IEEE Access
Multidisciplinary ⁝ Rapid Review ⁝ Open Access Journal

Received 26 February 2024, accepted 3 March 2024, date of publication 12 March 2024, date of current version 18 March 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3374529

RESEARCH ARTICLE

An Iterative-Based Optimum Power and Resource Allocation in Application-Dependent Scenarios for One-to-One D2D Communication

T. V. RAGHU, (Student Member, IEEE), AND M. KIRAN, (Member, IEEE)
Department of Information Technology, National Institute of Technology Karnataka (NITK), Surathkal, Mangaluru 575025, India
Corresponding author: M. Kiran (kiranmanjappa@nitk.edu.in)

ABSTRACT Efficient and timely sharing of critical information is crucial for Public Safety (PS) communications, which can be fulfilled using one of the cutting-edge technologies, Device-to-device (D2D) communication. During an emergency, the PS applications should be prioritized over other applications, ensuring the emergency messages reach the first responders in time. Due to its inherent characteristics, the evolved Node Base station will not prioritize or categorize the D2D communication based on its application type, thus treating all applications equally. Further, D2D communication introduces significant interference to cellular users and vice-versa while sharing resources, and it is vital to reduce the impact of these interferences to ensure the Quality of Service for all users in the network. Hence, this article proposes a novel interference management approach to increase the overall sum rate of the system. In addition, the proposed approach also allows more D2D communication in general, particularly PS application-based D2D communication, to be active in the network. As the formulated problem is a Mixed-Integer Non-Linear Programming (MINLP) type of problem, it is split into two sub-problems, namely, *Iterative Resource Allocation and Sharing* and *Iterative Power Optimization* to achieve a polynomial time complexity. The theoretical proofs adequately explain the algorithm's time complexity and convergence property. The simulation results show that the proposed system enhances the overall sum rate by allowing more active PS D2D applications in the network.

INDEX TERMS D2D communication, power optimization, interference management, iterative algorithm, one-to-one resource allocation.

I. INTRODUCTION

Industry and academic experts foresee that the users of cellular communications and the proliferation of connected multimedia devices will demand high Quality of Service (QoS) and data rates to support diverse applications [1]. As there is an exponential increase in the number of cellular users, efficient resource and QoS management for all the network users has become a big challenge for the evolved Node Base (eNB) station. Device-to-device (D2D) communication underlying cellular networks, one of the pillars of future cellular networks, has emerged as a promising approach to increase the data rate contemporarily [2]. Further, it has recently drawn several researchers' attention as a crucial technique to offload the traffic at the eNB as it facilitates direct communication between two physically proximate User Equipment (UE) without the involvement of an eNB. D2D communication significantly reduces the traffic load on the eNB, reduces network latency, and substantially improves system throughput. Furthermore, users can experience better QoS, more comprehensive network coverage, and enhanced energy efficiency by incorporating D2D communication into cellular networks [3]. Although D2D communication benefits cellular users, managing interference among different users in the network to maintain the QoS of the cellular system is still a challenging task and requires substantial research.

Recent research explores the possibility of sharing the Resource Blocks (RBs) (the smallest chunk of the spectrum)

The associate editor coordinating the review of this manuscript and approving it for publication was Hang Shen.

of Cellular User Equipment (CUEs) with D2D User Equipment (DUE) in underlay in-band communication to significantly enhance spectrum efficiency [4]. The different resource-sharing strategies in practice are one-to-one, one-to-many, and many-to-many. In the one-to-one technique, a CUE resource is shared by at most one DUE pair only, while in the one-to-many technique, multiple DUE pairs are allowed to share the resources of a CUE. In the many-to-many technique, multiple DUE pairs share the resource of multiple CUEs. Compared to the other two methods, the one-to-one technique eliminates interference between DUE pairs during resource sharing as the utmost one DUE pair shares the CUE resource. Contrarily, sharing the RBs between the CUEs and DUEs causes mutual interference and degrades the QoS of all users in the network [5]. Therefore, developing and exploring efficient resource management solutions, including power optimization strategies and interference mitigation, is essential to harness the benefits provided by D2D communication [6], [7].

D2D communication offers high spectrum utilization efficiency and low transmit power, making it an effective method for low latency, high speed, and energy-saving wireless communication. Hence, D2D communication is most appropriate and suitable for time-sensitive, crucial, and effective communications such as Public Safety (PS) communication (disaster relief supportive services) [8], [9]. D2D can also be used for streaming, data sharing, gaming, and many more, which are commonly known as commercial applications (CA). Thus, all D2D applications can be broadly categorized into PS applications and CA applications [10].

During an emergency, priority should be given to PS DUEs over CA DUEs due to the nature of its service. However, no such priority-based resource allocation can be found in the traditional resource allocation technique, which may cause PS applications to suffer from fewer resources, thereby causing hiccups in the transmissions. Meanwhile, a priority-based resource allocation for DUE pairs based on the type of application may provide an edge to the PS over CA applications during an emergency. As a result, the additional resources allocated to PS applications will enable more active PS DUEs to carry sensitive information to the first responders. Thus, in this paper, a comprehensive exploration is conducted to address a broader scenario involving the joint RB allocation and power optimization solution for DUEs and CUEs in a one-to-one strategy to enhance the system sum rate. The primary objective of this work is to optimize the transmit power of the DUE pairs and prioritize PS users over CA users during the resource allocation while ensuring the basic data rate requirements for all users. The following is the list of the novelties of the proposed work that were taken into account and met in the article.

- We present a joint resource allocation and power optimization framework to prioritize PS application over CA for resource allocation during an emergency context under a one-to-one strategy to maximize the system sum rate.
- The proposed algorithm increases the number of active D2D users during emergencies, particularly PS D2D communication, and yields a maximum system sum rate in the network.
- The proposed algorithm assures QoS to all the users and attenuates interferences in the system by finding the best transmit power for all the DUEs.

The remainder of this paper is structured as follows: Section II explains the different state-of-the-art technology in D2D communication. Section III outlines the system scenarios and problem formulation. Section IV presents a proposed methodology for the defined objectives by breaking down the problem into manageable subproblems, namely, resource allocation and sharing and power optimization. The performance of the algorithms is evaluated through simulations in Section V. Finally, Section VI concludes the work carried out and future scope.

II. RELATED WORK

The authors in [11], [12], [13], and [14] comprehensively detail various issues and diverse methods for optimizing resource allocation in D2D communication. The work in [15] proposes a fuzzy clustering approach to improve the system throughput by grouping the D2D users into different categories. The authors have used the game theory concept to optimize the transmission power of each DUE in several groups to improve energy efficiency. The work in [16] combines the wireless resource virtualization concept with D2D communication to enhance spectrum efficiency and system throughput. The authors have proposed two heuristic algorithms for efficient resource allocation for CUEs and DUEs. The work in [17] proposes a multiagent deep Q-network algorithm for heterogeneous cellular networks to optimize channel allocation and mode selection in D2D communication. This optimization problem maximizes the system sum rate under the constraint of QoS of CUEs and DUEs. The multi-antenna base station is considered in the study [18], where the authors propose the modes of operations for D2D transmitters. The authors first compare the bounds of the transmission power and then select the mode for the D2D transmitter that allows the lowest feasible power usage in the network. The joint channel allocation and power control scheme is proposed in [19], where swarm optimization is used for efficiently managing the interference to improve the network throughput.

The work in [20] uses the D2D-assisted fifth-generation network to enhance the performance of virtual reality broadcasting. Additionally, the authors employed reinforcement learning to determine the most optimal transmission energy for broadcasting. The relay selection and resource allocation are jointly addressed in [21] under network coding-assisted D2D communication. This work uses coalition formation and greedy algorithm-based games for relay selection and resource allocation. The work in [22] discusses optimizing joint subcarrier assignment and power allocation in energy harvesting D2D underlaying cellular networks. The authors aim to maximize the overall sum rate of the system while adhering to QoS constraints. The research conducted in [23] focuses on improving the overall data rate of the system by identifying the best possible matches between DUE and CUE users for spectrum sharing. To optimize the pairing of CUEs and DUEs, a bipartite graph is used. The weight for the graph is the maximum ergodic sum rate.

In the work [24], different factors, namely admission control, mode selection, partner assignment, and power allocation, were considered to optimize network performance for spectrum-sharing problems. This analysis identified QoS and resource allocation as primary constraints to maximize access and network sum rates. The work in [25] takes into account the varying QoS requirements of different applications while allocating resources and optimizing transmit power. The study focuses on two types of applications, streaming and file-sharing, and aims to coordinate resource-sharing mode between CUE and DUE. To increase the energy efficiency of D2D communications, authors in [26] have devised optimized strategies for resource allocation and power control. The fractional programming properties are exploited in this work, and an iterative algorithm for allocating resources and controlling transmit power is introduced. In [27], a distributed resource allocation method is suggested, which aims to manage interference, maintain the QoS of CUE, and optimize the data rate of DUE. The authors achieve this by utilizing optimal transmit power for each DUE. In the context of relay-aided D2D communication, a resource allocation framework is proposed in [28]. The main objective of the proposed work is to use a stable matching approach to maximize the system capacity of the two-hop network while ensuring the QoS of all users in the network.

The work in [29] presents a two-way relaying model that maximizes the data rate of D2D links and preserves QoS for all users in the network. The best relay node is selected to optimize the data rate, and the relay can harvest energy from the attached solar panel as well as the received radio frequency signal. The resource allocation in the cooperative D2D communication network is proposed in [30], which uses the Markov Decision Process (MDP) model for the resource allocation. The work in [31] focuses on the resource allocation for the Unmanned Aerial Vehicle (UAV) network to maximize the active D2D users by joint resource allocation and power control mechanisms guaranteeing the QoS requirements of all types of users. The Non-Orthogonal Multiple Access (NOMA) is considered in the study [32] to present an efficient power allocation approach for imperfect Successive Interference Cancellation (SIC) decoding in a D2D communication system. Lagrange duality and the sub-gradient descent technique addressed the problem's non-convexity caused by integer restrictions and coupling variables. Relaxation-Pruning Algorithm (RPA) and Cardinality-Constrained Subchannel Assignment Algorithm (CCSAA) are the two algorithms proposed in [33] for allocating resources to the D2D pairs. The sharing of resources for D2D communication among multiple service providers is discussed in the article [34], which proposes a joint resource allocation and power control framework intending to maximize the active number of UEs for communication and also to ensure QoS.

Deep reinforcement learning is presented in the work [35] to allocate resources, control the power of UEs, and maximize the throughput of the cellular network. D2D pairs are treated as distributed multiple agents where each agent can choose the required resources and power for the transmission to control the effect of co-channel interference. The many-to-many resource-sharing strategy is suggested in the article [36], which offers a scalable framework for resource allocation and power control for D2D communication. The set partition method and imperfect channel state information are used for the resource allocation sub-problem, whereas power optimization is designed based on the quadratic transform method. In [37], authors have proposed a framework to maximize the sum and access rate of the network and provide the QoS to all the users. The proposed framework used the distance between the D2D pair and the base station and SINR values as parameters to form D2D candidate groups. Further, the proposed framework utilized relay-assisted transmission if direct communication fails to provide the required QoS. Stackelberg game theory is used for application-based resource allocation in [10], where D2D users are categorized into three main groups based on their practical application or service. Different utility functions are designed for each application class which will help to assign implicit priority to each category of services considered.

A framework for resource allocation and power control is presented in the article [38], where the resource allocation is done based on the ratio of channel gain to interference link. The K-means clustering algorithm is used to form the clusters of DUE pairs, and maximum and average power constraints are used to optimize the power. In [39], the matching theory is used for allocating resources in heterogeneous networks, and a one-to-one sharing strategy is employed for resource sharing. The proposed algorithm aims to achieve a stable matching that maximizes the data rate of the network while minimizing interference to meet the QoS requirements for D2D communications.

A channel assignment framework is proposed in [40], where clusters of the D2D pairs are formed based on the mutual interference among the D2D pairs. CUE and DUE pairs from different clusters are combined into one cluster via channel-based clustering. Channel assignment is determined by the ratio of channel coefficients between communication and interfering links. The proposed algorithm utilized the Hungarian algorithm to allocate channels to DUE pairs efficiently. A pure D2D model referred to as the D2D Resource Allocation and Power Control (DRAPC) algorithm is proposed in [41], where multiple DUEs can reuse the resources by maintaining the QoS of CUEs present in the network. The main objective of the proposed model is to maximize the number of communication links supported by available resources in a network. In [42], a resource-sharing model is proposed that maximizes global energy efficiency by using the same RB of cellular users with multiple D2D pairs. The proposed model uses the Dinkelbach algorithm for power optimization and a message-passing technique for RB allocation.

The literature review highlighted that resource allocation and power optimization aiming to enhance the throughput of the cellular network are the foremost concerns in D2D communication research. Resource allocation enhances spectrum utilization, while power optimization ensures the QoS of all users in the network. Among the different techniques used, game theory [15], [10], deep learning [17], [20], [35], graph theory [21], [23] and convex optimization [32], [36] are the dominating techniques used by researchers to reduce the interference effects and allocate resources efficiently to D2D users. The implementation overhead and computation complexity of all these techniques are higher when compared to the iterative methods. These techniques do not consider all the possible combinations of CUE and DUE pairs for selecting the best combination for resource allocation and improving the system throughput. The literature review also shows a need for more exploration of priority-based resource allocation for D2D users where the public safety D2D users get the upper hand over other D2D users for resource allocation during emergencies. Hence, in this paper, we use an iterative technique to consider all possible combinations of CUE and DUE pairs for allocating resources and select the best combination for improving the system throughput. Furthermore, an iterative power optimization phase is also used to find the optimum power for D2D users that guarantees the QoS of all users and minimizes interference in the network.

A. MOTIVATION AND CONTRIBUTIONS

D2D communication offers two key advantages: it saves energy for terminal devices and improves the spectrum efficiency of the overall cellular network [7]. On the other hand, sharing RBs between the CUEs and DUEs causes mutual interference and degrades the QoS of all users in the network. Therefore, it is essential to explore and develop efficient resource management solutions, including power optimization strategies, to harness the benefits provided by D2D communication while mitigating interference challenges. In this paper, a comprehensive exploration is conducted to address a broader scenario involving the joint RB allocation and power optimization solution for DUEs and CUEs to enhance the system sum rate. The primary objective is to minimize the total power consumption while ensuring the fulfillment of basic data rate requirements for all users and prioritizing PS users over CA users.

In this study, we allow a DUE pair to share RBs of CUEs in a one-to-one scenario by exploiting the flexibility of D2D communication and avoiding interference among the DUE pairs. The literature survey shows that all articles discuss the challenges and concerns related to resource allocation and power optimization for D2D communication across various applications. Nevertheless, recognizing the significance of PS communication, it is imperative to invest in additional research and emphasize the effective utilization and prioritization of D2D communication for PS applications in contrast to CA applications. We formulated the problem as a Mixed Integer Non-Linear Programming (MINLP) problem, which is an NP-hard problem that cannot be solved directly. To effectively tackle the problem at hand, it is imperative to split the defined problem into two subproblems, namely *resource assignment for CUEs and DUEs* and *optimal power allocation for DUEs* that can be solved within polynomial time complexity. This approach will make it more manageable and increase the likelihood of finding a viable solution. The primary contributions of this paper can be summarized as follows:

- We present an innovative solution that efficiently manages resource allocation and optimizes power consumption to maximize the sum rate of the system under a one-to-one D2D communication scenario. We focus on prioritizing the PS application over the CA application while guaranteeing the QoS of all users in the cellular network. The proposed problem is a MINLP type and is divided into two subproblems to make it resolvable, namely *Resource allocation and sharing*, and *power optimization*.
- Firstly, the DUEs are categorized into PS and CA types based on the *Application_Type* attribute for resource sharing. Then, the proposed resource allocation and sharing framework first allocates resources to CUEs based on the maximum channel gain and then allows the DUEs to share the CUE's resources for communication. During the resource-sharing phase, the algorithm will find all possible combinations of CUE and DUEs and the best combination that would yield the maximum system sum rate will be allowed to share the resources.
- The power optimization subproblem finds the optimum power required for guaranteed transmission for the DUEs. For each DUE, the maximum allowable power for transmission is initially set, and then the algorithm gradually decreases the power to find the optimal power required for guaranteed transmission. Consequently, it minimizes the interference effects while sharing the resources and assures the QoS of all users in the cellular network.

III. SYSTEM MODEL AND PROBLEM FORMULATION

A. SYSTEM MODEL

For the study, we are considering a D2D-enabled uplink cellular network communication in a single cell, as shown

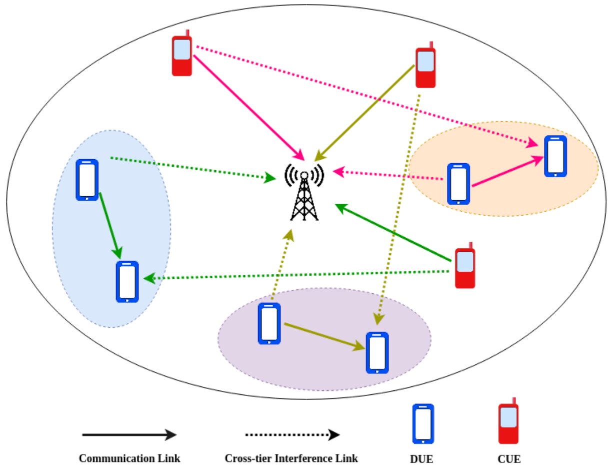


FIGURE 1. System model: One-to-One D2D underlay cellular communication.

in Fig. 1. The network includes a single eNB, N CUEs, and M D2D pairs. Let $\mathcal{C} = \{ c_1, c_2, c_3, \ldots, c_N \}$, $\mathcal{D} = \{ d_1, d_2, d_3, \ldots, d_M \}$, and $\mathcal{K} = \{ r_1, r_2, r_3, \ldots, r_K \}$ denote the set of CUEs, DUEs, and RBs, respectively. The RBs are exclusively and orthogonally assigned to CUEs only to avoid any interference among CUEs. DUE pairs are allowed to reuse the resources of CUEs under a one-to-one strategy so that there is no interference between the DUE pairs, as shown in Fig. 1. We assume that the eNB has access to and availability of Channel State Information (CSI) for all links within the network [43]. All users in the network are assured a minimum QoS and the Signal-to-Interference-plus-Noise Ratio (SINR) is used as the quality measure for both DUEs and CUEs within the cell. Therefore, the transmit power of the DUE pair is optimized to keep the minimum data rate for the communication and also ensure that it does not exceed the maximum power limit P_{max} while sharing the RB with CUE. On the other hand, CUEs can use the maximum power value for their transmissions. In the transmit power optimization phase, we consider path loss, fast fading from multi-path propagation, and slow fading from shadowing. We assume that each link undergoes independent block fading. Based on this assumption, the instantaneous channel gain of the j^{th} D2D pair on k^{th} RB is designated as h_j and is given as follows [44]:

$$h_j = G\beta_j\delta_j d_j^{-\alpha}, \tag{1}$$

where G is path loss constant, α is path loss exponent, β is fast fading coefficient, δ is slow fading coefficient and d_j is distance between transmitter and receiver of j^{th} D2D pair. Similarly, different channel gains namely $h_{i,B}$ (channel gain between i^{th} CUE and eNB), $h_{j,B}$ (channel gain between the transmitter of j^{th} D2D pair and eNB), and $h_{i,j}$ (the channel gain between i^{th} CUE and receiver of j^{th} D2D pair) are represented in the system inline with Eqn. 1.

TABLE 1. List of symbols and meanings.

Symbols	Description
N	Set of CUEs
M	Set of DUE pairs
K	Set of RBs
P_{max}	Maximum transmit power of UE
h_j	Channel gain of the j^{th} D2D pair on k^{th} RB
G	Path loss constant
α	Path loss exponent
β	Fast fading coefficient
δ	Slow fading coefficient
d_j	Distance between transmitter and receiver of j^{th} D2D pair.
$h_{i,B}$	Channel gain between i^{th} CUE and eNB
$h_{j,B}$	Channel gain between the transmitter of j^{th} D2D pair and eNB
$h_{i,j}$	Channel gain between i^{th} CUE and receiver of j^{th} D2D pair
P_C^i	Transmit power of i^{th} CUE
P_D^j	Transmit power of j^{th} DUE
N_0	Additive White Gaussian Nois power
$\bar{\gamma}_C^i$	SINR of i^{th} CUE without sharing RBs with DUEs
γ_C^i	SINR of i^{th} CUE during sharing RBs with DUEs.
$\gamma_D^{i,j}$	SINR of j^{th} DUE during sharing i^{th} CUE RBs.
$\gamma_{C\,min}$	Minimum SINR value of CUE
$\gamma_{D\,min}$	Minimum SINR value of DUE
$\bar{R}_C^i$	Data rates of i^{th} CUE without sharing RBs with DUEs
R_C^i	Data rates of i^{th} CUE during sharing RBs with DUEs
$R_D^{i,j}$	Data rates j^{th} DUE during sharing i^{th} CUE RBs
N_{PS}	Total number of PS DUE pairs
N_{CA}	Total number of CA DUE pairs
$y_{i,k}$	Indicate k^{th} RB is used by i^{th} CUE
$x_{i,j}$	Indicate i^{th} CUE RB is used by j^{th} DUE

B. PROBLEM FORMULATION

The received signal strength of i^{th} CUE at eNB when it is not sharing its RBs with DUEs is given by:

$$\bar{\gamma}_C^i = \frac{P_C^i h_{i,B}}{N_0}, \tag{2}$$

where P_C^i and N_0 are the i^{th} CUE transmit power and Additive White Gaussian Noise (AWGN) power, respectively. In order to improve the total network throughput and effective spectrum utilization, it is assumed that the RB allocated to a particular CUE is shared by one of the D2D pairs in a one-to-one strategy. Hence, this sharing of RBs causes interference, which in turn affects the SINR of the users within the cell.

The SINR value for the i^{th} CUE and j^{th} DUE pair, when a CUE RB is shared with DUE, is written as follows:

$$\gamma_C^i = \frac{P_C^i h_{i,B}}{P_D^j h_{j,B} + N_0}, \tag{3}$$

$$\gamma_D^{i,j} = \frac{P_D^j h_j}{P_C^i h_{i,j} + N_0}, \tag{4}$$

where P_D^j is the transmit power of j^{th} DUE pair in the cellular network. The Shannon capacity determines the maximum amount of data that j^{th} DUE and i^{th} CUE can transmit on k^{th} RB and can be calculated using the expression as follows:

$$\bar{R}_C^i = B_0 \log_2(1 + \bar{\gamma}_C^i), \tag{5}$$

$$R_C^i = B_0 \log_2(1 + \gamma_C^i), \tag{6}$$

$$R_D^{i,j} = B_0 \log_2(1 + \gamma_D^{i,j}), \tag{7}$$

where R_C^i and $\bar{R}_C^i$ denote data rates of i^{th} CUE considering the two instances, when RB is shared and when RB is not shared to D2D users. At the same time, $R_D^{i,j}$ represents the data rate of the j^{th} DUE pair when it shares the k^{th} RB of i^{th} CUE in the cell. Furthermore, the total number of DUE pairs running the PS applications (N_{PS}) and CA applications (N_{CA}) is written as follows:

$$N_{PS} = \sum_{\substack{i=1\\ i \in PS}}^{N} N_i, \tag{8}$$

$$N_{CA} = \sum_{\substack{i=1\\ i \in CA}}^{N} N_i. \tag{9}$$

Our primary goal is to improve the system sum rate of D2D underlay cellular networks and prioritize the PS DUE pairs over the CA DUE pairs by jointly optimizing the RB assignment and transmit power of the DUE pair. Furthermore, the data rate requirement of all users of the cellular network should be ensured. Hence, the following objective function has been formulated in this study, accompanied by a set of constraints. The variables $y_{i,k}$ and $x_{i,j}$ are of binary types and provide information about whether the k^{th} RB is assigned to the i^{th} CUE and the j^{th} DUE reuses the i^{th} CUE RB. The γ_{Dmin} and γ_{Cmin} are the minimum data rates required for the DUE and CUE transmission to maintain QoS, respectively.

$$\max_{y_{i,k}} \sum_{i=1}^{N} \sum_{bl=1}^{K} R_C^i + \max_{P_D^j,\ x_{i,j}} \sum_{i=1}^{N} \sum_{j=1}^{M} R_D^{i,j}, \tag{10}$$

$$\text{Subject To: } \bar{\gamma}_C^i \geq \gamma_{Cmin}, \quad (\forall i \in \mathcal{C}), \tag{10a}$$

$$\sum_{k=1}^{K} \sum_{i=1}^{N} y_{i,k} \leq 1, \tag{10b}$$

$$y_{i,k} \in \{0, 1\}, \quad (\forall i \in \mathcal{C}, \quad \forall k \in \mathcal{K}), \tag{10c}$$

$$N_{PS} > N_{CA}, \tag{10d}$$

$$x_{i,j} \gamma_D^{i,j} \geq \gamma_{Dmin}, \quad (\forall i \in \mathcal{C}, \forall j \in \mathcal{D}), \tag{10e}$$

$$x_{i,j} \gamma_C^i \geq \gamma_{Cmin}, \quad (\forall i \in \mathcal{C}, \forall j \in \mathcal{D}), \tag{10f}$$

$$0 \leq P_D^j \leq P_{max}, \quad (\forall j \in \mathcal{D}), \tag{10g}$$

$$\sum_{j=1}^{M} \sum_{i=1}^{N} x_{i,j} \leq 1, \tag{10h}$$

$$x_{i,j} \in \{0, 1\}, \quad (\forall i \in \mathcal{C}, \forall j \in \mathcal{D}). \tag{10i}$$

The constraint (10a) is enforced to ensure a seamless transmission for CUE during RB allocation. The binary variable $y_{i,k}$ stores information about whether or not the k^{th} RB is being used by CUE, with a value of either 0 or 1, and only one RB will be assigned to a CUE. Constraints (10b) and (10c) are used to maintain this information. We give priority to PS applications over CA during resource allocation. As a result, the number of active PS DUEs should be higher than CA. To implement this restriction, we use constraint (10d). In-band underlay D2D communication has the advantage of sharing CUE resources, and this resource sharing should not affect the QoS of CUEs in the network. Accordingly, constraints (10e) and (10f) are used to maintain the QoS for DUE and CUE during the RB sharing phase. There is an upper bound of maximum power value used for transmission in the network, and only positive power values are allowed for the transmission, and this principle is set forth by constraint (10g). Constraint (10h) uses binary variable $x_{i,j}$ to restrict the sharing of CUE RB with a single DUE. Rule (10i) dictates that $x_{i,j}$ must be restricted to a value of either 0 or 1 and displays whether the j^{th} DUE pair shares an RB of the i^{th} CUE.

IV. PROPOSED METHODOLOGY

The problem devised in Eqn. 10 is a MINLP problem and is hard to solve within polynomial time [45]. Hence, we have solved the defined problem by dividing it into two subproblems, namely, *Iterative Resource Allocation and Sharing* (IRAS) and *Iterative Power Optimization* (IPO). We assume that all CUEs in the network are authorized to operate at maximum transmit power due to the expectation that the cellular network's performance will not be affected by the resource-sharing process. The IRAS, in turn, will call the IPO to optimize the transmit power of the DUE pair during the resource allocation and sharing process. Both IRAS and IPO are explained in detail in the following subsections.

A. ITERATIVE RESOURCE ALLOCATION AND SHARING

IRAS includes two iterative algorithms for RB allocation to CUEs and for choosing the right DUE pair for sharing the RBs of the CUEs. Algorithm 1 will describe the different steps involved in the RB allotment process. Constraints (10a) - (10c) are used to allocate RB to CUEs in the network. Initially, the value of the variable $y_{i,k}$ is set to zero at line number 1. Then, the algorithm iterates sequentially through all available CUEs in the network and allocates RB to each CUE according to the constraints defined in (10a) to satisfy the QoS. Further, the algorithm iterates through each CUE to find its maximum channel gain specified in line numbers 3-12 during the RB allocation process. The searching process stops

```
Algorithm 1 Iterative Resource Allocation Algorithm for CUEs
    Input  : Set of CUEs $\{c_i\}$ and RBs $\{r_k\}$
    Output: $y_{i,k}$ and $\bar{\gamma}_C^i$  $\forall i \in \mathcal{C}, \forall k \in \mathcal{K}$
 1  $y_{i,k} \leftarrow 0, \forall i \in \mathcal{C}, \forall k \in \mathcal{K}$;
 2  foreach $i \in \mathcal{C}$ do
 3      repeat
 4          $[maxChanValue, ChanIndex] \leftarrow$
              max $(ChanGain(:, i))$;
 5          $k \leftarrow ChanIndex$;
 6          $h_{i,B} \leftarrow maxChanValue$;
 7          if $y_{i',k} == 0$ then /* $i' \in \mathcal{C}$ and $i' \neq i$
              */
 8              Find $\bar{\gamma}_C^i$ using Eq (2);
 9              Find $\bar{R}_C^i$ using Eq (5);
10              $y_{i,k} \leftarrow 1$;
11          end
12      until $\left(\bar{\gamma}_C^i \leq \gamma_{C\,min}\right)$;
13  end
```

until the algorithm finds the required QoS specified in line 12. The constraint (10b) confines that only one CUE will use an RB, and line 7 is used to maintain this condition. On line 10, the value of $y_{i,k}$ is set to 1 to reveal to all other CUEs in the network that the k^{th} RB has been allocated to a specific CUE. The properties of Algorithm 1, such as its time complexity and termination criteria, are discussed in Theorem 1 and are outlined below.

Theorem 1: The time complexity of Algorithm 1 is O(K.N) where N is the total number of CUEs, and K is the total number of RBs in the cellular network, and the algorithm will terminate after a finite number of iterations.

Proof: Algorithm 1 uses a single for loop (lines 2-13) and an unconditional loop (lines 3-12) inside the for loop. The for loop will run N times since it has to allocate RBs to all CUEs in the network. In the worst case, the unconditional loop searches for K times for each CUE. Hence, the time complexity of Algorithm 1 will be O(N.K). The stopping condition of the for loop is specific and terminates after sequentially iterating one by one through the set of CUEs. Meanwhile, the unconditional loop stops after the condition specified in line number 12 is satisfied. All CUEs in the network can operate at maximum transmit power P_{max}, and there is no other form of disturbance to the signal strength. Hence, all CUEs at line 12 of Algorithm 1 will satisfy the QoS requirement. Eventually, the algorithm will stop after a finite number of iterations.

```
Algorithm 2 Iterative Resource Sharing Algorithm for DUE Pairs
    Input          : Set of CUEs $\{c_i\}$ and DUEs $\{d_j\}$
    Output         : Set of PS_List and CS_List
    Initialization: $PS\_List = \{\emptyset\}$ and $CA\_List = \{\emptyset\}$
 1  foreach $i \in \mathcal{C}$ do
 2      foreach $j \in \mathcal{D}$ do
 3          if $(DUE(j).Allocated == false)$ then
 4              Calculate optimal transmit power, $P_D^j$
                  and $\mathcal{SC}^{i,j}$ using Algorithm 3;
 5              if $\mathcal{SC}^{i,j} == 1$ then
 6                  Find $\gamma_D^{i,j}$ using Eq (4);
 7                  Find $R_D^i$ using Eq (7);
 8                  Find $\gamma_C^i$ using Eq (3);
 9                  Find $R_C^i$ using Eq (6);
10                  $\left[R_S^j\right] \leftarrow R_C^i + R_D^i$;
11              end
12          end
13      end
14      $[maxThroughtput, DUEIndex] \leftarrow$ max $\left[R_S^j\right]$;
15      $j \leftarrow DUEIndex$;
16      if $DUE(j).Application\_Type ==$ '$PS'$ then
17          $PS\_List \leftarrow j$;
18          $PS\_count \leftarrow PS\_count + 1$;
19          $DUE(j).Allocated == true$;
20          $x_{i,j} \leftarrow 1$;
21      else
22          $[maxThroughtput, DUEIndex] \leftarrow$
              Secondmax $\left[R_S^j\right]$;
23          $j \leftarrow DUEIndex$;
24          if $DUE(j).Application\_Type ==$ '$PS'$ then
25              $PS\_List \leftarrow j$;
26              $PS\_count \leftarrow PS\_count + 1$;
27              $DUE(j).Allocated == true$;
28              $x_{i,j} \leftarrow 1$;
29          else
30              $CA\_List \leftarrow j$;
31              $CA\_count \leftarrow PS\_count + 1$;
32          end
33          $DUE(j).Allocated == true$;
34          $x_{i,j} \leftarrow 1$;
35      end
36  end
```

Once the RB is allocated to the CUE, the second phase of the IRAS starts, which involves the RB sharing process, and the constraints defined in (10d) - (10i) are utilized for this purpose. Algorithm 2 outlines the various steps carried out during the RB sharing process and completes the execution in two phases. During the initial phase (lines 2-13) of Algorithm 2, the algorithm sequentially iterates through all potential unallocated DUE pairs to search for the most appropriate reuse partner for each CUE in the set. If a DUE pair does not receive any RB of CUE (line 3), the system will determine the data rate for both DUE and CUE in that particular combination. The combined data rates of CUE and DUE (line 9) will be stored in a vector R_S^j. This operation will be repeated for all unassigned DUEs in the network (lines 2-13). While exploring the best possible combination of CUE and DUE to maximize the system sum rate, the IPO subproblem (line 4) (Algorithm 3) is used to determine the guaranteed transmission power for each DUE to preserve the QoS of all users in the network.

In the second phase of the algorithm (lines 14-35), we retrieve the maximum value from the vector R_S^j (line 14), and we check the application type of the corresponding DUE pair for the combination of CUE on line 16. If the application type is PS, then that specific DUE pair is authorized to access the RB of the corresponding CUE (lines 17-20). To improve the likelihood of sharing the RB of CUE with the PS DUE pair, we select the second-highest element (lines 21-35) from the R_S^j vector to prevent the possibility of encountering the initial highest value of the CUE and CA DUE pair combination. This action leads to an increase in the possibility of the number of active PS DUE pairs and satisfies constraint (10d). The time complexity and termination conditions of Algorithm 2 are explained in Theorem 2.

Theorem 2: The execution of Algorithm 2 requires performing O(N.M.P) operations where N, M, and P represent the total number of CUEs, DUE pairs, and power levels in the cellular network respectively and terminates after a certain number of iterations.

Proof: Algorithm 2 has two phases. In the first phase, the Algorithm thoroughly searches for all unallocated DUEs to find the most suitable CUE for sharing RB to enhance the system sum rate. The inner for loop at line 2 has to execute for all unallocated DUE for each combination of CUE specified at the outer for loop at line 1. At this juncture, Algorithm 2 invokes Algorithm 3 to find the optimum transmit power for DUEs. The run-time complexity of Algorithm 3 is O(P), and hence, it induces a total of O(N.M.P) operations in Algorithm 2 to find an optimal match of the CUE and DUE combination. The second phase of the Algorithm uses only basic instructions to verify whether the DUE falls in the PS or CA category, and these operations will contribute a constant amount of time to the completion of the execution. As a result, the total time required to complete the execution of two phases of Algorithm 2 is O(N.M.P). Algorithm 2 is designed to avoid indefinite blocking, as the conditional loops within the Algorithm prevent such situations from occurring. Suppose the number of CUEs and DUEs in the system is finite. In that case, execution will eventually cease, leading to the termination of Algorithm 2 after a specific number of operations have been carried out.

B. ITERATIVE POWER OPTIMIZATION

The IPO subproblem determines the optimal transmit power required for all DUEs in the system and ensures satisfactory QoS for all network users. Different steps involved in IPO are shown in Algorithm 3, and its implementation is subject to the restrictions of constraints (10e) to (10g). Algorithm 3 is called from Algorithm 2 during the resource allocation and sharing process. At the beginning of the algorithm, the power of DUE, P_D^j, is assigned with maximum transmit value P_{max}. The value of P_D^j is decremented by a very small quantity of $\triangle$ iteratively in the loop (lines 2-5) until it reaches the minimum value necessary to meet the QoS requirements of the DUE pair. The value of P_D^j explicitly denotes the optimal power for the j^{th} DUE to share the i^{th} CUE's RB. Once the algorithm finds the most efficient power level for DUE, it verifies whether the chosen transmit power has any adverse impact on the QoS of the CUE. If such is the case, a value of zero will be assigned to the variable $\mathcal{SC}^{i,j}$ (line 8). However, if the algorithm does not find QoS degradation, a value of 1 will be set to the variable $\mathcal{SC}^{i,j}$ (line 10). Algorithm 3's time complexity and stopping condition will be defined by Theorem 3 as follows.

Algorithm 3 Iterative Power Optimization Algorithm

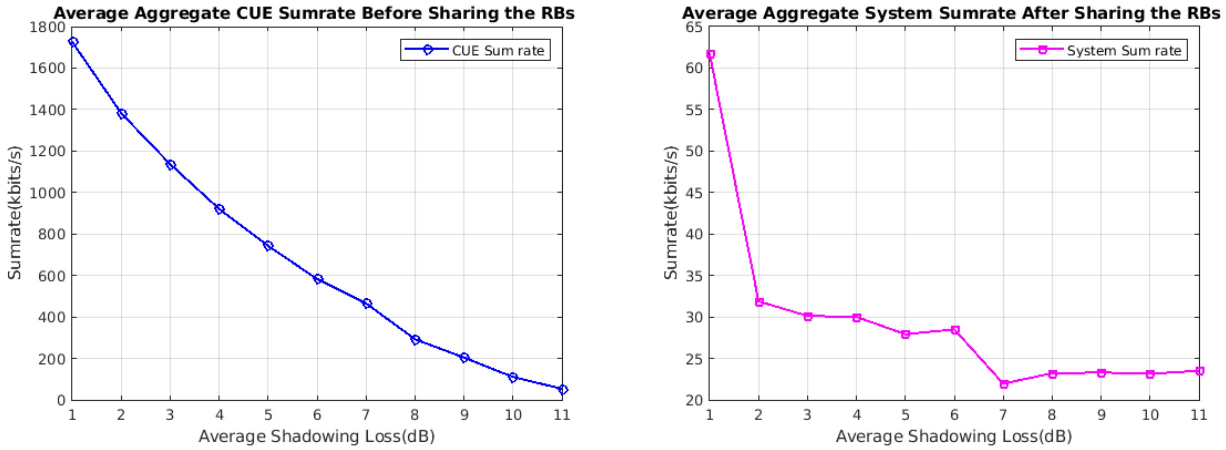
```
    Input  : DUE pair j, $\{d_j\}$
    Output: Optimal Transmit power of DUE pair j,
            $\{P_D^j\}$ and $\mathcal{SC}^{i,j}$
 1  $P_D^j \leftarrow P_{max}$;
 2  repeat
 3      Find $\gamma_D^{i,j}$ using Eq (4);
 4      $P_D^j \leftarrow P_D^j - \triangle$;
 5  until $\left(\gamma_D^j \geq \gamma_{Dmin}\right)$;
 6  Find $\gamma_C^i$ using Eq (3) using $P_D^j$;
 7  if $\left(\gamma_C^i \leq \gamma_{Cmin}\right)$ then
 8      $\mathcal{SC}^{i,j} \leftarrow 0$;
 9  else
10      $\mathcal{SC}^{i,j} \leftarrow 1$;
11  end
12  Return $P_D^j$ and $\mathcal{SC}^{i,j}$;
```

Theorem 3: The execution of Algorithm 3 requires O(P) operations where P represents the total number of power levels for DUE in the cellular network.

Proof: Consider P as the total number of power levels in the range specified by constraint (10g) and is a constant value. In this algorithm, an unconditional loop statement and an if-else statement are used, where the if-else statements will contribute constant time for the complete execution of the algorithm. On the other hand, during each iteration of the loop, the power value of the DUE will be decreased by a small amount "△" from its current power value. This process will continue until the condition specified in line 5 no longer holds good. The loop is designed to determine the optimum power needed for transmission by testing various power levels, and once it has found the optimal power, it will exit the loop. In the worst-case scenario, the loop must go through all the power levels before terminating the executions. Therefore, the time required to complete the execution of algorithm 3 is O(P).

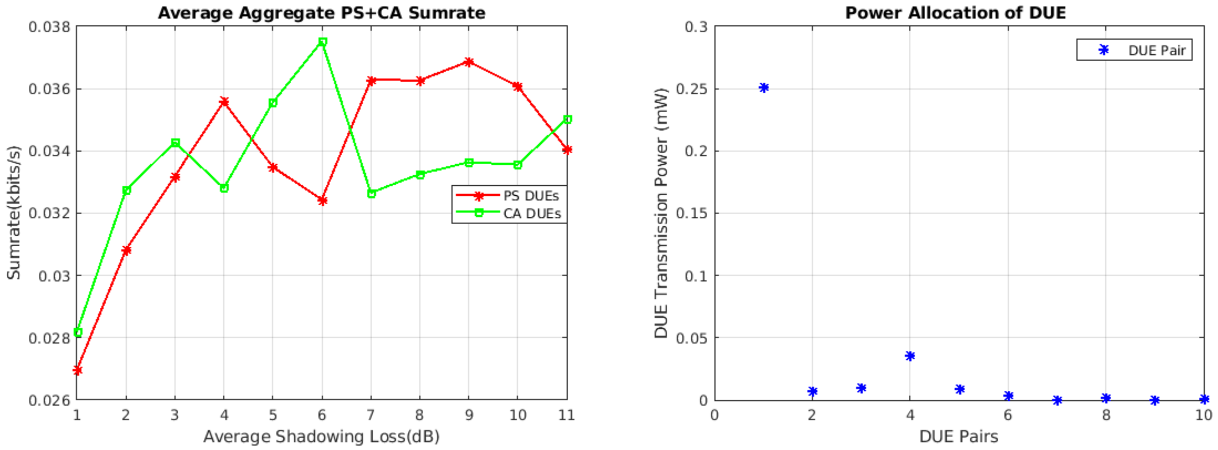
TABLE 2. Simulation parameters and values.

Parameter	**Value**
Cell radius	500 m
Uplink bandwidth	5 MHz
Number of RBs (K)	50
Noise power (N_0)	-174 dBm
Path loss exponent (α)	4
Pathloss constant (G)	0.01
Fast fading coefficient (β)	Exponential distribution with unit mean
Slow fading coefficient (δ)	Log-normal distribution with standard deviation of 8 dB
Number of CUE (N)	10
Number of DUE pairs (D)	50
Maximum UE Tx power (P_{max})	24 dBm
Minimum DUE SINR ($\gamma_{D_{min}}$)	7 dB
Minimum CUE SINR ($\gamma_{C_{min}}$)	20 dB
Maximum DUE pair Distance	15m



(a) CUE's sum rate Before Sharing RBs with DUE Pairs.

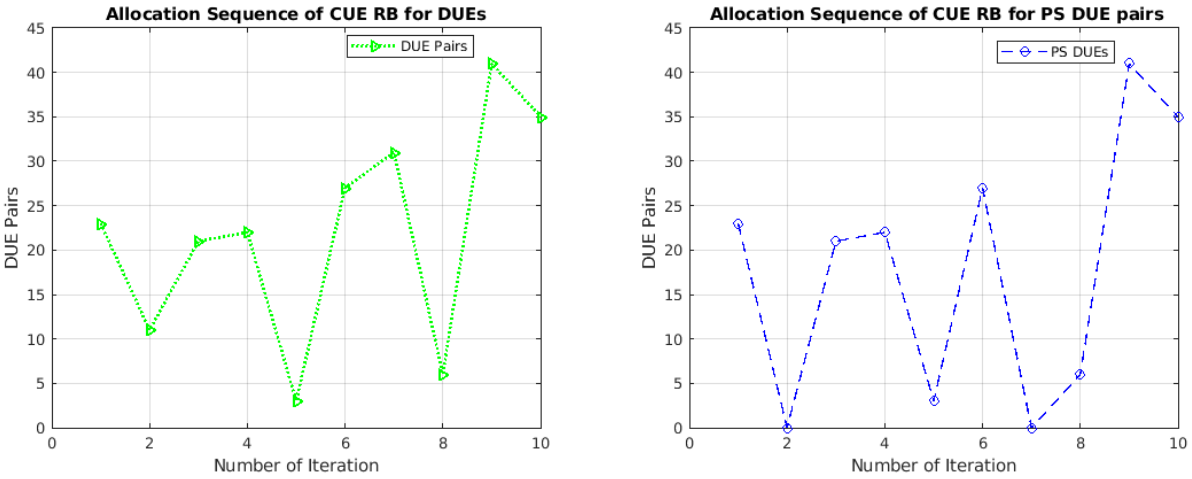
(b) System sum rate After Sharing RBs with DUE Pairs.



(c) PS and CA DUEs Sum ate.

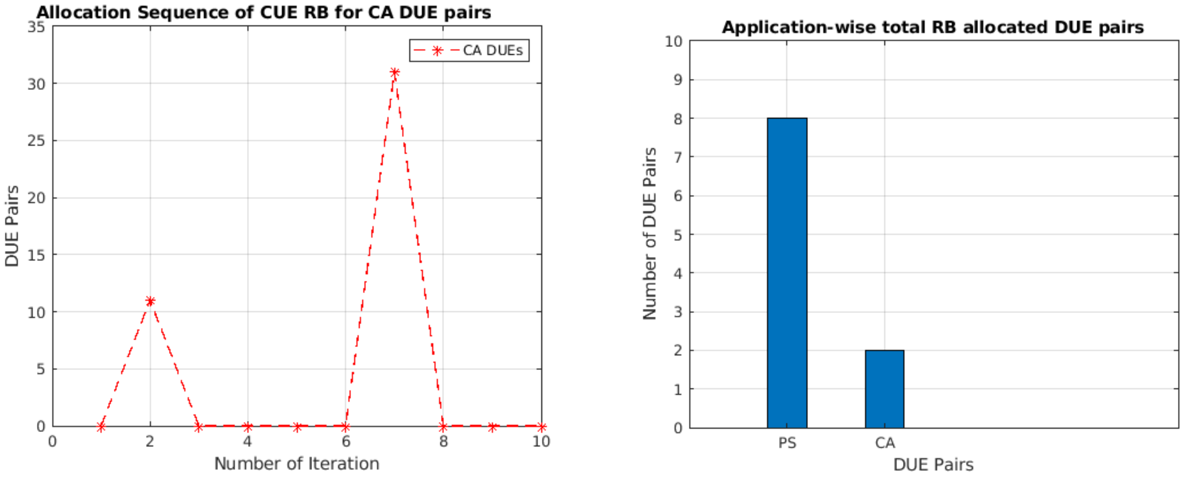
(d) Optimize power consumption for each DUE pair.

FIGURE 2. Performance analysis of cellular network.



(a) Allocation Sequence of DUE pairs.

(b) Allocation Sequence of PS DUE pairs.



(c) Allocation Sequence of CA DUE pairs.

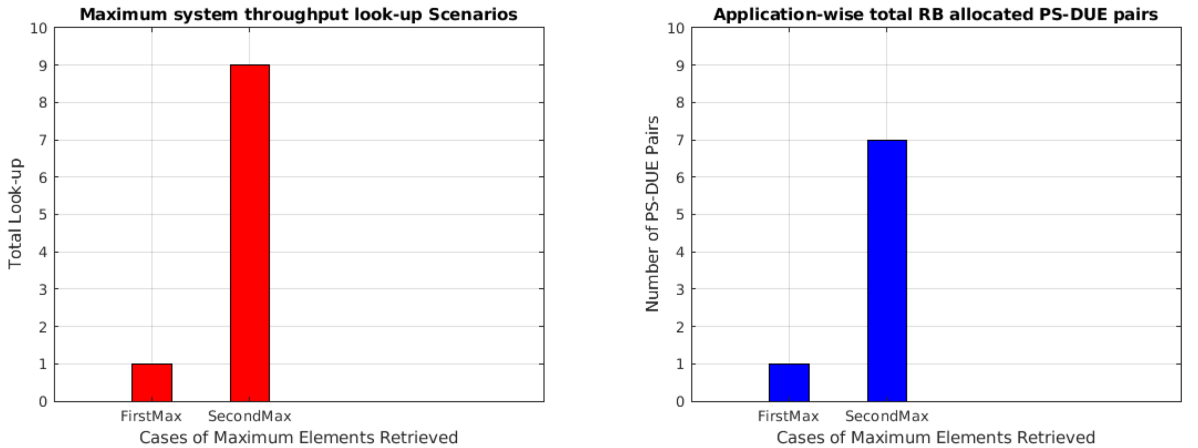
(d) Application-wise RB allocation.

FIGURE 3. **An analysis of RB sharing for cellular systems based on application type of DUE pairs.**

V. PERFORMANCE EVALUATION

This section extensively examines the proposed system through simulations using the MATLAB platform. The CUEs and DUEs are randomly and uniformly distributed within a 500m transmission range of a single-cell eNB. The eNB will allocate RBs to CUEs at each transmission time interval. The assumed distance between the DUE transmitter and receiver ranges randomly from 5m to 15m. We employed a one-to-one strategy, and a total of 50 DUE pairs and 10 CUEs are considered in this study, where each DUE pair is labeled from DUE1 to DUE50. The DUEs are categorized into two types, either PS or CA, based on the *Application_Type* attribute. Among the 50 DUE pairs, we included an equal number of CA and PS types, comprising 25 DUE pairs each, and ten out of 50 DUE pairs are allowed to share the CUE's RB. During RB allocation, a minimum SINR of 20 dB is used for CUE to maintain the QoS, while a minimum SINR of 7 dB is used for DUE during RB sharing activities. A signal strength of 7dB signifies a medium strength, while a signal strength of 20dB is considered excellent [46]. Therefore, cellular users with the strongest signal in the network are given more importance than other users in the network. The following section will present a comprehensive and in-depth analysis and interpretation of the simulation outcomes. Table 1 depicts the various simulation parameters and their values used in the experiments.

Fig. 2a shows the average aggregate sum rate of CUEs before sharing its resources with DUE. A total of 10 CUEs are considered under study, and based on the maximum channel gain, the RBs are allocated to CUEs. The graph shows that as the average shadowing loss increases, the channel condition worsens, leading to a corresponding decrease in the curve. Fig. 2b shows the average aggregate sum rate of the overall system (both CUEs and DUEs) when the CUE's resources are shared with DUE. The DUE reuses the RBs assigned to CUE for their transmission, thus improving the overall spectrum utilization. We can also observe from Fig. 2b that the sum rate of the system has decreased when



(a) Searching cases of Maximum throughput retrieved. (b) Searching cases of Maximum PS DUEs throughput retrieved.

FIGURE 4. **Analysis of maximum throughput search cases.**

compared to Fig. 2a because the RBs of CUEs are shared with DUE pairs causing interferences, which influences CUE communication. However, we ensured the QoS for the cellular as well as the D2D by keeping the minimum SINR values as expressed by the set constraints in the defined objective function to improve the spectrum utilization.

Fig. 2c shows the average aggregate sum rate of both PS and CA DUEs, and it can be observed that the sum rate of the DUE pairs increases with an increase in average shadowing loss. This is mainly because the channel conditions between the combinations of CUE and DUE pairs become worse, leading to less interference effects on DUE pairs caused by CUE. Furthermore, the DUE pairs get the advantage of proximity compared to cellular communication, which will also contribute to an increase in the SINR values of D2D communication. One can observe that the two curves in the graph are unstable and show up and down. This is mainly because the sum rate depends on the allocation sequence of RBs to different DUE pairs. The RB of a CUE can be assigned to either the PS or CA DUE pair, and when the RB is allocated to PS, the sum rate of CA comes down and vice versa. The optimal transmit power required for the guaranteed transmission of D2D communication is calculated by Algorithm 3 and is depicted in Fig. 2d. It can be observed that only one D2D pair utilizes the maximum power value for communication, and the rest of the pairs operate at the minimum power for transmission. Therefore, compared to cellular communication, which uses full power for communication, D2D communication saves energy and increases the battery life of UEs. As a result, this approach is considered a more eco-friendly option for communication and, in turn, leads to green communications.

Fig. 3a shows the allocation sequence of RB to all types of DUE pairs, including PS and CA. We are using a one-to-one strategy for the RB sharing process, and out of 50 DUE pairs under the study, only 10 DUEs can reuse the RBs of 10 CUEs. Algorithm 2 analyzes all the possible CUE and DUE combinations and only grants access to DUE pairs that will result in the highest possible throughput for the system. The particular RB allocation sequence to DUE pairs from Fig.3a are DUE23, DUE11, DUE21, DUE22, DUE3, DUE27, DUE31, DUE6, DUE 41, and DUE35. Figures 3b and 3c show the separate allocation sequence for PS and CA DUE pairs during the iterations. From Fig.3b, it can be inferred that RB allocation for PS DUEs did not occur during the second and seventh iterations out of ten iterations. Fig. 3c reveals that only two CA DUEs are getting permission to reuse the RB of CUEs during the second and seventh iterations. Thus, achieving our main objective to prioritize the PS application over the CA application by giving PS DUE pairs more chances to share RB than CA DUEs, as expressed by the constraint (10.d) of the objective function (10). Fig. 3d depicts that in the proposed system, the number of PS DUE pairs reusing the RBs of CUEs is higher than CA DUE pairs, and when examining the figure, it becomes clear that a total of 8 PS DUEs are active when compared to 2 CA DUEs.

Algorithm 2 proposes to retrieve the second-highest throughput combination to give the PS DUE pairs an upper hand in the possibility that the DUE pair retrieved during the first search is of the CA application type. Fig. 4a displays searching cases of maximum elements retrieved throughout the simulation. Fig. 4a illustrates that there is only one case where the PS DUE pair has the highest maximum elements, while in all other cases, the retrieved elements are the second maximum elements during the iterations to prioritize PS. Fig. 4b indicates the searching cases for PS DUEs only. Fig. 4a and Fig. 4b disclose that nine times the second maximum element was retrieved during the iteration, and out of nine times, 7 are PS DUEs, and two are CA DUEs. Therefore, we are prioritizing the PS application over other applications.

It is evident from the obtained simulation results that the proposed frameworks achieve the defined objectives and are practical, efficient, and straightforward to implement with minimal complications. At first, the RBs will be assigned to CUE, and then the same RBs are shared with the DUE pair. While sharing, the proposed algorithm ensures QoS for all users in the cellular network. It is also observed that during the RB sharing process, the proposed framework prioritizes the PS over CA and optimizes the transmit power of DUEs, thereby fulfilling our listed objectives.

VI. CONCLUSION AND FUTURE WORK

In this study, we have analyzed and formulated objective functions for resource allocation, sharing, and power optimization for DUEs in a single-cell uplink D2D-enabled cellular network. The defined objective functions and set of constraints guarantee the minimum QoS for both DUEs and CUEs in the network while prioritizing the PS applications over CA. The problem devised is a MINLP, and thus, it is divided into two iterative subproblems, namely Iterative RAS and Iterative PO, to solve it efficiently. The Iterative RAS subproblem is used for RB allocation and sharing, whereas Iterative PO is used to find the optimal power required for D2D transmission. The Iterative RAS takes care of allotting RB to CUEs first and gives an edge to PS rather than CA during the RB sharing process. Meanwhile, iterative PO finds the optimum transmit power for the DUEs to minimize the interference in the system. The simulation results exhaustively check the significance of the proposed framework, which is observed to be efficient. The proposed algorithm can be extended to one-to-many and many-to-many cases, as only one-to-one scenarios are explored in this study. Further, we have suggested the highest and second highest possible combination for prioritizing the DUEs, which can be extended to any other method in the future.

REFERENCES

[1] A. Gupta and R. K. Jha, "A survey of 5G network: Architecture and emerging technologies," *IEEE Access*, vol. 3, pp. 1206–1232, 2015.

[2] L. Lei, Z. Zhong, C. Lin, and X. Shen, "Operator controlled device-to-device communications in LTE-advanced networks," *IEEE Wireless Commun.*, vol. 19, no. 3, pp. 96–104, Jun. 2012.

[3] A. Asadi, Q. Wang, and V. Mancuso, "A survey on device-to-device communication in cellular networks," *IEEE Commun. Surveys Tuts.*, vol. 16, no. 4, pp. 1801–1819, 4th Quart., 2014.

[4] J. Liu, N. Kato, J. Ma, and N. Kadowaki, "Device-to-device communication in LTE-advanced networks: A survey," *IEEE Commun. Surveys Tuts.*, vol. 17, no. 4, pp. 1923–1940, 4th Quart., 2015.

[5] C. Kai, H. Li, L. Xu, Y. Li, and T. Jiang, "Joint subcarrier assignment with power allocation for sum rate maximization of D2D communications in wireless cellular networks," *IEEE Trans. Veh. Technol.*, vol. 68, no. 5, pp. 4748–4759, May 2019.

[6] I. F. Akyildiz, S. Nie, S.-C. Lin, and M. Chandrasekaran, "5G roadmap: 10 key enabling technologies," *Comput. Netw.*, vol. 106, pp. 17–48, Sep. 2016.

[7] C. Kai, H. Li, L. Xu, Y. Li, and T. Jiang, "Energy-efficient device-to-device communications for green smart cities," *IEEE Trans. Ind. Informat.*, vol. 14, no. 4, pp. 1542–1551, Apr. 2018.

[8] G. Fodor, S. Parkvall, S. Sorrentino, P. Wallentin, Q. Lu, and N. Brahmi, "Device-to-device communications for national security and public safety," *IEEE Access*, vol. 2, pp. 1510–1520, 2014.

[9] W. Yu, H. Xu, J. Nguyen, E. Blasch, A. Hematian, and W. Gao, "Survey of public safety communications: User-side and network-side solutions and future directions," *IEEE Access*, vol. 6, pp. 70397–70425, 2018.

[10] N. Sawyer and D. B. Smith, "Flexible resource allocation in device-to-device communications using Stackelberg game theory," *IEEE Trans. Commun.*, vol. 67, no. 1, pp. 653–667, Jan. 2019.

[11] T. V. Raghu and M. Kiran, "A survey on device to device communications," in *Proc. Int. Conf. Advancement Technol. (ICONAT)*, Jan. 2022, pp. 1–6.

[12] T. Islam and C. Kwon, "Survey on the state-of-the-art in device-to-device communication: A resource allocation perspective," *Ad Hoc Netw.*, vol. 136, Nov. 2022, Art. no. 102978.

[13] P. Gandotra and R. K. Jha, "Device-to-device communication in cellular networks: A survey," *J. Netw. Comput. Appl.*, vol. 71, pp. 99–117, Aug. 2016.

[14] M. K. Pedhadiya, R. K. Jha, and H. G. Bhatt, "Device to device communication: A survey," *J. Netw. Comput. Appl.*, vol. 129, pp. 71–89, Mar. 2019.

[15] M. H. Zafar, I. Khan, and M. O. Alassafi, "An efficient resource optimization scheme for D2D communication," *Digit. Commun. Netw.*, vol. 8, no. 6, pp. 1122–1129, Dec. 2022.

[16] A. Moubayed, A. Shami, and H. Lutfiyya, "Wireless resource virtualization with device-to-device communication underlaying LTE network," *IEEE Trans. Broadcast.*, vol. 61, no. 4, pp. 734–740, Dec. 2015.

[17] Y. Zhi, J. Tian, X. Deng, J. Qiao, and D. Lu, "Deep reinforcement learning-based resource allocation for D2D communications in heterogeneous cellular networks," *Digit. Commun. Netw.*, vol. 8, no. 5, pp. 834–842, Oct. 2022.

[18] W. Santipach and K. Jiravanstit, "On selecting transmission mode for D2D transmitter in underlay cellular network with a multi-antenna base station," *Digit. Commun. Netw.*, vol. 8, no. 2, pp. 194–207, Apr. 2022.

[19] J. Xu, C. Guo, and H. Zhang, "Joint channel allocation and power control based on PSO for cellular networks with D2D communications," *Comput. Netw.*, vol. 133, pp. 104–119, Mar. 2018.

[20] L. Feng, Z. Yang, Y. Yang, X. Que, and K. Zhang, "Smart mode selection using online reinforcement learning for VR broadband broadcasting in D2D assisted 5G HetNets," *IEEE Trans. Broadcast.*, vol. 66, no. 2, pp. 600–611, Jun. 2020.

[21] C. Gao, Y. Li, Y. Zhao, and S. Chen, "A two-level game theory approach for joint relay selection and resource allocation in network coding assisted D2D communications," *IEEE Trans. Mobile Comput.*, vol. 16, no. 10, pp. 2697–2711, Oct. 2017.

[22] U. Saleem, S. Jangsher, H. K. Qureshi, and S. A. Hassan, "Joint subcarrier and power allocation in the energy-harvesting-aided D2D communication," *IEEE Trans. Ind. Informat.*, vol. 14, no. 6, pp. 2608–2617, Jun. 2018.

[23] L. Wang, H. Tang, H. Wu, and G. L. Stüber, "Resource allocation for D2D communications underlay in Rayleigh fading channels," *IEEE Trans. Veh. Technol.*, vol. 66, no. 2, pp. 1159–1170, Feb. 2017.

[24] Y. Li, T. Jiang, M. Sheng, and Y. Zhu, "QoS-aware admission control and resource allocation in underlay device-to-device spectrum-sharing networks," *IEEE J. Sel. Areas Commun.*, vol. 34, no. 11, pp. 2874–2886, Nov. 2016.

[25] X. Ma, J. Liu, and H. Jiang, "Resource allocation for heterogeneous applications with device-to-device communication underlaying cellular networks," *IEEE J. Sel. Areas Commun.*, vol. 34, no. 1, pp. 15–26, Jan. 2016.

[26] Y. Jiang, Q. Liu, F. Zheng, X. Gao, and X. You, "Energy-efficient joint resource allocation and power control for D2D communications," *IEEE Trans. Veh. Technol.*, vol. 65, no. 8, pp. 6119–6127, Aug. 2016.

[27] H.-H. Nguyen, M. Hasegawa, and W.-J. Hwang, "Distributed resource allocation for D2D communications underlay cellular networks," *IEEE Commun. Lett.*, vol. 20, no. 5, pp. 942–945, May 2016.

[28] M. Hasan and E. Hossain, "Distributed resource allocation for relay-aided device-to-device communication under channel uncertainties: A stable matching approach," *IEEE Trans. Commun.*, vol. 63, no. 10, pp. 3882–3897, Oct. 2015.

[29] M. M. Salim, H. A. Elsayed, M. A. Elaziz, M. M. Fouda, and M. S. Abdalzaher, "An optimal balanced energy harvesting algorithm for maximizing two-way relaying D2D communication data rate," *IEEE Access*, vol. 10, pp. 114178–114191, 2022.

[30] X. Li and G. Chen, "D2D cooperative communication network resource allocation algorithm based on improved Monte Carlo tree search," *IEEE Access*, vol. 11, pp. 72689–72703, 2023.

[31] P. Chen, X. Zhou, J. Zhao, F. Shen, and S. Sun, "Energy-efficient resource allocation for secure D2D communications underlaying UAV-enabled networks," *IEEE Trans. Veh. Technol.*, vol. 71, no. 7, pp. 7519–7531, Jul. 2022.

[32] G. Wu, G. Chen, and G. Chen, "Energy-efficient utility function-based channel resource allocation and power control for D2D clusters with NOMA enablement in cellular networks," *IEEE Access*, vol. 11, pp. 45001–45010, 2023.

[33] B. V. R. Gorantla and N. B. Mehta, "Interplay between interference-aware resource allocation algorithm design, CSI, and feedback in underlay D2D networks," *IEEE Trans. Wireless Commun.*, vol. 21, no. 5, pp. 3452–3463, May 2022.

[34] W.-K. Lai, Y.-C. Wang, and H.-B. Lei, "Joint resource and power management for D2D communication across multiple service providers," *IEEE Syst. J.*, vol. 16, no. 3, pp. 3488–3499, Sep. 2022.

[35] H. Xiang, Y. Yang, G. He, J. Huang, and D. He, "Multi-agent deep reinforcement learning-based power control and resource allocation for D2D communications," *IEEE Wireless Commun. Lett.*, vol. 11, no. 8, pp. 1659–1663, Aug. 2022.

[36] W. Li, X. Qin, Z. Jia, J. Bi, and X. Li, "Resource sharing for cellular-assisted D2D communications with imperfect CSI: A many-to-many strategy," *IEEE Syst. J.*, vol. 16, no. 3, pp. 4454–4465, Sep. 2022.

[37] T. Islam, C. Kwon, and Y. Noh, "Transmission power control and relay strategy for increasing access rate in device to device communication," *IEEE Access*, vol. 10, pp. 49975–49990, 2022.

[38] P. Pawar and A. Trivedi, "Interference-aware channel assignment and power allocation for device-to-device communication underlaying cellular network," *AEU Int. J. Electron. Commun.*, vol. 112, Dec. 2019, Art. no. 152928.

[39] S. Shamaei, S. Bayat, and A. M. A. Hemmatyar, "Interference management in D2D-enabled heterogeneous cellular networks using matching theory," *IEEE Trans. Mobile Comput.*, vol. 18, no. 9, pp. 2091–2102, Sep. 2019.

[40] R. Gour and A. Tyagi, "Cluster oriented resource allocation and power optimisation for D2D network in cellular communications," *IET Netw.*, vol. 9, no. 4, pp. 170–179, Jul. 2020.

[41] W.-K. Lai, Y.-C. Wang, H.-C. Lin, and J.-W. Li, "Efficient resource allocation and power control for LTE—A D2D communication with pure D2D model," *IEEE Trans. Veh. Technol.*, vol. 69, no. 3, pp. 3202–3216, Mar. 2020.

[42] B. Ozbek, M. Pischella, and D. Le Ruyet, "Energy efficient resource allocation for underlaying multi-D2D enabled multiple-antennas communications," *IEEE Trans. Veh. Technol.*, vol. 69, no. 6, pp. 6189–6199, Jun. 2020.

[43] D. Feng, L. Lu, Y. Yuan-Wu, G. Y. Li, G. Feng, and S. Li, "Device-to-device communications underlaying cellular networks," *IEEE Trans. Commun.*, vol. 61, no. 8, pp. 3541–3551, Aug. 2013.

[44] R. Gour and A. Tyagi, "Channel selection and power allocation for device-to-device enabled cellular networks," *IET Commun.*, vol. 12, no. 15, pp. 1854–1863, Sep. 2018.

[45] S. Boyd and L. Vandenberghe, *Convex Optimization*. Cambridge, U.K.: Cambridge Univ. Press, 2004.

[46] A. Stafecka, A. Lizunovs, G. Ivanovs, and V. Bobrovs, "Dependence between signal parameter values and perceived Internet access service QoS in mobile networks," in *Proc. Photon. Electromagn. Res. Symp. (PIERS)*, Nov. 2021, pp. 1419–1427.

T. V. RAGHU (Student Member, IEEE) received the M.Tech. degree in computer and information science from Cochin University of Science and Technology, Cochin, India, in 2013. He is currently pursuing the Ph.D. degree with the Department of Information Technology, National Institute of Technology Karnataka (NITK), Surathkal, India. He has eight years of teaching experience. His current research interest includes D2D communication.

M. KIRAN (Member, IEEE) received the Ph.D. degree from the National Institute of Technology Karnataka (NITK), Mangaluru, India, in 2014. He is currently an Assistant Professor with the Department of Information Technology, NITK. He has 13 years of teaching and research experience. His research interests include next generation computer networks, the IoT, and blockchain technologies.

• • •