilot contamination, spatial modulation and generalized spatial modulation.

Ju Liu received the B.Sc. and M.Sc. degrees both in electronic engineering from Shandong University, Jinan, China, in 1986 and 1989, respectively, and the Ph.D. degree in signal processing from Southeast University, Nanjing, China, in 2000. Since July 1989, he has been with the Department of Electronic Engineering, Shandong University, and now he is a Full Professor. From July, 2002 to December, 2003, he was a Visiting Professor in the Department of Signal Theory and Communication, Polytechnic University of Catalonia, and Telecommunications Technological Centre of Catalonia, Barcelona, Spain. From November 2005 to January 2006, funded by DAAD, he was a Visiting Researcher in the Department of Communication Engineering, University of Bremen, and the Department of Communication Systems, University of Duisburg–Essen, in Germany. From June to December 2009, from July to August 2012, and in January 2019, funded by CSC, he was a Senior Research Fellow in the Department of Electrical Engineering, University of Washington, Seattle, WA, USA, in the Department of Electrical and Computer Engineering, University of California, San Diego, CA, USA, and in the School of Electronics and Computer Science, University of Southampton, UK, respectively.