Ain Shams Engineering Journal 12 (2021) 2385–2393

Contents lists available at ScienceDirect

Ain Shams Engineering Journal

journal homepage: www.sciencedirect.com

Game theoretic and non-game theoretic resource allocation approaches for D2D communication

Roopsi Rathi *, Neeraj Gupta

K.R. Mangalam University, Gurgaon 122103, India

ARTICLE INFO

Article history:
Received 30 May 2020
Revised 24 September 2020
Accepted 30 September 2020
Available online 4 March 2021

Keywords:
D2D communication
Resource allocation
Game theory

ABSTRACT

Device to Device communication involves communiqué between two devices without routing the packet through the cellular network. Ideally, the process involves reutilizations of the ideal resources of the cellular network for communication purpose. This ensures better management of radio spectrum and reduces communication delay. However, resource allocation has also been a major challenge because it contributes to various problems like interference, throughput issues and many other. A lot of work has been carried out in the recent past to address the above issue. The current paper reviews the work done in the area of resource allocation in the context of device to device communication. Among various mathematical tools available it was bring into being that game theory has been extensively used to address the problem. The main contribution of the paper, it provides the insight into the evolvement that has been made in the area of resource allocation and highlight various open issues that needs to be addressed.

1. Introduction

Due to a rise in the number of portable devices, there is a need for networks which can support a higher data rate. It is predicted that the data traffic will raise 1000 times within coming next 10 years [1,2]. This extensive need for channel capacity asks for spectral efficiency. Device-to-Device (D2D) communication technology allows the devices to connect with each other with or without the participation of network accessories like a base station or access point [3–5]. The communication between mobile users is initiated by either utilizing ideal cellular licensed spectrum or through dedicated unlicensed spectrum without traversing to the core network [6,7]. The close proximity between the different D2D users improves the reliability of users, offload traffic, system capacity, spectral efficiency, higher throughput, delayed time and energy efficiency within the wireless network which is not possible in traditional cellular communication [8,9]. Fig. 1 describes as a general scenario for the device to device (D2D) communication, it includes vehicle communication, relaying of data, content distribution in concerts, cellular video streaming. The next-generation communication technology, including 5G guarantees more devices to be associated more efficiently (see Tables 1 and 2).

By the assertion of spectrum sharing, the device to device correspondence can be organized into two types, i.e. in-band and out-band [10,11]. Fig. 2 illustrates the classification of D2D communication based on the spectrum. The in-band D2D recommends using the cellular spectrum for both cellular and D2D devices. The same radio resources of the cellular users can be reused by the D2D users in the underlay in-band D2D communication, due to which the problem of interference mitigation occurs between both D2D and cellular connections. In contrast, in overlay in-band D2D communication, assigns a dedicated portion of cellular resources to D2D devices and the rest of the spectrum resources used by cellular devices. In out-band D2D communication discard the interference problem between cellular and D2D devices by utilizing the unlicensed spectrum like Bluetooth and Wi-Fi direct [12,13]. The out-band D2D is considered as controlled and autonomous. In controlled out-band D2D, the radio interfaces are either handled by the access point or BS, whereas in autonomous out-band, these radio interfaces are handled through the users themselves.

The majority of literature work is contributed towards the underlay in-band D2D communication. D2D communication in

* Corresponding author.
E-mail address: profroopsi@outlook.com (R. Rathi).

Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.asej.2020.09.029
2090-4479/

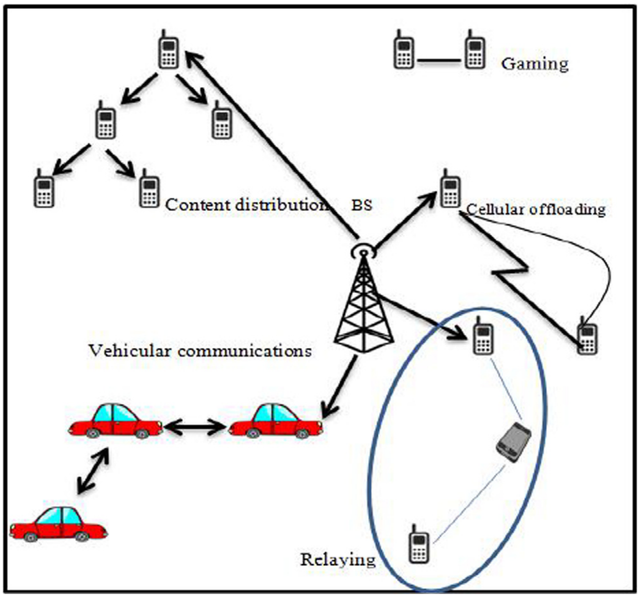

Fig. 1. A general scenario for the device to device (D2D) communication.

underlay cellular network shares the same radio resources with cellular users to improve the system capacity and throughput. This leads to the problem of resource allocation the same cellular resources to D2D users. In literature various solutions for allocating the resources efficiently has been proposed, including game theory, graph method, column generation method and heuristic optimization. It is observed that among all the mathematical tools game theory is prominently used because as a decision-making tool, it can easily analyze the complex interaction amongst interdependent rational entities/players and predicting their set of approaches [15,16].

The current paper provides a detailed survey concerning the resource allocation in the D2D communications. The Game Theory has been extensively used to address the problems concerning resource allocation. The main contribution of this article is it gives insight into literature concerning the application of game theory in resource allocation in context to D2D communication. The Section 2 of the paper concerns with the basis of D2D communication

Table 2
Represents the comparison of different game theoretic-based resource allocation algorithms for D2D communication.

Reference	Objective	Game theory model	Algorithm
[66,67]	Channel distribution for D2D users by reiterative best response algorithm	Stackelberg game theory (Leader and Follower)	Joint scheduling and resource allocation algorithm
[74,75]	Assigning the channel for D2D users by reiterative bid Algorithm	Auction game theory (Bidder and Auctioneer)	A reverse iterative combinatorial auction (RICA) algorithm
[64]	Power allocation in D2D communication for all users by reiterative bid algorithm	Non-cooperative static Game	Joint power allocation for D2D
[84]	Power and route algorithm using dynamic scheduling	Coalitional graph game	Myopic dynamic algorithm
[39]	Channel assignment and power allocation sub- problem	Nash bargaining game	Optimal resource allocation Algorithm
[70]	Resolve the selfish behaviour of UE/BS and acquired the equilibrium	Nash Equilibrium and game theory	Linear search Algorithm for UQBS System
[33]	Efficient allocation of resources by max-coalition	Coalition formation game approach	Merge and split based Algorithm
[85]	Power allocation and rate enhancement of relationships between device users	Matching Theory social	Utility function maximization (UFM) D2D links redistributive algorithm

Table 1
Represents the comparison of different non-game theory-based resource allocation algorithms used for D2D communication.

Reference	Objective	Algorithm used	Description
[49]	Maximize throughput. Optimal Spectrum utilization. More D2D users get into the communication.	Greedy heuristic Algorithm	Common resource blocks (RBs) are formed as a Base Station assigns the unassigned RBs of CUEs to the DUEs.
[56]	Intra and inter-cluster Interference management. Optimizing the resource allocation and power for all the user and accomplishing Necessary transmission rate.	Power control and Resource allocation Algorithm	Provides required QoS. Cluster based interference and Power management. Minimum energy consumption in high rate services.
[57]	Energy Efficient resource allocation and distribution in D2D communication	Heuristic Algorithm and nonlinear Programming	Optimal allocation of resources. Provides maximum throughput Minimizing the transmitted power of DUEs.
[58]	Maximize DUE to pair with a QoS constraint	CAC scheme	Call admission control works on a first come first serve basis. Maximum D2D pairs and its average transmission power are analyzed with full CSI. Maximum transmit power constraint.
[47,48,59]	Maximizing the system capability with the presumption of higher DUs as compared to CUs.	Colouring algorithm which allocates resource blocks to each CU and DU	DUs give inclination over CU. For Resource Block allocation.
[55]	Better system performance may be achieved. Minimize CU interference.	Heuristic Optimization resource Allocation (HORA) Algorithm	Guarantees the channel quality to D2D users. The channel quality of DUs and transmission requirements of CUs measured in parallel.
[43]	Better spectrum efficiency and throughput. Achievable access pattern for joint power control and RB scheduling.	Column generation approach, branch-bound algorithm	Maximum power constraint. Minimum transmission length of time slots for D2D connections by considering resource block scheduling.
[60]	Maximizing weighted sum throughput for D2D users and minimizing the rate for cellular users.	Iterative resource allocation algorithm	Iterative approach is based on two segments, i.e. power sub channel and bandwidth sub channel assignment.
[28]	Optimization of data sum rate, which considers resource allocation, it also observes energy/ transmit power	Resource sharing in cellular and D2D communication	Data transmission in non-orthogonal, orthogonal, reuse cellular resource modes are developed to achieve maximum data sum rate
[54]	Better fairness and system throughput	Adaptive time division (ATD) scheduling algorithm	By using Proportional fairness scheduler, D2D users reuse cellular resources for a time slot.

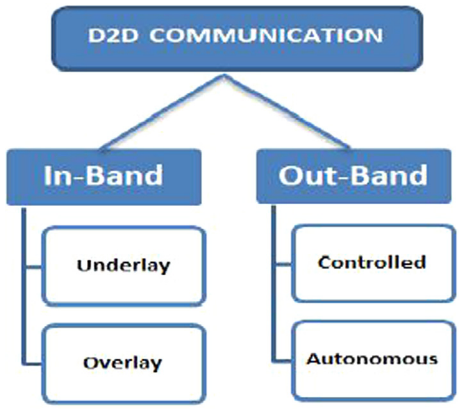

Fig. 2. D2D communication based on spectrum sharing.

and various parameters on which such networks can be classified. Section 3 presents the work done in the area of the resource allocation and subsequent work done addressing this issue. The application of Game theory in resource allocation and the consequent literature is summarized in Section 4. The Section 5 concludes with the significant pointer to the solutions that are available and future work that can be pursued to enhance the existing solutions.

2. Background

2.1. D2D basics and its classification

The Device to Device communication cab be broadly classified into three categories: D2D link management, scenarios, and D2D resource management. The Fig. 3 illustrates the classified approaches with further sub classifications.

2.1.1. D2D link management

The D2D link management is concerned with discovery of the nodes and control of D2D communication. The D2D link management can be classified by a few aspects as follows:

D2D Discovery. The objective of the D2D discovery process is to discover the presence of a device that would probably communicate directly [10]. D2D discovery or identification is done in two ways, i.e. Prior method, and Posterior method. In Prior method, D2D communication happens after the devices in a pair are found. In Posterior method, communication among the devices already established and then the devices in a pair are established [9,17,18].

D2D Control. D2D control deals with the management and supervision of D2D communication. In full control, D2D communication is fully controlled by the system [13]. The network is responsible for the D2D identification process during D2D discovery. The advantage of this method is that the network can efficiently coordinate between D2D and cellular communication. This ensures that the network can avoid or reduce interference among users and radio spectrum can be efficiently allocated between D2D user equipment's (DUEs) and Cellular user equipment's (CUEs) [19]. In loose control, devices can autonomously connect. The involvement of the network is very limited and is responsible only for authentication of the D2D discovery and identification. The advantages of this approach are that process is freed from signaling overhead. As suggested in [14] the loosely controlled D2D is usually deployed in the unlicensed spectrum (Wi-Fi or Bluetooth). In hybrid D2D control approach, network is responsible for the D2D authentication process [20]. In this, the

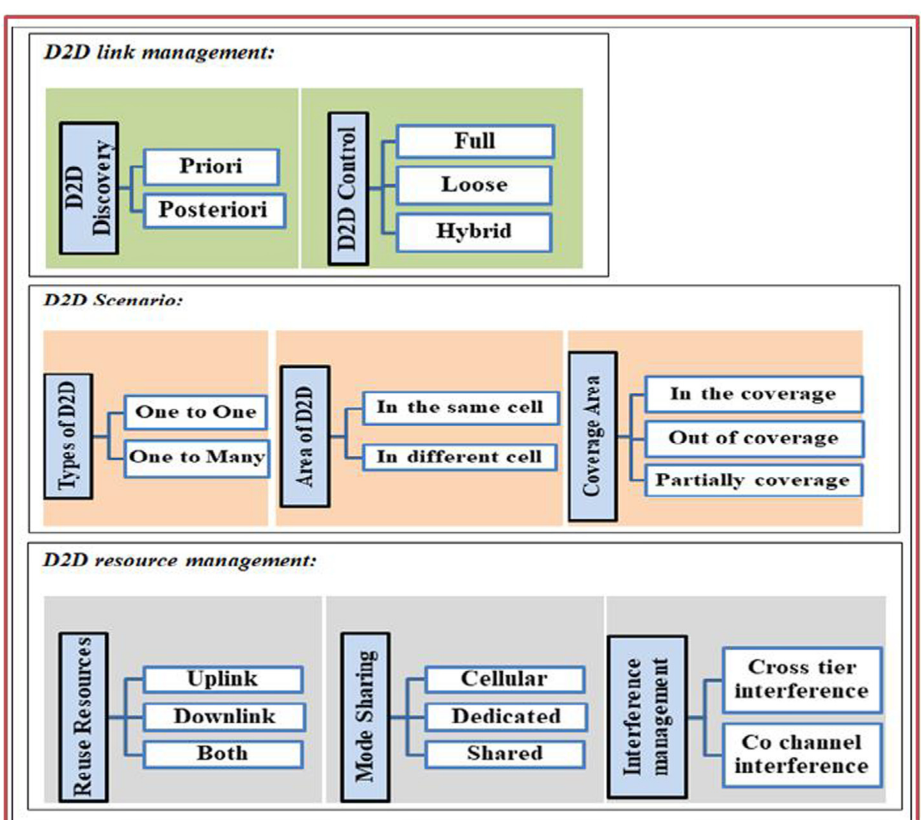

Fig. 3. Classification of D2D communication.

DUEs can manage resource allocation and power control autonomously.

2.1.2. D2D scenarios

This section emphasizes individual scenarios that might be taken into reflection for D2D communication. The different scenarios that are assumed by authors while contributing towards the solution can be broadly categorized into three categories.

Types of D2D communication. This scenario explicitly state how many devices are involved in D2D communication. Direct communication between two devices constitutes one D2D pair and commonly referred to as one to one communication. When the device transmits data to several devices the network can be referred to as one to many communication in the network.

Area of D2D communication. The components distinguishing whether both communicating devices are assisted by the same cell or not. In a single-cell scenario, the D2D users, which create a D2D pair are linked to the same evolved node base station (eNB). On the other hand in the different cell scenario, the D2D users, which belong to the same D2D pair are linked to different evolved node base stations (eNBs).

Coverage area. This segment differentiates whether the D2D pairs are under the coverage range of the cellular network. When both D2D users falls in the range of the cellular network the scenario is called the coverage area. When one D2D user of D2D pair is in the coverage range and another one is out of coverage range of the cellular network is called partially coverage area. Finally, when both D2D users are outside the cellular network is called out of coverage area, this aspect is mainly considered as public safety cases [21].

2.1.3. D2D resource management

From the resource management point of view, D2D can be grouped based on the following parameters: reuse of resources, mode sharing, and interference management.

Reuse of resources. In the D2D communication, resources initially allocated for the uplink (UL), the downlink (DL) or both and these resources can be reused for D2D direct communication. In most of the available literature, mostly uplink resources of the cellular network are used [22–25]. The resources can be retrieved either in the time division or frequency division duplexing mode [26].

Mode of sharing. This segment identifies whether D2D communication users use the same resources as cellular communication or they allocate the dedicated resources either from cellular spectrum or unlicensed spectrum. There are major classification categories: Cellular mode, dedicated mode, and shared mode [27,28]. In cellular mode, as traditional cellular communication DUEs communicates via the base station and no direct communication takes place between DUEs. The advantage of this mode is that interference can be easily managed. In dedicated mode, there is direct communication between two DUEs without the involvement of the base station. Though, the base station has to dedicate resources for the DUEs and CUEs. The advantage of dedicated mode such the BS doesn't need to handle the interference between different UEs. In sharing mode, DUEs and CUEs use same radio resources which occurs sophisticated interference [29,30].

Interference management. The interference will always occur when the same resources are shared between DUEs and CUEs. The interference between affected nodes (i.e. DUEs, CUEs, eNB) depend on the mode of communication and the resources used (uplink/downlink) for D2D communication. The interference in the system can lie between two tiers: cross-tier interference and co-channel interference in term of who's the interrupter and who's the victim of the interference. In cross-tier interference, the D2D transmitter user (an aggressor) interrupts the cellular user (a victim) and vice versa. In co-channel interference, the D2D transmitter user interrupts co-channel D2D user. It affects the system capacity and efficiency. According to literature survey authors pro-

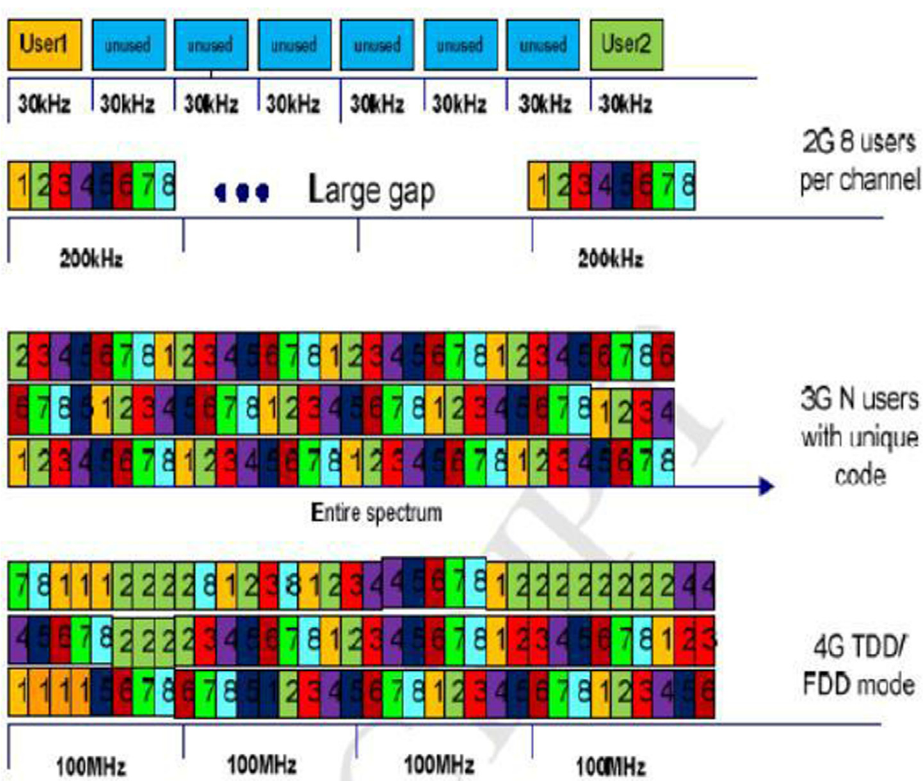

Fig. 4. Allocation of resources from 1G to 4G [40].

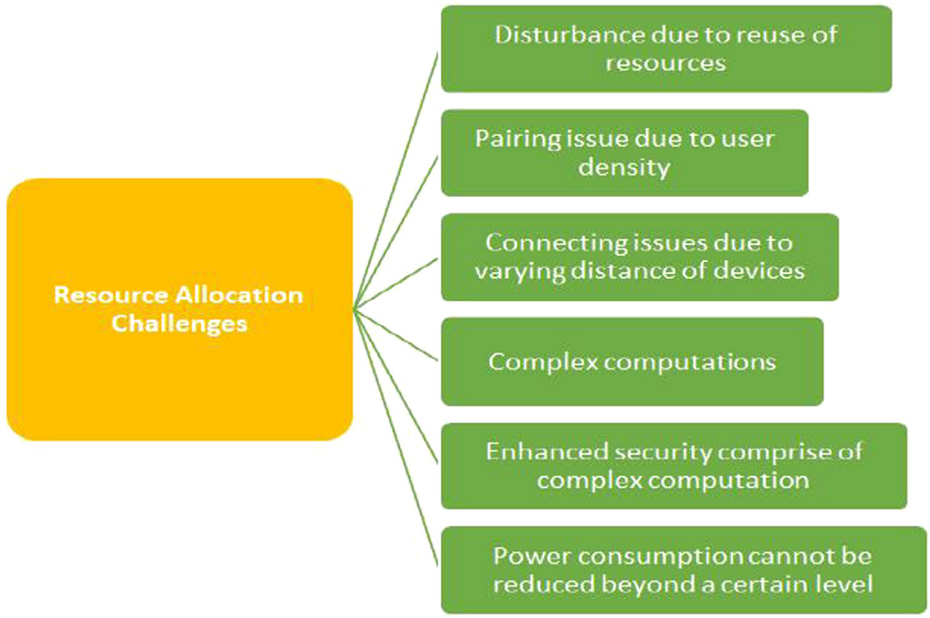

Fig. 5. Open issues that need to be addressed during resource allocation.

posed some techniques (i.e. Interference cancellation, randomization, avoidance) to overcome / avoid the interference[31,32].

3. Resource allocation

In D2D communication the basic resource for communication between two devices is the radio spectrum. The band of the frequencies allocated to the particular cellular cell along with the multiplexing technique defines the spectral efficiency that can be achieved. The efficiency of communication between the devices is typically measured with the rate of data it transfers and capacity of the overall system to accommodate a maximum number of users [36–38]. From the available literature, it can be easily visualized how the process of software changes from very low data transfer speed to high-speed processors.

Fig. 4 exemplifies the resource allocation in terms of channel bandwidth and multiplexing from the 1st Generation to the 4th Generation. In 5G communication technology provision has been made to decrease latency, maximize data rate, and provide channel state information depending on the type of service that users have demanded.

In the close proximity, devices begin communicating among themselves without the need of base stations. Multiple D2D users can reuse resource blocks (RBs) which are lying idle to cellular users. The reuse of the resource can cause interference between the transmission of the cellular users and D2D user if used in a non-deterministic way. Thus, it is necessary to make sure that resources are allocated with the utmost care. Following factors need to be considered for resource allocation among D2D UE's and cellular UE's [40]:

1. The distance among D2D Tx (transmitter) and D2D Rx (receiver) along with the radius of D2D UEs from the base station.
2. BS can suffer interference from D2D Tx in uplink and from cellular UE to D2D UE or D2D UE to cellular UE in the case of the downlink.
3. The pair up of cellular UE and D2D UE for reusing alike resources. Mode of resource allocation for D2D devices.

Whenever the D2D users need to communicate the devices need to sense the network environment to ensure that the cellular resources are not utilized to avoid interference with cellular UEs [27].

The Fig. 5 shows the open issues that need to be addressed concerning resource allocation are: BS assigns resources to the cellular users and these resources are reused by D2D users. Due to reuse of the same resources between different users the disturbance or interference occurs within the network which affects the system performance. The number of D2D pairs reuses cellular user's resources throughout the network, each D2D pair requires different transmit power so there is a pairing issue due to user's density. Also, in order to transmit data between D2D pairs each D2D user should be under the close proximity and for the reuse of resources the cellular and D2D pairs should be in a specific range. Since the transmission and reuse of resources depending on the distance between devices, therefore the connecting issue occurs due to the varying distance of devices. As the same resources being reused between cellular and D2D users which creates a security issue and due to the same reason power and energy consumption cannot be reduced beyond a certain level within the network.

3.1. Modes of resource allocation

The resource can be allocated either in a distributed way or in a centralized manner to the D2D users underlying in the particular cellular system cell.

Centralized approach. In a centralized approach, BS (base station) performs as a supervisor and allocates the resources to cellular and D2D users to accomplish the system goal. The majority of the existing network grids are using a centralized resource allocation approach, the resources are given by base stations to D2D and cellular networks. This approach is not appropriate for large networks because of high insolubility [41].

Distributed approach. In distributed resource allocation all the devices contend to accomplish the individual objective. An individual objective accomplishment varies as the interference from the cellular and D2D users. In this mode [42], each D2D link has to be fully aligned with the network environment so that utilization of resource can be optimally achieved without having any interference with the cellular users. The modes could be used partially as a message-passing or fully distributes model. On the other hand, the distributed resource allocation mode reduces the signal overhead on the base station (BS). This model has also encountered issues like high message exchanges and low distributiveness [43–45].

3.2. Techniques of resource allocation in D2D

There are various mathematical models that contributed to literature to address the challenges posed by resource sharing in D2D communications. The current section summarizes, various non-game theory-based resource allocation schemes as proposed in the literature. The authors of [46] proposed a graph-based resource allocation approach, a graph G(V, E) in which vertex indicates a D2D or cellular link and each edge connects two vertices. They frame the optimum resource allocation as NP-hard non-linear problem. The simulation outcomes show that this graph-based approach achieves an efficient throughput with low computational complexity. In [47,48] the graph coloring scheme, assign a color to each vertex. Here the two vertices with same assigned color show their corresponding D2D pair and it makes so-called D2D reuse group. The authors address the problem of allocating the accessible resource block to individual D2D reuse groups either by fair /opportunistic assignment. As a result, the total throughput is improved with satisfying the QoS.

In [49,50] authors consider uplink (UL) transmission in a single cell network. The objective is to accomplish the mitigating interference, high-level transmission power for D2D pairs and increase overall system throughput. The authors' design a greedy heuristic algorithm which performs the channel allocation and power assignment. The first segment of the work deals with the group the D2D users who reuse the same resource blocks. The second segment addresses the power control procedure is used to restrict energy consumption. The simulation consequence was taken according to the realistic environment wherever a large no. of D2D users are considered. In [34,35] authors proposed Hungarian algorithm as an optimal solution for NP hard problem. This approach improves the system capacity and satisfying the required QoS by minimizing the interference between D2D links. Xiaoshuai et. al [14] proposed a joint power and resource scheduling (JPRS) approach, it works for long time slots which offers a realistic environment for the D2D communication system. This proportional scheduling helps to achieve an extensive enhancement in the system fairness and system throughput.

Phunchongharn et al. [43] proposed column generation approach, in which optimization problem is disintegrated into master and pricing obstacle and then solve it iteratively. For the optimized solution, the master obstacle obtains the dual variable and these dual variable moves onwards to the pricing obstacle. The pricing obstacle is used to recover the new column variable as a feasible access pattern. The master problem can be resolved by the branch-bound method [51,52] and pricing problem was addresses using the greedy algorithm. The main objective is to achieve better spectrum efficiency by minimum transmission length of time slots for D2D connections by considering resource block scheduling [53].

In [54] the authors propose an Adaptive time division (ATD) scheduling system, in which D2D users are allocated the time slots by using proportional fairness scheduler to ensure fairness and improved throughput. The authors of [55] proposed Heuristic Optimization Resource Allocation (HORA) algorithm, which ensures that the sharing of cellular resources is more effective with minimum interference. It guarantees the channel quality to D2D users. Consequently, overall better system performance may be achieved. The iterative resource allocation algorithm considers two important parameters, i.e., Data rate and power consumption. The resources are allocated to the users having better optimization of data rate and lesser power consumption for each iteration executed [38].

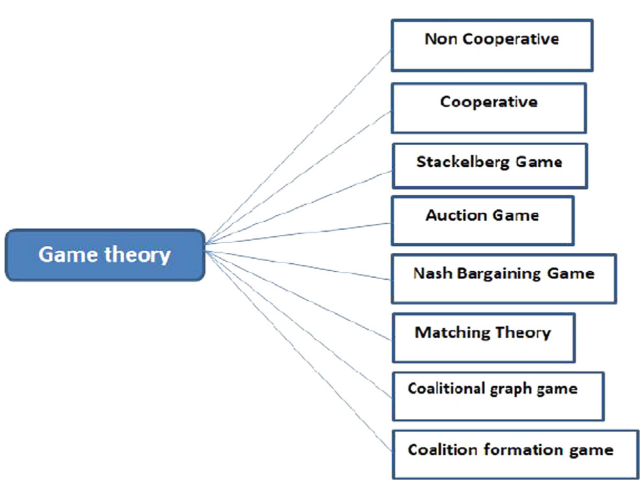

Fig. 6. Types of Game theory model.

4. Game-theoretic model for resource allocation

In context of device to device communication the game theory has proved be effective tool to address the challenges posed for resource allocation. The importance of this tool increase particularly when the D2D nodes utilizes the cellular spectrum for communication. It becomes imperative that any communication between DUEs should not interfere with existing communication by CUE's or other devices present in its vicinity. Game theory is a mathematical model of scientific devices which analyze the behavior/actions of individual or number of players [15,16]. In other words, it is used as a decision-making tool for rational players. The game theory has three fundamental components, i.e. players, strategies/actions and the payoff or utility functions [63]. The players are nodes or users which takes decisions in the game. The strategies are the actions which are chosen by the players. The payoff or utility function shows the outcome of every player in the game. The game theory model was developed to address the problems in area of economics, but the theory has been successfully applied in wireless networks, especially for the resource allocation problems in D2D communication [61,62]. Fig. 6 illustrates some different game theoretic models such as non- cooperative, cooperative, Stackelberg game, auction based, and Nash bargaining etc.

4.1. Different game theory models used for analysis of resource allocation in D2D communication

Below we discuss techniques from game theory that have been utilized to address the resource allocation problem. The solution discussed results in the higher gain as compared to a simple interference reduction and/ or other avoidance methods. However, the mathematical complexity of the solution is increased as compared to other techniques.

Non-Cooperative and Co-operative game theory. Non-Cooperative game theory, each user has to choose their independent strategy/decision that maximizes their payoff. Each user cares about their payoff, which creates interference in the network. In this approach, users don't cooperate with other users. In cooperative game theory, mobile users can bond between participated users and they have mutual benefits. As the name suggests users coordinate for choosing their strategies because the total payoff is being divided between them [63–65].

Stackelberg Game theory. Stackelberg game is a hierarchical design system which is based on leader and follower. The leader is cellular users and followers are D2D users. The leader act first, then the follower observes the leader's behavior and decides their strategy [72,73,81]. The leader owns the resources and it can charge the leader some fictitious money for accessing the resources/channels. It enhances the utility function of the leader as well as the follower. The pairing of leader and follower depends on the network environment such as one leader-one follower, multiple leaders- one follower, and one leader- multiple followers [68,69,71]. This game theory approach has used to evaluate the optimal strategy for users, optimal price for leaders, and optimal power for followers, for proper allocation of resources which help to improve system throughput and efficiency [77–80].

Auction Game theory. It is based on the bidder (cellular users) and the auctioneer (D2D users) [82]. Xu et al. proposed an Reverse Iterative Combinational Auction (RICA) which allows an agent (the bidder) to fix bids on groupings of resources, called "packages", rather than a distinct resource block (RB) [74,75]. Some auctions include double auction, share auction, and VCG auction [76]. In [83], the authors proposed a second price auction, victor users have to pay the second-topmost bid. By choosing the optimal strategies users can achieve better throughput and proper utilization of the available resources.

Collision graph game theory. In [84] the author proposed the myopic dynamic algorithm which is based on the collision graph game approach in which the utility function of the players can be represented by specific/direct graph. Here, vertexes are BS and edges involve BS to D2D links.

Wang et al. [85] proposed resource allocation scheme with matching dynamic game theory which shows a better social relationship of mobile users. This approach is formulated to optimize the transmission data rate for achieving maximum utility in the network [86–89].

Coalition formation game. In this approach, players are D2D users and a coalition signifies a set of players to gain better payoff. In [33] author proposed merge and split algorithm which has two following operations:

Merge: multiple coalitions are merging when mutual utility endures.
Split: A coalition can be split whenever this splitting provides better utility.

Nash Bargaining. The Nash bargaining game model is part of cooperative game theory. In [39] authors proposed a mechanism for resource allocation using the Nash bargaining approach to maximize throughput and utility function of both cellular and D2D users.

5. Conclusion

This paper provides a detailed survey of the existing literature on D2D communication. We have categorized the D2D into three broad categories based on the link management, the position of D2D nodes in the cellular network and resource management. It is observed that the resource allocation problem is more severe in the underlay network in comparison to overlay networks. The major problems in resource allocation are communication between devices that depends upon user density and distance between two nodes. This can lead to the problem of managing the power control for effective communication. Spectral efficiency is another key area that needs to be addressed for better re-use of D2D pairs. Various solutions have been proposed in the literature to address the issue. It is concluded that game theory provides the necessary tools and techniques to effectively address the problem. Various game theory approaches have been proposed and discussed in the paper for efficient spectral re-use and better power control so as to reduce the interference in nearby nodes. As a future work the machine learning algorithm along with game theory can be utilized to efficiently manage the system. Most of the current work assumes homogeneous conditions to simply the mathematical expression. It is important to consider the heterogeneous condition so match the realistic approach.

References

[1] Zhou Z, Ma G, Xu C, Chang Z. A Game-Theoretical approach for green power allocation in energy-harvesting device-to-device communications. In: 2016 IEEE 83rd Vehicular Technology Conference (VTC Spring), Nanjing; 2016, pp. 1–5. doi: 10.1109/VTCSpring.2016.7504069.
[2] Gandotra P, Jha RK, Jain S. Green communication in next generation cellular networks: a survey. IEEE Access 2017;5:11727–58. doi: https://doi.org/10.1109/ACCESS.2017.2711784.
[3] Tehrani MN, Uysal M, Yanikomeroglu H. Device-to-device communication in 5G cellular networks: challenges, solutions, and future directions. IEEE Commun Mag 2014;52(5):86–92. doi: https://doi.org/10.1109/MCOM.2014.6815897.
[4] Gupta A, Jha RK. A survey of 5G network: architecture and emerging technologies. IEEE Access 2015;3:1206–32. doi: https://doi.org/10.1109/ACCESS.2015.2461602.
[5] Doppler K, Rinne M, Wijting C, Ribeiro CB, Hugl K. Device-to-device communication as an underlay to LTE-advanced networks. IEEE Commun Mag 2009;47(12):42–9. doi: https://doi.org/10.1109/MCOM.2009.5350367.
[6] Asadi A, Wang Q, Mancuso V. A survey on device-to-device communication in cellular networks. IEEE Commun Surv Tutorials 2014;16(4):1801–19. doi: https://doi.org/10.1109/COMST.2014.2319555.
[7] Asadi A, Mancuso V. Network-assisted outband D2D-clustering in 5G cellular networks: theory and practice. IEEE Trans Mobile Comput 2017;16 (8):2246–59. doi: https://doi.org/10.1109/TMC.2016.2621041.
[8] Zhou Z, Dong M, Ota K, Wu J, Sato T. Energy efficiency and spectral efficiency tradeoff in device-to-device (D2D) communications. IEEE Wireless Commun Lett 2014;3(5):485–8. doi: https://doi.org/10.1109/LWC.2014.2337295.
[9] Fodor G et al. Design aspects of network assisted device-to-device communications. IEEE Commun Mag 2012;50(3):170–7. doi: https://doi.org/10.1109/MCOM.2012.6163598.
[10] Gandotra P, Jha RK. Device-to-device communication in cellular networks: a survey. J Netw Comput Appl 2016;71:99–117. doi: https://doi.org/10.1016/j.jnca.2016.06.004.
[11] Abrardo A, Moretti M. Distributed power allocation for D2D communications underlaying/overlaying OFDMA cellular networks. IEEE Trans Wireless Commun 2017;16(3):1466–79. doi: https://doi.org/10.1109/TWC.2016.2646360.
[12] Zhang H, Liao Y, Song L. D2D-U: device-to-device communications in unlicensed bands for 5G system. IEEE Trans Wireless Commun 2017;16 (6):3507–19. doi: https://doi.org/10.1109/TWC.2017.2683479.
[13] Lei L, Zhong Z, Lin C, Shen X. Operator controlled device-to-device communications in LTE-advanced networks. IEEE Wirel Commun 2012;19 (3):96–104. doi: https://doi.org/10.1109/MWC.2012.6231164.
[14] Li X, Shankaran R, Orgun MA, Fang G, Xu Y. Resource allocation for underlay D2D communication with proportional fairness. IEEE Trans Veh Technol 2018;67(7):6244–58. doi: https://doi.org/10.1109/TVT.2018.2817613.
[15] Han Z, Niyato D, Saad W, Başar T, Hjørungnes A. Game theory in wireless and communication networks: theory, models, and applications. Cambridge: Cambridge University Press; 2011. doi:10.1017/CBO9780511895043.
[16] Song L, Niyato D, Han Z, Hossain E. Game-theoretic resource allocation methods for device-to-device communication. IEEE Wirel Commun 2014;21 (3):136–44. doi: https://doi.org/10.1109/MWC.2014.6845058.
[17] Mumtaz S, Lundqvist H, Huq KMS, Rodriguez J, Radwan A. Smart direct-LTE communication: an energy saving perspective. Ad Hoc Netw 2014;13:296–311. doi: https://doi.org/10.1016/j.adhoc.2013.08.008. ISSN 1570-8705.
[18] Yang MJ, Lim SY, Park HJ, Park NH. Solving the data overload: Device-to-device bearer control architecture for cellular data offloading. IEEE Veh Technol Mag 2013;8(1):31–9. doi: https://doi.org/10.1109/MVT.2012.2234052.
[19] Xiao X, Tao X, Lu J. A QoS-aware power optimization scheme in OFDMA systems with integrated device-to-device (D2D) communications. In: 2011 IEEE Vehicular Technology Conference (VTC Fall), San Francisco, CA; 2011, p. 1–5. doi: 10.1109/VETECF.2011.6093182.

[20] Chen T, Charbit G, Hakola S. Time hopping for device-to-device communication in LTE cellular system. In: 2010 IEEE Wireless Communication and Networking Conference, Sydney, NSW; 2010, p. 1–6. doi: 10.1109/WCNC.2010.5506254.
[21] Mach P, Becvar Z, Vanek T. In-Band device-to-device communication in OFDMA cellular networks: a survey and challenges. IEEE Commun Surv Tutorials 2015;17(4):1885–922. doi: https://doi.org/10.1109/COMST.2015.2447036.
[22] Xu S, Wang H, Chen T, Huang Q, Peng T. Effective interference cancellation scheme for device-to-device communication underlaying cellular networks. In: 2010 IEEE 72nd Vehicular Technology Conference - Fall, Ottawa, ON; 2010, pp. 1–5. doi: 10.1109/VETECF.2010.5594601.
[23] Xu S, Wang H, Chen T. Effective interference cancellation mechanisms for D2D communication in multi-cell cellular networks. In: 2012 IEEE 75th Vehicular Technology Conference (VTC Spring), Yokohama; 2012, p. 1–5. doi: 10.1109/VETECS.2012.6240205.
[24] Min H, Lee J, Park S, Hong D. Capacity enhancement using an interference limited area for device-to-device uplink underlaying cellular networks. IEEE Trans Wireless Commun 2011;10(12):3995–4000. doi: https://doi.org/10.1109/TWC.2011.100611.101684.
[25] Pei Y, Liang Y. Resource allocation for device-to-device communications overlaying two-way cellular networks. IEEE Trans Wireless Commun 2013;12(7):3611–21. doi: https://doi.org/10.1109/TWC.2013.061713.121956.
[26] 3GPP TS 36.300: Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 11), V11.7.0; Sep.2013.
[27] Wei L, Hu RQ, Qian Y, Wu G. Enable device-to-device communications underlaying cellular networks: challenges and research aspects. IEEE Commun Mag 2014;52(6):90–6. doi: https://doi.org/10.1109/MCOM.2014.6829950.
[28] Yu C, Doppler K, Ribeiro CB, Tirkkonen O. Resource sharing optimization for device-to-device communication underlaying cellular networks. IEEE Trans Wireless Commun 2011;10(8):2752–63. doi: https://doi.org/10.1109/TWC.2011.060811.102120.
[29] Doppler K, Yu C, Ribeiro CB, Jänis P. Mode selection for device-to-device communication underlaying an LTE-advanced network. In: 2010 IEEE Wireless Communication and Networking Conference, Sydney, NSW; 2010, pp. 1–6. doi: 10.1109/WCNC.2010.5506248.
[30] Yu CH, Tirkkonen O, Doppler K, Ribeiro C. Power optimization of device-to-device communication underlaying cellular communication. In: 2009 IEEE International Conference on Communications, Dresden; 2009, pp. 1–5. doi: 10.1109/ICC.2009.5199353.
[31] Nam W, Bai D, Lee J, Kang I. Advanced interference management for 5G cellular networks. IEEE Commun Mag 2014;52(5):52–60. doi: https://doi.org/10.1109/MCOM.2014.6815893.
[32] Shalmashi S, Miao G, Ben Slimane S. Interference management for multiple device-to-device communications underlaying cellular networks. In: 2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), London; 2013, p. 223–27. doi: 10.1109/PIMRC.2013.6666135.
[33] Wang T, Song L, Han Z. Popular content distribution in CR-VANETs with joint spectrum sensing and channel access. EAI Endorsed Trans Wireless Spectrum 2014;1(2). doi: https://doi.org/10.4108/ws.1.2.e4.
[34] Han T, Yin R, Xu Y, Yu G. Uplink channel reusing selection optimization for Device-to-Device communication underlaying cellular networks. In: 2012 IEEE 23rd International Symposium on Personal, Indoor and Mobile Radio Communications - (PIMRC), Sydney, NSW; 2012, p. 559–64. doi: 10.1109/PIMRC.2012.6362848.
[35] Kai C, Xu L, Zhang J, Peng M. Joint uplink and downlink resource allocation for D2D communication underlying cellular networks. In: 2018 10th International Conference on Wireless Communications and Signal Processing (WCSP), Hangzhou; 2018, p. 1–6. doi: 10.1109/WCSP.2018.8555896.
[36] Wang F, Xu C, Song L, Han Z. Energy-efficient resource allocation for device-to-device underlay communication. IEEE Trans Wireless Commun 2015;14(4):2082–92. doi: https://doi.org/10.1109/TWC.2014.2379653.
[37] Shams F, Bacci G, Luise M. A survey on resource allocation techniques in OFDM (A) networks. Comput Netw 2014;65:129–50. doi: https://doi.org/10.1016/j.comnet.2014.03.017. ISSN 1389-1286.
[38] Pischella M, Zakaria R, Le Ruyet D. Resource block-level power allocation in asynchronous multi-carrier D2D communications. IEEE Commun Lett 2017;21(4):813–6. doi: https://doi.org/10.1109/LCOMM.2016.2640273.
[39] Liu T, Wang G. Resource allocation for device-to-device communications as an underlay using nash bargaining game theory. In: International Conference on Information and Communication Technology Convergence (ICTC). p. 366–71.
[40] Pedhadiya MK, Jha RK, Bhatt HG. Device to device communication: a survey. J Netw Comput Appl 2019;129:71–89. doi: https://doi.org/10.1016/j.jnca.2018.10.012. ISSN 1084-8045.
[41] Zhou Y, Fang Y, Zhang Y. Securing wireless sensor networks: a survey. IEEE Commun Surv Tutorials 2008;10(3):6–28. doi: https://doi.org/10.1109/COMST.2008.4625802.
[42] Feng D, Lu L, Yuan-Wu Y, Li GY, Li S, Feng G. Device-to-device communications in cellular networks. IEEE Commun Mag 2014;52(4):49–55. doi: https://doi.org/10.1109/MCOM.2014.6807946.
[43] Phunchongharn P, Hossain E, Kim DI. Resource allocation for device-to-device communications underlaying LTE-advanced networks. IEEE Wirel Commun 2013;20(4):91–100. doi: https://doi.org/10.1109/MWC.2013.6590055.
[44] Ye Q, Al-Shalash M, Caramanis C, Andrews JG. Distributed resource allocation in device-to-device enhanced cellular networks. IEEE Trans Commun 2015;63(2):441–54. doi: https://doi.org/10.1109/TCOMM.2014.2386874.
[45] Shah ST, Hasan SF, Seet B-C, Chung PHJ. Device-to-device communications: a contemporary survey. Wireless Pers Commun 2017:1247–84. doi: https://doi.org/10.1007/s11277-017-4918-4.
[46] Zhang Rongqing, Cheng Xiang, Yang Liuqing, Jiao Bingli. Interference-aware graph based resource sharing for device-to-device communications underlaying cellular networks. In: 2013 IEEE Wireless Communications and Networking Conference (WCNC), Shanghai; 2013, p. 140–45. doi: 10.1109/WCNC.2013.6554553.
[47] Tsolkas D, Liotou E, Passas N, Merakos L. A graph-coloring secondary resource allocation for D2D communications in LTE networks. In: 2012 IEEE 17th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD), Barcelona; 2012, p. 56–60. doi: 10.1109/CAMAD.2012.6335378.
[48] Hajiaghayi M, Wijting C, Ribeiro C, et al. Efficient and practical resource block allocation for LTE-based D2D network via graph coloring. Wireless Netw 2014;20:611–24. doi: https://doi.org/10.1007/s11276-013-0626-5.
[49] Guizani Z, Hamdi N. Spectrum resource block reuse and power assignment for D2D communications underlay 5G uplink network. In: 2016 24th International Conference on Software, Telecommunications and Computer Networks (SoftCOM), Split; 2016, pp. 1–5. doi: 10.1109/SOFTCOM.2016.7772182.
[50] Zulhasnine M, Huang C, Srinivasan A. Efficient resource allocation for device-to-device communication underlaying LTE network. In: 2010 IEEE 6th International Conference on Wireless and Mobile Computing, Networking and Communications, Niagara Falls, ON; 2010, p. 368–75. doi: 10.1109/WIMOB.2010.5645039.
[51] Aida K, Natsume W, Futakata Y. Distributed computing with hierarchical master-worker paradigm for parallel branch and bound algorithm. In: CCGrid 2003. 3rd IEEE/ACM International Symposium on Cluster Computing and the Grid, 2003. Proceedings., Tokyo, Japan; 2003, p. 156–63. doi: 10.1109/CCGRID.2003.1199364.
[52] Lawler EL, Wood DE. Branch-and-bound methods: a survey. Oper Res 1966;14(4). doi: https://doi.org/10.1287/opre.14.4.699.
[53] Bertsimas D, Tsitsiklis JN. Introduction to linear optimization 1997;vol. 6:479–530.
[54] Chen B, Zheng J, Zhang Y. A time division scheduling resource allocation algorithm for D2D communication in cellular networks. In: 2015 IEEE International Conference on Communications (ICC), London; 2015, p. 5422–28. doi: 10.1109/ICC.2015.7249186.
[55] Jiang F, Wang B, Sun C, Liu Y, Wang R. Mode selection and resource allocation for device-to-device communications in 5G cellular networks. China Commun 2016;13(6):32–47. doi: https://doi.org/10.1109/CC.2016.7513201.
[56] Wen S, Zhu X, Lin Z, Zhang X, Yang D. Energy efficient power allocation schemes for device-to-device (D2D) communication. In: 2013 IEEE 78th Vehicular Technology Conference (VTC Fall), Las Vegas, NV; 2013, p. 1–5. doi: 10.1109/VTCFall.2013.6692186.
[57] Moubayed A, Shami A, Lutfiyya H. Power-aware wireless virtualized resource allocation with D2D communication underlaying LTE network. In: 2016 IEEE Global Communications Conference (GLOBECOM), Washington, DC; 2016, pp. 1–6. doi: 10.1109/GLOCOM.2016.7842159.
[58] Li X, Zhang W, Zhang H, Li W. A combining call admission control and power control scheme for D2D communications underlaying cellular networks. China Commun 2016;13(10):137–45. doi: https://doi.org/10.1109/CC.2016.7733038.
[59] Tang R, Zhao J, Qu H, Zhang Z. User-centric joint admission control and resource allocation for 5G D2D extreme mobile broadband: a sequential convex programming approach. IEEE Commun Lett 2017;21(7):1641–4. doi: https://doi.org/10.1109/LCOMM.2017.2681664.
[60] Hoang TD, Le LB, Le-Ngoc T. Joint subchannel and power allocation for D2D communications in cellular networks. In: 2014 IEEE Wireless Communications and Networking Conference (WCNC), Istanbul; 2014, p. 1338–43. doi: 10.1109/WCNC.2014.6952364.
[61] Badr B, Francine K. Game theory applications in wireless networks: a survey. In: Proceedings of the 13th International Conference on Software Engineering, Parallel and Distributed Systems; 2014, p. 15–7.
[62] Yang D, Fang X, Xue G. Game theory in cooperative communications. IEEE Wirel Commun 2012;19(2):44–9. doi: https://doi.org/10.1109/MWC.2012.6189412.
[63] Wang B, Wu Y, Ray Liu KJ. Game theory for cognitive radio networks: an overview. Comput Netw 2010;54(14):2537–61. doi: https://doi.org/10.1016/j.comnet.2010.04.004. ISSN 1389-1286.
[64] Wang F, Xu C, Song L, Zhao Q, Wang X, Han Z. Energy-aware resource allocation for device-to-device underlay communication. In: 2013 IEEE International Conference on Communications (ICC), Budapest; 2013, p. 6076–80. doi: 10.1109/ICC.2013.6655574.
[65] Félegyházi M, Hubaux J. Game theory in wireless networks: a tutorial; 2006.
[66] Wang Feiran, Song L, Han Z, Zhao Q, Wang X. Joint scheduling and resource allocation for device-to-device underlay communication. In: 2013 IEEE Wireless Communications and Networking Conference (WCNC), Shanghai; 2013, p. 134–39. doi: 10.1109/WCNC.2013.6554552.
[67] He Y, Wang F, Wu J. Resource management for device-to-device communications in heterogeneous networks using stackelberg game. Int J Antennas Propag 2014;2014. doi: https://doi.org/10.1155/2014/395731. Article ID 395731, 10 pages.

[68] Sawyer N, Smith DB. Flexible resource allocation in device-to-device communications using stackelberg game theory. IEEE Trans Commun 2019;67(1):653–67. doi: https://doi.org/10.1109/TCOMM.2018.2873344.
[69] Moon J, Başar T. Discrete-time stochastic Stackelberg dynamic games with a large number of followers. In: 2016 IEEE 55th Conference on Decision and Control (CDC), Las Vegas, NV; 2016, p. 3578–83. doi: 10.1109/CDC.2016.7798807.
[70] Huang Bo-Yuan, Su Shih-Tang, Wang Chih-Yu, Yeh Che-Wei, Wei Hung-Yu. Resource allocation in D2D communication - A game theoretic approach. In: 2014 IEEE International Conference on Communications Workshops (ICC), Sydney, NSW; 2014, p. 483–88. doi: 10.1109/ICCW.2014.6881245.
[71] Başar T, Srikant R. A stackelberg network game with a large number of followers. J Optim Theory Appl 2002;115:479–90. doi: https://doi.org/10.1023/A:1021294828483.
[72] Sawyer N, Smith D. U-BeAS: a stackelberg game for device-to-device communications. arXiv preprint arXiv:1603.00104; 2016.
[73] Yang H, Xie X, Vasilakos AV. A robust stackelberg game based uplink power control for device-to-device communication with channel uncertainty and outage probability constraints. Wireless Pers Commun 2016;90:551–73. doi: https://doi.org/10.1007/s11277-015-3097-4.
[74] Xu C et al. Efficiency resource allocation for device-to-device underlay communication systems: a reverse iterative combinatorial auction based approach. IEEE J Sel Areas Commun 2013;31(9):348–58. doi: https://doi.org/10.1109/JSAC.2013.SUP.0513031.
[75] Xu C, Song L, Han Z, Li D, Jiao B. Resource allocation using a reverse iterative combinatorial auction for device-to-device underlay cellular networks. In: 2012 IEEE Global Communications Conference (GLOBECOM), Anaheim, CA; 2012, p. 4542–47. doi: 10.1109/GLOCOM.2012.6503834.
[76] Wang X, Chen X, Wu W. Towards truthful auction mechanisms for task assignment in mobile device clouds. In: IEEE INFOCOM 2017 - IEEE Conference on Computer Communications, Atlanta, GA; 2017, p. 1–9. doi: 10.1109/INFOCOM.2017.8057198.
[77] Zhang G, Hu J, Heng W, Li X, Wang G. Distributed power control for D2D communications underlaying cellular network using stackelberg game. In: 2017 IEEE Wireless Communications and Networking Conference (WCNC), San Francisco, CA; 2017, p. 1–6. doi: 10.1109/WCNC.2017.7925878.
[78] Yin R, Zhong C, Yu G, Zhang Z, Wong KK, Chen X. Joint spectrum and power allocation for D2D communications underlaying cellular networks. IEEE Trans Veh Technol 2016;65(4):2182–95. doi: https://doi.org/10.1109/TVT.2015.2424395.
[79] Wang Q, Wang W, Jin S, Zhu H, Zhang NT. Quality-optimized joint source selection and power control for wireless multimedia D2D communication using stackelberg game. IEEE Trans Veh Technol 2015;64(8):3755–69. doi: https://doi.org/10.1109/TVT.2014.2355594.
[80] Ding J, Jiang L, He C. Energy-efficient power control for underlaying D2D communication with channel uncertainty: User-centric versus network-centric. J Commun Networks 2016;18(4):589–99. doi: https://doi.org/10.1109/JCN.2016.000082.
[81] Shah ST, Gu J, Hasan SF, et al. SC-FDMA-based resource allocation and power control scheme for D2D communication using LTE-A uplink resource. J Wireless Com Network 2015;2015:137. doi: https://doi.org/10.1186/s13638-015-0340-3.
[82] Wei W, Wang Q, Yang L, Hu X. Auction Based energy-efficient resource allocation and power control for device-to-device underlay communication. In: 2016 IEEE 84th Vehicular Technology Conference (VTC-Fall), Montreal, QC; 2016, p. 1–6. doi: 10.1109/VTCFall.2016.7880914.
[83] Xu C, Song L, Han Z, Zhao Q, Wang X, Jiao B. Interference-aware resource allocation for device-to-device communications as an underlay using sequential second price auction. In: 2012 IEEE International Conference on Communications (ICC), Ottawa, ON; 2012, p. 445–49. doi: 10.1109/ICC.2012.6364509.
[84] Wang T, Song L, Han Z. Coalitional graph games for popular content distribution in cognitive radio VANETs. IEEE Trans Veh Technol 2013;62(8):4010–9. doi: https://doi.org/10.1109/TVT.2013.2245353.
[85] Wang L, Li C, Zhang Y, Gui G. Game-theoretic social-aware resource allocation for device-to-device communications underlaying cellular network. Wireless Commun Mobile Comput, 2018:5084842. https://doi.org/10.1155/2018/5084842.
[86] Wang X, Guo Y, Bai C, Liu S, Liu S, Han J. The effects of weather on passenger flow of urban rail transit. Civil Eng J 2020;6(1):11–20.
[87] Abdollahi MM, Tehrani M. Designing a novel reversible systolic array using QCA. Emerg Sci J 2017;1(3):158–66.
[88] Kalistratov D. Wireless video monitoring of the megacities transport infrastructure. Civil Eng J 2019;5(5):1033–40.
[89] Astaneh AA, Gheisari S. Review and comparison of routing metrics in cognitive radio networks. Emerg Sci J 2018;2(4):191–201.

Roopsi Rathi pursuing PhD from K.R. Mangalam University, Gurugram, India. Before that, she studied MCA from MDU university, Haryana, India.