A Review on Interference Mitigation Techniques in 3GPP Device to Device Communication

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Abstract**—** New generation i.e. 5G of cellular network is expected to support data rates almost 1000 times that of the existing 4G network. Meanwhile, the Long Term Evolution (LTE) and Third Generation Partnership Project (3GPP) are considered to employ D2D as the potential solution to support growing communication demand. As a result, D2D technology plays an important role in improving the performance of cellular system and promises to be an essential technology in the next generation wireless communication systems [2]. Device to Device (D2D) communication is very important in that regard inspite of its implementation challenges. D2D communication is an innovative feature of 5G cellular networks that facilitates peer to peer communication between two closely located users by transmitting signal directly without traversing the Base Station (BS). D2D communication promises drastically low latency for communication among users in close proximity. D2D communication can happen in licensed as well as unlicensed spectrum. Exploiting direct communication between nearby devices, D2D offers multifold advantages like spectral utilization, energy efficiency, reduced end to end latency, improved overall throughput, traffic offloading for BS and congestion control in networks. However, integrating D2D into cellular networks imposes many technical issues which must be mitigated for providing smooth communication. Some of the challenges are device discovery, interference management and power control. We analyzed one of the most exigent issues, Interference Management between D2D users and cellular users in this paper. Approaches to minimize interference are Graph theory, Game theory, Clustering users and Cognitive radio to name a few. This study aims to analyze various game theoretic approaches to mitigate interference by suitable allocation of radio resources.

Keywords— *Device to Device; Interference Mitigation; Resource Allocation; Game Theory; LTE; 3GPP; LTE-A*

I. INTRODUCTION

With the evolving technologies, mobile users are getting access to multimedia rich services which generate a high demand for higher data rate wireless access. As a solution, a new wide area wireless technology LTE-A (Long Term Evolution- Advanced) has been introduced in 4G cellular network [6-8]. Due to the explosive growth in cellular communication, a need to lessen the congestion in network traffic becomes the default priority. D2D communication, a feature supported by 3GPP, LTE and LTE-A is one of the potential solution in this direction. Device to Device communication allows two user equipments (UEs) in proximity to communicate directly using a direct link instead of a radio signal which travel all the way via the core network and Base Station (BS).

The basic scenario of D2D communication can be thought of consisting of a base node which is mostly referred as BS situated at the center of the cell. It is also called Evolved Node B (eNB) in 3GPP LTE-A network. Group of cellular users are connected to eNB via communication link. There is a specific coverage wherein communication takes place. The DUEs are connected in a LAN having D2D data signal between them inside the Local Area Network (LAN). They get a signal from BS through cellular data signal. D2D direct shows that D2D User Equipments (DUEs) are connected to each other with D2D data signal. This scenario is shown in Fig. 1.

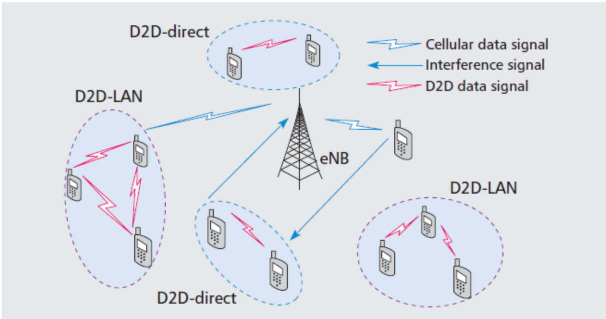

Fig. 1. D2D Communication Underlaying Cellular Network [5]

There are many advantages of D2D communication like it intensifies energy efficiency (number of bits per Joule), throughput, spectral efficiency of network (number of bits transmitted per Hz), more coverage, diminishes delays in transmission, reduces traffic burden for BS and lessen congestion in communication networks. For the integration of D2D communication into the cellular network, architecture of cellular network has been modified to two tier architecture. First tier, the conventional macro cell layer facilitates communication between Cellular Users (CUEs) and BS. A new tier known as device tier is introduced which provides D2D communication among DUEs. This new architecture consisting of two tier improves upon conventional architecture in terms of coverage, throughput and low latency. However, this addition of D2D communication into the cellular network induced several technical challenges for both DUEs and CUEs like locating devices, setting up D2D session, allocation of D2D resources to ensure the Quality of Service (QoS) and interference management. These technical challenges need attention and remedies to yield the possible goodness in D2D communication. Out of all technical challenges, the most critical one is interference management between DUEs and CUEs for D2D communication in sharing mode.

Based on the spectrum used for D2D communication, it is categorized into two types namely In-band D2D communication and Out-band D2D communication. In In-band D2D, the cellular users are allocated a licensed spectrum which they can access in a shared or in a dedicated mode for D2D communication also. Alternatively, Out-band D2D exploits unlicensed spectrum other than the cellular band (e.g. 2.4 GHz ISM band) to support straightforward communication between D2D devices. In-band D2D communications are more preferred over out-band D2D communications due to better control over licensed spectrum. In-band D2D can share the licensed spectrum in either Overlay or Underlay mode. Overlay spectrum divides the licensed spectrum into two parts via orthogonal channel assignment. Thereafter, D2D and cellular users use the allocated set of orthogonal time/ frequency resources. This way overlay spectrum sharing eliminates interference within cell. Sharing with underlay spectrum permits DUEs for simultaneous use of the same spectrum [9-10]. As a result, efficiency and utilization of spectrum is increased. At the same time, this sharing mode increases interference in terms of addition of new situations of interference between DUEs and CUEs. Therefore, extra efforts are required to control this increased interference which otherwise does not harvest the potential benefits of D2D communication and in turn degrade the overall cellular efficiency and capacity To resolve this interference issue, high complexity resources allocation methods can be introduced but this in turn increase the computational overhead of the eNB handling DUEs.

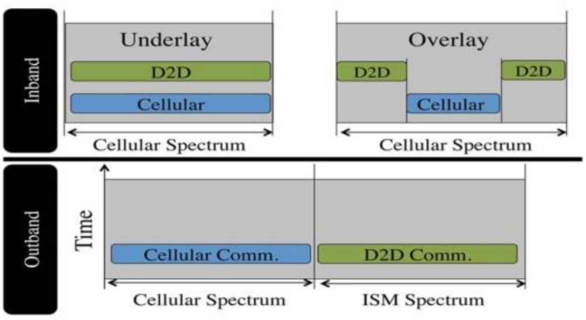

Fig. 3. Types of D2D communication [12]

Interference mitigation techniques greatly reduce the channel interference and increase the spectral efficiency. This criticality of interference mitigation motivated us which is the main emphasize in this study.

The paper is organized as follows; Section 2 briefly describes the existing game theoretic models for interference management between DUEs and CUEs. Section 3 analyzes the various models and compares them based on various features' parameters and Section 4 gives the conclusion of the study.

II. EXISTING METHODS

Extensive research has been done to mitigate interference between DUEs and CUEs using mathematical theories like graph theory, queuing theory, evolution theory, game theory and stochastic geometry. In this technological era, many complex and competitive problems are solved during communication in networks using game theory.

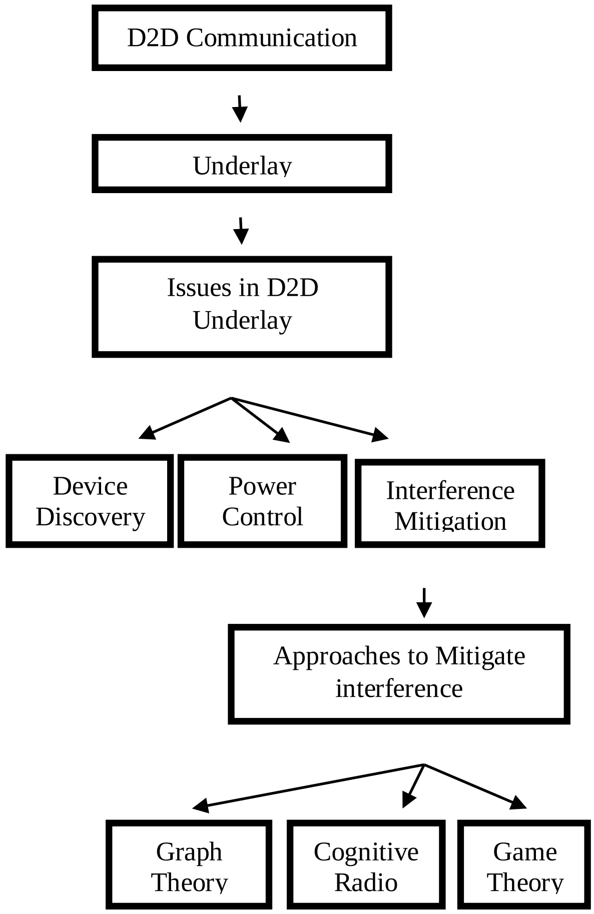

Fig. 4. Flow of Device to Device Communication and Approaches to Mitigate Interference

A competitive interaction among intelligent decision making players can be modeled, designed and analyzed to understand the individual or group behavior of D2D users using the mathematical tools of game theory [11]. It has been proved very efficient in understanding complex interactions among self-governing players [6]. Game theory's tools predict the selection policy of players while sharing the spectrum resources. Game theory based resource allocation has also been applied in Device to Device communication to mitigate interference issue in sharing mode. A number of logical/ intelligent players play in a game with their own utility function. To resolve interference issue in device to device communication, various game theoretic models are used such as Stackelberg game, non-cooperative static games, coalition and auction. They are broadly categorized into three types namely Cooperative games, Non-cooperative games and Stackelberg games. Cooperative game model allows both the D2D and cellular users to act as players while Non-cooperative game model allows DUEs to act as players who can compete for the resources. It creates the scenario just like playing a game in D2D environment. Players take their turn to use the channel efficiently. This section of study analyzes the pros and cons of various game theoretic approaches.

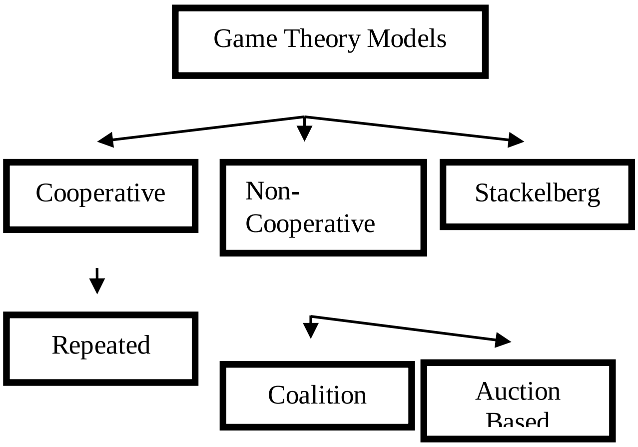

Fig. 5. Game Theoretic Models

A. *Static Repeat Model*

There have been enormous solutions proposed for allocating resources among users in intra-cell scenario. However, Static Repeat model aims to allocate resources among the users in inter-cell scenario. In this model, it is assumed that two DUEs can communicate while they are located in the overlapping area of two neighbouring cells as depicted in Fig. 6. Cellular users are located in each cell and communicate with the BSs. There can be more than one BS which act as players. They can completely observe the resource allocation strategies of each other. The DUEs and CUEs use the common resources of both the cells.

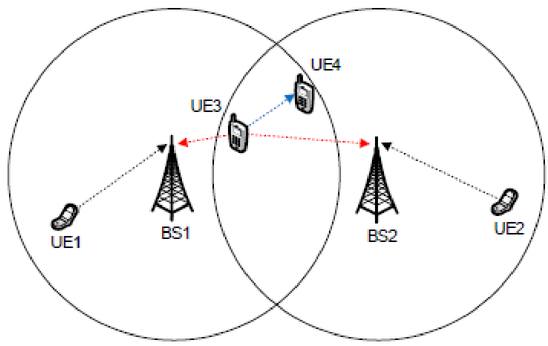

Fig. 6. Static Repeat Model Assumed Scenario [1]

There is a competition between BSs for resource allocation. BSs as players own the resources which in turn charges DUEs for using their resources. Utility of a player can be considered into two parts in this model. The first part comes from the fees collected from CUEs while the second part is the fees charged for D2D communications. This model is then extended to repeated version where the game is repeated for a finite number of times. By using and analyzing the Nash Equilibrium (NE) derivation and analysis, the resource allocation algorithm is designed to allocate resources with maximum benefit for the players. NE can be defined as a stable state of a system which involves interactions between participants and none of the participants can gain by a unilateral change of strategy if other participant keeps the same strategy. In this algorithm, one BS shares the parameter information through some message mechanism with another BS and DUE pair. This messaging mechanism makes the information publicly available which in turn is commonly known to all the players in the cell. In this way, BSs can know the strategy of each other by prediction. After DUEs are assigned the proposed resources, they can inform the BS to terminate the game. As long as the sum of allocation reaches to the constraint, the BSs continue the game. This allows the BSs to allocate maximum resources to DUEs and this leads to increased performance [1].

B. *Stackelberg Model*

With D2D inband underlay communication, radio resource allocation can be modeled using Stackelberg game. This game has a hierarchical structure, in which the players are cellular users (act as leaders) and D2D users (act as followers) as depicted in Fig. 7. Games might have multiple single leader-follower pairs or a single leader with multiple followers. A leader owns the radio channel and has the right to decide some cost of the bandwidth as a seller. Cost is decided based on some function which further depends on the users' demand for the resource. The cellular user charges the fees from a D2D user and therefore has an incentive to share its resources with D2D user. Given the charging cost, D2D users compete among themselves to buy the appropriate amount of bandwidth and choose the transmit power to maximize their utilities.

The game aims to increase the utility of the leader as well as the followers. The utility of the leader can be considered as it own throughput and the revenue earned from the D2D users. The utility of the follower can be taken as the difference between its throughput and the fees paid to the cellular user against the resource utilization. Based on the utilities, a priority queue is formed by the leader and the followers which is then used by the system to schedule the DUEs according to their orders. In this game, the leader takes the initiative to act first and the follower decides its strategy after observing the behavior of the leader. The game aims to achieve an equilibrium between the leader and the follower. Stackelberg game is proposed for handling scheduling, power control and resource allocation in case of sharing mode [2].

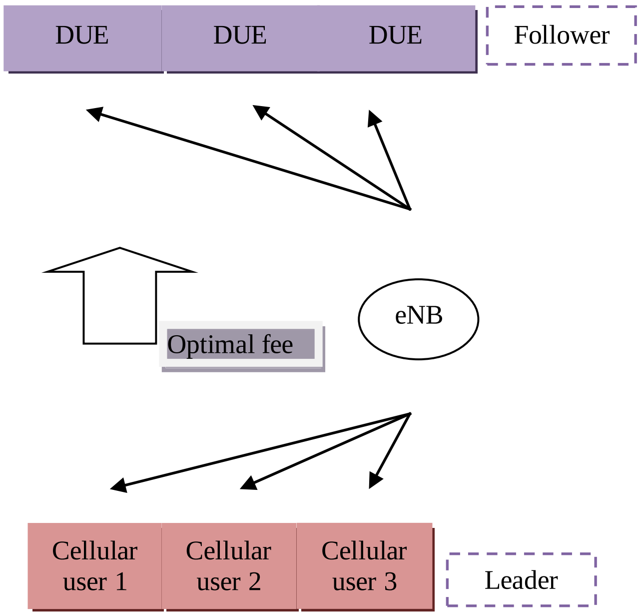

Fig. 7. A Stackelberg Approach

C. Coalition Model

This model considers two types of communications namely traditional communication between BS and CUEs and the direct D2D communication. This model basically emphasize on intracell communication. Resource Blocks (RB) are allocated to CUEs and DUEs for which both have same priorities. The users have some threshold through which it is decided which user whether DUE or CUE can obtain resources from BS. Each user has own identity through which they communicate in the sharing mode. CUEs and

DUEs form a strengthened bond with each other of cooperative nature which leads to better RB allocation to both the users. Thus their utility in form of resource allocation can be transferred between DUEs and CUEs in this cooperative type of environment. This mechanism is called coalition. In this model, the players which have the same identity can form a coalition group to transmit the information for resource sharing. This allows the players to form a larger coalition group to obtain more optimal RB. The cooperative game is divided into different sub-games. Each sub-game addresses the resource allocation of one specific RB. Each user has the ability to leave one sub-game and join another sub-game by changing its identity. This model supports distributed system resource sharing by using merge and split algorithm. In this algorithm, each player tries to obtain optimal RB to transmit data in the communication network along with sharing RB with other players belonging to the same resource group. The utility of both CUEs and DUEs is the transmission rate which can be achieved through appropriate RB allocation to them. This model gives considerable increase in performance of the system in sharing mode [3].

D. Auction Based Model

This model considers a single cell scenario in which multiple users communicate for resource sharing. Reverse iterative combinatorial auction algorithm is used. In this algorithm, all the spectrum resources are taken as a set of resource units. It is assumed that the total spectrum resources are separated into C units with each one providing communication service to one cellular user already.

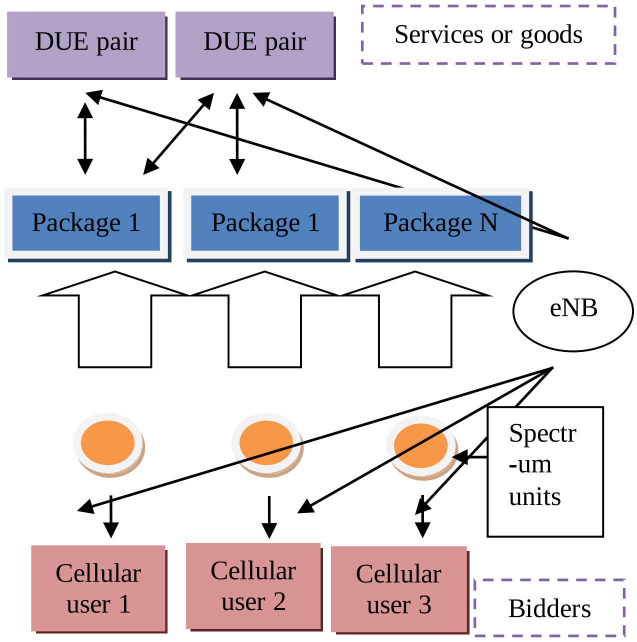

Fig. 8. Auction Based Approach

Using the auction game, N number of user packages is assigned the spectrum units having at least one D2D pair in each package as shown in Fig. 8. The auctioneer announces an initial price for each item after which the bidders submit their bids at the current price to the auctioneer. The auctioneer updates the corresponding price as long as the demand exceeds the supply or vice versa and this way the auction goes to the next round. This approach is based on the real time auction of different products but here it is in the form of channel or resources. Channel rate is improved while obtaining D2D communication with the competition of spectrum units. The resources act as bidders who participate in a competitive game to obtain business whereas D2D users act as services or goods which are to be sold. In this way, for every round, resources or the services of D2D are auctioned off. The resources are allocated in an impartial manner and algorithm is converged in finite number of steps which leads to low complexity. This approach is divided into two steps: first it formulates the valuation of each resource unit thereafter an algorithm known as non-monotonic price descending auction algorithm is used. This approach proves to be efficient in performance [4].

III. ANALYSIS OF EXISTING MACHINE LEARNING TEXT CATEGORIZATION APPROACHES

Many techniques are developed to mitigate interference and game theory is one of them. It is inevitable that most of the techniques of game theory mitigate interference through different strategies and algorithms. However, analyzing these techniqu

TABLE 1 PARAMETRIC COMPARISON OF GAME THEORETIC APPROACHES FOR INTERFERENCE MITIGATION

Method / **Parameter**	Repeated [1]	Stackelberg [2]	Coalition [3]	Iterative Combinatorial auction [4]
Single cell/ multicell	2 cells	Single	-	Single
Theory used	Non-cooperative	Stackelberg-Leader and Follower	Cooperative	Cooperative
Intercell/Intracell	Intercell	Intercell	Intracell	Intracell
Players	BS	D2D, cellular	D2D	D2D, cellular
Strategy used	Repeated resource allocation	Joint scheduling	Merge and split	Non-monotonic descending price auction
Reuse link	Uplink/downlink (based on scenario)	Uplink for D2D and cellular	Downlink for D2D and cellular	Downlink for D2D and cellular
Consideration of fairness of station	Yes	Yes	Yes	Yes

The game theoretic models can be analyzed based upon the following parameters:

- **Cell scenario:** Single cell and multi-cell are two scenarios in which communication between the DUEs and cellular users can be done. In single cell, communication happens within a cell and in multi-cell, communication happens in more than one cell.

- **Theory used:** Cooperative, Non-cooperative and Stackelberg are basically three types of models. Cooperative: In a Cooperative game approach, players can build contracts benefitting them mutually. The players need to cooperate for the maximum benefit for which they coordinate different strategies and agree on total payoff division between them. In non-cooperative model, the players interact with the self-interested DUEs and cellular users, they share the same channel and control the transmitting power. CUEs and DUEs act as leader and follower in Stackelberg model.

- **Cell type:** Cell type is divided into inter-cell and intra-cell; the former means the interaction between two or more cells and the latter means interaction within a single cell.

- **Player's consideration:** This indicates what type of user will be considered as player. This makes an important strategy by choosing the best player so that maximum throughput is obtained and interference is minimized.

- **Strategy used:** This indicates the type of algorithm used in game theory models. The algorithm allows the players to get maximum interference mitigation and devises the communication in such a way that resources can be allocated properly among the users.

Link to be reused: For any communication to be better and scalable, it is necessary to reuse resources so that maximum utilization of resources can be done and all the users can get required resources whenever necessary. This means the user can reuse either the uplink or downlink.

- **Fairness consideration**: Fairness is considered in D2D communication for better designing of resource allocation among the users. This allows the user to get the fair and unbiased share of resources.

Table 1 compares the four existing game theoretic models for interference mitigation based on the parameters discussed above. The table describes different parameters that can be used to evaluate the game theoretic models.

IV. CONCLUSION

We have presented a brief overview of different types of D2D communication modes. There are many problems that exist while communicating through D2D. We have considered one of the major challenges i.e. interference management. Resource management can be considered as one of the solutions to mitigate interference. We have analyzed various game theory based resource allocation methods to manage resources. These game theoretic methods are easy to understand and solve the problems using mathematical models and design. Game theory models are mainly divided into Cooperative, Non-cooperative and Stackelberg model. We have analyzed four models of interference mitigation. Performance and efficiency is increased in almost all the model discussed above. Static repeat model uses repetitive approach for resource allocation which leads to better scheduling and power control. We can observe that throughput is improved in Stackelberg approach due to its leader-follower strategy. Auction based strategy in iterative combinatorial auction improves channel rate.

REFERENCES

[1] J. Huang, Y. Zhaoy, K. Sohrabyy: "Resource Allocation for Intercell Device-to-Device Communication Underlaying Cellular Network: A Game-Theoretic Approach", 2014.

[2] F. Wang, L. Song, Z. Han, Q. Zhao, X. Wang: "Joint Scheduling and Resource Allocation for Device-to-Device Underlay Communication", In: IEEE Wireless Communications and Networking Conference (WCNC): MAC, 2013.

[3] R. Zhang, L. Song, Z. Han, X. Cheng, B. Jiao: "Distributed Resource Allocation for Device-to-Device Communications Underlaying Cellular Networks" In: Ad-hoc and Sensor Networking Symposium, IEEE ICC, 2013.

[4] C. Xu, L. Song, Z. Han, X. Cheng: "Efficiency Resource Allocation for Device-to-Device Underlay Communication Systems: A Reverse Iterative Combinatorial Auction Based Approach", In: IEEE Journal on Selected Areas in Communication/ Supplements, Vol. 31, No. 9, 2013.

[5] L. Song, D. Niyato, Z. Han, E. Hossain: "Game-Theoretic Resource Allocation Methods for Device-to-Device Communication", In: IEEE Wireless Communications- 2014.

[6] D. Feng, L. Lu, Y. Yuan-Wu, G. Ye Li, S. Li, G. Feng: "Device- to- Device Communications in Cellular Networks": In: IEEE Communications Magazine, 2014.

[7] D. Feng, L. Lu, Y. Yuan-Wu, G. Ye Li, G. Feng, and S. Li "Device-to-Device Communications Underlaying Cellular Networks" In, IEEE Transactions on Communications, Vol. 61, No. 8- 2013.

[8] L. Sang, J. Shen, Evolved Network planning and optimization for UMTS and LTE, Auerbach publications, CRC press, 2010.

[9] M. Hicham, N. Abghour, M.Ouzzif, "Device-To-Device (D2d) Communication Under Lte-Advanced Networks", International Journal of Wireless & Mobile Networks (IJWMN) Vol. 8, No. 1, 2016.

[10] U. Narayana Kar, D. Kumar Sanyal, "An overview of device-to-device communication in cellular networks", 2017.

[11] M. Nouran, R. Nordin "A survey on interference management for Device-to-Device (D2D) communication anditschallengesin5Gnetworks", Journal of Network and Computer Applications, pp.130–150, 2016.

[12] A. Asadi, Q. Wang, V. Mancuso, "A Survey on Device-to-Device Communication in Cellular Networks", IEEE Communications Surveys & Tutorials, 2013.