Device to Device Communication using Stackelberg Game Theory approach

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Abstract- **The constant growth in the heterogeneous devices needs to enhance the network capability to fulfill the increased demand of the users. Such a huge number of devices require higher sum rates, superior throughput, system capacity, minor delay, and QoS. The accessible resources are finite and must be flexibly utilized by the subscribers and operators with the expanding requirement. The objective of the paper is to analyze the resource allocation aspects of D2D communication. Furthermore, discuss a game theory approach mainly focuses on the Stackelberg game for resource allocation in the heterogeneous network and how it affects system performance and throughput.**

Keywords— D2D communication; Resource allocation; Game theory; Stackelberg Game.

I. INTRODUCTION

By the instant evolution of rational applications, the cellular networks are experiencing an exceptional burden inflicted by the unpredictable progress of the data traffic and huge growth of connected devices[1-3]. To alleviate this constraint, D2D communication is developed to increase the spectrum exploitation of cellular systems[4]. Device-to-device communication technology allows the devices to connect each other with or without the participation of network accessories like a base station or access point[5][6]. In other words, it opens new device-driven communication that regularly requires no immediate communication with the network infrastructure and it relies upon their direct communication with the device. The devices can be used in various terms like mobile phones, laptops or vehicles. Simultaneously, there is an extensive range of potential applications/ use-cases for D2D communication like messaging, gaming, voice calling, data sharing, and content distribution[5][8]. In D2D communication, the spectrum access can be any licensed or unlicensed i.e. in-band or out-band respectively [7].

D2D communication provides numerous advantages to the system to improve the cellular capacity, spectral efficiency, QoS, energy efficiency, and increase the throughput for cellular and D2D users[8][9][12]. Nevertheless, D2D communication confronts many challenges as resource allocation or sharing, interference management, transmission power control, and mode selection. Resource allocation is a crucial aspect in D2D communication, as D2D users can share/reuse the UL or DL (uplink/ downlink) resource blocks (RBs) of the cellular users, as a consequence severe intracell interference among users which reusing the same RB. So,it is essential to adapt the resource allocation and interference mitigation schemes to synchronize and lessen the intracell interference in the network. Figure 1 shows a single cell set-up in D2D communication, in which two D2D pairs are directly connected and it also shows the interference between among users.

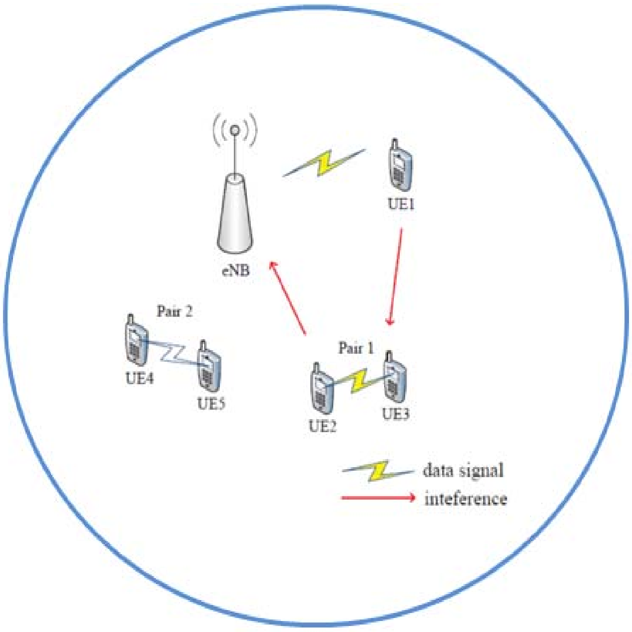

Fig1 A single-cell setup in D2D communication[10]

Game theory has been used significantly to focus the resource allocation aspect in D2D communication. Game theory known as a decision-making tool to analyze interactions between rational players vying for resources[16][17]. A game involves a set of rational players as D2D and cellular users, each player chose a strategy/action to achieve maximum payoff/utility function. In this paper, the Stackelberg game approach has been considered, which has leader/s and follower/s with the hierarchical structure. In this game approach, firstly leaders (cellular users) set charges which are compensated by followers (D2D users) for sharing their spectrum.

The following paper is structured as: Section II defines the overview of D2D communication followed by Resource allocation in section III. Then Section IV presents the Stackelberg game theory model to maximize the throughput and spectral efficiency of the users. Finally the conclusion is explained.

II. D2D COMMUNICATION

The spectrum can be accessed either licensed (in-band) or unlicensed (out-band) for device link formation in D2D communication. Figure 2 shows, that in-band D2D and Out-band D2D are grouped as an overlay and underlay, controlled and autonomous respectively.

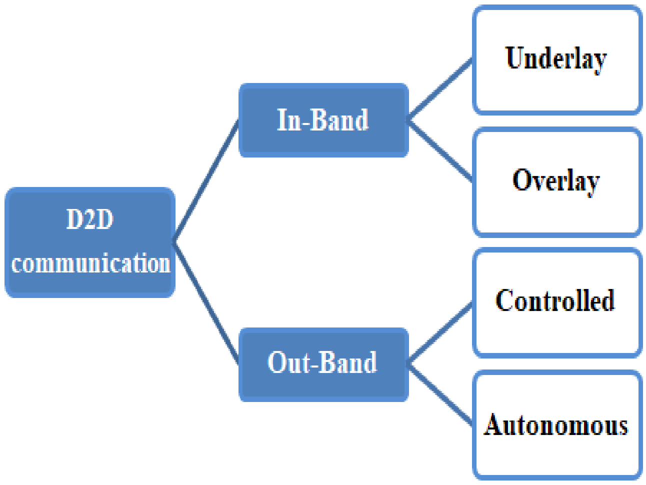

Fig 2 Classification of D2D

In underlay D2D, both (D2D and cellular) users shares the same cellular spectrum, whereas in overlay D2D, available resources are devoted to D2D and cellular users. This inband method, increase the efficacy of the cellular system by sharing/reusing the same spectrum or allocates dedicated resource to D2D users. As a result, interference occurs between both the D2D and cellular links. Nevertheless, this interference between users must be wisely avoided and controlled. In out-band D2D grouped as autonomous and controlled . Controlled out-band, where the radio interfaces are handled by the BS, whereas in autonomous out-band, these radio interfaces are handled through the users themselves. Bluetooth and WiFi are examples of unlicensed D2D communication.

Figure1 shows the system structure with two links, i.e. D2D links and cellular links in this kind of system, interference can be divided as co-channel interference and cross channel interference. Here, the interference is described as who's the interrupter and who's the victim of the interference.

- Cross channel interference: During this interference approach, the D2D transmitter user (an interrupter) interrupts the cellular user(a victim) and vice versa.
- Co-channel interference: In this interference approach, the D2D transmitter user (an interrupter) interrupts co-channel D2D user (a victim).

Thus, to reduce/overcome the interference inside the system, some schemes are proposed by authors such as interference avoidance, cancelation or randomization that must be used for effective D2D communication[11][17]. Unlike traditional networks, the resource allocation in D2D contains the proper assignment of RBs to D2D users. Explicitly, the allocation of resources can be done as:

- Local resource allocation: In this mode, resources are fixed for cellular users and D2D users have to adjust.
- Global resource allocation: In this mode, resources are jointly controlled by both D2D and cellular users.

III. RESOURCE ALLOCATION

In wireless networks, the system information like the number of users, channel gain, SINR measurement is typically uncertain and inaccurate. This uncertain information must be carefully tackled for proper resource allocation. Resource allocation is essential for improving the spectral capacity for D2D communication. While D2D users need to connect underlaying cellular networks, there is a significant obstacle that how to assign cellular resource for D2D transmission since interference among users should be reduced[13]. Resource allocation can be distributed or centralized in D2D communication. In [14]centralized technique, BS has fully responsible for assigning/controlling the resources for users. If D2D communication is auspicious for D2D pairs, then the users require to sense the system environment, approach the cellular resources beyond the harmful interference. Because of the high complexity, the centralized technique may not be appropriate for a large number of users. In contrast, the distributive scheme provides less signal overhead. This scheme can be used either by fully distributed or message passing technique. In message passing, D2D users have to share local information with their neighbor nodes for achieving a near-optimal result. Low distributiveness and high message passing are the main disadvantages of this technique. The distributed scheme will be needed for effective spectral sensing and retrieve method for tradeoff among the distributiveness, optimality, and complexity[15]. Game theory can propose a prominent solution for this resource allocation issue in D2D communication[17].

IV. STACKELBERG GAME THEORY

In D2D communication where D2D users share the licensed resources of the cellular system, the formation of Stackelberg game is suitable for analyzing the resource allocation. The

Stackelberg model is formulated and designed to find communication strategies for D2D and cellular users. This game approach has a hierarchical structure along with players as leader and follower. It grouped cellular and D2D users as a leader - follower pair. The pairing of leader-follower depending on the system environment such as one leader-one follower, multiple leaders-one follower, and multiple leaders-multiple followers. The main components of the Stackelberg game are:

- Leaders: Cellular users/BS
- Followers: D2D users
- Utility function: The final outcome that can achieve by the coordination between users by charging fees and choosing to transmit power which affects the total throughput.

As a leader, the cellular users act first and then D2D users as followers observe the cellular user's behavior and choose their strategy. The cellular users have owned the resources and they can charge D2D users some charges for sharing the resource channel. The charges are fictional amount to limit the transmission and coordinate the D2D users. Therefore, the cellular users have reason to share the resource to D2D users and they can decide the amount. By the given fees, D2D users can select the resources and transmit power for maximizing its utility.

The utility of cellular and D2D users can be measured as:

- Utility of cellular user: Its Own Throughput + Additional Cost.
- Utility of D2D users: Its own throughput- Additional Cost.

(Here, the additional cost is the amount paid by the D2D users to cellular users for sharing the channel resource)

In [10][17-19] the authors formulated the optimization problem for leader and follower.

- Optimisation problem for the leader:

$$\max U_L (x_i, p_k)$$
$$\text{s.t.} \quad x_i > 0$$

Where U_L means the utility of the leader, x_i means charging price and pick means transmit power.

- Optimisation problem for the follower:

$$\max U_F(x_i, p_k)$$
$$\text{s.t.} \quad p_{min} \leq p_k \leq p_{max}$$

Where U_F utility of D2D users and p_k transmit power. The optimal power should be maximized for the proper utilization.

In [19] authors proposed flexible distributed allocation method to improve D2D users QoE and also provides a service corresponding to their connection requirement. This proposed a dynamic environment along with single leader-multiple followers. Here the followers are divided into three classes, i.e. casual, interactive and streaming. The distributed approach finds the best base station satisfaction fees and sharing/reusing fee and also provides optimal transmission power for followers. The authors mainly focused on the throughput and QoE to expand the utility of the D2D users [1][2].

In [18]authors proposed joint scheduling and resource allocation approach to raise spectral performance for heterogeneous networks. They consider a Femto/macro/D2D users, which grouped as two leaders-one follower pair in a same cell scenario. It is presumed that the transmit power and resource of femto/macro users are fixed. In D2D communication the proximity between users can enhance system capacity and total throughput of the system. The transmission power of D2D users must be appropriately controlled so that the interference occurs from D2D to cellular could be limited. This proposed approach analyzes the utility function, optimal price and optimal power for the proper allocation of resources and power control which enhance spectral efficiency and throughput. This proposed approach focused on the fairness and sum rate.

But this approach fails to work efficiently when the large number of users involved in the networks. The authors work on the static environment, but this approach is not really appropriate for the dynamic or realistic network.

V. CONCLUSION

D2D communication technology probably solves the numerous tribulations in the network, and effectively fulfill all the necessities of the users. In a heterogeneous environment, sharing the same spectrum is quite challenging which affects the spectral efficiency and system performance. In this paper, we discuss the game theory models which are significant for proposing the resource allocation approach for achieving an effective and efficient solution. Here, we discussed Stackelberg game technique that focus on the fairness, throughput and sum rate, which indicates the better utilization of resource in the system. We also outline some important facts such as QoS and a realistic approach that should be addressed in future research.

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