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A Novel Methodology for Resource Allocation in D2D Communication Based on Hypergraph

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Abstract: The exploration of Device-to-Device (D2D) communication has become well-known as a prominent alternative to alleviate congestion in licensed spectrum bands. D2D communication serves as a cornerstone in offloading cellular traffic and ameliorating network congestion, thereby reducing latency and enhancing network responsiveness. The present work describes a research study that uses a Hypergraph-based technique to allocate resources in D2D communication within a Hexagonal Cellular network. The research addresses resource allocation difficulties using Linear Programming by formulating constraint matrices and right-hand side vectors. The simulation examines the allocation of resource blocks to cellular users and how it affects data rates, revealing important insights for system optimization. The complexity study of the Hypergraph-based technique for Resource Allocation suggests that its scalability is directly proportional to the cube of the sum of A and B, where A represents the number of cellular users and B represents the number of D2D couples. Graphical analyses demonstrate significant patterns: the correlation between resource blocks and cellular users highlights the necessity for effective allocation schemes, while the influence of resource availability on data rates stresses the significance of optimal allocation systems. Finally, the relationship between throughput and the distance between D2D users emphasizes the impact of geographical factors on performance. Potential areas for future research involve simplifying resource allocation methods and increasing cell capacity to improve D2D communication and the performance of cellular networks, specifically in optimizing channel capacity and spectral efficiency.

Keywords: *Channel Allocation, Channel Interference, D2D Communication, Hypergraph, Network Performance*

1. Introduction

Communication between D2D pairs has evolved as a transformative paradigm within the realm of wireless communication, offering a decentralized approach that complements traditional cellular networks. The concept of D2D communication traces its roots back to the initial development of wireless technology, where the prominent focus was primarily on establishing direct links between nearby devices without the need for intermediate infrastructure. Initially conceptualized for ad-hoc networks and peer-to-peer applications, D2D communication has undergone significant evolution, driven by advancements in technology and the growing need for dependable and effective communication.

The development of D2D communication has gone through multiple phases. D2D communication owes its origins to the principles of ad hoc networking, which allowed for the establishment of direct connections between nearby devices [1,2]. D2D communication became popular with the advent of wireless standards such as Wi-Fi and Bluetooth, prompting attempts to standardize it and incorporate it into existing protocols [3,4]. Particularly with in-band communication techniques, the scope of device-to-device (D2D) was broadened with its inclusion into cellular networks. D2D communication has been a key component of network architecture since the introduction of 5G, which promises increased efficiency and opens the door to new applications [5-8]. In the future, direct-to-device communication could improve connection on the Internet of Things (IoT) and mission-critical communications, leading to innovation in many different areas.

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From proximity-based services to public safety and emergency communication, Internet of Things connectivity, communication in vehicles, and content delivery/offloading, D2D communication shows tremendous promise in many areas [9]. D2D allows devices in close proximity to one another to engage in direct interaction for purposes such as file sharing and gaming inside proximity-based services. When it comes to public safety, it guarantees dependable communication even in places with spotty service or heavy network usage [10]. Reducing dependency on centralized gateways provides an efficient solution for device interaction for the Internet of Things. D2D communication between vehicles helps make roads safer and enables autonomous driving systems to work [11, 12]. Furthermore, direct device-to-device (D2D) content exchange allows for effective offloading and delivery in cellular networks by lowering infrastructure pressure.

D2D communication, while promising, faces significant challenges. These include interference management, resource allocation optimization, security and privacy concerns, mobility management complexities, and scalability and deployment issues [13-16]. Efficient techniques are needed for interference mitigation, resource allocation optimization, and ensuring security and privacy [17-19]. Additionally, managing mobility and ensuring scalability requires robust protocols and standards for seamless integration into existing networks.

The rise of D2D communication presents a compelling alternative to conventional cellular communication methods, particularly in addressing issues of traffic overload and latency associated with reliance on base stations or evolved Nodes (eNBs) [20]. Efficient spectrum utilization becomes critical to enhance spectral efficiency and alleviate network congestion. In the realm of 5G wireless communication, in-band D2D communication emerges as a highly sought-after technology, with various resource allocation techniques devised to mitigate interference and maintain communication link quality [21,22]. This strategic resource allocation not only offloads data traffic efficiently but also boosts cell capacity and minimizes end-to-end latency. D2D communication's advantages—such as high data rates, low latency, reduced power consumption, and enhanced cellular capacity—hold promise for diverse applications, fostering innovation and improved user experiences. Addressing interference management challenges and developing effective resource allocation strategies are central to advancing D2D communication in cellular networks, unlocking its vast potential for future wireless technologies [23-25]. By facilitating seamless and efficient communication between cellular and D2D users, this research aims to contribute to the evolution of communication systems, achieving enhanced connectivity and resource utilization while supporting a wide array of innovative applications.

Research on a Novel Hypergraph-Based Methodology for Resource Allocation in D2D Communication is important due to the rising requirement for effective resource utilization in D2D networks. With the increment in the number of mobile devices and the ever-increasing need for dependable, rapid communication, optimizing resource allocation is taking on greater significance. This study aims to offer novel approaches that improve resource allocation using hypergraph-based techniques to boost network performance, reduce interference, and improve the user experience in D2D communication systems.

The paper aims to achieve the following objectives:

1) "Resource Allocation in D2D communication" is the subject of preliminary research and explanation.

2) To propose an innovative Hypergraph-based approach to Resource Allocation in Direct-to-Device Communication. The approach used mainly involves modelling the constraint matrix and the right-hand side vector making use of the linear programming based on Hypergraph for solving the Resource allocation problem.

3) To validate the proposed method using several performance measures like throughput, resource blocks, rate, distance between D2D pairs, and D2D pair counts.

4) To compare the Proposed solution with the allocation involving only the D2D pairs and Cellular users individually.

Section 1 provides an introduction to the topic, followed by Section 2, which delves into the literature review of various researchers. Section 3 outlines the preliminaries, leading to Section 4, which details the proposed methodology. Section 5 discusses the experimentation, results, and analysis. Section 6 provides a comprehensive discussion of the study, and finally, Section 7 concludes the paper, highlighting the future scope for research.

2. Literature Review

A review of the literature reveals that many authors have attempted this method and published their results.

Li et al., (2023) [26] proposed an algorithm for resource allocation, which involved multi-agent communication between D2D pairs based on an important metric or approach called Advantage Actor Critic (A2C). The results of simulations showed that, in comparison to MAAC (multi-agent actor-critic) and DQN (deep Q-network), the throughput of the system had improved by 12.5% and 26%, respectively.

Gao et al., (2023) [27] introduced a distance grouping-based resource allocation algorithm, considering the varied interference from Cellular Users (CUs) to Device Users (DUs) at varied distances. The simulation results indicated significant enhancements in system throughput and performance with this algorithm. Moreover, the algorithm's computational complexity was reduced, thereby enhancing the overall communication quality of the system.

Zhuansun et al., (2023) [28] delved into investigating a resource allocation problem involving the management of power and joint channel allocation in cross-cell networks of IIoT. The goal was to reach the maximum possible throughput or net sum rate for cellular Machine Devices (cMDs) and device-to-device couples based on NOMA (Nonorthogonal multiple access). The results demonstrated that the proposed algorithms outperformed the graph-based algorithm in terms of throughput or average sum rate and significantly improved spectrum efficiency.

Xie et al., (2022) [29] suggested a cellular communication system that supports D2D communication and is based on filtered orthogonal frequency division multiplexing (filtered-OFDM). This system was designed to respond to users' diverse communication needs. The results demonstrated that the resource allocation scheme that was proposed significantly enhanced the quantity of user links present in the network, taking into consideration interference introduced by filtered-OFDM D2D communication between D2D pairs.

Zhuansun et al., (2022) [30] identified and formulated the problem of resource allocation as an optimization problem of sum rate or throughput, ensuring Quality of Service (QoS). The results of the simulation demonstrated that the approach surpassed both graph-based algorithms and certain algorithms that were based on hypergraphs in enhancing the throughput of the system.

Yu et al., (2022) [10] presented a solution to reduce interference between D2D users as well as cellular users through efficient subchannel allocation as well as user pairing. Numerical results demonstrated that pairing techniques and subchannel assignment were critical in reducing the total transmitted power of the network that supported both cellular users as well as D2D devices.

Zeb et al., (2021) [5] demonstrated that the optimization problem, which was based on spectrum allocation and joint power, exhibited time complexity of the exponential order, which escalated as the quantity of direct-to-direct pairs increased and resource blocks corresponding to certain frequencies. For several reuse strategies, the simulation results demonstrated an effective intensity of D2D nodes, $\mathbf{O}(\varepsilon)$, with a fixed outage restriction of $\varepsilon = 0.1$.

Jeon et al., (2020) [31] presented algorithms for mode selection as well as resource allocation based on graph theory for D2D communication systems that can implement a full-duplex (FD) scheme. The numerical analysis showed that the proposed system significantly reduced the utilized frequency range while maximizing the sum-rate performance. Accordingly, D2D pairs were permitted to share the resources, or the spectrum provided that one pair was adequately distant from another.

Zhao et al., (2020) [32] proposed a technique to find the solution to a power and channel allocation problem, with the latter making use of 3D based Hypergraph matching. The outcomes of the simulation confirmed that the suggested plan enhanced throughput performance in comparison to other algorithms by a minimum of 6%.

Xu et al., (2020) [33] designed the Interference Limited Area (ILA) to protect the potential cellular users' coverage areas. The authors adopted a strategy where D2D users at all locations were modelled using a Poisson point process. The results of the simulations showed that compared to the traditional and random allocation schemes, the proposed one significantly improved performance.

Kumar et al., (2020) [34] focused on the problem of hyperedge prediction. The authors predicted the hyperedge using an algorithm based on resource allocation, which represented the pioneering algorithm designed to address these problems. Extensive experimentation reveals that HPRA (Hyperedge Prediction using Resource Allocation) consistently outperforms existing methods, yielding statistically significant improvements in performance.

Saied et al., (2020) [35] proposed a scheme for the allocation of resources to address the challenges of resource allocation. The proposed scheme optimized the utility function, thereby reflecting system performance expressed in the form of network sum rate or throughput. Simulation results demonstrated that the proposed scheme achieved nearly ideal performance and surpassed existing algorithms in the throughput achieved.

Wang et al., (2019) [36] presented NOMA (nonorthogonal multiple access) as a potential solution for 5G mobile communication networks. A D2D upgraded V2X network's quality-of-service (QoS) requirements necessitated an increase in network capacity while simultaneously decreasing accessing and transmission latency. The simulation findings confirmed that the suggested IHG-3DM resource allocation algorithm greatly improved the network throughput for the NOMA-integrated V2X communications that were studied.

Zhao et al., (2018) [37] proposed a novel greedy-based channel assignment algorithm for optimal allocation of resources in D2D communication. The results indicated that the proposed algorithm not only dramatically improved the network capacity but also enhanced the fairness among devices.

Liang et al., (2018) [11] examined the resource allocation challenge within vehicular communications through device-to-device (D2D) connections, specifically focusing on utilizing slow-fading statistics obtained from channel state information (CSI). The results showed that updating vehicle-to-vehicle (V2V) clustering took more iterations when using the suggested greedy and random algorithms.

According to the reviewed literature, graph-based methods were not performing well when faced with high-dimensional, large-scale data that had complicated linkages and dependencies between entities. A further difficulty with traditional techniques was the difficulty in adapting graphs to changing contexts and the difficulty in associating varied properties to nodes and edges. It turns out that the best way to distribute Resource Blocks in cellular communication to users and D2D pairings is by using hypergraph-based methods. To solve interference problems and improve spectrum efficiency, use a simulation model based on Hypergraph linear programming, as described in Section III. Consequently, better methods, such as Hypergraph-based resource allocation, must be adopted to address these issues.

3. Preliminaries

In this section, the authors discuss some preliminaries which are necessary for the understanding of the proposed scheme.

a. Hypergraph

A hypergraph, represented as H = (V, E), is a generalized graph where V represents a finite set and E represents a family of subsets of V called hyperedges, denoted as $(e_z)_{z \in I}$. Alternatively, V can be denoted as V(H) and E as E(H). The order of the hypergraph, denoted as H = (V, E), is determined by the cardinality of V, expressed as |V| = n; its size is defined by the cardinality of E, denoted as |e| = m.

If

$$\bigcup_{z=1}^{q} e_z = V \quad (1)$$

Then, the hypergraph is with Isolated vertex

b. A simple hypergraph denoted as H = (V, E) is characterized by the property such that: $e_i \subseteq e_j \Rightarrow i = j$. In short, a basic hypergraph does not have any duplicate hyperedges [38].

Simple Hypergraph Algorithm

Algorithm 1: Simple Hypergraph

```
Input: H ← (V, E) hypergraph
Output: H^sh ← (V, E^sh) simple hypergraph
begin
    for each e_i ∈ E do
        for each e_j ∈ E do
            if i ≠ j and e_j ⊆ e_i then
                E ← E\{ e_j }
            end
        end
    end
    E^sh ← E
    H^sh ← (V, E^sh)
    return H^sh
end
```

c. Incidence Matrix

Let H = (V, E) be a hypergraph V= {v1, v2, v3……….vn} and E = {e1, e2, e3……en} with no isolated vertex then H has a n*m incidence matrix.

A=(amn) where:

$$a_{mn} = \begin{cases} 1, \ if\ v_m \in e_n \\ 0\ otherwise \end{cases} \quad (2)$$

The matrix may also be written as a r*c matrix where r denotes the number of edges and represents the number of vertices in a given hypergraph.

$$\begin{array}{c} \\ e_1 \\ e_2 \\ e_3 \end{array} \begin{array}{c} \begin{matrix} v1 & v2 & v3 & v4 \end{matrix} \\ \begin{bmatrix} 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \end{bmatrix} \end{array} \quad (3)$$

where e1 is the edge containing the vertices v1, v2 and v4 and e2 is the edge containing the vertices v2, v3, v4 and e3 is the edge contain the vertices v1 and v2 of the Hypergraph.

d. Generalization

An extension of the concept of a Hypergraph involves considering hyperedges as potential vertices. This implies that a hyperedge, labelled as 'e', can include not only vertices but also other hyperedges, which are treated as distinct from '[38]. For example,

- Let V = {a1; a2; a3}
- E = {e1 = {a1; a2}; e2 = {a2; a3; e1}; e3 = {a1; e1; e2}}

In this particular hypergraph variant, the incidence matrix is a matrix whose dimensions are defined by the sum of the cardinality of the hyperedges (E) and the vertices (V). As an illustration, the hypergraph that was discussed has an incidence matrix that is displayed below.

a1 a2 a3 e1 e2 e3

$$\begin{matrix} e_1 \\ e_2 \\ e_3 \end{matrix}\begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{bmatrix}$$

4. Proposed Methodology

Resource allocation in D2D communication plays a pivotal role in optimizing network performance and efficiency. Hypergraph theory presents an innovative approach to allocating resources in D2D communication. Hypergraph-based resource allocation methods enable efficient utilization of resources by modelling the communication links between D2D pairs as hyperedges, capturing complex relationships beyond traditional graph models. This strategy enables the dynamic allocation of resources like frequency bands, time slots, and power levels, considering factors like interference mitigation and quality of service requirements. By leveraging Hypergraph theory, D2D communication systems can achieve enhanced spectral efficiency, reduced interference, and improved overall system capacity, making it a promising avenue for future wireless networks.

4.1. System model

The Rayleigh fading model is used to model the wireless channels during wireless communication and take into account interference and multi-path propagation. It is a statistical model that assumes the magnitude to follow the Rayleigh distribution of the signal that is received at the evolved node (eNB) or the signal that is received at the D2D receiver [39]. The channel gains are calculated as the product of the distance-dependent path loss (d) and the fading channel (f). Distance-dependent path loss is evaluated using:

$$\mathrm{d} = \mathrm{rpl} + \mathrm{SF} * \log_{10}(\mathrm{distance}) \qquad (5)$$

where rpl represents reference path loss at a reference distance. It takes into consideration various factors such as transmission power and environment-specific properties, SF denotes the scaling factor, which depends on the main characteristics of the wireless channel, such as environment and the frequency used. Logarithm helps in capturing the relationship between the path loss and the distance, as path loss follows a trend that tends to be logarithmic in systems pertaining to wireless communication [40].

Further, the channel gain for the established link for communication between a D2D transmitter as well as receiver and the cellular user and the base station is represented using:

$$\mathrm{G}_{\mathrm{n^{th}}_{\mathrm{D2Dpair}}} = (\mathrm{d} * \mathrm{f})_{\mathrm{n^{th}}_{\mathrm{D2Dpair}}} \qquad (6)$$

$$G_{m^{th}_{CU}} = (d * f)_{m^{th}_{CU}} \qquad (7)$$

Where $G_{n^{th}_{D2Dpair}}$ and $G_{m^{th}_{CU}}$ Denotes the channel gain for mth D2D pair mth Cellular user respectively [41]. The channel gain for the interference caused to the receivers and the base station is evaluated as:

$$G_{D2DtransmittertoeNB} = (d * f)_{D2DtransmittertoeNB} \qquad (8)$$

$$G_{CUtoD2Dreceiver} = (d * f)_{CUtoD2Dreceiver} \qquad (9)$$

where $G_{D2DtransmittertoeNB}$ and $G_{CUtoD2Dreceiver}$ denotes the channel gain for the link from (D2D transmitter to eNB) and the channel gain for the link from (CU to D2D receiver), respectively. The channel gain of the interference link between two pairs of D2D transmitters and receivers is likewise computed similarly. Statistical properties play a crucial role in characterizing thermal noise. It satisfies the normal Gaussian distribution with variance σ2 and 0 mean [42].

The signal-to-noise ratio (SINR) of a cellular user's (CU) signal received at the base station across a certain resource block 'r' is expressed as

$$sinr_{m^{th}_{CU}} = \frac{P^{CU} * G_{m^{th}_{CU}}}{\sigma^2 + \sum_{n \in T} P^{D2D} * G_{D2DtransmittertoeNB}} \qquad (10)$$

where P^{CU} represents the transmission power of the Cellular user, GmthCU denotes the channel gain for the mth Cellular user, and GD2DtransmittertoeNB denotes the channel gain for the link from (D2D transmitter to eNB). Moreover, the value of the SINR for the signal that is received at the D2D receiver over a certain resource block ’r’ can be written as:

$$sinr_{n^{th}_{D2Dreceiver}} = \frac{P^{D2D} * G_{n^{th}_{D2Dpair}}}{\sigma^2 + \sum_{n \in T} P^{CU} * G^{CU,r}_{m,n} + \sum_{n \in T} P^{D2D} * G_{D2D^{t,r}_{q,n}}} \qquad (11)$$

where P^{D2D} represents the transmission power of the D2D pair, GnthD2Dpair denotes the channel gain for nth D2D pair, $G^{CU,r}_{m,n}$ denotes the channel gain for the interference link from the mth cellular user to the receiver of the nth D2D pair, and G denotes the channel gain for the interference link from the qth D2D transmitter to the nth D2D receiver.

4.2. Network Model

As expressed in Fig. 1., the model in this research paper considers an uplink transmission framework with one hexagonal-shaped cell network for essential D2D communication in a cellular network. R is the radius of the cell with a Base station residing at the centre of the Hexagonal cell. The Hexagonal cell is taken in order to ensure that the adjacent cells are laid without any overlap which further helps in assuring that no gaps are there while building a cellular network. The network facilitates communication between both cellular users and D2D pairs [43]. The network consists of Cellular user equipment represented as CUi, the base station also called evolved Node B represented as eNB, and D2D pair with D2Dt representing the D2D transmitter and D2Dr representing the D2D receiver. Both D2D pairs and cellular user equipment in the network utilize the same spectrum.

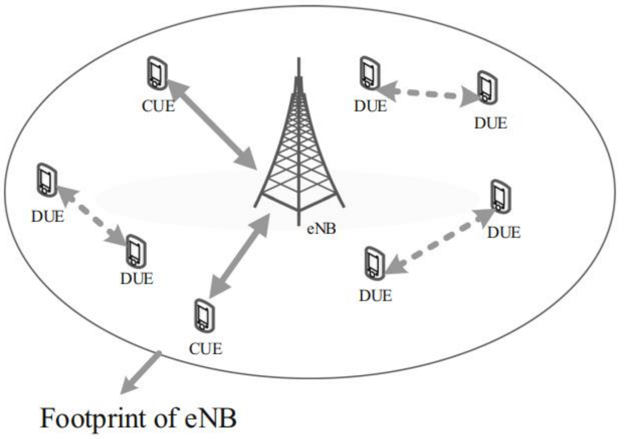
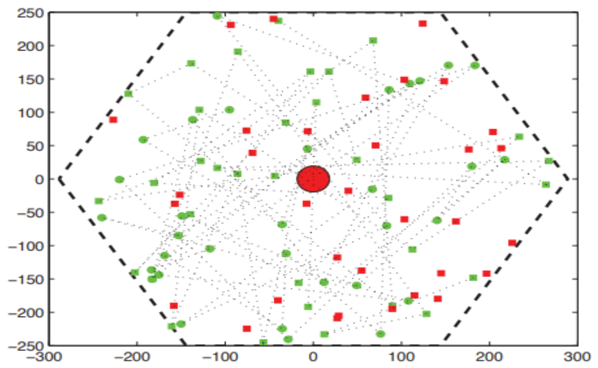


Figure 1. Architecture of D2D Communication [44]

A graphical representation of the D2D pairs as well as cellular users is given in Fig. 2. considering a few constraints such that the number of users is limited to 75 and the maximum D2D pair distance should not exceed 15m. Further, the Hexagonal cell-shaped network considered in the model has a radius of 250m [45].

Figure 2. Hexagonal Cell Corresponding to Users Distribution [46].



The interference in the cellular network mainly comprises three types:

- The interference experienced by the eNB is due to the transmitter (D2Dt) of the D2D pair.
- The interference at D2Dr due to CUi
- The interference received at D2Dr of one D2D pair due to D2Dt of another D2D pair which are sharing the same channel.

In the realm of graph theory, the utilization of a Bipartite matching scheme is applied to enhance resource allocation in Hexagonal cellular networks. By allowing each D2D link to reuse the resources of only a single cellular user, this scheme effectively reduces cross-interference arising from the coexistence of Device-to-Device(D2D) pairs and cellular users [47]. This approach improves communication by mitigating interference and enhances the overall system capacity. Compared to traditional Graph-Based techniques, the Bipartite matching scheme demonstrates superior performance. However, to address the issue of cumulative interference, additional measures were required. While the Bipartite graph approach improved spectrum utilization, the problem of cumulative interference could be further mitigated through the use of Hypergraph. By introducing Hypergraph, it becomes possible to tackle the problem of cumulative interference more effectively, leading to enhanced spectral efficiency. Hypergraph serves as a solution to alleviate the challenges associated with cumulative interference [48].

4.3. Architecture And Working

Hypergraph is basically a generalized Hypergraph in which the edge can comprise even more than two vertices which appears to be an effective mechanism of modelling the interference through hyperedges. Fig. 3. illustrates a hypergraph. The Hypergraph is different from previous graph-based approaches in a way that it considers the problem of cumulative interference.

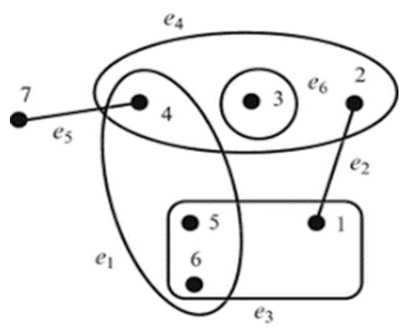


Figure 3. Hypergraph [49]

It is used for modelling the problem of interference. Fig. 4. depicts the incidence matrix or the constraint matrix of the above-drawn sample Hypergraph.

	1	2	3	4	5	6	7
e1	0	1	1	0	0	0	0
e2	1	1	0	1	0	0	0
e3	0	0	0	1	1	0	0
e4	0	0	0	1	0	0	1
e5	0	0	1	0	0	1	1

Figure 4 Incidence Matrix of the Hypergraph

The construction of the Hypergraph mainly involved 2 steps. Firstly, the independent interferer recognition is done. Cellular users and D2D pairs are separate sources of interference for a D2Dr or eNB, and they both reduce the SINR. The underlying assumption is that a cellular user can utilize a maximum of one channel. Since one cellular user is considered an independent interferer of the other, an edge is formed between them [50]. Next, for every CUi, authors search for more independent interferers in a manner similar to graph-based. Secondly, after the identification of independent interferers, a number of CUi's are considered, and the cumulative interference is compared with a threshold to evaluate whether they might come into interferes if combined. The interferers that decrease the SINR notably are cumulative interferers. Afterwards, the resource allocation is done by colouring the hypergraph in such a manner that the vertices connected by the edge are not assigned the same colour [30].

The algorithm for resource allocation of the resource blocks based on hypergraph is as follows:

Algorithm 2 allocate resources (hypergraph, resource blocks)

1: num nodes ← length (resource blocks)
2: num hyperedges ← length(hypergraph)
3: A ← matrix of zeros, shape (num hyperedges, num nodes)
4: b ← array of ones with length num hyperedges
5: for i ← 0 to num hyperedges − 1 do
6: for node in hypergraph[i] do
7: A [i, node] ← 1
8: end for
9: end for
10: c ← negative of resource blocks
11: bounds ← array of tuples (0, None) repeated num nodes
12: result ← solve linear program (c, A eq = A, b eq = b, bounds = bounds)
13: if result.success is true then
14: allocation ← result.x
15: optimal ← result.fun
16: return [allocation, [optimal]]
17: else
18: raise ValueError("Failed to allocate resources.")
19: end if

5. Experimentation, Results And Analysis

This section presents the experimentation key findings of the research and provides a thorough analysis of the results within the broader context of the field.

5.1. Simulation Setup And Parameters

Let X denotes a finite set X = X1, X2, X3,...., Xp where X1, X2, X3,...., Xp represents the vertices and E = (E1, E2, E3,………, Eq) where the sets E1, E2, E3,...., Eq are the subsets of X which represent the hyperedges. A hypergraph H = (X, E) on X is a family

E such that.

$$E_z \neq \phi\{ z = 1,2,3,4 \ldots . . q\} \quad (12)$$

where p and q denote the quantity of nodes and hyperedges, respectively.

$$\cup_{z=1}^{q} E_z = X \quad (13)$$

The simulation was carried out using Python. The simulation parameters mentioned below in Table 1 were used for checking the variation of Throughput with a number of D2D pairs and with respect to the distance between D2D pairs [51,52].

Table 1 Parameters for Simulation

Cell Radius	500 m
Number of Cellular Users	20
Number of D2D pairs	20
Number of Resource blocks	25
Carrier Frequency	2.3 GHz
Transmission Power P_{CU}	23 dBm
Transmission Power P_{D2D}	13 dBm
Transmission Bandwidth	20 MHz
Threshold $\delta_{CU} = \eta_{CU}$	25 dB
Threshold $\delta_{D2D} = \eta_{D2D}$	20 dB
D2D link Path Loss exponent	5 dB
Maximum D2D Pair Distance	30 m

In the simulation, a hexagonal cell is utilized to provide concurrent communication between cellular users and D2D couples, with the ability to share channels. The distribution of D2D users and cellular users is done in a random form. The count of cellular users has been set to 20, and the count of D2D pairs is also set to 20, with the count of Resource Blocks fixed at 25. There is one more underlying assumption that D2D communication cannot occur if the distance is greater than the maximum D2D pair distance, which happens to be more than 30m.

δCU and δD2D are the values of the threshold that help in determining the strength of the signal against the interference, which involves the D2D pair and Cellular user, which indicates the intensity of interference. It helps in evaluating whether a hyperedge can connect different nodes or not.

5.2. Performance Metrices

The net sum rate/throughput, also known as throughput, in D2D communication can be calculated using the following mathematical formula:

$$Net\ sum\ rate\ or\ Throughput = \sum_{i=1}^{N} log_2(1 + \frac{P_i G_{ii}}{I_i + \sigma^2}) \quad (14)$$

where,

- N is the count of D2D pairs Pi is the power transmitted by D2D pair i.
- Gii is the channel gain of D2D pair i.
- Ii is the interference experienced by D2D pair i, which includes interference from other D2D pairs and possibly from cellular users.
- σ^2 is the noise power

This formula considers the logarithmic representation of the SINR (Signal-to-Interference-plus-Noise Ratio) for every D2D pair and then sums up these values to obtain the net sum rate or throughput. Let T be the Net sum rate/Throughput, Ci denote the achievable rate for device i, and xi is a binary variable indicating whether device i is active or not, and A be the adjacency matrix of the hypergraph.

The achievable rate Ci can be calculated based on SINR for device i, and the goal is to maximize the Net sum rate/Throughput subject to certain constraints such as power constraints, interference constraints, and connectivity constraints.

The idea is to maximize

$$T = \sum_i C_i x_i \quad (15)$$

subject to

$$\sum_i P_i x_i \leq P_{max} \quad (16)$$

SINR constraints for each device i

$$A.x \geq 1 \quad (17)$$

Here, Pi represents the power allocated to the device I, Pmax is the maximum allowable transmit power, and the SINR constraints ensure that the received signal strength is sufficiently higher than interference and noise.

6. Results and Discussions

Channel capacity refers to the maximum data transmission capability of a communication channel. Cell capacity, on the other hand, is defined as the maximum data rate that can be supported in a cellular network within a specific cell. Throughput is defined as the actual rate at where data is successfully received or transmitted in a communication network. The term "bit/s/Hz" denotes the spectral efficiency or data rate efficiency, which signifies the quantity of information transmitted within a second relative to the available bandwidth. In contrast, "bit/s" represents the actual data rate or throughput, indicating the total number of bits transmitted or received per second.

6.1. Variation of Cellular users with the number of Resource Blocks

Fig. 5 in D2D communication, a Hypergraph is constructed to represent the relationship between cellular users and resource blocks. This graph helps visualize the allocation of resource blocks to different cellular users for D2D communication. In the graph, each cellular user is represented by a node, and the resource blocks are represented by edges connecting the nodes. The presence of an edge between a cellular user node and a resource block edge indicates that the corresponding resource block is allocated to that cellular user for D2D communication. By analyzing this graph, one can gain insights into the allocation of resource blocks among cellular users in the context of D2D communication. The graph can be further analyzed to optimize the allocation scheme, manage interference, and improve overall system performance.

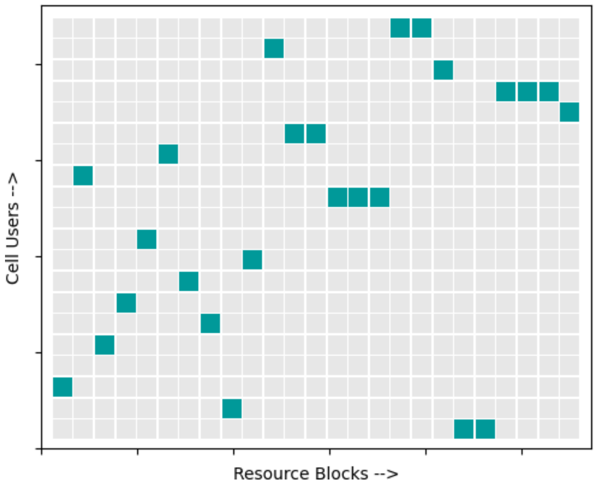


Figure 5. Variation of cellular users with the change in the number of Resource Blocks

6.2. Relationship between Rate bar-plot and the number of Resource Blocks

Figure 6 of D2D communication, the rate barplot represents the data rate or throughput achieved by D2D user pairs as a function of the number of allocated resource blocks. It provides a visual representation of how the data rate changes with the varying availability of resource blocks. The rate barplot consists of a set of bars, where each bar represents the achieved data rate for a specific number of resource blocks allocated to D2D user pairs. The height of each bar represents the data rate. A rate barplot helps in evaluating the efficiency and capacity of D2D communication in terms of achievable data rates. By analyzing the rate barplot, one can identify the optimal number of resource blocks that maximize the data rate or achieve a desired level of performance. Overall, the rate barplot provides valuable insights into the relationship between the number of resource blocks and the achieved data rate in D2D communication, facilitating better resource management and optimization in cellular networks.

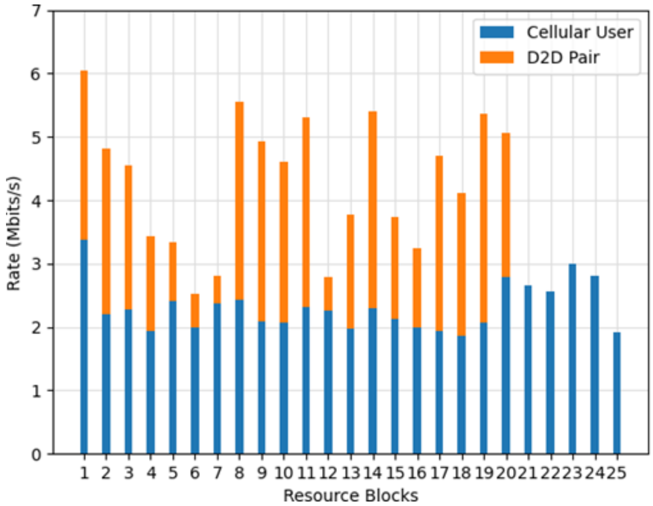


Figure 6 Variation of Rate with the Number of Resource Blocks

6.3. Variation of Throughput with the number of D2D pairs

In Fig. 7., researchers illustrate the throughput by adjusting the count of D2D pairs, while maintaining the maximum count of cellular users fixed at 20., the maximum value of the number of Resource Blocks to be 25, and the distance between each D2D pair to not exceeding beyond 30. It can be inferred that the Throughput increases as D2D pairs increase, that is, 4 Mbits/sec when D2D pairs are 4 and 40 Mbits/sec at 20 pairs, whereas the throughput remains constant, i.e. 61 Mbits/sec when only the cellular users are taken into account. But when the throughput is looked upon, keeping in consideration both the D2D pair as well as cellular users, it surpasses the value of throughput which was achieved for both D2D pairs as well as Cellular users at the individual level. The throughput increases progressively as the number of D2D pairings rises from 4 to 20. The data transfer rate rises from 70 to 105 megabits per second.

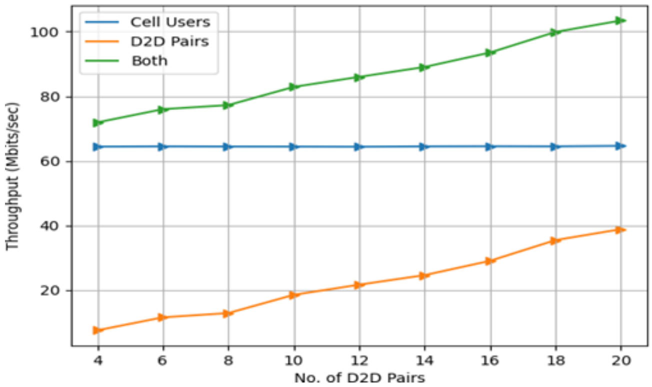


Figure 7 Variation of Throughput with respect to Number of D2D pairs

6.4. Variation of Throughput with Distance between the D2D users in a Pair in a Cellular Network

Figure 8 represents the variation of throughput by altering the distance between pairs of D2D users while keeping the maximum number of cellular users fixed at 20. The maximum value of the number of Resource Blocks is 25. At a pair distance of 20 m, throughput is 47 Mbits/sec, and at a pair distance of 100 m, throughput drops to 10 Mbits/sec. This suggests that the throughput value decreases with increasing pair distance. And achieved a consistent throughput of 61 Mbits/sec for Cell users exclusively. Throughput attains its maximum value in both cases, that is, in the case for D2D pairs alone and in the case where the throughput is measured for both D2D pairs and cellular users in a combined manner when the distance between D2D users in a pair is at 20 the throughput is 110 Mbits/sec. As the distance between D2D users in a pair increases, the throughput keeps on decreasing. It reaches 78 Mbits/sec when the pair distance is 100 m, as it is very difficult to establish a connection between D2D users in a pair. Even if the connection gets established, it becomes very difficult to maintain an efficient link all along in cellular communication.

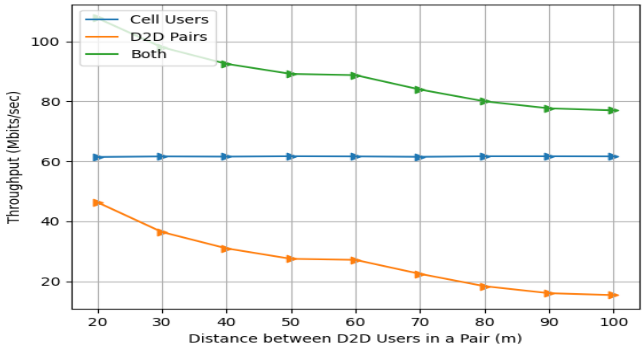


Figure 8 Variation of Throughput with respect to distance between D2D users in a pair

7. Conclusion And Future Scope

The study presents a novel hypergraph-based approach (HBT) for optimizing resource allocation in D2D communication within hexagonal cellular networks. By utilizing linear programming, the model effectively addresses resource allocation complexities, with computational complexity scaling proportionally to $O(A+B)^3$, where A denotes cellular users and B signifies D2D pairs. Through comprehensive analysis, the research uncovers critical insights into resource allocation dynamics, emphasizing the paramount importance of efficient schemes in enhancing system performance.

Visual representations aid in elucidating the intricate process of resource block allocation and its consequential effects on data transmission rates, thereby underscoring the significance of resource availability in dictating communication efficiency. Furthermore, the study delves into the nuances of throughput variations concerning changes in the number of D2D pairs and distances between them, elucidating the profound influence of spatial factors on communication effectiveness. Notably, the observed downward trend in throughput as the distance between D2D users increases highlights the inherent challenges in establishing and sustaining efficient connections within cellular environments, particularly in D2D scenarios. Further, the research suggests avenues for future exploration, including streamlining the HBT technique to reduce complexity, augmenting cell capacity to accommodate more users and D2D pairs, and enhancing channel capacity and spectral efficiency to bolster overall system performance. These endeavours hold promise for advancing the optimization of cellular networks, fostering improved resource utilization, and ultimately facilitating seamless communication experiences for users.

Author contributions

Arun Kumar Sharma: Conceptualization, Methodology, Software **Sonal Chawla:** Data curation, Writing-Original draft preparation, Software, Validation., Field study, Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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